The State of SCIENCE in South Africa

ASSAf
ACADEMY OF SCIENCE OF SOUTH AFRICA

Edited by Roseanne Diab and Wieland Gevers

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NALEDI PANDOR – MINISTER OF SCIENCE AND TECHNOLOGY

The South African science sector has evolved dramatically since the dawn of democracy. The 1996 White Paper on Science and Technology, the 1999 National Research and Technology Foresight project and the 2002 National Research and Development Strategy laid the basis for South Africa's science and technology system. The emphasis has been on strengthening research and development.

In 2008 we published a ten-year innovation plan and we are currently putting it into place. The plan is ambitious. It contains five 'Grand Challenges' that build on and expand our current research strengths. These areas offer great potential to steer South Africa towards a new economy based more on the importance of knowledge than on the extraction of resources as in our past.

The first challenge is to tap the potential of our bio-economy for our pharmaceutical industry. We have the world's third-largest biodiversity resource base, and a solid foundation of expertise. We need a systematically managed product value chain to exploit these advantages for the establishment of a globally competitive pharmaceutical industry.

The second challenge is to build on our investment in space science and technology. The establishment of a National Space Agency will assist us to grow and manage, in a coordinated fashion, our satellite industry and a range of innovations in space sciences, earth observation, communications and navigation for socio-economic benefits.

The third challenge is to move towards the use of renewable energy. Today, every nation is grappling with the issue of energy supply and the possibilities of a green economy. The productive capabilities of emerging economies are dependent on a secure supply of safe, clean, and affordable energy. Working closely with industry, South Africa is exploring opportunities in clean coal technologies, nuclear energy, renewable energy and hydrogen and fuel cell technologies.

The fourth challenge is to play a leading, regional role in climate change. South Africa's geographic position, unique biodiversity and a large base of expertise enable us to play a leading role in climate change science. We serve as a unique laboratory, given our proximity to the Antarctic, the Southern Ocean, and the interactions between the Agulhas and Benguela currents. We plan to make a major contribution to understanding climate change, and offer modelled solutions to the world.

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The fifth and final grand challenge is termed 'human and social dynamics'. This challenge is at the core of nearly every major challenge facing South Africa – from climate change to creating a competitive and innovative workforce. The fifth grand challenge is to increase South Africa's ability to anticipate the complex consequences of change. It's the challenge to understand the dynamics of human and social behaviour at all levels better. It's a challenge to understand the cognitive and social structures that create and define change better. It's a challenge to help people and organisations manage profound or rapid change better. In addition, we need social scientists to manage change.

South Africa plays an important regional role in global scientific innovation. South Africa hosts the African component of the International Centre for Genetic Engineering and Biotechnology, which opened in Cape Town in September 2007. This centre attracts world-class researchers from all over the world in an effort to face health and agricultural challenges, such as tuberculosis, malaria, and HIV through biotechnology and genetic engineering research. South Africa also hosts the regional offices of the World Association for Industrial and Technical Research Organisations (WAITRO), the International Council for Science (ICS) and the European and Developing Countries Clinical Trials Partnership (EDCCTP).

South Africa is working towards winning the bid to host the Square Kilometre Array (SKA) Radio Telescope in partnership with, and for the benefit of, the entire African continent. We are seeking to increase our activities in astronomy by coordinating an international bid that includes many African partners. The SKA is not only a set of dishes in the *Karoo*, but also a project that combines fundamental developments in radio frequency technology, information and communication technology, and high-performance computing.

The field of astronomy has been a particular success. This is not just because of our geographic position, although this gave us a great advantage. Initiatives such as the Southern African Large Telescope, launched in November 2005, and our membership of the Group on Earth Observation (GEO), a progressive multilateral body, have brought us a step closer towards the objective of creating a hub of astronomy research in southern Africa. Our leadership role in GEO has ensured that our satellite ground stations at the Council for Scientific and Industrial Research will be central to the download and processing of China-Brazil Earth Resource Satellites imagery and its distribution, cost-free, throughout Africa.

South Africa has set itself ambitious and inspirational goals to become competitive in the global knowledge economy. This book highlights South Africa's achievements in the past and indicates the challenges we still hope to overcome in the future.

NALEDI PANDOR – MINISTER OF SCIENCE AND TECHNOLOGY

Preface

This book has been prepared to mark the occasion of the hosting of the Academy of Sciences for the Developing World (TWAS) conference by the Academy of Science of South Africa (ASSAf) in October 2009 in Durban. TWAS is the largest and most significant individual-based, multinational science academy in the world. The visit to South Africa of some of the world's most eminent scientists from the developing world provides an opportunity to profile science in our country. Through the publication of this book we hope to reflect on the state of science in South Africa; to consider the historical context and the key features that have shaped scientific research in the country and are determining its current trajectories; to highlight some of the future challenges and opportunities; and to celebrate some of the achievements of South African scientists.

The Academy of Science of South Africa, as the official national academy of science (in its broadest sense of encompassing all empirical research), has been recognised through an Act of Parliament, *Act 67 of 2001*, and aspires to be the apex organisation of science in the country. It is therefore uniquely positioned to provide a landmark overview of the state of science in South Africa. We have relied heavily on our Membership to author and review the various chapters, and we gratefully acknowledge these contributions from many of South Africa's most distinguished scholars, including the contributions from the younger generation of scientists in the final chapter which provide a set of personal glimpses into the future of science in the country.

It is hoped that this book will serve as a useful reference for local and international scholars interested in the development of science in South Africa, and that it will provide a valuable perspective on the current state of South African science and the challenges that its researchers face in the various disciplinary fields. It will serve also as an informative text for students who are seeking to gain an understanding and appreciation of their particular and other disciplines, and the historical development and contributions that have been made. The value of an overview of the state of the full spectrum of science disciplines, including the humanities, in one consolidated text is the opportunity to capture and analyse major themes that have shaped the scientific landscape in South Africa.

The book is organised into chapters based on disciplinary areas. This is both a strength and a weakness; a strength in that each of the chapters is authored by a disciplinary expert(s), but a weakness in that these traditional approaches tend to overlook some of the most exciting research in the newer multidisciplinary and transdisciplinary fields, as aligned with the National Research Foundation (NRF) funding in many cases. Compilation of a book of this nature is unavoidably high-risk in that it purports to provide an overview of the state of science in each of the disciplines, an ambitious task indeed, and one that is likely to leave a number of gaps in important sub-disciplinary fields. Our view is that the hosting of the prestigious TWAS conference presented an opportunity to reflect on the status of South African science and that this collection should be viewed as a work in progress, and one that will hopefully have a further life after the hosting of the TWAS conference, perhaps in future editions. This initial collection can then be developed further and improved upon, without some of the serious time and other constraints that the Academy has faced in its present compilation.

The introductory chapter by Johann Mouton and Wieland Gevers traces the long and interesting history of South African scientific endeavour, highlighting the post-World War II boom in science, marked by the establishment of large strategic industries and the Council for Scientific and Industrial Research (CSIR), supporting rapid technological development and industrialisation; the ensuing proliferation of other science councils; the development under anti-apartheid siege of a considerable energy and military/defence research industry; and an increasing focus on research at some of South Africa's established universities, such that the 1960s and 1970s came to be referred to as an apparently thriving period of South African science. This was soon overtaken by progressive isolation of South African science and scientists and serious damage to the science system marked by massive emigration of the country's talent, both young and old, related to the apartheid government policies and their internal and external consequences. The major interventions of the new democratic government in the post-1994 era are documented, of which the establishment of a separate Ministry/Department of Science and Technology (DST) is the most noteworthy. Aspects of public higher education institutions in South Africa relevant to their research capacity are described, including the complex array of 'historically black' and 'historically white' tertiary institutions, the evaluation or 'rating' system of individual scientists operated by the NRF, and a number of inter-dependent national and institutional policies, that have greatly increased the productivity of the country's active researchers. Bibliometric evidence, documenting these changes, is provided, as part of an overview of the human capital base and international visibility of South African science. The chapter concludes by noting that the full mobilisation of the whole talent pool of the nation is both the biggest challenge and simultaneously, the greatest opportunity in advancing the country's science.

Against this backdrop, the disciplinary chapters follow, each with its own character and emphasis. In some chapters, the focus is on the human capital and infrastructure base, in others it is on the research foci and contributions to knowledge, and in at least one chapter, the emphasis is on an analysis of the circumstances that gave rise to the current state of the discipline rather than a survey of its state. The diversity enriches the text and provides insights to the distinctive challenges that each discipline faces.

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In Chapter 2, Kathy Driver documents the current position of the mathematical sciences, comprising pure and applied mathematics, mathematical statistics, theoretical computer science and mathematics education. The chapter places a heavy emphasis on student enrolments and success rates, clearly sketching the many concerns within the discipline. Chief among these is the fact that the mathematical sciences have the lowest 'degree success rate' of all disciplines. Others include the lack of growth in mathematical sciences majors, despite an increase in undergraduate enrolments; a decline in the number of honours (year 4 of study) students; and the relatively small cohort of secondary school students who are eligible to study mathematical sciences at university because of the poor state of mathematics education in South African schools. Addressing these issues is of paramount importance if the mathematical sciences are to fulfill their rightful role in the tertiary education system. In contrast with these gloomy statistics, some of the positive research trends are highlighted, including the evidence of an increase in total research output in the field, a relatively high mean output per researcher, evidence that mathematical scientists comprise more than a quarter of all NRF grantees, and that in terms of impact of published research (as measured by an internationally recognised indicator), mathematical sciences are ranked first of 20 science disciplines in South Africa that were considered.

As in the case of the mathematical sciences, the long history of physics in South Africa, which dates back to the 1830s when astronomical observations commenced at the Royal Observatory in Cape Town, is noted as a strength by Harm Moraal in Chapter 3. South Africa was a founding member of the International Union of Pure and Applied Physics in 1923. Moraal describes how, ironically, the isolation of the apartheid era strengthened South African physics as the country sought to become self-sufficient in nuclear energy and developed a sophisticated armaments industry. The physics undertaken at universities at the time was of high quality and innovative, but much of it was of a classified nature and did not reach the open literature. Moraal traces the adjustments to the discipline that were required in later years as national priorities shifted. He highlights the significant role of the South African Institute of Physics in fostering the development of the discipline, including recognising the value of large and established physics laboratories; flagship projects in physics and astronomy (which explain the current emphasis on astronomy in the country); and recommending interventions to improve physics education in schools. Finally, the strengths and characters of various specialist sub-disciplines, including applied physics, astrophysics and space science, are described.

In the chapter on chemistry, Raymond Haines describes how student numbers and focal areas have changed in response to external drivers such as rationalisation in the chemical and pharmaceutical industries; a paradigm shift to socially relevant research in South Africa; and, the positive interventions of the DST in the form of research chairs and centres of excellence at universities that have greatly benefited chemistry. The role of the National Chemical Research Laboratory at the CSIR, before it was dissolved in 1988, was highly significant as the laboratory was a major employer and developer of research chemists whose work was of world-class standard. Research is now also carried out by statutory bodies such as Mintek and the Nuclear Energy Corporation of South Africa (Necsa), as well as by industry, for example the giant oil-from-coal company Sasol. The strengths and character of each of the various sub-disciplines are reviewed in detail. The sub-discipline of inorganic chemistry was initially dominated by organometallic chemistry, but over time the focus has shifted to catalytic research and research of a more interdisciplinary nature. A major global focus on nanotechnology has revitalised inorganic chemistry, and coupled with the strong support of the DST, major growth can be expected in this area in the future. Organic chemistry has experienced a resurgence of interest as a result of the establishment of testing facilities in the country, the country's rich and diversified flora, and its history of traditional medicines which has led to a focus on indigenous knowledge in the national research programme of the NRF. Local research in medicinal chemistry is also enjoying growing international attention stimulated by the societal impact of diseases such as HIV/AIDS, tuberculosis and malaria. Significant achievements in the sub-discipline of physical chemistry include contributions in gas chromatography and mass spectrometry, details of which are given in the chapter. Another early achievement that has had a major impact on the South African economy is the development of a modified catalyst from local material for the Fischer-Tropsch process that laid the foundation for Sasol, the world's biggest producer of liquid fuel from coal. Finally, there is a substantial focus on research in analytical and/or environmental chemistry, much of which is of an applied nature aimed at addressing and understanding key problems in South Africa.

The fifth chapter on the biological sciences underscores the breadth and strength of this large multidisciplinary area in South Africa. The extremely rich biodiversity, the long research history founded on indigenous knowledge and knowledge dating back to colonial times, and the world-renowned national collections of plant and animal species serve as the background to the biological sciences in the country. It is noted that the biological sciences in South Africa have contributed more to the global literature than any other discipline, and that student enrolments at universities are strong and growing. Comprehensive accounts of plant sciences, animal sciences, molecular biology and biotechnology and conservation biology are given.

The earth sciences chapter embraces geology, oceanography, hydrology and atmospheric sciences. It refers to South Africa as one of the most valuable pieces of real estate in the world as a result of its mineral riches. The existence of a large and active mining industry has greatly benefited science, with the result that South African mining engineering and geological sciences have always enjoyed a degree of global recognition that far outweighs the size of the population or the economy. A brief background on the focal areas in geological sciences at each of the universities is given. The discipline of oceanography is primarily based at a single university, the University of Cape Town. The geographical location of the Cape provides an ideal natural laboratory for research on the Benguela and Agulhas currents of the Atlantic

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and Indian Oceans respectively, as well as the Southern Ocean stretching from the Cape to Antarctica. The establishment of the new Africa Centre for Climate and Earth Systems Science (ACCESS) is highlighted as an example of collaboration between oceanography and atmospheric sciences. The atmospheric sciences received a resurgence of interest in the 1990s as climate change and air quality issues came to the fore. In South Africa, the large international Southern African Fire Atmosphere Research Initiative (SAFARI) in 1992 and again in 2000 propelled South African scientists on to the global stage. Although there is a widespread interest in atmospheric sciences at South African universities, meteorology is taught at a single university, the University of Pretoria, and is geared towards the training of meteorologists for the South African Weather Services. In a water scarce country such as South Africa, it is not surprising that hydrological research is strong and is well supported by the Water Research Commission.

In Chapter 7, William Pick provides an interesting account of the early history of health and medical sciences in South Africa, and highlights some of the significant achievements in the first part of the twentieth century. These include pre-eminent research in diseases affecting mineworkers, such as tuberculosis, silicosis and asbestosis; significant virological research and the development of vaccines against typhus, plague, influenza and yellow fever; influential research on nutritional diseases that can also be traced to the needs of the mining industry; a few global firsts in transplant surgery; and research that contributed to the development of diagnostic imaging equipment, some of which resulted in the subsequent award of a Nobel prize. The 1990s marked a major shift towards socially relevant research and an upsurge in international contacts. The Medical Research Council (MRC) identified tuberculosis, malaria, nutrition intervention, trauma, AIDS and urbanisation as research priorities and introduced a system of national research programmes in these priority areas. Since 2000, there has been a dramatic increase in government funding to the MRC, such that medical research accounted for over 15% of South Africa's research and development spend in 2006. There has also been a large injection of external funding into the country which has significantly benefited medical research. Some recent research highlights include the European and Developing Countries Clinical Trials Partnership, which is hosted by the MRC and provides funding for clinical trials research on malaria, tuberculosis and HIV/AIDS; the South African AIDS Vaccine Initiative (SAAVI), which has over two hundred South African-based scientists and technicians working synergistically with colleagues in developed countries, and which has made remarkable progress in the development of potential vaccines against HIV/AIDS, but has also led to the development of modern laboratories where advanced biomedical techniques are employed; and the Centre of Excellence for TB research, which has undertaken work of global significance in combating multiple drug resistant (MDR) and extensively drug resistant (XDR) tuberculosis in South Africa and beyond. Another exciting new development is in the field of biotechnology, with South African companies, government agencies and universities actively developing products, many of which will have relevant health applications.

In Chapter 8 on the humanities and social sciences, Peter Vale presents a combination of report and analysis. He argues that the humanities and social sciences, which played a central role in bringing an end to apartheid, have been 'orphaned', and in the context of neo-liberal approaches to policy-making, are said to have failed post-apartheid South Africa. Vale notes how the humanities in South Africa have mirrored global trends, which saw the humanities being central to university education until the 1980s, but then pushed to the margins of intellectual enquiry as students opted for 'professional' qualifications and university managers sought to balance their budgets. The role of the critical discourse of the humanities in the fall of apartheid is highlighted. Central to this was the rise in Marxist ideology in the 1970s and 1980s and the heated, but fecund emancipatory, debates that characterised this period. Vale argues that the humanities have been marginalised in the new order of post-apartheid South Africa, in which scholarship seems dominated by market-driven initiatives, which the humanities have failed sufficiently to critique. The chapter closes by identifying a number of initiatives to recover and recoup the critical edge of the humanities in South Africa; these include a consensus panel organised by the Academy of Science of South Africa.

Chapter 9 on archaeology and palaeoanthropology by Alan Morris highlights the long and rich archaeological record of South Africa, referring to it as an ancient heritage that few other nations possess. He traces the growth of the discipline of archaeology, from one dominated in the early years by amateur interests to the increasing professionalism of the discipline in the 1970s. Major research themes are identified, commencing with a focus on stone tool typology and the understanding of archaeological cultures to a more ecological focus, as researchers attempted to improve their understanding of past human behaviour, beliefs and diets. The all important scientific discoveries that make up the palaeoanthropological roots of South Africa and which led to the recognition of the country as the 'cradle of mankind' are documented.

The chapter on engineering underscores the importance of the engineering discipline to the South African economy but paints a somewhat gloomy picture that clearly identifies engineering as one of the scarce skills in the country. South African universities produce on average about 1 200 graduate engineers per annum, which is only 50% of the target set by the government; the situation is even worse in respect of the production of engineering technologists from the universities of technology, which is only one-third of the government target. The ratio of engineers to total population is 1:3166 in South Africa, compared with 1:130 in China and 1:227 in Brazil. Against this background, engineering highlights and challenges confronting the engineering profession in SA are documented. The chapter concludes with a look into the future role of engineering, including clinical engineering and its role in the health sector, and electronic engineering with its focus on broadband wireless technologies.

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In the concluding chapter, some of the underlying themes that have been revealed through this overview of the state of science in South Africa are captured. These include, *inter alia*, the impact of the apartheid era on science; the influential roles of a strong industrial sector and robust science councils; the richness of the natural heritage of South Africa that has not only provided an exceptional natural laboratory but has given the country a competitive advantage in many fields; and the pockets of excellence that exist but are focused on a few individuals and a few institutions presenting sustainability and equity challenges. Finally, the chapter concludes with some messages from younger scientists in South Africa, who reflect on their visions for the future.

ROSEANNE DIAB AND WIELAND GEVERS

Authors' Biographies

BIOGRAPHIES

PATRICIA BERJAK

Patricia Berjak is professor emeritus and senior research associate at the University of KwaZulu-Natal in Durban. Her PhD was awarded in 1969 by the University of Natal, after which she spent some years at Leeds University (UK), returning to a senior lectureship at the University of Natal, where she progressed to the rank of senior professor. Her research focuses on seed cell biology. She is a fellow of the University of Natal and the Academy of Sciences for the Developing World.

She holds the Silver Medal of the South African Association of Botanists and, in 2004, received the Distinguished Woman Scientist award of the Department of Science and Technology.

DAVID BRITTON

David Britton is an associate professor in the department of physics at the University of Cape Town, where he has been employed since moving to South Africa in January 1995.

He is the previous chair of the Condensed Matter Physics and Materials Science specialist group of the South African Institute of Physics and also past chair of the South African Nanotechnology Initiative. After obtaining his PhD from Royal Holloway College London in 1988, he worked as a postdoctoral fellow in the Netherlands, Finland and Germany. His current research interests include the characterisation, development and applications of novel nanomaterials.

DON COWAN

Don Cowan was educated in New Zealand at the University of Waikato and completed a period of postdoctoral study there before moving to University College, London as a lecturer in 1985. He is currently a senior professor in the department of biotechnology at the University of the Western Cape. In 2002 he established, and is director of, the Institute of Microbial Biotechnology and Metagenomics. He serves on the editorial boards of 12 international journals.

RICHARD COWLING

Richard Cowling is professor of botany at the Nelson Mandela Metropolitan University and honorary professor in botany at the University of Cape Town (UCT). He was awarded a PhD in plant ecology from UCT in 1983 and completed a postdoctoral fellowship at Curtin University (Perth) in 1984. He was president of the International Society of Mediterranean Ecologists (1997-2000), has received many awards for his conservation research and action. He currently serves on the editorial boards of six international journals.

BIOGRAPHIES

HANNES DE W RAUTENBACH

Hannes Rautenbach received his doctoral degree in meteorology in 1999 from the University of Pretoria (UP). In 2006 he was appointed head of the department of geography, geoinformatics and meteorology at UP. Currently he is president of the South African Society for Atmospheric Sciences, serves on the board of the National Association of Clean Air, and is acting director of the Water Institute of UP. He is a co-lead author of the South African *Second National Communication Report* to the United Nations Framework Convention on Climate Change.

TREVOR DERRY

Trevor Derry has degrees from Cambridge and Witwatersrand (Wits) Universities, is a chartered physicist and fellow of the Institute of Physics (UK). He is committee chairman of the Applied Physics Group of the South African Institute of Physics. He has chaired the Schonland Co-ordinating Committee and is currently user group chairman of iThemba LABS (Gauteng). He is the co-ordinator of the diamond focus area for the DST/NRF Centre of Excellence in Strong Materials, and leads the Ion Implantation and Surface Science Research Programme at Wits. His research interests are the ion-beam modification and/or ion-beam analysis of the (near) surface of diamond and other useful materials.

PHILIP DE VAAL

Philip de Vaal obtained his PhD (1990) from the department of chemical engineering at the University of Pretoria. He is the current head of the department of chemical engineering. He established the tribology laboratory in the department and has a specific interest in laboratory evaluation of lubricant performance and in laboratory automation. He is a member of the South African Institute of Tribology.

ROSEANNE DIAB

Roseanne Diab obtained her PhD in environmental sciences from the University of Virginia (USA). She is a senior professor at the University of KwaZulu-Natal (UKZN) and since May 2008 has been the executive officer of the Academy of Science of South Africa. She is a fellow of UKZN and the South African Geographical Society. She chairs the editorial board of the *South African Journal of Science* and serves on the International Ozone Commission and the Stratospheric Processes and their Role in Climate Working Group of the World Climate Research Programme.

KATHY DRIVER

Kathleen Driver is currently professor of mathematics and dean of the faculty of science, University of Cape Town. She took up this position in January 2006 having been head of the school of mathematics at the University of the Witwatersrand (Wits) from 1999-2005. She obtained her BSc and BSc (Honours) at Wits, MSc at Stanford University and her PhD from Wits. She was a member of the international panel commissioned by the DST/NRF to review mathematical research in South Africa in 2008.

BIOGRAPHIES

PAT ERIKSSON

Patrick Eriksson obtained his PhD from the University of KwaZulu–Natal and Dr.rer nat habil, from the University of Ludwig-Maximilians, Munich. He is head of the department of geology at the University of Pretoria (UP). He is an associate editor of *Gondwana Research*, the *Journal of Marine and Petroleum Geology*, and one of two editors-in-chief of the *Journal of African Earth Sciences*. He specialises in Precambrian sedimentation systems and basin analysis.
Honours include a Medal for Academic Excellence, Centenary Research Medal, Chancellors Medal (all from UP) and the South Africa Medal (Gold) of the Southern African Association for the Advancement of Science.

KEITH FERGUSON

Keith Ferguson received the MSc degree in electronic engineering from the University of Natal and his PhD from the Institute of Science and Technology, University of Manchester (UK) in 2000. He was the technical director of a spin-out company, Video and Image Coding Specialists Ltd. that he co-founded in Manchester. The company developed novel video technologies and successfully built a fully integrated multimedia delivery platform for mobile phones and other devices. This led to the sale of the company to 2Ergo Group Plc, UK in 2006. He is currently a principle researcher and heads the Real-Time Video Coding research group at the Meraka Institute of the CSIR in Pretoria, South Africa.

ANDREW FORBES

Andrew Forbes received his PhD (1998) from the University of Natal, and subsequently spent several years working as an applied laser physicist, first for the South African Atomic Energy Corporation and then later in a private laser company. He is presently chief researcher at the CSIR National Laser Centre and is the research group leader for Mathematical Optics and Advanced Photonic Materials.
He is chair of the SPIE international conference on laser beam shaping, as well as of the South African Institute of Physics Laser Optics and Spectroscopy specialist group. He holds honorary positions with the University of Stellenbosch and the University of KwaZulu-Natal.

WIELAND GEVERS

Wieland Gevers has both a medical degree from the University of Cape Town (UCT) and a D Phil in Biochemistry from Oxford University. He has been successively president, executive officer and general secretary of the Academy of Science of South Africa.
He was previously deputy vice-chancellor for academic matters at UCT and is emeritus professor of medical biochemistry at that university, where he directed a large Medical Research Council Unit and served as founding/interim director of the Institute of Infectious Disease and Molecular Medicine. He was founder president of the South African Society for Biochemistry and Molecular Biology.

BIOGRAPHIES

DIANE GRAYSON

Diane Grayson holds a PhD in physics from the University of Washington and an honorary doctorate from Umeå University, Sweden in teacher education. She is currently academic development manager in the faculty of engineering, built environment and information technology at the University of Pretoria and professor extraordinarius in physics. She held the education portfolio on the council of the South African Institute of Physics for three terms and served two terms as elected member of the International Commission on Physics Education. She has represented South Africa at two general assemblies of the International Union of Pure and Applied Physics and science education meetings organised by the Network of African Science Academies.

RAYMOND HAINES

Raymond Haines obtained a BSc (Hons) from the University of Natal and a PhD from the University of London (1966). He was professor of inorganic chemistry at the University of Natal, Pietermaritzburg (1976-2004), and dean for extended periods between 1983 and 2002. He directed the University of Natal/CSIR Unit of Metal Cluster Chemistry (1981-1990) and, at present, is a member of the Executive Evaluation Committee of the National Research Foundation.

THOKOZANI MAJOZI

Thokozani Majozi is a full professor in the department of chemical engineering at the University of Pretoria (UP). He is also an associate professor in computer science at the University of Pannonia in Hungary. He holds a PhD from the University of Manchester's Institute of Science and Technology. He is a National Research Foundation President's awardee and has received numerous awards including the S2A3 British Association Medal.

NHLANHLA MBULI

Nhlanhla Mbuli is employed by Eskom Holdings as corporate consultant for grid planning and operations. He serves on the councils of both the South African Institute of Electrical Engineers (SAIEE) and the Engineering Council of South Africa (ECSA). He is a senior member of SAIEE is and registered with ECSA as a professional engineer. He is a postgraduate lecturer (adjunct) at the University of KwaZulu-Natal and is a research associate at Tshwane University of Technology. He holds a DIng from the University of Johannesburg.

HARM MORAAL

Harm Moraal obtained his PhD in physics in 1973 from the former Potchefstroom University for CHE, currently North-West University (NWU). He is professor of physics at NWU, having been appointed in 1973, and served as director of the school of physics from 1991 to 2002. He is a space scientist, concentrating on heliospheric physics and Antarctic science. He served on the council of the South African Institute of Physics, being president from 2005 to 2007. He is an associate editor of the *South African Journal of Science* and has served on the Cosmic Ray Commission of the International Union of Pure and Applied Physics, stepping down as chair in 1996.

ALAN MORRIS

Alan Morris is a professor in the department of human biology at the University of Cape Town. He has a PhD in anatomy from the University of the Witwatersrand. His research interests include the origin of anatomically modern humans, and the physical anthropology and skeletal biology of the Later Stone Age, Iron Age and Historic populations of Malawi, Namibia and South Africa. He is currently also an associate editor of the *South African Journal of Science*.

JOHANN MOUTON

Johann Mouton is director of the Centre for Research on Science and Technology (CREST) and professor in the department of sociology and social anthropology at the University of Stellenbosch. He received his PhD from the Rand Afrikaans University in 1983. He has taught at Potchefstroom University and Rand Afrikaans University, after which he joined the Human Science Research Council. He joined the University of Stellenbosch in 1994. He has extensive research and research management experience.

SIMON MULLINS

Simon Mullins obtained his DPhil in nuclear structure physics from the University of York (UK) in 1989. He is presently head of department of iThemba LABS (Gauteng) in Johannesburg, having moved up from the Western Cape after nine years at iThemba LABS (Faure) near Cape Town. His main research interests concern the structure of atomic nuclei under extreme conditions of high rotation, large deformations and exotic modes of angular momentum generation.

NORMAN PAMMENTER

Norman Pammenter is professor emeritus and senior research associate of the University of KwaZulu-Natal. He was elected a fellow of the former University of Natal in 2003, and in 2005 was awarded the Silver Medal of the South African Association of Botanists.

WILLIAM PICK

William Pick is a professor emeritus and former head of the school of public health at the University of the Witwatersrand, honorary professor at the Universities of Cape Town (UCT) and Western Cape. He graduated in medicine in 1964 from UCT, where he later specialised in community health. He is the past president of the Public Health Association of South Africa and past chairperson of the Epidemiological Society of Southern Africa, and retired as the interim president of the Medical Research Council in 2005. His areas of interest include population-based, policy-related research in urban health, women's health and human resources for health.

ROBERT SCHOLES

Robert (Bob) Scholes was appointed a CSIR fellow in 1994, fellow of the Royal Society of South Africa in 1999, member of ASSAf in 2000 and honorary professor at the University of the Witwatersrand in 2003. He is a systems ecologist in the CSIR's Natural Resources and the Environment unit, and a specialist in the ecology of African savannas. He has served on the science steering committee of several international research programmes: (GCTE: 1998-2004, GTOS (chair): 2001-4, Millennium Ecosystem Assessment 2003-2007, DIVERSITAS: 2006 to present) and on the Board of the World Centre for Agroforestry (2000-2006) and the South African National Parks (2006 to present).

FREDERIK SCHOLTZ

Frederik Scholtz obtained his PhD from Stellenbosch University in 1987. He was appointed as professor in mathematical physics in 1998 at the physics department of Stellenbosch University. He served two terms as head of the physics department. Since August 2008 he has held the appointment of director of the National Institute for Theoretical Physics (NITheP) and has been a member of the Council of the South African Institute of Physics (since July 2009).

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ACRONYMS

AAS	atomic absorption spectroscopy
ACCESS	Africa Centre for Climate and Earth Systems Science
AEB	Atomic Energy Board
AEC	Atomic Energy Corporation
AECI	African Explosives and Chemical Industries
AES	atomic emission spectrometry
AFRODITE	African Omnipurpose Detector for Innovative Techniques and Experiments
AGA	Astronomy Geographic Advantages
AIMS	African Institute of Mathematical Sciences
AISA	Africa Institute of South Africa
AMS	atomic mass spectrometry
ANC	African National Congress
APSG	applied physics specialist group
ARC	Agricultural Research Council
ASAPA	Association of Southern African Professional Archaeologists
ASS	astrophysics and space science
ASSAf	Academy of Science of South Africa
ATRP	atom transfer radical polymerisation
BEE	black economic empowerment
BIF	banded iron formation
BPI	Bernard Price Institutes
BRICS	biotechnology regional innovation centres
CAT	computer-assisted tomography
CE	capillary electrophoresis
CERM	Consortium for Estuarine Research and Management
CERN	European Organisation for Nuclear Research
CERSA	Centre for Epidemiological Research in Southern Africa

ACRONYMS

CeSTII	Centre for Science, Technology and Innovation Indicators
CfG	Council for Geoscience
CFR	Cape Floristic Region
CHPC	Centre for High-Performance Computing
C•I•B	Centre for Invasion Biology
CoE	Centre of Excellence
CORIS	Coronary Risk Factor Intervention Study
CPP	citations per publication
CPU	central processing unit
CPUT	Cape Peninsula University of Technology
CREST	Centre for Research on Science and Technology
CRG	Climatology Research Group
CRM	cultural resource management
CSD	Centre for Science Development
CSIR	Council for Scientific and Industrial Research
CUT	Central University of Technology
CWU	chemical work-up
DACST	Department of Arts, Culture, Science and Technology
DDT	dichlorodiphenyltrichloroethane
DEAT	Department of Environmental Affairs and Tourism
DEBITS	Deposition of Biogeochemically Important Trace Species
DEIC	Dutch East India Company
DFT	density function theory
DME	dimethylether
DoHET	Department of Higher Education and Training
DSP	digital signal processing
DST	Department of Science and Technology
DUT	Durban University of Technology
ECSA	Engineering Council of South Africa
EDI	Electricity Distribution Industry
EGRI	Economic Geology Research Institute
EGRU	Economic Geology Research Unit
EIA	Environmental Impact Assessment
ENHR	Essential National Health Research
ELISA	enzyme-linked immunoassay

ACRONYMS

ESI	Electricity Supply Industry
ESKOM	Electricity Supply Commission
ET	electrothermal atomisation
FABI	Forestry and Biotechnology Institute
FACTS	Flexible Alternating Current Transmission System
FEI	Fluorochemical Expansion Initiative
FET	Further Education and Training
FIFA	*Fédération Internationale de Football Association*
FMG	Forest Molecular Genetics
FRD	Foundation for Research Development
FTE	full-time equivalent
GC	gas chromatography
GDP	gross domestic product
GDR	giant dipole resonance
GERD	gross expenditure on research and development
GET	General Education and Training
GIS	Geographic Information Systems
GMO	genetically-modified organism
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GTL	gas-to-liquid
GTS	Grenoble Test Source
HARG	Historical Archaeology Research Group
HartRAO	Hartebeesthoek Radio Observatory
HBU	Historically Black University
HE	Higher Education
HEMIS	Higher Education Management Information System
HEQC	Higher Education Quality Committee
H.E.S.S.	High Energy Stereoscopic System
HF	High Frequency
HG	Higher Grade
HIV	Human Immunodeficiency Virus
HMC	Historical Monuments Commission

ACRONYMS

HMO	Hermanus Magnetic Observatory
HPLC	High Performance Liquid Chromatography
HRU	Hydrological Research Unit
HSDPA	High-Speed Downlink Packet Access
HSRC	Human Sciences Research Council
HTFT	High-temperature Fischer Tropsch
HTR	high temperature gas-cooled reactor
IBSS	International Bibliography of the Social Sciences
ICASA	Independent Communications Authority of South Africa
ICCT	Information and Communication Technologies
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICSU	International Council for Science
IGCC	Integrated Gasification Combined Cycle
IGRBC	Institute for Geological Research on the Bushveld Complex
IGS	Institute for Groundwater Studies
IMU	International Mathematical Union
IP	internet protocol
IPCC	Inter-Governmental Panel on Climate Change
IPUF	Indigenous Plant Use Forum
IT	information technology
IUPAP	International Union of Pure and Applied Physics
IUPPS	International Union of Prehistoric and Protohistoric Sciences
IWR	Institutes of Water Research
JINR	Joint Institute for Nuclear Research
KAT	Karoo Array Telescopes
K-RITH	KwaZulu-Natal Research Institute for TB and HIV
LABS	Laboratory for Accelerator-Based Sciences
LD	liquid desorption
LECUS	Laboratory for Ecological Chemistry at the University of Stellenbosch
LOS	Lasers, Optics and Spectroscopy
LRP	living radical polymerisation

ACRONYMS

MCM	Marine and Coastal Management
MDR	multiple drug resistant
MEDUNSA	Medical University of South Africa
MEMS	Micro Electro-Mechanical Systems
METF	Minerals Education Trust Fund
MLIS	Molecular Laser Isotope Separation
MRC	Medical Research Council
MRI	magnetic resonance imaging
MUT	Mangosuthu University of Technology
NACI	National Advisory Council on Innovation
NASA	National Aeronautics and Space Agency
NASSP	National Astrophysics and Space Science Programme
NCNSM	National Centre for Nano-structured Materials
NCRL	National Chemical Research Laboratory
Necsa	Nuclear Energy Corporation of South Africa
NEPAD	New Partnership for Africa's Development
NERSA	National Energy Regulator of South Africa
NHLS	National Health Laboratory Service
NIH	National Institutes of Health
NIM	National Institute for Metallurgy
NITheP	National Institute for Theoretical Physics
NLC	National Laser Centre
NMMU	Nelson Mandela Metropolitan University
NMR	nuclear magnetic resonance
NPRL	National Physical Research Laboratory
NRF	National Research Foundation
NRIO	National Research Institute for Oceanology
NWP	numerical weather prediction
NWU	North-West University
OECD	Organisation for Economic Cooperation and Development
OSL	optically stimulated luminescence
OTP	Organisation of Theoretical Physics
PAC	Pan-African Congress

ACRONYMS

PBMR	Pebble Bed Modular Reactor
PCB	polychlorinated biphenyls
PCR	polymerase chain reaction
PFIAO	Percy Fitzpatrick Institute of African Ornithology
PGCR	Plant Germplasm Conservation Research
PGM	platinum group metal
PGR	plant growth regulator
PISA	Photonics Initiative of South Africa
PLAAS	Programme for Land Agricultural and Agrarian Studies
PRI	Public Research Institutions
PUCHE	Potchefstroom University for Christian Higher Education
QGP	Quark Gluon Plasma
RAFT	Reversible Addition-fragmentation Chain Transfer
RCMP	Research Centre for Nuclear Physics
R&D	research and development
R&DD	Research and Development Department
RDP	Reconstruction and Development Programme
RED	Regional Electricity Distributors
RF	radio frequency
RIND	Research Institute for Nutritional Diseases
RU	Rhodes University
SAAO	South African Astronomical Observatory
SAAVI	South African AIDS Vaccine Initiative
SABONET	Southern African Botanical Network
SABS	South African Bureau of Standards
SACI	South African Chemical Institute
SADC	Southern African Development Community
SAEON	South African Environmental Observatory Network
SAFARI	South African Fire-Atmosphere Research Initiative
SAHRA	South African Heritage Resources Agency
SAHUDA	South Africa Humanities Deans' Association
SAICE	South African Institute of Civil Engineers
SAIEE	South African Institute of Electrical Engineers
SAIMM	Southern African Institute of Mining and Metallurgy
SAIMR	South African Institute for Medical Research
SAIP	South African Institute of Physics

ACRONYMS

SAISI	South African Iron and Steel Institute
SAJP	South African Journal of Physics
SALT	Southern African Large Telescope
SANAE	South African National Antarctic Expedition
SANAP	South African National Antarctic Programme
SANBI	South African National Biodiversity Institute
SANCOR	South African Network for Coastal and Ocean Research
SANERI	South African National Energy Research Institute
SANi	South African Nanotechnology Initiative
SANRAL	South African National Roads Agency Limited
SANTED	South Africa-Norway Tertiary Education Programme
SAPP	Southern African Power Pool
SARChi	South African Research Chair Initiative
SASRI	South African Sugarcane Research Institute
SAWB	South African Weather Bureau
SAWS	South African Weather Service
SBSE	Stir Bar Sorptive Extraction
SCI	Science Citation Index
SciELO	Scientific Electronic Library Online
SEP	sample enrichment probe
SHARE	Southern Hemisphere Auroral Radar Experiment
SKA	Square Kilometer Array
SSC	Separated Sector Cyclotron
SSH	Social Science and Humanities
S&T	Science and Technology
STD	sexually transmitted diseases
STEM	Science, Technology, Engineering and Mathematics
STIAS	Stellenbosch Institute for Advanced Study
SU	Stellenbosch University
SuperDARN	Super Dual Auroral Radar Network
SVC	Static VAR Compensator
TB	tuberculosis
TBHQ	tertiarybutyl hydroquinone
TDS	thermal desorption
TEM	Transmission Electron Microscopy
THRIP	Technology and Human Resources for Industry Programme

ACRONYMS

TIA	Technology Innovation Agency
TUT	Tshwane University of Technology
TV	television
TWAS	The Academy of Sciences for the Developing World
UCOR	Uranium Enrichment Corporation
UCT	University of Cape Town
UFH	University of Fort Hare
UFS	University of the Free State
UJ	University of Johannesburg
UK	United Kingdom
UKZN	University of KwaZulu-Natal
UL	University of Limpopo
ULF	ultra-low frequency
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNISA	University of South Africa
UP	University of Pretoria
US	United States
USA	United States of America
UV	University of Venda
UWC	University of the Western Cape
UZ	University of Zululand
VHE	very high energy
VLF	very low frequency
VUT	Vaal University of Technology
WAC	World Archaeological Congress
WHO	World Health Organisation
WiMAX	Worldwide Interoperability for Microwave Access
WiPiSA	Women in Physics in South Africa
WISER	Wits Institute for Social and Economic Research
Wits	University of Witwatersrand
WRC	Water Research Commission
WSU	Walter Sisulu University

ACRONYMS

XDM	eXperimental Development Model
XDR	extensively drug resistant

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ROSEANNE DIAB AND WIELAND GEVERS

INTRODUCTION

INTRODUCTION

1 CHAPTER

JOHANN MOUTON & WIELAND GEVERS

1.1 GENESIS AND HISTORY OF PUBLIC SCIENCE IN SOUTH AFRICA

Initial dynamics of science development

South African science has a long and proud tradition. Born in the mid-eighteenth century from the works of amateur natural historians and astronomers who travelled to the then Cape Colony to satisfy their intellectual curiosity, it has developed into a major science base on the African continent. The initial excursions of amateur scientists soon gave way to more formalised and institutionalised modes of knowledge production in the 19th century, with the establishment of the Royal Observatory in 1820 and the South African Museum in 1825. With the discovery of gold and diamonds and the subsequent industrialisation of the Witwatersrand[1], came a new demand for mining engineers and geologists. This was soon followed, because of various economically significant problems (mining-related occupational diseases, infectious animal epidemics and a variety of plant-crop diseases), by the establishment of major research centres (most notably the Onderstepoort Veterinary Institute and the South African Institute for Medical Research) around the turn of the twentieth century. The period between the two World Wars witnessed further consolidation of these and other research institutes (still mainly outside higher education institutions, which focused primarily on teaching – see below) and more expansion.

During this period, the first national and well-funded social science study – the Carnegie-funded investigation (1929-1932) into the plight of the poor white Afrikaner – was undertaken. In the wake of World War I and due also to increasing employment of cheap black labour on the mines, the position of many white Afrikaners deteriorated rapidly. This was further aggravated by the world depression of the early thirties, and poverty became endemic. The Carnegie study of the poor white problem (as it would subsequently become known) is recognised to be the first major interdisciplinary, applied and policy study in the social sciences in South Africa which involved both academics and government policymakers.

Post-war industrialisation

As elsewhere in the world, the period following World War II was associated with a major stimulus for science development. Standing out in this respect was the estab-

1 The area surrounding Johannesburg comprising a low range of hills rich in mineral deposits and the largest urban conglomeration in the country.

lishment of three key organisations still part of the macro-industrial landscape, namely the Iron and Steel Corporation (Iscor, now Mittal Steel South Africa), the Electricity Supply Commission (Eskom) and the Industrial Development Corporation (IDC). The key mover in all three cases was the physicist, HJ van der Bijl, who had been Director-General of War Supplies in World War II, and had come to the realisation during the execution of his duties that South African industry needed an organisation to promote the development and assimilation of new technologies. This gave rise to the establishment of the Council for Scientific and Industrial Research (CSIR), the biggest and best-resourced science laboratory complex in the country.

Since its establishment in 1945, the CSIR has played a major role in carrying out and promoting cutting-edge scientific research, and through its influence ultimately ensured a wider appreciation of the developmental role of scientific research within the country. It also, directly and indirectly, gave rise to the establishment of many of the other science councils which were formed between the 1950s and 1970s: the Mineral and Energy Technology Council (Mintek), the South African Bureau of Standards (SABS), the Human Sciences Research Council (HSRC) (1969), the Medical Research Council (MRC) (1969) and the Council for Geoscience.

A siege society under apartheid

The emphasis within the science councils was on strategic research in order to serve the national goals of the then government, many of which were security-related. This eventually led, *inter alia*, to the development of an indigenous nuclear research industry that was able, amongst other activities, to build a small number of atomic bombs (destroyed voluntarily in 1993). This was part of a powerful energy and defence research industry built up in the 1970s and 1980s, centred on the Atomic Energy Corporation (AEC), the arms manufacturer ARMSCOR and the oil-from-coal giant Sasol. Some of the research and development (R&D) related to these developments was located in certain universities (which still have well-resourced engineering faculties and spin-off companies). It is estimated that spending during the mid-eighties on energy and military/defence R&D, quantitatively the most significant research activity at the time, was higher than all civil R&D expenditure combined.

Both these developments, the proliferation of science councils and the development of a world-class energy and military/defence research industry, together with an increasing focus on research at most of South Africa's established universities, led to a major increase in national knowledge production. In one of the very few bibliometric analyses of South African science in the 1960s and 1970s, Reynhardt (1982) referred to this period as the 'golden years' of South African science. He showed that South African-authored natural science papers in the Science Citation Index (SCI)

INTRODUCTION

during the period between 1967 and 1974 grew almost exponentially, doubling in output every four years (compared to the contemporary world average of every sixteen years). This growth flattened out in the mid-seventies, however, and even started to decline by the 1980s.

It was in this time that South Africa sprang to world prominence with several noteworthy achievements – the world's first heart transplant, an indigenous uranium enrichment process, unique Fischer–Tropsch applications in oil-from-coal technology, new carbon-in-pulp technology in steelmaking, the beginning work on computer-assisted tomography (CAT scanning) amongst others.

In a more recent bibliometric assessment of South Africa's share of world science between 1980 and 2000, Ingwersen and Jacobs (2004) showed a further fluctuation: from a low base of below 0.6% of world science in 1980 (expressed as the percentage of (any) authors with South African addresses out of all authors of all indexed papers), South Africa's share of world science peaked in the period between 1985 and 1990 at around 0.77%.

The 1960s and 1970s represented the period of strongest growth in scientific institutions and knowledge production in the history of South African science up to that time. This coincided, as far as can be established in a mostly classified environment, with the biggest expenditure on R&D in the history of state support of science, although it was heavily skewed towards investment in military R&D.

Ironically, although the era of 'apartheid science' (between the late 1960s and the late 1980s) was apparently the 'best of times' for South African science, it was also the worst of times. Emigration (an old problem that was associated with no fewer than four Nobel Prizes being awarded to South African-born scientists whose main work was done overseas – M Theiler, A Cormack, A Klug and S Brenner) increased dramatically, affecting both established and potential talent and robbing the country of a large proportion of its best scientific talent. Many young graduates opted to move overseas rather than to serve under conscription in the armed forces on the country's embattled borders.

This was worsened by the 'internal emigration' of many talented young Afrikaans-speaking graduates into a government system drawing for the recruiting of its officials on only a tiny fraction of the South African population, and weakening the universities that were their natural academic preserve.

Progressive isolation of a science system

The apartheid policies of the National Party[2] government resulted in the gradual and widespread isolation of South African science and scientists over this period. Although the party came to power in 1948, South Africa's political isolation can be traced to various critical events that

2 The National Party won the 1948 election on a policy of apartheid.

occurred in the late 1950s and early 1960s – the banning of the African National Congress (ANC)[3] in 1960; Prime Minister Verwoerd's decision to leave the Commonwealth in 1961; the Sharpeville massacre[4] in 1960; Nelson Mandela's incarceration in the same year; and subsequent United Nations arms embargoes commencing in 1963. These were soon followed by comprehensive cultural sanctions (enacted for the most part in the 1970s and 1980s), which included severing academic links and contacts with South African scholars and scientists. South African scientists could not for the most part attend international conferences and meetings, visits by foreign scholars to South Africa dwindled, and scholarly exchanges of most kinds became negligible. International scientific collaboration became nearly impossible, as increasing numbers of South African societies and professional associations were banned from being members of international bodies (such as the United Nations Educational, Scientific and Cultural Organisation (UNESCO), the International Council for Science (ICSU) and many others).

The South African government, through its censorship laws, further contributed to academic isolation by banning books by authors (mostly Marxist and neo-Marxist) that it saw as a threat to the civil order. The pariah status that was assigned to the government spilled over to its citizens and also its scientists.

Exacerbation of weakness through internal dysfunction

The ideology of apartheid also had major negative effects on the state of South African science itself. On the one hand, it led to increasing polarisation within the white academic community at the historically white universities, and, on the other, to the creation of the historically black universities (HBUs) or so-called 'bush colleges' (see below). This gave rise to huge inequalities within the higher education system, with very little or no contact between white and black academics. As to the former, the relations between Afrikaans- and English-speaking scholars, or between more conservative and more liberal academics, within both universities and science councils, became ideologised and polarised. A significant number of scientists and academics sided with the government and supported institutions such as the *Broederbond* (a secret society of government supporters which exerted a major influence in all spheres of society and government) and the *Suid-Afrikaanse Akademie vir Wetenskap en Kuns* (an exclusively Afrikaans *Academy of Science and the Arts)*.

Some scholars in fields such as education, anthropology, history and sociology not only publicly supported the apartheid ideology, but provided scientific and academic justifications for it. A majority of the country's academics, on the other hand, dissoci-

3 The ANC is the party of Nelson Mandela and the governing party of South Africa. It was formed in 1912 and is the oldest political organisation in the country.

4 A confrontation between South African police and black protestors that occurred in the township of Sharpeville, south of Johannesburg on 21 March 1960, which led to the killing of 69 people.

ated themselves from the apartheid state and engaged in varying degrees of critique, dissension and protest.

These divisions soon spilled over into a form of internal academic isolation which was most clearly manifested in the social sciences. Academics in such fields as sociology, anthropology, psychology and education split along ideological lines, while liberal and progressive scientists refused to apply for funding from government or to collaborate with conservative academics. A number of professional societies split over issues of membership of black academics, which led, during the 1960s and 1970s, to the establishment of separate professional societies respectively for anthropology, sociology, education and psychology. In each case, one society would not allow black academics to join and would often be closely aligned to the political leadership of the day; the other society (more liberal and critical) would be open to all within the respective disciplines, and would encourage critiques of the apartheid state.

Apartheid-driven academic engineering

The creation in the 1960s of the HBUs and their systematic marginalisation and mismanagement under government control led to a different kind of polarisation, i.e. between 'privileged' white universities and 'disadvantaged' black universities. The HBUs in their conception and implementation were aligned with the apartheid government's policy of establishing homelands for each ethnic group. Hence, the University of Zululand was established to serve the Zulu community, the University of Bophuthatswana to serve the Tswana ethnic group, and so on. The HBUs were also viewed as predominantly teaching institutions, with little scholarly investment and little encouragement to engage in postgraduate studies, research and scholarship.

Because of international bans and boycotts, many South African scientists had little scientific contact with their international colleagues during the 1970s and 1980s. Equally, if not more serious, however, was the lack of contact within the scientific community in South Africa. Collaboration with colleagues across political and racial divides was minimal to non-existent, leading to an internally isolationist scientific culture in a system that was compartmentalised in the extreme.

The tide turns – transition to an inclusive democracy

The late 1980s were associated with an increasing liberalisation of government policies. Sustained international pressure (sanctions, boycotts) and internal political and economic realities made it inevitable that the apartheid government would eventually accede to demands for a democratic state. By the beginning of the 1990s, it was clear that change was imminent. On 27 April 1994 the first democratic election was held in South Africa's history, which resulted in the ANC coming to power. The new government quickly moved to eradicate all vestiges of apartheid, including that within the national science and technology (S&T) system. A new S&T policy framework was developed, new governance structures were put into place, and various initiatives were launched to restructure and re-position scientific institutions.

The most significant feature of the new order has been the central role of a new Ministry, first combined with arts and culture, then separated to become the Ministry/Department of Science and Technology (DST). A series of important policy statements has been instrumental in the unfolding of an agenda that has positioned S&T as a form of national investment with large socio-economic returns. A 'National Science and Technology Forum' established for systemic consultation in the transition has survived to play a useful role in the settling-down period. The National Advisory Council on Innovation (NACI) advises Cabinet through the Minister of Science and Technology.

A new science academy

The Academy of Science of South Africa (ASSAf) was established in 1996 as the new national science academy, with an inclusive approach to all empirical disciplines and a mandate to generate evidence-based advice along the lines of the United States (US) National Academies and the Royal Society in the United Kingdom (UK); it became a statutory organisation in 2001 but operates independently of the government. The roles of the non-statutory, 100-year old 'Royal Society of South Africa' and '*Akademie vir Wetenskap en Kuns*' have respectively become the advancement at grass-roots level of the natural sciences and the promotion of science and the arts in the highly-developed indigenous language, Afrikaans. ASSAf has published comprehensive reviews of scholarly publications produced in and from South Africa in journals and in books, as well as several other significant reports. It publishes the flagship *South African Journal of Science* and the country's leading science magazine, *Quest–Science for South Africa*.

Rapid evolution of a new and dynamic national S&T system

The initial approach of the new government to the essential features of the national research landscape was to require the science councils to raise up to half their resources from external contract income, to see that the universities concentrated on their teaching role in the new, much more inclusive admissions context, and to allow business/industry to look after itself. This has rapidly changed to a much improved and more unified strategy where government itself has driven new science-based initiatives (such as the Pebble Bed Modular Reactor (PBMR) and the bid for the 'Square Kilometre Array' (SKA) mega-radiotelescope), where science councils are seen as key research resources in strategic areas, 'research-led universities' are being fostered, the expansion of the national pool of high-level 'human S&T capital' is a core agenda, a highly innovative business sector is encouraged, and foreign partnerships and alliances are selectively fostered.

Successive ministers and chief civil servants have been able to unlock funding from the National Treasury to increase the national R&D spend in terms of gross domestic product (GDP) to nearly 1%, from a low base in 1994 of 0.4%. A national R&D policy accepted by Cabinet in 2002 formally created five new 'missions' to replace the dominant military and energy-substitution drivers of the past, and a follow-up 'Ten-Year Innovation Plan' adopted in 2008 refined the trajectory in terms of specific targets. Recently, the passage of an Intellectual Property Protection Act and the establishment of the Technology Innovation Agency (TIA) have served to underline a very clear commitment to innovation in the country's future.

1.2 Higher education institutions in South Africa

A well-developed, newly reorganised university system

Lack of space prohibits providing a full description of the 23 public higher education institutions in South Africa. Table 1.1 lists them in their three categories, universities, comprehensive institutions, and universities of technology, with main locations, total student numbers, numbers of registered Masters and Doctoral students, and total numbers of academic and research staff. The table reflects the reorganisation of institutions conducted in 2002-4, when many of the distinctions between the 'historically (disadvantaged) black' and 'historically (advantaged) white' institutions were blurred but certainly not extinguished through deliberate mergers.

The higher education sector accounts for 23% of research expenditure and 33% of full-time equivalent (FTE) human resources engaged in research. There are approximately 50 000 postgraduate students (Masters and Doctoral levels) enrolled at South African universities (figures for 2007).

General features of the university system

All the public higher education institutions are funded by the Department of Higher Education and Training (DoHET) through a complex, formula which takes account of both (prospective) teaching loads (inputs) and (retrospective) research activity (outputs), and also includes field-specific factors and a variety of developmental parameters. As state subsidies declined in relation to the operational needs of especially research-active institutions, student fees have risen sharply and 'third-stream' income has increased. As a crude generalisation, capital infrastructure (buildings, equipment and general facilities) by international standards varies from good to impressive, while student-staff ratios would be considered high to very high, particularly if the poor pre-university preparation of a majority of undergraduates is taken into account.

The academic model used by South African universities was derived from Scottish/British precursors, offering a mix of 3-year general and 4-year professional Bachelors degrees, selective-entry, 1-year Honours programmes which are expected to deepen knowledge and prepare especially talented students for research activities, and sequential research/taught Masters and research-only Doctoral degree oppor-

Table 1.1: Public higher education institutions in South Africa, 2007

Name of University	Main location(s)	Total students	(Masters/ Doctoral students)	Academic/ Research staff
North-West University (NWU)	Potchefstroom, Mafikeng	38 708	3 699	889
Rhodes University (RU)	Grahamstown	5 915	846	323
University of Cape Town (UCT)	Cape Town	21 188	3 908	1 658
University of Fort Hare (UFH)	Alice, Bisho, East London	8 527	500	261
University of the Free State (UFS)	Bloemfontein	24 684	3 022	1 083
University of KwaZulu-Natal (UKZN)	Durban, Pietermaritzburg	37 850	4 901	1 472
University of Limpopo (UL)	Polokwane, Tshwane	17 469	1 817	1 984
University of Pretoria (UP)	Pretoria/Tshwane	53 080	6 536	2 249
University of Stellenbosch (SU)	Stellenbosch	23 439	4 953	786
University of the Western Cape (UWC)	Cape Town	14 838	1 487	376
University of Witwatersrand (Wits)	Johannesburg	25 101	5 717	1 231
COMPREHENSIVE INSTITUTIONS				
Nelson Mandela Metropolitan University (NMMU)	Port Elizabeth	24 245	1 708	510
University of Johannesburg (UJ)	Johannesburg	41 613	2 085	2 792
University of South Africa (UNISA)	Pretoria/Tshwane	227 538	5 408	1 393
University of Venda for Science & Technology (UV)	Thohoyandou	10 968	307	245
University of Zululand (UZ)	Ulundi	9 317	473	308
Walter Sisulu University (WSU)	Mthatha, East London	24 120	162	683
UNIVERSITIES OF TECHNOLOGY				
Cape Peninsula University of Technology (CPUT)	Cape Town	28 952	710	657
Central University of Technology (CUT)	Bloemfontein	10 478	271	816
Durban University of Technology (DUT)	Durban	22 702	359	566
Mangosuthu University of Technology (MUT)	Durban	10 096	0	143
Tshwane University of Technology (TUT)	Pretoria/Tshwane	51 446	1 825	855
Vaal University of Technology (VUT)	Vanderbijlpark	16 146	208	840

Source: SARUA Handbook 2009: A Guide to the Public Universities in Southern Africa, accessed on 4 September 2009 at http://www.icsu-africa.org/docs/handbook-sarua.pdf.

tunities. The DoHET controls the 'qualification mix' that can be offered by individual institutions, both in terms of fields on offer and the levels at which students can be registered and taught. A large proportion of students entering university study through the systemic gate of a national school-leaving examination is under-prepared, mainly due to serious problems in the schooling system that have unfortunately been largely refractory to improvement measures since the democratic transition of 1994. All institutions accordingly dedicate considerable resources to 'academic development programmes', comprising a mix of special and/or extended curricula, support units, financial aid and modified admission and/ or progression rules. The state operates a large-scale National Student Financial Aid Scheme offering loans (sometimes convertible into bursaries) to needy students.

The 'core resource' neglected – university-based staff doing research as a side-line

Academic staff promotion grades at South African universities are similar to those used in the UK system, with the ranks of lecturer and senior lecturer rising to associate and full professorship. Traditionally, much of their research activity has been in the nature of a kind of 'cottage industry'. Government-sourced research funding has been channelled to higher education institutions mainly through the NRF (already mentioned above) in respect of the natural, engineering, social and human sciences, and the MRC, with small coordinated contributions from bodies such as the Water Research Commission (WRC). This mostly comprises various kinds of project-related grants and bursary-type funding to both individual student applicants and investigators, both predicated on the provision of institutional infrastructure. This funding pattern is in effect a 'sprinkler system' distributing limited funds on a widespread basis.

It is fair to conclude that the nadir of science productivity in the early 1980s described above was associated with academic isolation, the reorganisation of the CSIR, and the poorly differentiated and 'sprinkler-maintained' university research system.

The 'core resource re-energised – university staff with time to do research

The widespread previous practice of pyramidal fixed hierarchies in university departments evolved along US lines into a system where, in addition to new competitive appointments into advertised posts, all internal staff members could be annually promoted to higher ranks on an *ad hominem* basis. This change has had dramatic effects on the system, encouraging the building of critical-mass research groups with senior co-workers, improving postgraduate supervision, and retaining many talented researchers in the country. A second factor favouring research concentration has been the recent rapid expansion of the postdoctoral fellow tier in academic departments and research groups, funded from within institutions, from state agencies, and from charitable foundations both in the country and in overseas (developed) countries. These usually very talented people would in earlier days invariably have proceeded overseas to further their careers, with high risks of 'brain drain'; now they are able to provide almost ideal support to hard-pressed academic staff in terms of keeping research activity going in groups, institutes, units or centres.

The research system of the higher education institutions has to a large extent been moulded since the 1980s by the adoption by the national funding agency (the National Research Foundation, NRF) of a 'rating system' for scientists and scholars by means of which they are formally and publicly classified for five years at a time into a number of categories on the basis of an extensive international multiple peer-review process. Categories 'A' and 'B' reflect international recognition in the respective field, category 'C' steady national eminence, and 'P' a bright star of the future. As might be expected, the rating system is highly controversial across different fields and modes of practising scholarship.

Strategic high-level human capital development in S&T – the new priority

The most recent systemic injection into research concentration has been the national research chairs programme sponsored by the DST and administered by the NRF. About a third of the projected total of 210 chairs has been established to date, competitively providing salary and significant support packages to incumbents across the university system for renewable periods of five years. Many have been 'brain gain or regain' appointments, bringing 'new blood' into the country's science system. The smaller, but individually better resourced national 'centres of excellence' programme (which has established seven large concentrations of especially productive scholars in several institutions), has been built on an older and still persisting model of research units/groups/centres set up by funding agencies in strong or priority areas.

Together with the national equipment programme, and very significant foreign programme funding in certain fields like health, these interventions have been particularly effective in addressing the problems inherent in a generalised model for academic staff of heavy teaching duties and limited research time. Many institutions have in fact positioned themselves to gain from these programmes by organising their internal research development efforts in focused ways that promote competitive advantage in gaining access to the external funding.

Finally, it should be mentioned that the 'supply-side' subsidisation stream for public higher education institutions generated by formula on the basis of research outputs (about R 1.5 billion per annum each for Masters- and Doctoral-level graduations, on the one hand, and for accredited publications, on the other) outweighs the total flows generated by the competitive 'demand-side' grants distributed by the NRF, MRC. WRC and other agencies, which do not for that reason, cover overhead costs. Institutions have used some of this discretionary funding to establish effective and efficient research directorates working in concerted ways to build capacity and maximise benefits under unfolding national policy. There is much debate whether the balance between the two overall funding streams is appropriate, but it seems that productivity and quality enhancement have in fact been materially assisted by the mix of autonomous and steered support of institutional research systems.

1.3 Public research institutions, including the science councils, government-based units, and national research facilities

Key national research resources: public entities

There are currently 12 major public research institutions (PRIs), which are exclusively R&D performing institutions. (The exception is the MRC, which also has an agency function.) Space precludes mentioning here more than simply the existence of these important and productive organisations: many of the extensive research activities of these organisations will be described in the chapters of this book.

The first and largest PRI, the CSIR, was established in 1945, although the model dates back to the mid-1930s in certain other Commonwealth countries. The other PRIs are the Agricultural Research Council (ARC), the HSRC, Mintek (for minerals processing research), the MRC, the South African Bureau of Standards (SABS), South African Weather Services, the Council for Geoscience, the South African National Energy Research Institute (SANERI), the South African National Biodiversity Institute (SANBI), the Marine and Coastal Management division (a division of the Department of Environmental Affairs) and the Africa Institute of South Africa (AISA). In principle, the funding of the PRIs consists of a parliamentary component (on average 50% of the total budget of the institution) and income generated through contract activities. The most recent *National R&D Survey (2006/7)* shows that science councils accounted for 17.3% of total national expenditure on R&D and employed 23% of the total full-time equivalent (FTE) R&D workforce.

Each PRI is mandated by an act of parliament to undertake R&D for the benefit of the country. Many of the extensive research activities of these organisations will be described in the chapters of this book.

Government research

A second category of R&D bodies comprises several relatively modest public R&D enterprises that have been established by government departments to serve functions integral to their core functions, including the National Health Laboratory Service (administered by the Department of Health) and the Water Research Commission (a funding agency reporting to the Department of Water Affairs).

These units are mostly governed and funded by the relevant department and managed by specially appointed staff. Their R&D outputs are intended primarily for utilisation by the line department and only secondarily for the general public.

'Big science' in South Africa – the national research facilities

A limited number of unique national research facilities are managed by the NRF on behalf of the DST. They are grouped by field into several categories:

Astro/Space/Geo Sciences:

- South African Astronomical Observatory (SAAO)

- South African Large Telescope (SALT)
- Hartebeesthoek Radio Astronomy Observatory (HartRAO)
- Hermanus Magnetic Observatory

Biodiversity/Conservation
- South African Institute for Aquatic Biodiversity
- South African Environmental Observatory Network (SAEON)
- National Zoological Gardens of South Africa

Nuclear Sciences
- iThemba Laboratory for Accelerator Based Sciences

Each of these facilities has staff, equipment and other resources designed to support full-time research and capacity development at the highest possible levels in the fields concerned; many of their projects and programmes will be described in the other chapters of this book.

1.4 Overall investment in science

R&D spending as a function of GDP

Investment in science in the years immediately before and after 1994 had been on the decline and this accordingly became one of the main strategic priorities of the new government. Figure 1.1 illustrates how state expenditure since 1993 has been increasing exponentially in nominal terms (from just above R2 billion in 1992/93 to over R16 billion in 2006/7). The expenditure in real terms has also increased substantially, although growth has been more gradual.

Key indicators

Table 1.2 lists some of the key indicators of the current South African science system. The expenditure in R&D over the past 15 years has meant that Gross Expenditure on R&D (GERD) in 2006/7 constituted 0.95% of GDP. This means that the target of 1% as set in various policy documents of the DST is within sight. The biggest share of this (89%) is civil R&D, another indication of the huge decline in expenditure on military/ defence R&D over the past two decades. The business sector now consistently spends the most on R&D (approximately 56%), followed by higher education (about 20%) and the science councils (17%).

Information on the scientific workforce in Table 1.2 reveals very little growth in the total number of researchers in terms of both the total headcount or in FTEs. In fact the total number of researchers per 1000 of total employment has remained stable at 1.5 for the past five years. An international comparison (Fig. 1.2) shows that South Africa does not compare favourably with selected countries as far as human resources for S&T are concerned.

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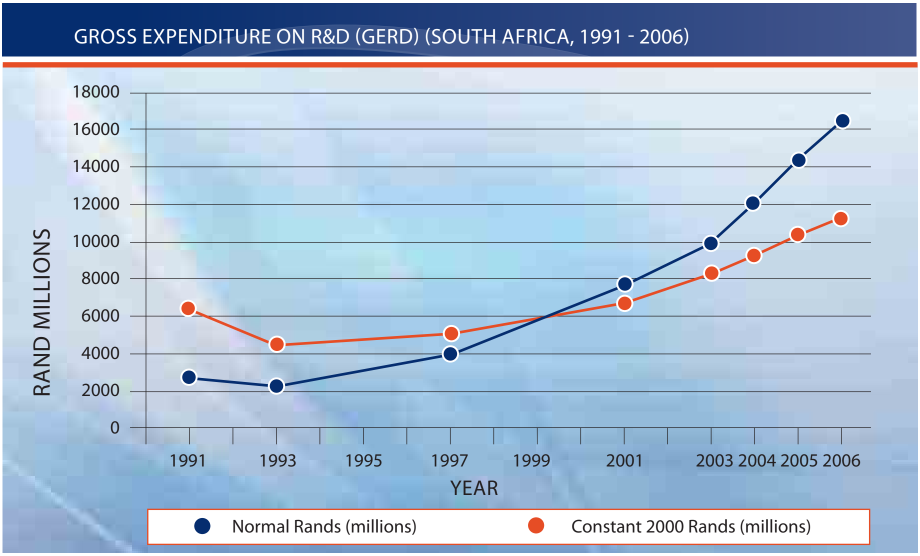

Figure 1.1: Gross expenditure on R&D (GERD)
Source: HSRC: R&D Survey 2006/7.

Table 1.2: Key R&D indicators

Indicator	Value 2006/7	Value 2005/6	Value 2004/5
Gross domestic expenditure on R&D (GERD) (Rand million)	16 520.6	14 149.2	12 010.0
GERD as a percentage of GDP	0.95	0.92	0.87
Total R&D personnel (FTE)[5]	30 986	28 798	29 696
Total researchers (FTE)[6]	18 572	17 303	17 915
Total researchers per 1 000 total employment (FTE)	1.5	1.5	1.6
Civil GERD as percentage of GDP	0.89	0.86	0.80
Total researchers headcount	39 591	39 264	37 001

5 Full-time equivalent.
6 Following Organisation for Economic Co-operation and Development (OECD) practice, Doctoral students are also counted as researchers.

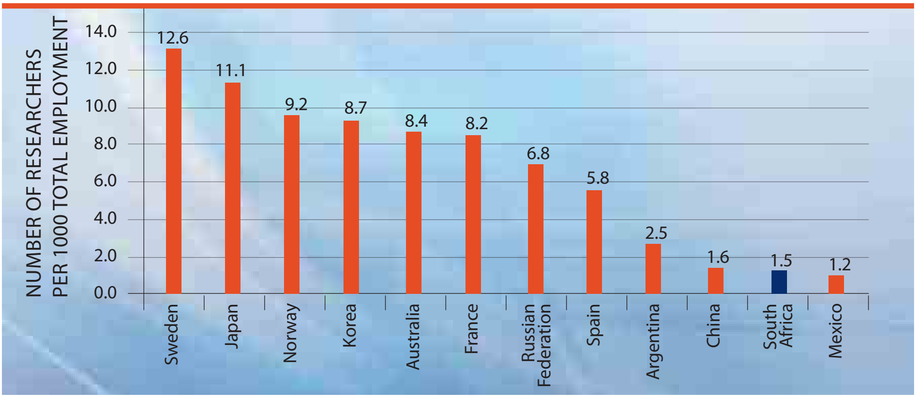

Figure 1.2: International comparison of the number of full-time equivalent (FTE) researchers per 1 000 total employment in 2006

Breakdown of the research spend

The biennial R&D surveys conducted by the HSRC also measure the broad types of research being conducted in the country. The 2006/7 survey showed that most of the work (46.3%) was classified as experimental development, 35.1% as applied research and only 18.6% as basic research. This distribution changed when differentiated by main sector; for example, in the university sector, the basic research percentage is 41%. Nevertheless, as Figure 1.3 shows, South Africa's investment in basic research (18.6% of total R&D expenditure) does not compare favourably with other major countries.

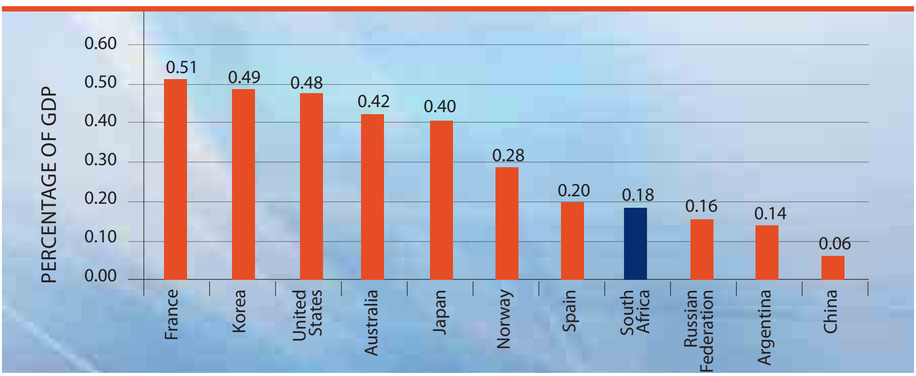

Figure 1.3: International comparison showing basic research as percent of GDP

Source: National Survey of Research and Experimental Development, 2006/7.

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In summary, the steady growth in investment in science over the past decade is a testament to the government's commitment to public science. At the same time, there are clear indications in the statistics that investment in basic and fundamental research does not receive sufficient attention. A notable feature is the lack of growth in the size of the scientific workforce, which means that despite the marked gains in productivity, South Africa may find it increasingly difficult to compete in the global knowledge economy. Together with other trends (such as the ageing of the active workforce), the broadening of the human resources base for S&T continues to pose a big challenge to the national system of innovation.

1.5 Trends in research output

Problems in the application of bibliometric methodology to developing countries

Measuring South Africa's research output is not straightforward[7]. The results are dependent on the set of scientific journals taken as the basis for the measurement. Many countries depend on analysis of the sets of journals indexed in the Thomson Reuters (ISI) Web of Science (the Science Citation Index, Social Sciences Citation Index and the Arts and Humanities Citation Index), and most bibliometric scholars use the same reference journals in order to make comparison across countries possible. It is well documented, however, that the ISI-journals have a significant Anglophone and developed-country bias which penalises Francophone and other non-English speaking countries, as well as developing countries in general. In the latter case, journals in developing countries (including South Africa) are not well covered in the ISI database simply because many of them are very local journals with small subscription bases and consequently very low international visibility.

As mentioned previously, South Africa has a unique system of state funding of research output through the official recognition of a set of so-called 'accredited journals', as managed by the national Department of Higher Education and Training (DoHET). As a result, more than 250 local journals across all fields of science benefit indirectly as South African academics publish in these journals in order that their institutions can qualify for the publication subsidy (an amount of R106 000 in 2007). (The Academy of Science of South Africa is currently engaged in a DST-supported programme aimed at raising the quality, quantity and visibility of articles published in the local journal and scholarly book system.)

Unless research output in local journals is included in any measurement of national research output, the result is a very skewed picture of knowledge production, particularly for the social sciences and humanities.

7 The measurement of research output is confined to research articles in peer-reviewed journals in order to make international comparison possible.

Table 1.3: Research output in ISI-journals: country total versus higher education (1995-2007)

YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Country papers	3 711	4 114	4 197	4 395	4 535	4 338	4 460	4 791	4 684	4 854	5 712	6 168	6 245
Higher Education (HE) papers	2 987	3 317	3 402	3 555	3 691	3 560	3 701	3 977	3 974	4 140	4 899	5 342	5 346
HE share	0.80	0.81	0.81	0.81	0.81	0.82	0.83	0.83	0.85	0.85	0.86	0.87	0.86

It is now known that local journals published in developing countries can have high impact factors in a regional, language-restricted or field-specific manner. Hence, in the discussion that follows, trends in research output as counted in both these journal sets – in ISI-journals only, and in all accredited journals – are presented.

Outputs in ISI-indexed journals

An overview of South Africa's total output in ISI-indexed journals for the period 1995 to 2007 is presented in Table 1.3. There has been a steady increase in output since 1994, with a near doubling of total output. The table also shows how the share of output of academics at universities has increased over this same period: from 80% in 1995 to 86% in 2007.

In addition to the staff at universities, the other main contributors to South Africa's research output are staff employed by the science councils (most notably the CSIR, HSRC and ARC), the national research facilities (e.g. SAAO and the Hartebeesthoek Radio Astronomical Observatory) and some government research institutes (such as the National Health Laboratory Services and the South African National Biodiversity Institute). The diminishing share of the non-university sector could be an indication of the increasing commercialisation of the research portfolio at the science councils which have been forced increasingly to earn large parts of their operating revenue through contract research. Closer inspection of the contributions of the individual science councils also shows that the ARC has recorded no growth in its output over this period, reflecting perhaps the impact of recent organisational difficulties at this council.

Differential performance of different universities and fields

As far as the universities are concerned, eleven universities have produced more than 1 000 papers in ISI-journals over this period, constituting 92% of total output by the sector. The individual shares of universi-

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Table 1.4: University shares of South African research output in ISI-journals (1995-2007)

	TOTAL (1996-2007)	SHARE (%)
University of Cape Town (UCT)	10 219	19.7
University of the Witwatersrand (Wits)	8 523	16.4
University of Pretoria (UP)	6 998	13.5
University of KwaZulu-Natal (UKZN)	6 670	12.9
Stellenbosch University (SU)	6 150	11.9
University of the Free State (UFS)	2 181	4.2
Rhodes University (RU)	1 963	3.8
University of Johannesburg (UJ)	1 562	3.0
North-West University (NWU)	1 456	2.8
University of the Western Cape (UWC)	1 212	2.3
Nelson Mandela Metropolitan University (NMMU)	1 047	2.0

ties in descending order are summarised in Table 1.4.

A breakdown by main scientific field (Fig. 1.4) shows clearly that South Africa's research output in ISI-journals is dominated by the natural and agricultural sciences (53% combined) and health sciences (26%).

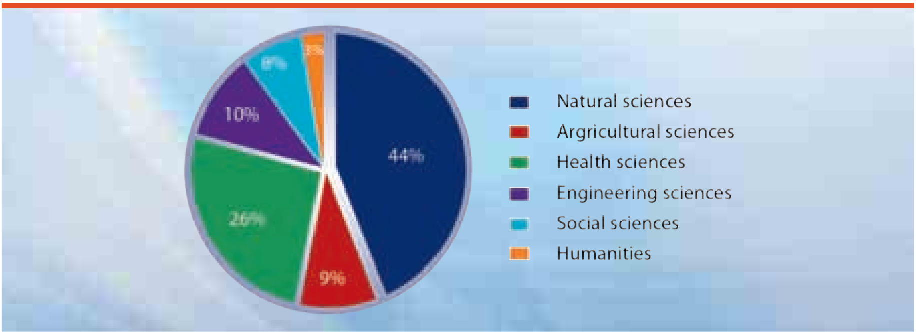

Figure 1.4: South African ISI-output by main field (1995-2007)[8]

8 This graph represents 'article units', i.e. fractional counts of research output. This enables the DoHET to assign research subsidy fairly in those cases where articles have multiple authors both from more than one South African university as well as from overseas universities.

The contribution of the social sciences and humanities is only 11%, although this proportion has increased in recent years.

Outputs in journals accredited by the Department of Higher Education and Training

A second point of reference is to look at research publications in ISI- and non-ISI journals (local and International Bibliography of the Social Sciences (IBSS)-journals) as recognised under the DoHET's system of research output-generated institutional funding (since 2003)[9]. Based on information captured in SA Knowledgebase[10], one can take a long-term view of research article output at South African universities.

The total article output (fractional counts) remained very stable from the inception of the funding framework in 1987 until the revision of the original policy in 2003. With the promulgation of the new policy framework in 2003 (which came into effect in 2005), there occurred the first significant increase in 15 years – a trend that has continued until 2006 (when the system reached its recent peak of 7400 article units) (Fig. 1.5).

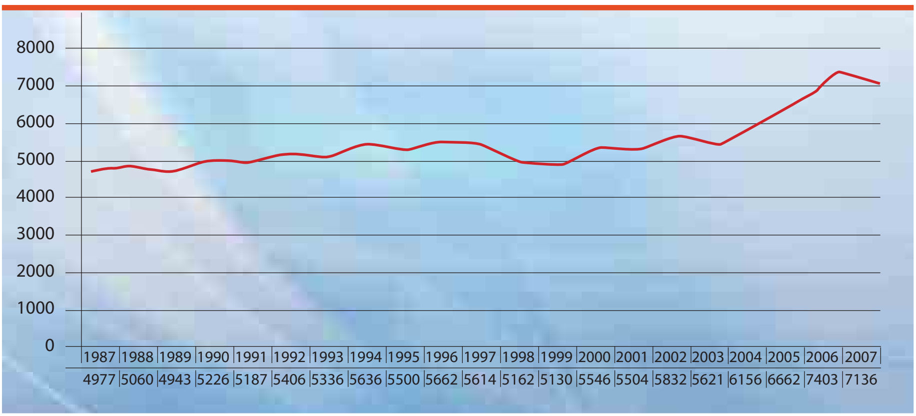

Figure 1.5: Higher education article unit output (1987-2007) [11]

9 The DoHET funding system only applies to papers published by staff affiliated with one of the 23 universities in South Africa, hence this measurement excludes all non-university publications. Given that the higher education sector dominates research output in the country (86% of all ISI-papers in 2007 were authored by university academics), this still represents a significant measurement.

10 *SA Knowledgebase* is a bibliometric database housed at the Centre for Research on Science and Technology (CREST) which contains bibliographic and demographic information on scientific articles produced in accredited journals (ISI and non-ISI) since 1987 by any South African author.

11 It is important to emphasise that this graph represents 'article units', i.e. fractional counts of research output. This enables the DoHET to assign research subsidy fairly in those cases where articles have multiple authors both from more than one South African university as well as from overseas universities.

The increase in output from 2004 onwards is such that it calls for an explanation, as it is not been associated with an increased number of producing scientists and scholars in the system. The factors described in an earlier section (the changes in promotion and retention policies at institutions, the incentives provided by the rating system operated by the NRF, the introduction of research chairs and centres of excellence, the establishment of several large research institutes, the overall strategic approach to research capacity development now being adopted at both national and institutional levels, etc) have probably, in different combinations in different settings, provided the momentum for the observed enhancement of the national R&D system. It is unlikely that aberrations in policy-responsive behaviour on the part of publishing scholars are a serious issue in the face of the increasing internationalisation of the research outputs described previously, and the efforts by ASSAf to improve the quality of local journals.

Overall performance in broad research fields

South Africa's research output as a function of main disciplinary fields is shown in Figure 1.6, which presents the breakdown for the period 1990–2006 for output in all DoHET-

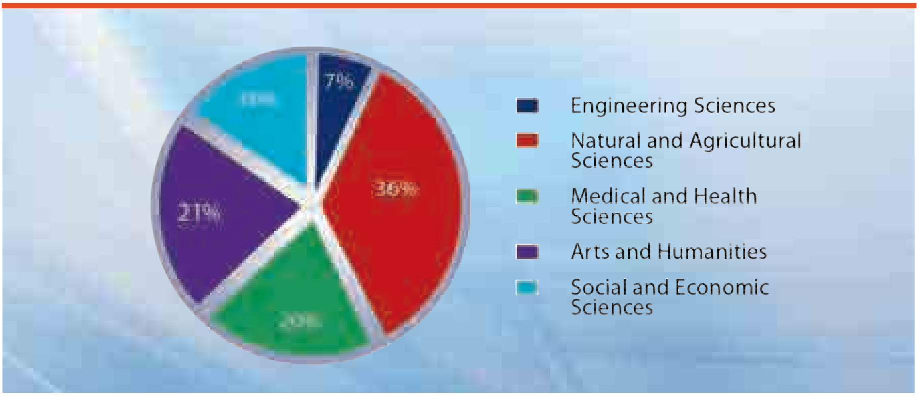

Figure 1.6: Total South African article output by broad disciplinary field, 1995-2006

accredited journals, i.e. for local (non-ISI) as well as ISI and IBSS-journals.

The general picture presented in Figure 1.6 has remained remarkably unchanged over the 17-year period covered; the respective contributions of the natural sciences (36%) and the social sciences and humanities combined (37%) have remained virtually the same over the period. But this general picture hides quite large disciplinary differences when broken down according to whether the work was published in ISI-journals or in local (non-ISI) journals, as shown in Figures 1.7 and 1.8, respectively.

South Africa's output in ISI-journals has been dominated by the natural sciences (43 – 46%), followed by the health sciences (25 – 28%) and engineering sciences (10%). The social sciences and humanities, combined, have produced between 9 and 11%[12] of all outputs. Figure 1.7 essentially presents the same picture as Figure 1.4, but now over the period of 12 years.

The distribution of output in non-ISI journals (all South African journals) is virtually a mirror image of the previous figure; the social sciences and humanities represent approximately three quarters of the output in local non-ISI journals.

These figures show the co-existence of two 'publication cultures' in South Africa; scholars in the social sciences and humanities who publish predominantly in South African journals, and scholars in the natural and health sciences who publish much more in foreign journals. This is almost certainly due to the fact that social science scholarship is typically deeply embedded in the local social and cultural context of a specific country, while the work of natural and health scientists is not, or less so. This means, unfortunately, that much of this potentially valuable scholarship is invisible in international indexes such as the Thomson Reuters Web of Science. The development by ASSAf of a free online, quality-assured platform for locally published journals within the SciELO (Scientific Electronic Library Online) system first developed in South America, is an appropriate response to this problem.

Institutional differences in publication patterns

Recent studies by CREST have revealed large variations between South African universities in terms of publication behaviour. A breakdown of institutional profiles as far as publication in ISI versus non-ISI journals is concerned is shown in Table 1.5. A distinction can also be made between those South African journals that are indexed in the Web of Science (approximately 40, mostly in the natural and health sciences) and those that are not.

In the group of the most productive universities, large differences are clear between the three (historically English-medium) and

12 The majority of South African journals that are indexed in the ISI Web of Science are either natural or health sciences journals. This means that publications in these 'local' ISI-journals tend to skew the picture especially in some fields such as botany, medicine, zoology and others where large proportions of South African scholarship are published in these local ISI-journals.

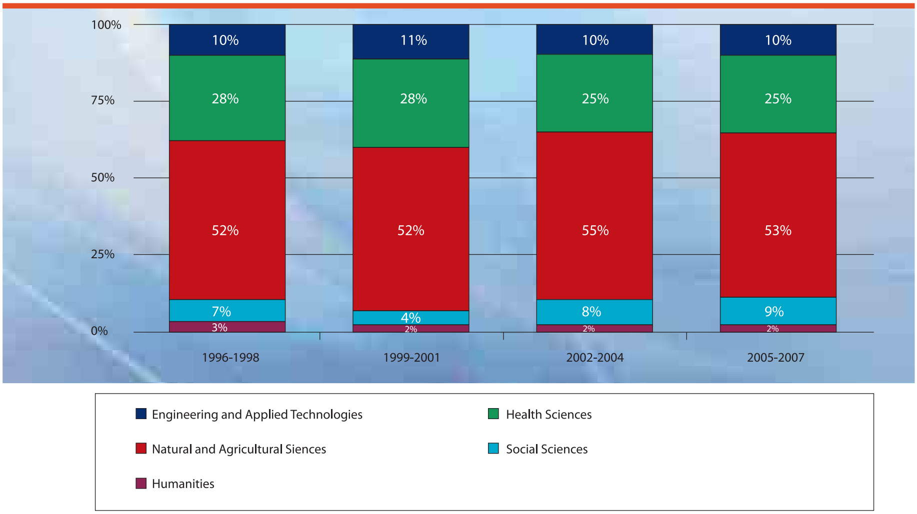

Figure 1.7: Broad scientific field distribution of South African article output in ISI-journals (1996-2007)

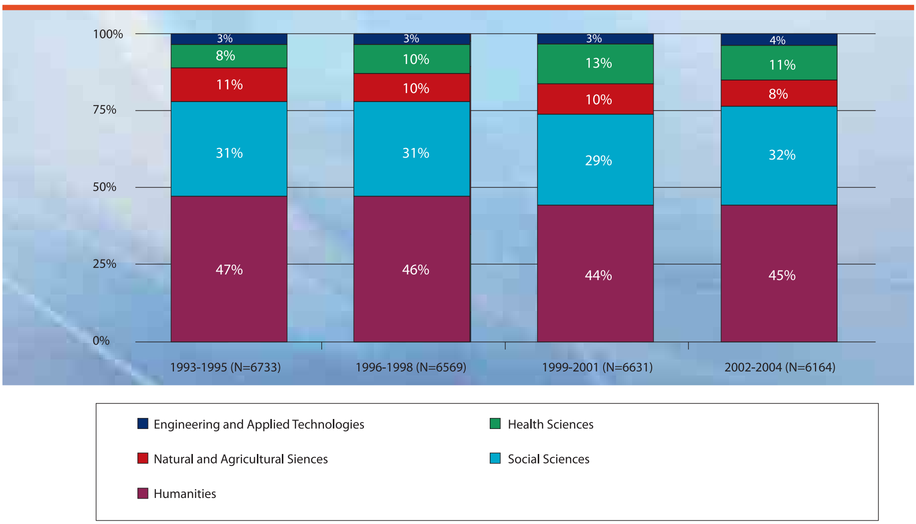

Figure 1.8: Broad scientific field distribution of South African article output in non-ISI journals

Table 1.5: Percentage distribution of ISI and non-ISI articles by institution

University[13]	%ISI-articles (non-SA journals)	%ISI-articles(SA journals)	Total ISI-share for most recent year	%non-ISI SA journals	%IBSS-journals[14]	Total article equivalents recorded[15]
UCT	67.2%	12.3%	83%	15.0%	1.4%	17 204
Wits	56.9%	12.9%		26.5%	3.6%	16 352
UKZN	53.8%	13.9%		30.5%	1.8%	12 804
SU	40.4%	9.6%		50.0%	N/A	13 740
UP	39.1%	14.5%		44.9%	1.4%	14 967
UFS	34.0%	13.8%		56.7%	1.1%	6 304
RU	33.8%	15.0%		51.2%	N/A	3 103
UWC	33.0%	9.0%		52.0%	6.0%	1 588
NWU	32.4%	7.0%		57.7%	2.8%	5 542
UNISA	13.0%	4.0%		80.0%	3.0%	6 878
NMMU	12.5%	39.7%		45.4%	2.5%	2 527
DUT	64.8%	10.7%		20.2%	4.3%	347
TUT	46.3%	12.1%		30.7%	10.9%	486
UFH	42.6%	14.7%		37.6%	5.2%	639

the two (historically Afrikaans-medium) universities. The relatively high proportions of outputs from UCT, Wits and UKZN in foreign ISI-journals (all above 50%) contrast with their relatively small output in local non-ISI journals; conversely, UP and SU academics still publish extensively in local South African journals.

In the outputs of medium-sized institutions, some of these differences are even more apparent. With the exception of RU, the other universities in this category are either historically Afrikaans or dual-medium universities. These patterns have to be understood in conjunction with the dominance of the social sciences and humanities at the

13 Durban University of Technology (DUT); University of Fort Hare (UFH).
14 International Bibliography for the Social Sciences – an index of approximately 400 journals in the social sciences recognised by the DoHET for subsidy purposes.
15 The total number of article equivalents listed here does not reflect total output for a certain period. These figures are based on institutional profiles completed over the past 4 years for the Higher Education Quality Committee (HEQC). The time frames for the various universities are therefore different. The initial recording period (1990) is the same for all universities, but the most recent year ranges from 2004 to 2007. Universities have been ranked in descending order according to their output in ISI-journals (column 1). The universities have also been clustered according to volume of output: large (more than 10 000 papers), medium (between 1000 and 9999) and small (less than 1000 papers) over the period.

traditionally Afrikaans-medium universities. The profile for RU could be explained partly by the fact that it does not have a medical school (publication in the health sciences is more prevalent in foreign journals). It is also clear from the institutional profile that the social sciences and humanities are quite strong at RU (constituting nearly 42% of total output).

The three universities in the small-sized category have interesting profiles as they all produce significant numbers of papers in ISI-journals. This is mainly due to small pockets of capacity and knowledge production in such areas as agriculture (UFH), engineering and the built environment, physics and chemistry (TUT) and materials sciences and biotechnology (DUT).

In summary, differences between universities in the production of ISI-indexed papers are evidently related to historical factors, the presence or absence of specific faculties and schools, as well as to research niche areas. Most universities have adopted research policies to encourage their staff to publish more of their work in ISI-indexed journals, to become rated in the NRF system, and to collaborate internationally. This is proving to be a sound strategy, not so much because the ISI Web of Science necessarily indexes only the top journals in the different fields (this is evidently not the case in all fields as reflected by the advent of the Scopus database that lists more than 14 000 journals compared with the approximately 9 000 in the Web of Science), but because it is important to publish in highly cited journals and, by implication, in journals with large readerships. The ASSAf study on the state of scientific journals in South Africa (prior to 1996) provided conclusive evidence of the very limited international visibility of many local journals[16]; papers published over the past 15 years in nearly a quarter (60) of the 254 South African journals published papers did not receive a single citation in any of the 9 000 ISI-journals over a 15-year period. As mentioned above, this problem is being addressed in a concerted manner by the ASSAf programme in scholarly publishing in South Africa.

Institutional field differences

In addition to differences in publication behaviour across different scientific fields, the shape of knowledge production differs markedly across institutions as well. Some of these differences are simply due to the presence or absence of specific faculties such as agriculture, engineering or medicine. Another important factor that contributes to the 'shape' or 'form' of knowledge produc-

16 Report available at: http://www.assaf.org.za/strat_report.html.

Table 1.6: Distribution of research output by main scientific field for selected universities (1990-2005)

University	Engineering & Applied Sciences	Natural Sciences	Agriculture	Health Sciences	Social & Economic Sciences	Humanities
UFS	0.0%	25.3%	16.7%	18.6%	13.7%	25.7%
NWU	4.0%	25.9%	0.0%	11.7%	58.4%	
UCT	4.8%	38.5%	0.0%	31.5%	14.4%	10.8%
UP	7.6%	23.7%	16.8%	17.5%	13.3%	21.1%
UNISA	1.2%	10.5%	0.0%	3.2%	29.5%	55.6%
UKZN	4.7%	29.0%	12.6%	22.0%	17.5%	14.1%
SU	6.0%	16.9%	11.1%	24.0%	17.0%	25.0%
NMMU	47.0%		0.0%	7.0%	25.0%	21.0%
Wits	7.6%	31.7%	0.0%	33.1%	16.1%	11.5%
UWC	0.0%	19.0%	0.0%	13.0%	31.0%	37.0%
UFH	0.0%	37.0%	15.0%	6.0%	19.0%	23.0%
DUT	16.4%	40.2%	0.0%	21.7%	15.0%	6.7%
TUT	22.4%	33.5%	10.4%	19.1%	0.4%	10.6%

tion is the relative volume of social science and humanities (SSH) scholarship output at each university (Table 1.6). SSH scholarship predominates at UNISA (85%), UWC (68%) and NWU (58%), and provides above-average shares of overall total output at NMMU (46%), SU (42%) and UFS (39%). Within the humanities, the presence of a theological seminary (or a strong theological faculty) also makes a difference – this is certainly the case for UFS (26%), SU (25%), UP (21%) and NWU (the biggest proportion of 58%). The fact that the former Afrikaans-medium universities (UP, UFS, NWU and to a lesser extent SU) are strong in the humanities undoubtedly reflects their historical interest in the production of lawyers and ministers of divinity.

An analysis of output by scientific field over time (not presented here) shows that these proportions have remained fairly stable over the past 15 years. This is not entirely unexpected, as institutional shifts in research occur over very long time frames. The figures presented above take into account the 'post-merger landscape' of institutions since 2003. Thus, for example, the profile for UKZN has been 'corrected' to reflect the scientific field-breakdown for both the former University of Natal and that of the University of Durban-Westville for the 1990 to 2005 period.

The differences in field profiles are interesting not only because of what they reveal about the history of these institutions, but they also promote the understanding of institutional differences in patterns of publication in local and foreign journals. The latter, in turn, is a major determinant of the extent to which a university enjoys high or low international recognition. The international rankings of universities worldwide that have recently become topical have identified a number of South African universities in the 'top-500', but only UCT (out of all local and continental institutions), was included in the first 200, improving its position from rank 200 to rank 167 in one year in one of the most widely-publicised rankings.

1.6 Transforming the human capital base

The imperative to broaden the knowledge base for public science in the country has been an integral element of all science and higher education policy documents and strategies in the post-1994 era. This imperative gained even more importance when figures published by CREST in 2002 showed that the participation of women and black scholars in knowledge production was far below desired levels. Despite the improved overall productivity of the R&D system described in previous sections of this chapter, it has become clear that additional gains are contingent on addressing the under-utilisation of the vast potential talent pool of the whole population.

Detailed breakdowns of the demographics of South African research show the extent of the transformation challenge very clearly. Previous statistics presented at the system-level only are here augmented by data on demographic trends at the level of scientific field and institution.

Demographics by gender, race and age

The demographic trends discussed in this section focus on three variables: gender, race and age of author. Table 1.7 presents a comparison of the gender and race profiles for the periods 1990-1992 and 2002-2004, respectively. There has been a general increase in the number of female authors across all fields but one (psychology) over this period. Female authors are best represented in the fields of education and public and community health (50%), followed by substantive (more than 33%) proportions in language and linguistics, sociology and other social sciences. The biggest increases in female representation have been in the health sciences, as well as in the agricultural, biological and engineering sciences (see Table 1.7). The national average of female contribution to research output was nevertheless only 22% for the 2002 to 2004 period.

There has also been a general increase in the number of black authors in all fields. Given the small proportions of black authors in most fields in 1990, it is not surprising that some of them have recorded high percentage increases. For example, the fields of

Table 1.7: Comparison of gender and race profiles of research output (1990-1992 versus 2002-2004)

Scientific field	Gender		Race	
	% of article equivalents by female authors		% of article equivalents by black authors	
	1990-92	2002-04	1990-92	2002-04
Agricultural Sciences	14%	24%	1%	7%
Biological Sciences	15%	25%	3%	8%
Chemical Sciences	10%	19%	4%	16%
Earth Sciences	15%	25%	1%	5%
Mathematical Sciences & Information & Communication Technologies	9%	13%	5%	9%
Physical Sciences	5%	7%	6%	12%
Multidisciplinary Sciences	13%	22%	2%	4%
Engineering & Applied Technologies	6%	11%	3%	10%
Basic Health	20%	30%	8%	17%
Clinical Health	14%	27%	8%	16%
Public/Community Health	26%	50%	6%	15%
Economic & Management Sciences	11%	21%	4%	11%
Education	27%	50%	7%	21%
Psychology	29%	26%	7%	11%
Sociology & Related Studies	27%	34%	10%	12%
Other Social Sciences	32%	33%	6%	16%
Language & Linguistics	29%	38%	5%	15%
Law	24%	29%	3%	9%
Religion	4%	9%	3%	9%
Other Humanities & Arts	21%	26%	2%	6%

INTRODUCTION

chemical sciences, basic health, education, social sciences and language and linguistics by 2004 had the highest proportions of black authors, but the national average of black contribution to research output has still been only 10% for the most recent period.

It is worth pointing out with respect to both these transformation areas that the improvements recorded are still far from achieving any degree of gender or race parity as far as knowledge production is concerned. The 22% contribution of female academics and scientists to the knowledge base is well below par, despite the fact that female academics now constitute more than 40% of the university workforce.

Similarly, the 10% of black scholars contributing to knowledge production is clearly far too low, black academics now constituting approximately 35% of the university workforce.

Disaggregation by scientific field shows that all twenty fields have witnessed a significant ageing of publishing scientists over the period 1990 to 2004 (Table 1.8). In nine of these fields, more than half of all outputs are now being produced by authors over the age of 50. The majority of these fields are in the humanities and social sciences and the health sciences. This general trend also means that production of output by authors under the age of 30 has declined significantly in all fields except for mathematics (where the small sample might have an effect on these trends).

Table 1.8: Summary of author age demographics per scientific field, 1990-1992 and 2002-2004

Scientific field	All authors				Top 20% of authors			
	% of article equivalents by persons <30 years		% of article equivalents by persons 50+ years		% of article equivalents by persons <30 years		% of article equivalents by persons 50+ years	
	1990-92	2002-04	1990-92	2002-04	1990-92	2002-04	1990-92	2002-04
Agricultural Sciences	8%	3%	23%	42%	7%	1%	24%	46%
Biological Sciences	7%	5%	20%	41%	7%	3%	21%	44%
Chemical Sciences	6%	7%	32%	47%	6%	5%	34%	53%
Earth Sciences	7%	3%	18%	42%	5%	1%	18%	47%
Mathematical Sciences & Information & Communication Technologies	8%	2%	21%	34%	6%	22%	0%	37%

Table 1.8: Continues

Scientific field	All authors				Top 20% of authors			
	% of article equivalents by persons <30 years		% of article equivalents by persons 50+ years		% of article equivalents by persons <30 years		% of article equivalents by persons 50+ years	
	1990-92	2002-04	1990-92	2002-04	1990-92	2002-04	1990-92	2002-04
Physical Sciences	8%	5%	34%	49%	7%	2%	35%	**54%**
Multidisciplinary Sciences	8%	2%	25%	53%	6%	<1%	23%	**61%**
Engineering & Applied Technologies	10%	5%	26%	39%	8%	3%	27%	42%
Basic Health	5%	4%	27%	42%	4%	2%	29%	48%
Clinical Health	2%	2%	31%	48%	2%	1%	32%	**54%**
Public / Community Health	6%	3%	32%	46%	6%	2%	31%	**55%**
Economic & Management Sciences	6%	5%	21%	36%	3%	<1%	22%	44%
Education	2%	1%	19%	52%	1%	0%	12%	**74%**
Psychology	5%	3%	15%	32%	4%	0%	15%	33%
Sociology & Related Studies	9%	4%	17%	38%	8%	2%	17%	43%
Other Social Sciences	7%	3%	19%	41%	6%	<1%	19%	45%
Language & Linguistics	4%	<1%	23%	51%	2%	0%	22%	**55%**
Law	7%	5%	17%	38%	6%	1%	17%	47%
Religion	1%	<1%	28%	64%	<1%	0%	27%	**68%**
Other Humanities & Arts	4%	2%	25%	52%	4%	<1%	24%	**59%**

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In summary, although significant progress has been made in achieving greater female and black participation in knowledge production, the country is still very far from reaching parity. While these figures are in themselves far from satisfactory, the promise of better mobilisation of talent probably presents the best opportunity for gains in productivity of the S&T system in the immediate future, and there is every hope that this will succeed in the current policy environment contingent on the biggest challenge faced by the country– the improvement of the functioning of its school system.

1.7 Conclusion

This overview of the state of public science in South Africa has highlighted a number of positive features and trends. South Africa has a rich history of well-functioning scientific institutions, universities and public research institutions that had become seriously damaged by the end of the apartheid era. Since then, a remarkable and patently unfinished renaissance has seen a new, well-coordinated national public R&D system emerge, with increasing productivity and international visibility in diverse fields, described in much more detail in the succeeding chapters. This analysis has identified many contributing factors that have in combination helped to bring this about, and it has become clear that the full mobilisation of the talent pool of the nation is both the biggest challenge and the biggest opportunity in taking the country's science to new heights in the service of national development and competitiveness.

Mathematical Sciences

CHAPTER 2

Kathy Driver

2.1 Introduction

The importance of mathematics in the intellectual, philosophical and scientific development of human civilisation has been recognised, implicitly and explicitly, for centuries. In medieval days, mathematics was considered a core area of study at universities in Britain and Europe and, when formal higher education began in the Cape Colony of South Africa in the mid-nineteenth century, the role of mathematics was also appropriately recognised. From 1850, mathematics was one of three subjects examined when employing civil servants in the Cape Colony. In 1877, the University of the Cape of Good Hope began to offer a Master of Arts degree in mathematics and arts and natural science. From 1881, mathematics and physical science constituted one of four faculties at the Stellenbosch College.

As universities and technikons[1] increased in number across South Africa during the 20th century, mathematics as a core discipline, as well as a service course in engineering and commerce, played a central role in relevant undergraduate curricula throughout the higher education sector. However, the percentage of academics in mathematics departments holding Doctoral degrees was relatively modest until the 1970s, and only increased slowly during the following twenty years. This was primarily due to a shortage of Doctoral supervision capacity, exacerbated by the practice of the traditionally research-oriented universities in South Africa to encourage strong Honours[2] graduates in mathematics to pursue graduate education in the United States or United Kingdom. In addition to losing the vast majority of our mathematically well-trained young Honours graduates, international boycotts during the 1980s caused the isolation of researchers and the stagnation of mathematical curricula. The apartheid education system also essentially blocked the mathematical sciences as an area of potential higher education strength for black South Africans and, prior to 1990, there were very few locally trained black South African Doctoral graduates in the mathematical sciences.

In examining and analysing the current status of research in mathematics in South Africa, the focus will be strongly on the post-1994[3] response as a system of higher education to the challenges of creating and building capacity in the various subdisciplines that constitute the mathematical sciences. Mathematical sciences can be broadly conceived as incorporating pure

1 Technikons were higher education institutions in South Africa that focused on technological training.
2 Honours is a 1-year programme that follows a 3-year Bachelor's degree.
3 1994 marks the year of South Africa's first democratic elections.

mathematics, applied mathematics, mathematical statistics, and theoretical computer science and mathematics education.

2.2 Research capacity

Qualified instruction and research professionals

Research capacity can be defined as the number of qualified teaching and research mathematicians in the South African higher education sector, as well as qualified (usually with a PhD) research-active mathematicians working in industry, commerce or science councils. This number for the mathematical sciences represents approximately 4 % of the academic population in the higher education sector and has grown from 511 in 2002 to 618 in 2006, an increase of approximately 17% in 5 years (Table 2.1).

Table 2.1: Instruction and research professionals in mathematical sciences

Year	Mathematical Sciences	Total in All Fields
2002	511	13 794
2003	516	14 239
2004	491	14 200
2005	529	14 167
2006	618	14 968

Source: Higher Education Management Information System (HEMIS) database.

Research pipeline

The research capacity pipeline consists of students at the various academic levels in a discipline. As indicated in Table 2.2, enrolments (represented as full-time equivalent (FTE) students) in courses in the mathematical sciences at both undergraduate and postgraduate levels have increased from a total of 18 242 in 2002 to 21 147 in 2006, a similar percentage increase to that of permanent academic staff in the mathematical sciences. The ratio between FTE enrolments and student headcount is typically 0.75:1 in residential universities, so the actual current student headcount enrolment for courses in the mathematical sciences is roughly 27 000.

Hence, the ratio of student headcount in mathematical science courses, including service courses, to permanent academic staff is of the order of 44:1. This is extremely high in the context of a research-active university environment, particularly one in which the level of preparedness of entering students is very variable and requires resource-intensive bridging programmes to address learning deficits. It should be noted that these numbers represent enrolments in courses in mathematical sciences, which includes all service and other non-major mathematical science course enrolments, as well as enrolments in courses leading to mathematical science majors. In that sense, the numbers in Table 2.2 do not accurately represent the research pipeline. Nevertheless, they are useful and relevant in quan-

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Table 2.2: Total enrolments[4] in mathematical sciences courses

Year	African	Coloured	Indian	White	Unknown	Total
2002	9 416	943	1 171	6 060	652	18 242
2003	11 160	1 048	1 938	6 341	42	20 529
2004	12 016	1 140	2 134	6 569	54	21 913
2005	11 809	1 153	2 103	6 422	44	21 531
2006	11 855	1 107	1 971	6 154	60	21 147

Source: Higher Education Management Information System (HEMIS).

tifying the academic teaching workload carried by mathematicians in South African universities.

African students are by now substantially in the majority across the higher education sector in South Africa in both the mathematical sciences enrolments and total student enrolments in all disciplinary categories. In the case of total student enrolments across all disciplines, the ratio of African to white enrolments has changed from 2.03 in 2002 to 2.24 in 2006; in the mathematical sciences, the ratio of African to white enrolments has changed from 1.55 in 2002 to 1.93 in 2006.

The legacy of the apartheid education system, as well as socio-economic and educational-preparedness factors for students in the different racial categories, manifests itself in a degree success rate of 58% for black African students compared with a 72% degree success rate for white students. The overall percentage of degree success rates in the mathematical sciences hovers in the band 62% to 64%, with no significant change in the past five years. Female students, although statistically under-represented, consistently outperform their male counterparts in terms of throughput rates. The ratio of male to female students in the mathematical sciences has moved slightly from 1.472 in 2002 to 1.443 in 2006, so the gap is not narrowing in a significant way.

Two comments are relevant here. First, the degree success rate in mathematics is the lowest of all the disciplinary categories across the entire higher education sector and there is no sign of progressive improvement. On the other hand, enrolments in the mathematical sciences have risen sharply in the past five years so that, although the percentage degree success rate remains essentially unchanged, the numbers of mathematically skilled graduates produced by the South African higher education sector has increased over the past five years by approximately 17%. Second, the success rate for African students has risen slightly from 55% in 2002 to 58% in 2006, despite the

[4] Enrolments are expressed as a function of race for mathematical sciences as the influence of apartheid is probably most strongly expressed in this disciplinary field.

fact that the percentage increase in African enrolments is disproportionately large relative to the other groups. Nevertheless, the low overall degree success rate of students in the mathematical sciences, both in absolute and in comparative terms, represents serious wastage of human capital in the South African higher education system. It should be noted further that this low success rate occurs among a group of students that already constitutes a very small fraction of the school-leaving cohort in the sense that they have passed mathematics at the appropriate level to enrol for mathematical science courses at university. This is an issue that demands urgent enquiry and, almost surely, strong intervention in order to supply sufficient numbers of qualified mathematical science graduates that are necessary to feed an emerging knowledge economy.

The rise in undergraduate enrolments in all mathematical science courses, including service courses, is not the result of an overall growth in the number of students majoring in the mathematical sciences. On the contrary, Table 2.3 shows that the overall numbers, including undergraduate and postgraduate, are at best stable with a worrying decline in Honours enrolments from 955 in 2003 to 805 in 2006.

Table 2.3: Headcount enrolments in mathematical sciences

Year	Undergraduate	Honours	Masters	Doctoral
2003	8 700	955	554	181
2004	9 310	864	491	202
2005	8 654	671	452	186
2006	8 775	805	618	246

Source: Higher Education Management Information System (HEMIS).

Higher degree students

The total number of Masters and Doctoral enrolments in the mathematical sciences across the country has grown from 735 in 2003 to 864 in 2006, which bodes well for the research pipeline. However, a breakdown between Masters by coursework (including a research report) and Masters by research (dissertation only) shows that 60% of Masters enrolments are Masters by research, which is low in comparison with comparative science disciplines, such as physics, where the research Masters comprises over 85% of Masters degrees.

During this period, postgraduate student research projects were predominantly in applied mathematics, which accounted for 62 of the 223 project entries on the database developed by the Centre for Science Development, Human Sciences Research Council. This was followed by the subdisciplines of algebra and number theory, and general mathematics, with 22 entries each. A February 2009 report to the John Templeton Foundation from the Developing Countries' Strategies Group, International Mathematical Union (IMU), entitled *Mathematics in Africa: Challenges and Opportuni-*

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ties, states that (in South Africa): "most postgraduates and staff are foreign-born". The report continues: "South Africa has become a destination of choice for thousands of students from sub-Saharan Africa wishing to pursue postgraduate studies. The country's institutions make available modern research tools and facilities to other African countries, helping to boost mathematical development. South Africa, in turn, benefits by gaining excellent foreign talent, who now dominate the faculties of some universities." It is not possible, nor desirable, to obtain data on the nationality of mathematics staff in universities across South Africa, but in the case of postgraduate enrolments, the assertions made in the IMU report regarding the nationality of Masters and Doctoral students are demonstrably not correct, as shown in Table 2.4.

Table 2.4: Nationality of higher degree students in mathematical sciences in 2006

Nationality	South African	SADC*	Other African	Other Foreign
Masters	497	61	38	11
Doctoral	168	28	29	17

*SADC – Southern African Development Community comprising 15 member states from southern Africa.

Far from the claim that a majority of higher degree students in the mathematical sciences are foreign born, enrolments show that 80% of Masters 'head count' enrolments and 68% of Doctoral enrolments are South African students. The number of international students is healthy and desirable as this enhances the international nature of research and creates future networks and linkages that are beneficial in a broad context. Nevertheless, the IMU report does make a correct and relevant point that does not bode well for achievement within the mathematical sciences sector, namely the ambitious objectives outlined in the Department of Science and Technology (DST)'s Human Capital Development Plan 2008-2028, one of which is to achieve a five-fold increase in the number of PhD graduates by 2024. Another important objective in the DST plan is to improve the participation and graduation rates of black South African students.

As indicated in the IMU report, there are many lucrative employment opportunities for students holding a vocationally-orientated Masters degree by coursework in one of the mathematical sciences and this constitutes a significant challenge to the impetus to increase Doctoral enrolments in the mathematical sciences.

It is evident from Tables 2.1 and 2.3 that the ratio of available qualified research-active academic mathematicians to higher degree students is relatively high and indicates that there is significant research capacity within the higher education sector that is currently not being utilised. However, this is offset by the high student/staff ratio at undergraduate level (including service courses) which militates against a productive research environment. It would be problematic to simply increase the numbers of higher degree students in the mathematical sciences, if that were possible, without also increasing academic staff numbers.

The total number of annual Masters and Doctoral graduates in the mathematical sciences across the country has grown from 113 in 2003 to 170 in 2006 (Table 2.5). The largest increase is in the Masters by research category which is a positive development. The number of PhD graduations in the mathematical sciences increased from 22 in 2003 to 28 in 2006, a rather modest rise off a low base. It should be noted from Table 2.5 that Doctorates awarded between 2003 and 2006 as a percentage of all senior degrees awarded in the mathematical sciences varies from 19.4% in 2003 to 16.4% in 2006. This percentage is consistently lower than that for a comparative discipline, physics, where the percentage of Doctoral graduates among all senior degree graduates was 22.7% in 2006. In addition, the increase in numbers during the past few years of higher degree graduates across the whole science sector, including the mathematical sciences, can be attributed, at least in part, to a focused effort by the research-intensive and research-niche universities to reduce the average time taken by a student to complete a Masters or a Doctoral degree.

Table 2.5: Masters and Doctoral graduates in mathematical sciences

Year	Masters Coursework	Masters Research	Doctoral	TOTAL
2003	47	44	22	113
2004	49	69	26	145
2005	45	70	28	143
2006	58	83	28	170

It is of interest to note that the database of MathSciNet, the electronic publication of the American Mathematical Society, indicates that the number of PhD holders in mathematical sciences in South Africa, as of 2007, was 502. This number may not include all 'applied' mathematical scientists but provides an indication of South Africa's current research capacity.

2.3 Research quality and impact

A number of indicators are commonly used in the research evaluation environment to assess the scholarly status and impact achieved by researchers. Examples include prestigious and honorary awards, membership of national and international panels of experts, committee membership of international professional associations, membership of editorial boards of high- impact journals, and publication outputs in journals, to name a few. Here, peer-reviewed journal outputs are used as a proxy for research productivity. Field-normalised citation rates will be used to give an indication of the quality of research output. In addition, the number of National Research Foundation (NRF)-rated scientists and the number of NRF grantholders will provide a good indication of the ascribed status of researchers and the international competitiveness of their research.

NRF-rated and NRF grant-holder numbers

In 2006, there were 150 NRF-rated researchers in pure and applied mathematics, statistics and mathematics education, almost all of whom hold an academic position at a university. This number has shown modest but steady growth since the inception of the rating system. Of the 150 NRF-rated researchers in 2006, the number of A and B ratings, indicative of researchers with international recognition, was only 48. It is anticipated that this number will increase as newly rated younger mathematicians become more established in the international research community. A key driver of this anticipated trend is the number, the strength and the quality of international research networks and linkages that are established. In this respect, recently established bi-lateral agreements which provide funding for research cooperation between South Africa (through the NRF) and several other countries including Japan, Norway, Brazil, India and the European Union countries are an extremely positive and constructive development. Joint research and collaborative projects with regional, national and African partners should also be recognised as a high priority within the New Partnership for Africa's Development (NEPAD) initiative.

The breakdown of NRF-rated mathematical scientists within the different sub-disciplines is, by nature, inexact but there are approximately 105 in pure and applied mathematics, 35 in statistics and ten in mathematics education.

The number of NRF grant holders is linked with, but not identical to, the number of NRF-rated scientists, the former being significantly larger. In the mathematical sciences, the number of NRF grant holders has grown by nearly 21.9 per cent between 2005 and 2008, an extremely positive trend, and mathematical scientists now account for 27.4 per cent of all NRF grant holders. In addition, the total amount of funding awarded to researchers in mathematical sciences has grown by 28.5 per cent between 2005 and 2008 with an average grant currently being of the order of R62 000 per annum.

Women are relatively well represented in the mathematical sciences, with 29% of NRF-rated mathematical scientists being female. Black researchers in mathematical sciences remain a minority and constituted only 18% in 2006. NRF programmes such as Thuthuka have had some success in growing participation among under-represented groups.

General novice researcher capacity development (researchers in training, scholarships and fellowships, and the Technology and Human Resources for Industry Programme (THRIP) represents a significant component of the funding portfolio of mathematical sciences.

Research productivity: articles in peer-reviewed journals

Productivity in terms of peer-reviewed research article output per annum in the mathematical sciences has almost doubled over the past 17 years from 120 articles to 216 articles in ISI-accredited journals. Applied mathematics and pure mathematics have shown sustained increases over the period, while mathematical statistics has remained more or less stable. The international journals of greatest choice among South African authors include the *Journal of Mathematical Analysis and Applications*, *Ars Combinatoria* and *Applied Mathematics and Computation.*

Not only is the journal article output of the mathematical sciences pool on a significant upward curve, but the annual mean rate of articles per author (1.29) over the period between 2002 and 2006 is more than respectable by comparison with the highest international benchmarks. Of course, this annual mean rate of articles per author only applies to the research-active cohort of mathematical scientists and there remain a large number of qualified, or partially qualified, mathematical science professionals who produce no visible research output at all. It is interesting to note that mathematical science researchers have a relatively limited propensity for collaboration on jointly-authored papers. A recent Centre for Research on Science and Technology (CREST) study showed that almost 70% of ISI-indexed articles by researchers in the mathematical sciences were written by one or two authors, which contrasts with the more than 40% of the articles in physics that were produced by four or more authors. Almost a quarter of the foreign authors of co-authored articles were from the United States.

Active researchers in mathematical sciences are performing very well relative to their counterparts in all comparator disciplinary fields. There are also signs within universities of a real commitment to elevating the status of the research field as evidenced by, for instance, the increase in the number of researchers obtaining NRF ratings. The challenge would be to reinforce these trends and to increase the number of ratings of black and female mathematicians who remain significantly under-represented.

A worrying statistic is that which shows that researchers in mathematical sciences aged between 40 and 49 produced an average of almost 40% of the peer-reviewed journal article output between 2003 and 2006. Researchers less than 40 years old were responsible for only about 10% of journal outputs. Another cause for concern is that over 80% of the article output is produced by white mathematical scientists, with black researchers producing approximately 10%. Female authors account for about 15% of article equivalents. Five universities (Pretoria, KwaZulu-Natal, Witwatersrand, Cape Town and Stellenbosch) account for over 75% of all research journal article output in the mathematical sciences.

Impact and quality of research

Reinforcing the preceding favourable finding about the high mean productivity of individual researchers in the mathematical sciences is the important finding about the high impact rate of journal articles. The citation impact rates of mathematical sciences have been rising since 2000 and are currently significantly higher than the world average.

Citation impact analysis is based on the number of references to a published paper in ISI-indexed journals. The citation indicator introduced and used by the Centre for Science and Technology Studies at the University of Leiden in the Netherlands is the field-normalised citation impact which gives the ratio: CPP/FCS where CPP is the mean number of citations per publication in a field and FCS is the field-based worldwide mean impact. An analysis shows that the impact of papers in mathematical sciences has increased sharply, from below the international impact standard, which is equal to 1, to significantly above that standard between 2002 and 2006; in 2002, the ratio stood at 0.6 and by 2006, it had risen to over 1.2. Indeed, Pouris (2008) found the impact of mathematical sciences to be the highest of 20 natural science disciplines in South Africa in 2006.

The Leiden study also shows that the citation impact of internationally co-published papers in mathematical sciences is systematically higher than either intra-institutional or nationally co-published papers, and the impact of internationally co-authored papers in mathematical sciences has increased from below the international standard to significantly above that standard since 2000. What emerges from this analysis is that, in terms of this measure of research impact, the quality of research activity in the mathematical sciences in South Africa is high in comparison to field-normalised citation impact rates worldwide.

2.4 Sub-disciplines

Pure mathematics

The research-intensive universities, as well as some of the less research-focused universities, in South Africa offer Honours and Masters by coursework degrees in pure mathematics and achieve a standard that compares very favourably with the top echelon of international universities. Mathematics graduates are well equipped to compete for places at top graduate schools around the world, or to pursue PhD studies locally, having appropriate levels of rigorous knowledge of the subject. There is clearly spare PhD supervision capacity within the system and it is an ongoing challenge to persuade suitably qualified black South African students to continue with Doctoral studies after they complete Masters degrees that ensure lucrative salaries in the employment sector. A significant but minority percentage of Masters and Doctoral students currently studying at South African universities are black African students from SADC and further afield.

Mathematical areas in which major advances have been made in South Africa include pockets or groups of activity in topology, graph theory, functional analysis, discrete mathematics, combinatorics, category theory, universal algebras, special functions, group theory, number theory, algebraic and differential geometry, real and complex analysis.

Applied mathematics

There are significant strengths in traditional classical areas that are currently enjoying a great resurgence of interest as new computational technologies facilitate breakthroughs previously hampered by size and scale, for example, astrophysics, cosmology and relativity. Strong teams of applied mathematicians are working in computational mechanics; theoretical physics; and the applications, both theoretical and numerical, of solutions of differential equations in several fields. Lie group symmetries, numerical approximation including quadrature, numerical and computational analysis along with cosmology, relativity, soliton theory, are areas of research where South Africa has a significant international presence. The level of interaction with industry is relatively weak although there have been some very good recent initiatives in this direction with a workshop involving applied mathematicians and interested industrial partners having taken place on an annual basis since 2003. Research in financial mathematics is growing slowly and has yet to achieve a critical mass of active, internationally recognised researchers. At this point, demand from students and employers for financial mathematical expertise focuses on coursework knowledge at the Honours or Masters level rather than on a research-orientated degree.

Statistics

South African research in probability and statistics enjoys a good profile in several areas of applied statistics and stochastic analysis, particularly Bayesian statistics applied to medicine and other areas, stochastic analysis applied to the financial industry and statistical modelling applied to mining, medicine, and finance. Other areas of strength include multivariate statistical processes, neural networks, optimal designs and applications, nonparametric analysis, econometrics, biostatistics, linear models, and statistical learning theory. However, the older members of the current cohort of research statisticians are not being replaced at a sustainable rate due to the increasing demand from the private and public sector for qualified statisticians. The majority of those who have reached the status of international leaders in pure or applied statistics are found in the research universities, and most of them are due to retire soon.

Internationally, the discipline of statistics, despite its ever-increasing use in every aspect of modern life where data are analysed and used as a guide or even as a basis for decision-making, is in crisis. Departments of statistics are being absorbed into other units as the critical mass of academics collapses. Equally, in South Africa, there is acute shortage of qualified statisticians with no senior established academic in some of the statistics departments at universities in South Africa. There is danger of the imminent collapse of research activity in statistics when the present cohort of senior researchers retires.

Research in statistics, as in other areas of mathematics, tends to be built around core groups of people, as distinct from facilities or laboratories. Nevertheless, modern statistics research requires significant computational capacity and that is lacking in many of our universities.

Mathematics education

Research in mathematics education in South Africa is strong in relation to the number of NRF-rated researchers. There is one area of particular strength, namely, research into language issues in mathematics teaching and learning. Our eleven official languages make the South African classroom a wonderfully rich experimental and experiential locus for researching the role played by multiple languages in the teaching of mathematics to primary and secondary schoolchildren. There is also research activity in the developing area of undergraduate mathematics education, incorporating language and technology issues.

A promising new development is the introduction of South African mathematics education chairs, a jointly funded initiative of the Department of Science and Technology and FirstRand Bank.

2.5 Summary

In general, there is a substantive body of good research by international standards in all the mathematical sciences (pure mathematics, applied mathematics, statistics, and mathematics education) in South Africa. This research is done predominantly, although not exclusively, by NRF-rated and/or NRF-funded researchers and their research teams, including postgraduate students.

There are three positive trends that are worthy of highlighting. First, the positive growth in research outputs in terms of journal publications; second, the relatively high mean number of articles per mathematical author; and, third, the indisputably high impact rates achieved by journal contributions in mathematical sciences by researchers living and working in South Africa.

Challenges

The ultimate health and strength of the mathematical sciences depends upon strengthening the foundation of mathematics in schools, identifying and nurturing the best students at the secondary level, and encouraging such students into programmes in the mathematical sciences. As noted in the 2009 IMU report referred to earlier, South Africa has some excellent secondary schools but the situation is dismal in rural areas. The vast majority of mathematics teachers do not have Bachelor's degrees, nor is it a requirement that they should. It is imperative that interventions like in-service teacher training be augmented by other schemes such as introducing teacher internships at universities around the country. In such a scheme, a mathematics teacher would retain his/her permanent teaching position at a school and would spend a period of time, six or twelve months, in a mathematics department at a university, learning appropriate level university mathematics coursework and, where possible, contributing to work in the department by teaching or tutoring first year students.

Second, any expectations about the future of research in South Africa in the mathematical sciences must factor in the human resource pipeline and its productivity. Three comments are pertinent. First, the sector must ask the question about the proportion of academic mathematical scientists who hold a PhD and are actively involved in research and the publication of original work. Second, attention should be drawn to the lack of any significant growth in the number of students majoring in mathematics and the very modest growth, off a low base, of higher degree students in the mathematical sciences. Third, the racial and gender demography of research mathematicians is not in any way reflective of undergraduate enrolments, and the throughput rate of black South African students to postgraduate study needs attention. The research pool has grown in absolute numbers but the almost non-existent growth in the number of students completing a Doctorate is likely to affect succession over the medium to longer term. This is the most evident cause for concern.

Aligned closely with the previous point, is the worrying fact that researchers in the mathematical sciences of 40 years of age and older accounted for more than 60% of the total peer-reviewed journal article output between 2003 and 2006. These findings would suggest that the productive section of the research community is approaching the latter part of its professional life, and attention should be given to strategies for effectively involving more members of the younger generation, women and black scholars in the research and publication process.

Finally, the staff-student ratio of approximately 40:1 is unacceptably high if South Africa seeks to achieve the objectives of the DST's Human Capital Development Plan. Undergraduate contact teaching hours of mathematicians, applied mathematicians and statisticians in the universities across South Africa are the highest among all the science disciplines. This is difficult to justify when one considers the importance of mathematics as a core discipline and the relatively low running or operational cost of mathematical research.

2.7 Concluding remarks

During the past five years, the African Institute of Mathematical Sciences (AIMS) project of connecting the scientific community in South Africa to the global scientific community by bringing in distinguished lecturers to give courses to postgraduate students who come from all countries in Africa is an innovative and notable experiment. The students spend nine months at AIMS in Muizenberg studying for a postgraduate diploma and many of them continue with Masters or Doctoral degrees at South African universities upon completion of their diploma. This has benefited applied mathematics graduate programmes around the country in terms of recruitment of students outside South Africa. As a Pan-African endeavour, it is to be applauded. However, there are, to date, virtually no South African graduates associated with the programme. In that sense, as an initiative to advance South African mathematical sciences, it has not been so successful. This is an aspect of the programme that should receive urgent attention, namely the alignment of the programme with the southern, rather than the northern, hemisphere academic timetable. Participation of South African postgraduate students in this wonderful formative experience should be made a top priority for the Department of Science and Technology and the Department of Higher Education and Training, both of which are providing significant funding to AIMS.

MATHEMATICAL SCIENCES

The apartheid-era intellectual isolation of South Africa gave rise, in a natural way, to the creation of 'in-house' journals in order for researchers to have an outlet for their publishable work. This legacy of apartheid is still with us and a significant proportion of South African-authored research publications in the mathematical sciences is published in local rather than international journals. Some of these articles are narrow in terms of their impact, have very limited readership, and are often self-referential and out of date in terms of contemporary international interest and activity in mathematics. A number of areas that were prominent 30 to 40 years ago but no longer attract much international attention are among those that are active in South Africa and the advances made in these areas can best be described as incremental. In particular, it is notable how little attention is given at South African conferences or workshops in the mathematical sciences to topics that feature in the plenary or invited sections of the International Congress of Mathematicians held every four years. One could question how many seminars are held in the mathematics departments of universities in South Africa to discuss the Poincare Conjecture and the geometrisation theorems of Perelman or Fermat's Last Theorem and the work on modular forms of Andrew Wiles or, indeed, the work of any Field's Medal winners in recent years. A regular visiting mathematician programme, which is relatively easy and inexpensive, would go a long way towards ensuring that we maintain the strengths of our current position and that we enhance our presence in the international community of mathematical scientists.

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Physics and Astronomy

PHYSICS

AND ASTRONOMY

3

CHAPTER

HARM MORAAL,
WITH CONTRIBUTIONS BY DAVID BRITTON, TREVOR DERRY, ANDREW FORBES, DIANE GRAYSON, SIMON MULLINS, FREDERIK SCHOLTZ AND RAMOTHOLO SEFAKO

3.1 Developments up to 1990

Physics in South Africa dates back to the astronomical observations of Sir John Herschel at the Royal Observatory in Cape Town in the 1830s, the introduction of geomagnetic and surveying work, and the establishment of several universities and university colleges in the second half of the 19th century. The establishment of the mining industry early in the 20th century and the subsequent industrialisation in the years before World War II significantly boosted the discipline, with physics research at several universities becoming a fully established activity. On the international scene, South Africa became a founding member of the International Union of Pure and Applied Physics (IUPAP) in 1923.

It was not until the founding of the Council for Scientific and Industrial Research (CSIR) in 1945, however, under the patronage of then Prime Minister Jan Smuts, that physics emerged as a nationwide and unified discipline. Smuts had been a member of Churchill's war cabinet, and through his active involvement in the subsequent restructuring of the world order, recognised the need for South Africa to have a strong science establishment for its development. The CSIR's National Physical Research Laboratory (NPRL) immediately created a new market for physicists, as did similar laboratories for chemistry and mathematics. In response to new research funding from the CSIR, the universities also began to strengthen their postgraduate research and training programmes.

These early developments are covered in three chapters of AC Brown's (1977) book on *A History of Scientific Endeavour in South Africa*.

In 1961, South Africa became a republic and was expelled from the British Commonwealth for its policy of apartheid. As a result, South African physics took a different route from that in other Commonwealth states. The political and economic isolation led to a centralist approach from government to use science and technology (S&T) to overcome the concerted international anti-apartheid campaign, and to meet the perceived strategic needs of the country. This development had already started with the founding of the Atomic Energy Board (AEB) in the 1950s, with the vision to utilise and enrich South Africa's uranium to make the country self-sufficient in nuclear energy. During this time, there was also an emphasis on nuclear weapons and in 1993 the government revealed that it had developed six nuclear weapons devices. Similarly, over the same period, the division of defence research at the CSIR developed into a sophisticated armaments industry, with the establishment of Armscor and its subsidiaries, to overcome the ever-strengthening arms boycott.

Physics co-incidentally prospered under these developments because most of the technologies are, naturally, physics-based. A by-product was generous funding for large physics laboratories such as the Southern Universities' Nuclear Institute (later the National Accelerator Centre, and currently the iThemba Laboratory for Accelerator-Based Sciences, or LABS). There were also extensive non-military projects at the AEB (later the Atomic Energy Corporation, AEC, and currently the Nuclear Energy Corporation of South Africa, Necsa).

Two older laboratories were those of Mintek for minerals research and beneficiation, and the Hermanus Magnetic Observatory (HMO) for geomagnetic information needed for navigation and exploration. Experimental nuclear physics and materials science research at universities directly benefited from the developments at these laboratories, performing high-quality and innovative work, especially at the level of technological physics. While it is ironic that physics in South Africa should have been strengthened by the country's isolation, there was also a down side, as much of this work was 'classified' (secret), and many scientists who wished to develop their careers submitted 'classified' MSc dissertations and PhD theses at the universities concerned. Many of them were never published again.

In 1983, the agency function by which the CSIR funded university research was transferred to the newly-established Foundation for Research Development (FRD). The FRD became independent from the CSIR in 1990, and in 1999 it became the National Research Foundation (NRF), which also had responsibility for the social sciences and humanities. Initially, the FRD vision was generally one of open or 'blue skies' research, which was meant to support and retain high-quality scholars. Physics research naturally falls into this category, and hence physics again benefited. The FRD established an evaluation or rating system by means of which scientists could be benchmarked on the basis of their standing in the opinion of international peers (see Chapter 1).

This new development came at the right moment for physics because centrally-driven physics research at large laboratories, such as the CSIR and the AEC, imploded at the time. Within the CSIR, a major restructuring exercise in the mid-1980s changed the driving force to one that was largely commercial and financial. Under its new mission, the CSIR favoured technology, engineering and applied science above basic science. At the AEC, the change was mainly due to changing strategic/political considerations leading up to the democratic dispensation of the country in 1994. These changes had a ripple effect on many other laboratories and universities. Large numbers of nuclear physicists, many of them only in mid-career, became effectively redundant. In this climate the new FRD/NRF evaluation system played a significant role to ensure that the broad academic sector of physics did not suffer the same fate, and it provided an opportunity for the subject to readjust itself within rapidly changing national priorities.

3.2 The role of the South African institute of Physics (SAIP)

A natural consequence of the post-World War II flourishing of scientific activity was the establishment of professional scientific societies. The first attempt to establish such a society for physics happened in 1948, but did not succeed. A second attempt, launched in 1953 by C B van Wyk, eventually led to the establishment of the South African Institute of Physics (SAIP) on 7 July 1955, at the University of Pretoria, with S Meiring Naudé as its first president (see http://www/saip/org/za). The attendance register was signed by 102 practising physicists. The institute organised itself into a number of specialist groups that represented the main themes of physics practised in the country. Solid state physics and nuclear physics were natural strongholds. The institute rapidly grew to a membership of between 300 and 400, and its core activity was the annual three-day conference in July to provide a forum for progress reports in the various disciplines.

Growth was so healthy that a *South African Journal of Physics (SAJP)* was launched in 1978, as well as a quarterly newsletter called *Meson*. The *SAJP* was subsidise by the newly established Bureau for Scientific Publications. The SAIP also played a facilitating role in respect of other developments in physics. For instance, when a decision about the site for the National Accelerator Centre was needed, the decision was reached under the leadership of the SAIP council. Section 3.8 describes how the National Laser Centre (NLC) was also established under the auspices of the SAIP.

The promotion of education has always been a central concern of the SAIP. Alongside the education specialist group, where the emphasis is on research and teaching practice, the council has always had its own education portfolio to ensure that national and provincial strategies are implemented. A special feature has also been the annual heads-of-department meeting during the annual conference. While this forum has never had any decision-making powers, it has fostered sufficient debate and activity to ensure that all physics degrees awarded in the country have always been recognised by all institutions.

Even during the apartheid era, SAIP membership was open to all, and its constitution never differentiated on the basis of race or gender. It is also true, however, that the SAIP could have been more pro-active to promote change and to extend its membership. In an exchange of letters between institute presidents in 1987, the American Physical Society expressed concern about the effects of apartheid on South African physics, and proposed joint actions "to improve access to physics for all talented persons in South Africa". The SAIP president at the time responded immediately and positively, closing his letter in the hope that "this could very well be the beginning of a useful and effective collaboration". The actual benefits of this positive exchange are hard to identify, however. Towards the end of the apartheid era, a combination of the brain drain, the change in focus at the CSIR and the AEC, and much-reduced funding for research, in spite of the new FRD/NRF initiative, led to a decline in SAIP membership and in the number of students who studied the subject. A symptom of this decline was that the *SAJP* became unsustainable and the last issue was published in December 1993.

3.3 Physics and the SAIP in the post-apartheid era

The African National Congress (ANC)[1] was highly pro-active with respect to its S&T policies. Even before taking office, it commissioned a study on the state of the S&T system in 1993, and as the new government it produced a White Paper on S&T in 1996. The establishment of the Department of Arts, Culture, Science and Technology (DACST) in 1994 was a completely fresh start. Its separation into two separate departments in 2002, and the establishment of a dedicated Department of Science and Technology (DST) demonstrated the strategic importance accorded to S&T by the government. The National Research and Technology Audit of 1998 provided a comprehensive overview of the S&T system. Based on these studies, the DACST and DST initiated many new strategies.

The physics community, however, took time to react. There were several challenges at the time: student numbers were static; the new strategies had not yet had a measurable impact; SAIP membership hovered below 400; and the annual conference attendance had declined to about 300. The SAIP realised that it should entirely reposition itself in the post-apartheid era, and the council launched a project called 'Shaping the Future of Physics in South Africa' in co-operation with the DST and NRF. An investigation was carried out by an eight-person panel, including five influential international scientists, and their report was published in April 2004.

The report's 15 recommendations caused a dramatic 'turn-around'. First, they emphasised the value of large and established physics laboratories and activities such as iThemba LABS and Necsa in the nuclear sciences, the NLC at the CSIR, the South African Astronomical Observatory (SAAO), the Hartebeesthoek Radio Observatory (HartRAO), and the HMO. Further, it highlighted several flagship projects in physics and astronomy that already existed or were under development. Examples are the Southern African Large Telescope (SALT), the MeerKAT radio telescope as a pathfinder for the planned huge international project, the Square Kilometer Array (SKA), the Pebble Bed Modular Reactor (PBMR) to generate nuclear energy, and the National Institute for Theoretical Physics (NITheP). The report further emphasised that the physics community should focus on such facilities and opportunities without sacrificing the smaller-scale research activities practised in university departments,

[1] Known by its initials, ANC, this is the governing party of South Africa. It was formed in 1912 and is the oldest political organisation in the country.

which were regarded as the sustainable cornerstone of basic physics research. The report expressed concern about the grave situation in physics education, and recommended several interventions that could be made in part by the SAIP. Finally, it pointed out that a voluntary organisation such as the SAIP, with only honorary officers, could not hope to make an impact without a full-time office.

Other opportunities quickly arose from various strategic interventions by the DST. These included a Nanotechnology Strategy, an Astronomical Geographical Advantages Act, a South African Space Agency Act, a Photonics Initiative of South Africa (PISA), and the establishment of a number of centres of excellence and research chairs at universities.

The DST and NRF have also developed a focus to dramatically increase the number of high-quality PhDs in S&T in the medium term to keep South Africa on track in its development curve. Increases of up to a factor of five have been mentioned. To redress the demographic imbalance, the government naturally wants these numbers to come largely from the black community, but there is a problem of supply.

There are approximately 8 000 students each year who complete their secondary school education in science and mathematics at a sufficiently high level to gain direct entrance into science and engineering faculties at universities. Of these, fewer than 3 000 are black. About 75% of them enter the professional fields of medicine, health sciences and engineering, leaving only some 800 to be distributed among about 20 science faculties, i.e. 40 per institution. This implies that each of the four basic science disciplines of biology, chemistry, mathematics and physics at each university has a maximum annual pool of about ten black entrants at first-year university level. This hard reality underscores the key challenge facing South Africa, that of people development through effective primary and secondary school education.

The physics community reacted to the *'Shaping the Future of Physics in South Africa'* report by using it as an authoritative source to conduct its planning and to motivate funding applications. The SAIP itself took up the challenge to establish with effect from January 2008 a full-time office, funded to a large extent by government. Brian Masara was appointed as the first Executive Officer, and is supported by a core administrative and marketing/outreach staff.

With this office the new SAIP now conducts and coordinates a number of well-structured programmes that include:

- A membership drive through which the number of members has now increased to 547, a healthy 36% of them being postgraduate students. Conference attendance rose from 314 in 2002 to 540, 437 and 496 during the last three years.

- Women in Physics in South Africa (WiPi-SA) initiative, started in 2005, which has made such an impact that it submitted a successful bid to host the 4th IUPAP International Conference on Women in Physics in Stellenbosch in April 2011.
- BSc curriculum initiative which investigates what physics should be taught (and how) at this crucial phase. This is in response to the DST/NRF drive to increase the number of high-quality PhDs, and in view of the reality that secondary education in the physical sciences and mathematics is not demonstrably improving.
- A South African physics graduate database which aims to develop a physics graduate support system, given the very small pool of students that meet the entrance requirements in the physical/mathematical sciences.
- A Biophysics Initiative to build and strengthen this new interdisciplinary research field as a cornerstone for 21st century physics in South Africa.
- Physics for Development, which strives to implement the recommendations of the 2005 World Conference on Physics for Development. For example, a workshop on entrepreneurship for scientists and engineers from developing countries in Africa is being hosted in November 2009.
- A Pan-African Physics Forum to strengthen African networks; a meeting for heads of physical societies is planned for November 2009.
- Physics Comment, an electronic magazine to communicate with the physics community and the relevant stakeholders and decision-makers.
- The establishment of the OR Tambo Memorial Awards and Lecture Series to commemorate and honour OR Tambo's contributions as a physics teacher in South Africa and, while in exile, also in the United Kingdom (UK).
- A project called Physics 500 to promote physics in industry by publishing the careers of up to 500 industrial physicists as role models.
- A Further Education and Training (FET)[2] education project to expose university lecturers to the outcomes-based FET curriculum so that they can effectively incorporate this into their teacher-training courses.
- A revision of the 55-year old SAIP constitution, completed in 2009, to comply with modern practices.
- A History of Physics in South Africa, to be published in 2010, which will concentrate on the most recent 50 years, over the lifespan of the SAIP.

The immediate success of the office is due to the fact that it implements DST strategies and NRF programmes at the ground level. It works directly in, and with, the physics community, which the policy-making and funding agencies cannot do as easily.

The remainder of this chapter will discuss how these new opportunities for physics in

[2] Formal education in South Africa is categorised according to three levels – General Education and Training (GET) comprising grades 1 to 9, Further Education and Training (FET) comprising grades 10 to 12 and Higher Education (HE).

South Africa are being exploited within the individual disciplines, grouped according to the current SAIP specialist groups. They are presented in alphabetical order.

3.4 Applied physics

Applied physics is probably the largest sector of the physics profession. It is estimated that fewer than half of all South African physicists are members of the SAIP, and that the majority of non-members are employed in industry, or use their physics expertise as S&T innovators outside the academic sphere. In view of this, there has been some debate in recent years as to the exact remit of the applied physics specialist group (APSG) within the SAIP. For a while the name 'applied and industrial physics' was used, but it was felt that this was too broad, and that this sub-group should be concerned primarily with work at research institutions in which applications of the physical principles were under development.

Applied physics naturally intersects with the interests of other specialist areas, such as nuclear physics or solid-state physics. Virtually all universities are involved in some aspect of applied physics, often in collaboration with industrial partners. Materials science is a good example of an area which includes much applied physics. Research from a conglomeration of institutes which form the DST/NRF Centre of Excellence in Strong Materials centred at the University of Witwatersrand (Wits) is much in evidence. Diamond physics has been a South African speciality for many years and continues to be important, with applications including both its strength and its novel electronic properties.

Several South African universities are working on renewable energy systems, notably the use of solar power via photovoltaic panels or direct heating, and many evaluative studies have been reported on materials and the characterisation of devices. Much attention has been given to the work on thin, light and cheap panels done at the University of Johannesburg (UJ) over the last decade, which has led to a significant production contract in Germany. Luminescent and other photonic materials are also researched, and a separate biennial conference is held locally in this area.

Another area of national importance which is very visible, both within the APSG and at other local conferences, as well as in postgraduate courses, is that of the safe handling of ionising radiation and its practical applications, either for research or for more direct benefit. The Mafikeng Campus of North-West University (NWU), for instance, has a postgraduate course in Applied Radiation Science and Technology. In this area, the APSG has recently nominated a representative to the SAIP sub-committee which liaises with the Nuclear Industry Association of South Africa.

Biophysics is small and underdeveloped in

South Africa, and the initiative mentioned above is an attempt to develop it as another cross-cutting aspect of applied physics, mainly in collaboration with the strong laser community (discussed in section 3.8).

In the past year, some members of the APSG have been involved in the establishment of the Physics 500 Project of the SAIP, the aim of which is to find and describe working physicists outside academia. This stems from the recommendation of the 'Shaping the Future of Physics' in South Africa project, to help students find role models and opportunities in industry, and to help industry inspire students to pursue careers in physics. In this way the creation of research collaborations between industry and academia is a continuing initiative for the benefit of the country.

3.5 Astrophysics and space science

Astrophysics and space science (ASS) in South Africa encompass the fields of optical and infrared astronomy, radio astronomy, gamma-ray astronomy and space physics. South African scientists produce internationally recognised research output in ASS, and South Africa is a major role player because of its geographic advantage and scientific productivity.

The building of a 10-m class optical telescope called SALT, the largest in the southern hemisphere, participation in the world's foremost ground-based gamma-ray telescope, the High Energy Stereoscopic System (H.E.S.S.), and the building of the pathfinder MeerKAT for the envisaged SKA, are a few major astrophysical projects in which South Africa is involved.

Astrophysics research in South Africa is mainly optical and infrared, with the majority of researchers based in the Western Cape. The two major observatories, which are national facilities under the NRF, are the SAAO and the HartRAO. Together with H.E.S.S. in Namibia, they are the main astrophysical facilities for South African researchers, and they are financed partially or fully by government through the DST.

The SAAO is the main custodian of optical facilities and operates five small telescopes, as well as SALT on behalf of its international partners. SAAO telescopes are at Sutherland, 360 km north of the headquarters in Cape Town. The small telescopes contribute to international research and to the training of future astronomers. They are also important for the future success of SALT, either as support telescopes or in its calibration.

SALT is operated by SAAO on behalf of the international consortium which owns it and in which South Africa is the major shareholder; other shareholders include institutions from the United States (US), Poland, UK, India, Germany and New Zealand. The telescope is optimised for optical spectroscopy and has niche capabilities in spectropolarimetry and high-speed photometry. The infrared arm of the spectrograph is under construction and will make SALT an important instrument for cosmology.

Currently there are six other telescopes hosted by SAAO at Sutherland on behalf of, or in collaboration with, international partners and institutions. Some of these are run robotically by the international partner, with SAAO providing technical assistance, maintenance and services. South African researchers have access to at least some data from each of these. Other non-astronomical facilities in Sutherland include a seismograph and a geodesic observatory. Many of these facilities are part of global networks. Sutherland is important for geographical and geological reasons, as well as for hi-tech infrastructure.

HartRAO is the national facility for radio astronomy, and has operated a 26-m radio telescope near Krugersdorp, west of Johannesburg, since 1975. It was built by the National Aeronautics and Space Agency (NASA) in 1961 as part of their Deep Space Station 51, for tracking US space probes. It was transferred to South Africa 14 years later when NASA withdrew. Because of its location the telescope has played an important role in 'Very Long Baseline Interferometry' networks and geodesy. It was particularly useful in pulsar timing, interferometry, spectroscopy and radiometry. The antenna suffered a major failure in 2008 and it is currently (July 2009) inoperable. The prototype 15-m eXperimental Development Model (XDM) of the Karoo Array Telescopes (KAT) is being considered as a replacement for the 26-m telescope to continue some of the monitoring programmes until decisions are made whether to repair or replace the 26-m telescope.

South Africa has been shortlisted, with Australia, to host the SKA telescope. The KAT will be used to test technologies leading up to the development of the SKA. The first seven antennae are currently under construction, and the full array of about 80 dishes (the MeerKAT) will be operational in 2012. If the SKA is to be built in South Africa, the central array will be located near Carnarvon in the Northern Cape. The rest of the dishes may be spread out as far as Ghana and Mauritius.

Using the above optical, radio and gamma-ray facilities, postgraduate training and significant research is carried out at the University of Cape Town (UCT), University of the Free State (UFS), NWU, Rhodes University (RU), University of South Africa (UNISA) and the University of the Western Cape (UWC). In addition, theoretical cosmology is practised at UCT, the University of KwaZulu-Natal (UKZN), UWC and the University of the Witwatersrand (Wits).

South Africa is involved in ground-based gamma-ray astrophysics via the participation of NWU in the highly successful international collaboration that operates H.E.S.S. in Namibia. This university has a research chair in the field, and this forms the core of a broader participation by other South Africa institutions in H.E.S.S. II, which is currently (2009) under construction. H.E.S.S. is a system of Imaging Atmospheric Cherenkov Telescopes capable of detecting cosmic rays in the 100 GeV to 100 TeV energy range.

It is a collaboration of mainly European institutions, with South Africa and Namibia as the sole African representatives. The main goal is to explore the production, propagation and acceleration of very high energy

(VHE) particles in the universe. The extreme astrophysical sites of cosmic acceleration or sources of non-thermal radiation that produce VHE photons include supernovae, giant molecular clouds, starburst galaxies, clusters of galaxies, and supermassive black holes in active galaxies. H.E.S.S. has detected or confirmed over 50 VHE sources as gamma-ray sources.

Astronomy Advantage Areas have been declared around Sutherland and Carnarvon to protect and maintain the radio-quiet regions for the SKA and the Sutherland observatory against light and dust pollution. The Astronomy Geographic Advantages (AGA) Act was passed in 2007, to ensure that South Africa will be able to participate as a partner in global-scale science projects.

On the space science side of this main grouping, there are several activities in space and upper atmosphere physics, extending to Antarctic research. In this field and its related technologies, South Africans have worked historically in the fields of geomagnetism, ionospheric physics, heliophysics, and plasma physics. The birth of space-weather research in Africa and the increased human dependence on space technology have added to the interest. The HMO specialises in fundamental space physics research, as well as the development of research infrastructure, promotion and marketing of space physics.

The HMO is responsible to the international science community for a number of infrastructure networks that extend as far as Antarctica and deep into Africa, where space physics collaborations are being established. In particular, it is one of four observatories worldwide whose observations are the basis of the Dst index, a measure of variation of the earth's magnetic field, e.g. due to solar activity. The South Atlantic Anomaly has a strong effect on the main geomagnetic field in Southern Africa, and studies by the HMO of its temporal variation are yielding interesting results. The HMO also carries out ionospheric tomography using Global Positioning System (GPS) satellite data. RU has a long history of research in ionospheric physics. Currently, in conjunction with HMO, it operates a network of ionospheric observatories.

As one of the original 12 signatories of the Antarctic Treaty in December 1959, South Africa has maintained a scientific base in Antarctica since 1960. The treaty sets aside the continent for research purposes, and South Africa celebrated its 50th anniversary in Antarctic research at a mid-winter function on 17 June 2009 at the South African National Antarctic Programme (SANAP) headquarters in Cape Town. The current South African National Antarctic Expedition (SANAE) base is situated on a rocky outcrop 240 km from the edge of the ice shelf. The proximity to the magnetic pole and the auroral zone means that measurements in upper-atmosphere physics provide a ground-based 'window into geospace'. The flagship project of SANAP at SANAE is the Southern Hemisphere Auroral Radar Experiment (SHARE) high frequency (HF) radar, which probes a large region of the ionosphere over Antarctica, and it is part of the international network known as SuperDARN (Super Dual Auroral Radar Network). It was developed as a project of the former Universities of Natal (now UKZN), responsible for data management, and Potchefstroom (now NWU), who carried out the construction from 1994 to 1996, and who were responsible for engineering operations for the subsequent eight years. The SHARE group and HMO have a long history of working on ultra-low frequency (ULF) geomagnetic pulsations arising from solar-terrestrial effects. Observations of naturally-occurring very low frequency (VLF) waves by UKZN and HMO are related to particle precipitation effects in the auroral region. Cosmic-ray neutron monitors at SANAE have been operated by the research group at NWU (Potchefstroom campus) continuously since 1964, providing a valuable long-term data resource which contributes to valuable insights into the modulation of cosmic rays.

Since 1974, the group at NWU has focused strongly on the theoretical side of cosmic-ray transport in the heliosphere. Their models are based on numerical solutions of the cosmic-ray transport equation, and they provide explanations for the observations made over many decades, ground-based as well as by spacecraft throughout the heliosphere, of how the sun modulates the cosmic-ray intensity. These insights are applicable to new so-called astrospheres that are being discovered and to cosmic rays created in the remnants of supernova explosions.

For many years there has been a strong involvement at UKZN in theoretical research on linear and nonlinear waves in plasmas. Their interests in space plasma physics include studies of electrostatic solitons, dusty plasmas, waves in kappa distribution plasmas, and geomagnetic field line resonances.

This discipline as a whole strongly experiences the enabling effects of government policy and legislation to provide South Africa with world-class facilities for astrophysics and space physics. The Space Agency Bill of 2008 strives to integrate the space applications more strongly with the basic space sciences. The big challenge remains to educate more South Africans to a level where they can make full use of these facilities.

The ASS group has a specific focus on student training and development. The National Astrophysics and Space Science Programme (NASSP) was formed in 2003 to address the problem of shortage of South African astronomers that are capable of using SALT, and the extreme lack of black South African astronomers. The programme has been quite successful in producing postgraduate students with various skills that can also be applied in a range of other fields and industries. The primary problem so far has been attracting sufficient black South Africans into the programme, but this is addressed with the introduction of an extended programme that caters for South African students with disadvantaged educational backgrounds.

3.6 Condensed matter physics and materials science

Materials physics is the most widely practised branch of physics in South Africa, and also one of the oldest and most established. Researchers such as FRN Nabarro and JH Van der Merwe pioneered the field in the 1950s and 1960s, and currently there are established groups at about ten universities, together with research laboratories at the CSIR, iThemba LABS, and Mintek, as well as Element 6 in industry.

Recent years have also seen a stronger overlap with research in other physics sub-disciplines (applied physics, optics and spectroscopy, and theoretical physics), and even with other disciplines (chemistry, biology and engineering) and research areas (nanosciences, biotechnology, and microscopy). Details are given under the descriptions of each of the respective fields.

A research chair in nanotechnology was awarded in 2008 to the physics department of Nelson Mandela Metropolitan University (NMMU) for work on thin-film semiconductor materials. The NRF has also established a National Centre for High-resolution Transmission Electron Microscopy (TEM) in the same department. It will operate the first double-corrected atomic resolution TEM in Africa. This facility is, however, only the most high-profile of a series of similar facilities established throughout the country for research on nanomaterials and other interdisciplinary science. Only three years ago, near-atomic resolution microscopy in South Africa was a dream, with researchers and students having to use their scarce resources for travel. Now there are facilities at UWC, UCT, Wits and the CSIR. The same pattern has been repeated throughout the recent investment in interdisciplinary research equipment. The major share has been used to purchase analytical equipment for materials characterisation, and it is these tools of condensed matter physics and materials science which are driving the resurgence of applied and interdisciplinary research.

This cross-fertilisation with other disciplines and investment in much-needed infrastructure has led to an equal growth in human capacity. Almost every university in the country now has either an active research group in the field, or a successful postgraduate programme, often in collaboration with other institutions and disciplines. In this respect, the new teaching and research activities at the UFS's Qwa-Qwa campus, and at the University of Zululand (UZ) in collaboration with UWC and the materials research group at iThemba LABS, are particularly noteworthy. Even the established universities and the science councils have seen a resurgence in an interdisciplinary approach to materials research, with the establishment of the Centre of Excellence for Strong Materials at Wits, and the National Centre for Nano-structured Materials at the CSIR. The UFS has established, through its applied and basic research on nanophosphors, strong collaborative links with chemistry departments. Both NMMU and UCT have a broad programme of research, ranging from the fundamental physics of nanomaterials through to the applied physics of solar cells – one being based on thin-film compound semiconductors and the other on printable nanoparticulate silicon. While not formally having a solid-state physics group, Stellenbosch University (SU) is actively pursuing the study of materials using femtosecond laser techniques, specifically second-harmonic generation at semiconductor interfaces and ultra-fast electron diffraction. The University of Pretoria (UP) has maintained its traditional strength in semiconductor materials and ion beam analysis, while developing industrial links to conduct research on the materials for the PBMR. Theoretical and computational solid-state physics, traditionally the preserve of the Materials Modelling Centre at the University of the Limpopo (UL) and the Wits physics department, has been enhanced by the activities of the theoretical physics community, namely the establishment of NITheP and the Centre for High Performance Computing in Cape Town. UJ, UCT, UFS and UZ are now actively conducting research in this area. On the experimental side, UJ has become the *de facto* national centre for studies of the magnetic properties of materials.

3.7 Education

Physics education activities within the SAIP take place at four levels – curriculum, pupils, teachers and undergraduate. In the past few years, South Africa has introduced new secondary school curricula that are designed to be modern and based on the principles of outcomes-based education. The focus is on what students know and can do, rather than on what the teacher teaches. The curriculum for Grades 10 to 12 was phased in between 2006 and 2008. Members of the SAIP were centrally involved with designing the physics component of the physical sciences curriculum. There are three physics, two chemistry and one integrated strand, each of which is taught in each of the three years of secondary school. The selection and sequence of physics topics were intended to facilitate conceptual progression, while helping students see the relevance of physics to everyday life. Applications related to South African-based science were also included, such as the SALT and laser physics.

Between 2005 and 2009, the SAIP received funding from the DST to support teachers in implementing the new Grade 10 to12 physics curriculum. Since the new curriculum required greater depth of understanding of the physics content, it was essential that physicists were involved in in-service teacher development. DST funding has been used to develop materials for workshops for teachers to be run by physics university lecturers. The national Department of Education (now the Department of Basic Education) has also called on SAIP members to run workshops for subject advisers and teachers. In addition, physicists at several universities are involved in teaching formal teacher education programmes, to both pre-service and in-service teachers. Greater involvement of physicists in teacher education and professional development will lead to greater understanding of subject matter amongst teachers, as well as greater appreciation amongst physicists of the background of incoming students at university level.

In order to stimulate interest and nurture talent in physics amongst pupils, the SAIP has been working with DST to establish a physics olympiad. In 2009 it will be written by a subset of pupils writing the more general science olympiad. In the future there are plans to expand participation and performance in the physics olympiad by offering training camps.

South African physicists have conducted research in physics education for more than 30 years. In the 1970s and 1980s, much of the research focused on students' alternative conceptions and reasoning difficulties, in line with international physics education research at the time. In the 1990s there was a strong political and social imperative to provide access to science degrees for students who came from economically and educationally disadvantaged backgrounds. Several universities created programmes that extended the BSc degree by one year and included additional components to help overcome gaps in students' background knowledge and to explicitly develop their cognitive and metacognitive skills. A great deal of research was carried out during this time by physicists specialising in physics education research. The impetus behind much of the research in physics education was to identify obstacles to success for students in foundation programmes and interventions to overcome them. This led to research focused on students on the one hand, and the learning environment on the other. The research topics encompassed the identification and evaluation of appropriate curriculum elements for foundation and extended courses; the interplay between language and conceptual understanding (the great majority of South African students study in a language that is not their mother tongue) and between writing and learning; the effect of metacognition on enhancing learning; student understanding of the nature of scientific measurement; strategies for enhancing problem-solving skills; and effects of peer-group learning. The research has yielded insights into aspects of curriculum, teaching approaches and student learning environments that can lead to more effective physics learning.

Today, most universities in South Africa provide some form of foundation physics course that is offered as part of an extended BSc degree. These courses are intended to provide access to university science-based degree programmes for students who have been academically disadvantaged. Over the past two decades, physics education research led to the identification of key concepts, cognitive skills, mathematical tools and philosophical elements that need to be explicitly incorporated into physics curricula at the foundation and introductory levels. Physics education research continues to inform the design and development of the content, philosophy and teaching approaches for these courses. In several universities, this research is also influencing the content and teaching approaches in the introductory courses, including the design of introductory laboratory work.

A few studies have also been carried out over the years on physics teachers. Such studies have identified teachers' conceptual difficulties, which are likely to be passed on to students. Others were about the relationship between teachers' content knowledge, teaching approaches and professional attitudes.

A more recent line of research involves the relationship between indigenous knowledge and traditional physics. This is aimed at identifying aspects of indigenous knowledge that can be directly related to physics concepts and then incorporation into physics curricula. It is hoped that the effect will be to both preserve indigenous knowledge and to help students value it. Furthermore, the use of local contexts may make the physics concepts more accessible to students.

3.8 Lasers, optics and spectroscopy

South Africa has a long history of optical spectroscopy, and it continues to be an important field in the country, both as a tool and in terms of fundamentals. Examples are the research undertaken at the NPRL of the CSIR and at SU and UKZN (Pietermaritzburg campus). This expertise led to South Africa being an early adopter of laser technology, the first lasers being built in the 1960s at the NPRL and at UKZN. Despite this early introduction, there was little activity in photonics in the country until the early 1980s, when the AEC started investigating the process of Molecular Laser Isotope Separation (MLIS) as an alternative to the ubiquitous centrifuge technology for uranium isotope separation for enrichment. This required a large investment in laser and photonic technology in terms of both infrastructure and equipment, as well as in competency. It is estimated that several hundred millions of Rands were spent on this chimera.

South Africa is often praised for its voluntary halting of all nuclear enrichment programmes, but this left the photonics community in South Africa in a quandary, when in 1997 the MLIS programme, with a staff of more than 300 well-trained scientists and technicians, and an estimated R20 million worth of laser and photonic equipment, was terminated. Interventions from the SAIP with the then DACST led to the inauguration of the NLC in 2000, but more importantly, a nationally co-ordinated programme (Rental Pool Programme) to promote lasers, optics and spectroscopy in South Africa.

The outreach activities of the SAIP lasers, optics and spectroscopy (LOS) specialist group members, together with that of the Rental Pool Programme, has seen photonics in South Africa enjoy significant expansion from 1998 onwards. Technical, scientific and infrastructural support has meant that any university in South Africa can now consider photonics research regardless of lack of experience or equipment. This approach has seen photonics adopted across disciplines, whereas previously it was predominantly the domain of physicists, and has seen the LOS group become one of the largest and most active in the SAIP community. There has been a concomitant increase in publication outputs and student involvement in photonics research, with four of the research chairs appointed in photonics: photonics, ultra-fast and ultra-intense laser science (SU); quantum information processing and communication (UKZN); medicinal chemistry and nanotechnology (RU); and nanophotonics (NMMU). The main research centres in photonics are concentrated at the NLC and SU, where both basic and applied research is undertaken in a wide range of fields, including a growing activity in ultrafast science. Extensive application of photonics is to be found at other institutions such as Wits (materials), UJ (biology), UKZN (quantum optics), NMMU (fibre optics and photonic materials) and RU (chemistry).

The extension of activity into the rest of continental Africa is strong and well-focused, with the recent establishment of the African Laser Centre which currently has 19 partner countries and the growth of which is set to continue.

Photonics is one of the fastest growing technology fields worldwide; for the first time, in 2005, worldwide revenue from photonics exceeded that of microelectronics, heralding the so-called 'century of the photon', where photons are mooted as the electrons of the 21st century. This is apparent in everyday life, where photonic components are steadily replacing electronic components (such as communications over fibre optic instead of copper wire). The DST strongly supports laser research in South Africa, identifying it as an important emerging research area and one in which it is believed that researchers in South Africa have the potential to contribute to leading-edge global knowledge.

Ten years since the small LOS community established the NLC, the members (now numbering about 70) have again mobilised to take photonics into the future through the Photonics Initiative of South Africa (PISA). Offered as a direct intervention for flagship-type programmes as suggested in the 'Shaping the Future of Physics in South Africa' report, PISA has presented to DST a strategy for photonics in South Africa involving a R700 million investment in photonics over a five-year period, starting in 2009. PISA aims to position South Africa as a globally competitive player in photonics by strengthening human capital development, investing in pure and applied photonics research, and fostering a national photonics industry.

3.9 Nuclear, particle and radiation physics

Since the advent of democracy in 1994, many collaborative research partnerships have been established with other countries in the fields of nuclear, particle and radiation physics. Many efforts, both experimental and theoretical, are underway in South Africa and abroad, with the overall goal being the production of a cohort of skilled, dynamic young scientists who reflect the full diversity of South Africa's population. Some of these initiatives are discussed below.

In collaboration with a considerable number of South African universities, accelerator-based academic and applied nuclear research is carried out at the Cape Town and Gauteng sites of iThemba LABS, at Necsa, and at UP. This represents a substantial research infrastructure that is a key asset to the country as it seeks to develop the skills required by the nuclear power and medical industries, as well as delivering other potentially beneficial spin-offs.

In the Cape, iThemba LABS makes use of its two main accelerators, namely the K=200 Separated Sector Cyclotron (SSC) and the single-ended 5MV Van de Graaff. The SSC produces 200 MeV protons for research and proton therapy, up to 250 μA of 66 MeV protons for isotope production and neutron therapy, and a wide range of ion beams from ^{3}He to ^{136}Xe for academic research. A new 'beam-splitter' has been installed so that high and low-current production of radio isotopes can be carried out simultaneously. In addition, new electron cyclotron resonance ion sources are currently being installed to enhance the opportunities for cutting-edge academic research. The challenge remains as to how best to divide the SSC accelerator's beam-time between the nuclear power and medical sub-disciplines. Clearly, the only long(er) term viable solution would be to have dedicated accelerators for the medical and isotope production functions, which would free the SSC to be used exclusively as a research tool.

Of the suite of smaller accelerators, the 5 MV van de Graaff at iThemba LABS South is mainly used for materials, nanoscience, geological and biological research. The accelerator located at the iThemba LABS Gauteng site is a 5 MV EN tandem which has recently been refurbished by grants from the DST. Currently, some of the equipment required for a commercial service for Atomic Mass Spectrometry (AMS) is being installed for ^{14}C dating and the studies of many trace materials. There is also apparatus for materials and nuclear research. The major facility at Necsa is the SAFARI reactor with a variety of thermal neutron beams and activation facilities. UP has a 1 MV single-ended Van de Graaff accelerator, used mostly for implantation and channelling studies.

The largest investment in human and technical capital in pure nuclear physics research in South Africa resides at iThemba LABS in the western Cape. A long-standing collaboration with the Research Centre for Nuclear Physics RCMP in Osaka, Japan, has resulted in the very large magnetic spectrometer at iThemba LABS becoming one of only two spectrometers in the world to achieve an energy resolution of better than 20 KeV for protons above 100 MeV. This has produced the first measurements of the fine structure in giant dipole resonances, measured with inelastic proton scattering, in a collaboration including Wits and the Technical University in Darmstadt, Germany. The latter study has made use of wavelet analysis in which different energy-scales of the fine structure of the GDR can be uncovered. The use of the spectrometer in the operationally challenging, but scientifically rewarding zero-degree mode has recently been harnessed over an extended running period. Such measurements will become more common if the applied and medical applications of the iThemba LABS SSC are moved onto dedicated accelerators.

The 'African Omnipurpose Detector for Innovative Techniques and Experiments' (AFRODITE) gamma-ray spectrometer at iThemba LABS South is amongst the ten most powerful instruments in the world for the investigation of the quantum structure of nuclei. These spectrometers can be used in a wide variety of experiments, often in conjunction with additional specialised detectors. Many experiments have been carried out using AFRODITE, including collaborative measurements with physicists from Australia, Bulgaria, China, France, Hungary, Italy, Sweden, Slovenia, Turkey, and the UK. For example, there is a formal collaboration with the ATOMKI Institute in Debrecen, Hungary, under the auspices of a governmental bilateral agreement. This has resulted in the ATOMKI DIAMANT array of charged-particle detectors being available for experiments with AFRODITE. Both AFRODITE and DIAMANT are in the process of being connected to a state-of-the-art 'triggerless' data-acquisition system. These developments, along with the in-progress procurement of the first high-volume, highly segmented TIGRESS-type clover germanium detector will boost the detection sensitivity for the study of weakly populated structures of significant and cutting-edge physical interest. Of particular relevance to this is the desire to study exotic nuclear species with large neutron excesses which can be produced in the fragmentation of intense, fast beams of stable nuclei. Such beams will be available from the new Grenoble Test Source (GTS) electron cyclotron resonance ion source which is under assembly at iThemba LABS.

There is a formal agreement with the Joint Institute for Nuclear Research (JINR) at Dubna in Russia, where South African physicists have joined in experiments within the associate membership framework. Tangible benefits to the nuclear physics infrastructure in South Africa have resulted from this membership, both in terms of knowledge sharing and technological developments.

A number of world-leading projects in particle physics are underway at the European Organisation for Nuclear Research (CERN) in Switzerland to which South Africa makes significant contributions. Recently, a South African team successfully tested their software for the fast di-muon trigger of the ALICE (a large ion collider experiment) detector on the Large Hadron Collider.

Sources of positrons from 22Na, manufactured by the radio-nuclide production group at iThemba LABS, have been used to produce anti-hydrogen at CERN. UCT is a world-leader in the application of thermodynamic approaches to understanding the properties of the Quark Gluon Plasma (QGP) that is thought to be produced by the collisions of very energetic heavy nuclei. A group at UJ is taking part in the ATLAS (a toroidal LHC apparatus) experiment, which is aimed at obtaining a definitive determination of the mass of the Higgs particle.

The Centre for High-performance Computing (CHPC) in Cape Town is an important facility that grew out of a physics proposal in this specific field. Most of the flagship projects that are listed in their brochure are physics-based. It obviously has a much broader user base, and it is another example of DST investment in S&T infrastructure.

3.10 Theoretical physics

Theoretical physics has a long and productive history in South Africa. The first formal structure to promote research and training in theoretical physics was created in 1974 at the founding meeting of the Organisation of Theoretical Physics (OTP). A committee was elected, with CA Engelbrecht elected as the chair, and thereafter re-elected every year until 1989. In the first year, 35 members joined the organisation, and within a few years it grew to about 60 members, which then included staff and students from all universities. The first success of the OTP was in 1976 when the CSIR president, C van der Merwe Brink, agreed to sponsor a regular summer school series through which theoretical physicists and university students could become acquainted with important developing areas in modern physics. After the death of Engelbrecht in 1991, the OTP felt that it was appropriate to name this summer school series after him as initiator of this initiative. The Chris Engelbrecht Summer School series, later sponsored by the NRF, has become known internationally, and has attracted numerous high-profile lecturers, including a number of Nobel laureates. (A list of previous summer schools can be found at http://www.nithep.ac.za.)

Another initiative of the OTP was a series of theoretical physics seminars. From the inception of the OTP in 1974 until 1980, this annual series became the major organised activity of the OTP. It obtained official status within the SAIP, and in the annual SAIP conference programme a dedicated session was established for these OTP seminars.

The April 2004 report on 'Shaping the Future of Physics in South Africa' contained among its recommendations the following: "The state of theoretical physics is characterised as internationally competitive in some areas, but there is fragmentation and a coherent policy is needed. We recommend the establishment of a national theoretical physics facility (either real or virtual); the theoretical physics community will then be able to respond nimbly to national science policy initiatives."

The theoretical physics community was able to respond quickly, and in July 2004 a working committee was elected to draft a formal proposal in response to this recommendation. In consultation with the broad community of stakeholders in theoretical physics, consensus was reached that the model of a geographically distributed National Institute for Theoretical Physics ('hub-and-spokes' model) would best serve the needs and interests of the physics community. In a proposal to DST and NRF in November 2004, and formally endorsed by the SAIP council, it was accordingly recommended that NITheP (the National Institute for Theoretical Physics) be established with its main centre at the Stellenbosch Institute for Advanced Study (STIAS), and with regional centres at Wits and UKZN. This proposal was formally approved by the DST and NRF in February 2006. Finally, in April 2008, after an interim phase in which progress was monitored by a management committee, the first full-time director, FG Scholtz, five full-time researchers and a number of postdoctoral fellows were appointed.

The inauguration of NITheP at STIAS took place on 13 May 2008 with Minister M Mangena of the DST delivering the opening speech. The inauguration was attended by Stephen Hawking, who gave a personal message of support, as well as by Nobel laureates David Gross and George Smoot.

NITheP is now firmly established and is earmarked to become a national facility in the near future. It supports around 90 postgraduate students in theoretical physics and closely related fields, and has around 30 associate members from all South African tertiary institutions. NITheP aims to create a national, African and eventually international network of researchers that will drive research and training in theoretical physics in a coherent and sustainable way throughout South Africa and Africa.

Currently, the main research thrusts in the South African theoretical physics community, which are also reflected within the NITheP network through researchers and associates at various universities, are in the broad fields of statistical and condensed matter physics (SU), fundamental high-energy physics and classical and quantum gravity (Wits and UCT), quantum computing and information (UKZN), high-energy phenomenology (UCT and Wits), cosmology and astrophysics (UCT and UKZN), space plasma physics (UKZN), and computational physics (UL, UP and Wits).

More information on NITheP's structure and activities are described at http://www.nithep.ac.za.

3.11 Assessment and the future

The discipline of physics and astronomy in South Africa is clearly healthy, and core to the National System of Innovation. From a slow and sometimes uncertain start 15 years ago, the physics community has learned how to focus on the needs and the expectations of the new democratic South Africa, and how to build on the existing S&T infrastructure. The government underscored the importance of this infrastructure with its strong and sustained investment in new equipment and opportunities such as telescopes, analytical equipment, research chairs, centres of excellence, new national institutes and interdisciplinary science and technology facilities. This has already had a significant effect, most notably in the increase in the number of practising physicists, as reflected by the rapid growth of SAIP membership and the annual conference attendance. The age of this membership has dramatically reduced due to the increase in the number of postgraduate students, and the demographic balance amongst these students is becoming more fully representative each year.

The challenge for the future is twofold. The mission statement of the SAIP is to be the 'voice of physics in South Africa', and through its list of initiatives, it finds itself in a continuing learning curve of how to stimulate the subject. The much bigger challenge is the poor state of science and mathematics teaching in many secondary schools, leading to too few entrants at the tertiary level, thus threatening the long-term sustainability of the basic sciences. The science and mathematics communities are continually addressing this challenge, but a much larger intervention at the national level is needed.

CHEMISTRY

CHAPTER 4

RAYMOND HAINES

4.1 Introduction

The expansion and development of the petrochemical industry in the post-World War II era was no doubt responsible at that stage for chemistry globally attracting some of the largest classes at universities. Chemistry graduates had no difficulty in obtaining employment, often being able to pursue research at larger local chemical companies. Although South Africa did not have multinational chemical companies like countries in Western Europe or the United States, chemistry in this country was nonetheless considered a subject worth pursuing and one where employment was almost guaranteed. From the mid-1980s, however, in spite of the considerable increase in the total number of students attending tertiary institutions in South Africa, chemistry student numbers remained more or less static, and compared with commercial and financial subjects, there was a relative decline in the popularity of the subject. Furthermore, over the period from 1997-1998 to about 2002-2003 there was an almost 50% decrease in student numbers, although the current numbers appear to have returned to those of 1997-1998. Some of the reasons for this decline were global, with chemistry often being accused of being responsible for many woes of the world, while the 1990s saw a major rationalisation of the chemical and pharmaceutical industries. However, the number of students in chemical areas graduating from technikons[1] remained static over the five-year period mentioned above, with a slight increase since then.

The early 2000s witnessed major changes in the tertiary education landscape in South Africa as a consequence of the government's decision to rationalise most of the universities and technikons (see Chapter 1). Notwithstanding these merger processes, which have undoubtedly led to some rationalisation as far as departments (or schools as they are commonly now known) of chemistry are concerned, the country still has 20 tertiary institutions with chemistry departments, with some schools/departments being located on more than one campus.

An important source of employment several decades ago for those who wished to pursue careers in chemistry research was the National Chemical Research Laboratory (NCRL) at the Council for Scientific and

[1] Technikons were higher education institutions in South Africa that focused on technological training. They are now called universities of technology.

Industrial Research (CSIR) and some of the country's outstanding research emanated from it. Equally important, the laboratory was a nursery for university academics, and many university professors, most of them now retired, started their careers at the NCRL. Similar to the universities, the CSIR underwent a radical rationalisation process in the late 1980s brought about by financial constraints that forced it to increase its income from the private sector and to bring it closer to meeting the developmental and societal needs of the country. This necessitated a paradigm shift from a 'blue skies' approach to research to one of relevance, and one in which the CSIR needed to play an integrated role in the national science and technology strategy. This structural change resulted in the formation of totally new divisions, such as Processing and Chemical Manufacturing Technology and Food Science and Technology within the CSIR and the effective closure of the national laboratories such as the NCRL and the National Physics Research Laboratory (NPRL). Clearly this structural change had a major impact on the fundamental research output of this country. However, recent policy shifts resulting from the 'Beyond 60' [2] vision at the CSIR have been accompanied by a new approach, in which research programmes remain relevant but have again become more fundamental in nature.

Two other statutory bodies which employ research chemists are Mintek (previously the Council for Mining Technology and subsequently the National Institute for Metallurgy (NIM)) and the Nuclear Energy Corporation of South Africa (Necsa) (previously the Atomic Energy Board (AEB)). The research carried out by Mintek is, not surprisingly, very focused and in line with the mandate of the organisation; the research has a more developmental and less fundamental bias, but all the same some outstanding achievements have been made. The focus of the research programme at Necsa is biased towards physics and engineering, but does include some work on radiochemistry and fluorine and uranium chemistry.

Many industrial organisations in South Africa employ chemists but purely in a quality-control capacity. Probably the only exceptions to this have been AECI (previously African Explosives and Chemical Industries), Sentrachem and Sasol. Both AECI and Sentrachem have ceased their research operations, however, the former as a consequence of major financial constraints and the latter as a consequence of the company being taken over by Dow Chemicals. Sasol has gradually increased its research output, and today is a major employer of research chemists. A more detailed account of its contribution to South African science is provided below.

Until relatively recently, technikons had essentially no, or a very limited, research ethos. The National Research Foundation (NRF) has addressed this situation by in-

[2] The Beyond 60 vision aims to strengthen and transform the CSIR's S&T base so as to refocus on scientific research as the core of the organisation.

troducing special funding programmes to encourage and promote research at these institutions. The programme has met with some success, and there has been a considerable improvement in the research outputs at some of the new universities of technology.

The Department of Science and Technology (DST) has taken on a direct role in promoting and shaping South Africa's research future by providing the funding for the Innovation Programme, for research chairs at universities, and for the establishment of centres of excellence (see Chapter 1). Chemistry has been one of the main beneficiaries of this source of funding.

Chemistry is taught and undoubtedly will continue to be taught, particularly in the earlier undergraduate years, through the traditional sub-disciplines of inorganic, organic and physical and, in many cases, analytical chemistry. Furthermore, although research in chemistry is becoming increasingly interdisciplinary, chemists still operate essentially within their sub-disciplines. As a consequence, the state of South African chemistry research is reported below by sub-discipline but with industry and the statutory bodies being treated separately. It needs to be emphasised that this overview focuses on highlights and is not intended to be comprehensive.

4.2 Inorganic chemistry

Although classical inorganic chemistry research had been practised at a number of South African universities for some time, the birth of so-called modern inorganic chemistry in South Africa effectively took place in the early-1960s with the influx of several young postdoctoral fellows who had been trained at establishments abroad, either returning to South Africa or emigrating to it. This trend continued through the mid- to late-1960s although the numbers remained small. Because the global focus of inorganic chemistry at that time was on organometallic chemistry, it is not surprising that the expertise that these returning postdoctoral fellows brought with them was in this particular area. In fact, organometallic chemistry would dominate the local inorganic chemistry scene for the next 25 to 30 years. The main focus of the studies initially was on the synthesis of novel organometallic complexes with characterisation being achieved by means of infrared and nuclear magnetic resonance (NMR) spectroscopy; the utilisation of X-ray crystallography for structural characterisation was still in its infancy and very time-consuming.

The next generation of inorganic chemists likewise focused on synthetic organometallic chemistry, with many also having received their training abroad. They played a leading role in the development of inorganic chemistry in the country. Other areas of inorganic chemistry were by now starting to develop, however. For instance, the CSIR Unit of Uranium Chemistry was established at the University of Port Elizabeth (now the Nelson Mandela Metropolitan University), while bio-inorganic chemistry was introduced into the country through the appointment of an overseas candidate from the University of Oxford and the laboratory of RJP Williams, one of the founding laboratories of bio-inorganic chemistry, to the newly established chair of inorganic chemistry at the University of Witwatersrand (Wits). Although this area of research has never grown to the same extent as organometallic chemistry, the appointment created a platform for the generation of inorganic chemists who have had a substantial impact, both nationally and internationally. Mintek at this time established a group involved in coordination chemistry with the aim of developing new solvent exchange processes.

During the late-1970s, and in particular the 1980s, the research of South African inorganic chemists received considerable international recognition, driven to a great extent by the outstanding organometallic research produced by the chemistry group at the CSIR and the novel work that was emanating from the CSIR Metal Cluster Chemistry Unit at the University of Natal, Pietermaritzburg (now the University of KwaZulu-Natal). This clearly had an impact on the growth of inorganic chemistry, and organometallic chemistry in particular, and a new generation of locally trained inorganic chemists who researched the area of organometallic chemistry started to make their presence known and to become today's leaders.

The major paradigm shift at the CSIR, discussed above, which led to the closure of the national laboratories such as the NCRL, resulted in the cancellation of all programmes involving fundamental research in organometallic chemistry. Ironically, these developments coincided with the period during which globally organometallic chemistry started to lose its lustre and oil companies started to decrease their support for research programmes in and related to homogeneous catalysis.

An important development in respect of inorganic chemistry that took place in 1981 was the establishment of the South African Chemical Institute's (SACI) Inorganic Chemistry Conference Series, similar to the Warren Conferences in Organic Chemistry. This event permitted the inorganic chemistry community in South Africa to meet regularly as a body for the first time.

During the 1990s, South Africa experienced major political changes that were accompanied by far-reaching policy investigations to redirect the research agenda in accordance with new missions. The demise of research in classical science fields at the CSIR and to some extent at Mintek had been associated with a loss of scientists from the profession and the departure of many inorganic chemists overseas. This scenario coincided with worldwide shifts in funding support from curiosity towards relevance, which in South Africa, also translated into a move towards social relevance. First, the major public research agency, the Foundation for Research

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Development (FRD) and then its successor, the National Research (NRF, established in 1999) provided new guidelines for research support, and together with the Technology and Human Resources for Industry Programme (THRIP), created opportunities for chemists to do more 'industrial' research.

In the early- to mid-1990s, many organometallic chemists doing research at universities made changes to their research programmes in line with these international and local trends. In particular, inorganic chemists in the country started working on catalysis research programmes. The other area of growth was the move towards coordination chemistry and its relationship to physical properties. Thus, after 1990, the dominant role of organometallic chemistry in South African inorganic chemistry was in decline.

The past ten years have again witnessed major shifts in inorganic chemistry in South Africa. Several factors have accounted for this. In particular, the creation of research chairs and centres of excellence by the DST has led to new configurations in research groupings. Furthermore, research programmes in the country have followed global trends and become far more interdisciplinary, leading to inorganic chemists spanning a wider research spectrum and undertaking research over a wide area.

A major global focus is that of nanotechnology, and two of the DST/NRF national research chairs in chemistry were awarded in this area *viz*. those of Thobela Nyokong at Rhodes University and Neerish Revaprasadu at the University of Zululand. The former heads the Mintek Nanotechnology Centre for Sensors, a multidisciplinary initiative involving graduate students from chemistry, physics and biotechnology and working on projects in a range of areas from photochemistry to biotechnology and from solid state chemistry to medicinal chemistry. A major focus involves the development of sensors based on nanostructured phthalocyanine materials and in particular self-assembled monolayers of phthalocyanines and porphyrins for the analysis of neurotransmitters and other biologically important molecules. This is coupled with the synthesis of phthalocyanine and porphyrin complexes, the study of their photochemical and electrochemical properties and their use in photodynamic therapy of cancer. The design of ultramicro electrodes for direct use in cells or *in vivo* is another focus. The group led by Revaprasadu is focused on the synthesis of nanostructured materials such as semiconductors and metals, using various solution and high-temperature precursor routes. Earlier studies involved the synthesis of CdS nanoparticles and nanocomposites using single molecule precursors. Areas to which the group currently directs its attention include the synthesis, shape control and functionalisation of semiconductor nanoparticles of materials such as CdS, ZnS, CuS, PbS and MnS, as well as the synthesis, shape control and functionalisation of precious metal nanoparticles, in particular that of gold, and the encapsulation of these particles by water-soluble polymers, in addition to, theoretical studies on the growth dynamics of silver nanoparticles, and the synthesis of water-soluble selenium based nanoparticles.

A National Centre for Nano-structured Materials has been established at the CSIR; the focus is on materials with many of these being inorganic in nature (see section 4.6). A number of the current projects in one of the focus areas of the DST/NRF Centre of Excellence in Strong Materials headed by Lesley Cornish at Wits, *viz.* that of carbon nanotubes and strong composites, are inorganic, and include investigations on the use of organometallic complexes for carbon nanotube synthesis, the functionalisation of carbon nanotubes and fullerenes, and the synthesis and characterisation of mesoporous silica materials. Significantly, the emergence of the generic field of nanochemistry has revitalised the study of main group elements, and South African inorganic chemists are now involved in these areas.

The other area of inorganic chemistry that has grown in stature and significance is that of bio-inorganic chemistry. A third DST/NRF national research chair in inorganic chemistry, that of Helder Marques at Wits, is in bio-inorganic chemistry. The research interests of the group under his leadership focus on the inorganic chemistry of biological systems, with particular emphasis on cobalt, iron and the lanthanides. Programmes which reflect the current interests of the group include the exploration of the kinetic lability of Co(III) in vitamin B12 systems, the synthesis and molecular modelling of metalloporphyrins, and the design of new lanthanide metal complexes with macrocyclic and acyclic chelating ligands as suitable contrast agents in magnetic resonance imaging (MRI) or as luminescent devices in biomedical applications. Another programme in bio-inorganic chemistry that is also producing world-class research is that centred on the mechanism of malaria pigment (haemozoin) formation and the mechanism of action of quinoline and related antimalarial drugs. This information is being used to develop principles for the design of new antimalarials. Other groups with programmes in inorganic biochemistry include those currently investigating benzimidazole derivatives as anti-microbial and anti-tuberculosis agents, rhenium coordination compounds with antitumour activity, and the detection of amyloid plaques in the brain for the diagnosis and treatment of Alzheimer`s disease.

Organometallic chemistry still receives attention by groups at a number of universities in the country, with the focus being on homogeneous catalysis; the majority of these groups are associated with one of the DST/NRF centres of excellence *viz.* the Centre of Excellence in Catalysis (c*change) headed by Michael Claeys at the University of Cape Town (UCT). Extensive research has been carried in the area of anionic Fischer-type metal carbene complexes, particularly in respect of the coinage metals. Other significant programmes include those involving the utilisation of Fischer-Tropsch streams to produce value-added commodity chemicals, and the design of homogeneous catalysts for the oligomerisation and polymerisation of alkenes. Significantly, increasing attention is being devoted to the development of organometallic compounds as, *inter alia*, anti-cancer and anti-malarial agents.

The area of classical coordination chemistry is being pursued at a number of universities and has received increased industrial support in recent years. Programmes include those focusing on the design of appropriate coordination compounds as solid state sensors and the design and development of ligands for d- and f-block elements and, in particular, for the separation of the platinum metals.

It is clear that the field of inorganic chemistry as practised today is very different from that practised in the 1950s. The classical techniques such as infrared and NMR spectroscopy and X-ray crystallography still dominate in the characterisation of homogeneous systems, but the advent of nanotechnology, driven by materials science, has led to the use of new techniques, in particular the microscopies (transmission and scanning electron microscopy and scanning probe microscopy) and solid state NMR for studying solid systems. The strong support given to this area by the DST through the South African Nanotechnology Initiative (SANi) will mean remarkable growth in this area in this country in the future. Furthermore, in line with international trends, computational chemistry methods (and especially the Density Function Theory (DFT) method) will continue to be increasingly utilised by inorganic chemists.

Inorganic chemistry is clearly moving in two distinct directions in South Africa. One is in the area of an organic/inorganic merge (bio-inorganic chemistry, medicinal chemistry, ligand design) and the other of an inorganic/physical merge (materials science, heterogeneous and, to some extent, homogeneous catalysis). Indeed, in the latter case the difference between a 'physical chemist' and an 'inorganic chemist' is not always obvious. A key defining issue might relate to the ability of inorganic chemists to synthesise non-organic compounds. Once made, the characterisation techniques merge the disciplines.

One shortcoming in the inorganic research scene is the limited research carried out at universities that relates to the South African mining industry. This applies in particular to the chemistry of minerals extraction. It is not clear why South Africa has not developed world-class groups in this important area. This is an area that should be stimulated as the country switches from being a provider of raw materials to being an exporter of value-added products.

4.3 Organic chemistry, including bio-organic and biological chemistry

Organic chemistry research at South African universities has for a long period been relatively healthy; one of the doyens of chemistry, let alone organic chemistry, was Frank Warren, who was noted for his work in natural products. The late-1960s and the 1970s witnessed the return of many young South African chemists who had studied abroad, as well as the arrival of many young chemists from Europe, and this undoubtedly had a considerable influence in creating and providing a platform for an era of some outstanding research. A focal point of organic research activity was the NCRL, where leading research on mycotoxins and steroids was being carried out, the former focusing more on structural aspects and the latter on synthesis. Organic chemistry research was also making great strides at various universities around the country; very few of the larger universities did not have thriving organic groups. A range of areas was covered, including natural products, development of synthetic methodologies in respect of chiral synthesis, structural and synthetic aspects of flavinoids, and structural and synthetic studies relating to alkaloids.

The past twenty to thirty years have witnessed major international shifts in the vision and practice of organic chemistry, driven to a large extent by the growing interdisciplinary interfaces with biology and material sciences, and the increasing power of predictive computational methodology and modelling to identify molecules of interest and to support synthetic strategy and methodology. Pharmaceutical research continues its relentless quest for new and improved expressions of bioactivity, but revolutionary changes pioneered by combinatorial chemistry principles and practice increasingly exploit natural products as a point of departure rather than a primary source of future medicinal agents.

Organic chemistry in South Africa has not been immune to these influences, but is perhaps restricted in its capacity to maintain high levels of creative activity on all fronts, owing largely to its remoteness from mainstream areas of the fine chemicals industry, and influenced by limited human and material resources.

The overall level of conventional activity in the isolation, structure elucidation and derivative chemistry of natural products diminished in the early part of this period, partly because certain aspects became trivialised to a certain extent by the modern tools of structure elucidation and were unsustainable without rational structure-activity follow-up and ready access to high-throughput bioassay facilities. Nevertheless, some academic centres maintained programmes in this area, while recently, the country has witnessed a resurgence of interest in line with a global increase in activity in this area. World authorities from the National Cancer Institute in the United States assert that "the utility of natural products as sources of novel structures, but not necessarily as the final drug entity, is still alive and well" and in so doing make reference to the area of anti-hypertension, noting that of 74 formally synthetic drugs, 48 can be traced back to natural product structures/mimics.

Several factors have undoubtedly contributed to this local increased interest in natural products of marine and terrestrial origin. First, over the past ten years, testing facilities for a variety of afflictions have been established in the country, both at universities and by private institutions. For example, antimicrobial, antimalarial, anti-inflammatory, hypoglycaemic and erectile dysfunction tests can now be carried out at a number of universities in South Africa. Second, South Africa has a rich history in respect of traditional medicines and, in fact, indigenous knowledge is a focal point of the national research programme. Third, the country has an extremely rich and diversified flora; while fourth, various minor and, in some cases, major successes and the interest of international pharmaceutical companies, have undoubtedly played a significant role.

A plant that has created a great deal of excitement amongst natural products chemists, not only locally but also overseas, is *Sutherlandia frutescens,* commonly known as cancer bush or '*kankerbos*'. The broad spectrum of uses that has been described for the constituents of this plant include indigestion, stomach complaints, dysentery, kidney conditions, diabetes, internal cancers, uterine problems, liver conditions and rheumatoid arthritis. Recent *in vitro* and *in vivo* studies have in fact shown components of this species to possess anti-proliferative, anti-HIV, anti-diabetic and anti-thrombotic properties. The active constituents that are responsible for the reputed efficacy of this species, either individually or collectively, appear to be amino acids (such as canavanine), pinitol, flavonols, and triterpenes of various kinds. Studies are now at a stage where the proven non-toxicity of the constituents, coupled with all the supporting evidence, justifies controlled clinical studies being embarked upon.

Hoodia gordonii, studied by the CSIR for its appetite-suppressant properties (see section 4.6) has also attracted the interest of scientists worldwide. Currently, there are more than 20 patents on this species, and numerous *Hoodia*-containing commercial preparations (many unfortunately of dubious origin) on the world market. There is a growing demand from the international market for *Hoodia* material, and cultivation of the plant in South Africa, Namibia and Botswana has the potential to generate income for the people who have been the custodians of the indigenous knowledge.

The pyrano-isoflavones isolated from *Eriosema krausssianum* and the xanthones isolated from *Securidaca longepedunculata*, have been shown to be active in respect of erectile-dysfunction, and as such provide a natural remedy as an alternative to Viagra. *Eriosema* is in fact already being exported to Germany. Isolation and purification of the components of these plants is time-consuming, but local synthetic work is far advanced.

A number of plants from the Helichrysum family, plants used by local indigenous people to interact with their ancestors and to treat a variety of infections, *viz. Helichrysum aureonitens, H. caespititium, H. trilineatum, H. tenax* and *H. gymnocomum,* have revealed very promising anti-microbial activity. Very significantly in this respect, one of the compounds isolated from *H. tenax* has been shown to exhibit activity against *Staphylococcus epidermidis,* a source of nosocomial infections of hospitalised patients in intensive care units.

Finally, considerable attention is being devoted to the so-called 'African potato' (*Hypoxis hemerocallidea*), long used traditionally for a wide range of ailments and, reputedly, to boost the immune system. Recent research has provided some initial evidence of the activity of rooperol (the major phenolic constituent of *H. hemerocallidea)* against cancerous and pre-malignant cancer cells.

The above examples represent but a few of the studies being undertaken on natural products in South Africa where a more classical approach is being adopted, in general in collaboration with plant scientists and pharmacologists.

Natural products offer logical interfaces with organic synthesis. Total synthesis of challenging natural product targets constitutes an ongoing area of high international interest, but human resource demands continue to limit local activity to a few larger groups in this country. One such group focuses its programme on the total synthesis of alkaloids. With bioactive heterocycles containing nitrogen extremely well represented in nature, and also dominating the pharmaceuticals industry, the objective is to devise novel, efficient and stereochemically well-defined routes to saturated nitrogen heterocycles in particular, and to adapt the methods to the enantioselective synthesis of alkaloids, antibiotics and related biologically active targets.

Methodological studies in this theme centre on the synthesis and reactivity of thiocarbonyl compounds, beta-acylated enamines and related compounds. Specific projects currently underway or completed in the recent past include methodological developments for, and total synthesis of, indolizidine and quinolizidine alkaloids from animals (ants and amphibians) and plants (lupin alkaloids, phenanthroindolizidines, hydroxylated glycosidase inhibitors); antimalarial quinazoline alkaloids (febrifugine and analogues); and antibacterial and anticancer antibiotics (quinolones, aziridinomitosens). In another programme, the total synthesis of the bioactive alkaloids lepadiformine, tacamonine and castanospermine is being targeted with the emphasis on new synthetic methodologies.

The development and application of new and adapted synthetic methodology offers appealing and cost-effective opportunities for creative research and advanced student training, and this is perhaps the most widely practised current area of organic chemistry research in South Africa, having a large following in the many graduate schools of chemistry. It features, in particular, reagent and reaction development, functional group transformation, cyclisation and general ring-forming strategies, enantioselective reagents and processes, and modification and partial synthesis of natural products. Thus, in the knowledge that many natural and synthetic aromatic compounds and their quinone analogues are broad-spectrum antibiotics, anticancer agents, antitubercular agents, or active against HIV, one particular programme has involved the design and development of new methods for the construction and functionalisation of condensed aromatic, biaryl and polyaryl systems. The methodology so developed is applied to the synthesis of selected natural product targets. The research embraces the *de novo* construction of aromatic and heteroaromatic rings by a novel light- and base-induced cyclisation, the synthesis of isochromanes and related oxygen heterocycles, the synthesis of quinones, palladium-mediated couplings for the synthesis of biaryls, and stereocontrol at benzylic positions via arene-chromiumtricarbonyl complexes. In another programme, novel applications of Baylis-Hillman methodology have been and are being employed for the synthesis of heterocyclic compounds with medicinal potential. Complementary aspects of biosynthesis and enzyme-mediated chemistry are also in evidence in some programmes. In one such programme the focus has been on fumonisin B and related metabolites, the former being implicated in human oesophageal cancer in the Eastern Cape and being the cause of a neurological disorder, leukoencephalomalacia, in horses worldwide. Initial work involved stereochemical studies in order to determine the chirality sense of the different chiral centres. The subsequent development of a synthetic sequence, leading to the fumonisins, is based on the principles of retrosynthetic analysis, asymmetric synthesis and, most importantly, the use of enzymes as catalytic reagents.

Research in the general area of medicinal chemistry is receiving increased attention and has made major progress in recent years. The relevant programmes, which in many cases are integrated into all aspects of the foregoing activities, are often multidisciplinary and involve, for example, the modelling and synthesis of lead compounds for the development of new-generation agents for treatment or prevention of HIV/AIDS, tuberculosis, malaria and parasitism. This has been stimulated by the major relevance and societal impact of these and other disease areas in South Africa, and local research is enjoying growing international attention and support in this respect. The multidisciplinary approach of some of these programmes is well illustrated by that of the group led by Kelly Chibale, the holder of a DST/NRF national research chair in drug discovery at UCT. It involves the development of novel anti-infective (antimalarial, anti-tuberculosis, anti-HIV/AIDS and anti-trypanosomal), anti-hypertension and anti-cancer agents and which has as its three main objectives:

(i) the development of target-directed inhibitors;
(ii) the development of single agents that provide target-directed inhibition of multiple disease-causing organisms or cells; and
(iii) the development of single agents that provide maximal anti-infective and anti-cancer activity by acting against multiple targets.

The programme is collaborative and multidisciplinary in nature, and involves aspects of synthetic organic chemistry, chemical biology, biochemistry, molecular biology, pharmacology, computational chemistry and molecular modelling. More specifically, it involves 'hit to lead' and 'lead optimisation' and attendant integration of *in silico* (computational), as well as *in vitro* and *in vivo* drug metabolism and pharmacokinetic studies to guide the synthesis of new drug leads.

The above-mentioned research in medicinal chemistry has been stimulated by its obvious relevance and potential societal impact in South Africa, and local research is enjoying growing international attention and support in this respect.

4.4 Physical chemistry, including polymer and theoretical chemistry

A physical chemist who was very influential at both experimental and theoretical levels was Victor Pretorius, whose research in gas chromatography (GC) and mass spectrometry, together with that of the University of Pretoria's Institute of Chromatography (of which he was the director), resulted in many innovations and improved detectors. In particular, the group was involved in the development of the flame ionisation detector, turbulent flow chromatography, the theory of high-performance liquid chromatography, and the initiation of a thorough study into the solvent effect in GC-inlet techniques, which culminated in the development of the dynamic solvent effect inlet. Another earlier achievement by physical chemists that warrants comment is that of the development by a Sasol team, in collaboration with a number of German chemists, of a modified catalyst from local material for the Fischer-Tropsch process, to be adopted in a new Sasol plant.

Over the last 20 to 30 years, major contributions in physical chemistry have been made in the areas of solution thermodynamics, kinetics and thermodynamics of solid-state reactions, Raman spectroscopy in solid state chemistry, chemical kinetics, electrochemistry and X-ray crystallography.

X-ray crystallography has in fact long played a major role in the research activities of a number of research groups in South Africa. Researchers at the NPRL were essentially the first in the country to use this technique for the determination of the crystal structures of compounds, but they were soon followed by a number of younger academics at universities adopting this very important structural tool. Today at least six South African universities have X-ray diffractometers as part of their research armory. Developments in X-ray detector technology and computing has meant that whereas it took several months at one stage to solve a structure, this can now be achieved in a matter of hours. The technique is the basic tool for crystal engineering or supramolecular chemistry, an area that is receiving considerable attention world-wide.

Significantly, one of the incumbents of the two DST/NRF national research chairs in physical chemistry, namely Len Barbour at the University of Stellenbosch, who has a chair in nanostructured functional materials, leads a group working in this area, especially in the study of the encapsulation of small compounds by noncovalent molecular assemblies. This includes the sorption of gases into lattice interstices as well as the capture of substrates in large molecular capsules or tubules assembled by means of hydrogen bonding or amphiphilic interactions. By exploiting such interactions in relatively simple polyhedral arrangements of molecules for instance, the group has assembled complex, multicomponent capsules with internal volumes of up to 1300 Å^3. A further programme involves the design of highly porous materials with large lattice voids by desolvating inclusion compounds. Significantly, the group established that the low-density apohost phase of sublimed *p*-tert-butylcalix[4]arene possesses zero-di-

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mensional lattice voids of ~235Å^3. Despite an apparent lack of porosity (i.e. channels that access the voids), these crystals readily and reversibly absorb volatile gases such as N_2, O_2, CO_2 and CH_4 at room temperature and relatively low pressures. Since no uptake of hydrogen gas is observed under these conditions, this material can be utilised to separate H_2 and CO_2 from a mixture of these gases.

Further studies are aimed at exploring new systems of organic compounds that are unable to pack efficiently. Specifically, molecules that have poor self-complementarity of shape are targeted, thus ensuring the presence of lattice voids as potential sites for gas storage. The group has also been very involved in the development of novel research tools for the study of solid state phenomena. Research tools include a levitation balance for the study of gas/vapour inclusion reactions; a computerised volumetric system for monitoring gas system processes; software for crystallographic analysis and presentations; and, a unique miniaturised gas cell for the collection of single-crystal diffraction data under pressure (0 – 80 atmospheres). This device provides unprecedented atomic scale positional information that is proving to be exceptionally useful for understanding solid-gas interactions.

A second group, with a supramolecular chemistry thrust that focuses on the chemistry of molecular assemblies and the intermolecular bond, has a programme which includes investigations into the preparation of drug polymorphs, drug transport, the storage of volatile compounds and the separation of close isomers. In addition, the physical chemistry of supramolecular compounds is being explored. Specific projects include the encapsulation of insoluble drugs to enhance their bioavailability, the synthesis and characterisation of open framework structures with various useful applications, and the altering of the dissolution characteristics of existing drugs and rendering them more, or less, soluble, depending on the application, by converting one polymorphic form of a drug into another, by preparing a solvated derivative or by complexing the drug with another molecule (e.g. a crown ether or a cyclodextrin). The modified species has a different crystal structure from that of the parent drug and the resultant difference in solubility and other physical properties can affect drug performance very significantly.

An experimental study of the crystal packing in the polymorphs of alkyl- and aryl-ammonium salts (mostly ammonium halides, nitrates, etc. of long-chain alkanes and their derivatives) is the research theme of a third group. The aim of the study is to establish the relative importance of hydrogen bonding and other intermolecular forces in directing molecular packing. Other programmes in which X-ray crystallography plays a significant role include that concerned with the physiochemical and biochemical factors which are involved in the formation of kidney stones. In addition, several other groups have more recently established programmes in crystal engineering, where metal-containing synthons, which will be the building blocks for more complex three-dimensional structures, are being developed. The aim of these programmes is to produce materials that will have a porous metal-organic framework structure.

The second DST/NRF national research chair in physical chemistry is that of Bert Klumperman at the University of Stellenbosch, working on advanced macromolecular architectures. Living radical polymerisation (LRP) is used by the group as the central technique in the synthesis of advanced macromolecular architectures. Self-assembly of these architectures and heterogeneous polymerisation processes are used to create ordered structures on a larger length scale. In order to optimise the degree of control in LRP processes, mechanistic studies are conducted to increase the understanding of the fundamental processes involved. The field in which the group's research has had the largest impact in the past ten years is the kinetics and mechanisms of reversible addition-fragmentation chain transfer (RAFT) mediated polymerisation. The group has led the way to a deeper understanding of the initial stages of the RAFT process, as well as in studies into the later stages of this process. A selective initialisation process was discovered in which the original RAFT-agent is converted into its single monomer adduct. The work is being expanded in various directions. Use will be made of nitroxide-mediated polymerisation in order to determine relevant kinetic constants. Another related field of research in which the group has made very significant contributions is mechanistic and kinetic studies of atom transfer radical polymerisation (ATRP). A number of contributions have placed the group among the world leaders in kinetic and mechanistic studies of ATRP. They were the first to show experimentally that there is a transition in kinetic behaviour if the concentration of deactivator is increased. In the programme focusing on advanced macromolecular architectures, the group is involved in the design, the synthesis and the characterisation of complex macromolecular structures, with the main emphasis being on molecular brushes and polymer-protein conjugates. Densely grafted alternating copolymers are among the target structures. Next to the chemical characterisation of the structures, an increasing focus will be on their solution properties. From a synthetic point of view, the emphasis is on living radical polymerisation techniques but complementary techniques are used when required. Over the last two years, the majority of new research projects in the group have had a biomedical focus such as drug delivery, anti-microbial fibres, immobilisation/conjugation of proteins and enzymes, and a sampling device for TB diagnostics.

Research in heterogeneous catalysis is carried out at a number of departments of chemistry in the country as part of the DST/NRF Centre of Excellence in Catalysis mentioned above. Not surprisingly, the emphasis is on reactions which form part of the Fischer-Tropsch regime and the development of potential gold and platinum metal catalysts. Programmes of one particular sub-centre include the catalytic action of nanogold, direct conversion and catalytic decomposition of methane, methanol-mediated routes for gas-to-liquid and related reactions, zeolites and acid catalysis and catalytic properties of nanometal-polymer composites. The emphasis in the former programme is on understanding the behaviour of gold supported on oxides and zeolites for reactions such as the water gas shift reaction, CO oxidation and alkene hydrogenation. In respect of the gas-to-liquid studies, research is focused on the solid acid catalysed conversion of methanol/dimethylether (DME) to hydrocarbons, the synthesis of methanol/DME mixtures from syngas and the decomposition and/or steam reforming of methanol. Special emphasis is being placed on the role of gold and other noble metals in the reactions involving synthesis or conversion of methanol. A second sub-centre is involved in research into the catalysis of oxidation and oxidative dehydrogenation reactions.

Some excellent research has been carried out in the area of thin films and membranes in the last ten years and, in particular, in the development of special membranes for bioreactors, and more important membranes for ultrafiltration used for the provision of drinking water. The success of the research is illustrated by the fact that the latter membranes are now being produced commercially by the procedure developed by the group responsible for the research. Ongoing research with process and mechanical engineers continues with the aim of producing ultrafiltration membranes in hollow fibre form. Research on the monitoring of the fouling and the continuously cleaning of membranes at low cost, without disrupting the membrane operation, has also been very successful, as has a major drive to incorporate nanoclay platelets through exfoliation into emulsion-based coatings. The latter is now being followed up by a major paper manufacturer, in work on 'green coatings' for packaging.

Other research programmes at various universities include:

- studies on the influence of impurities on the formation of minerals during gasification and combustion processes of South African coal, with the aim of improving the efficiency of the gasification process, reducing the environmentally unfriendly aspects of the process and developing new technology for CO_2 conversion and reduction;
- kinetic studies, using ^{11}B NMR spectroscopy, of the hydroboration of internal olefins as part of the programme to develop methods for the conversion of internal olefins into alpha-olefins for subsequent polymerisation;
- studies of molecular complexes, initially by means of matrix isolation infrared spectroscopy, but more recently by *ab initio* molecular orbital calculations with the aim of elucidating the common features among charge transfer, hydrogen-bonded and Van der Waals complexes;
- studies on the kinetics of catalysed oxidative processes, with a focus on ozone as a reagent and of the oxidation of long chained saturated hydrocarbons using zeolite-like materials;
- studies involving the design and electrochemical interrogation of 'smart' materials (nano-phase hydro gels, conducting polymers, multinuclear metallodendrimers) for application in targeted drug or controlled ion delivery to candidate biological cells.

Programmes in theoretical chemistry research are limited to a few universities in the country, but nonetheless, one of the

DST/NRF national research chairs is in this sub-discipline. The chair is that of Kevin Naidoo in computational chemistry at UCT, whose group is involved in research that employs computational methods to calculate physical properties, not accessible experimentally, of carbohydrates (glycobiology), dendrimers (polymers) and platinum group metal complexes. New methods in computational chemistry have been developed to investigate the condensed-phase behaviour of macromolecules, including methods for calculating chemical reaction surfaces in condensed phases (solution and enzymes, etc.). The solution properties of carbohydrates and, in particular, the effect of the glycosidic linkage on macromolecular solubility and reactivity have been investigated in studies involving a combination of computer simulations and NMR spectroscopy, using maltose, isomaltose, panose and cyclodextrins in solution. A 'Carbohydrate Solution Force Field' that has since been used by various groups for carbohydrate computer simulations was developed and, using density functional theory and Bader's 'Atoms in Molecules' methods, the electronic factors governing glycosidic linkage conformation preferences investigated. In the process, a procedure that allows for the determination of the strength of intramolecular hydrogen bonds in biomolecules such as oligosaccharides was established. Protocols for the simulation of single polysaccharide strands that are subjected to a stretching force have been developed which led to force-extension curves that allowed for the description of the unfolding of polysaccharides and oligosaccharide macromolecules. Methods based on umbrella sampling have been used to address the problem of sample size in computer simulations; in the process, the free energy surface as a function of glycosidic linkages and rotational groups in saccharides was obtained. Finally, protocols for the simulation anion cation association mechanisms for platinum group metals in organic and aqueous solvents have also been developed.

The discovery of a general periodic law which applies to all stable nuclides as a function of atomic number, neutron number or mass number has recently been reported by another group involved in theoretical chemistry. This novel and relevant discovery introduces a completely new point of view on the composition of atomic nuclei and the meaning of the empirically determined magic numbers of nuclear physics. It accounts for the stability and periodicity of all atomic matter in terms of a few concepts from elementary number theory, such as rational fractions, Farey sequences, Fibonacci series and the golden ratio. Different forms of the periodic table of the elements are derived without the use of higher mathematics or wave mechanics, leading to a simple model of nucleogenesis and abundance, and the chirality of space-time and matter/antimatter.

4.5 Analytical and environmental chemistry

Virtually all universities and universities of technology in the country undertake research in analytical and/or environmental chemistry; a good proportion thereof is applied to very applied, and is essentially problem-solving in nature. Much of the research in environmental pollution, an area in which a number of university chemistry departments are involved, falls into this category. All the same, there are a number of research programmes at universities which can be classified as being either analytical and/or environmental chemistry, and which are undoubtedly ground-breaking.

The Laboratory for Ecological Chemistry (LECUS) at the University of Stellenbosch focuses on the development of techniques for the analysis of trace quantities of volatile organic compounds and the application of these methods in the analysis of insect, mammalian, avian and reptile semiochemicals (e.g. pheromones), the analysis of air and water pollutants, and the identification of 'off-flavours' in food and beverages. In respect of insect pheromones, all of the dung beetle pheromones that have so far been identified worldwide were isolated, characterised and assayed by LECUS. The high cost of game-capturing operations has created a need for the development of alternative methods for controlling the movement and translocation of wild animals. In this context, LECUS has contributed a large volume of chemical knowledge on the exocrine secretions of mammals. For instance, it has produced an estimated 40% of all the verified chemical information that is currently available on mammalian semiochemicals, with practically the entire volume of information currently available on the chemical composition of the exocrine secretions of South African antelope being produced by the laboratory. A current investigation involves the characterisation of the territorial marking fluid of the Bengal tiger, *Panthera tigris*; preliminary field tests with some of the constituents of the fluid have produced promising results. In respect of new analytical techniques, the laboratory has developed and patented a novel modulator for comprehensive two-dimensional gas chromatography (GC x GC) of semiochemical secretions and other complex samples. It costs a fraction of available commercial instrumentation, and has practically no running costs. Furthermore, the development of a patented, high-capacity (high-sensitivity) sample enrichment probe (SEP) is a major contribution to semiochemical sample enrichment technology.

A major programme covers the area of atmospheric chemistry, aimed at providing key information to support the development of sustainable air quality policies and practices in Southern Africa. The influence of activities associated with human and industrial development as well as natural biogeochemical processes typical of the region (e.g. biomass burning) are the main focus points. The research of the programme is three-pronged: theoretical studies (including modelling), laboratory experimentation and environmental analysis. Specific current research projects include the study of the mechanisms of oxidation processes of atmospheric pollutants; the biofiltration of volatile organic carbon compounds, including methane; the effect of the C2 chlorohydrocarbons on crop plants; the deposition of trichloroacetic acid on the vegetation of different pollution gradients (a joint German-South African project); and the development of predictive capabilities by using atmospheric models. As part of the

International Global Atmospheric Chemistry and the Deposition of Biogeochemical Important Trace Species (DEBITS) initiative, studies are being done that use ground-based passive sampling techniques at various sites in southern Africa, as well as aircraft, to determine the vertical distribution of water-soluble pollutants on the interior highveld plateau of the country.

A number of programmes at different universities are focused on advanced separation science and the application of the techniques developed. Thus, a major proportion of the research carried out by one particular group, using gas chromatography (GC), has involved 'Stir Bar Sorptive Extraction' (SBSE), a novel and sensitive sample pre-treatment method developed by the group. In particular, SBSE in combination with thermal desorption (TDS) and GC has successfully been applied in, amongst others, the analysis of wine aroma volatiles, benzoic acid in beverages (yoghurt), fungicides (and other contaminants) in wine, oestrogens in urine samples of HIV-positive patients, stress markers in urine, drugs of abuse, pesticides, polychlorinated biphenyls (PCBs), coffee volatiles and preservatives in soft drinks, and in the diagnosis of tuberculosis by measuring tuberculostearic acid in sputum. In addition, SBSE in combination with liquid desorption (LD) and capillary electrophoresis (CE), has been used to study the hop-derived bitter acids in beer. In the field of high-performance liquid chromatography (HPLC), comprehensive two-dimensional liquid chromatography (LC) (LC x LC) is currently being investigated as a means of improving the separation power of LC for the analysis of natural products.

A group originating from the Institute of Chromatography to which reference was made above has also focused its research on new instrumental techniques for the analysis of complex chemical mixtures found in the environment, in industry, in food and in living systems. The focus, in particular, has been on the design of equipment and methods for the analysis of compounds (typically toxins) at very low concentrations, more reliably, in less time and at lower cost. Because of the complexity of samples, the approach has been to use one or more chromatographic separation steps followed by in-line spectrometric detection, normally mass spectrometry to achieve the necessary specificity for correctly identifying and quantifying compounds of concern. Areas of application have included: air and water pollution, clinical diagnostics, occupational health, essential oils, flavours and fragrances, industrial process control, petrochemicals, bio-diesel and forensic analysis.

One of the departments of chemistry, in developing its own particular niche, has focused on the fundamentals and applications of atomic absorption spectroscopy (AAS) and to a lesser extent atomic emission spectrometry (AES). An associate member of the department has developed what is termed a filter furnace for use with electrothermal atomization (ET) AAS, and is developing an instrument, for which he has a provisional patent, that could be termed a continual-source ET AAS. The department has considerable expertise in slurry nebulisation for sample introduction, and makes use of its overall expertise in investigations with regard to the analysis of materials with difficult matrices, cement, platinum group metals and coal.

Niche areas of some of the other departments researching in environmental and analytical chemistry include bio-analytical chemistry, the modelling of solution equilibria and the development of predictive models, chemometric data analysis, solid phase extraction and micro-extraction and the use of electrospun nano-fibres for environmental and pharmaceutical samples.

4.6 The Council for Scientific and Industrial Research (CSIR)

With the NCRL being one of the founding institutes of the South African CSIR, it is not surprising that chemistry has always been a major activity of the organisation. It would be fair to say that at its peak, the NCRL was a truly world-class research facility, having by far the largest number of high-profile chemists ever assembled in a single institute in South Africa. As described earlier, the laboratory was dissolved in 1988 leading, at different stages, to many of the laboratory's personnel leaving the CSIR and becoming mainstays of the country's university system for the next 15 years. The retirements of these scientists over the last five years has left a void of senior chemistry personnel across the academic sector.

Key programmes within the NCRL in the decade prior to its dissolution included that focusing on mycotoxins, where the isolation and characterisation of these fungal metabolites was pioneered. Associated with this was a programme on aflatoxins which produced representative standards for food-quality assessment which are still in use today, while a programme relating to aflotoxin metabolites played a major role in elucidating the mechanism of action of these fungal carcinogens. Another major activity involved the laboratory synthesis of steroids and the generation of a wide range of analogues. The steroid programme continued at UCT, and has provided significant insights into the structure-activity relationships of biologically active steroids, often resulting in an understanding of therapeutic possibilities. A third major programme was that devoted to the synthesis of organometallic derivatives of ruthenium and osmium. A vast number of extremely novel complexes was developed as potential synthons for homogeneous catalysts.

Research and development at the CSIR is currently pursued in eight defined areas, two of which have programmes in chemistry. These are biosciences and materials science and manufacturing. The current groups in the biosciences conglomerate involved in synthetic chemistry can be considered as being loosely descended from two very different predecessors: the former NCRL, and the Research and Development Department (R&DD) of African Explosives and Chemical Industries (AECI) at Modderfontein, east of Johannesburg, the latter group having been acquired by the CSIR in 1999 with the reorganisation of the AECI . This company had had a composite research department, ranging from the development of new chemical (and biological) processes for value-added (or fine) chemicals, to polymer technologies and support for existing chemical plants. The fine-chemical research resulted in new plants for food additives (such as the anti-oxidant tertiarybutyl hydroquinone (TBHQ)), new approaches for the preparation of aroma chemicals (vanillin, carvone, raspberry ketone etc.), and approaches to generic pharmaceuticals (naproxen, paracetamol and antihelminthics etc.), many of which pioneered the new (to South Africa) approach of incorporating both chemical and biological steps in a single process. After its absorption by the CSIR, this activity became the first CSIR Division of Biological and Chemical Technologies (Bio/Chemtek).

During the period of evolution from one of the initial groups to becoming a component of the current CSIR Biosciences operating unit, there were active chemistry groups in the CSIR Division of Food Technologies (Foodtek), the CSIR Bio/Chemtek and, as a result of a merger between these two divisions, the CSIR Division of Food, Biological and Chemical Technologies (also known as Bio/Chemtek).

After the dissolution of the NCRL and before the creation of Bio/Chemtek, the emphasis on synthetic chemistry in the CSIR declined significantly. Natural product chemistry, however, continued unabated through the advent of 'bioprospecting' activities (assessing the commercial and pharmaceutical potential of South Africa's natural resources). This activity is believed to be the first example in the world where benefit sharing agreements were signed with holders of indigenous knowledge, the first such example relating to the appetite suppressing properties of the *Hoodia* cactus and the potential for use against obesity (see above); investigations in this area are continuing. Many of the current activities of the biosciences operating unit stem in fact from earlier ones, and the bioprospecting group is at present evaluating potential new plant-based anti-malarials, anti-asthmatic/anti-inflammatories and possible retrovirals amongst other activities. The processing section has recently contributed towards the development of a new natural sweetener, monatin, that is licensed and currently under evaluation for human use.

Major changes in the activities of the CSIR began in 2005 as a result of the already described internal review termed 'Beyond 60'. The review resulted in a realignment of the organisation with its mandate, and Bio/Chemtek became Biosciences with a renewed interest in human health, particularly tuberculosis (TB), HIV and malaria. This emphasis took the form of the discovery and development of new molecular entities as potential future therapeutics, an area poorly serviced in South Africa. This activity can be seen as complementary to the activities of the Medical Research Council with its more clinical focus. As a result of this focus, CSIR Bioscience has two series of novel anti-malarials (operating at sub-nanomolar levels) that are entering the development phases, a series of inhibitors of a novel bacterial kinase target and non-nucleosidic HIV reverse transcriptase inhibitors active against both the isolated enzyme and on a cellular basis.

The CSIR Biosciences drug discovery and development area utilises synthetic and medicinal chemistry, natural product-based discovery, pharmacology and computational chemistry skills as parts of a single unit in order to discover and progress candidates to the clinic. A comprehensive effort of this type has not been previously undertaken in South Africa. Consequently, many of the required skills have had to be developed over time or outsourced. New personnel from the university system will form a critical part of the ongoing programme, a solid grounding in synthetic organic chemistry being of more value than a medicinal chemistry-based degree without the emphasis of core synthetic skills. It is hoped that such programmes can be prioritised within the university sector, with the result being mutually beneficial interactions between multiple institutes of the tertiary sector.

As indicated above, the second defined area of research and development at the CSIR in which programmes in chemistry are involved is that of materials science and manufacturing. This grouping which essentially originated from Mattek at the CSIR has been consolidated into six competency areas, together with the National Centre for Nano-structured Materials (NCNSM), and it is in the latter that chemistry is primarily pursued.

The research focus of the group is on the design, modelling and synthesis of nanomaterials with specific properties and various possible applications. The initial focus is on carbon nanotubes, silicon nanoparticles and nanolayer deposition techniques. The group collaborates with units and centres in the CSIR, universities, science councils, the private and public sector and international research institutions.

4.7 Nuclear Energy Corporation of South Africa (Necsa)

Necsa and its predecessors have a proud history of achievements in research and applications of chemical processes and technologies. The two main areas of application involving chemistry were, or still are, uranium isotope enrichment and the production of radioisotopes.

The process gas utilised in the former Uranium Enrichment Corporation (UCOR) isotope separation process consisted of a mixture of UF_6 and H_2. A detailed understanding of the gas and surface reactions of UF_6 was thus necessary. It was shown that UF_6 gives rise to a series of lower uranium fluorides as a result of reduction side-reactions, and to a series of uranium oxyfluorides from hydrolysis reactions. These undesirable solid products could be converted back to UF_6 by employing any one of a number of in-house produced powerful fluorinating agents, including the halogen fluoride series and also the noble gas fluoride series. Today this knowledge forms the basis of the product range of Pelchem (Pty) Ltd, a Necsa subsidiary, which produces a host of fluorochemicals such as HF, F_2, NF_3 and XeF_2 for the local and international market. The Pelchem subsidiary Fluoro Pack (Pty) Ltd markets permeation solutions to the plastics industry based on surface fluorination treatments.

Apart from the vast knowledge of uranium and fluorine chemistry that was developed and which is still being expanded at Necsa, plasma processing technology is an important research focus. Through high-temperature processes, many nano-oxides were synthesised in the past, and one-step conversion processes for UF_6 to lower uranium fluorides or oxides were developed. Today, plasma technology plays an important role in mineral beneficiation programmes undertaken at Necsa. In future this technology will also play an important role in nuclear waste volume reduction in the form of matrix destruction of compressible waste.

Necsa, through its subsidiary NTP Radioisotopes (Pty) Ltd, is the world's third largest producer of radiochemicals, which serve as raw materials for the formulation of radiopharmaceuticals for diagnostic studies or therapeutic applications. The main radioisotope in this regard is Mo-99, with I-131 being another important isotope. The chemical processes to extract and purify these fission products from irradiated targets containing U-235 was developed in-house by Necsa scientists. Isotope production research is complemented by the development of new radiopharmaceuticals and radiolabelled compounds, for use in either clinical applications or research on the biodistribution and treatment efficiency of non-radioactive pharmaceuticals.

No significant nuclear activity is complete without addressing the safe treatment and disposal of radioactive waste. The invaluable contribution of Necsa scientists have resulted in the establishment of Vaalputs, the national repository for low- and medium-level radioactive waste, situated in the Northern Cape.

4.8 Mintek

Mintek, an autonomous statutory body, is South Africa's national mineral research organisation mandated to serve the country's interest through research, development and technology transfer in the promotion of mineral technology and in the fostering of industries in the field of minerals and products derived from them. In particular, it specialises in mineral processing and extractive metallurgy, with chemistry being the basis of many of the projects and programmes. Three major programmes involving chemistry have respectively focused, and continue to focus, on cyanide usage in the gold mining industry, on the development of new industrial and commercial uses of gold, and on flotation processes.

In collaboration with the gold mining industry, the organisation, through its scientists and engineers, has developed a unique set of products and services to assist with risk minimisation in the use of cyanide. The knowledge generated during early phases of research was applied to the production of online analysers, to assist with compliance audits, and to discharge monitoring services based on accredited analysis. These services found acceptance and are now applied throughout the gold mining industry of Africa and further afield. The industry has benefited in particular from reduced reagent additions, minimised risk exposure, and the facilitation of reaching compliance to the requirements of the International Cyanide Management Code.

The programme, Project AuTEK, was initiated in 2000 as a joint research venture between Mintek and the three major South African producers of gold, with the aim of developing new industrial uses of the metal. The programme has three focus areas, catalysis (co-sponsored by AngloGold Ashanti), nanotechnology (co-sponsored by Gold Fields) and biomedical applications (co-funded by Harmony Gold).

The first target was the development of a catalyst for the oxidation of CO to CO_2 at room temperatures. Gold particles with diameters in the range 4-10 nm dispersed on the surface of inert oxide substrates proved very useful in this context. The key to the success of this venture was the development of the necessary conditions for the precipitation of hydrated gold oxides on the oxide surface to achieve eventually a uniform and well-dispersed precipitation of gold particles of the correct diameter. The research has resulted in the construction of a semi-commercial plant for producing sufficient quantities of the catalyst, marketed under the trade name AURO*lite*™, for prototype evaluation by potential clients. Gold catalysts have also been developed for chemical process reactions such as epoxidation and selective hydrogenation.

The principles of nanoscience and nanotechnology that were developed during this project have since been extended into research aimed at exploiting the inherent catalytic properties of the platinum group of metals and culminating in the Mintek/DST Nanotechnology Innovation Centre, an initiative of DST, which was launched in November 2007.

The biomedical programme focuses on the discovery of new types of gold-based biomedical agents with emphasis on HIV/AIDS, cancer and malaria. Relatively recently, a strategic decision was taken to focus internally on HIV, with the cancer and malaria research programmes being continued at the universities, but still being directed by Mintek.

Early research at Mintek on flotation, an important and relatively widely used technique for the separation and recovery of a particular valuable mineral from an assemblage of unwanted waste minerals, focused on the development of small-scale flotation devices to understand how the surface properties of minerals are influenced by chemical additives, and how this affects the flotation of a range of minerals. Later research was directed towards the identification of appropriate collectors, depressants, and frothers for local ores. Major developments have included an understanding on how the adsorption and desorption of chemical species to-and-from the mineral surfaces of prepared mixtures of fluorite, apatite, and calcite controls the separation of fluorite and apatite from calcite, a knowledge of the mechanism of talc depression by polysaccharide-based reagents as applied to the separation of this mineral from base-metal sulfide minerals and the activation of sulphide and gangue minerals by dissolved metal ions. More recently, research has focused on the associated chemical and physical problems of designing complete flotation process flowsheets with the flotation of the platinum group metals ores being a particular focus, but work also embracing copper, graphite, phosphate, fluorspar, andalusite and many other ores of economic importance.

4.9 Sasol

Sasol, formed in 1950 and for some time the world's largest producer of liquid fuel from coal, was the first company, in 1955, to commercialise the Fischer-Tropsch process for the large-scale conversion of coal to liquid fuel and chemicals. Its plant at Secunda, Mpumalanga is the largest synthetic fuels facility in the world, and provides approximately 28% of South Africa's fuel needs. In the early 2000s, the plant at Sasolburg, south of Johannesburg, was converted from coal feedstock to natural gas piped from Mozambique. This involved the introduction of licensed reforming technology, while still making use of the proprietary low-temperature, iron-based Fischer-Tropsch technology. More recently in 2007, Sasol has started production of liquid fuels from natural gas feedstock in Qatar, using new Fischer-Tropsch technology based on slurry phase cobalt catalysis.

The company has always placed a high premium on R&D, although in the early days the chemistry used was limited to catalyst development, with the major focus being on process technology. Today, Sasol's corporate R&D facility numbers approximately 600, of which 200 are scientists and 80 are engineers, and with 200 having either Masters or Doctoral degrees. Some key areas of research and development undertaken are as follows:

- Coal science and conversion;
- Iron- and cobalt-based Fischer-Tropsch catalysis;
- Acid-base catalysis: dehydration, etherification, esterification;
- Refinery catalysis: hydrotreating, hydrocracking, hydroisomerisation, catalytic polymerisation, platforming;
- Operations support: catalyst optimisation, side reactions, contaminations, catalyst recovery, corrosion chemistry;
- Syngas conversion to chemicals;
- Olefin manipulation: oligomerisation, metathesis, hydroformylation;
- Oxidation of paraffins and olefins;
- Organic chemistry focused on ligand synthesis.

It is apparent from this list that chemistry plays an important role in the research activities of Sasol. At the same time, chemistry research is not carried out in isolation, and all major programmes are undertaken on an interdisciplinary or a multidisciplinary basis.

A snapshot of but a few of the technological developments by Sasol over the last 20 to 30 years is provided below:

- With the start-up of its Oryx JV Plant, Sasol now operates three proprietary and distinct types of Fischer-Tropsch processes:
    - o Low-temperature cobalt: Oryx Gas-

to-Liquid (GTL) fuels production;
- o Low-temperature iron: Sasolburg wax and chemicals production;
- o High-temperature iron: Secunda fuels and chemicals production.

The Sasolburg and Secunda processes are based on iron catalysts. During the 1990s, Sasol scientists focused on the development of low-temperature cobalt-based catalysts for Fischer-Tropsch synthesis. Such catalysts afford a far simpler product distribution than iron-based high-temperature Fischer Tropsch (HTFT) catalysts, and produce a product slate eminently suitable for distillate (mostly diesel and jet fuel) production. Extensive studies were carried out not only on catalyst formulation and the optimisation of reaction conditions, but also on issues such as syngas purity (cobalt is more sensitive than iron, especially to sulphur) and heat and mass transfer from the highly active catalyst which led to the design by the process engineers of improved slurry phase distillate reactors. The research culminated in the construction and commissioning in January of 2007 of the 34 000 barrels per day Oryx plant in Qatar, a joint venture between Sasol and Qatar Petroleum.

- The HTFT process affords a plethora of compounds. During the 1980s, Sasol entered the chemicals arena and the concept of 'Chemical Work-Up' (CWU) was developed in order to extract the abundance of lower oxygenates which are present in the Fischer-Tropsch reaction water stream. This was commercialised in the 1990s with the successful extraction of a range of alcohols, ketones, aldehydes and acids, applying in-depth understanding of the physical properties of chemical components in order to achieve separations of complex mixtures to high purity chemical products. In the late 1990s and early 2000s, this chemicals extraction was extended to the separation of alpha olefins from the Fischer-Tropsch hydrocarbon product. In particular, novel technology for the extraction of 1-hexene and 1-octene has elevated Sasol to a major player in the global co-monomers business. Given the complexity of the Fischer-Tropsch streams, the stringent purity requirements for these co-monomers renders this a significant achievement.
- An ethyl acetate plant was started up in Secunda in May 2001 based on technology co-developed by Sasol and Kvaerner Process Technology. This process produces ethyl acetate via novel ethanol dehydrogenation technology, thereby alleviating the traditional feedstock dependence of ethyl acetate on both ethanol and acetic acid.
- Sasol achieved beneficial operation of a third 1-octene plant in June 2008. This plant differs greatly from the two octene extraction trains, being a first-of-a-kind continuous unit which converts lower value 1-heptene to 1-octene via the sequential steps of hydroformylation, hydrogenation and dehydration. 1-Octanol is produced via in-licensed technology from Davy Process Technology, but the dehydration technology to selectively convert 1-octanol to 1-octene was conceptualised and developed by Sasol scientists. Its novelty lies in the fact that

while dehydration is a relatively simple reaction, it is achieved over acid catalysts which also catalyse the isomerisation of the double bond. Terminal selectivity is therefore difficult to achieve and maintain, and careful selection of catalyst and operating conditions is required to maintain the required 95% 1-octene selectivity.

- During research initially targeting selective trimerisation for 1-hexene production, Sasol scientists discovered a new reaction: selective ethylene tetramerisation. This reaction proceeds via a hitherto unknown reaction mechanism, and has elicited intense interest from both academia and industry, with many researchers attempting to follow Sasol's lead. Intense research is ongoing within Sasol to further develop this process and strengthen its patent portfolio, with a view to commercialisation of a third proprietary 1-octene technology.

In summary, Sasol has long recognised that technology advantage is critical in order to enable business growth. Although Sasol's R&D capability is not large in a global context, it is very significant for a South African company. Furthermore, the vast majority of Sasol's R&D employees are South African-born and -trained. In this context it should be noted that over the period 2006-2008, R70.6 million was allocated by Sasol to selected South African universities under the University Collaboration Scheme.

4.10 Future challenges and concluding remarks

A unique feature of South African academic research is the evaluation process adopted and administered by the NRF, whereby academics at tertiary institutions are evaluated on the basis of the quality of their research outputs over long timeframes (see Chapter 1). A current disturbing aspect in respect of the process, and of concern to many, is the average age profile of the higher-rated researchers, with many having recently retired or being relatively close to retirement. This scenario applies to most scientific disciplines, with chemistry being no exception. The challenge is to find ways of reversing the trend, and in particular to attract quality graduates into academic chemistry once again.

Sourcing research funding will be a further major challenge for researchers. With the world, including South Africa, experiencing a major recession, funding is likely to become constrained. Although the DST, through its various initiatives, has created new funding opportunities, these are mostly in respect of targeted programmes. As a consequence, research proposals will have to be designed to meet the requirements of the sponsorship, rather than researchers independently designing programmes and subsequently seeking funding for them. For this and a variety of other reasons, much of chemistry research will take place as components of multidisciplinary programmes interfacing with broad areas such as materials, on the one hand, and biology and the health sciences, on the other.

Finally, chemistry will continue to make extensive and increasing use of very expensive sophisticated equipment. Various programmes are in place to meet the equipment needs of departments/schools of chemistry at universities in the country, but in spite of this not all schools have the same access to some of the more expensive pieces of equipment. Schools of chemistry are very expensive to run; with a reduction in the global demand for chemists and increasing difficulties in recruiting quality staff, it is likely that the question will arise as to whether there should be a reduction in the number of university schools of chemistry and/or whether all schools should offer PhD programmes.

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Biological Sciences

CHAPTER 5

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5.1 Introduction

Several happy coincidences have contributed to the relative strength of biological sciences in South Africa. First, southern Africa, by tectonic and evolutionary accident, is one of the most biologically diverse places in the world; home not only to the famous Cape Floral Kingdom, but also several other less well-known centres of endemism of plants and animals, on land, in freshwater and in the oceans. Second, the region has been inhabited since the very origins of *Homo sapiens*, and thus there is an accumulation of well-tested indigenous knowledge regarding plants and animals. The colonisation and exploration of southern Africa by Europeans, starting in the 18th century, coincided with a popular and scientific surge of interest in 'natural history'. The Cape was a rich source of material for the pioneers of modern biological science, including Linneus, Darwin and their disciples. The early focus on description and classification was complemented, starting in the 20th century, by a growing curiosity regarding function, process and use, and as the depletion of the natural resource assets became apparent, by a concern for conservation and management.

At the beginning of the 21st century, the biological sciences in South Africa are both broadly-based (spanning the scale range from molecular biology, through genetics, evolution, physiology to ecosystem science) and, in several sub-disciplines, exceptionally deep. In the decade 1996 to 2005, the plant and animal sciences contributed more publications to the global literature than any other South African disciplinary area (Jeena and Pouris, 2008). Bearing in mind that South Africa spends somewhat less than 1% of the global investment in science, and thus has a correspondingly small fraction of global researchers and published output, the contributions by South Africans in selected areas have been disproportionately large. Several of these areas are in the biological sciences (Lovegrove and Johnson, 2008), where South Africa ranks 18th in the world in terms of published output, and several South African universities are in the top 1% of cited institutions, worldwide, in biological fields (Pouris, 2007).

This introduction sketches four themes in the development of biological sciences in South Africa, broadly labelled evolution, ecology, agriculture and medicine. It builds a platform for a series of more detailed discussions of the contributions and current state of several key sub-disciplines. The focus in the chapter as a whole is on the recent period since about 1990.

The early fascination with collecting and classifying exotic plants and animals led to several globally-significant biological specimen repositories located in South Africa. The national herbarium, headquartered at the South African National Biodiversity

Institute (SANBI) in Pretoria, but with hundreds of electronically-linked collaborating collections throughout South and southern Africa, has a million and a half accessions of its own, and direct access to a million more, making it the largest plant collection in the southern hemisphere. South Africa has been a leader in the digitisation of voucher label information, providing an important global information resource. The herbaria are associated with a system of nine national botanical gardens that are famous for their horticulture, but also undertake research and *ex-situ* conservation. The national insect collections, for instance of termites and bees, curated by the Agriculture Research Council (ARC), ants at the South African Museum, and Coleoptera by the Northern Flagship Institution are indispensible for the study of African species, as is the fish collection at the South African Institute of Aquatic Biodiversity in Grahams-town. There are renowned specialists in the taxonomy of several plant and animal groups, but the coverage is not comprehensive, and apparent failure of this scarce human resource to regenerate itself is an oft-repeated concern. However, the broader field of systematics, embracing the evolutionary processes within populations and the relationships among groups of species, continues to be strong in South Africa, and has gained recent impetus from technical advances in molecular genetics. Thus South African scientists are actively engaged in genome studies and in such enterprises as the *Barcode of Life*. The field of evolutionary studies has been stimulated by the rich regional palaeontological record, particularly in the Karoo sediments, and by the ongoing regional palaeoanthropological discoveries. It has reached into other fields, such as work on the origin of the spectacular species richness in the various centres of endemism and the evolution of diseases and their vectors.

A second flourishing branch of biological sciences in South Africa had its roots in economically important natural resources. The early economy of South Africa was absolutely dependent on forests, grazing and wildlife, and when it became clear around the mid-1800s that they were rapidly becoming depleted, a dual interest arose: in their ecology, on the one hand, and conservation and management on the other. Studies of the ecological effects of wildfire became a strength, breaking decisively from European and North American worldviews that saw fire as always destructive and disturbing, and embracing an African perspective that fire is a key process in regional ecosystems. There is a strong tradition of population ecology, well represented in fisheries biology, ornithology and botanical studies in the *fynbos* and *Karoo*. There are two strong schools of systems ecology in the country; one in the north with a focus on savannas, and the other in the south focusing on the marine Benguela upwelling system. These ecosystem studies, largely university-based and catalysed by the precursors to the current National Research Foundation (NRF), prepared several South African researchers to take leading positions in the emerging field of global change, or earth systems science.

The other branch of this 'natural resource' focus grew into the contemporary South African strengths in conservation biology, invasion biology and biodiversity management. The appointment of the 'Cape Conservator of Forests', following the disastrous fires of the 1850s, placed conservation onto a scientific path. The game reserves proclaimed in Zululand in the 1880s, and the *Zuid Afrikaanse Republiek* in the 1890s are among the oldest in the world. A notable feature of biodiversity conservation in South Africa is the unusually tight coupling between science and management, which has had the spinoff of making the protected areas of South Africa an important research facility for both local and international scientists. A recent feature has been the massive expansion of privately-owned conservation lands, to the point where nearly a fifth of the landscape is under some form of biodiversity-based land use, of which only a third is in state-owned protected areas. The demand for conservation planning and management services has stimulated leading centres of expertise in the fields of wildlife veterinary science, community-based natural resource management, spatial conservation planning, coastal resources management, ecosystem service assessment and the adaptation of biodiversity to global change, among others. Several universities, the Council for Scientific and Industrial Research (CSIR), the branch of Marine and Coastal Management (MCM) of the Department of Environment Affairs, the South African National Parks Board and several provincial parks agencies are the key institutions in these fields.

A third branch of the biological sciences supports agriculture, forestry and related fields. While agriculture in the broad sense (including crops, horticulture, forestry, poultry, aquaculture and livestock) has shrunk to a minor part of the aggregate economy, it remains the main economic activity over most of the land mass, the largest water user and a vital source of rural employment. Several universities have faculties of agriculture, the ARC has research facilities in all the major agroclimatic zones, and there is significant private sector research involvement. Classical breeding techniques led to strength in several areas of crop and livestock genetics, from subtropical fruit through traditional African cattle to ostriches. Recent biotechnological approaches have been responsibly embraced, with areas of expertise particularly in hybrid eucalypts and the genetic modification of grains to enhance their nutritional value. There is a particular strength in seed physiology, and another in insect physiology. A key ecophysiological issue has been water use, particularly by plantations of fast-growing trees. Many years of research, now located in the CSIR and funded by the Water Research Commission (WRC), overturned the prevailing global wisdom that forests increased the quality and quantity of stream flow, leading among other things to an innovative set of water laws, and policies that target the elimination of invasive alien trees as a simultaneous water conservation and poverty-relief activity.

The final branch of biology we wish to highlight is intertwined with medical science. Their close association is perhaps not surprising, given that many prominent figures in South African biology originally trained as medical doctors, The steady support for biological research from the Medical Research Council (MRC) is another factor, driven by the medical challenges provided by the African environment (most recently, for instance, by emergent diseases such as human immunodeficiency virus (HIV)). Parasitology and vector studies are areas of obvious overlap between zoology and medicine, as is the convergence between oncology and cell biology. The health sciences, broadly speaking, share technologies with veterinary science and plant pathology, which are also relatively well-established in South Africa. There is a centuries-long tradition of ethno-pharmacological studies in South Africa. In recent decades it has taken on a stronger element of intellectual property protection, benefit-sharing and bio-prospecting. Large fractions of the biota have been screened for potentially useful properties, and several have attracted in-depth studies.

5.2 Plant sciences

Since the field is vast, a comprehensive survey is not possible. Some of the major research themes being pursued in South Africa are highlighted here.

5.2.1 Taxonomy and systematics

The inter-related fields of taxonomy (describing, identifying, naming and classifying organisms) and systematics (relationships and diversification of organisms over time) provide the basis for all studies in the plant sciences. Nevertheless, the worldwide trend in research in the plant sciences has moved away from taxonomy and systematics, to the extent that these have virtually assumed the status of scarce skills. It is ironic that in South Africa, with its wealth of indigenous plant species, the practice of alpha taxonomy (the naming, classification and revision of plant families) dwindled to the extent that work started in 1960 and intended to culminate in the definitive *Flora of Southern Africa*, has not yet been completed. However, some alpha taxonomy continues to be undertaken, especially by SANBI and at some universities. The Southern African Botanical Network (SABONET) programme under the aegis of SANBI has proved to be an excellent enterprise, fostering collaborations among southern African botanists and generally raising the level of expertise, and improving and expanding collections in herbaria and botanical gardens. Before it was finalised in 2005, the SABONET programme attracted and forged lasting links among taxonomists, scientists focused on plant diversity, as well as horticulturalists, from ten countries of the Southern African Development Community (SADC) Region. Taking cognisance of the dearth of taxonomists and systematists, the South African Biosystematics Initiative (SABI), created under the aegis of the Department of Science and Technology (DST) and the NRF, is a current programme aimed at significant enhancement of capacity in biosystematics research.

The advent and increasingly wide use of molecular methodologies have also revived interest and provided a much-needed impetus for studies in plant systematics. Thus, analysis of DNA sequence data is being used to study the evolutionary development and diversification (phylogenesis) among plant genera, families or orders. South African plant systematists embraced molecular methodology in the early- to mid-1990s, starting with DNA fingerprinting at the higher taxonomic levels. Since then, the focus has shifted towards the level of species, and presently, intraspecific studies are also being undertaken.

Phylogenetic studies using molecular methodology on species from the Cape Floristic Region (CFR) are contributing significantly to an understanding of its evolutionary history, origins and age. These studies are facilitating evaluation of biogeographic hypotheses in the context of the flora of Australasia and South America. Phylogeographic studies on individual or closely related species are gaining popularity for plant taxa having strong affinities for specific biomes. Use of these candidate taxa is invaluable in elucidating the origins, age and distributional changes of biomes in South Africa. Other molecular phylogenetic studies are focused on invasive alien plant species in anticipation of control of their spreading, and the technology also has potential implications in conservation planning.

Several scientists in South Africa are also involved in the international *Barcode of Life* project, which involves sequencing of fast-evolving, short-length genes as unique tags for individual species. Successful identification of such unique genetic tags will assist significantly in studies on species and speciation among the more than 18 000 taxa constituting the South African flora.

In some institutions, biosystematics data are being integrated with information on taxonomy, evolution, genetics, pollination and reproductive biology and biogeography, thus providing holistic systems overviews of plant taxa.

5.2.2 Ethnobotany

Indigenous knowledge about native species and their uses predates all systematic, scientific studies of plants. More specifically, while ethnobotanical investigation in South (and southern) Africa has its foundations in the traditional uses of a wealth of plant species, research is aimed at testing, verifying and cataloguing medicinally active principles; contributing meaningfully to conservation and sustainable use of the wide range of species involved; as well as documenting their cultural value and economic potential. An underlying tenet pertaining to all ethnobotanical work being carried out in South Africa, is that the holders of indigenous knowledge are protected by law and provision is made for them to share equitably in any emergent benefits. The legislation also includes strict procedures to control bioprospecting, thus further providing protection against exploitation of the county's flora and of the holders of indigenous knowledge.

With the enormous regional species diversity, it is not surprising that teaching, training and research in ethnobotany is carried out in many of the country's universities, and is a focus in several research establishments. For example, SANBI maintains an active ethnobotany programme, embracing bioprospecting to develop new phytomedicines, particularly for the suite of neglected African diseases, including malaria, tuberculosis (TB) and diabetes. Furthermore, informative displays of plants used for medicinal and cultural purposes are a feature of all nine of the national botanic gardens. Another major programme is centred at the CSIR, focusing on identifying potential new drugs based on the extensive spectrum of bioresources and indigenous knowledge in South Africa. Aiming for scientific validation of traditional medicines, the research also emphasises development of herbal treatments applicable to TB, malaria and HIV/AIDS.

Widespread interest and involvement in ethnobotany in South Africa led to the formation of the NRF-sponsored Indigenous Plant Use Forum (IPUF), with the stated objectives "to promote the cultural, socio-economic and scientific benefits to be derived from the sustainable use of the southern African flora". The IPUF holds annual symposia, attracting a wide spectrum of participants, from natural scientists, through anthropologists, resource managers to business people and policy-makers.

5.2.3 Plant reproductive biology

Two main lines of plant reproductive biology which are prominent in the current research arena in South Africa are pollination biology and seed science.

Pollination biology

Research on pollination has become prominent internationally and this is also reflected in South African plant science currently and in the recent past, building on historic origins established during the Darwinian era, although with a distinct 'lean' period from then until the mid-20th century. Local activity in pollination biology is borne out by the current compilation of a special issue of the *South African Journal of Botany*.

Pollination biology in South Africa is described as being largely in the exploratory phase, with the results of studies on relatively few South African plant families consistently revealing new plant-pollinator interactions. Work in this initial descriptive phase is loosely categorised as: identification of effective pollinators; the distribution of pollinators, described as the pollination landscape; floral advertising (flower colours and scents) and rewards (nectar and pollen); breeding (distribution of sexes in flowers and ability for self-fertilisation) and mating systems (realised rates of out-crossing); and third-party interactions, i.e. the involvement of organisms additional to traditionally recognised pollinators.

Seed science

Earlier work in South Africa on orthodox (desiccation-tolerant) seeds contributed to a considerable body of knowledge particularly on the phenomenon of dormancy, the effects of plant growth regulators, deterioration in storage, and vigour. An important enduring research area (particularly in the MRC) focuses on the toxins produced by the xerotolerant seed-associated mycoflora, and effects on the consumers of such contaminated seeds.

The major fungi-producing pathogenic mycotoxins which accumulate in the tissues of poorly-stored seeds, are species of *Fusarium, Aspergillus* and *Penicillium* which

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are common contaminants of maize grains. Maize is a dietary staple in South Africa (and most of Africa), and consumption of infected grain and grain products on a daily basis is linked to a spectrum of diseases in humans and stock animals.

While the original studies on seed pathology and vigour focused on diseases of cowpea in Africa, current investigations have extended to seed pathology of a range of different crops. Centred at the University of Pretoria (UP), the work includes evaluation of both new chemical products and plant extracts for control of seed-borne diseases, and the effects of the treatments on seed vigour and germination. Significantly too, this programme has outreach implications and includes evaluation of seed storage facilities of subsistence farmers.

One of the highlights of the work of the Research Centre for Plant Growth and Development at the University of KwaZulu-Natal (UKZN-Pietermaritzburg) involves the effects of smoke from burning vegetation matter on seed germination. Fire has long been known to stimulate germination in seeds of many species. Recent work has shown that it is a component of the smoke, rather than heat, which is the activating factor. Recalcitrant seeds, which lack, or cannot entrain, the mechanisms facilitating desiccation tolerance in orthodox seeds, remain desiccation-sensitive throughout their development and after they are shed. In Africa, a spectrum of tree species, as well as species of plants used in traditional medicine, produce short-lived, heavily predated recalcitrant seeds. Studies identifying the basis of seed recalcitrance, and developing means for conservation of the genetic resources of recalcitrant-seeded species have established the Plant Germplasm Conservation Research (PGCR) Group of UKZN-Westville as world leaders in this field. The investigations have linked ongoing active metabolism with the inability of recalcitrant seeds to withstand dehydration; and have characterised two different facets of desiccation-induced damage – metabolism-linked damage which accompanies slow water loss, and desiccation damage *sensu stricto*, occurring at low hydration levels.

A key breakthrough was the development of flash-drying technology, which minimises metabolism-linked damage, thus providing specimens which are available for cryopreservation. Cryopreservation, which is a major focus of the PGCR, has the potential to provide planting material for current environmental restitution programmes, as well as amassing a stock of resources for habitat restoration in the face of climate change.

Although *ex situ* conservation of indigenous plant genetic resources *via* seeds is of prime importance, the inherent vigour and persistence of seeds of alien invasive species constitute a major problem (see also below). For example, in the battle to control Australian invasive *Acacia* species, work from the Centre for Invasion Biology (C•I•B) at Stellenbosch University (SU) has highlighted three stages of intervention that could reduce seed numbers, *viz*. evaluation, identification and release of further biocontrol agents, and perhaps less effectively, burning to reduce leaf litter and the upper seed bank and management of the lower seed bank *via* containment, rehabilitation and restoration.

5.2.4 Resurrection plants

South Africa is the main home of a group of extraordinary plants, able to withstand extreme tissue desiccation. Collectively called resurrection plants, these species tolerate desiccation by entraining particular mechanisms, only to regain full metabolic potential when water is again available. In-depth systems-based research to understand desiccation tolerance (which is the reverse side of the coin of desiccation sensitivity) is conducted at the University of Cape Town (UCT). The research covers the spectrum from gene transcription and regulation, through characterisation of the proteins produced and their regulation, examination of putatively protective metabolites produced, to the whole-plant ecophysiological level. The phenomenon of 'shutting down' metabolism when dry, and its resumption on rehydration is also studied on lichens and mosses at UKZN-Pietermaritzburg.

5.2.5 Biotechnology

Plant-based biotechnology comes into so many programmes at universities and research institutes in South Africa that it makes it impossible to survey the field in detail in this chapter. Hence, information is provided on a few institutional endeavours. Research in many centres is focused on drug discovery from the wide range of biodiversity afforded by the South African flora and the indigenous knowledge which abounds. Much effort goes into validation of medicinal efficacy of both newly-discovered compounds, and established herbal remedies.

Sugar industry

Knowledge of the identity of genes participating in the delivery of important traits or displaying tissue- or organ-specific expression is advantageous in the development of rational molecular breeding strategies for crop improvement. Over the past 15 years, the South African Sugarcane Research Institute (SASRI) has enjoyed considerable success in the discovery of such genes in locally-bred sugarcane varieties, which have been used within marker-assisted breeding and genetic engineering strategies. Using a linkage disequilibrium mapping approach, identified genes have facilitated the development of genetic markers depicting resistance or susceptibility to the sugarcane stalk borer, *Eldana saccharina*, and to sugarcane smut disease caused by *Ustilago scitaminea* infection. The success of this approach resulted in the South African sugar industry being the first to apply marker-assisted sugarcane breeding within a commercial context.

Recombinant DNA and *in vitro* culture technologies have been used in concert at SASRI to genetically engineer sugarcane. The purpose of such research has been two-fold, *viz.* to establish proof-of-principle regarding the delivery of novel input and resistance traits to sugarcane and to investigate the genetic basis of sucrose accumulation. Underpinning these goals has been the in-house development of essential genetic resources, including the isolation of appropriate transgenes and gene promoter elements, and the optimisation of transformation and tissue culture technologies. With regard to the latter, emphasis has been placed on the development of tissue culture strategies that minimise the potential for somaclonal variation, while maximising the efficiency of germplasm transformation, selection, regeneration and acclimation. The isolation of promoters to drive high-level and targeted transgene expression, as well as the identification of DNA sequences with the potential to deliver the desired phenotype, have been strongly driven by advances in gene discovery and expression technologies.

Vegetables

A priority of the ARC Vegetable and Ornamental Plant Institute at Roodeplaat is the safe and secure *in vitro* maintenance of 307 breeding lines, 254 cultivars and 438 other important accessions utilised in the local potato-breeding programme. Potato cultivars on contract for private clients, as well as for Potatoes South Africa, are also maintained *in vitro*. In addition, collections are conserved *in vitro* of vegetatively-propagated crops of sweet potato, cassava, indigenous flowering plants and traditional roots utilised in other breeding programmes.

The *in vitro* gene bank supplies the potato industry with disease-free, true-to-type mother material, and propagates any other plant material requested on a contract basis. The potato *in vitro* gene bank is the start of the Potato Certification Scheme in South Africa. Virus-elimination is performed on advanced potato breeding lines through the use of heat therapy, meristem culture and chemotherapy with the subsequent testing of material through three tuber phases before it can be released as 'virus-free'. All material that tests positive during the process is destroyed.

For the production of plants, tissue culture techniques are applied. Systems include nodal cuttings as well as the propagation of plants by adventitious shoots depending on the type of material and crop propagated. Plants are propagated on request for clients on an *ad hoc* basis.

Plantation forestry

There is considerable emphasis on modern biotechnological research and its applications in plantation forestry in South Africa, where species and hybrids of eucalypt and pine are mainstays of the pulp and paper and timber industries. Commercial production and deployment of transgenic trees are currently curtailed, in the context of present uncertainty about any undesirable consequences of genetic modification. However, there are other advanced biotechnological procedures which are being applied, e.g. in the Forest Molecular Genetics Programme at UP, which is part of the portfolio of the Forestry and Biotechnology Institute (FABI). Investigation of the molecular genetics of xylem development in fast-growing eucalypts and tropical pines is a particular focus, xylem quality being of fundamental importance in wood products. The FMG programme includes gene discovery and functional genetics research, allele discovery, and development of molecular breeding tools in order to improve tree species.

Wine industry

Researchers at the Institute for Wine Biotechnology at SU have undertaken an extensive programme aimed at engineering both grape (*Vitis vinifera*) and yeast (*Saccharomyces cerevisiae*) genetic systems in order to enhance wine production, both in volume and quality. So far, perceived consumer resistance has prevented many of these engineered and enhanced strains from entering the commercial sector.

5.2.6 Ecological sciences

In a country as large and climatically diverse as South Africa, it is only to be expected that the ecological sciences are well represented, and this interest is heightened by potential effects of elevated atmospheric CO_2 concentrations and climate change.

Ecological botanical research

Descriptive research of community structure and composition, with the correlated environmental variables such as rainfall, temperature and the standard chemistry that describe soil fertility, formed the basis of botanical ecology historically, and continues, with one or two research groups producing descriptions each year. To date, three broad vegetation maps of South Africa (and Lesotho and Swaziland) have been produced, with the most recent being a comprehensive treatment. Vegetation descriptions and environmental correlations at smaller scales are also being conducted, but are mostly confined to protected areas, and large parts of the country are, as yet, not described this way.

The major current thrust in plant ecology is focused on the interactions among soil chemistry, herbivory, fire and rainfall. Several local and international research groups are conducting a range of field experiments and using direct observation, in a number of different localities; these aim to determine the influence of soil moisture and nutrients on plant species composition, and of herbivory, fire and other disturbances on plant growth, fecundity and survival. The effects of climate and soils on plant demographics are also a focus in several studies related to the restoration of systems that have undergone marked change.

The effects of climate change on plant distribution are being studied at a broad level by two or three research groups examining environmental envelopes in terms of rainfall, temperature, aspect, altitude and broad soil classifications. For a few species the focus is more detailed.

Plant demography has been poorly researched in South Africa to date, but is currently receiving attention from a few research groups seeking to establish the factors influencing growth, fecundity and survival in several species including grasses, herbs, forbs and woody species.

Climate change

There are multiple connections between the issue of climate change and the biological sciences, some of which are fundamental to the continuing evolution of modern society within the biosphere. It is now clear that human-caused climate change represents both threats and opportunities to

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the way in which people and society draw benefits from biodiversity in its broadest sense. However, there is much yet to be learned about the complex effects that climate change is having, and will continue to have, to the biological basis for human well-being.

Essentially, there are three main areas of immediate and significant biosciences-related interest with regard to the ongoing and potential impacts of climate change. These are: first, the biological basis for food security, and other direct-use benefits of biological diversity; second, the ecosystem services that flow from managed, semi-managed and unmanaged ecosystems, and how these might be used to adapt to, or even assist in mitigating actions to reduce the adverse effects of climate change; and third, the biodiversity assets that exist in the country, and their conservation as a store of potential value for future generations.

The development of this field of enquiry in South Africa is not insubstantial, but is unevenly spread across the biological sciences as a whole. There has been surprisingly little exploration of the food security and direct-use benefits issue, while ecosystem services are only now starting to emerge as a growing focus of research attention. Most advances have been made through the engagement of several South African scientists and institutions in studies of how biodiversity assets might be affected by climate change. Unfortunately, few definite conclusions can yet be drawn due to the large uncertainty that exists, first in the rate and extent of climate change projected for the country, and second, due to inadequate tools and approaches to assess the impacts. Nevertheless, South African findings are among the international forefront on issues such as the ecosystem-level impacts of changing fire regimes, understanding of the role of atmospheric CO_2 on ecosystem structure and function, and experimentation and monitoring in extreme environments such as warm deserts and sub-Antarctic Islands.

Ecological research in savannas and grasslands

Attention has been paid to most of the biomes of South Africa, including the *fynbos,* the Eastern Cape thickets, the diminishing forests and the sub-Antarctic islands. However, particular attention is paid here to savannas and related grasslands because of the extent of their spread in Africa, and their importance to the livelihoods of millions of people.

Some of the reasons for this focus are that these biomes are among the youngest on the planet; the dominant grasses have the C4 pathway; and these biomes are particularly susceptible to increases in atmospheric CO_2. C4 grasses have photosynthetic advantages over their C3 relatives at low atmospheric CO_2 levels and where growing season temperatures are warm to hot. They flourished under the extremely low atmospheric CO_2 (~200 ppm) of the last glacial period but are expected to lose their photosynthetic advantage over C3 grasses in the next few decades if CO_2 emissions continue on their current trajectory.

Global vegetation models suggest that grasslands and savannas occur in regions suitable for forests, and it is probably frequent fires that restrain the growth of woody vegetation. Mean annual rainfall, and fire, are the most important correlates of tree cover, with African megafauna, particularly elephants (where they still exist) contributing to open grassy structure. The advent of satellite imagery has led to an increased appreciation of fire in impacting on both vegetation structure and global climate change.

The future of savannas and grasslands is uncertain. The direct effects of increasing atmospheric CO_2 are likely to be considerable, given that C3 woody vegetation is likely to respond more than the C4 grasses. A consequence of this is that woody species may grow sufficiently rapidly to escape the flame zone and thus become well established. The overall effect of increasing CO_2 in grassy ecosystems is to promote woody plants within savannas, leading to increased woody cover. Indeed, in South Africa, scrub forest has invaded savannas in conservation, commercial ranching and communally farmed areas. Acting against CO_2-induced increases in woody cover are climate-induced increases in tree mortality from drought or high-severity burns.

Changes in woody cover have many consequences, both positive and negative, for pastoralists, timber-use, biodiversity, and ecosystem function. Changes in tree cover can have important ecosystem consequences with feedbacks to the earth-atmosphere system, including the role of trees as carbon sinks and their influence on energy budgets and hydrology.

The costs and benefits of changes in woody cover in the tropical grassy biomes vary, depending on ecological and socio-economic contexts, and spatial scale. Carbon sequestration projects have become a source of income in some regions where increased tree cover is a desirable goal. Elsewhere, tree increase is undesirable, as in African savanna parks and livestock farming areas. Forest spread into grasslands could cause cascading changes in biodiversity. Holistic studies of the consequences of changes in savanna landscapes are needed to evaluate fully the social and economic impacts on society and on nature; this is an area that requires further directed research in South Africa.

Grassland science

Grassland science is an applied form of plant science in South Africa referring to the ecology and management of natural grassland and cultivated pasture. The term can be somewhat misleading in that grass-dominated vegetation occurs in many of the biomes (other than the grassland biome) occurring in South Africa. Internationally, 'rangeland' is a more commonly used term to describe natural, grass-dominated vegetation.

In South Africa, grassland science originated out of a need to understand and manage the vast natural veld used primarily for livestock production. The origins can be traced to the *Drought Investigation Commission Report* of 1923, in which many recommendations pointed to the development of a focused attempt to improve veld and livestock management and soil conservation. At the time, vegetation management in conservation areas was considered to be less of a priority. Several agricultural research stations were set up across the country around 1930, with the aim of studying livestock and fire impacts on veld, as well as additional forage production in the form of pasture development. This was followed by the development of specialist degrees at several universities, as well as specialist training at agricultural colleges.

Over time, the emphasis has shifted from a strong agricultural production focus to a more conservation-orientated focus with a strong emphasis on management for biodiversity, ecosystem services and hydrology. This has necessitated forging stronger links with environmental and ecological fields closely allied to conservation biology.

Major research themes in grassland science are currently focused around biodiversity, the impacts of climate change and climate change mitigation. Many of these themes incorporate some of the more traditional aspects of soil/plant/animal/fire interactions to a greater or lesser extent. Ecosystem reconstruction has emerged as a significant grassland research theme, with the aim of developing functional ecosystems on grassland degraded by mining, agriculture, timber production or other development. This has largely been driven by progressive legislation emphasising restoration of biodiversity.

The grasslands programme run by SANBI is a national initiative which aims to sustain and secure the rich biodiversity and ecosystem services of the grasslands biome for current and future generations. This has provided a major thrust in attempting to mainstream biodiversity management into all aspects of grassland utilisation and management.

Invasion ecology

Invasion ecology, the study of the introduction, establishment and spread of organisms to new locations beyond their natural ranges, is, perhaps not surprisingly, a thriving field of plant science research in South Africa. Local researchers have produced some of the most highly-cited papers in the global invasion literature, and South Africa is one of only three regions outside the US where such a concentration of highly-cited researchers in the field is found. While the primary focus of research to date has been on basic issues such as the production of conceptual frameworks, definitions to understanding the process of invasion as well as the mode of introduction, distribution, abundance and impacts, there is an increasing awareness of the need to understand the link between invasions and management actions.

Mounting evidence connects alien plant transformer species to declines in ecosystem integrity and services. In South Africa, a semi-arid country with limited water resources, woody invasive plants such as Australian *Acacia* spp, have transformed riparian zones and have been linked to significant reductions in water supply. Such evidence led to one of the world's largest initiatives to clear watersheds of invasive trees, the *Working for Water* programme. This programme, with joint aims to enhance ecological integrity, water security and social development, has been operating since 1995, and has provided researchers with important opportunities to link research with management questions at both national and local scales. Invasion research received an additional boost when, in June 2004, the C•I•B was established. With its hub at SU, this interdisciplinary, interinstitutional DST-NRF Centre of Excellence has rapidly become established as a world leader of research into biological invasions, building upon an already substantial and well-recognised science base.

5.2.7 Plant physiology

Plant physiology can be divided into cellular/biochemical and whole plant or ecophysiological studies, although there are studies that span the range, and stress response can be seen as a common theme. Much of the cellular physiology has biotechnological leanings and some of the physiological studies are covered elsewhere in other sections of this chapter.

Ecophysiology

There is a small group of active ecophysiologists in the country; some of whom specialise in a particular biome, whereas others have an interest in a particular aspect of physiology and investigate this over a wide range of biomes. There has been some good work on the *fynbos* biome, savannas, the arid *Karoo*, coastal sand dunes and sub-Antarctic islands. In addition, studies have been undertaken on managed ecosystems, and there is substantial physiological input into the sugarcane industry and commercial forestry plantations.

Plants in these systems have been studied in terms of growth, biomass partitioning, water relations, nutrient relations and photosynthetic characteristics, using both gas exchange and chlorophyll fluorescence techniques.

There is some excellent work on evolution and ecology of C4 grasses which is challenging some of the accepted dogma on this topic. Similarly, some of the work assessing interactions between transpiration and nutrient uptake is strongly influencing current thinking. There have also been some good studies on plant hydraulics, linking hydraulic characteristics to plant survival, growth and distribution. Studies have been undertaken on tree-grass interactions in terms of water relations and, especially, the importance of atmospheric CO_2 concentrations on these relationships.

Cellular physiology

Cellular physiology studies in South Africa cover a wide range. There is considerable work on plant growth regulators (including the action of smoke as a germination stimulant), and their importance in developmental physiology, including seed development and dormancy. Studies have been undertaken on the control of sucrose production in sugarcane, linking this to source-sink relationships. There is also work on plant-pest interactions, particularly some fungal pests and aphids. In common with worldwide trends, a major thrust in cellular physiology is the study of gene regulation associated with various biotic and abiotic stresses, with the ultimate possibility of genetic modification to improve stress resistance.

5.3 Animal sciences

5.3.1 Freshwater life sciences

Long before inland waters were studied as ecosystems, European systematists such as GO Sars were describing new species of crustacean from South Africa's fresh waters. While collectors brought specimens of plants back home to Europe for their botanical colleagues to describe and name, Sars' colleagues would send him packets of dry mud from the bottoms of temporary ponds in the Cape Town, Knysna and Port Elizabeth areas. Sars would add water to the dried mud and describe the numerous species of small crustacean that hatched out. Keppel Barnard carried on where Sars left off, collecting and describing numerous groups of crustaceans, insects and fishes from the 1930s to the 1950s. After Barnard, the momentum soon declined, though, and the individual species of many groups of aquatic invertebrates have not even been described. Almost all of our understanding of the biology of these lesser-known groups is drawn from studies on species living elsewhere in the world. On the other hand, some invertebrates and some fish taxa are relatively well known taxonomically and genetically; such studies often show very high levels of endemism relating to flocks of cryptic sibling species, especially in the CFR. With regard to aquatic and riparian plants and algae, while most have been described, we are sadly ignorant about almost every aspect of their biology and distribution.

The earliest true limnological work was performed by G Evelyn Hutchinson in the 1920s and 1930s. Hutchinson, together with Grace Pickford and Johanna Schuurman, all from the University of Witwatersrand (Wits), investigated a number of pans and other inland waters. The study of South Africa's rivers began with the groundbreaking work of Arthur Harrison and his colleagues, whose studies on the Berg River were some of the first in the world to examine seasonal changes in water chemistry and invertebrate assemblages down the entire length of a river.

The heyday of fundamental research in the aquatic sciences was reached in the 1980s, a remarkably productive period in which a series of national scientific programmes, including one on the ecology of reservoirs, another on the *fynbos* biome, another on the large Nylsvley wetland and yet another on wetlands in general, was funded through the CSIR. Termination of funding ended these programmes and since then, research funding in the aquatic sciences has, with a few notable exceptions, been almost entirely directed towards applied research. While there is still a great deal to learn on every aspect of aquatic ecosystems and their inhabitants, the more fundamental aspects of the science have given way to pressing conservation and management issues. Although this research is entirely useful and valid, we are at risk of running out of what might be termed 'knowledge capital'. We are living on the interest of the intellectual capital gained in the past. If we are to be innovative in our approach to the conservation and management of aquatic ecosystems, we need to generate new capital in the form of new, undirected, 'blue-water' research.

The applied research being undertaken in this country is, nonetheless, of considerable value and some of it is at the cutting edge of management-related science. An example concerns the quantification of water allocations for maintenance of aquatic environments. The idea of allocating water for this purpose was first mentioned in South Africa in the 1970s. By the mid-1980s, scientists and engineers were working together to come up with methods for quantifying 'instream flow requirements' for rivers. Such co-operation was fruitful ground for innovative ideas in water management and South Africa's new National Water Act, promulgated in 1998, was the first in the world to require that rivers, wetlands and groundwater would have priority of use of their water (except for a small amount to be set aside for basic human needs). Quantification of the amounts and quality of water needed to maintain rivers in a sustainable condition has been challenging, but South African aquatic scientists and managers are world leaders in the field.

Because of the need to monitor the condition ('health') of rivers and wetlands, and more particularly because of the need for methods to quantify water allocations, South African aquatic scientists have developed a number of bioassessment techniques. One, using invertebrates to assess water quality, has been successfully applied for several years, while others are presently being developed or tested. A River Health Programme has been established and *State of the Rivers* reports produced for various parts of the country. The continued success of this programme, too, is threatened by issues of management and human capacity.

Modern aquatic sciences in South Africa are largely supported by the WRC, a parastatal body, which in turn is funded by a small levy placed on the sale of water; this remarkably innovative and successful model, which seems to be unique to South Africa, is the envy of aquatic scientists in the rest of the world.

5.3.2 Estuarine biosciences

South Africa has a relatively low annual rainfall by comparison with many other countries in the world. The eastern areas are better watered than the western areas, but being steep, the relatively broken topography has resulted in a great many small estuaries. The situation in South Africa is similar in many ways to that of Australia and both countries follow the research results of the other very closely.

Estuaries have the characteristic of being open either permanently or occasionally to the sea. When open, they have freshwater flowing in to them from the land and seawater flowing in and out as the tides rise and fall. If the flow of river water stops, the mouth closes because the sea washes sand into the mouth. If the mouth is not flushed out by river water the estuary ceases to exist as an ecosystem. Estuaries act as areas of important activity with respect to breeding of marine fishes, amongst other things, which have a direct monetary impact on the country's gross domestic product.

As South Africa develops, and the population rises, there is increasing pressure on river water supplies for human use and the environment. The National Water Act of 1998 requires that water be made available for both human use and for the environment. The need for water for the environment is because there is understanding that water resource protection is inseparable from the environmental protection of rivers.

Every estuary has a minimum requirement for river water to keep the mouth open in order to maintain the marine river connection. Each estuary has an absolute requirement for minimum quality water to meet standards needed for the estuarine biota. The abstraction of river water for the human activities of irrigation, industrial activity and municipal supplies means that there is less water available for estuaries. Agriculture uses water some of which is lost *via* evapotranspiration but some leaches out to the groundwater taking with it fertiliser residues that eventually result in estuary eutrophication. Mining activities produce pollutants of various types that negatively affect estuarine biota, while municipal use results in the discharge of excessive amounts of minerals that cause estuaries to become eutrophic.

Estuarine bioscience activities in South Africa are a combination of management, which attempts to apply the results of basic and applied research to the problems described above. Government, in the form of the Department of Water and Environment Affairs, is active in implementing the Resource Directed Measures programme that specifically attempts to match basic research on hydrology, hydrodynamics, sedimentology, water chemistry, macrophytes, microalgae, zooplankton, macrobenthos, fish and birds to the specific freshwater needs of every estuary. Provincial governments and some municipalities are active in implementing the management requirements of estuaries under their jurisdiction.

Estuarine physical, chemical and biological sciences are undertaken by a closely knit group of scientists, most of whom belong to the Consortium for Estuarine Research and Management (CERM). This group is voluntary, has no membership fees and functions to keep the different scientific and management disciplines in contact *via* a website, email and discussions. No research or management funds are handled by CERM with the result that there is no competition within the organisation. Membership is encouraged for persons outside South Africa and correspondence flows freely between South Africa, Australia, the UK, the US and some sub-Saharan African countries.

5.3.3 Marine biosciences

Given its land area of some 1.2 million km^2, South Africa has a relatively short and very linear coastline of little over 3 100 km (less than 20% of that of the UK and only 7 cm per citizen). However, the country lies at the junction of three of the world's great oceans, the Atlantic, Indian and Southern Oceans, thus offering a remarkably diverse oceanographic regime to researchers.

The east coast, dominated by the warm, southerly-flowing Agulhas current, contains some of the world's most southerly coral reefs, while along the west coast the cold Benguela current facilitates development of kelp beds and provides livelihood for seals and penguins.

Because of its physical diversity, the region also supports a remarkably rich marine biota for its size. This currently comprises 12 760 described species, of which 4 233, or 33%, are endemic (Griffiths *et al*., in press). However, many taxa remain poorly investigated and waters deeper than 1 000 m (75% of the Exclusive Economic Zone) have barely been sampled. The area is thus fertile for further discovery and thousands more species undoubtedly remain to be discovered there. Another feature of the region is the strong gradients of both productivity and biodiversity around the coastline. The cold, productive, up-welled waters of the west coast support relatively few species, but several major commercial fisheries, whereas the warmer, nutrient-poor east coast has greater species richness, but fewer smaller fisheries.

Although European explorers collected marine specimens in the Cape as early as the 1700s and the South African Museum, which included marine collections, opened in 1825 (one of the earliest outside Europe), indigenous research in marine biology in the region is generally regarded as dating from 1895, when John D Gilchrist was appointed as government marine biologist, and later as both a curator at the South African Museum and (in 1907) as chair of zoology at the South African College (later UCT). From these humble beginnings, marine biosciences have developed into one of the more active and productive fields of research in the country, contributing significantly to the country's high research output in the biological sciences.

The current marine bioscience community in South Africa is small by global standards; regional symposia normally attracting some 300 delegates, many of them students. Research activities are extremely diverse, but can perhaps be grouped into three main categories.

Researchers based at museums and national facilities have as their primary role the maintenance and description of taxonomic collections. The most important collections remain those at the South African Museum (129 000 records), but the major collections of some taxa are housed at other institutions, notably fish (56 000 records) at the South African Institute for Aquatic Biodiversity in Grahamstown, mollusks (63 000) at the Natal Museum and algae at both Rhodes University (RU) (32 000) and UCT (11 000). Unfortunately, permanent posts for staff to both maintain and work on these collections seem to be dwindling.

A second research group is that employed by government departments, notably the MCM, plus smaller groups in national and provincial conservation authorities, and whose mandate is largely one of management. MCM houses the largest single group of marine scientists in the region and their responsibility is mainly research into and management of, the nation's commercial, recreational and subsistence fish stocks. Recently, the institute has also developed an active aquaculture section that is playing an important role in developing new target species. MCM also plays an important na-

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tional role as publisher of the *African Journal of Marine Science*, the primary vehicle for marine bioscience publications in the region.

The last and most diverse group comprises researchers at universities and non-governmental organisations. Several coastal universities have significant marine bioscience groupings, notably UCT, University of the Western Cape (UWC) and SU in the Western Cape, and UKZN, RU and Nelson Mandela Metropolitan University (NMMU). Other organisations include the Oceanographic Research Institute and Natal Sharks Board in Durban. Researchers in such groupings have considerable freedom to pursue wider research agendas and their interests are correspondingly diverse. However, some co-ordination of marine research within the country has been encouraged and sustained by the South African Network for Coastal and Ocean Research (SANCOR), which provides a forum for interaction and collaboration among local researchers and has developed a series of co-ordinated thematic research programmes.

5.3.4 Mammalian zoology

Mammalogy has been a strong discipline in the biological sciences within South Africa for the past 50 years, with a number of universities (UP, UCT, RU, NMMU and UKZN) playing major roles in its development. The Iziko, Northern Flagship, McGregor, the Durban Natural Science Museum and the National Museum of Bloemfontein have had a strong involvement in maintaining collections of mammals. Undoubtedly though, much of the major research over the past four decades has been spearheaded by the Mammal Research Institute at UP. African mammalogy has embraced both the marine and terrestrial environments; marine mammalogy has concentrated on the cetaceans and pinnipeds that frequent the coastline and the sub-Antarctic islands, whereas terrestrial mammalogy can be divided into research on the large and charismatic mammals of the sub-region, and the less studied smaller mammal fauna. The major disciplines of ecology (including behavioural ecology and conservation ecology) and ecophysiology have been the main thrusts in large mammal biology. The fields of ecophysiology, sociobiology, ecology and behavioural ecology have been the major focus of work on small mammals. In addition, work on mammalian systematics, conducted principally by groups at SU, UP and several museums, embraces standard morphological as well as modern molecular phylogenetics and the use of chromosome painting that have greatly advanced our knowledge of the relationships of mammals at the ordinal and family level. In the field of ecology, the deployment of the latest electronic technology has allowed for the satellite tracking of large marine and terrestrial mammals.

There are strong research groups in South Africa currently working in the disciplines of thermophysiology, evolutionary ecology, ecology, behavioural ecology, reproductive physiology and systematics. This is further recognised by the awarding of two DST-NRF research chairs in the broad field of mammalogy.

5.3.5 Ornithology

The efforts of the early collectors notwithstanding, the launching pad for modern ornithology in South Africa was the publication of Edgar Layard's *Birds of South Africa* in 1867. This was subsequently expanded and co-authored with Richard Sharpe, resulting in a multi-volume work completed in 1884. Following accelerating interest in birds in the late 19th century, the South African Ornithologists' Union, the first ornithological society in Africa, was established in 1904 and the first issue of its journal appeared the following year.

The early years of the journal and its successors (including *Ostrich*, which is still published today) contained many contributions by the first South African-born ornithologist to achieve an international reputation, *viz.* Austin Roberts. Most of the work published by Roberts was summarised in his 1940 book, *Birds of South Africa*. This book has been the South African 'bird bible' since its first publication and survived in something approaching its original format for 65 years, before being completely rewritten as a fully referenced handbook in 2005. It remains the best-selling African natural history book of all time.

The publication of 'Roberts', as it is popularly known, caused an immense upsurge in interest in ornithology. Today, in terms of the numbers and quality of handbooks, field guides and other birding books, South Africa stands head and shoulders above most countries in the world. But if Austin Roberts earns recognition as the father of modern ornithology in South Africa, then the accolade of 'mother' must surely go to Cecily Niven.

Cecily Niven was the only daughter of Sir Percy FitzPatrick, author of the South African classic *Jock of the Bushveld*. In 1954, shortly before she became president of the South (later Southern) African Ornithological Society (now BirdLife South Africa), she invited the International Ornithological Congress to hold its next meeting in South Africa. This was declined, but a year later she initiated the first Pan-African Ornithological Congress, which was held at Livingstone, Zambia, in 1957. These meetings are still held every four years.

Cecily Niven's commitment to ornithology in South Africa went far beyond conferences and workshops. In 1958, assisted by her husband Jack, she garnered the support of the SAOS when she announced that the Percy FitzPatrick Memorial Trust would make available the initial capital endowment to launch the Percy FitzPatrick Institute of African Ornithology (PFIAO). Despite strong competition from RU, UCT's promise to provide a dedicated building for such an institute swung the decision in its favour. The PFIAO remains the only institute of ornithology in the southern hemisphere, and one of only a handful in the world.

The first director of the PFIAO assumed office in 1960. Interestingly, even though the PFIAO will be celebrating its 50th anniversary in 2010, there have only been four directors to date. Today, the PFIAO's Niven Library stands as a memorial to the Niven family's vision. From humble beginnings, it is the most comprehensive ornithological library in the southern hemisphere, and probably the most comprehensive collection of African bird literature in the world.

Although several ornithologists, some of considerable international acclaim, worked at institutions other than UCT, the establishment of the PFIAO provided a formal home for ornithology as a professional science in South Africa. The 1960s saw unprecedented developments in the public standing of science and technology. Funds for research were available from abroad as well as locally, but this bounty was not fully exploited by the PFIAO. Much of the first decade of the PFIAO involved the documentation of the region's avifauna which, despite handbooks dating back to the 1860s, was still poorly known. Namibia also featured prominently on the PFIAO's agenda, being the first step towards the institute realising its mission as a centre for the study of African ornithology.

Under new directorship, the PFIAO built up a critical mass of graduate students by the mid-1970s and its research prospered, including the setting up of major research programmes on the South African-owned Prince Edward Islands in the sub-Antarctic Ocean. These have subsequently expanded to include the British-owned Gough Island and the Tristan Group, as well as Antarctica. But scientific expansion into the remainder of continental Africa was slower, accelerating only from the 1990s. By the mid-1980s, politically imposed intellectual sanctions were firmly in place, with many journals refusing to consider contributions from South Africa. Despite this, in 1989, ornithology was identified as the South African scientific discipline with the greatest international impact (of 108 analysed), ranking third, equal with Canada behind the US and the UK.

Among the natural sciences, ornithology has benefited by its large public appeal, fuelled in part by popular books produced by amateur and professional ornithologists alike. The 1980s saw a significant growth in what has come to be known as 'citizen science', using birdwatchers to gather large data sets, especially about the distribution and abundance of birds. The biggest such project to date was the *Atlas of Southern African Birds*. This project, started under the aegis of the PFIAO, was subsequently handed over to UCT's department of statistical sciences. As it grew, it led to the formation of the Avian Demography Unit (now the Animal Demography Unit), which is now responsible for many other, similar projects across a suite of taxa. The bird atlas collated information from thousands of volunteers in six countries. At the time it was the largest biodiversity project ever carried out in Africa, culminating in the production of a two-volume analysis in 1997. Preparation of the second regional atlas is now underway.

Whilst the value of birdwatchers to ornithology should never be dismissed, there is a widespread misconception that birdwatching and ornithology are necessarily synonymous. This is far from true; some of the most seminal concepts in biology have arisen from scientific studies of birds. The formulation of Darwin's *Theory of Natural Selection* was strongly influenced by observations of birds, as were the advances in behavioural science of Tinbergen and Lorenz.

Ornithology in South Africa continues to provide such far-reaching insights. For example, a study emanating from the PFIAO and published in 2008, proved experimentally for the first time the existence of teaching (and Pavlovian) behaviour in a wild bird species. This is likely to have wide-reaching ramifications for many aspects of scientific research, including cognition and behavioural ecology.

Several factors have contributed to the recent rise of ornithology in South Africa, including advancing technologies (such as tracking and molecular techniques) that have added immense value to behavioural and demographic data, increasing cross-disciplinary fertilisation in terms of ideas and techniques, and the integration of citizen scientists and the post-apartheid expansion of networks of international collaborators. Ornithology has come a long way since the intellectual isolation of the 1980s and all indications are that it is set for a healthy future.

5.3.6 Entomology

Human recordings of insects in southern Africa were first discovered in San rock paintings that depict swarms of honeybees, honey hunting activities from colonies in rock crevices and drawings of honeycombs. The San were also adept at using insects as a source of venom for their arrowheads that made hunting large animals a more successful enterprise. Insects, particularly the large larvae of silk moths are regarded as a culinary delicacy (mopane worms).

The entomological fauna of southern Africa was extensively collected in the 18th and 19th centuries and this material was deposited in the natural history museums of Europe and the UK. The scientific study of insects based in South Africa was established in the late 19th century, with the founding of natural history museums and with the recognition that agricultural development was dependent on a careful study of the insect pests of agricultural crops. Appointment of applied entomologists in colonial government service served as the basis for the development of applied entomology. During the early part of the 20th century, systematic entomology was the preserve of the natural history museums, while the Department of Agriculture was responsible for applied entomological research. Two very significant areas of research were in the control of swarms of locusts that could do extensive damage to agricultural production and control of the mosquito vectors of the malaria parasite.

After World War II, a significant number of research institutes were founded and established programmes dealing with particular crops and their associated insect pests; for example, mosquito-control programmes in an attempt to eradicate malaria; tick-control programmes in an attempt to control livestock diseases. In addition, the National Collection of Insects that is housed in the Plant Protection Research Institute in Pretoria became a focus of work in systematic entomology, particularly in relation to agricultural pests. This collection and those of the natural history museums contain an invaluable record of the arthropod biodiversity of southern Africa which will be of

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inestimable value in monitoring the effects of climate change.

The establishment of departments of entomology in the agricultural faculties of a number of South African universities led to a flourishing of studies of insect natural history and to the production of the entomologists who would staff the research institutes, both of the public and the private sectors. The research carried out by these individuals led to a significant rise in agricultural productivity and an increase in livestock production.

Research areas in which South Africa has had and continues to have a significant international impact, have been in developing the systematics of particular groups of insects, insect conservation biology, biological control of weeds, medical entomology, forest entomology and veterinary entomology.

5.4 Biotechnology and molecular biology

Biotechnology has played a central role in the development of the molecular biological sciences in South Africa. Under the government's 2001 National Biotechnology Strategy, a series of development vehicles, enacted and managed through the DST, have been created. The traditional focus on biotechnology research, supported by the NRF, has been substantially broadened with the establishment of organisations aimed at transforming basic research outputs into commercial initiatives.

The Biotechnology Regional Innovation Centres (BRICs), *viz.* the Cape Biotech Trust (Western Cape), BioPad (Gauteng), and in KwaZulu-Natal, LifeLab (Durban) and PlantBio (Pietermaritburg); the Innovation Fund and various technology platforms (such as the Centre for Proteomic and Genomic Research) and National Equipment Program facilities (such as the Solexa sequencer at UWC), all contribute to a substantial stimulation of biotechnological activities in South Africa.

As is typical in many developing countries, biotechnological research and development in South Africa tends to focus on national needs, issues and resources. Biomedical research is well developed, but with particular emphasis on high profile diseases such as HIV, malaria and TB. The commercialisation of biotechnological developments in the biomedical field, led by the Western Cape BRIC (Cape Biotech), includes pharmaceutical product developments (Shimoda), biomedical devices (Biovac) and diagnostic methods (Synexa).

5.4.1 Biodiversity and bioprospecting

South Africa is geologically, climatically and environmentally diverse. The western Cape, in particular, is a biological 'hotspot', recognised as one of the world's six most biodiverse regions and natural habitat to some 6 000 different indigenous plant species. Such extensive biodiversity has led to substantial interest in bioprospecting for new bioactive compounds from national and international agencies and researchers. This interest in bioprospecting South Africa's plant diversity has in the past been strongly underpinned by indigenous knowledge, based on the use of certain plants as therapeutic agents over millennia by the indigenous peoples of the country. Notable successes from this programme include the appetite-suppressive drug derived from the desert plant *Hoodia* and trials on the use of *Sutherlandia* to boost immune systems in clinical AIDS sufferers. Bioprospecting among other groups of organisms, particularly endemic fungal and bacterial diversity has, until recently, received little attention. However, at the time of writing two exciting initiatives are in progress. The first is the growing interest in metagenomics in the country. The term, coined in the late 1990s, refers to studies of biological diversity which focus on multiple organisms and their genomes (metagenomes) rather than single organisms. Two research groups have been very actively involved in this field for the past five to eight years: the research group at UWC and the BioPad-funded Metagenomics Platform at UFS, the latter focusing on arguably one of the most exciting and unique biomes in the world, South African deep mine biodiversity.

An appreciation of the country's unique genomic diversity has stimulated several major legislative and structural developments in the country. The former Department of Environmental Affairs and Tourism (DEAT) (now Department of Water and Environmental Affairs) recently promulgated new regulations relating to the processes of bioprospecting and exploitation of biological resources. Central to these guidelines are new protocols for acquiring permits which include a formal requirement for profit sharing agreements with the 'owners' of the biological resource. As they stand, these guidelines contain a number of anomalies, although DEAT has already taken steps to engage the users, to identify anomalies and bottlenecks and to resolve some of the more substantial limitations of the legislation.

A second major initiative, currently under discussion is the development of a Bioprospecting Platform. Early suggestions are that this platform may be built around new robotic high-throughput screening technology, capable of rapid screening of large genomic and metagenomic DNA libraries. This technology has wide application in the identification of new bioactive compounds (such as enzymes, antimicrobial compounds, therapeutics etc.) and can be expected to be an important component of the growing national biotechnology industry.

5.4.2 Plant biotechnology

Arguably the best-developed biotechnology sector in South Africa is the field of plant biotechnology. The reliance of the country's economy on primary production, the climatic extremes of much of the region and the growing uncertainties around food security have all led to a surge of interest in plant genetic engineering, whether for enhanced crop production, reduced pathogen sensitivity or improved environmental resistance (see section 5.2.5).

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5.4.3 Biofuels

Given that South Africa does not have natural oil reserves, the incentive to develop economic alternatives to fossil fuels is high and biofuels research is currently an important research focus. Unlike many northern hemisphere countries, South Africa does not have huge grain surpluses that might be used to generate bioethanol. The recent debate over the social and political impacts of diverting food-grade carbon (such as maize) to biofuel production has led to a government policy framework aimed at protecting food supplies. As a consequence, biofuels researchers have refocused on non-edible lignocellulosics as a potential source material for biofuels production.

Two organisations have taken an active role in promoting biofuels research: these are the South African National Energy Research Institute (SANERI) and the BRIC, PlantBio. Both organisations have provided substantial support for biofuels research and development (R&D). PlantBio has recently allocated R20 million to a consortium of laboratories comprising researchers at UWC, SU, CSIR and Cape Peninsula University of Technology (CPUT) to develop the enzymology of lignocellulosic digestion. SANERI co-sponsors the biofuels research chair at SU.

5.4.4 Structural biology

The history of structural biology can be traced back to the contributions of Aaron Klug, who after completing his MSc in crystallography with RW James at UCT, and his PhD at Cambridge, went on to postdoctoral studies on virus structure with Rosalind Franklin at Birkbeck College in London. It was this remarkable work in laying the foundations of modern structural biology that ultimately earned him a Nobel prize in 1982.

Several early attempts at Wits and then at the CSIR to establish structural biology laboratories did not succeed. However, a major boost to structural biology in South Africa occurred through Wellcome Trust grants which facilitated collaboration between local researchers at UCT and international researchers and resulted in the X-ray crystallographic structure determinations of a number of proteins, including the structure of angiotensin converting enzyme. The Wellcome Trust also funded the move of the Jeol 1200EXII cryo-electron microscope from Birkbeck College to Cape Town, creating significant local capacity and resulting in the publication of the first macromolecular structure determined entirely on the African continent (Sewell *et al.,* 2003).

Recently, a joint UWC/UCT structural biology initiative funded by the Carnegie Foundation (2003-2006), supported the acquisition of South Africa's first X-ray diffractometer (UWC) and the upgrading of SU's 600mHz NMR to protein-NMR capacity, which is also developing rapidly at other universities around the country (UKZN, UFS, RU). A second X-ray diffractometer was purchased and a DST/NRF research chair in structural biology was created at Wits in 2008. There has also been pressure from researchers to establish a nationwide structural biology platform. At the time of writing, this platform is still in the formative stage, but is likely to provide long-term stimulation of structural biology through support for the technology, the research and the technical expertise.

5.4.5 Environmental genomics

One of the 'quantum leaps' in the field of biology over the past decade has been the arrival of relatively inexpensive high-throughput sequencing capacity. The ability to generate gigabasepair volumes of sequence data in very short time periods (typically 4-10 days, depending on the sequencer) has revolutionised the approaches to many aspects of molecular and environmental biology. It is now possible, for example, to use whole genome sequencing as a primary tool for acquisition of single genes or operons, as a viable alternative to more classical gene library or PCR approaches.

Following the commercial availability of Roche '454' sequencers in the early 2000s, South Africa rapidly entered the market with the acquisition of two machines, one unit operated commercially by Inqaba Biotechnology (Gauteng) and the other sited in the the LifeLab BRIC. A third high-throughput sequencer, Illumina Genome Analyzer II (formerly known as a Solexa), was subsequently installed at UWC. At the time of writing, two of the three machines are heavily used with a variety of genome, metagenome and EST sequencing projects. Many groups have obtained full microbial genome sequences (typically 2-5 million base pairs) and larger sequencing projects, such as the apple and pear genomes, are underway. In addition, numerous projects in the area of total transcriptome sequencing are rapidly producing quantitative descriptions of plant and fungal gene transcripts, while deep sequencing of viruses from plants and humans is revealing much about the complexity of mixed infections and disease syndromes.

Projects to sequence multiple genomes are just starting, and an initiative to sequence 1 000 genomes from *Mycobacterium tuberculosis* promises to revolutionise our understanding of the drug resistance and virulence genetics of this pathogen. The recent entré into genome sequencing has yet to yield a significant volume of publications, but a large increase in the outputs from this technology is expected in the next few years. Interestingly, there is evidence that the capacity to obtain sequence data has (temporarily) outstripped the country's capacity to manipulate those data, and the computational infrastructure for assembly and annotation of genome (and metagenome) sequence data is currently inadequate. This problem has already been partly resolved with the commissioning as national resources, of the new IBM BlueGene/P and Sun M9000 supercomputers. These systems, which are due to come online in September 2010, will be used for genome assemblies (and much more). The approaching launch of the new structure to support bioinformatics research and development in South Africa and the establishment of SANReN (South African National Research Network), which will allow the movement and use of the very large datasets, will together contribute strongly and very positively to effective handling of high- volume sequence data.

5.4.6 Biocatalysis and industrial enzymology

South Africa's contribution to this huge international field of research and commerce is surprisingly small in spite of the enormous local biodiversity and widespread commercial use of enzymes in local industry. In a global industrial enzyme market worth in excess of US$2 billion, South Africa's research activities are restricted to the extensive research and development at CSIR Biosciences and to a limited number of university laboratories. Industrial enzymology is generally underpinned by gene discovery, a field most active in the UWC and UFS metagenomics platforms. Leading university enzyme application laboratories are restricted to CPUT, UFS and UCT, although there are valuable contributions from other laboratories at RU, SU and the Durban University of Technology (DUT). Commercially, several South African firms, such as at Faizyme Laboratories and BBI Enzymes SA (previously Seravac) in the Cape, produce small quantities of enzymes for niche or local markets.

5.5 Conservation biology

South Africa has a long history, starting in the early-20th century, of scientific research and application in what today is known as conservation biology. Conservation biology emerged as a self-standing discipline only in the late 1970s. In the early- to mid-1900s, South African research in this as yet unrecognised discipline, dealt mainly with agricultural applications such as soil conservation, range degradation and invasive alien plant control (see section 5.2.6). Considerable attention was given also to the description and mapping of botanically characterised communities, later to become entities for assessing conservation goals. Concern about the extirpation of game, already raised in the mid-1800s, led to the proclamation of several game reserves in the northern and eastern parts of the country and, concomitantly, there was a marked growth in research for the scientific management of wildlife populations, mainly large or rare mammals. However, the main focus of research was on managing ecosystems for the services they provide for humans, namely livestock production, game products and water yields. Management for ecosystem service delivery is now a highly fashionable branch of conservation biology in which South Africa is a leading participant.

The vulnerability of the world-acclaimed Cape flora to inappropriate fire regimes and invasive alien plants was highlighted in a landmark publication by Wicht in 1945, which was the first comprehensive conservation assessment of a South African biome. Ken Tinley was a pioneer of the landscape-ecological approach to conservation, both in South Africa and globally, by highlighting the linkages between watershed condition and the conservation status of coastal ecosystems and species. Under Brian Huntley's leadership, the 1977-1987 decade witnessed a surge of co-operative ecological research, much of it with a conservation angle, which yielded a healthy crop of scientific products and personnel. Huntley also anticipated the massive growth during the 1990s on biodiversity research by initiating a southern African-wide assessment of the topic in the late 1980s. South Africa is signatory to the Convention on Biological Diversity, which, along with the region's exceptionally high biodiversity and capacity for research and implementation, resulted in the inflow of large amounts of donor funding for conservation. In some fields of conservation biology, research has flourished.

Given space constraints, research achievements in selected sub-disciplines of conservation biology are highlighted.

5.5.1 Terrestrial conservation planning

Conservation planning is the identification and implementation of conservation areas using scientific methods. It comprises three phases: assessment, planning and management. South African research on all three phases has been hailed as groundbreaking. Noteworthy is that South African research has operated in a real-world context of limited budgets, donor-driven deadlines and expectations of action. This has led to a research-for-implementation approach that is not typical of conservation planning research undertaken elsewhere in the world.

Systematic conservation assessment, which uses decision-support tools to identify priority conservation areas that are representative of regional biodiversity, was pioneered in Australia and South Africa. This approach seeks to redress biases in reserve systems resulting from opportunistic strategies that invariably resulted in the overrepresentation in protected areas of landscapes of marginal economic value. Since the mid-1990s, South Africa has received generous funding from international and domestic sources for regional conservation planning. Researchers have made important contributions to assessment techniques, particularly target setting and incorporating ecological and evolutionary dynamics spatially. However, perhaps the greatest contribution has been research on translating outputs of systematic assessment into knowledge that can be used for 'doing' conservation. The key ingredients of this 'planning-for-implementation' approach are careful design, conservation planning processes, skills for conservation assessment teams, collaboration with stakeholders, and interpretation and mainstreaming of products (e.g. maps) for stakeholders. Another recent and important South African contribution has been the integration in a real-world context of requirements, both from assessment and implementation perspectives, of terrestrial and freshwater biodiversity features into conservation plans.

5.5.2 Wildlife and ecosystem management

The existence of a relatively large state-owned conservation estate in South Africa from the early part of the 20th century led to both an opportunity and need to investigate the management of wildlife and African ecosystems in their near-natural state. At the same time, several iconic species (such as the square-lipped rhino) were in imminent danger of extinction. Expertise in the capture, translocation and veterinary care of large mammals became a national speciality. Research into population biology, habitat needs and wildlife feeding patterns also proliferated during the 1960s, leading to the establishment of a research chair in wildlife management and a Mammal Research Institute at UP and the *South African Journal of Wildlife Research*.

By the early 1970s it became clear that some of the pressing problems (largely outside the protected area network) were not amenable to a piecemeal approach. Strongly influenced by the International Biosphere Programme experience in the emerging field of 'ecosystem research', South Africa initiated a series of ecosystem programmes which proved to be seminal in establishing both a collaborative approach to science and a cohort of ecologists whose influence is still strongly felt. Brian Huntley was a key figure in managing the Cooperative Scientific Programmes, initially out of the CSIR and later out of its offshoot, the Foundation for Research Development, now the NRF. The first established was the South African Savanna Ecosystem programme, based at Nylsvley, followed soon thereafter by the Fynbos Biome Programme, the Benguela Ecosystem Programme (in the marine environment) and eventually by programmes in the aridlands of the *Karoo*, the grasslands and the forests. Brian Walker was attracted from Zimbabwe, and had a lasting influence on ecosystem science in South Africa.

South African wildlife management in formal protected areas was internationally admired for its efficiency, but the model had severe limitations in the remainder of the landscape. For a range of reasons, wildlife was becoming an important land use outside of reserves. New approaches to conservation, particularly on communal or private land, originated in Zimbabwe (then Rhodesia) and came south, influencing management both inside and outside protected areas. Among the many innovations was a view of managed natural ecosystems, often wildlife-based, as opportunities for job creation and economic development; a participatory approach to land management; and the implementation of adaptive management as a way to deal with variability and uncertainty.

The strong body of scientists with experience in interdisciplinary work and an ethos of sustainable use rather than strict preservation meant that South Africa (with Zimbabwe) was well positioned to enter the field of ecosystem services ('the benefits that people derive from nature') when it blossomed in the early years of the 21st century. The Southern African Millennium Ecosystem Assessment was an important project in establishing this approach. The experience gained in scientific assessments fed back into wildlife management, for instance in the scientific assessment of elephant management in South Africa.

5.6 Concluding comments

The biological sciences in South Africa have a strong base. Government interventions (through the DST) throughout the first decade of the 21st century have dramatically improved national funding for biological research and the infrastructural base required by modern molecular biology. This commitment has been particularly evident in the field of biotechnology. It is pertinent to note that in July, 2009, the Minister of Science and Technology, Ms Naledi Pandor stated that South Africa aims to be among the top ten countries worldwide in the biotechnology industry, in terms of the pharmaceutical, nutraceutical and biopesticide industries (among others) by 2018. She went on to say that structures, which would operate under the aegis of the recently-established Technology Innovation Agency (TIA), had been established on a nationwide basis to enhance research and innovation in biotechnology.

Student enrolment in biology at tertiary education institutions remains strong and growing. Gender equality has broadly been achieved at undergraduate level in this field. Racial transformation is making good progress among the student body, and is gradually working its way through the ranks, with much leakage into other fields of endeavour. One of the fastest-growing sectors of the economy is nature-based tourism, and biotechnology continues to be attractive to both students and research funders. The challenges of a biosphere under stress inspire many young people to join in the search for local and global solutions.

The South African academic community is small and widely dispersed. It is dominated by an ageing research population. The acquisition of young active researchers, who have the potential to become national research leaders of the next decade, is constantly under threat by the attractions of higher salaries outside the university sector and by strong international laboratories (and currencies). Despite these threats, there is considerable cause for optimism. Opportunities for higher degree research in South Africa are excellent, in that bursaries to support Masters and PhD researchers are readily available and easily accessible. With the government's commitment to the biotechnology industry and the knowledge economy, there is every reason to believe that the sector with continue to grow and that the nation's international competitiveness on the global stage will continue to expand. Many aspects of the biological sciences have now become mainstreamed in the South African economy, and the platform for the future is overall healthy, dynamic and robust, even as historically-strong sub-disciplines lose their primacy and new, unimagined ones arise.

A shift in focus in the second half of the decade from fundamental to applied research is seen by some as a substantial threat, but is more widely perceived as a necessary re-orientation in order to exploit scientific expertise and productivity for the growing knowledge economy.

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6 CHAPTER

PG ERIKSSON, F SHILLINGTON AND C-J DE W RAUTENBACH

6.1 Introduction

South Africa's unique earth science heritage provides an exceptional natural laboratory for the earth sciences, at the same time affording the country's earth science professions and educational institutions an opportunity to take their rightful place as global leaders and innovators.

A comparison of global hypsometric curves demonstrates that the African continent has the highest average elevation above mean sea level, with South Africa comprising a high-lying interior, with marginal escarpments leading down on to relatively narrow coastal plains, bordered in most areas, except the southern coast, by narrow continental shelves. This unique physiography and geographical location has endowed the country with particular oceanographic and meteorological characteristics.

South Africa is surrounded by two of Earth's greatest oceans and is situated astride the subtropical high pressure belt which determines its meteorology. In addition, the geological heritage of the country is arguably the greatest endowment of any country or even region on Earth, providing equally unique economic geological and hydrological riches.

However, against this backdrop of a unique and globally relevant natural history and the opportunities it provides, there are many challenges facing the earth sciences, including funding constraints, increasing student numbers, pressure to redress past imbalances in the racial composition of the student population, and an ageing and predominantly white male teaching staff. Although common to most other disciplines, the impact of the first two pressures is particularly severe in the earth sciences because of their heavy dependence on field work.

6.2 Geological Sciences

South Africa's mineral riches make it literally the most valuable piece of real estate in the world, with the exception of the oil-rich Middle-Eastern areas. However, the long-term viability of hydrocarbon supplies cannot compare to the longevity of most of South Africa's mineral deposits. Some pertinent examples, expressing proportions of global mineral reserves in South Africa (using latest available figures, from 2007) are: 88% of platinum group minerals; 80% of manganese; 72% of chrome; 40% each of gold and vermiculite; and 32% of vanadium. Exploration spending in South Africa was the eighth highest of any country globally in 2007, and in that year the local minerals industry contributed almost 8% to gross domestic product (GDP), while employing approximately 10% of all registered taxpayers. This enormous industry and the wealth it creates bring untold benefit to the geological sciences in the country.

Many large international mining houses have their own research teams and laboratories that cooperate closely with many universities. Indeed, some tertiary institutions house industry laboratories. There is a close working relationship between industry and academia, not least through the Minerals Education Trust Fund (METF), which currently subvents salaries of geological science teaching staff at six universities. About one third of all geological science students at the large departments have bursaries from either private or state sectors in the industry, and the regular consulting services of academics contribute to their own expertise provide postgraduate projects and funding. The advantages of practising earth sciences within a large and very active minerals and mining industrial sector cannot be overstated in terms of contributing to quality and global status. As a consequence, South African mining engineering and geological sciences have always enjoyed global recognition far in excess of either the size of the population or economy (South Africa comprises about 1% of the global economy).

Further advantage accrues to the geological sciences through South African institutions such as the Council for Geoscience (CfG), Mintek, and the Council for Scientific and Industrial Research (CSIR; specifically Miningtek, now known as the Natural Resources and Environment Division). The CfG employs a large geological staff whose prime duty is to map and assemble basic, as well as applied, geological data, for the entire country. It also houses valuable mineral, rock and fossil collections, a very large set of maps, publications, borehole cores and borehole logs, plus analytical laboratories, geophysical and engineering geological sections. Access to these databases and facilities is open to all academic geologists, at special rates or even without payment. Mintek also employs a large, predominantly mineralogical and metallurgically qualified, staff component, and houses excellent analytical facilities. Again, cooperation with academia is ongoing. The CSIR undertakes mainly applied research, particularly in mining technology and cooperates with many university geological science departments countrywide. State funding through the National Research Foundation (NRF) and the government subsidy to universities on the basis of research publications in a set of recognised journals are benefits that apply across a broad spectrum of disciplines.

The number of staff in geological science departments at universities in South Africa is shown in Table 6.1. The department at the Witwatersrand (Wits) University is the largest with 27 staff, followed by a group of seven departments with between eight and13 staff each, and ranging down to some even smaller departments. The large staff component at Wits is an anomaly in that it includes two endowed institutes (Bernard Price Institutes for Geophysics and for Palaeontology) and some unusual specialisations (Table 6.2). When these posts are excluded, Wits fits well into the second group

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of what might be called average departments which are adequately staffed; however, each department within this dominant group of departments is about half the size of a typical geological science department within first-world countries. If the academic staff situation at the average South African geological science department is less than luxurious, support and technical staff components are a good deal worse off in most cases. Staff members lacking PhD qualifications (Table 6.1) may reflect either a young staff component (e.g. UP), or the merging of mainstream university geological science departments with those from the former technikons[1] (e.g. UJ).

Table 6.1: Number of teaching staff in geological science departments at South African universities, divided according to position and qualification

University with geological science departments	Total teaching staff (additional vacant posts are indicated in brackets)	Professors*	Lecturers (with PhD)	Lecturers (without PhD)
Witwatersrand (Wits)	27	13	12	2
Pretoria (UP)	12 (+1)	5	3	4 (+1)
Johannesburg (UJ)	12 (+1)	4	3	5 (+1)
KwaZulu-Natal (UKZN)	10 (+2)	4	6 (+2)	
Stellenbosch (SU)	11	6	5	
Cape Town (UCT)	10	6	4	
Western Cape (UWC)	8 (+1)	5 (+1)	1	2
Free State (UFS)	8	5	2	1
Rhodes (RU)	6	2	4	
Nelson Mandela Metropolitan (NMMU)	4 (+2)	1 (+1)	1	2 (+1)
Fort Hare (UFH)	5	2	2	1
Venda (UV)	5	1	2	2
North-West (NWU)	4	1		3
Tshwane University of Technology (TUT)	2 (+2)		1	1 (+2)
Limpopo (UL)	1 (+1)			1 (+1)

Source: websites and personal communication, March 2009.
*The terms professor and lecturer are used in the generic sense.

1 Technikons were higher education institutions in South Africa that focused on technological training.

An analysis of speciality fields of teaching staff for the entire country shows an overall bias towards igneous petrologists and igneous geochemists, with a secondary concentration in the fields of structural geology and geodynamics (Table 6.2). Staff in small departments that are not listed in Table 6.2 have the following specialities: UV has five staff members who are all in the fields of mining geology and environmental geology; the speciality fields of staff at UL and TUT are unknown. The sedimentological and metamorphic fundamental disciplines are relatively small, with mineralogy being very weak. Provision of staff in the equally fundamental fields of stratigraphy and pal-

Table 6.2: Number of teaching staff by geological science sub-discipline at South African universities

MAJOR DISCIPLINE	NMMU	NWU	RU	UCT	UFH	UFS	UJ	UKZN	UP	SU	UWC	WITS	TOTAL
Igneous & Igneous Geochem.	1	1	2	4		3	2	1 VP	1	3	1	4	23
Structural and Geodynamics	1	1	1	2		2	1	3	1	1	2	2	17
Sedimentology and Basin An.		1	1	1			2		2	1		1	9
Metamorphic				1		1	1	1	1	3		1	9
Mineralogy								1	1				2
Stratigraphy					1							1	2
Palaeontology												4	4
Mining Geol.												1	1
Econ. Geol.			2		1	1		1		1	2		8
Environ. Geol. and Geochem.					1		1			2	1	1	6
Hydrology					1			1			1(+1)	1	5
Geophysics				1	1							4	6
Geochemistry				1									1
Engineering Geology								2(+1)	2(+1)				6
Other*	2(a)	1(b)				1(a)	5(c)	1(d)	2(a) 2(e)		1(f)	7(g)	22

Source: websites and personal communication, March 2009.

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* Subdisciplines under Other are as follows:
(a) no specialisation;
(b) soil scientist;
(c) two geoeducationalists, one palaeomagnetist, two geometallurgists;
(d) marine geologist;
(e) natural hazard geoscientist;
(f) geomorphologist;
(g) three palaeoanthropologists, two geoeducationalists, one Quaternary geo chemist, one atmospheric geochemist.

aeontology would be considered by many in South Africa as a luxury, and the actual numbers are consequently also low. Applied geological fields, incorporating the fields of mining geology to engineering geology in Table 6.2, also comprise relatively small groups of specialists. Notwithstanding the somewhat arbitrary definition of categories and the difficulty of classifying some individuals, it is clear that:

1 The number of specialist geoscientists in any field is very small by international standards;
2 The distribution of this limited population amongst so many departments and universities would appear to be unwise;
3 The role of highly competent and productive individuals is almost certainly greater than would be the case in the large, well-endowed institutions in the first world, making any department and team very vulnerable to retirement or resignation losses.

This rather parlous situation is exacerbated when considering individual scientists who are viewed as international leaders or are internationally recognised in their fields (Table 6.3). Again, the role of a small number of people is emphasised and their loss through any circumstance would be significant to their host institutions. This total of only 20 leading individuals amongst 15 geological departments countrywide over a 26-year period (1983-2008) is very small.

Table 6.3: National Research Foundation (NRF) ratings for geological scientists over the period 1983-2008 (where an individual has changed institution over time, the individual is assigned to the institution where the rating was initially obtained)

Category of leading international scientist	UCT	WITS	UJ	UP	UKZN	Iziko Museum, Cape Town
A1	3	1	2	0	0	0
A2	1	0	0	2	0	0
B1	3	5	0	0	2	1
Total	7	6	2	2	2	1

NRF ratings are:
A1 = recognised by all reviewers as international leader;
A2 = recognised by majority of reviewers as international leader;
B1 = recognised by some reviewers as international leader.

In terms of speciality, these individuals comprise eight igneous petrologists-geochemists; four geodynamicists; two sedimentologists; two palaeontologists; and one in each of geophysics, engineering geology, economic geology, and marine geology. The same dominance in the igneous and structural geology fields is observed as noted earlier.

A number of fully or partially endowed research chairs exist within the geological science departments as follows:

- Wits: Platinum Industry Chair in Igneous Petrology; SARChI (South African Research Chair Initiative) Chair in Exploration, Earthquake and Mining Seismology; Chamber of Mines Chair of Mining Geology;
- UCT: Philipson-Stow Chair in Mineralogy and Geology; Chamber of Mines Chair in Geochemistry;
- UWC: United Nations Educational, Scientific and Cultural Organisation (UNESCO) Chair in Hydrology;
- UJ: SARChI Chair in Geometallurgy;
- US: SARChI Chair in Experimental Petrology;
- RU: Minerals Industry Chair in Exploration Geology;
- UP: Kumba-Exxaro Chair in Geodynamics; Aon-Benfield Chair in Natural Hazard Research.

A summary of the characteristics of geological science departments at South African universities follows.

University of Limpopo (UL)

UL is trying to rebuild its department after a lapse of several years. A degree programme was restarted in 2008 and UL currently has a single staff member and 26 first-year and 16 second-year students.

North-West University (NWU)

NWU, partly comprising the former Potchefstroom University for Christian Higher Education (PUCHE), had a small yet vibrant department from 1935-1992, known for its research on the Vredefort Dome (led by Andries Bisschoff, who was the head of the department from 1976-1986) and for contributing geologists particularly for the Witwatersrand gold fields. NWU is currently rebuilding their department.

University of Venda (UV)

UV has degree programmes focused essentially on mining and environmental geology, but without a full component of fundamental geological science sub-disciplines, graduates from the university experience problems finding suitable employment. UV has large student numbers at BSc level.

Nelson Mandela Metropolitan University (NMMU)

NMMU, previously the University of Port Elizabeth, opened a geology department in 1970, under the leadership of Izak Rust (head of the department from 1970-1995), who was succeeded by Russell Shone. Two vacant positions at the university have not been filled for some time and with the imminent retirement of the senior geoscientist (Shone) NMMU faces an uncertain future. The university has large student numbers at BSc level.

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Rhodes University (RU)

RU has a rich history of Bushveld and Karoo basalt research (led by respectively, Hugh Eales and Julian Marsh, both previous heads of the department), as well as Karoo sedimentology. RU has an MSc course in exploration geology (run since 1978 by John Moore) which has gained international recognition and critical support from the mining industry. The imminent retirement of Moore affects the viability of this course and, in the longer term, the future of such a small department.

University of Fort Hare (UFH)

Geological sciences at UFH started 44 years ago. The single undergraduate programme emphasising traditional fundamental subdisciplines is complemented by a highly applied Honours offering (economic geology, geophysics, engineering geology and hydrology). The current head is Baojin Zhao.

University of Cape Town (UCT)

UCT has always had a strong bias towards petrology and mineralogy, with geochemistry indubitably tied into a focus particularly on igneous petrology. A separate, yet allied geochemistry department, founded in 1962 under the world-renowned Louis Ahrens, laid an important foundation for this still extant focus of the UCT geology department. Two products of the geochemistry department, John Gurney and Tony Erlank, rose to great prominence, locally and abroad. Erlank succeeded Ahrens as the second and last head of this discipline, from 1978-1992 when the two departments amalgamated once again. Gurney achieved international prominence through work on kimberlites, diamonds and upper-mantle petrology. These interests are still strongly represented in the current department, which enjoys international leadership in these fields. Andrew Duncan and Anton le Roex continue to lead this department within igneous petrology and geochemistry. Cooperation with the global diamond industry, particularly the De Beers Group is significant, and the accent remains on mafic-ultramafic rocks rather than more acidic types, which have been a long-time focus at the neighbouring Stellenbosch University (see below).

Other specialist fields at UCT, particularly the structural and sedimentological aspects have never enjoyed quite the same status, although the Precambrian Research Unit, which focused largely on the geology of highly deformed and metamorphosed terranes in Namaqualand and Namibia in the west of the southern African subcontinent, contributed substantially to such aspects locally and internationally. Despite this, the individual within this department in recent times with the greatest measure of international recognition is Maarten de Wit, who joined the university in 1986. De Wit has a notable global reputation, within several fields: greenstone and cratonic evolutionary studies; the history of the Gondwana supercontinent; spatial aspects of the geosciences; structural and geodynamic studies; and analytical geosciences. He is probably best known for his 'intra-oceanic model' for early island arc and continental crustal genesis, one of the standard models accepted worldwide, encompassing also the chronological aspects of ocean volume growth leading to drowning of previously exposed mid-ocean ridges. This research, tied intimately to ocean basalt geology, places De Wit's work also squarely within UCT's traditional petrological focus. Marine geoscience is the other noted discipline within the history of UCT geology, having begun under Eric Simpson's urging, during his tenure as head (1957-1974), with Richard Dingle achieving prominence internationally and heading up the Marine Geoscience Unit, to be followed, part-time, by Ben-Avraham (Tel Aviv University) until its disbandment in 1994.

University of the Witwatersrand (Wits)

The school of geosciences at Wits has a large and diverse staff and highly multidisciplinary history. The school encompasses the two Bernard Price Institutes (BPI); that for Palaeontology (founded in 1945), together with the allied palaeo-anthropology group, and has a well-recognised international standing, particularly for hominid work (in cooperation with several other departments at the university) and for Karoo reptile and mammal-like reptile fossils (Bruce Rubidge, current head, BPI Palaeontology). Wits has the only palaeontological research institutes at a university in South Africa and curates a very large and scientifically valuable collection of fossils, mainly from the Karoo and from the hominid-bearing sites of Taung, Makapansgat and the Sterkfontein Valley. The institutes also have the necessary preparation facilities and staff to prepare and curate these collections. This is fortunate in a time that the number of palaeontologists and curation staff employed by museums in the rest of the country is declining. BPI Geophysics (founded in 1936) currently enjoys less recognition and focuses on theoretical aspects rather than on applied geophysics, yet is the only recognised centre for this discipline in the country (there are only two other individuals in the field, at UCT and UFH). Recently, the Africa Array initiative across the continent has been enhancing their status. The status of geophysics at Wits and, indeed, in South Africa can be attributed to Louis Nicolaysen (BPI Geophysics 1954-1993; director 1963-1992). His contributions were in many fields: geochronology; mine safety including seismic events and rockbursts; oceanic work around the country; the famous Vredefort impact site; geodynamic research related to mantle stresses; and Gondwana geology.

Perhaps the major field characterising the Wits geosciences school lies in economic and mining-related geology, also stimulated by the long-lived Economic Geology Research Unit (EGRU; now EGRI), which was founded in 1957 and has always had a strong Witwatersrand gold focus. Led in earlier years by Des Pretorius (1966-1990) and successor Carl Anhauesser, it gained prominence as a result of the work of LJ Robb, who is noted for his seminal work on the Witwatersrand basin. This department has also shone within the igneous petrology field and through work on the Bushveld Complex, led in recent decades by Grant Cawthorn and Lewis Ashwal. Ashwal worked closely with De Wit of UCT, particularly on greenstone belts and Archaean crustal evolution, and is also an international authority on anorthosites. He has a strong African research interest, with recent work on crustal rocks in Madagascar. The sheer variety of expertise at Wits is underlined by other internationally acclaimed scientists, such as Terence McCarthy (geochemist and environmental geologist, noted for sedimentological work on the Okavango Delta and for fluvial studies), Tim Partridge (engineering geology, geomorphology, stratigraphy of hominid fossil-bearing caves in the Malmani dolomite) and Alan Wilson (geochemistry). Other work at Wits that has attracted international recognition is the impact cratering group there (led initially by Uwe Reimold, now Roger Gibson). The school at Wits has always enjoyed a close and distinctively supportive relationship with the South African (now more international) mining industry, which has been of great benefit to the unversity, both scientifically and financially, thus making it possible for Wits to support such a large staff complement and wide range of activities within the geosciences.

University of Stellenbosch (SU)

Geology at SU dates back to 1895, and from the late 1970s onward, this department has had several focus areas: e.g. geochemistry (Dave Cornell and Dieter Hallbauer), gemology (HS Pienaar), alkaline rocks (Wilhelm Verwoerd) and structural geology (Ingo Hälbich). With the appointment of Abraham Rozendaal to the chair in 1995, economic geology became a dominant focus area for teaching and research by the staff complement of six. Student numbers were very limited, with approximately 20 undergraduates, 15 Honours students and ten MSc and PhD candidates. From 2000 to 2006, the department underwent a period of change, with high turnover of both staff and postgraduates; the staff complement grew to seven posts and a young and research-orientated group was formed. Student numbers grew but research productivity also advanced significantly. In 2007, geology and geography merged to form a new department of geology, geography and environmental studies. Coincident with this, a new stream in environmental geochemistry was begun and two new positions were filled in this area. The enormous increase in undergraduate student numbers seen in all geological science departments countrywide, also affected SU, and in excess of 400 first-year students are now registered. On the positive side, this has begun to stimulate geology numbers at higher levels, with an effective doubling of second- and third-years, and with Honours currently up to 18, while there are ten MSc and seven PhD candidates.

The new department, a reconstituted staff, and greatly enhanced student numbers coincided with the appointment of a world-renowned (granitic) igneous petrologist, John Clemens, in late 2007. He also brought in equipment to further enhance the experimental petrology laboratory, already a unique facility in Africa. This, together with the recent appointment of Ian Buick, an internationally recognised metamorphic petrologist, allied to a SARChI chair for Gary Stevens in experimental petrology, has transformed the SU department into one with a distinct and powerful focus on hard rock petrology, embodied in the Centre for Crustal Petrology. Research publications in the best international journals are starting to result, with the department making significant contributions globally to research on partial melting of the crust; the formation of granitic magmas in Archaean and post-Archaean environments;

the geotectonic evolution of the Barberton and Damara belts; and the understanding of sedimentary and igneous ore deposits. Planned expansion of the staff complement, to address Geographic Information Systems (GIS) technology, hydrology and the broad environmental and earth-system aspects of geoscience, as well as a chair in statistical geography, are in the offing.

University of Pretoria (UP)

Geology at UP, which started in 1908, has a strong tradition of Bushveld Complex geological studies (dating back to the 1940s) and expertise in mineralogy, a relatively uncommon sub-discipline in South Africa. With the founding of the Institute for Geological Research on the Bushveld Complex (IGRBC) in 1975, under the leadership of Gerhard von Gruenewaldt (head of the department 1978 -1991), Bushveld studies at UP came of age, and the vision of earlier department heads such as BV Lombaard (1947-1952) and particularly of Johannes Willemse (1952-1967) was realised. This institute gained widespread international recognition and brought many noted igneous petrologists to UP and the country. During its 18-year history, the IGRBC ensured that a strong team of such specialists (notably Martin Sharpe) remained at UP and produced world-class research under von Gruenewaldt's leadership. At the same time, teaching in the hard rock and mineralogical fields, amongst others, was led by stalwarts such as CP Snyman (1956-1999) and Erich Förtsch (1964 -1999).

Applied geology at UP began in the late 1970s with engineering geology (inspired by department head, Dirk Visser, 1968-1977), led by Monte van Schalkwyk from 1979-2003. Currently this sub-discipline, offered elsewhere only at UKZN, is growing in terms of student numbers, and the staff complement was recently increased from two to three. A full-scale study programme in exploration geophysics ran from 1984-2006, when staff resignations and small student numbers led to its end. With the launch of the essentially externally-funded Aon-Benfield Natural Hazard Centre, Africa, in 2008, the sub-discipline of geophysics, allied to the insurance and actuarial industry, has been reborn, with two staff members and a strong accent on seismology and mine-induced seismicity. UP now focuses on its traditional areas of Bushveld geology and mineralogy, with allied strengths in Precambrian crustal evolution and basin analysis (led by Pat Eriksson), metamorphic petrology and geodynamics (Kumba-Exxaro Chair), in addition to the applied disciplines discussed above. Applied mineralogical research is centred on a very fruitful and growing cooperation with the South African Police Services' forensic laboratory in Pretoria.

University of KwaZulu-Natal (UKZN)

UKZN has a more complex history than most universities, geology having begun in 1910 in Pietermaritzburg. In 1942 the department head, Lester King, an internationally respected geomorphologist and experienced Antarctic researcher, moved the department to the Durban campus. While a full department continued in Durban, the poor relation in Pietermaritzburg struggled on with only a first-year course and a succession of part-time lecturers. In 1968, Victor von Brunn, a noted glacial

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geologist, was appointed and stayed until its closure, in 1999. He was joined by Dave Hobday who began modern sedimentology as an academic discipline in the country. The Pietermaritzburg department finally reached maturity with the appointment of Don Hunter, an acclaimed Precambrian specialist. He built the department into a very effective unit with limited staff, including Allan Wilson, who succeeded him in 1993. Wilson, a globally recognised igneous petrologist and geochemist, joined the Wits geosciences school in 2007 after having succeeded Fred Bell as head of the amalgamated Pietermaritzburg and Durban departments.

In the meantime, the main branch in Durban had continued to flourish, with Ron Taverner-Smith (an experienced coal geologist and sedimentologist from Belfast) replacing King in the Chair in 1972 (until 1989). A double major in geology introduced in King's time later allowed the development of geology and applied geology streams, with a full Honours course in engineering geology. This was initially led by Rodney Maud, and in later years by Allan Kerr and then Colin Jermy. Apart from the UP department, UKZN is the only other that offers this specialisation field in South Africa. The discipline was further strengthened in 1990 with the appointment of the new department head, Fred Bell, an engineering geologist of international repute. In 1989, Ted Saggerson and Peter Matthews retired after long and very successful careers, having become the doyens, respectively, of mineralogy-metamorphic petrology and structural geology at UKZN and with wide South African reputations. Peter Matthews was one of the first people to teach modern concepts of plate tectonics in South Africa (much to the abhorrence of the 'luddite' King) and set a foundation for the structural field which endures at UKZN till today. The UKZN school of geological sciences is currently one of the larger departments in the country and is the strongest centre of structural geology and geodynamics in the country, with a strong accent on Precambrian terranes, led by Steve McCourt (current department head since 2007) and Mike Watkeys. There is also a small yet effective marine geoscience section which collaborates with the local office of the Council for Geoscience.

In 1978, geology was also launched at the University of Durban-Westville (UDW) as a subject, with a fully autonomous department launched in 1983, headed by Ingo Forster, a recognised ore petrologist. In 1985, a noted invertebrate palaeontologist, Michael Cooper, was appointed. He was acting head following Forster's retirement in 1991, until the arrival of Steve McCourt in 1995. The latter continued to build the UDW department until its amalgamation with the Durban department in 2004.

University of the Free State (UFS)

Geology at UFS began in 1910. More recently, from 1967 to 1990, under the leadership of Ben Botha and then Nick Grobler, the UFS department was built up into one of the larger and more significant centres in the country. Geochemistry (still a strength today) and hydrology were initiated, with the launch of the Institute of Groundwater Studies led by Frank Hodgson, marking an important milestone in the earth sciences in

South Africa. During the 1970s and 1980s the UFS department undertook extensive mapping (on contract to the Geological Survey) in the Bushmanland area of Namaqualand and in adjacent southern Namibia – this not only provided welcome research funding but also gave multidisciplinary field-based training to a generation of postgraduate students, particularly in structural geology, mineralogy, geochemistry and economic geology. This work was led by HJ Blignault and later AE Schoch and bears testament to the vision of Ben Botha. The large and long-running mapping project was balanced by extensive research into Karoo geology, led by JNJ Visser and LC Loock, particularly on Dwyka, Ecca and Beaufort stratigraphy and uranium deposits, and also on Karoo dolerites. Seminal work on the Dwyka and Transvaal basin glaciation by Johan Visser (department head, 1990-1997) gained him an international profile.

Willem van der Westhuizen, the current department head, together with Derik de Bruiyn, established the UFS department as a noted centre for Precambrian volcanological research, particularly on the Ventersdorp Supergroup and its geochemistry. Van der Westhuizen was also instrumental in establishing a partly taught, internet-based MSc degree in mineral resource management, which has run successfully since 2001. The UFS department in recent years, and currently, has undertaken a large range of projects: Cape granites, Quaternary drainages and hot springs, groundwater research, stratigraphy and palaeontology of the Kango Group, kimberlites, economic geology (including the platinum group elements in the Bushveld Complex, the Dominion Group, Black Reef gold, Nkomati nickel, Witwatersrand basin), neotectonism, metamorphic studies in subduction zones, meteorite research, and alpine tectonics. Throughout recent decades, the UFS geology department has managed to maintain a unique flavour of research and to produce significant numbers of quality earth scientists, despite the competition of larger and supposedly more prestigious departments. This bears testimony to the leadership this department has enjoyed.

University of Johannesburg (UJ)

The department of geology at UJ (formerly Rand Afrikaans University) was founded in 1967 under Willem van Biljon. He built up a strong unit which soon established itself both locally and internationally. Soon after its inception, three staff members, who became the core of this department and who established significant reputations, joined. First amongst these was Nic Beukes, who began his sedimentological studies in the upper Karoo, but with his PhD work moved into chemical sedimentology, Precambrian basin analysis and the broader field of Precambrian crustal and atmospheric evolution. Beukes is an international leader in these fields, being regarded as a doyen amongst those studying banded iron formation (BIF) genesis, iron and manganese deposits, as well as Precambrian palaeoclimatic and palaeoenvironmental settings. Together with Maarten de Wit of UCT, he is one of the few South African geologists to have become a global leader in multiple earth science fields. The other core members were Dirk van Reenen, just retired, and Chris Roering. The former has long been recognised internationally as a metamor-

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phic petrologist and expert on the origin and evolution of the Limpopo belt, and the latter is regarded as the founder of the modern and rigorous practice of structural geology in South Africa. Chris Roering led the department from 1984 -1994 and built on the foundation laid by Willem van Biljon to place the UJ department amongst the best in the country, particularly in terms of highly acknowledged individuals and certain research focus areas.

Over the past 20 years, with changes in staff, the research focus areas branched out into broader economic geology, particularly coal deposits (led by Bruce Cairncross, current head), and more recently geometallurgy. Research conducted at UJ has set an international benchmark for the global understanding of the genesis and evolutionary importance of banded iron formations *per se*, and of the large iron ore deposits of the Northern Cape, and for the formation of terrestrial manganese deposits, notably the Kalahari Manganese Field (through the Palaeoproterozoic Mineralisation research group led by Beukes). Globally acknowledged research into the origin of Earth's early atmosphere and the evolution of oxygen therein was undertaken by investigating the Archaean Witwatersrand and Pongola Supergroups and the Transvaal Supergroup rocks. More recently, investigations are underway in the Bushveld Complex, trying to unravel the setting, origin and mode of formation of the enigmatic platinum deposits. A specialisation which is currently unique to UJ, is its status as the only facility in Africa with a palaeomagnetic laboratory.

University of the Western Cape (UWC)

Geological sciences at UWC were established in 1981. The department has taken a different approach to most other larger departments in South Africa, by focusing strongly on applied subjects; they offer two programmes, from BSc up to PhD levels, in applied geology and in environmental and water sciences. This strategy serves to distinguish them from the two highly regarded departments in close proximity (UCT and US) which have strong foci in fundamental petrological disciplines. There is cooperation between all three departments in the presentation of postgraduate training within the petroleum geosciences.

6.3 Oceanography

The department of oceanography at UCT has been in existence for nearly 50 years and is the only department undertaking teaching and research in both physical oceanography and atmosphere science in sub-Saharan Africa. Other centres from which oceanographic work has been driven are UKZN (currently a single staff member) where there is direct cooperation with the Marine Geoscience Unit of the Council for Geoscience, and NMMU (where Eckart Schumann, now an emeritus appointment, has been the single oceanographic scientist over a long period).

The UCT department has grown steadily in size and stature, and has six permanent staff at present, including four professors: Chris Reason, George Philander, Johann Lutjeharms and Frank Shillington. Previous eminent oceanographers at UCT include emeritus professor Geoffrey Brundrit, emeritus honorary professor Vere Shannon, previously director of the Department of Environmental Affairs and Tourism (DEAT)'s Sea Fisheries Research Institute (now Marine and Coastal Management - MCM), and emeritus professor, John Field, director of the UCT Marine Research Institute (MA-RE). The main fields of oceanographic research have been in the Benguela upwelling ecosystem off the west coast of southern Africa, the Agulhas current off the east coast of Africa, and the Southern Ocean south of Africa to Antarctica. Research tools have included the use of research ships, tide gauges, satellite marine remote sensing, and most recently, ocean numerical modeling. Phenomena investigated have been the discovery of coastal trapped waves around the southern African coast, and the impact of sea level rise (Brundrit); giant filaments exporting pelagic eggs and larvae away from the Benguela upwelling system (Shillington); meanders in the Agulhas current called Natal pulses (Lutjeharms); and numerical modeling of coupled ocean and atmosphere (Reason).

Oceanographic research in South Africa passed through a rather depressed phase in the 1990s when the CSIR National Research Institute for Oceanology (NRIO) was systematically disbanded in favour of commercially driven (mainly) terrestrial and coastal environmental research; the smaller oceanographic research ships such as the CSIR's RV *Meiring Naudé* and UCT's RV *Thomas Davie* were decommissioned and sold, and South Africa's sea-going research capacity was severely depleted. Oceanographers continued to use the polar supply vessel, MV *Agulhas,* in the Southern Ocean, and MCM's RV *Africana* and *Algoa* for coastal ocean studies on the continental shelf. Recently, however, as the threat of global change, and particularly climate change has come to the fore, the ocean and atmospheric science community has rallied to form the new Africa Centre for Climate and Earth Systems Science (ACCESS) directed by George Philander (UCT and the University of Princeton). This initiative is opportune for South Africa to take the lead in setting up the new venture of 'operational oceanography', as the ocean is flooded with 3 000 autonomous vertically profiling Argo ocean floats, and oceanography is placed on a similar footing to meteorology and atmospheric science. The time is now right for a new cohort of young oceanographers and earth system scientists to rise to the challenge of unravelling the problem of how the oceans will take up excess atmospheric carbon dioxide, and become more acidic; how the great ocean conveyor may change the flow of salt and heat past the southern tip of Africa, and how the upwelling system and its productive fisheries ecosystems off the west coast will react in a warmer world.

6.4 Hydrology

This field is a very extensive one, overlapping with disciplines such as the broad biological sciences, geosciences, environmental sciences, chemical sciences, mathematics, medical sciences and also with social upliftment and educational fields. As a result, expertise and centres of training are widely scattered amongst many universities and institutes/departments. The Water Research Commission (WRC) plays a very positive role in this field of earth science within the country, acting as a hub of expertise and fostering research through its funding and publications.

There are three major players in hydrology in the country (reference to hydrology practised within geology departments is excluded as it has already been discussed): the Institute for Groundwater Studies at UFS; the Institute for Water Research at RU; and the department of hydrology (and the Hydrological Research Unit (HRU)) at UZ. Several other universities cover aspects of hydrology: the School of Environmental Sciences and Development at NWU; a research group in hydraulic engineering within the department of civil engineering at UCT; aspects are covered within the departments of geosciences and of zoology (water quality and assessment) at NMMU; the Centre for Water in the Environment (staffed by an ecologist and a hydraulics specialist), focused largely on hydraulics, and forming part of the Faculty of Engineering and the Built Environment at Wits; the UP Water Institute, with the emphasis on water management, biochemical and microbiological aspects – this centre is allied to the CSIR locally and the Georgia Institute of Technology, USA, internationally. A BSc Engineering (Agriculture) degree course in hydrology is offered by a staff complement of three (including two associate professors) in the school of bioresources engineering and environmental hydrology at UKZN. For several decades, Roland Schulze at the Pietermaritzburg campus led hydrological research for this university and even for the country. Much of his work revolved around water resource management, climate change, hydrological modelling and relationships to the broad agricultural industry.

The leading centre for geohydrological studies for over 30 years has been the Institute for Groundwater Studies (IGS) at UFS, founded in 1974. Thus far, it has produced over 500 postgraduate students. For many years, the leading scientist in this institute was FDI Hodgson, who also played a role in the founding of the Ground Water Division of the Geological Society of South Africa in the late 1970s. This division has played a very positive continuing educational role in local scientific circles, with regular short courses and conferences, aimed largely at the practising professionals in geohydrology. The UFS Institute provides training at Honours, MSc and PhD degree levels and currently has a permanent staff of four, with contract/temporary staff numbering nine (of this total of 13, two are professors and three others have PhD qualifications). The research at the IGS has traditionally been focused on the South African mining and industrial sectors, with a significant emphasis on the nature and behaviour of the country's aquifers (including computer models for aquifer management).

In contrast to the geohydrological focus at UFS, the Institute for Water Research (IWR) (encompassing also the Unilever Centre for Environmental Water Quality) at RU has addressed itself more to the ecological, geochemical, and broader biological aspects of hydrology. The IWR offers MSc and PhD degrees in either hydrology or water resources management. It has a staff of seven (including one professor, Denis Hughes, and two staff with PhD qualifications). The IWR has expertise in hydrology generally, incorporating also integrated water resource management, freshwater ecology, water quality and toxicology, biomonitoring, management of water services, and community education. The Unilever Centre focuses on ecotoxicology, biomonitoring and water chemistry.

The department of hydrology at UZ, has a staff of four (including one professor, also director of the HRU), and offers BSc degrees in hydrology, in hydrosciences (double major: hydrology with various basic and applied science combinations) and in water resource management, with higher degrees up to PhD level offered in hydrology.

Research in hydrological sciences in recent years has focused mainly on interactions of groundwater and surface water, rainfall-runoff modelling, establishing and improving regional water resource data bases, assessing relationships between land-use and hydrology, the ecological reserve, and on investigating climate change and its likely consequences. In addition, research has also been dedicated to supporting the National Water Act, *Act 36 of 1998*, and towards enhanced access to clean water of previously disadvantaged communities (as part of a poverty alleviation strategy), as well as in improving various levels of the water management system. The ecological reserve refers to the water quantity/quality needs of natural aquatic ecosystems, with the emphasis being on quantifying these parameters, towards sustaining and protecting existing aquatic environments. Integrated water resource management has striven to better coordinate the groundwater and surface water fields (and their practitioners). Modelling (particularly user-friendly packages) methodology and practical application thereof to rainfall-runoff systems, with use also of a GIS platform, remains an important research focus. Modelling has also moved towards improved flood estimation techniques, particularly to improve understanding of extreme rainfall events which are likely to increase as climate change looms ever larger in all scientifically-based activities, including obviously hydrology also. The use of satellite technology has also become a new research direction in South African hydrology. Apart from the major threat of climate change to all agricultural and hydrological activities within the country, a dearth of young professionals entering the field represents an additional challenge for the future.

6.5 Atmospheric Sciences

The weather and climate of South Africa pose challenges to meteorologists not only because the subcontinent is surrounded by vast oceans, but because it is located in the dry subtropics of the Southern Hemisphere, and as such experiences the influence of both midlatitude and tropical weather systems.

In earlier years, training and research in South Africa were divided into the fields of meteorology and climatology. Meteorology, or the study of diurnal variations in weather systems and their characteristics, was accommodated by the South African Weather Bureau (SAWB), where Jan Taljaard and Har-

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ry van Loon did groundbreaking work by describing the formation and propagation of South Africa's most influential weather systems. The only university degree in meteorology was then presented by staff of the SAWB, through the department of applied mathematics at UP. Meteorology graduates, who averaged about five per year, mostly became SAWB employees. At the same time climatological research (study of longer term averages and variability of weather events) had advanced significantly at Wits, with several papers and books on climate, climate variability and even palaeoclimates published by Peter Tyson of the Climatology Research Group (CRG). Many Wits graduates from that era are still leading scientists in the international community (e.g. Mike Harrison (UK), Janette Lindesay (Australia) and Simon Mason (USA)). Climate research also formed an important part of the UCT oceanography group's sea-air investigations (Johan Lutjeharms, Mark Jury and later, Chris Reason).

During the early 1990s, UP decided not only to facilitate, but to host training in meteorology, and one professor (Johan van Heerden from the SAWB) and two lecturers (Hannes Rautenbach and Thinus Truter) were appointed in the cordata Chair of Meteorology in the department of civil engineering – because of that department's strong hydrology section managed by Will Alexander. Student intake was still in the order of five students per year, but the CORDATA chair managed to draw significant research funding to UP, mainly from the WRC. Research ranged from climate variability (seasonal forecasting) to numerical atmospheric modelling and radar-rainfall estimations in cooperation with the SAWB cloud physics group at Bethlehem. During those years Wits had also become involved in cloud modification (also known as cloud-seeding) experiments at Bethlehem.

Significant changes took place in the atmospheric sciences in South Africa in the 1990s and early 2000s as global attention began to focus on the recognition of anthropogenic influences on atmospheric processes through air pollution; these discoveries included the Antarctic ozone hole, and later the realisation of possible climate change as a result of increasing levels of greenhouse gasses in the atmosphere. A landmark event in South Africa was the Southern African Fire-Atmosphere Research Initiative (SAFARI-92) in 1992. This initiative was a large international experiment focused on biomass burning and its influence on atmospheric composition. It led to an improved understanding of the effects of anticyclonic recirculation on the build-up of pollutants, particularly ozone, over the subcontinent and the role of westerly off-shore flow in increasing tropospheric ozone concentrations in downwind locations in the Indian Ocean. This experiment created awareness amongst atmospheric scientists of the risks that air pollution posed, and encouraged strong collaboration amongst local and international scientists, leading to the development and growth of previously smaller research groups in South Africa. At UKZN there was a focus on tropospheric ozone (Roseanne Diab) and at Wits there was also a shift of focus from climate variability towards air quality (Harold Annegarn and Stuart Piketh). Many South African scientists participated in the follow-up SA-

FARI 2000 experiment, and subsequently became actively involved, even as leading authors, in the Inter-Governmental Panel for Climate Change (IPCC)'s assessment reports (Bruce Hewitson (UCT), Coleen Vogel (Wits), Bob Scholes (CSIR) and Clive Turner (ESKOM)). These events have led to the establishment of the Climate System Analysis Group at UCT under the leadership of Bruce Hewitson, which has a strong focus on climate change modelling.

Another significant event that has changed the scope of atmospheric sciences in South Africa was the commercialisation of the SAWB during the early 2000s, which has led to the birth of the South African Weather Service (SAWS) with the Department of Environmental Affairs and Tourism (DEAT) being its largest client. Although training in meteorology was still seen as a UP responsibility, the SAWS started to incorporate training in climatology from UCT and Wits when hiring newly-qualified staff.

It is noteworthy how integrated meteorological and climatological research has become over recent years with collaborative research taking place on climate variability and change, air quality, numerical weather prediction (NWP), seasonal forecasting and even numerical model development (Reason *et al*., 2006). An important and exciting recent development is the creation of the Department of Science and Technology (DST) Centre of Excellence in Earth System Sciences (led by George Philander from Princeton University) known as ACCESS (section 6.3). This is a national facility hosted by the CSIR, which aims to offer a multi-institutional/multidisciplinary Masters degree in Earth System Sciences with components of weather/climatology and oceanography.

6.6 Concluding Thoughts

With respect to the geological sciences in South Africa, the potential synergies and concentration of expertise within the Western Cape region between the SU and UCT geology departments are obvious for the overall field of hard rock petrology (Table 6.2), with the Cape Town mafic igneous-geochemistry emphasis being complemented by the Stellenbosch experimental petrology-granitic-metamorphic emphasis; both departments also share competence and interest in the earth-systems and broad environmental sciences. From a broad perspective, it can be suggested that where there are geographic groupings of geology departments (e.g. Gauteng, Cape Town region, eastern Cape), it makes sense for there to be a subdivision between those concentrating on strong fundamental disciplines and those with a much more applied focus. In an ideal situation, the former could take control of all lower degree training through use of common BSc degree structures, with higher degrees being offered in both basic and applied fields by *all* departments in the cluster, and students having potential articulation to any Honours programme in the group. This would also increase the speciality menu offered to potential Honours students. Smaller departments could then use their limited staff much more efficiently and would have a unique function within the cluster rather than struggling to compete on an uneven playing field. This could enable departments, where such geographic clusters exist, to really build strong foci within sensible groupings of geological science disciplines.

The major bottleneck in training geological science students within the country lies at the BSc-Honours transition, with many departments only accepting a third to a quarter of their own graduates into Honours degrees, the level required for professional registration within the minerals industry. With regional clusters of departments and certain departments specialising only in honours and higher level degrees, this problem can be partly overcome. There is no point for the state to push for increased entrants into BSc degrees with the Honours bottleneck in place, as no greater number of professionally qualified geologists will result at the end of the four-year pipeline.

One has to question the wisdom of several universities (e.g. NWU, TUT and UL) in having geological science departments at all, especially bearing in mind the large proportion of vacant posts (Table 6.1). Within the bigger picture outlined in this paper, it would appear to be a moribund exercise restarting small departments at institutions like NWU and UL. Equally, the wisdom of launching the NMMU geology department in 1970 against the backdrop of the very successful Rhodes department (founded in 1905) is questionable. NMMU can serve as an example of a more recently launched small geology department, which is currently under threat. In the past 30 years of its resource- and personnel-starved life, its over-burdened and excellent staff has produced approximately 150 Honours graduates, this being the level required for professional registration within the minerals industry. The large effort in doing so equates to four to five years of production from a single large department, staffed by less stressed, and thus more effective, more numerous staff. The economies of scale are obvious to anyone examining the basic statistics and history of geological science departments in the country. The problem lies in the deeply rooted and strongly held conviction of academic freedom endemic to universities, allied to the drive by institutions to have a flagship comprising as many disciplines as possible.

A totally different picture applies to the single departments of meteorology (UP) and oceanography (UCT) in the country; without at least two centres for each there is an inherent danger of inbreeding, at university and national level, and it will be essential to maintain adequate staffing, student numbers and research funding for these critically important departments, especially bearing in mind the looming threats of global warming. For the field of hydrology, a much healthier situation is apparent, although the still relatively limited university departments and indeed, the WRC, also serve as the locus of expertise for an entire continent, endemically plagued by water shortages and severe droughts, a situation likely to be exacerbated as global warming increasingly becomes a reality.

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Health and Medical Sciences

CHAPTER 7

William Pick

7.1 A history

7.1.1 Early colonisation

The current state of health and medical sciences in South Africa is a function of its history. As all health and medical knowledge has its origins in the totality of the human experience, the historical process that led to the present-day state of health and medical sciences in South Africa includes acquisition and exploitation of knowledge that underpinned the rich pre-colonial traditions of health care at the Cape of Good Hope and elsewhere in the country. It is well known that before the process of colonisation started, ill sailors were regularly disembarked at the Cape and placed in the care of traditional Khoikoi healers. These healers made use of a variety of healing methods which included the use of local herbs derived from the rich Cape flora (this later led to intensive botanical interest, the development of 'Dutch remedies', and the export and inclusion in European *pharmacopoeias* of indigenous Cape plants like 'buchu'and aloes). The knowledge that formed the basis for the indigenous healing practices at the Cape was the result of centuries of experiential learning and experimentation.

With the establishment of an outpost at the Cape by the Dutch East India Company (DEIC) in 1652, with the purpose of revictualling its ships *en route* to the East, a new wave of experimentation in search of the cause of the killer disease, scurvy, ensued. The DEIC spared no expense in seeking a cure for this dreaded disease. Ships' doctors had to keep records of all symptoms, fresh water was produced by distillation, ventilators were introduced to pump fresh air through the ships, vinegar was sprinkled and gunpowder burnt between decks in attempts to reduce the incidence of scurvy. The Cape also had access to other medical- scientific developments in Europe and smallpox vaccination (variolation) was implemented before the 1767 epidemic. When a Portuguese ship carrying slaves who had been vaccinated with cow-pox entered the harbour, local arm-to-arm vaccination was done on slave children to test its efficacy and safety.

Britain took over the administration of the Cape Colony in 1795 which led to an increase in British imperial influence on health and medical research. Owing to a lack of critical mass (only 45 licensed doctors in 1807-8), however, it took a little longer for Cape doctors to engage in experimental medicine, and the successful use of the anaesthetic machine by William G Atherstone in 1847 was arguably the most famous medical experiment at the time. Despite the Cape's richly diverse flora and the interest shown in its medicinal properties by Europeans, only a limited number of experiments involving folk and indigenous plant remedies were conducted at this time by Joseph Mackrill, James Barry, William Atherstone and Samuel Bailey. District surgeons showed little interest in responding to a government request to submit accounts of their experiences with indigenous plants and their medicinal use. In the late nineteenth century, most colonial science was tied up with the objectives of the British Empire, part of which focused on the containment of diseases which affected black workers and white colonists. It became policy in the early twentieth century to create entities for research and technical assistance that would serve the empire's economic and political interests. With the advent of the Commonwealth in the 1950s, increasing influence was exerted by the powerful scientific community in Europe and the United States of America. A relationship akin to imperialism in research ensued, with funding, equipment, the research agenda and publication dominated by the more developed countries.

7.1.2 The driving role of mining in medical research

Given the mineral-based economy of the country, much of twentieth-century medical research was focused on supplying a pool of healthy, cheap labour to the mining industry. Research was characterised by projects that were urban-based. The establishment of the Colonial Bacteriological Institute for laboratory work on rinderpest (for the study of which epidemic Robert Koch visited South Africa) and leprosy in 1891 marked the start of government investment in medical research. This was followed by the establishment of the South African Institute for Medical Research (SAIMR) in 1912, funded partly by the Chamber of Mines. With the establishment of science councils by the Smuts government, the Council for Scientific and Industrial Research (CSIR) was the major source of state funding for medical research until the Medical Research Council (MRC) was established in 1969 as an off-shoot of the CSIR. Given the interest of the mining industry in maintaining a healthy workforce, much effort went into producing a vaccine against pneumococcal pneumonia, a leading cause of death in otherwise fit young miners. The first pneumococcal vaccine trial was published in 1914, and the research continues to this day at the SAIMR - now the National Health Laboratory Service (NHLS) - part-funded by the MRC. Other diseases that affected mineworkers were tuberculosis (TB), silicosis and asbestosis. The research response to TB was the institution of a TB Commission by the Union Government in 1912, followed by the establishment of a TB Research Committee by the Union Government and the Chamber of Mines in 1926, which culminated in the establishment of a TB Research Unit at the CSIR in 1963. Despite the considerable investment in TB research, there was very little progress in lessening the TB disease burden because the social and economic circumstances of the mineworkers and the majority of the population remained largely unchanged. The South African science community was also extensively engaged in asbestosis and silicosis research, but many of the research

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findings were suppressed as a result of the reluctance of both government and industry to acknowledge responsibility for these diseases in mineworkers.

7.1.3 Other research initiatives: infections, nutrition, genetics, medical technology and epidemiology

Research on prevalent parasitic diseases such as amoebiasis and bilharziasis received funding from the CSIR at an early stage, and research units were established in 1949, so that by the 1950s and 1960s South African scientists were making significant international contributions to the diagnosis and treatment of amoebiasis, in particular. In research on viral diseases, the role of the Onderstepoort Veterinary Research Institute, which laid the foundation for virology in the country, cannot be overestimated. Vaccines against typhus, plague, influenza and yellow fever were developed in South Africa, and work on polio vaccine led to the establishment of the Poliomyelitis Research Foundation laboratories in 1953, which later became the National Institute for Virology (1973), renamed the National Institute for Communicable Diseases in 2002.

It was not unusual for research on nutritional diseases to have its origin in the needs of the mining industry. As early as the 1920s, scurvy was found to be a problem in South African mines, where mineworkers subsisted on a diet of mainly maize meal. Work on kwashiorkor and scurvy was funded by the Union Department of Health, the CSIR and the World Health Organisation (WHO). In the 1950s, the CSIR established a National Nutrition Research Unit, later the Research Institute for Nutritional Diseases (RIND), which continued work on the link between lipid metabolism and coronary artery disease. Work on dietary iron overload and deficiency, aflatoxins and liver cancer contributed to the extensive South African contributions to clinical nutritional research.

The emergence of transplant surgery stimulated a field of medical science which had far-reaching ramifications and allowed South Africa to achieve a few global 'firsts' in the field. The first human heart transplant in 1967, which was followed by the first human fallopian tube vascular transplant in 1975, led to the development of cardiology research, while the potential for rejection of transplanted organs prompted immunological research of a cutting-edge nature. Programmes in renal transplantation added to this impetus and led to experimentation with total lymphoid radiation to control organ rejection. It is fair to say that the prominent role of local transplantation surgery added a whole new dimension to the field of immunological studies in this country.

Historically, genetic research had been influenced by the founder effects in the case of certain genetic diseases like porphyria, for which a research group was established by the CSIR in 1957, pioneering techniques for the diagnosis and classification of locally prevalent forms of disease. Familial hypercholesterolaemia is another disease that occurs with unusual frequency in certain South African populations, and was rendered largely controllable by local innovations in diagnosis and care. Genetic diseases of bone and cartilage became another speciality. Notable work in the genetic structure of local populations was done by South African geneticists.

South Africa also has a history of contributing to the development of diagnostic medical equipment. The work by Zwarenstein and Shapiro on a diagnostic test for pregnancy and by Goetz on digital plethysmography were examples of this. The 1979 Nobel Prize for medicine was a joint award for computerised tomography; the first tomographic scanning machine was based on Cormack's work at Groote Schuur Hospital, Cape Town, in the 1950s.

The 1980s saw the emergence of epidemiology as a major field in South African health and medical research. The establishment of the Centre for Epidemiological Research at the MRC in 1988 led to a national push to re-establish the discipline after decades of neglect. South Africa had contributed significantly to the field internationally through the work of pioneers in epidemiology, a significant number of whom had emigrated in response to the policy of apartheid. While population-based research had been conducted by South African scientists for decades, the renewal of interest in epidemiology coincided with an increasing focus on the societal benefits of research. A new emphasis on the implementation of research findings led to grant-making by the MRC being conditional upon scientists formulating implementation objectives in research proposals. This marked a shift away from so-called 'basic' research to more so-called 'applied' research. The emergence of HIV/AIDS and its common co-morbidity, tuberculosis, saw the establishment of the MRC HIV/AIDS Research Unit in 1987, and a number of major donor-funded, multi-centre research programmes, many engaging productively in vaccine research.

7.1.4 Political transition

The political transition in South Africa, heralded by talks between the South African government and liberation movements in the early nineties, reflected itself in the health and medical science environment. Inevitably, the national research agenda was influenced, shaped and distorted by the minority government's policy of apartheid, which served to legislate the existing racial inequalities in South African society. The anti-apartheid academic boycott adversely affected all South African science activity. The political turbulence of the 1980s, which presaged the failure of apartheid, reflected itself in the changing nature and emphases in health and medical research in South Africa.

Notwithstanding the fact that most health and medical research is conducted at higher education institutions, the MRC, South Africa's premier health and medical research organisation, which collaborates with virtually all the major health scientists and institutions in South Africa, serves as a useful prism for viewing the change in the nature of South African health and medical sciences. The MRC's annual report for 1989 raised the question 'whether the manner in which research is practised, supported and

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managed is still suitable in a rapidly changing South Africa'. The futile efforts at establishing international links (colloquia were held with Taiwanese and Israeli scientists), and a recognition that the government's policies, including its influx control policy, were failing, saw the creation of the Centre for Epidemiological Research in Southern Africa (CERSA), the main aim of which was to study the interaction between urbanisation and health. (The prime purpose of the decades-old influx control policy had been to restrict the movement of black people from rural areas to the cities; decades of forced removals from urban to impoverished rural labour reserves and the criminalisation of the process of rural-to-urban migration had led to untenable population pressure in the Bantustans, which were created as quasi-independent mini-states for black South Africans). The MRC also reformulated its mission statement to reflect its role as providing the research base for the improvement of the health of all South Africans. Research highlights in that year were work on air and water pollution, parasitic diseases in communities, infectious diseases in developing communities, urbanisation and health, the importance of exercise, heart attacks and heart disease, diet and cardiovascular disease, organ transplants, nutrition in developing communities, and trauma, a far cry from the disease- and laboratory-oriented rubrics cited earlier.

The impact of political change was further highlighted in the MRC President's report the following year (1990), thus: "……… fast changes in political, economic and social spheres of South African life caused major demands on research practice and management". The MRC responded to this change in the research environment by making major changes to its research programmes with "greater stress on community health research in an attempt to improve the quality of life of all population groups in South Africa". For the first time, the MRC annual report mentions the evaluation of health care as a research highlight, reflecting a new emphasis on the relevance of research to the provision of health services, in a changing discourse in health and medical sciences.

Significantly, the MRC experienced an upsurge in international contacts following the unbanning of liberation organisations in 1990. The academic boycott was relaxed, and opportunities for communication and scientific exchange mushroomed. South African scientific collaboration was no longer limited to Taiwan and Israel, and visiting scientists to the country increased dramatically. This was accompanied partly by the formation of bilateral links with some African countries. In the words of the MRC President in the 1992 annual report: "It now only needs a political settlement here to enable us to fully develop and implement our research development programmes with our neighbouring countries as our full partners for the benefit of all the people of Africa." This was a dramatic shift indeed! By 1991, the Fogarty International Centre of the National Institutes of Health in the United States provided six postdoctoral bursaries to South Africans, premised on a selection process that was openly affirmative in character.

The early nineties also saw the establishment of a National AIDS Research Programme, almost a decade after the first patients were reported in the country. Interestingly, it was AIDS research that established a 'breakthrough in international relations' through a visit of a delegation from the US Centres for Disease Control in 1991. The largest longitudinal study in Africa, the Birth-to-Ten study, launched in 1990, examined the relationship between social, economic and environmental factors and child health over a decade. Studies on causes of infant death, adolescent death and risk-taking behaviour in teenagers, diabetes prevalence in urban populations and trauma in urban areas were conducted from 1991 onwards. Environmental research focused on air pollution in the Vaal Triangle[1], respiratory tract illnesses in smoking households, indoor air pollution, childhood lead exposure and the use of environmental health services by urban populations.

The new legislation, the South African Medical Research Council Act, *Act 58 of 1991*, changed the way in which the MRC was governed. For the first time the board was chaired by an independent chairperson, and it immediately identified tuberculosis, malaria, nutrition intervention, trauma, AIDS and urbanisation as research priorities. The MRC introduced a system of national programmes in these priority areas in order to facilitate the networking of research and researchers across science councils (Human Sciences Research Council (HSRC), CSIR, Foundation for Research Development (FRD)), higher education institutions (universities and technikons[2]) and non-government organisations, and to ensure that the whole spectrum of research would be carried out. The new system envisaged that 'basic' research would be conducted mainly in the higher education sector, while epidemiological and community-oriented research would be conducted by the MRC and its associates. The MRC, consonant with the activities of the South African government, established contact with the African National Congress[3] and hosted its Secretary for Health, amongst other internal organisations - thus marking a dramatic shift in policy.

In the same year the MRC's National AIDS Research Programme mounted a series of studies which ranged from improving diagnostic methods to developing strategies to encourage reductions in risk behaviour. (The dire predictions made by scientists in 1991 would come to pass some years later). The year 1991 was also the year in which a major initiative in malaria research, involving a number of countries in southern Africa (Mozambique, Zambia, Zimbabwe, Swaziland, Namibia and South Africa), was planned. It was to become one of the most significant international contributions made by South African scientists. Research into rapid methods of tuberculosis diagnosis led to the MRC's Centre for Molecular and Cellular Biology at Stellenbosch Univer-

1 A heavily industrialised and urban area situated to the south of Johannesburg.
2 Technikons are tertiary education institutions which focus on technical instruction. They are now referred to as universities of technology.
3 The African National Congress (ANC), South Africa's present-day ruling political party, was for decades declared an illegal organisation by the apartheid government.

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sity developing a technique for Polymerase Chain Reaction testing of sputum samples which could be performed in mass screening for the disease. Significant community-based studies on coronary risk factors were conducted in this year which provided an opportunity to re-assess interventions in the Coronary Risk Factor Intervention Study (CORIS) in three towns in the Western Cape, and to determine the nature of coronary risk factors in urban Africans in the Cape Town metropole. Other major events included the discovery of the chromosome on which the gene for albinism was located, and the launch of a national collaborative programme to advance the development of technology for health care.

The year saw studies into the provision of health services in Port Elizabeth, the evaluation of health services in two Cape Town teaching hospitals, an investigation of the attitudes of private practitioners to health care provision, and a consultative approach to establishing the priorities for a post-apartheid health system. All of these marked a radical departure from the traditional research agenda of the MRC up to that time, and heralded the beginning of a different emphasis on the role of research in the health of populations. Concurrent with this were efforts at defining newer sampling techniques in peri-urban areas, and the creative use of routinely collected data in these atypical environments.

7.1.5 Changes in research governance

A constant refrain throughout the new era has been decreasing state funding of medical research, associated with increased reliance on private-sector and donor support. Due to financial constraints, a number of national programmes had to be discontinued, *viz*. the Bilharzia Research Programme and the Environmental Health Programme. Governance of the MRC was changed when three new standing committees reporting directly to the board were established. In 1992, a significant step was taken when an affirmative action employment policy was formally introduced within the MRC, causing a shift from traditional support patterns. The negative economic growth experienced by South Africa reflected itself in further reduced state allocations to health and medical research. The MRC began to show large increases in the non-state (contract) funding of its intramural programmes. The research agenda also began to include the implementation of results as part of the process during 1992. The MRC initiated a new Technology Development and Transfer directorate, with a view to greater interaction with the private sector and translation of research results into patents and other forms of intellectual property. AIDS education, condom-use and seroprevalence studies, TB and AIDS, a multi-drug TB register and research into early bactericidal activity of anti-TB drugs formed the bulk of research into AIDS and TB. The research into nutritional diseases highlighted the prevalence of nutritionally-induced (mainly iron deficiency) anaemia. In addition, researchers pledged support for a national nutritional surveillance programme and involvement in developing nutrition research capacity, both significant departures from traditional nutrition research.

The National Malaria Research Programme was established in 1992, the year in which the programme leader participated in the Global Ministerial Summit on malaria in Amsterdam. This was the start of a regional initiative which was to lead to striking improvements in malaria control in southern Africa, despite the increased migration consequent upon the political changes in the region. The Amoebiasis Research Programme, with the most comprehensive bank of amoebae in the world, continued its cutting-edge research in diagnostic and therapeutic measures, distinguishing between pathogenic and non-pathogenic species through iso-enzyme electrophoresis.

The discovery of a faulty gene that caused deafness and blindness was discovered by genetic researchers in 1992. It was also found that a deficiency in the sixth component of complement, which made subjects susceptible to recurrent bouts of meningococcal meningitis, was common in the Western Cape. Exciting work on new antibiotics, cloning the receptor which responds to gonadotrophin releasing-hormone, new anti-cancer agents, and advances in biophysics and nuclear medicine continued in a number of centres. At the level of health service provision, the cost-effective identification of high-risk pregnancies using Doppler flow velocimetry by the MRC's Perinatal Mortality Research Unit and the new MRC/University of Natal Pregnancy Hypertension Unit were important translational activities. A Rural Injury Surveillance Study, multi-sectoral strategies towards child safety and the completion of the Cape Metropolitan Trauma Study, the first of its kind in Africa, marked the research contribution to our understanding of these major public health problems. Laboratory research on temperature regulation, vascular research and diabetes produced significant new findings, while dental research and bone research were especially productive. Urbanisation research addressed adolescence, violence prevention and the health risks of domestic fuel use.

The Centre for Epidemiological Research in Southern Africa diversified the scope of its activities to include work on epidemiology and health systems, biostatistics, and research into chronic diseases of lifestyle. The new Technology Development and Transfer Initiative of the MRC marked the beginning of the implementation of the broader mandate provided by *Act 58 of 1991*.

In 1993, the MRC adopted the philosophy of 'Essential National Health Research' (ENHR), which altered its approach to research management. The distinction between so-called 'basic' research and so-called 'applied' research was to be no more. National health problems would be addressed scientifically in an integrated manner, and all research efforts would be utilised to answer pressing research questions. Regrettably, the organi-

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sation's early efforts to engage in private-sector technology development met with financial disaster. Millions of Rands were lost, and the organisation suffered staff retrenchments as a result. Research efforts continued, however, and a significant new finding was the discovery of a monoclonal antibody to overcome post-transplant bone marrow rejection, while progress was reported in xenotransplantation for kidney disease in animal models.

Major research activities included the initiation of Action TB, a R30 million initiative funded by a pharmaceutical company aimed at globally curbing TB, which brought leading scientists in South Africa and the United Kingdom together. Three South African centres of excellence, which included scientists from a number of universities and the SAIMR, concentrated in this area on molecular genetics and drug resistance, virulence determinants and host-cell interaction, the provision of bulk mycobacterial organisms, and the maintenance of mycobacterial strains. July 1993 saw the establishment of a network of clinical researchers in TB and HIV, signalling a recognition of the implications for TB of the HIV/AIDS epidemic affecting the country.

Studies in identifying receptors involved in the induction of dysentery, including the use of enzyme-linked immunoassay (ELISA) and immune-electron microscopic techniques for the detection of small viruses causing gastroenteritis, was conducted with international scientists; the effect of the Edmonston-Zagreb strain of measles vaccine on child immunity was tested by scientists in South Africa and the United States; while the effectiveness of the 1990 mass measles immunisation campaign was assessed by the CERSA . Home-based care for HIV/AIDS, regional surveillance of HIV/AIDS, the role of sexually transmitted diseases (STDs) in HIV transmission, the role of traditional practitioners in combating the HIV/AIDS epidemic, primary care for HIV-infected subjects, and the use of simplified tests for diagnosis of HIV infection, amongst others, were on the research agenda in 1993. The malaria research programme included the development of a Malaria Information System, drug resistance, prophylaxis, mosquito repellants and malaria vector surveillance, while bilharzia research included testing different methods of disease control, including the use of newer drugs and the development of newer diagnostic techniques. At the same time, innovative diagnostic techniques for amoebiasis and the discovery of a link between amoebiasis and Wegener's Disease elicited great international interest.

Researchers discovered two new mutations of the gene for familial hypercholesterolaemia and a mutation in a gene that codes for one of the apolipoproteins, and developed diagnostic methods to identify gene defects in a number of conditions, including retinitis pigmentosa, Leber's hereditary optic neuropathy, and Usher's syndrome. Other activities included research into Tay-Sachs disease, porphyria, genetic cardiac disease, and the discovery of a previously unknown genetic disorder.

Research in perinatal mortality, women's health in a peri-urban area, ongoing follow-up in the Birth-to-Ten project, premature labour, prenatal care, midwife education and a review of abortions dominated maternal and child health research, while population-based nutrition surveys, iron supplementation in schools, the distribution of iodised salt, and vitamin D deficiency formed the bulk of nutrition research.

Health systems research included the integration of curative and preventive services, evaluating the role of community health workers, a review of the registration of births and deaths, the stimulation of health promotion, the 'Healthy Cities' Project, and the introduction of violence-prevention projects.

Cardiovascular disease and lifestyle research included a costing of the burden of cardiovascular disease in South Africa, risk factors for coronary heart disease in adolescents, and the role of sodium in hypertensive heart disease. At the level of laboratory and animal experiments, studies clarified the role of monocytes in arterial disease, the prevention of heart attacks, and the relationship between certain endocrine cells and diabetes. Research into exercise physiology, oral and dental health, health care technology, and radiobiology continued to contribute to the increasingly diverse pool of health and medical science.

A conference organised by the Essential Health Research Group (later renamed the Community Health Research Group) of the MRC in June 1993 identified a number of key issues affecting health and medical research in South Africa. The need to develop capacity in public health research, a concomitant need to develop research capacity at historically black universities[4], and the over-riding need to make research results rapidly available to policymakers, were identified during the conference. This led to the allocation of 20% of the funds for proposal applications, bursaries, fellowships, internships and research trainee posts for historically black universities, and the establishment of the Research Capacity Development Group in the MRC. The excitement surrounding the political changes in the country also led to the MRC seeing an important role for researchers in policy development, and contributions were made to the National AIDS Convention in Southern Africa, the national advisory committees on primary health care, AIDS, tuberculosis, trauma, nutrition and malaria. The organisation also played a facilitatory role in shaping a national cancer control policy for the country.

The number of visitors to South Africa continued to rise and the MRC alone hosted 123 international guests during 1993. The year also saw increasing contacts between South African scientists and scientists in southern Africa.

4 Under apartheid, South African universities were established for different racial groups. Those created for black South Africans were under-resourced and under-funded, thus limiting their capacity for research.

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7.1.6 Re-shaping health and medical sciences in South Africa

The establishment of a Government of National Unity[5] in 1994 heralded a new era in the history of South Africa. This was accompanied by major changes in the governance structure of the MRC. A new Ministry of Arts, Culture, Science and Technology assumed responsibility for scientific research, including health and medical studies. A new MRC board was appointed through a democratic and public process, the first of eight science councils to be constituted thus. Fourteen new members were appointed to a complement of seventeen board members. The year saw the implementation of an integrated research agenda composed of both 'basic' research and 'applied' research, which fitted with the new government's blueprint for development, the Reconstruction and Development Programme (RDP)[6]. A major new thrust in the science environment nationally was the increased emphasis on capacity development and corrective action.

In keeping with the renewed energy in health and medical science, buoyed by increased international contacts, the number of collaborative research units and centres in the universities was increased. The health and medical research community made significant contributions to the evolution of national plans, as well as provincial ones. Contacts with African researchers, especially malaria researchers, grew exponentially and a WHO Collaborating Centre for Urban Health, which involved a leading university and the largest city in South Africa, was established in 1994. An international tuberculosis conference was held in March 1994, the National AIDS Plan, informed by scientists, was accepted as government policy, malaria distribution maps assisted in targeting anti-malaria interventions, and air pollution studies and studies with sister science councils into community participation were conducted to inform policy. In response to a dire shortage of epidemiology skills, courses were conducted by researchers in collaboration with higher education institutions, primarily through Schools of Public Health. Partnerships extended beyond the traditional, and a collaborative project on the benefits of electrification was initiated with the Electricity Supply Commission (ESKOM). A health legislation research project explored deficiencies in health legislation education, and tobacco-control research informed the process that led to the promulgation of tobacco-control legislation. Laboratory-based researchers found themselves increasingly located in multidisciplinary units. One such example was the Pneumococcal Research Unit at the SAIMR which had activities that included molecular biology, clinical research, epidemiology and vaccine production. Financial support for capacity development in health and medical research was provided by the

5 As part of a political settlement a Government of National Unity comprising the old apartheid government and the liberation organisations was formed to oversee the period of transition before the first democratic elections in 1994.
6 A socio-economic policy implemented by the ANC government after 1994 to address the issues of poverty and the shortage of social services across the country.

FRD, and a number of initiatives sought to develop research infrastructure, research capacity, research training and grantsmanship at historically disadvantaged institutions. Technology development saw a dramatic increase in funding for research collaboration between science councils, higher education institutions and industry during the year. Significantly, the annual report of the MRC for the years 1994/5 included a separate Health Impact Report signifying a dramatic shift of emphasis in the practice of health and medical sciences in South Africa, coupled with a concerted effort to inculcate a research culture in disadvantaged, newer higher education institutions. South African scientists began to play significant roles in international professional organisations and the WHO.

The areas of research were expanded with the addition of work on the quality of care, health promotion and women's health. By 1995, the new MRC board had reshaped the vision, mission and goals of the organisation. Greater efforts at defining the relevance of research and improvement in the quality of research saw the establishment of the scientific strategy committee, composed largely of scientists, as well as a performance evaluation sub-committee of the board. New collaborative units included a Pneumococcal Research Unit at the SAIMR and a Diarrhoeal Diseases Research Unit at the Medical University of Southern Africa (MEDUNSA), a first at a historically disadvantaged institution.

7.2 Fifteen years post-apartheid

The last fifteen years have been remarkable for the rapid growth in health and medical research in South Africa. Shaped by a reorganisation of science and technology under the new government, a comment from Gerald Keusch, Director of the Fogarty International Centre of the National Institutes of Health, USA, captures this phenomenon eloquently: "The accomplishments of the South African Medical Research Council since the transition in government is nothing short of outstanding. The advancement of research capacity in your country is stunning, and the productivity you and your colleagues have achieved is a tribute to the standards of excellence in research you have done so much to promote". This comment reflects the advances in health and medical sciences in South Africa as a whole. The expansion of research was aided by an increase in the government grant to the MRC from 2000 onwards. A concomitant increase in grant funding in higher education, science councils, not-for-profit non-governmental organisations, and business sectors reflected itself in a dramatic increase in research activity across the country. Apart from an increased output in most areas of health and medical research, the increased vigour in the research environment also manifested itself in the creation of exciting new fields of research, while programmes that had fulfilled their mandates or became less relevant were closed. The years 2000/1 saw the emergence of new programmes which included the South African Aids Vaccine Initi-

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ative, HIV prevention and vaccine trial units, the national telemedicine programme, the first national programme of the global Cochrane Collaboration, and the launch of the Global Alliance for TB Drug Development. An Office of Indigenous Knowledge Systems was established in 2001, which was to develop a most innovative clinical trials platform for evaluating traditional medicines. This led to the establishment in 2004 of a Traditional Medicines Reference Centre which straddled the MRC and the CSIR.

The new millennium also saw the emergence of rural health research through initiatives in Bushbuckridge and rural KwaZulu-Natal, which tracked populations over time, thus contributing significantly to global demographic and health surveys. In April 2003, the United States Track and Field Association announced that all future races in the United States would be run according to guidelines developed by the MRC's Exercise Science and Sports Medicine Research Unit at UCT in South Africa. A study on blood lead in schoolchildren showed that levels of exposure were high and exceeded international reference levels. The first Phase IIb clinical trial of a South African AIDS vaccine was launched in 2007, and the work of the HIV Prevention Research Unit was recognised through its designation as a United States National Institutes of Health (NIH) Clinical Trial Unit. In addition, a number of sites in South Africa have been designated for paediatric and adult HIV clinical trials units, funded by the NIH.

A significant advance has been the alignment of South African ethics committees with internationally recognised and accepted standards of good practice, particularly in the conduct of clinical trials. Coupled with an increasing number of postgraduate students from other universities and institutions on the continent, South Africa has seen a remarkable increase in the number of students completing postgraduate work in South Africa, co-supervised by South African scientists. Much more can be written about South Africa's health and medical research at present. Suffice it to say that South African health and medical science is thriving and growing stronger by the day. In assessing the current state of health and medical science in South Africa, it is necessary to examine its resource base.

7.3 Expenditure on health and medical research in South Africa

South Africa spent 0.87% of its Gross Domestic Product on research and development (R&D) in 2004/5, an increase from 0.81% in fiscal year 2003/4. This figure rose through 0.92% in 2005/6 to 0.95% in 2006/7, close to the national target of 1%. The total domestic expenditure (includes local and foreign funding) on R&D in fiscal year 2006/2007 was over R16.5 billion (up from about R10.1 billion in 2003/2004), of which 15.1% was spent on health and medical sciences. The proportions of funds derived from this amount expended on health and medical R&D in the business, government, higher education, not-for-profit and science council sectors in 2004/5 varied from 10.1% in the not-for-profit sector, through 11.9% in the science council sector, 14.7% in the business

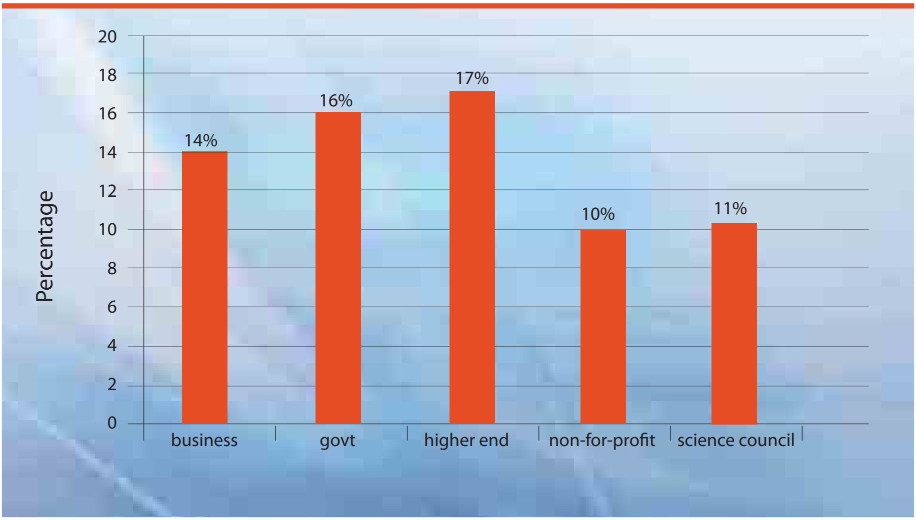

Figure 7.1: Percentage of total health/medical R&D spent by sector in fiscal year 2004/5
Source: National Survey of Research and Experimental Development (2004/05), CESTII.

enterprise sector, 16.4% in the government sector and 17.4% in the higher education sector (Fig. 7.1).

In addition, the proportions spent on biological sciences were 10.5% in the science council and government sectors, 7.6% in the higher education sector, 1.9% in the business enterprise sector and 0.4% in the not-for-profit sector. A small part thereof would conceivably have been spent on health and medicine-related research. In keeping with international best practice, as defined by the Organisation for Economic Cooperation and Development (OECD), R&D expenditure is related to certain socioeconomic objectives set by the country. When looked at from the perspective of the socio-economic objectives set by the Ministry of Science and Technology, the percentage spent on health R&D varies from 10.2% for science councils, 11.8% for the not-for-profit sector, 12.9% in the business enterprise sector, 13% in the higher education sector and 14.8% in the government sector (Fig. 7.2).

Over time, the proportion of total R&D spend on health and medical R&D increased substantially from 13.5% of total R&D expenditure in 2003 to 15.1% in 2006 (Fig. 7.3).

A more nuanced examination of research expenditure on the health and medical sciences reveals a mixed picture. While the percentage of the expenditure on health and medical R&D by socio-economic objective declined from 14.1% to 13% between fiscal years 2003/4 and 2004/5, there was a significant increase in business sector expenditure on health and medical R&D from 10.1% to 14.7% over the same period. A similar increase was found in business expenditure by socio-economic objective. This increase was found in spite of a

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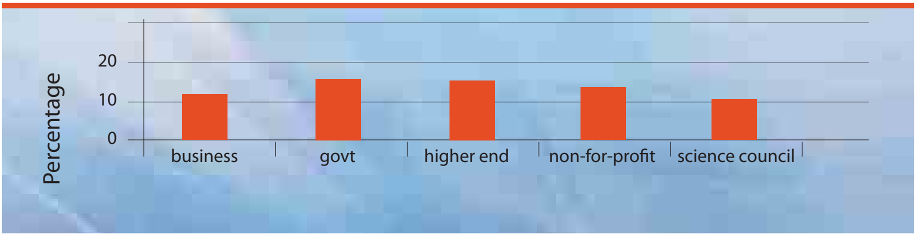

Figure 7.2: Percentage of health/medical R&D spent by socio-economic objectives for fiscal year 2004/5
Source: National Survey of Research and Experimental Development (2004/05), CESTII.

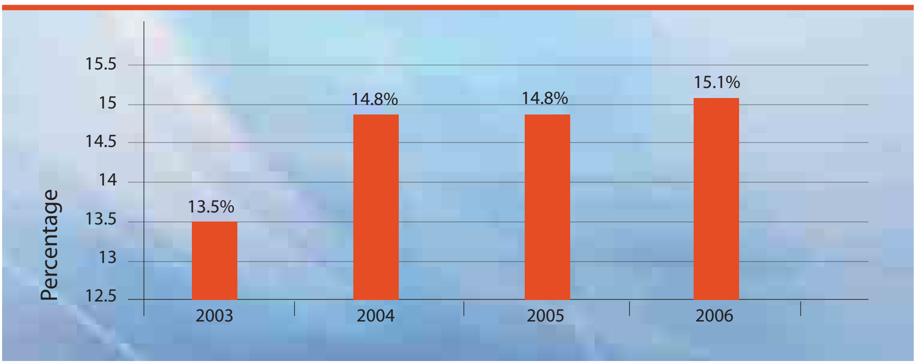

Figure 7.3: Percentage of total R&D spend devoted to health/medical sciences for the period 2003-6
Sources: Survey of Research and Experimental Development (2004/05), CESTII and National Survey of Research and Experimental Development 2006/07, Department of Science and Technology and HSRC.

decline in overall health and medical R&D expenditure by socio-economic objective, reflecting a markedly increased investment in health and medical R&D by the business community in South Africa.

The proportion of R&D expenditure in the higher education sector spent on health and medical research decreased from 20.9% in fiscal year 2003/4 to 17.4% in fiscal year 2004/5. The reasons are thought to be the increased service load on clinicians, which has eroded their ability to spend time on research, and the attrition in the number of clinical researchers. This is a matter of concern, given South Africa's research gains in this sector in recent decades.

Over the same period even greater declines (more than a third) have been noted in the not-for-profit sector's overall health and medical R&D expenditure, as well as expenditure by socio-economic objective. However, as stated in the National Survey of Research and Experimental Development of 2004/2005 the reason for this is largely methodological; many of the not-for-profit researchers were reclassified into other categories, thus accounting for the steep drop in all modalities. Science council R&D expenditure on health and medical research remained constant over the fiscal years 2003/4 and 2004/5 at 11.8% and 11.9% of the total science council R&D expenditure. However, the proportion spent on health and medical R&D by socio-economic objective by science councils increased from 7.7% in fiscal year 2003/4 to 10.2% in fiscal year 2004/5. This reflects a reduction in expenditure related to the advancement of knowledge (basic research) and an increase in expenditure on so-called applied research.

7.4 Numbers of health and medical researchers in South Africa

Based on the most recent survey conducted by the Department of Science and Technology (DST) and the HSRC, South Africa had 7 262 researchers, technicians and support staff involved in the medical and health sciences in 2006/7. (This does not include scientists working in the biological sciences). Of these, 64% were researchers, just less than 20% were technicians, and about 17% were made up of support staff. Of all R&D staff, more than half were women, while 48% of the researchers were women (Table 7.1). This is higher than the ratio in most countries. The majority of the scientists were working in the higher education and business sectors, followed by the science councils and government. It is important to note that the MRC has 45 collaborative research units, most of which are staffed by scientists in the higher education sector.

7.5 Scientific outputs

In measuring scientific outputs, the number of scholarly articles produced by South African scientists provides a good sense of the productivity as well as the quality of the different fields of health and medical research, indicated in Table 7.2. All information on this topic is derived from a draft report produced by the Centre for Research on Science and Technology (CREST) based at the University of Stellenbosch, *South African clinical research outputs in the recent past – what do they tell us about enhancing the future system?* For purposes of discussion, the health and medical sciences are divided into basic health sciences, clinical health sciences and public/community health sciences. Most of the journal articles published by South African health scientists are to be found in the clinical health sciences; basic health sciences account for about a quarter

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Table 7.1: R&D personnel working in the research fields of the medical and health sciences 2006/07

SECTOR	R&D personnel by occupational category: Researchers Male	Researchers Female	Technicians Male	Technicians Female	R&D support staff Male	R&D support staff Female	TOTAL Male	TOTAL Female
Business	309	473	185	299	132	427	626	1 199
Government	52	94	84	80	47	76	183	250
Science councils	114	167	89	242	54	81	257	490
Higher education	1 941	1 481	247	166	132	261	2 320	1 908
Not-for-profit	8	13	1	1	2	4	11	18
TOTAL	2 424	2 228	606	788	367	849	3 397	3 865

Source: DST (Department of Science and Technology) & HSRC (Human Sciences Research Council). 2009. National Survey of Research and Experimental Development 2006/07. Pretoria: DST & Cape Town: Centre for Science, Technology and Innovation Indicators (CeSTII), HSRC.

Table 7.2: Number of articles published by field for periods 1996-2000 and 2001- 2005

Fields	Number of articles: 1996-2000	% of total of 7 519	2001-2005	% of total of 8 843
Clinical health sciences	**5 679**	75.5%	**6 313**	71.4%
Basic health sciences	**1 795**	23.9%	**2 307**	26.1%
Public/community health sciences	**1 258**	16.7%	**1 434**	16.2%
Total	**7 519**	-	**8 843**	-

Note: Some journals are classified into several journal field categories. The inevitable double counting means that the totals do not add and percentages do not add to 100%.

of journal articles, while public/community health sciences account for 16% of all journal articles over the period 2001 to 2005. A comparison with the period 1996 to 2000 shows a decline in the proportion of journal articles published in the clinical health sciences over time (Table 7.2).

On examination of South Africa's share of articles in international journals (classified as ISI and non-South African, ISI and South African, and non-ISI and South African journals) by broad field, CREST found that basic health sciences research was almost exclusively published in overseas ISI journals

Table 7.3: Publication of articles by field and journal type for the periods 1996-2000 and 2001-2005

Fields	1996-2000				2001-2005			
	ISI & non-SA	ISI & SA	Non-ISI & SA	Total articles	ISI& non-SA	ISI & SA	Non-ISI & SA	Total articles
Clinical health sciences	56.5%	19.6%	24.0%	**5 679**	61.5%	18.2%	20.2%	**6 312**
Basic health sciences	100.0%	0.0%	0.0%	**1 795**	97.2%	0.0%	2.8%	**2 307**
Public/community health sciences	41.1%	0.0%	58.9%	**1 258**	55.6%	0.0%	44.4%	**1 434**
Total articles in health and medical sciences	**62.5%**		**22.8%**	**7 519**	**67.1%**	**13.0%**	**19.9%**	**8 843**

Note: Some journals are classified into several journal field categories. The inevitable double counting means that the totals do not add and percentages do not add to 100%.

Table 7.4: Publications as a function of gender and field for the periods 1996-2000 and 2001-05

Fields	1996-2000		2001-2005	
	Total SA authors of known gender	% female authors	Total SA a uthors of known gender	% female authors
Clinical health sciences	2 429	33.2%	2 454	35.9%
Basic health sciences	1 227	34.8%	1 388	36.7%
Public/community health sciences	824	43.0%	857	48.4%
Total	**3 056**	**35.7%**	**3 253**	**38.5%**

(100% in 1996-2000, and 97% in 2001-2005) (Table 7.3). Similarly, the share of articles in overseas ISI journals in clinical health sciences increased from 56.5% to 61.5%, while the share of public/community health sciences publications appearing in international journals increased substantially from 41.15 to 55.6%. South African scientists thus experienced an increased presence in the international science community in recent years.

South African publications also showed an increasing proportion of foreign co-authors, reaffirming the growing international stature of South African health and medical scientists.

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7.4.1 Outputs by gender, race and age

Inevitably, gender and race are important measures of the transformation of South Africa's health and medical sciences community. Of the three fields in health and medical research, public/community health sciences have the largest proportion of women publishers - 43% between 1996 and 2000, and 48% between the years 2001 and 2005 (Table 7.4). While the proportions of female authors in clinical health sciences and basic health sciences are lower than this, there has been a modest increase in female authors in all three fields of health and medical research.

Table 7.5 illustrates the distribution of authors by race. While the classification of authors is not always known (thus limiting the analysis), it is interesting that the proportion of black scientists was roughly the same for all three fields of health and medical sciences (just over 14%) between 1996 and 2000. It is also notable that this proportion had grown by 2001-2005, especially in public/community health sciences, suggesting an increase in activity by black scientists.

An examination of the age of authors reflects an ageing community of publishing medical scientists, in keeping with the trend in all of the sciences (Table 7.6). Between 2001 and 2005, no less than 13% of all authors in the field of clinical health sciences were over the age of 60 years, with neuro-imaging (78%) and gastroenterology and hepatology (46%) the most affected. But a number of other fields also face the same dilemma, with more than 15% of the authors over the age of 60 years, *viz.* cardiac and cardiovascular systems, clinical neurology, dentistry, oral surgery and medicine, dermatology and venereal diseases, haematology, oncology, paediatrics, peripheral vascular disease, radiology, nuclear medicine and medical imaging, rheumatology and toxicology.

Table 7.5: Publications as a function of race and field for the periods 1996-2000 and 2001-05

Fields	1996-2000		2001-2005	
	Total SA authors of known race	% black authors	Total SA authors of known race	% black authors
Clinical health sciences	2 097	14.8%	2 171	17.5%
Basic health sciences	1 094	14.2%	1 286	17.9%
Public/community health sciences	722	14.4%	783	20.8%
Total	**2 672**	**14.9 %**	**2 914**	**18.4%**

Table 7.6: Publications as a function of age and field for the periods 1996-2000 and 2001-05

Fields	1996-2000			2001-2005		
	Total article equivalents by SA authors of known age	% by author <30	% by author 60+	Total article equivalents by SA authors of known age	% by author <30	% by author 60+
Clinical health sciences	2 139.38	3.1%	9.9%	2 160.41	1.9%	13.1%
Basic health sciences	655.06	5.8%	8.1%	749.27	4.2%	10.1%
Public/community health sciences	491.48	4.6%	4.6%	514.93	2.7%	10.1%
Total	**2 830.33**	**3.8%**	**9.4%**	**3 039.80**	**2.5%**	**12.2%**

7.4.2 Quality of South African publications

Mere numbers of publications do not provide an indication of whether South African scientists are making a noteworthy contribution to health and medical knowledge globally. Using citation indexing, one is better able to make the judgement. Overall, South African authors have seen an increase in the average number of citations of their work over the past few years. However, an analysis which compares the citation rates of South African publications with international publications in the same field shows that South African publications had enjoyed above-average field-normalised citation rates for the period 2002 to 2006 in one-third (18) of 54 fields analysed. Of these, 16 were clinical research fields, two were from public/community health, while none were from the basic health sciences. This is clear evidence of the international standing of a large number of South African health and medical scientists.

7.5 Recent research highlights

Many highlights of South African health and medical sciences have been mentioned throughout this chapter. However, it is impossible to mention them all. Notwithstanding this, a few recent highlights bear mentioning.

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7.5.1 The European and Developing Countries Clinical Trials Partnership

One of the most significant endorsements of South Africa's status in health and medical sciences was the unanimous selection in 2004 of the MRC as the host institution for the European and Developing Countries Clinical Trials Partnership in Africa, after a bidding process which included 18 institutions. The partnership was formed to provide funding (some 400 million Euro) for clinical trials research on malaria, tuberculosis and HIV/AIDS.

7.5.2 HIV/AIDS

South Africa's high prevalence of HIV infection and its substantial scientific infrastructure makes it an ideal location for research in this field. Arguably, the most exciting developments in recent years have been in the science of HIV and AIDS. The South African AIDS Vaccine Initiative (SAAVI), which has over two hundred South African-based scientists and technicians working synergistically with colleagues in rich countries, exemplifies the rapid change in the way of working. Not only has it made remarkable progress in the development of several candidate vaccines against HIV/AIDS, but it has also led to the development of modern laboratories where advanced biomedical techniques are employed. Good examples are the Institute for Infectious Disease and Molecular Medicine at UCT and the Doris Duke Medical Research Institute at the University of KwaZulu-Natal (recently respectively augmented by the African Component of the International Centre for Genetic Engineering and Biotechnology (ICGEB) and the KwaZulu-Natal Research Institute for TB and HIV (K-RITH)). By 2005, three vaccine candidate products were going through regulatory processes, and by 2007 a number of clinical trials with vaccines produced elsewhere were underway, with two SAAVI-produced vaccines awaiting approval for Phase I clinical trials. A South African scientist received a World Technology Award for work in this field.
South African researchers have contributed significantly to the field of mother-to-child HIV transmission, exploring key options in evidence-based ways, and providing internationally useful (WHO) guidelines for breast-feeding and the use of anti-retroviral agents.

Another significant effort in South African HIV/AIDS research has focused on the possible use of microbicides in HIV prevention.

7.5.3 Malaria

The dramatic reduction of malaria prevalence by 88% in the Lubombo Spatial Development corridor[7], largely through the efforts of South African scientists, had much to do with the WHO's recommendation

7 The Lubombo Spatial Development Initiative (LSDI) is a tri-lateral government partnership between South Africa, Swaziland and Mozambique, aimed at fostering economic growth in an area broadly defined as Southern Mozambique, eastern Swaziland and north-eastern parts of South Africa. One of the most serious threats to the success of the initiative is malaria.

that residual indoor spraying with dichlorodiphenyltrichloroethane (DDT) be used in regions where the disease is endemic.

7.5.4 Tuberculosis

The Centre of Excellence for TB research, which straddles two university units in South Africa, namely the Molecular Mycobacteriology Research Unit and the Centre for Molecular and Cell Biology, has done significant molecular research which has proved to be of global significance in combating multiple drug resistant (MDR) and extensively drug resistant (XDR) tuberculosis in South Africa and beyond. The Centre for Molecular and Cellular and Cellular Biology has assembled one of the largest collections of TB samples in the world – 8000 drug-sensitive cultures and 3000 drug-resistant cultures.

7.5.5 Biotechnology

An exciting new development in South African science has been the dramatic increase in funding and activity in biotechnology. The national biotechnology audit of 2007 revealed that 78 South African companies were biotechnology active and 38 were core biotechnology companies. About a third were spin-offs, and of these 36% came from government agencies and 28% from universities. Biotechnology-active firms were involved in 1 542 products, while biotechnology core companies were involved with 559 products. A substantial proportion of these derived from, or had application to, the health and medical sciences. Almost 40% of products from non-core biotechnology companies were associated with human health. The aim of the biotechnology regional innovation centres (BRICS) is to deliver useful products for health interventions.

In conclusion, while the highlights of South Africa's health and medical sciences are too numerous to mention, it is clear that the state of health and medical sciences in South Africa reflects a thriving and growing enterprise which augurs well for the country and the continent.

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ORPHANING THE ORPHAN

CHAPTER 8

PETER VALE

“VICTORY HAS MANY FATHERS BUT FAILURE IS AN ORPHAN”

John F Kennedy’s 1961 reworking of Count Ciano’s foreboding of his own death[1] nineteen years earlier has seldom been used in post-apartheid South Africa. The reason is obvious: apartheid’s ending was the seminal moment in the life of a country still less than a century old. This chapter is not concerned with apportioning guilt or advancing congratulations over apartheid and its ending; it is tasked with assessing the current state of the humanities and the social sciences in South Africa. However, the rather obscure opening quotation does have a heuristic point: the human sciences – to use a phrase whose meaning will shortly follow – played a central role in bringing an end to apartheid but have been orphaned, and are now seen as failing post-apartheid South Africa.

Country-specific studies of scholarly disciplines are always risky undertakings. This is especially so in a field such as the humanities. So, four preliminary markers are necessary. First, as far as can be ascertained, this kind of exercise has never been attempted previously in South Africa. One possible reason is that the humanities in the country have traditionally operated within three epistemological niches; two of which were located within language differences, a little like the situation in present-day Belgium; while, the third niche predates apartheid but was deeply influenced by it in paradoxical ways. Second, this chapter will not directly enter the debate around the averred Euro-centricism of both the humanities and the social sciences. Nevertheless, this issue hangs heavily over the argument; South Africa will not be able to escape this conversation and, if anything, this contribution may reinforce the importance of the debate. Third, although mindful of the establishment and development of the humanities in South Africa as opposed to elsewhere, this is not primarily an exercise in comparison. Finally, a careful reading will show that there is no mention of the disciplines of law or education which, in some definitions, fall into the humanities. On these two areas there is, understandably, much to say; South Africa’s new Constitution has opened up a rich debate on social issues which have been touched by almost every facet of the law. Some have, however, stood out and merit a mention – transitionary justice and restorative justice. In contrast, the report-card on education is not as satisfactory. This issue remains one of the country’s biggest challenges, a full thirty-three years after Soweto’s defiant pupils mounted an

1 In his 1942 diary, the Italian diplomat, and son-in-law of Mussolini, Count Caleazzo Ciano (1903-44) wrote “La victoria trova cento padri, e nessuno vuole riconoscere l’insuccesso” (“As always, victory finds a hundred fathers but defeat is always an orphan”). The Ciano Diaries 1939-1943. Vol 2.

insurrection against apartheid education in June, 1976.

The facts and figures in this chapter on the status of the humanities and the social sciences in South Africa cannot be divorced from the profound social and political processes which have completely changed the country but, oddly enough, left many things in place. As social thinkers rediscover every day, this is not unusual. Even the deepest revolutions have left many, in fact most, social issues intact in their wake, confirming Weber's point that *ideas* that aim at change are worn down in the historical process as they are "codified and routinised by interpreters ... [and] ... gradually brought back in line with the *status quo*" (Abromeit, 1994:27). The necessity of bringing South African society back in line follows upon the near-revolutionary moment which the country had reached just before the breaching of the Berlin Wall twenty years ago. The revolt against apartheid, especially the struggle during the 1980s, was embedded within a complex series of ideas and interpretations which had to be filtered by, amongst other influences, those of the Cold War. Through this incomplete optic, local demands for basic human rights took on a distinct insurrectionary tone which generated anti-enlightenment demands, such as 'No Education without Liberation', which now seem to have been counterproductive. In negotiating this world, the humanities played an enormous role, at times by causing the political sphere to pause, but mostly by creating a language of both struggle and emancipation which helped South Africans to see beyond colonialism, apartheid and the Cold War. Without understanding these developments, there is no appreciating the circumstances in which the humanities and social sciences currently find themselves.

And so to a central argument: What has happened to the humanities in South Africa mirrors a global trend. As the American educationalist Sheila Slaughter has suggested,

> [a]cademics in the arts, social sciences and humanities were caught off guard by the rise of neo-liberalism. During the 1960s and 1970s, they had been at the centre of the university, close to the core of the social movements that expanded and changed undergraduate education. However, their … narrative did not compel students, funders, or donors. Undergraduate and graduate students moved to the … professional schools in droves. At many campuses, the arts and sciences became service courses that provided general education courses prior to students' entry into professional schools. (Slaughter, 2007:14)

Today it is common knowledge that the humanities are repeatedly the target of higher education policymakers and planners as well as managers, who seem preoccupied with promoting the so-called 'knowledge economy'. Let this single example from the University of South Africa (UNISA) make the point. In July 2007, the university's College of Humanities announced cut-backs in several departments including African languages, visual arts, community health, and psychology, Italian, Russian and Mod-

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ern Hebrew. Developments like these indicate the increased value accorded to the technical end of knowledge but they also, in Craig Calhoun's words, suggest "a failing" (McQuarrie, 2006:107).

Understanding this situation requires that attention be given to the place of the humanities during apartheid. The intention here is to highlight the rise and the efficacy of a critical discourse and political practice which helped to bring apartheid to its end. Thereafter, consideration will be given to the rise of the technical rationality represented by neo-liberal economics, especially by the reductionist perspective embedded in the idea of globalisation, a marked feature of public policymaking in the post-apartheid years. Both this political history and rise of the technical end of social science will assist in the understanding of the third: an analysis of the trends within the humanities both across, and within institutions and disciplines. The chapter ends with a consideration of some recent attempts to revive the humanities, both within the country as a whole and in institutions committed to this task.

This is an ambitious undertaking given the limited space available here. As a result, the approach adopted follows a 'Thieving Magpie' perspective on social analysis (an idea borrowed from the historian Simon Sharma). This technique enables us to draw illustrations from a range of disciplines in order to illustrate the general points that drive the argument.

8.1 Explaining the humanities in South Africa

In contemporary South Africa, the label 'humanities' is inclusive drawing together the traditionally defined 'humanities', 'social sciences' and the 'arts'. This brand name – to intentionally use the term much-loved by the new generation of university administrators – invariably reflects what Ted Schatzki has called the contingent facts of institutional, cultural, and educational history (Schatzki, 2009:31). It is important to note that the use of this name is recent. Until the 1980s, most South African universities used the label the 'arts' to name faculties which included the 'humanities', while some, but not all, of the country's universities organised the 'social sciences' into separate faculties. These definitional issues will highlight the power of the metropolitan hold on academic organisation in South Africa, and explain how the social sciences, in particular, were used to serve the purpose of modernity in South Africa as, indeed, they have been elsewhere.

Given that South Africa was founded within a "network of imperial knowledge" (Dubow, 2006:14), it is not surprising that the separation between the natural sciences and the humanities has been the primary feature of the country's knowledge system. Nevertheless, from the very earliest days the humanities were valued – certainly, early university leadership was provided by those who had trained in the field. An instructive example was Jan Hofmeyr, who was appointed the first principal of the University of the Witwatersrand at the age of twenty-four. After graduating with an MA degree from the University of Cape Town (UCT) at the age of fifteen, Hofmeyr read classics and 'greats' at Balliol College, Oxford, as a Rhodes Scholar. The post of university principal was to be the prodigy's first real job. Hofmeyr went on to become theadministrator of a province and was a very effective Minister of Finance and of Education. A love of the humanities, however, never left him; when he died, aged fifty-four, he bequeathed money to the University of the Witwatersrand conditional upon the Chair of Classics being named after him. Most importantly for these immediate purposes, the fact that the university in question was previously called 'The South African School of Mines' suggests that in 1920 it was thought that the excesses of the 'hard' sciences might need to be tamed by the 'soft' ones.

The temptation of American-style 'social *sciences*', with their liberal confidence in the receptiveness of human problems to intervention, proved difficult to resist, however. In 1927, the president and secretary of the Carnegie Corporation of New York visited South Africa, and their interest was drawn to the problem of white poverty in the country. Amongst those who were to join the staff of *The Carnegie Commission Report into White Poverty in South Africa* was EG Malherbe, son of a Dutch Reformed Minister[2], who had taken a Doctorate at Columbia University's Teachers' College. Malherbe was a ready champion of applied social science and was unafraid of tackling sensitive issues such as ethnicity and race. He would go on to direct the Bureau for Educational and Social Research (a prototype for the Human Sciences Research Council (HSRC), which was established in 1969 and continues life in post-apartheid South Africa – see below). But it was the professionalisation of the social sciences in the country which was his lasting contribution. The founding of a Faculty of Social Science at Rhodes University in 1930 was a response to a request from the National Council of Women which had called for the creation of a Bachelors Degree in Social Studies. In the midst of the Great Depression, the goal was training social workers, something that followed upon the professionalisation of this discipline in Britain and the United States. Indeed, the Carnegie Commission's Report, which appeared in 1932, recommended the creation of further training sites for social workers. The University of the Witwatersrand began this training in 1937 after an internal university memorandum from the liberal philosopher Professor RFA Hoernlé urging its necessity "for the development of the scientific study of social problems and the university training of students to deal practically with these problems from a scientific perspective" (Ross, 2007:1).

Professionalisation was only one aspect of the complex goals of social science in what Daniel Lerner later described as "Modernising Lands" (Lerner, 1959:32). It reflected

2 A family of Dutch Reformed Churches are seen by some as playing a major role in the implementation of apartheid. These are the progeny of the Reformed Churches which was brought to South Africa by the Dutch East India Company in 1652. A majority of Afrikaners continued to be members of the three strains of reformed thinking. In 1997 the reformed churches apologised for their role in apartheid before the country's Truth and Reconciliation Commission.

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what Dubow calls "the international vogue for expert knowledge, quantification and the pursuit of social efficiency" (Dubow, 2006: 7). It is not therefore surprising that Rhodes University, in the early 1960s, was able to claim that the

> scientific knowledge of social phenomena is important for an understanding of the contemporary world. The emergence of social, economic, racial and psychological problems has brought into being specialised services requiring trained personnel with a sound knowledge of the various social sciences such as Sociology, Economics, Anthropology and Psychology, and other fields of a cognate nature. (Rhodes University Calendar, 1961: Chapter XX)

The very idea of a 'science of the social' raises questions around the purpose of knowing, and while it is not necessary to plumb these deep waters on this occasion, it is worth noting that many have suggested that the intent is not so much to advance knowledge (by exploring that which is not yet known), but rather, to discipline the social world. So, the basic task of the social sciences – which, along with those already mentioned, including political science – may well have been to assist authorities "to get a firmer grip on the existing social order" (Parenti, 2006:502).

Given South Africa's social complexity and the continuous political struggle for the country, it should be no surprise that the social sciences in South Africa reflected this dark side. In intellectual circles, mainly (but not exclusively) those of the country's Afrikaners[3], the social sciences were often associated with the strengthening of racial ideology. One faux-discipline, known as *volkekunde*, played a decisive role in what Robert Gordon has called "the legitimating and reproduction of the apartheid social order on two levels: as an instrument of control and as a means of rationalising it" (Gordon, 1988: 536). Succinctly put, this approach to anthropology positioned the social category of race at the centre of its epistemology and, with time and the use of official resources, this view of the social cosmos rendered all alternative positions to be outside accepted routines of scholarship sanctioned by people, party and state. Nor was this an isolated case of ideology corroding knowledge. Consider the discipline of international relations, first taught in a separate academic department at the University of the Witwatersrand in 1963.

During the apartheid years, positivist approaches to thinking about the international became trapped within Cold War logic. With time, this "modern counter-enlightenment" – to use Nicolas Guilhot's recent description of early approaches to this discipline (Guilhot, 2008:284) – had penetrated the very fabric of national life and extended

3 Afrikaners are South Africa's largest white minority, who speak Afrikaans, which is a loose derivative of Dutch. Throughout the 20th Century they dominated the country's constitutional politics and, as such, were the backbone of the support for apartheid.

beyond the country's immediate borders where, mingling with apartheid's racial ideology, it caused death and destruction throughout the southern Africa region.

These two examples highlight the difficulties in describing the humanities (which includes, in the current understanding, the social sciences) in a deeply divided society like South Africa. As noted previously, however, there has not been one, but a number, of approaches to knowledge within the country – each of which pursued separate epistemological niches, each drawn from (and contributing to) separate cultures. Because they are so integral to the development of the humanities and the social sciences in post-apartheid South Africa it is necessary to describe these – albeit briefly.

Three waves of knowledge-making – 'Liberal/English', 'Nationalist/Afrikaner' and 'Pan-African' – marked the path of the humanities in South Africa. The first of these descriptors are akin to the standard liberal rendition of apartheid history, and reflect the stance of these categories towards apartheid. So, the liberal or English-medium universities (Cape Town, Witwatersrand, Natal (now called KwaZulu-Natal) and Rhodes) readily embraced the idea of admitting students of all races. Although their enthusiasm for this approach to education was somewhat uneven, this choice flew in the face of apartheid policy, particularly of two notorious pieces of legislation: the Separate University Education Bill of 1957, and the Extension of University Education Act, *Act 45 of 1959*. Cumulatively, these pieces of legislation made the issue of race the only criterion for admission to higher education.

The cultural roots of the so-called liberal universities drew them towards Oxbridge even though (as with all the country's universities) they were originally dependent on the University of London for the issuing of their degrees. In their academic programmes and their administrative form they were closer to the Scottish university tradition, however. These affinities strongly influenced the early organisation and the content of the humanities, the arts and the social sciences, and the intellectual hold of the cultural/academic metropole – especially that of 'the golden triangle' of Cambridge, Oxford and London. Arguably, the latter was broken only by the intellectual ferment (and the progressive politics) which followed upon the establishment of the University of Sussex in 1961. A number of South Africans, who were to make a deep impression on the humanities in the 1970s and the 1980s, did postgraduate work at Sussex; it was from the same place that the country's second democratically elected President, Thabo Mbeki, graduated with an MA in economics from the School of Social Studies.

Lawrence Wright has described South African English-speaking universities as instruments for "transmitting metropolitan knowledge and excitement in a colonial situation" (Wright, 2006:73). The resulting sense of inferiority – the 'cultural cringe' as the Australian AS Philips famously called it – slowed the indigenisation of the humanities in these institutions. Rarely was there any desire to challenge the metropolitan-determined paradigm. A number of inspiring teachers did challenge the *status quo* by instilling what the late Richard Rorty called

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"doubts in the students … about the society to which they belong" (Rorty, 1999:127). These departures were sometimes less epistemological in their purpose than they were openly political, and, interestingly, they drew more from European ideas than British ones. So, in the early 1970s, the University of the Witwatersrand experienced a strong critical surge in disciplines like political studies, African studies and anthropology. This exposed students to Habermasian critical theory and French post-structuralism. One particular course, called 'Freedom and Authority', was almost entirely devoted to a consideration of the work of Hannah Arendt. But these dissenting approaches were not readily accepted. Academics and students who pursued them were often censured both within and without the university walls. Some, like Dr Rick Turner, were less fortunate. In early January 1978, the political scientist-cum-labour activist was assassinated in the port city of Durban.

By nurturing the idea that the university should offer the fruit of its labour to the building of a nation ('die volk'), the country's Afrikaans-speaking institutions faced restrictions of their own epistemological making. However, their success in achieving their political goals may explain why it is that the traditional Afrikaans universities continue to be associated with the legitimacy they offered to apartheid. These are Stellenbosch, Pretoria, Potchefstroom University for Higher Christian Education (now called the University of the North-West), Orange Free State (now the University of the Free State); and later, the Rand Afrikaans University (now the University of Johannesburg), the University of Port Elizabeth (now the Nelson Mandela Metropolitan University) and UNISA). The oldest of these institutions, situated in the town of Stellenbosch, from which it draws its name, began as a Theological Seminary in 1863. An arts department was added in 1873 when professors were appointed to teach classics and English literature and mathematics and physical science. The arts department received its Charter from the Cape Parliament and, together with the seminary, became known as the Stellenbosch College. However, in 1877 – the Jubilee Year of Queen Victoria – its name, with Royal consent, was again changed – this time to the Victoria College of Stellenbosch. The University Act replacing the latter with the name Stellenbosch University came into effect in early April 1918.

This example confirms that South Africa's Afrikaans-medium universities were in fact also closely tied to the British tradition. As a result (and ironically) their origins were more diverse than those of their English counterparts; Pretoria University, for instance, commenced instruction in the English language, switching to Afrikaans a full twenty-three years after its founding in 1908. But their search for deeper involvement with Afrikaner nationalism, which commenced in the early 1900s, inexorably drew them on a different trajectory and this change in direction was speeded by their links to European universities. The Dutch were a strong influence; Leiden University graduated successive generations of Afrikaner lawyers, while Utrecht made an early impact on the study of theology. The University of the Orange Free State (now called the University of the Free State) was founded in 1904; its first principal, Johannes Brill, had graduated in classics from Utrecht where his father had been a professor.

But the European impact was most strongly felt in the 1930s and 1940s, when the German universities, in particular, were an important source of succour and support. Of crucial importance to this direction was the idea of a 'volksuniversiteit' – defined by the intellectual, Merwe Scholtz, as "a university which belongs to the *volk* and must therefore be of the *volk*, out of the *volk* and for the *volk*, anchored in its traditions and fired by the desire to serve the *volk* in accordance with its own view of life" (Degenaar, 1977:152). The intellectual and academic leader Jonathan Jansen has recently written *Knowledge in the Blood*, a powerful book on the legacy of this approach, which graphically captures the embeddedness of this perspective. In this nationalist project, the humanities were to play a crucial role: scarcely any of its sub-disciplines did not help to encourage the idea that a university education instilled in the student the notion of 'being bound to the people' (Degenaar, 1977:156). As we have already noted, the faux-anthropology, volkekunde, was important but so, too, was the discipline of history: a distinctive feature of this "scientific historical writing" – almost all of it in the Afrikaans language – was "that the conception of the past is based on the point of view of the Afrikaner" (Van Jaarsveld, 1964:135). Approaches represented by this "Afrikaner-centred" perspective on the humanities are drawn together in three volumes entitled *Kultuurgeskiedenis van die Afrikaner*[4], which were published over a five-year period.

It was through the Carnegie Commission's intervention that the importance of social science in building an Afrikaner nation became clear. The researchers in the investigation were drawn from both language groups, and amongst them was a young sociologist, HF Verwoerd, who used his involvement in the project to build a career successively in the academy, journalism and politics. Born in the Netherlands, Verwoerd was to become apartheid's leading intellectual and, before his assassination in 1966, was Prime Minister of the country. To date, Verwoerd has been the only South African head of state to have taken a Doctorate.

Given apartheid's grand vision of separating the races, it might be thought South Africa's other university tradition, the black (or in apartheid nomenclature, homeland[5]) institutions, would escape the narrowing strictures of the volksuniversiteit idea. But this was not to be the case. The oldest of these universities, the University of Fort Hare (UFH) (initially called The South African Native College), was founded in the enlightenment tradition by Scots Missionaries in 1916. In 1946, it gained semi-autonomous status with its degrees issued under the supervision of neighbouring Rhodes University. But UFH was far more than this

4 Translate as the Cultural History of the Afrikaner.
5 Homelands or Bantustans were areas set aside for the exclusive occupation of South Africa's black majority. The idea was that these places would cater for the national aspirations of the country's majority through the excise of their ethnic or tribal rights. The Bantustan policy was a cornerstone of apartheid.

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mundane and linear account suggests. It was here that Nelson Mandela and other leaders had both studied and honed the politics that would help to free their country. As a student in the humanities, Mandela, who organised a boycott, was expelled by the College's Principal during his final year of study.

While, the institution's formal academic and intellectual authority was largely destroyed by the 1959 Universities Act, its social and political capital remained intact notwithstanding the state's harrowing assault. The Act established four new universities for 'non-whites', to use the language of the legislation. These were the University of Zululand, the University of the Western Cape, the University of Durban-Westville, and the University of the North. With the attack on UFH came a parallel destruction of a number of revered missionary schools, such as Healdtown, Lovedale, St Marks to name only a few, that had fostered a generation of leaders of which Nelson Mandela is undoubtedly the most famous. In his autobiography, Mandela describes the impression made on him by a visit to Healdtown by the Xhosa poet, SEK Mqhayi.

As apartheid's grip on these institutions tightened, Afrikaner-Nationalist[6] academics were circulated through these tribal colleges, as they were also known, with the best of these being drawn back into the mainstream Afrikaner universities after a few years. The result was that the reach of the humanities – certainly in the classroom – was narrow and restricted. Syllabi were somewhat formal and often very contradictory: for example, at UFH in the 1970s, the political science syllabus was uncritically preoccupied with modernisation theory. While this pedagogy was taking place, the institution was, as Xolela Mangcu argues, "a cauldron of radical student politics" (Mangcu, 2008.24), and Mtutuzeli Matshoba recalled that he heard "the leading Black Consciousness figures including Strinivasa Moodley and Steve Biko, give inspirational talks at Fort Hare University in the early 1970s" (McDonald, 2009.327).

Administratively, too, these institutions were tightly controlled; mostly, ideologues were appointed to leadership positions and their budgets were drawn, not from the national education budget, but from that of the state department which was designated to deal with black affairs. For almost a decade and a half, these institutions seemed to be formally positioned outside the struggle for their rights in which the other university traditions seemed all too self-righteously engaged. This apparent marginalisation, and whispers over the question of standards, especially in the humanities, denied them the formal voice to defend themselves against their rightfully angry students and the apartheid government.

6 The ideology which sought to unite Afrikaans-speaking whites with a sense of their own ethnic identity in order to win political power though the National Party.

But outside the country, South African exiles, including the sociologist Ben Magubane and the anthropologist Archie Mafeje, were reinforcing a long-established critical tradition which apartheid simply denied. These scholars not only made deep contributions to both the humanities and the social sciences, but by challenging apartheid policy called into question the Westernesque epistemologies that were used in framing the very question of modernity. This work drew on a still-to-be-fully-explored intellectual tradition that reached back to the origins of Pan-Africanist thinking with its "concern for the emancipation of the continent from the ravages of foreign domination and underdevelopment and … (towards)…the building of a new Africa" (Mkandawire, 2005.2). In South Africa, this can be dated to the early-1880s with the founding of the first secular newspaper *Imvo Zababantusundu*[7] by John Tengo Jabavu. With an emancipatory impulse at its centre, this trajectory was continued by John Langalibalele Dube (author of the first Zulu language novel), R V Selope Thema (journalist, editor, historian), Pixley ka Isaka Seme (a Columbia and Oxford-trained lawyer and journalist), and Solomon T Plaatje (linguist, journalist and author). With other organic intellectuals, these men helped to launch the anti-tribalist New African Movement in 1904-6 and, in 1912, the African National Congress[8].

Although a remarkable community, history seems to have judged them harshly for their inability to look beyond the local and the parochial. However, their work continued in the 1940s in the writings and debates of HIE Dhlomo, a major figure in South African literature, Benedict Wallet Vilakazi, novelist, educator and the first black South African to receive a PhD and Jordan Ngubane, who was a journalist novelist.

The tri-focal optic used in this analysis needs, however, to be drawn together to gain a sense of the contradictory state of South African humanities in the early 1970s. An American political scientist then living in South Africa, John Seiler, offered a depressing assessment of the state of the country's international relations community of those times, which might be viewed as a reflection of the moribund state of some of the social sciences near four decades ago. "The published work", Seiler wrote,

> [t]ends to be justificatory, rather than analytical; often contains a moralising, or even specifically religious content; and shows a penchant for thoroughness, which is explicable by a notion of 'science', which is often no more than an unquestioning and uncritical search for and regurgitation of authoritative sources. Since the authorities turned to reflect these same characteristics, there is a repetitious resonance (Seiler, 1973:37).

7 Translate as Native Opinion.

8 Known by its initials, ANC, this is the party of Nelson Mandela and the governing party of South Africa. It was formed in 1912 and is the oldest political organisation in the country. It was banned for almost 50 years and operated both clandestinely and from exile.

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But beneath the arid surface that Seiler described, the ground was shifting, as the facet of the humanities most difficult to pin down – the interface between theory and practice – underwent a profound change. Although John Seiler had read the works of Sol Plaatje, he seems to have missed the shifting ground of which anti-assimilationists would have approved. Provisionally, two possible reasons for this may be suggested. First, state censorship kept much of the emerging literature underground and, second, his positivist instincts (and training) may well have kept his analysis within water-tight compartments.

But reflecting later on the changes which were then underway, sociologist Ari Sitas speaks of an "indigenous hybridity" (Sitas, 1997:16) which marked the radical intellectual formations of those years. "What can be traced", he writes,

> as an intellectual formation started being developed outside and despite University 'disciplinarities'. What started from the early 1970s onwards through marginal and harassed groupings of left intellectuals, white and black, was a social discourse which had a normative and political foundation…(this)a formation … provided the cultural levers to prize open departments and disciplinary fields of inquiry…(by promoting)…… narratives of emancipation…animated by egalitarian norms (Sitas, 1997:13).

The diversity within this new formation included not just white, left-inclined academics and students, but also intellectuals linked to the Black Consciousness Movement (BCM), which was founded in 1972 by a young medical student, Steven Bantu Biko, who would also die at apartheid's hands and whose legacy will linger forever in the humanities and, indeed, the country. These developments were to position the humanities at the centre of the university and the country in the 1980s. But, to explain this, it is necessary to return to intellectual history.

8.2 Discovering what will set you free

After World War II, liberal interpretations of South Africa's deepening racial quagmire argued that continued white domination undermined capitalist development and stifled economic growth – this, the argument ran, subverted any hope of social emancipation. The approach was exemplified in the two-volume *The Oxford History of South Africa* edited by Monica Wilson and Leonard Thompson. However, as soon as it appeared, a number of scholars, including South African exiles and émigrés, attacked the work of this 'Liberal School' of Southern African Studies. The 'New School' instead argued that racial domination was integral to the functioning of the South African economy. The most widely cited of this work is an article by Harold Wolpe, a lawyer turned sociologist, which argued that the [African] Reserves (later called the Bantustans), by preserving limited access to agricultural land by the families of black migrant labourers, subsidised urban wages and therefore served as a source of cheap black labour for industrial and mining capital.

The influence of the new thinking was immediately felt in the country's (still largely white) English-language universities. Its march, and the simultaneous re-activation of work-based and community-based organisations during the 1970s, enhanced a Marxist explanation of South African events and drew social theory and political practice closer. This was seen in the role played by intellectuals – academics and students, mainly – in the formation of black trade union movements in Durban and later in the country's financial capital Johannesburg and Cape Town, which is called the country's Mother City. The leading figure in this intellectual-activism was the Sorbonne-trained Rick Turner, whose name has already been mentioned. This is not the occasion to discuss Turner's life's work – neither his activism nor his writing – but it is necessary to note that long after his death, his ideas continue to inform many South African debates. We must however turn to the influence of the Western Marxism which inspired him, to appreciate the role of the humanities in South Africa's political change.

Two main perspectives and one theme emerged during early years of this 'Kuhnian revolution' in South African studies (Jubber, 1983:54). The sociologist Wilmot James called the two sides of the divide 'social history' and 'historical sociology'. The second issue, the thematic focus, was directed towards the study of labour – here the work of the sociologist Eddie Webster stands out. Unfortunately, there is no space here to discuss Webster's work and the profound effect he (and others) have had on the development of labour activism. This work, however, is in the case study mould, in which theory and practice are drawn together in a single emancipatory project.

The 'social historians' were associated with the work of London University's Institute of Commonwealth Studies, which, in the 1970s and into the 1980s, was directed by the South African-born historian Shula Marks. But the form and influence of this stream is best appreciated through the writing of the historian Charles van Onselen – especially his two-volume *Studies in the Social and Economic History of the Witwatersrand*. This approach to understanding South Africa's past, its present and its future was widely disseminated throughout the South African academy by the Annual History Workshop at Johannesburg's University of Witwatersrand. The cohort stressed social agency, and sought to reconstruct understandings of the country's history through sensitivities to the activities and practices of the country's popular classes. The other thread of Marxist thinking, as noted previously, was historical sociology: here the leading figure was Harold Wolpe; other members included the Canadian sociologist Frederick Johnstone and another exiled South African historian, Martin Legassick. They represented the structuralist tradition in sociology and, with time, their writing was

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strongly influenced by Nicos Poulantzas, whose impact was evident in the work of a second generation of South African writers.

A few further comments on this 'Marxist Moment' are required to round the point out. Generally speaking, South African Marxists were known for their parochialism and for treating racial domination in South African society as exceptional. But it was Belinda Bozzoli who raised the most difficult (if not embarrassing) concerns about South African Marxism by claiming that "[w]hat South African reality could demonstrate to the intellectual world has increasingly been pushed aside in favour of what that world can tell us about South African reality" (Bozzoli, 1981:54). This critique is a timely reminder of the hold of metropolitan thought over the development of the humanities in the country. Evidence of this was to emerge elsewhere too. Tracing a century of development of the social sciences at UCT, Ken Jubber suggested that, in terms of what was taught, the institution was like a 'displaced British university' (Jubber, 1983:58). But, whatever its lack of local authenticity, the Marxist Moment did raise questions far beyond mundane disciplinary debates, as the following example indicates: "What is this new South Africa we are working for?" a former Professor of Afrikaans literature and a Vice-Chancellor asked in the 1980s. "We are trying to find out. The … liberals … are geared for capitalism. We research alternatives" (Crary, 1988). Undoubtedly, then, the Marxist Moment sparked intense debates within and without the academy. Looking back on those times, the acclaimed South African historian Charles van Onselen called them "the most exciting two decades in the social sciences … [and the humanities] … in this country" (Van Onselen, 2004).

But the deep epistemic break – as Foucault called the moment when the unthinkable becomes thinkable – lay in the much-researched, but poorly understood, issue of race. The question, put in crude terms, was this: Who were South Africans? Were they, as the country's English-speakers claimed, bearers of the liberal heritage of imperial power? Were they, as Afrikaners hoped, an anointed European volk in Africa? Were they, as more crude Marxists often declared, an exploited proletariat on the periphery of a capitalist world? Or were they, as Pan-Africanists might have argued, colonised minds waiting emancipation in order to contribute to the rise of a new Africa?

Of course, South Africans were all of these, and none of them. The country was a community-in-the-making – to use Benedict Anderson's iconic idea of the nation as an 'imagined community' – and its making was contingent on the assumptions upon which thinking was provided by the humanities. But accepting the inherent instability of this idea was not possible within the dominant scientistic formulations that promised permanence and predictability. Drawing upon the writing of the Martinique intellectual Frantz Fanon, Steve Biko broke the impasse by famously declaring: "Black man, you're on your own" (Biko, 1978:97). This, the idea of Black Consciousness, was a fresh framing of South Africa's deepest social issue and, as importantly, its framing was not wholly anchored in metropolitan ideas. The body of this approach to social relations was forcefully drawn into an analysis of racism by the psychologist, Chabani Manganyi's 1973 book *Being Black in the World*. Its impact outside of its obvious political setting was profound because, as Biko had argued:

> The call for Black Consciousness is the most positive call to come from any group in the black world for a long time. It is more than just a reactionary rejection of whites by blacks…The philosophy of Black Consciousness …expresses group pride and determination by blacks to rise and attain the envisaged self. At the heart of this kind of thinking is the realisation by the blacks that the most potent weapon in the hands of the oppressor is the mind of the oppressed (Biko, 1978:149).

This thinking had been brought to the humanities in South Africa by what was later (recklessly called) global change. The colonialism which had given birth to the very idea of South Africa was changing, and Pan-Africanism was emerging as a powerful social idea. In the United States a new form of nationalism – which affirmed blackness, black pride, black solidarity, and (in some cases) argued for no alliances with white activists – was on the rise. But other influences were of longer duration: the *Négritude* movement of Léopold Sédar Senghor and Aimé Césaire, Frantz Fanon, and the music of artists like Nina Simone (notably, her track "To be young, gifted, and black").

In South Africa there were clear antecedents for Black Consciousness in Africanist movements of earlier periods which we have already considered, and which were identifiable with figures like Nelson Mandela and Oliver Tambo[9], and the Pan-African Congress[10].

As the appeal of Black Consciousness widened, the country's majority – confident of their ownership and power – played an increasing role in setting political and, indeed, intellectual agendas. Our immediate interest is in the second, so we must record that in the field of English literature, David Attwell points out that the resulting upheaval marked "a serious rift … between liberalism and radicalism" (Attwell, 2005:138).

If the rise of Black Consciousness formed one of the strategic wedges that brought apartheid to an end, another came from within Afrikaner ranks where, over time, intellectuals abandoned the ideology. Understandably, this did great damage to the idea of the *volksuniversiteit* and freed up room for adventure in the humanities – but breaking away was not easy. In a convoluted fashion, the acclaimed poet NP van Wyk Louw described how difficult it was to escape the gravitational pull of Afrikaner nationalism. Effective criticism, he argued, "emerges when the critic places himself in the midst of the group he criticises, when he knows that he is bound unbreakably

9 Close friend and confidant of Nelson Mandela. They both studied at the UFH and set up a legal partnership in Johannesburg. Tambo left for Lusaka, Zambia, in 1960 to set up the ANC in exile. He was the organisation's President during his years in exile. Tambo died in South Africa in 1994 shortly before the ANC was elected to power.

10 A political movement which was established in 1959 as a breakaway movement from the ANC; it was established by Robert Sobukwe, a leading intellectual. The PAC (as it is known) supported Pan-Africanism and was greatly influenced by anti-colonial movements elsewhere on the continent.

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… to the *volk* he dares rebuke" (Saunders, 2002:62). Although this 'loyale verset' – or loyal dissent – was the early form of break-out, eventually Afrikaner intellectuals were more daring. Another poet, the intellectual and activist Breyten Breytenbach, who was jailed for high treason in the early 1970s, was the most famous example of rebellion. But the real revolt by Afrikaners came as apartheid was collapsing in the 1980s, and in this the humanities – in literature, in music, in journalism, especially amongst the young – turned away from all that had gone before.

8.3 A new beginning

Although it was plain that the politics which underpinned apartheid were unsustainable, few predicted that 'New South Africa' would enthusiastically and so quickly embrace a new form of social conformity. This is not to suggest that those in humanities had no interest in, or concern for, the issue of liberation: indeed, this chapter has argued the very opposite view, namely, that they were at the forefront. Cumulatively, this energy was imagining a new society which was everything that apartheid was not. The form on offer was citizenship free of the fear and discrimination that had marked the country's unhappy past. It is necessary here to point out that at this time there was a deepening nexus between the humanities – especially in their critical form – and the world of policy. This emerging narrative was imbued with the enlightenment values that for two centuries had inspired the growth and the flourishing of the humanities throughout the world and from which South Africa, from the beginnings of apartheid, had increasingly been excluded through academic boycotts and the like.

As the struggle for South Africa intensified, much of the Marxist thought which has been discussed here (and its relevance for the country and its future) became acerbic and debased. In the politically charged atmosphere of the mid- and late-1980s, political rhetoric was heady and often by-passed open and free discussion. As a result, not a little vulgar thinking found its way into the curricula in all of South Africa's universities, with the humanities frequently acting as simple vehicles for political struggle. Quite rightly, these distortions were criticised, but it took a decade to realise the damage that was done during these years. But, in responsible places, the drawing together of theory and practice which had marked the humanities in the 1970s had reached an interesting point. So, with apartheid on the verge of collapse, and following the release from prison of Nelson Mandela, the American sociologist Michael Burawoy visited the country and glowingly wrote that "everywhere there were sociologists [and other academics] acting as organic intellectuals of the home-grown liberation movements" (Burawoy, 2004a:11). In the early 1990s the humanities in South Africa seemed all but on the edge of an age of retreat.

Ten years later, all this had changed, as research into the 'employment prospects' for graduates attested.

> The employability picture is bleaker for graduates from the faculty of humanities. Commenting on learners' chances of obtaining a job after graduation, deans said: `not anything significant', `not with the current programmes' and `not widespread within the faculty'. They realised that, so far, the programmes offered in their faculties are less demanded by employers and have a lower exchange rate in the market place, which puts students at a disadvantage. University funding for the faculties of humanities is yearly being reduced while funding for faculties that promise to produce more employable graduates is increased, so efforts are being made to turn the situation around. Innovative programmes like communication science and sport development are being introduced and strengthened (Maharasoa and Hay, 2001).

Formulating the answer to the question of what had happened provides a window on the humanities in the post-apartheid years. It is a story of confusion, of lost opportunities, of crass instrumentalism and power-point managerialism, of government pressure, and, not surprisingly, of despair. But it is also the story of resistance, of rebirth, of renewal and of rediscovery – all the features which place the humanities at the very centre of the human experience.

The explanation begins with the issue of timing. The end of apartheid occurred at a moment of enormous international change. The fall of the Berlin Wall paved the way for the collapse of Socialism, entirely removing those Archimedean points of reference – east and west – that had dominated thinking about the social world for forty years. In important, though as yet undocumented ways, the apartheid experiment was over-shadowed by the Cold War and, as has been seen, individual disciplines often lent themselves to its ideology. In the changing South Africa the contest over ideas about the social world was heightened by increasing violence, which was linked to the deepening political contestation. The holding power of the Marxist Moment quickly disappeared for two reasons. First, the collapse of the socialist states compelled political and social discourses to engage with neo-liberal social thought, which had been wholly ignored. Second, there was a flight of intellectuals from the academy towards policy research, consultancy or into the institutions of the state.

As a result, the increased influence of (what some called) 'the change-industry' used the self-styled ideas around 'freedom', on offer by free-market economics, to hone and stabilise an imaginary visioning of a 'New South Africa' based on the idea that history had ended with the fall of the Berlin Wall. This Hegelian-centred argument embraced the idea that liberal-democracy had emerged as the most desirable form of

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government, finally overcoming the challenge of Fascism (of which apartheid was a variant) and Communism (which had been embraced by many in the country's liberation movement). Public discourse was dominated by the idea that economics (especially its neo-liberal variant) had been at the centre of political change in the country. This was a return to the liberal logic of the post-Second World War world which, as illustrated, had been dislodged by the rise of Marxist thinking. In this narrative, the humanities had no place; indeed, the critical ideas that they fostered were threatening to the 'new order' under construction.

As this idea took hold, the promise of the enlightenment slipped further and further away from its open-endedness towards a vision of the future that rested on economics alone. These departures from the post-apartheid state's anticipated destination were often sponsored by northern institutions that were keen to see that South Africa should not deviate from the emerging consensus that there was no alternative to market-driven capitalism. In real ways, this outcome echoed earlier moments in the country's development. In his book on the history of scientific and social knowledge in South Africa, Saul Dubow repeatedly suggests that science in the country was flattered by "the glow of metropolitan attention" (Dubow, 2006:14-15). He goes on to argue that the requirements of its science "were often articulated in terms of the country's international standing or ... (economic)... competitiveness" (Dubow, 2006:198). After the end of apartheid, a deepening subservience to homogenising clichés like 'international best practice' in economic practice closed out any possibility that the local could offer anything fresh, or interesting, unless it had been approved by the metropolitan gaze.

The importation and appropriation of market fundamentalism was a re-run of the past horror for the humanities, because the approach passively accepted – as apartheid had once done with the question of race – a condition which should have been subjected to intellectual scrutiny and critique. Especially materially, but also methodologically, it was less and less possible to offer essential critique. Consider, as an example, the issue of method. The country witnessed a remarkable growth in the popularity of scenario-building – a reductionist approach to understanding social futures which is culled from management studies. Structured scenario-building exercises compress the possible futures which might be created from the social world into sound-bites which, when strung together, sketch a future which is predetermined and can only be mediated by market forces and its political twin, liberal democracy – a return to the 'end of history' thesis. Through this kind of reductionism, the arts, the critical social sciences – the humanities, in general – were increasingly regarded as superfluous to the imperative of exercising 'rational social choice' in the interests of a single outcome: economic growth.

This, of course, was the same intellectual pattern which makes up the popular master narrative called globalisation. Given the intensity of theoretical questioning that had once marked the humanities in South

Africa, it was remarkable that this idea was accepted as a social fact, as the country's only possible destination. By failing to raise questions, the humanities (both in South Africa and elsewhere) have paid a high price for the creation of what Emma Rothschild calls a "society of universal commerce" (Rothschild, 2002:250). One of these costs Vrinda Nabar has described as the view that "the humanities and languages are unnecessary indulgences" (Furedi, 2004:3).

This thinking, which has by now permeated deep into South African society, will now occupy our attention. Consider schooling: private schools report the view that parents assess education in investment terms, with the idea of 'value for money' playing a strong role; most want their children prepared for a 'lucrative career' and believe that the humanities will not equip their children for this trajectory. At the public end of schooling, the legacy of apartheid continues to blight the lives – and individual prospects – of the majority of the country's population. Teaching is poor, facilities inadequate, and access to the social capital essential for higher education is largely lacking. Within the universities, the humanities are largely charged with setting right these structural failings. In addition, the newly introduced 'outcomes-based' school curriculum is prescriptive: every pupil is compelled to do a mathematics course in the final three grades of school. Other compulsory subjects are English, a first additional language and a course called 'life orientation'. This leaves only three subjects to choose from to complete the total of seven. It is, therefore, not always easy to achieve a desirable balance between the sciences and the humanities. In addition, because they are considered to be an 'easy option' – even amongst the ranks of university recruiters – the bulk of poorly prepared students enter the humanities.

These issues are exacerbated by a public discourse which is unidirectional. The importance of mathematics, science and technology is a constant theme: their case is often highlighted by government spokespeople, by the business community and by think-tanks and public policy experts – the last two of which groupings seem entirely dominated by economists. Few examples of humanities-trained successes in the everyday world of commercial or industrial work are considered. In addition, television programmes, especially soap operas and sitcoms, depict characters with high-powered careers, usually in the field of business, which guarantee an affluent lifestyle. The value of a humanities education is seldom emphasised.

In general, these realities have expressed themselves in student growth rates in humanities that are substantially below the growth rates in total numbers of students, dominated by a fall-off in humanities students in the early- and mid-1990s.

Within the higher education system, planning has forced South Africa's government to use the national purse to steer higher education towards the market. So, for more than a decade, the national subsidy for producing a humanities graduate was less than that of a graduate in other disciplines. The rationale for this decision (only partly based on costs of instruction) were also partly pure public-choice theory: a gradu-

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ate in either science or commerce would help to 'grow the economy' while the value of a graduate in the humanities could be measured within the logic of economic rationality. This approach of course disregarded Edward Ayers's assertion that the "humanities are intrinsically inefficient" and that training in the humanities did "not obviously translate into the requirements for a first job" (Ayers, 2009:30). A new funding formula, which came into effect in 2004, changed this evaluative balance somewhat. The subsidy is now calculated according to the field of study (in a simple funding grid where most of the subjects in humanities are in the lowest-yielding category), as well as the level of the degree – so, a Bachelor's degree has less weighting than a Master's degree, which in turn is less than that of a Doctorate. This funding system is based on the input costs of training rather than on the output benefit to the economy. This has certainly increased the 'returns' – to intentionally use the accounting term – but the money available for humanities is still much less than it is for science fields.

Within the university funding formula, research outputs are rewarded by a cash payout to the author's respective home institution. The greater weighting of these rewards is for research which is published in academic journals, with books and especially book chapters generally yielding lower 'returns'. While some efforts are underway to repair this situation, there is an overall lack of appreciation of the deep scholarship necessary in the writing of a peer-reviewed book, which in turn shows a lack of understanding of the humanities on the part of policy steeped in free market thinking. This said, statistical and bibliometric evidence suggests that the humanities and social sciences (here the definition includes education) account for approximately 40% of all output in accredited journals in South Africa. However, this work chiefly appears in local journals which are not ISI-indexed and therefore not internationally recognised – interestingly, this outcome is a mirror of that in the natural and health sciences. When measured against ten similar science systems (Argentina, Brazil, Chile, Egypt, Malaysia, Mexico, Portugal, Singapore, Spain and Turkey), South African humanities-authored articles in ISI-indexed journals compared favourably in terms of international visibility, measured as citation rates. Social science articles were ranked in the sample behind Singapore and Brazil in terms of field-normalised citation rates, while the humanities were ranked fourth behind Argentina, Portugal and Egypt.

Complications have also arisen from the way in which research funding is organised and managed in the country. In apartheid times, the chief funding agency, the Foundation for Research and Development (FRD), was devoted to the financing of the natural sciences and technology; around this focus a distinct, and quite effective, operating culture had developed. At apartheid's end, along with most other institutions in the country, the FRD went though extensive reorganisation, resulting in the establishment of the National Research Foundation (NRF), through a merger between the FRD and the Centre for Science Development (CSD), the granting arm of the HSRC. By legislation, the NRF became responsible for the promotion and support of research in the humanities and the social sciences. This has not been a happy development. For one thing, during the time of the FRD, a simple system of 'rated scientists' was deployed, and these scientists were guaranteed access to funding; this system was re-crafted at the birth of the NRF to include the humanities. In its new (and very elaborate) form, guaranteed funding was removed from the rating, and the system began to operate on the basis of universities competing for the prestige attached to rated scientists. (More recently, however, in another revamp of the system, funding levels have been restored). Nevertheless, many in the humanities (and some in the experimental sciences, too) have turned their backs on the 'rating system' – as the programme is called. Because this is contested ground, a few lines of explanation are required. In a report issued in May 2009, the NRF claimed that the number of humanities and social science researchers had increased "from 21% to 31% of the total number of rated researchers over the last five years" (NRF, 2009:15). But an earlier report (NRF, 2007:4) – which supports this growth in numbers – indicated that in 2005 only 9.8 % of the total number of staff in both the humanities and the natural sciences in South Africa had been rated. A further obstacle in the relationship between the NRF and the humanities community involved an early effort to focus research into focus areas. These 'exclusionary modes' largely failed to take account of the critical tradition in the humanities.

In 2007, John Higgins, one of the country's leading thinkers and himself the recipient of the highest rating of the NRF, published a piece excoriating the NRF for its approach to the humanities (Higgins, 2007). The NRF has been responsive to this and other criticism, and sensitive management of the humanities portfolio may have made the academy more interested in co-operation, although several stumbling blocks remain. One of these has been the creation of government-funded research chairs which have been rolled out by the NRF. In these, 24 of 80 have been in the humanities and social sciences, including a number in the economic sciences, which are not routinely counted in with the humanities.

The humanities, as Edward Ayers (Ayers, 2009. 25) suggests, 'live' in many places and it is to a place other than the universities that attention will briefly turn. The HSRC, the prototype of which was suggested by Eddie Malherbe in 1921 (Smit, 1984), commands a central – if somewhat historically controversial – space in the humanities in South Africa. In the 1980s, as the struggle to end apartheid drew to a close, the HSRC was accused of legitimising the reform initiatives of the apartheid government by offering scientific support for social programmes (White, undated). Its current mandate "to act as a knowledge hub between research, policy and action; thus increasing the impact of research" – as its website states –reflects the organisation's interest in making a difference in people's lives. But this is not uncontroversial, since much of the HSRC's work is at the applied end of social *science*, in particular. It certainly has the greatest single concentration of researchers in the country (some 165 professionals in all), who are supported by technical colleagues, and it boasts that its four multidisciplinary research programmes, two cross-cutting re-

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search units and three research centres are focused "on user needs". These are:

- **Research programmes:** Child, Youth, Family and Social Development, Democracy and Governance, Education, Science and Skills Development, and Social Aspects of HIV/AIDS and Health;
- **Cross-cutting units:** Policy Analysis and Capacity, Enhancement Unit and Knowledge Systems;
- **Centres:** Education Quality Improvement, Poverty, Employment and Growth and Centre for Service Delivery.

The HSRC has come in for criticism for the high salaries paid to its researchers and for recruiting academics from the university system. It has also not shown deep interest in developing – or, rather, redeveloping – interest in areas like literature, history, philosophy, religion, art history, music, drama and the like. There are, it seems, some discussions within the HSRC to fill this lacuna in its work by directing attention towards the humanities, but ways to achieve this appear still to be at the embryonic stage. It is fair to say that the applied policy direction of the HRSC is understandable in a country like South Africa where poverty levels are high and where the gap between the richest and poorest is the largest in the world. It is also true that the HSRC has helped to open up space for humanities in the country. Its publishing house, the HSRC Press, operates on an open access system which provides free access to all it publications as part of it public purpose mandate. This is no trifling matter in a country where the selling price of books has greatly increased. However, weaknesses in its approach are evident. One of these has been an unwillingness to engage in the debates on macro-economic policy which, as this chapter has made clear, has helped to drive the humanities to the margins of intellectual enquiry.

8.4 In search of recovery

These are the somewhat gloomy circumstances that have confronted the humanities in South Africa for the best part of fifteen years. Once at the centre of the university (and, indeed, in the country), and at the forefront of the struggle to end apartheid, they now face shrinking budgets, economic determinism and managerialism. Of course, as the responses to a number of enquiries have shown, the South African humanities are not alone in facing

> declining proportions of students and faculty positions, low funding inside the university, a diminished audience beyond the academy, disorientating shifts in demography of students and faculty, and dislocating theoretical innovations (Ayers 2009:24).

But in South Africa, as these pages have argued, this outcome has been subjected to particular pathologies. To the question of how the humanities in South Africa have responded to these many challenges we must now turn.

In the late-1990s, the government appeared to encourage the idea that all the country's universities should adopt what was called a 'programme approach' to under-graduate education. This approach reflected the thinking of planners whose ideal-model is that of the (mostly professional) faculties where planned curricula are the norm, but the approach also fitted the modular agenda of the National Qualifications Framework which was set up by the South African Qualifications Authority. In practice, across the country, the 'programme approach' resulted in long-standing (and often very strong) humanities departments being merged, reorganised or simply disestablished. Some of the 'programmes' have continued, while others reflected instrumentalist 'morphing' into occupational studies like museum studies, tourism studies and the like. The overall consensus was that the move was a disastrous step for the humanities. A powerful and intellectually rich department of German studies at UCT, for instance, was wrecked by 'programmatic rationalisation' and a department of Afrikaans at the University of the Witwatersrand, which was at the cusp of literary studies in the country, was closed. Interestingly, one dean faced off the rush into programmes – it never was a directive from the government – by suggesting that all he would do was "learn the language". Like all efforts that hope to rupture the crafted balance upon which the humanities rest, this approach was corrosive rather than creative. Notwithstanding this, the temptation to make the humanities 'useful' to the market continues. (One institution has recently out-imagined even the Hegelian ingenuity of Fukuyama by proposing to launch a programme called the Bachelor of Commerce Honours in Peace, Security and Economic Development.)

Individual academics have published thoughts on their own fears for the humanities. This work is often a mix of fear for the future of the established canon mixed with the difficult political issues involved in political transformation, especially the consistent pressures to rethink and reconsider the curriculum in the cause of 'Africanisation' (see Cornwell, 2006). These same issues were dramatically highlighted in a controversy at the UCT in 1996 between the distinguished Africanist Mahmood Mamdani, who then held the AC Jordan Chair of African Studies, and the university authorities over the development of a syllabus for a foundation course in African studies. Mamdani's proposal, which drew strongly on a Pan-Africanist perspective, was rejected by his faculty colleagues; he later resigned to take up a Chair at Columbia. Undoubtedly, this was but the first salvo in deep and fierce debates that are certain to follow, and indicates why conversations on the epistemologies in the humanities and social sciences are necessary.

There have been interesting moves towards (what is sometimes called) the 'new disciplines' in South Africa. Embryonic interest in film studies has, for example, developed into a healthy and flourishing programme at UCT. The same university has also developed a strongly institutionalised gender programme through the African Gender Institute which publishes the continent's first regional gender studies journal, *Feminist Africa*. A number of other universities, too, have developed programmes in gender or women's studies. Other new disciplines have been developed around HIV/AIDS – an issue in which South Africa has an obvious interest given that it has the highest infection rate in the world. Here, the perennial interface between – in this case, medical sciences and the humanities – has generated many tensions, although an annual HIV/AIDS conference has witnessed interesting areas of co-operation. In this area, the HSRC has developed an international reputation in second-generation surveillance of the pandemic.

Studies into water have also seen innovative work done at the interface between the natural and the social sciences; some universities, like the University of the Western Cape (UWC), have developed cross-disciplinary postgraduate degrees in the field which are run through the recently established Institute for Water Studies. Equally successful, and at the same institution, has been the development of work dedicated to the sensitive issue of land, its redistribution and agricultural policy. This, the Programme for Land, Agricultural and Agrarian Studies (the acronym 'PLAAS' is the Afrikaans word for 'farm'), is focused on one of the most challenging issues facing a country in which access to the land was rigidly policed during the centuries of colonialism and decades of apartheid alike. Following Thabo Mbeki's championing of the notion, a Centre for African Renaissance Studies was established at UNISA in June 2003. A very interesting and innovative intellectual development was the establishment of a dedicated institute, called the Wits Institute for Social and Economic Research (WISER), at this university in 2001. Five things stand out in the successes which WISER has undoubtedly enjoyed: an unhesitating willingness to be reflective; a desire to speak directly to the public; the courage to explore difficult and controversial themes; freeing good researchers from teaching; and foreign funding. In other places – the Centre for the Humanities at UWC and the Centre for Critical Racism at the University of KwaZulu-Natal are examples – newer efforts at developing and strengthening the humanities in the country are underway.

Some individual disciplines, like African languages, have effectively had to reinvent themselves. To briefly explain: early settlers were involved in the codification of these languages and, during the apartheid years, the teaching and associated research related to African languages, especially in Afrikaans universities, was mainly aimed at language fluency; in the English universities, a move towards linguistics took these languages away from their moorings in the community. After 1994, most African language departments in the country experienced a drop-off in students, including mother tongue speakers. This fall-off was part of a multifaceted process: the shift towards English as the language of globalisation; the attitude of students towards studying their mother tongue; and the trivialisation of the teaching of African languages within the schooling system. As a result, the African languages have developed new courses for both mother tongue and non-mother tongue students. At Rhodes University this process has involved, ironically, access to foreign funding through the South Africa–Norway Tertiary Education programme (SANTED). This programme has involved the development of non-mother tongue vocational language courses in isiXhosa and the design of mother tongue courses in isiXhosa which are linked to market-related requirements. These offer courses in translation studies, language and technology, language and society, language planning, orthography and writing skills, communication and media studies, as well as the teaching of literature as a discipline which is related to society. While the result has been an exponential growth in student numbers, the turn towards the market in this success story seems undeniable.

More concerted efforts are underway to mobilise support for the humanities by organising across universities who are often forced to compete for students and funding. The deans of humanities faculties have recently met and committed themselves to the formation of an organisation called the South African Humanities Deans Association (SAHUDA). Whether these meetings can lead to anything more substantial – or even an organised process of lobbying – is still an open question. Perhaps, however, the most interesting development was a decision by the Academy of Science of South Africa (ASSAf) to create a consensus panel[11] on the state of the humanities in South Africa. Driven by some of the concerns that have been raised in these pages, the panel hopes to deliver a report on ways to revive the humanities within academe, and to explore ideas to reassert the centrality of the humanities in South Africa's national life. Of course, similar exercises have been tried elsewhere, and if Harpham (2005) is to be believed, these are merely reflections of the never-ending perception that the humanities are in crisis.

The new energy in South Africa's humanities – whatever its funding or its institutional base – has the single goal of bringing a deeper understanding of the importance of the humanities in a country in search of self. Recognising this brings us to a deeper explanation of the title of this chapter. From their commanding place in South Africa during the long struggle to end apartheid, the humanities have been orphaned by the rise of the 'New South Africa' and by the country's manufactured rejection of what the humanities can offer both the country and humankind. The challenge now is to find a way back – and to recognise, as the South African writer André Brink has suggested, that "*reality* only begins where *information* ends" (Brink, 2001:3-4).

This chapter – a mix of report and analysis – has tried to convey the idea that the 'New South Africa' is not what it once promised. In the opening paragraphs it was suggested that South Africa's experience of change adds empirical force to Max Weber's claim that revolutionary ideas are invariably 'disciplined' by social and political processes. If the rationality which was first projected upon social science by Weber was even-handed, however, then the sense

11 The establishment of a consensus panel is an accepted practice to the investigation of an issue by ASSAf. The consensus panel on the humanities was established in 2008 and will submit a report in 2010. It is chaired by ASSAf Vice-President Jonathan Jansen and the author of this paper, Peter Vale.

of loss experienced throughout the humanities in South Africa would be explainable, even perhaps tolerable. But policy in post-apartheid South Africa is increasingly determined by 'experts', few of whom are trained in the humanities, and by a technical language upon which their decisions rest. This has dealt a double blow to the humanities in the country: first, their commanding position within the academy has been supplanted by the rise of new ways of both knowing and explaining; and, second, their role in freeing South Africa has been entirely ignored.

Legacy issues, too, hang heavily over the humanities in South Africa. The three approaches to the humanities which have been examined here have left huge areas of contestation and disparities. So, who talks for (and in) the humanities is at the heart of an intense debate. Are they – and the entire South African academy – still trapped in Dubow's "network of imperial knowledge"? What will happen to the Afrikaans language which, unlike English, does not speak "as outsiders in their own society" (Mkandawire, 2005.7)? Can a crusading Afrocentrism bring the humanities in South Africa 'home' to the continent and the diaspora? Given the history we have traversed, it is not surprising that these questions are played out in the everyday institutional life of the humanities where appointments, and funding and publishing remain mortgaged to the country's unhappy and divided past.
Notwithstanding the hurdles and divisions described in these pages, the humanities continue to challenge South Africa as much as South Africa challenges the humanities. Drawing from Max Horkheimer's thinking, the social theorist Ted Schatzki recently described South Africa as an "evolving societal constellation". He goes on to say, "South Africa is positioned to contribute strongly in the future to the elaboration of social theories adequate to changing global constellations of power, finance, culture, production and governance" (Schatzki, 2009: 30).

But the perennial promise of the humanities is the never-ending hope of human ingenuity and the power of imagination, the spirit of enquiry, and the creation of a world of possibilities. This suggests that we should end with a question for the future. Do the orphan years of the humanities in South Africa lie before or behind us?

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ARCHAEOLOGY AND PALAEOANTHROPOLOGY

CHAPTER 9

ALAN G MORRIS

Michael Cronin wrote a short paper in the *South African Journal of Science* in 1982 documenting some new radiocarbon dates from the Eastern Cape (Cronin, 1982). The paper has not been recognised as groundbreaking, yet with hindsight the paper heralded a new phase in South African archaeology that began in the 1970s and flourished in the 1980s. Cronin's evidence of Early Iron Age settlement approximately 1 200 years ago on the Transkei coast of the eastern Cape[1] (Fig. 9.1) was in direct conflict with the politically motivated 'Christian National Education'[2] model of the apartheid government that prevailed at the time. Apartheid education taught that both Europeans and Bantu-speaking South Africans were new arrivals in South Africa, the former moving east from the western Cape and the latter moving down from beyond the Limpopo River, the current northern border of South Africa with Zimbabwe, and the two meeting at the Great Fish River in the eastern Cape in the 1770s. The implication was that the country was essentially 'empty' before then (ignoring the San hunters and the Khoe herders) and that the white settlers had as much right as black 'natives' to take the land for themselves. Cronin's new dates were hard evidence that showed the antiquity of settlement of Iron Age farmers in the country. Not only had these farmers been present for nearly two millennia in the Transvaal[3] as noted by the work of Revil Mason in the early 1970s, but they had even reached the far south-east by 750 AD.

Archaeology has always had an important role in the construction of national histories and has been susceptible to selective interpretation because of this, yet it is also a powerful tool to uncover information about the past that has been forgotten, ignored or is simply unknown. This is of special importance in South Africa as research in the discipline of archaeology has spanned the period of colonialism, apartheid and the new democratic order since 1994. The discipline has been abused in the past, but the hard work of professional and amateur scholars has accumulated a vast body of evidence that is finally starting to give us a more broadly inclusive picture of the past. This ranges from the distant origin of human ancestors through the long period domi-

1 South Africa consists of nine provinces which are shown in Figure 9.1.

2 Christian National Education was the official education policy of the apartheid government that not only separated the schools according to race, but also imposed a curriculum that was specifically adapted to each race group. The curriculum for black schools was intended to limit the academic attainment of the scholars to prepare them for menial employment, while the curriculum for white schools included specific propagandistic content that defended their position of superiority in society.

3 Former province that covered roughly the current Gauteng, North-West, Mpumalanga and Limpopo provinces.

nated by Stone Age foragers to the more complex societies of the last two millennia. Research like that of Cronin has provided us with solid evidence to refute mythology. From amateur roots at the beginning of the 20th century, South African archaeology has developed into a professional discipline that has not only shed light on the history of the region but has also broken new ground in methodology, placing South African archaeology firmly on the world stage. Archaeological and palaeoanthropological discoveries uncovered by South African research have helped Africa achieve dignity and self-respect as part of the African Renaissance[4].

9.1 Archaeological roots

Archaeological investigations in South Africa first began in the late 19th century. Louis Péringuey, an entomologist at the South African Museum in Cape Town, with an archaeological interest, did some preliminary work on stone tools, but without the ability to date any of the remains he was unable to compile any meaningful chronology. Archaeological exploration at this time was very much the realm of amateurs and informally trained professionals like Péringuey, but research on South Africa's past took a more systematic turn with the appointment of AJH Goodwin to the University of Cape Town (UCT) in 1923 as a research assistant in the department of ethnology. Goodwin's archaeological training had been under Burkitt and Haddon at Cambridge and this enabled him to introduce the latest ideas and methods to South Africa. He began by re-examining the stone tool collections assembled by Péringuey and sorted them in a typology based on the relative African sequence rather than the European standards. His collaborator in this project was Clarence 'Peter' van Riet Lowe, an engineer working in the Orange Free State, now known as the Free State province, who also had archaeological interests. Together they published *The Stone Age Cultures of South Africa* in 1929, and the terminology that they chose (Later, Middle and Earlier Stone Ages) is still with us today.

The careers of these two men were quite different. Goodwin was in a teaching post and trained several students who were to have great impact in later years. Van Riet Lowe became director of the Bureau of Archaeology (later known as the Archaeological Survey) when it was created in 1935. The collections of the bureau were kept at the University of the Witwatersrand (Wits) in Johannesburg and van Riet Lowe was given a joint appointment with the university at a professorial level. Although he did not train students, he employed several of Goodwin's students at the bureau. Amongst Goodwin's students was Berry Malan, who took over the directorship of the Archaeological Survey on van Riet Lowe's death and eventually moved to Cape Town when the Historical Monuments Commission (HMC, later the National Monuments Council) was

4 A Pan-Africanist policy initiated by President Thabo Mbeki which hopes to instil pride in being African.

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re-located there in the early 1960s. Another Goodwin student, Revil Mason, joined Van Riet Lowe at the HMC in the late 1940s and became curator of the Archaeological Survey collection at Wits in 1962 after the HMC's move to Cape Town. A third Goodwin student was Peter Beaumont who worked closely with Raymond Dart and later had a long career at the McGregor Museum in Kimberley.

Although the discipline of archaeology grew slowly before World War II, there was significant interest from government in the form of the then Prime Minister Jan C Smuts. Smuts not only supported the development of the Archaeological Survey, but when the first Pan-African Congress on Prehistory was launched in Nairobi in 1947, Smuts arranged for the South African delegates to be flown to East Africa on a military transport plane. This open support from government stopped when Smuts' party lost to the Nationalists in the 1948 general election. The new Afrikaner-dominated Nationalist[5] government was not friendly to archaeology because the evidence it was uncovering conflicted with biblical teaching about human origins, and also because it gave prominence to the study of native black populations and placed them on an equal footing in the history of the European colonists. The second Pan-African Congress on Prehistory was scheduled to be held in Johannesburg, but the new government withdrew their funding and it was moved to Algeria instead. Local interest in archaeology was kept alive by the palaeoanthropologists (see below) but also by Goodwin's launch of the South African Archaeological Society in 1945 along with its journal, the *South African Archaeological Bulletin*.

Lack of government support limited archaeological advancement during the 1950s and 1960s, but the situation began to change in the late 1960s as the country became more prosperous and the government began to increase funding for universities and museums. Revil Mason completed his PhD at UCT on 'The Prehistory of the Transvaal' in 1958 under the joint supervision of Goodwin and Van Riet Lowe. John Goodwin died in 1959, but his post was taken by Ray Inskeep in 1960 and the number of students began to expand substantially. Amongst Goodwin's last students were Glynn Isaac and Hilary Deacon. Isaac left South Africa to gain professional training overseas, while after a brief stint in geology, Hilary Deacon returned to archaeology and completed his MSc and PhD under Inskeep at UCT. Inskeep was able to generate a new interest in archaeology amongst his students. These included Carmel Schrire, Janette Deacon, Garth Sampson, Elizabeth Voigt, Graham Avery, Mike Wilson, Tony Humphreys and Tim Maggs, all of whom have become important South African archaeologists in their own right. Archaeology at UCT remained a sub-division of African studies until 1968 when it became a separate department with Inskeep as an associate professor, and in 1973 it appointed its first

5 The National Party won the 1948 election on a policy of apartheid. The electorate was overwhelming white with a few enfranchised coloured people and no black Africans.

full professor, Nicholaas van der Merwe, a South African trained at Yale University in the United States.

Van Riet Lowe died in 1956, but when the Archaeological Survey was closed in 1962, and Berry Malan relocated to the Cape as Director of the HMC, his legacy was carried on through the research of Revil Mason at Wits. Mason trained relatively few students at Wits, but he did extensive research especially on the Iron Age peoples of the Johannesburg area and the neighbouring Magaliesberg. Budgetary restrictions also prevented the growth of archaeology at Wits in the 1960s and the subject remained a division of anthropology. However, with increased availability of funding, the subdepartment of archaeology was split in the early 1970s into a teaching school and an Archaeological Research Unit under Revil Mason which he ran independently until it was closed down on his retirement in 1989. Tom Huffman, an Iron Age specialist who had been at the Queen Victoria Museum in Rhodesia (now Zimbabwe), was appointed the first professor of an independent department of archaeology in 1978. The new teaching department broadened its activities to rock art and Stone Age research and Lyn Wadley became its first PhD graduate in 1987.

The expansion in the 1970s professionalised archaeology in South Africa. Janette Deacon has outlined these developments and emphasises the shift from amateur to professionals in university and museum contexts (Deacon, 1990). When Inskeep joined UCT in 1960, his was the only academic position in the country and half of the articles published in the *South African Archaeological Bulletin* were written by amateurs with no professional training. Within ten years there were archaeologists in all major museums and six universities offered courses at an undergraduate level. By 1970, articles written by amateurs accounted for only 10% of the papers in the *South African Archaeological Bulletin*. Separate research units were created for palynology in Bloemfontein at the University of the Orange Free State (now University of the Free State), for radiocarbon dating at the Council for Scientific and Industrial Research (CSIR) in Pretoria, for archaeozoology at the Transvaal Museum also in Pretoria, and for rock art at Wits in Johannesburg. A professional body, the South African Association of Archaeologists (now called the Association of Southern African Professional Archaeologists (ASAPA)), was launched in 1970 and it and its older relative, the Southern African Society for Quaternary Research, offered biennial meetings in alternate years.

Membership of ASAPA now requires a minimum of an Honours degree in archaeology and draws membership from Botswana, Namibia and Zimbabwe and South Africa, as well as members from farther afield who are working on research projects in the region. Current membership stands at over 240 professionals. Active teaching departments producing Doctoral level train-

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ing can be found at UCT, the University of Pretoria (UP), Wits, the University of South Africa (UNISA), and until 1999, Stellenbosch University (SU). The museums in Cape Town, Pretoria, Kimberley, Bloemfontein, Grahamstown and Pietermaritzburg all have active divisions of archaeology and associated collections of excavated artefacts. Amateur interest in archaeology continues to be encouraged by the South African Archaeological Society in its branches in the Western Cape, along with the Free State/ Northern Cape, Gauteng and KwaZulu-Natal. Membership of the society is currently around 850, the vast majority of whom are interested amateurs. The *South African Archaeological Bulletin* continues to be a regular vehicle for archaeological publications along with its occasional *Goodwin Series* special volumes. Since 1982, the Albany Museum in Grahamstown has published the journal *Southern African Field Archaeology* and the Natal Museum in Pietermaritzburg continues to publish *Southern African Humanities* in which archaeological papers are prominent.

9.2 Major research themes in archaeology

The long-term legacy of Goodwin and Van Riet Lowe has been the rich body of knowledge generated by archaeologists since the 1970s. In the early years much of the focus was on stone tool typology and understanding the sequence of archaeological cultures in southern Africa. Research has now become more hypothesis-oriented. Initially, ecology was the central focus of the new research, but in recent years, this has moved on to examining belief systems and asking social questions.

The ecological theme was taken up by Hilary Deacon first at the Albany Museum in Grahamstown and, from 1972, at SU, as well as by John Parkington and his students at UCT. Hilary and Janette Deacon focused on the Eastern and Southern Cape, examining Late Pleistocene and Holocene subsistence patterns and adaptive changes in material culture over time. In the 1980s, Hilary Deacon focused on the key site of Klasies River[6] with its excellent record of environmental changes over the past 120 000 years. Parkington examined spatial variability in the western Cape, especially in the region of Elands Bay up the west coast of South Africa. Their models were those of the Kalahari San and social structure was matched to environmental ecology. Parkington developed a model based on seasonal mobility and proposed that Holocene hunters wintered on the coast and spent the hot summers inland in the mountains.

At about the same time, John Vogel of the CSIR in Pretoria began to examine stable light isotope research in biology. Vogel's laboratory was world-renowned in this research and developed the technique into a major research tool for life and environmental science. In collaboration with Vogel, Nick van der Merwe in Cape Town set up a

6 Locations of all archaeological sites mentioned in this chapter are shown in Figure 9.1.

Figure 9.1: Locations of archeological sites in South Africa

stable isotope laboratory to examine the biochemistry of once-living material to work out past diets by means of archaeometry. Amongst the first test cases of this work was the examination of human skeletons from the Cape west coast to test Parkington's seasonal mobility model. The resulting Masters thesis by Judith Sealy showed that the reality was not so simple and that the isotope readings of many of the human skeletons indicated that the people had not migrated seasonally. In a chemical assessment of

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'you are what you eat', subsequent research at the stable isotope laboratory used stable isotopes of carbon and nitrogen, along with trace levels of strontium and fluorine to examine Later Stone Age, Iron Age and historic diets, weaning practices, regional movements, and, of special interest to palaeoanthropology, diets of long extinct humans and non-human primates.

The biochemistry of ancient human bone bridges the field of archaeology with that of physical anthropology and significant research into the skeletal biology of past populations has been done during the last two decades and continues to be an important research thrust today. A spin-off of the stable isotope analysis has been the increased number of human skeletons dated by radiocarbon that has enabled physical anthropologists to ask questions about the biology of people over time. Alan Morris published a catalogue of *Holocene human skeletons in southern Africa* (Morris, 1992) that has formed the basis for much of the subsequent research. The number of new skeletal samples has also increased especially in the last decade as human burials are disturbed by development. Maryna Steyn and Erika L'Abbé have looked at Iron Age and historic Bantu-speaking samples, while Susan Pfeiffer and her Canadian students have done considerable work on health and lifestyle during the Holocene of the Cape. Morris and his students have studied the historic peoples of early Cape Town.

Iron Age research was built up by Revil Mason at Wits between 1962 and 1986. Although Mason was primarily interested in the Late Iron Age, he did important work at Broederstroom in which he demonstrated the presence of Early Iron Age farmers in the region between the 3rd and 5th centuries AD. His Broederstroom studies brought to light much information about these people and subsequent research has found evidence of this early settlement in the far northern province of Limpopo, east through Mpumalanga province and south into KwaZulu-Natal, ending with the settlements dated by Cronin just east of the Great Fish River in the Eastern Cape. Tom Huffman's work also encompassed the Early Iron Age, but he and his students also examined the important Late Iron Age sites that could be directly linked by pottery sequence to the living historical Bantu-speaking peoples of the region. Later, Tim Maggs and Martin Hall studied settlement patterns on the southern highveld[7] and coastal KwaZulu-Natal respectively, applying ecological models linked to ethnoarchaeology. By understanding the link between ecology and society in historical populations, these researchers were able to demonstrate the important relationships between settlement pattern and ecology in the prehistoric period.

Huffman's work also considered the larger sites in Zimbabwe and at Mapungubwe, and shed light on state formation in the period between the 10th and 15th centuries AD.

7 The high-altitude interior plateau of South Africa.

The discovery in 1933 of the elite settlement with its gold burials at Mapungubwe Hill brought UP into the archaeological fold. The earlier work, under the direction of the historian Leo Fouché and the British Egyptologist Captain Guy Gardiner, was more confusing than helpful. In the same manner as the Zimbabwe Ruins in modern Zimbabwe, there were vested interests who felt that 'foreigners' must have been responsible for the site's construction and that Bantu-speakers could not have erected them. Research since 1979 has re-examined the site at Mapungubwe and its sister site at K2 just a couple of kilometres away. Hannes Eloff and his student Andrie Meyer have examined much of the material culture and site structure, and Elizabeth Voigt has analysed the faunal remains and economy. Tom Huffman has contributed a valuable overview of the role of Mapungubwe in the development of trade and powerful kingdoms in the region. A range of other researchers from UP, UCT and Wits have produced excellent research on Late Iron Age sites in the Limpopo, North-West, Free State, KwaZulu-Natal and Mpumalanga provinces and in every case there are observable signs that these ancient settlements were of African origins, although direct links with specific modern Bantu-speaking peoples are not always obvious.

The colonial period[8] has also been of interest to archaeologists, although this only became an area of focus from the mid-1980s with the appointment in 1984 of Hennie Vos and Gabebah Abrahams at the cultural history museums in Stellenbosch and Cape Town respectively. They were the first appointments of archaeologists to posts which were specifically for the study of historic contexts. Much research had been done on historic architecture especially in colonial Cape Town, but Martin Hall, Antonia Malan and Carmel Schrire and their students saw the need to examine the history of the underclass of urban and rural poor along with the slaves. Very little was recorded about these people in the historical record, so archaeology was the ideal tool to obtain missing knowledge. The Historical Archaeology Research Group (HARG) at UCT was launched by Hall in 1987 in order to bring together archaeologists and other researchers actively interested in the history of the last six hundred years. The primary zone of interest was the historic Cape province, but a new focus launched in 2006 has extended this considerably. The '500-Year Initiative' hosted by Wits links historians and archaeologists and broadened the definition of historic archaeology to include oral as well as written testimony. Whereas HARG concentrated on the colonial expansion in South Africa as seen by the colonisers, the '500 Year-Initiative' is more interdisciplinary and emphasises the more distant contact between groups on a subcontinental scale. With this broader definition, historic archaeology now includes the study of African oral traditions over the last 500 years throughout the country and up the east coast into East Africa as well.

8 The colonial period in South Africa begins with the Dutch Settlement at the Cape in the mid-17th century.

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Rock art research has also benefited from an expanded horizon in the last few decades. The beautiful painted and engraved images found on rock surfaces through much of southern Africa have been of interest since the 1870s. Early research viewed them as primitive pictorial art, but as data were gathered from hundreds of sites, analysis changed to a numerical approach that required ever more data. A Rock Art Recording Centre was started at the South African Museum in 1967. An associated radiocarbon date of 27 500 years ago for art in the Apollo 11 in Namibia cave in southern Namibia indicated an antiquity as deep as the rock art from the caves of Palaeolithic Europe. A real advance in rock art research came in the 1970s with the work of Patricia Vinnicombe and David Lewis-Williams. They used San ethnography from the Kalahari and the historic Northern Cape to interpret the images. Lewis-Williams has been the greatest proponent of this new 'interpretive' focus and has argued that the images were essentially religious and could be linked to shamanistic beliefs and practices that included visions and other experiences connected to the trance or healing dance. Not all current researchers agree with Lewis-Williams' explicitly 'shamanistic approach' and much of the newest literature has attempted to dissect the nature of the rock art symbolism, especially with regard to women's roles and possible initiation practices. Other researchers are examining different traditions of rock art in terms of both style and authorship. There were other painters beside the San and some rock art can be linked to Bantu-speaking peoples and the Khoekhoe. Southern African research has transformed our understanding of human cognitive and artistic abilities in a way that stone tool studies cannot. The use of appropriate ethnography and neuropsychology to interpret rock art has inspired researchers in other countries to try the same methods and the results have made South African rock art researchers leaders in their international field.

The inclusion of ethnographic information in the interpretation of rock art has also impacted the analysis of sites and material culture in hunter-gatherer studies. The ecological approach, although still critically important, has been partly replaced by discussions of social relations and ideologies. Lyn Wadley has investigated the social implications of gender roles and aggregation and dispersion of foraging groups, and Aron Mazel has examined alliance networks seen through material culture and site use in the KwaZulu-Natal Drakensberg[9] foothills. The importance of spatial distribution of small sites and day-to-day activities of foragers has been studied by John Parkington and his students at Dunefields near Elands Bay in the Western Cape. Pastoral and foraging communities in southern Africa were technologically similar and therefore their sites have been notoriously difficult to differentiate. Andy Smith, Lita Webley and Karim Sadr have examined this question, and although no consensus has been formed, a

9 The Drakensberg mountain range or escarpment separates the interior highveld plateau from the surrounding coastal area. The Drakensberg mountains mark the western boundary of KwaZulu-Natal.

broad picture of Khoekhoe society in prehistoric and early historic times is starting to develop.

A final thrust of research to be considered is that which has focused on faunal analysis of Stone Age sites. Research from the South African Museum in Cape Town, the Transvaal Museum in Pretoria, SU, the National Museum in Bloemfontein and the Bernard Price Institute for Palaeontology at Wits has concentrated on animal bone and its use in the reconstruction of both climate and human hunting activity. Starting in 1969, Richard Klein of the University of Chicago (and later Stanford University) began annual visits in collaboration with the South African Museum. Klein, his students and South African collaborators, have studied the middle and Late Pleistocene and Early Holocene at a range of sites including Elandsfontein, Klasies River, Nelson Bay Cave, Boomplaas, Duinefontein and many smaller sites in the south-western Cape. James Brink at Bloemfontein has worked at Florisbad, another important Late Pleistocene site extending our knowledge of faunal ecology in the interior as well as at the coast. The south coast cave sites have been particularly important in our understanding of the emergence of modern human anatomy and behaviour. Richard Klein, Ronald Singer, John Wymer, Hilary Deacon, Anne Thackeray, Johan Binneman and Sarah Wurz all excavated or analysed artefacts or faunal remains from the Middle Stone Age sequence at Klasies River Mouth, and this has been followed more recently by excavations at Blombos Cave by Chris Henshilwood and Judith Sealy and at Pinnacle Point by Curtis Marean and his students. More about this research thrust into the origins of modern humans will be considered under palaeoanthropology, as will the work on the rich cave sites associated with the ancient Australopthecines that are the key to taking us back in time to Hominin species earlier than our own.

9.3 Palaeoanthropological roots

Research into fossil humans started very early and more systematically than did research on archaeology in general. Allied to the European system of anthropology, studies in physical anthropology and human evolution were the preserve of anatomists in the medical schools and palaeontologists in the museums. The earliest specimen of presumed antiquity was the Boskop skull discovered in 1913. This mineralised partial cranium was assumed to be of great antiquity and its large size associated with what were seen as San features suggested that it was different from previously described human crania and living southern African peoples. Although the skull was discovered at Potchestroom[10], it was the focus of a 'territorial' spat between Péringuey in Cape Town and FW FitzSimons at the Port Elizabeth Museum. The two museum directors were trying to assemble as many skeletons of native peoples into their collections as they could. The damage to

10 A small town situated to the west of Johannesburg in the North-West province.

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archaeology was immense because the digging was done literally with shovels and context was rarely recorded. Péringuey and FitzSimons both offered cash to purchase the new discovery at Boskop; FitzSimons offered the most money, so the skull went to Port Elizabeth, but Péringuey met with FitzSimons and negotiated for the first description to be done by the assistant director of the South African Museum, the young geologist Sydney Haughton.

Boskop had more influence than it should have had because of the notoriety created by the competition between Péringuey and FitzSimons. It was interesting in anatomy, but undated and with very little archaeological context, however, the assumed antiquity made it important to the museums. When FitzSimons discovered similar large, long-headed crania in the deeper levels from caves in the Tsitsikamma Mountains on the south Cape coast, he sent them to Raymond Dart, the new professor of anatomy at Wits, for analysis. The Boskop-like features of these few individuals suggested to Dart that a whole population of large-headed San must have existed in prehistoric times. Dart created the 'Boskop type' in order to represent this population.

By the 1920s and early 1930s, South African physical anthropology had already divided itself into distinct 'schools' at the medical schools at Wits and UCT and at the National Museum in Bloemfontein. The passion for 'types' of modern and ancient humans was a reflection of the importance of racial classification of people to both scholars and to the public at large at that time. This focus on race as the most important aspect of the study of archaeological humans did not significantly change until the work of Ronald Singer and Phillip Tobias in the 1950s and 1960s.

Although the Boskop discovery had triggered much interest in physical anthropology in South Africa, it was the discovery of the Taung child as announced by Raymond Dart in February 1925 that brought South Africa onto the world stage of human origins studies. The face, mandible and cranial endocast, encased in a block of breccia (solidified ancient cave fill), were brought to Dart in late-1924 from the Buxton lime mine at Taung, just north of Kimberley in the then Cape province. He spent several weeks carefully exposing the tiny skull and in the process recognised a set of anatomical features that marked it as human-like rather than ape-like. He gave the name *Australopithecus africanus* to his newly discovered specimen. Dart's published description in *Nature* early in 1925 was not met with approval from the palaeoanthropological community and his find was discounted by most authorities on the subject. For over a decade, the Taung child remained the only indication of very ancient human remains in Africa until new specimens were recovered by Robert Broom from Kromdraai, Sterkfontein and Swartkrans, all ancient filled caves in the Sterkfontein valley north-west of Johannesburg. The accumulating evidence finally convinced the experts in far away Europe and America that South Africa indeed held the evidence of the earliest origins of humanity. By the late 1940s, Dart's Australopithecines were recognised as human ancestors and Africa was recognised as the home of humanity.

While the early years of archaeology were dominated by Goodwin and Van Riet Lowe, the early years of palaeoanthropology were dominated by Raymond Dart and Robert Broom. Raymond A Dart, an Australian-trained anatomist, was appointed to the young Wits medical school in 1923. He had hoped to pursue advanced research on neuroanatomy, but the facilities in Johannesburg were still quite basic and bones and fossils were more accessible. Dart taught anatomy as a scientific rather than purely medical field of study right from the start of his tenure. He created undergraduate science courses, began the training of research students and started a museum of comparative anatomical and anthropological interest in the department. His legacy was the training of generations of students (both medical and scientific) who were instilled with an interest in human origins. Robert Broom, on the other hand, was a Scottish medical doctor with an impassioned interest in evolution. Although he had a brief stint as professor of zoology and geology at Victoria College (the University of Stellenbosch after 1918), and had an international reputation on the study of fossil mammal-like reptiles, he spent nearly the whole of his career in medical private practice. On retirement from his last clinical post in 1933, the ever-supportive Prime Minister Smuts had him appointed curator at the Transvaal Museum in Pretoria, and it was in that phase of his career that he became fully involved in the study of human origins. Although Broom did not train students, he was a frequent guest lecturer in Dart's classes and it was students from these classes that brought Broom's attention to the sites in the Sterkfontein Valley. Broom, in collaboration with other researchers, especially JT Robinson, his successor at the Transvaal Museum, produced a series of important monographs in the *Transvaal Museum Memoirs*. The number of discoveries continued through the 1930s and 1940s, but almost none of the discoveries was made under controlled excavation.

The fossil sites in the Sterkfontein Valley were the preserve of researchers at the Transvaal Museum long after Broom's death in 1951. After Robinson left for the United States, his place was filled by CK (Bob) Brain and later by Elisabeth Vrba. The sampling of miners' diggings as a method of excavation changed by the 1960s, when more modern and rigorous excavation techniques were adopted. Brain started a series of long-term excavations at Swartkrans aimed specifically at sorting out the process by which the caves formed and were subsequently filled.

In the years before World War II, Dart was primarily occupied with the expansion and administration of the medical school in Johannesburg, but after the war he withdrew from heavy teaching and administration duties and devoted more of his time to research on the fossil Hominins and their sites. Of particular interest was the new site at Makapansgat. Originally brought to

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Dart's attention in 1925 as a source of fossil animal bones in breccia, the location was visited by Phillip Tobias who led a student expedition to the Makapansgat valley in 1945. Dart opened the investigation of the limeworks site at Makapansgat in 1947 and the following year announced the discovery of Australopithecine bones in the deposits.

Phillip Tobias succeeded to the chair of anatomy at Wits on the retirement of Dart in 1959. Dart had already built a strong international reputation for Wits, but Tobias extended this by increasing the diversity of research and generating a substantial body of graduate students. Tobias has supervised over 30 PhDs in his career, amongst them John Wallace, Ron Clarke, Fred Grine, Alan Morris, David Ricklan, Peter Christie and Lee Berger, all of whom have done research on human origins. The growth of the Bernard Price Institution for Palaeontology has paralleled the growth in the field of anatomy, with research projects on the associated fauna and on the Hominins themselves in recent years under Lee Berger. Tobias and his senior technician, Alun Hughes, began systematic excavations at Sterkfontein in 1966 that have continued without break until today. Ron Clarke is the current director of these excavations, but others are also active in new excavations at the Australopithecine sites. Jeff McKee, now of Ohio State University, and Kevin Kuykendall, now of the University of Sheffield, both past academic staff in the department of anatomy at Wits, have examined the taphonomy of the fossil-bearing South African cave sites, specifically at Makapansgat, Taung and the Sterkfontein Valley site of Gondolin.

The discovery, excavation and analysis of the early Hominin sites by teams from the Transvaal Museum and Wits have been the main thrust of palaeoanthropological research in South Africa, but they have not been the only actors in the play. Matthew Drennan, Ron Singer and Keith Jolly from UCT explored the sand deflation site at Elandsfontein and reported the discovery of a Middle Pleistocene cranium in the early 1950s. TF Dreyer working out of the National Museum in Bloemfontein discovered another archaic cranium from the site of Florisbad in the 1930s, which is also of Middle Pleistocene age, although more recent that the Elandsfontein find. Interest in the origin of anatomically modern *Homo sapiens* has also been great. Peter Beaumont re-excavated the site of Border Cave, originally excavated by Dart and LH Wells in the 1940s and he has been able to construct an almost continuous archaeological sequence associated with some human remains going back over 100 000 years. The Klasies River site on the southern Cape coast has been excavated by Singer and Wymer, as well as Hilary Deacon over the years and there are secure associations of specimens with modern human anatomy going back 120 000 years. The South African sequence of fossils covering the period from the roots of humanity through to the rise of the modern human form have provided detailed anatomical information to generations of academics from around the world and continue to be magnets drawing scholars to South African institutions.

9.4 Major research themes in palaeoanthropology

According to a count by Kevin Kuykendall, over 1 000 specimens of Australopithecines and early *Homo* had been recovered from the South African sites by 2007. The debate has raged about the classification of these specimens right from their first discovery and continues today. How many species are represented and how are they distributed over space and time? Broom, a taxonomic splitter, had created names for each new specimen, but by the 1950s there was a general consensus that there were two Australopithecines, *Australopithecus africanus* and *A. robustus*, and an African form of *Homo erectus*. Discoveries at these sites and in East Africa from the 1970s have broken the consensus. The finding in 1976 of the Stw 53 skull in the Sterkfontein Extension site has been interpreted as evidence of *H.habilis* in the region and earlier discoveries of *Homo* species have been labeled *H.ergaster*. Most researchers have now placed *A. robustus* into its own genus, *Paranthropus,* indicating at least two fundamental lines of evolution amongst the Australopithecines. Debates about the relationships of these South African specimens to their contemporaries in East Africa continue. The announcement by Ron Clarke in 1997 of the discovery of a nearly complete skeleton (Stw 573) has also emphasised the value of the richness of the South African sites. This is the third discovery of multiple bone fragments from one individual (Sts 5/14 and Stw 431 are the other samples), but this new specimen is not only the most complete, it was also discovered still *in situ*. The specimen has been exposed but still remains to be removed from its rock encasement.

During the 1950s, Dart introduced his theory of 'Osteodontokeratics' or bone, tooth and horn tools to explain the breakage patterns of the animal bone from the Makapansgat limeworks. His model of aggressive Australopithecine hunters killing a wide range of animals for their meat struck a chord in the mind of the American populariser of science, Robert Ardrey. Ardrey became Dart's advocate in a series of books; *African Genesis*, *The Hunting Hypothesis*, and *The Social Contract*. Although no longer accepted as good explanatory models for human origins, Dart's papers and Ardrey's books triggered a debate about how the bones of animals and early humans found their way into the cave deposits in the first place. The result was the development of the field of 'cave taphonomy' whose main proponent has been Bob Brain of the Transvaal Museum. The mode of deposition at all the sites continues to be debated, with evidence suggesting a range of accumulators that may have been different at each site and at different times. That bone accumulation was undoubtedly complex is uncontested, but at Sterkfontein and Swartkrans there is good evidence that early humans other than Australopithecines were active. Kathy Kuman's work on the Earlier Stone Age tools from these sites is informative and ongoing.

The volcanic sediments of the East African Rift Valley have allowed the fossil sites in that region to be dated by radiometric means. Sadly, the dolomite caves of South

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Africa have not been that easy to date. Each cave represents multiple infilling episodes and therefore represents different times and changing environments. Faunal correlations with well-dated East African sites were done in the 1960s and 1970s but these were based on the assumption that the East African species were both equivalent and contemporaneous. Nick-point geomorphology was used to date the caves in the 1970s, but the results were controversial when it was suggested that the type site of Taung was comparatively young at around 2 million years. This was inconsistent with the faunal dating and the Australopithecine morphology. Palaeomagnetic dating has been reasonably successful in sorting some of the deposits, and most recently cosmogenic dating for Stw 573 has placed it between 3.5 and 4 million years, but this could be an overestimation. A secure dating for the Australopithecine sites is absolutely necessary in order to understand the progression of species in both place and time.

By the 1970s, a model of ecological differentiation between the gracile and robust Australopithecines had been proposed that suggested a more generalist diet for *Australopithecus* leading to the origin of *Homo*, and a specialised hard object vegetarian diet for *Paranthropus* that eventually led them to extinction. The evidence came from microscopic analysis of tooth wear on the molars of the various specimens. This simple model has been challenged in recent times by the analysis of stable carbon isotopes from the same teeth. Van der Merwe and Julia Lee-Thorp have managed to extract carbon from the teeth and have shown that all of these early Hominins were 'C4', indicating an open habitat and generalist diet for all of the Australopithecines and early *Homo*. The analysis of bone and plant remains from these sites continues and suggests that there were significant climatic differences on the interior highveld plateau of South Africa between then and now. Chemistry and microstructure of non-human bones have also led Andrew Sillen and Bob Brain to the conclusion that fire was present at the cave site of Swartkrans 1.3 million years ago. The burnt bone from this site is argued as indicating the maintenance, but not necessarily the making, of fire, an important landmark in the development of technology.

The most recent research on human origins in southern Africa has concerned itself with the rise of anatomically modern humans and especially modern human behaviour. With genetic evidence from living humans indicating an African origin for modern humans around 150 000 years ago, and the Khoesan people of southern Africa demonstrating the deepest roots of all living humans, the fossil remains from the end of the Pleistocene in South Africa have gained new importance. Critical to this new focus has been the dating of deposits beyond the range of radiocarbon. Zenobia Jacobs and Dave Roberts, amongst others, have explored the use of optically stimulated luminescence (OSL) and have revolutionised our understanding of Early and Middle Stone Age sites, especially those at Howieson's Poort and Still Bay.

This has enabled palaeoanthropologists to see the pattern of sequential change in material culture and subsistence pattern over the vital period at which the geneticists tell us that modern humans originated.

One thrust of this research has been on the remains of the early humans themselves. The human bone fragments from Border Cave and Klasies River have confirmed the presence of aspects of modern anatomy over 100 millennia ago and perhaps even older if Darren Curnoe's reassessment of the Cave of Hearth's mandible is accepted. But the recent dating of the Hofmeyr skull has suggested that the transition to the fully modern form was not a gradual process and may in fact have been relatively recent. Fred Grine, Alan Morris and their collaborators have shown the Hofmeyr skull from the southern *Karoo* to be about 36 000 years old, morphologically modern, but unlike any modern anatomical population of humanity. In fact, the closest match was to the Upper Palaeolithic humans of Europe. The suggestion is that Hofmeyr represents the morphology of the African parental group that emigrated from this continent into Europe around 40 000 years ago. The modern patterning of morphology that is sometimes referred to as 'racial variation' is later and possibly represents selection at the Late Glacial Maximum, something in the order of only 20 000 years ago.

Even if morphological change was uneven and relatively late, others have shown that modern behaviours have deeper roots. The reconstruction of palaeoenvironmental change at the end of the Pleistocene has allowed us to understand the human response to these changes. Richard Klein has already argued that modern behaviours include the widening of the use of food resources and Curtis Marean, Chris Hensilwood and their various South African collaborators have confirmed this. They have identified the gathering of sea food as an early innovation on the south Cape coast well over 100 000 years ago at such sites as Blombos and Pinnacle Point. Perhaps even more intriguing was the discovery by Chris Henshilwood and Judith Sealy of simple art in the form of engraved ochre from the site at Blombos dated to more than 70 000 years ago. This is long before the appearance of art in Europe. Published just a few months ago is some new evidence from Kyle Brown and Curtis Marean and their colleagues (Brown *et al.*, 2009) that the stone artefacts from the Pinnacle Point site had been treated in a fire before being shaped into tools, a sign of modern technological innovation between 77 000 and 50 000 years ago.

The accumulating evidence compiled by Marean, Hensilwood, Sealy, Parkington and many others suggests that a package of coastal adaptations, the manufacture of complex lithics, the use of bone artefacts, pigments and engraved objects are markers of the onset of human behaviour in South Africa earlier than elsewhere on the continent and in the world. Although controversial, could this be a sign that the dispersal of humans out of Africa came not from East Africa, but from South Africa?

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9.5 Archaeology and palaeoanthropology in the new millennium

In January 1999, UCT hosted the 4th World Archaeological Congress (WAC) under the chairmanship of Martin Hall. The conference was very much a welcoming of South Africa back into the international fold of archaeologists after the long dark period of apartheid. The 1983 South African Association of Archaeologists meeting in Gaborone heard a motion from its members in support of an explicit statement on the condemnation of apartheid along with other proposals to control the direction of research, but the resolution was not carried. It is unlikely that the overwhelmingly white membership was overtly racist, but there was a misguided attitude that somehow science and society were separate, and also a fear that political motions at conferences infringed on academic freedom.

The result was that some members withdrew from the association and international support for South African scientists was divided. In 1985, 19 South African and Namibian archaeologists were refused permission to join the meeting of the International Union of Prehistoric and Protohistoric Sciences (IUPPS) to be held in Southampton. There was acrimonious debate in the journals and in the newspapers in which arguments were aired both for and against the academic boycott. In the end, the issue caused the IUPPS itself to split and WAC was launched in September 1986 without the South Africans. The fact that South Africa had been at the root of the debate made the conference in Cape Town in 1999 an especially important symbol of a new era.

The impact of the 1999 WAC conference was not only political, but it has also sensitised archaeologists to the place of indigenous peoples in the discovery of their own history through archaeology. The presence of Khoe and San delegates from all over southern Africa gave them a voice that was heard by the professional body of scholars. Amongst the issues debated at the conference were the demand for the return and reburial of human remains of indigenous people taken overseas during the colonial era. Chief amongst these were the skeleton and body parts of Sarah Baartman who died in France in 1815. The demands of Khoe and San activists were met in 2002 when Baartman's remains were returned and given a state funeral in Hankey in the Eastern Cape.

The issue of the disturbance of graves and the reburial of previously excavated human skeletons has been at the forefront of discussions of both professionals and the lay public, but not all issues have been resolved satisfactorily. The attempt to prevent the excavation of 18th century burials in Cape Town during the redevelopment of a downtown district in 2003 was not successful, but the study of the human remains was blocked. This is a major loss to archaeological knowledge that has not occurred elsewhere in the country. Human remains from early 20th century Venda graves, the burials of mineworkers from the Gladstone site in Kimberley and the many burials from Mapungubwe and K2 have all been studied and reburied, and the two gold burials from Thulamela in the northern section of the Kruger National Park were excavated, studied and reburied, all with the local community's knowledge and co-operation. Local politics in Cape Town is at the heart of the failure to reach agreement there and it is clear that archaeology still needs to make itself relevant to the majority of South Africans before there will be an end to such conflicts.

One solution to making archaeology and palaeoanthropology more relevant to all South Africans would be to train South Africans of all origins as archaeologists. Despite active attempts to draw in more students of 'indigenous' origin, the total number of black archaeologists and palaeoanthropologists still remains dismally low, and several of those hired by universities in recent years have come from Zimbabwe rather than South Africa itself. Building on the work of Mason in trying to popularise archaeology at black schools in Johannesburg in the 1970s and 1980s, Amanda Esterhuizen and her colleagues at Wits have developed outreach programmes including popular publications, and John Parkington has built up the 'Living Landscape' project in Clanwilliam just north of Cape Town to train local people as archaeological guides and rock art interpreters. The Wits first-year archaeology class is now predominantly black and the number of black students in the senior years and Honours programmes in all departments of archaeology in South African universities is growing. Despite successes in the universities, the membership of the South African Archaeological Society remains primarily white and elderly, so there is still much work to be done in popularising the field in all communities.

The new National Heritage Resources Act, *Act 25 of 1999*, has changed the professional structure of archaeology to a significant degree. The legislation has firmed the role of the South African Heritage Resources Agency (SAHRA), and has set the framework for provincial heritage resources authorities that will devolve the administration of archaeological work to the provincial level. Under the Act, all archaeological and palaeontological material continue, as in earlier legislation, to be the property of the state and all excavations require a permit, but new rules have been legislated to deal with the sensitive issue of human burials. Where human remains are discovered accidentally or in the course of development, the age of the grave must be established in consultation with the police, and if it is older than 60 years and is outside a formal cemetery managed by a local authority, every effort must be made to trace relatives or a descendant community before it is removed. An even larger change brought about by the new Act is that property developers must have an assessment made by a professional archaeologist of the impact of their proposed development on heritage resources. These archaeological impact assessments have provided both employment for archaeologists and opportunities to explore new discoveries for information to fill the temporal and spatial gaps in our knowledge.

One important impact of the new legislation is the growth of the cultural resource management (CRM) section of professional

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archaeology. Professional archaeologists with a minimum of a Masters degree have set up private companies to do the necessary heritage resource assessments, and this has boosted the number of archaeologists gainfully employed in the country. But not all is positive. The current underfunding of the museums and the closure of the department of archaeology at SU have reduced opportunities in the academic sector. Many of the museum archaeologists have either supplemented their jobs with CRM work, or have left the museums entirely.

Of world importance is the proclamation of several South African archaeological and palaeoanthropological locations as United Nations Educational, Scientific and Cultural Organisation (UNESCO) World Heritage Sites. The first of these was the combined 'fossil hominid sites of Sterkfontein, Swartkrans, Kromdraai and environs' in 1999. The fossil sites, now also known as the 'Cradle of Humankind' not only contain places of scientific interest, but also locations of historical importance, two new museums, hotels and community social investment projects. The more distant fossil sites of Taung and Makapansgat were added in a UNESCO extension in 2005. The uKhahlamba/Drakensberg Park was listed in 2000 as a mixed heritage site not only for its natural beauty and fauna and flora, but also for its spectacular concentration of multicoloured rock paintings. The Mapungubwe Cultural Landscape was also declared a World Heritage Site in 2003 and plans are in advanced preparation to create a Transfrontier Park in the region shared by Botswana and Zimbabwe. These developments are extremely important in the development of ecotourism and also in the popularisation of archaeology on a national scale.

After a long period of development, the Institute for the Study of Human Evolution has finally been launched at Wits under its new director, Francis Thackeray. The institute is planned to be a home for the Hominin fossils held at Wits and will act as a research centre for scholars within the schools of geosciences and anatomical sciences and hopefully will also act as a focus for postgraduate studies and the training of South African students in palaeoanthropology.

The importance of archaeology and palaeoanthropology to South Africa must not be understated. There are more professional archaeologists and palaeoanthropologists in South Africa than in the rest of sub-Saharan Africa combined, and South Africa is the African leader in archaeological publications. The combination of our long archaeological record with its complexities of foragers, pastoralists, and agriculturalists sharing the landscape with the evidence of our ancient human roots in the form of the early Hominin sites, gives us an ancient heritage that few places on earth share. The importance of archaeology to the national psyche has been recognised in the new national medals awarded by government to South Africans of note. The 'Order of Mapungubwe' displays the gold rhinoceros found at the site against a background of the flat-topped Mapungubwe hill and is given to South African citizens who have demonstrated excellence and exceptional achievement in the public sphere, while the 'Order of iKhamanga' has one of the 6th century Early Iron Age terracotta heads from Lydenburg as a central motif and is awarded for excellence in the arts, culture, literature, music, journalism and sport. Fossil humans, archaeological sites and rock art are common themes on our postage stamp issues. Perhaps the most important theme from our past that is being used to bring us together is the motto on the 2004 national coat of arms. It reads: **!Ke e: /xarra //ke,** and means "Unity in Diversity" or more literally "Diverse People Unite". The words are in the language of the /xam, a San people whose language is no longer spoken and can only be found in the note books of Wilhelm Bleek and Lucy Lloyd written down in the 19th century, but the translated meaning of the words is a poignant call to nation building. Clearly the past has meaning in the present, and there will be a role for archaeologists and palaeoanthropologists for many years to come in South Africa.

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ENGINEERING

10 CHAPTER

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10.1 INTRODUCTION

This chapter presents a broad overview of the state of engineering in South Africa. Emphasis is given to the key drivers of the South African economy, highlighting some of the key challenges associated with economic growth. In particular, statistical analysis and contributions of various engineering disciplines to the development of the country are presented. An understanding of the statistical dimension is imperative in a complex society such as South Africa.

As a developing economy, South Africa faces many opportunities and challenges. Paramount among these is the issue of sustainability, given that South Africa, like most developing countries, is largely dependent on fossil fuels as a source of energy. The last 15 years have been characterised by unprecedented investment in infrastructure mainly due to the commitment of the government to a better life for all citizens of the country. Perhaps the most outstanding commitment in this regard is the provision of potable water to 15 million people who were previously not catered for in the formal supply infrastructure. The forthcoming 2010 *Fédération Internationale de Football Association* (FIFA) World Cup is serving as a catalyst for infrastructure development and maintenance across the country.

10.2 PROFESSIONAL SITUATION: PRACTICE AND TRAINING

Engineering encompasses a range of activities essential to a modern economy such as the development and maintenance of basic infrastructure, transport and energy, mining and minerals beneficiation, manufacturing and many other activities. Engineering professionals at various levels are required to service these and are regulated by the statutory Engineering Council of South Africa (ECSA) under the Engineering Profession Act, *Act 46 of 2000*. The core engineering disciplines recognised by ECSA are aeronautical, agricultural, chemical, civil, computer, electrical, electronic, industrial, mechanical, metallurgical and mining engineering. The major disciplines in terms of numbers of registered professional engineers are percentage wise (without considering various specialities) civil engineering (43%), electrical engineering (24%), mechanical engineering (19%), chemical engineering (5%), with other engineering disciplines constituting the remaining 10%.

With just under 15 000 registered professional engineers to service a population of 47 million people, or an engineer for every 3 200 people, engineering can be regarded as a scarce skill if the same level of service delivery is expected as, for example,