# Geological Atlas of Africa

Thomas Schlüter

# Geological Atlas of Africa

## With Notes on Stratigraphy, Tectonics, Economic Geology, Geohazards, Geosites and Geoscientific Education of Each Country

With contributions by Martin H. Trauth

2nd four-coloured revised and enlarged edition, with 417 figures and a CD-ROM

Springer

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ISBN: 978-3-540-76324-6 e-ISBN: 978-3-540-76373-4

Library of Congress Control Number: 2008923786

1st Edition 2006

Typesetting: Camera-ready by E. Sillmann

*Cover design:* WMXDesign, Heidelberg

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

# Acknowledgements

Over the last 10 years since the inception of the Geological Atlas of Africa Project, I have been fortunate to have had support from many individuals and institutions in several African, European and North American countries. My interest in the compilation of geological overview maps of Africa grew out from the conviction of my late supervisor, Walter G. Kühne, who had taught me that basic understanding of the geology of an area or region will never happen without initial observation of the respective available geological map. It is therefore my hope that by critical evaluation of the here presented maps further scientific work may be successfully carried out.

I am indebted to a great number of individuals for assistance in many areas beyond my own discipline of Historical Geology and Palaeontology. Financial support was received from DAAD (German Academic Exchange Service), namely Mr. Cay Etzold, Director of the DAAD Office in Nairobi from 2001–2005. My colleagues in the UNESCO Nairobi Office, Dr. Paul Vitta, Prof. Joseph Massaquoi, Alice Ochanda, and Dr. Robert Höft (now Toronto) provided an environment that was very innovative for the creation of the maps and the text of the atlas. Similarly I was encouraged by my colleagues at UNESCO Headquarters in Paris, Drs. Wolfgang Eder, Robert Missotten and Margarete Patzak, and at field offices in Windhoek, Alex Magarikakis, and Nairobi, Noeline Raondry-Rakotoarisoa. Profs. Britta Schütt (Berlin), Dieter Jäkel (Berlin), Jürgen Wohlenberg (Hannover), Volker Jacobshagen (Berlin), Wolf U. Reimold (Berlin), Martin Strecker (Potsdam), Eckart Wallbrecher (Graz, Austria), Peter van Straaten (Guelph, Canada), Theo Davies (Jos, Nigeria), Sospeter Muhongo (Pretoria, South Africa), Henry Kampunzu† (Gaborone, Botswana), Isaac Konfor Njilah (Yaounde, Cameroon), and Manuel Pinto (Porto, Portugal) contributed in many ways significantly to the final text and sometimes with photographs of various geosites. Dr. Andreas Berger (Potsdam), Wolfgang Zils (Berlin) and Dr. Christa Werner (Berlin) provided an invaluable mass of information on the geology of East Africa. To Dr. Wolfgang Wramik (Rostock) I am indebted for his contribution on the island of Socotra.

Digitizing of various printed maps was done by Dirk Spengler (Utrecht), Nadja Insel (Potsdam) and Stephen Mogere (Nairobi). The final layout of the maps and the complete page design was created by Dipl.-Ing. Elisabeth Sillmann (Landau/Pfalz).

I am grateful to Dr. Christian Witschel (Heidelberg) for the incorporation of this atlas into the Springer Geosciences Programme.

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# Preface

This atlas is intended primarily for anybody who is interested in basic geology of Africa. Its originality lies in the fact that the regional geology of each African nation or territory is reviewed country-wise by maps and text, a view normally not presented in textbooks of regional geology. It is my belief, that there has long been a need in universities and geological surveys, both in Africa and in the developed world, for summarizing geological maps and an accompanying basic text utilising the enormous fund of knowledge that has been accumulated since the beginning of geological research in Africa in the mid-19th century. I hope that, in part, the present atlas may satisfy this need.

The idea to compile the atlas resulted from my teaching experience at African universities for more than 20 years, and after I had witnessed that my colleagues there often had no access to geological overview maps, references and literature of other African countries, sometimes badly needed for teaching purposes. In western eyes Africa is often perceived only as a land of adventurers and explorers, but while Africa is undeniably diverse and different, it has never been a lost continent – only unfamiliar, underappreciated, misunderstood or forgotten. Anybody who has ever gone to Africa has taken a part of it away and left something behind. The results have not been always good, nor have they always been bad, but they have all gone into the mix that makes up the African society. The atlas is therefore intended to build capabilities and capacities at various places in Africa, so that the people there can later continue on their own with what I had begun.

The atlas is subdivided into four chapters centering on regional geological aspects of each African country or territory. The first chapter defines the scientific issues involved in the preparation of the atlas and provides some background for the arrangement of how the atlas was done. The second chapter is devoted to the history of geological mapping in Africa, necessary for a fuller appreciation of why this work in Africa is worth doing. Chapter 3 provides an executive summary on the stratigraphy and tectonics of Africa as a whole, i. e. in the context of no political boundaries. The main part of the atlas lies in Chapter 4, where in alphabetical order each African country or territory is presented by a digitized geological overview map and an accompanying text on its respective stratigraphy, tectonics, economic geology, geohazards and geosites. A short list of relevant references is also added. The atlas, essentially devoted to African geology, offers in a condensed way data on all aspects of current geoscientific issues that may in future contribute to the development of this continent.

Nairobi, February 2005 *Thomas Schlüter*

## Preface to the 2nd Edition

The commercial success and many well-aimed reviews of the first edition of this atlas have led after only 2 ½ years since its publication to a new edition, which in parts has been modified due to previously unknown data. Some of the maps are completely new and many photographs of geological sites were added. As the atlas shall be used preferentially by African geologists, I decided to add for each country or territory a paragraph on the current state of art of geoscientific education there. These data are based on departmental websites and were compiled mainly from a report on Geoscience Education in Africa submitted to the Ecological and Earth Science Division in UNESCO's Headquarter in Paris.

Nairobi, January 2008 *Thomas Schlüter*

**Fig. 1** Africa – survey of countries and territories

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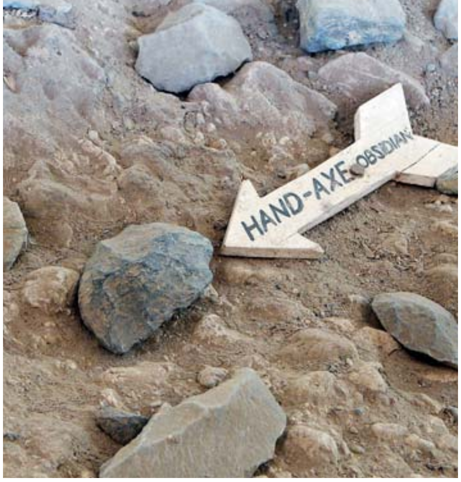
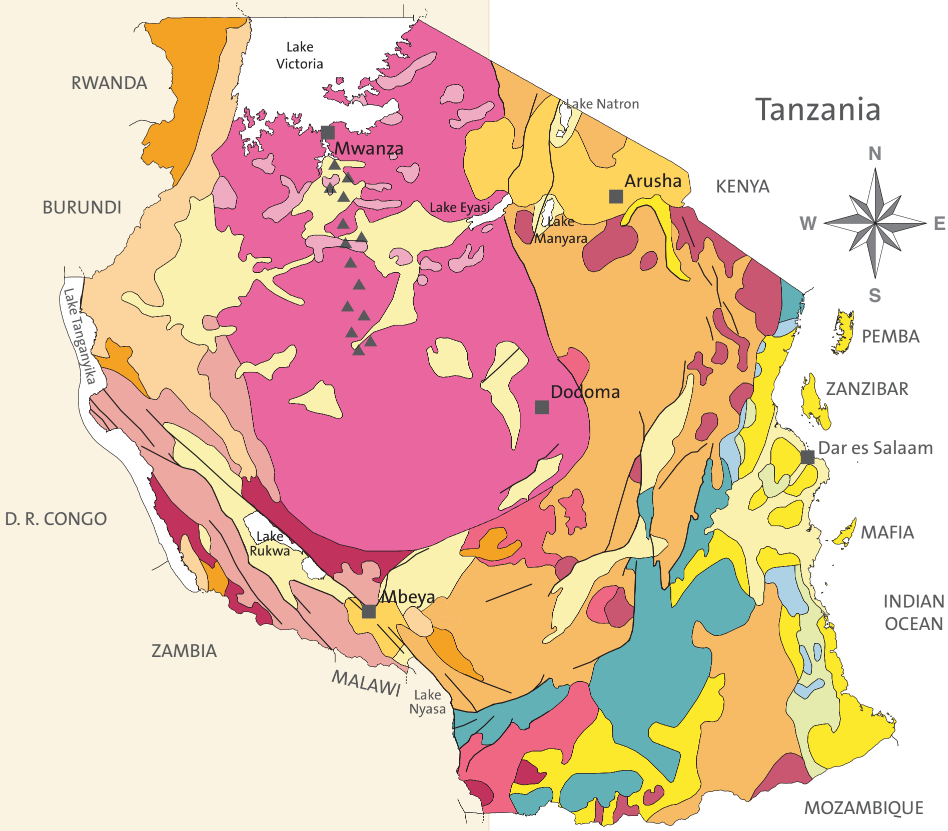


# Chapter 1

## Aims and Concepts of the Atlas



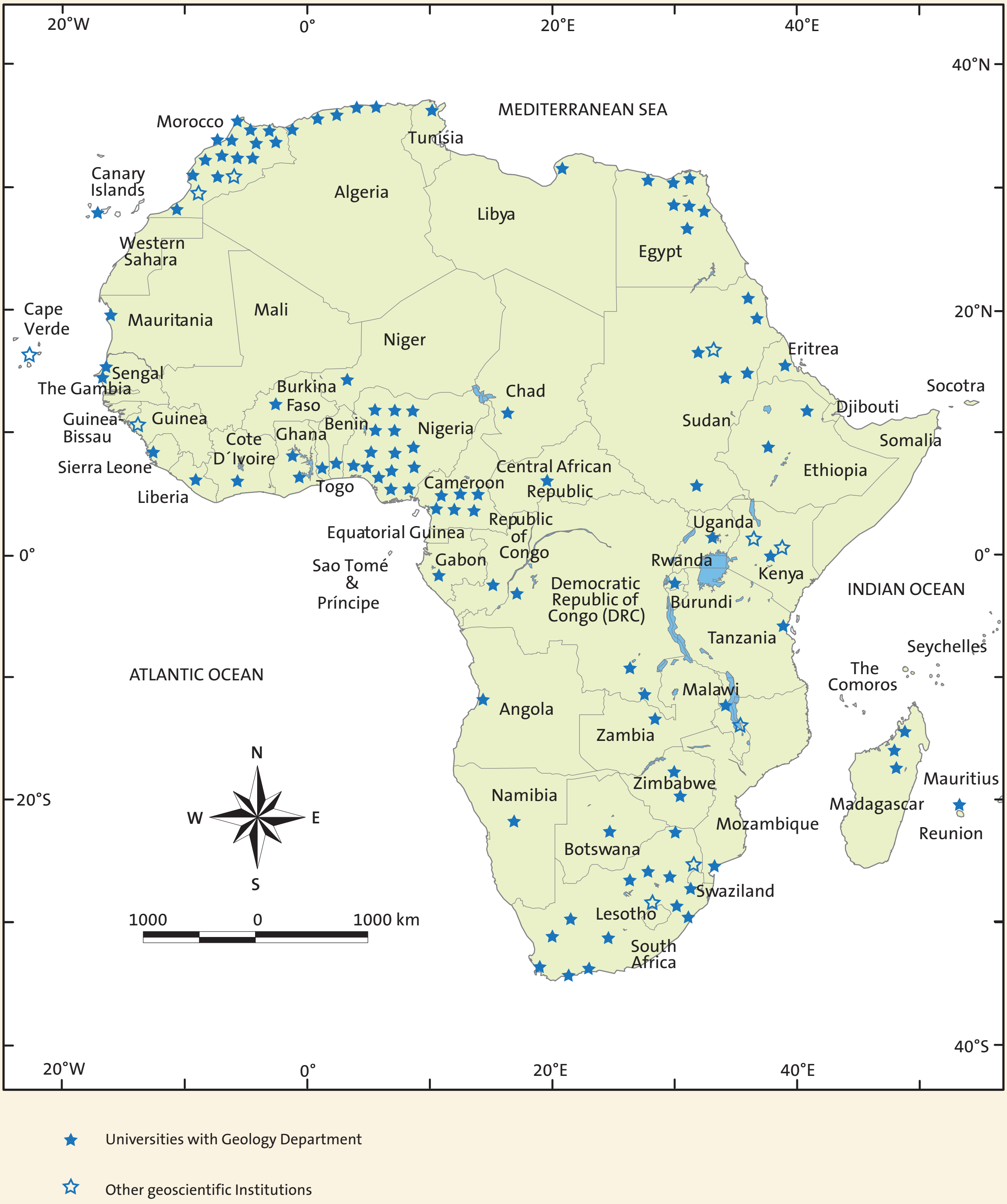


**Fig. 2** Universities with geology department and other geoscientific institutions in Africa (after Schlüter, 2007)

# Aims and Concepts of the Atlas

## 1 Geological Maps

The production of a geological map of a certain area is a means of making understandable the geology of this area in a relatively simple way. On such a map different rock types or related groups of rocks are represented, and these are shown as having formed at various periods during the history of the Earth. Each of these rocks formed under, or has been affected by, a definite set of conditions. Some of the rocks that are exposed at the surface today must at one stage have been deep down in the crust. Other rock types are from old mountain chains or old volcanoes. Some of the rocks formed under cold, glacial conditions, others in deserts, some in swamps, and many obviously under the sea. It is the piecing together of all the available information about the rocks themselves that will provide a picture of the geological development of each particular country or territory in this atlas.

Mapping of any topic has a long history. The oldest sketch maps were probably drawn on sand or snow thousands of years ago, whereas the most recent kind of maps are being created via the World Wide Web and can be sent to someone's mobile phone. There is, however, an inherent problem of maps: they are short-lived and need to be updated regularly. The Geological Atlas of Africa is aimed at compiling, enriching and updating the geological information that already exists, but which is distributed in a scattered way and often not available.

Production of the here presented geological atlas of Africa had to cope with discrepancies and differences on the following aspects:

- Level of detail; meaning that there are differences of details in the maps used as sources.
- Map scales. Due to the format used for the atlas, comparatively small countries appear in a very different scale than those that are larger.
- Harmonization of legends. All the geological maps used as sources have different colours for particular rock units and different definitions of stratigraphic and tectonic terms. The Global Stratigraphic Chart of the International Commission on Stratigraphy (ICS), published jointly by the International Union of Geological Sciences (IUGS) and UNESCO in 2000 (modified in 2004), indicates the international terms of the stratigraphic units currently in use, their relative and absolute age, and the respective colours of each unit, which shall be adopted for geological maps. However, these principles were in practice not always applicable in the geological atlas of Africa. To compensate this, additionally for a better discrimination in the here presented overview maps often colours used by the United States Geological Survey (USGS) were also applied.

## 2 Accompanying Text

The atlas seeks to portray the geology of each African country or territory as a whole, therefore apart from the digitized maps an accompanying text is included, which specifically is related to the stratigraphy and tectonics, economic geology, geoenvironmental hazards and geosites and the state of art of geoscientific education of each particular country or territory. Due to the available data it has rarely been possible to provide details significant at a regional level, and almost never at a local level.

### 2.1 Stratigraphy and Tectonics

As the text of the atlas tries to describe the geology of each African country or territory, it is basically related to their stratigraphy and tectonics, thus by building up a chronological sequence of events or processes through geological time. Once the sequence and the structure of a certain area are known, also the sequence of events and processes can be determined. To do this effectively involves, however, utilizing information and principles from virtually all of the diverse branches of geology. This is provided in the accompanying text on stratigraphy and tectonics for each country or territory, but it has to be considered that there exists for each country or territory its own geological nomenclature, based on the limited regional occurrence of certain rock types (Burollet, 2004).

### 2.2 Economic Geology

The 53 independent nations and six other territories of continental Africa and adjacent islands considered in the atlas are home for about 930 million people (2007). For many of these countries mineral exploration and production constitute significant parts of their economies and remain keys to future economic growth. Africa is richly endowed with mineral reserves and ranks first or second in terms of concentration (20 % to 80 %) of world mineral reserves of bauxite, chromite, cobalt, coltan (columbite-tantalite), diamond, gold, manganese, phosphate rock, platinum-group metals (PGM), titanium minerals (rutile and ilmenite), vanadium, vermiculite and zirconium (Coakley & Mobbs, 1999). Among industrial minerals the resources of limestone and dolomite were comprehensively investigated and reviewed by Bosse et al. (1996).

Although the continent attracted significant investment in mineral development, particularly in the gas and oil sector, widespread civil wars, internal ethnic or political conflicts and refugee displacements continued to destabilize a number of African countries and constrained new investment in mineral exploration and development in many areas. Countries directly affected in the early 21st century included Algeria, Angola, Burundi, the Democratic Republic of Congo, the Republic of Congo, Eritrea, Ethiopia, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Nigeria, Rwanda, São Tomé and Principe, Sierra Leone, Somalia, Sudan, Uganda and Zimbabwe. Negative economic impacts that resulted from the burden of military assistance provided to different sides of the civil war in the Democratic Republic of Congo were also felt by Angola, Namibia, Rwanda, Uganda and Zimbabwe.

The long-term implication of the HIV/AIDS epidemic on the workforce presents another disincentive to foreign investment and economic development on the continent. In several southern African countries, from about 20 to 35 % of the working age population are infected. HIV/AIDS is increasing the operating costs for the mining sector in many countries, where the social welfare and health-care costs of employees are absorbed by the mining companies (Smart, 2004).

International mineral exploration companies, in general, were cutting exploration expenditures over the last decade, some down to the minimum required to hold leases. Additionally, the lack of skilled labour remains a significant factor in the slow pace of mineral project development. The information on economic geology provided in the atlas is adopted from various informal sources and may not always bereflecting the latest state of art of exploration and exploitation of the respective mineral resources.

Geologists are not only instrumental in searching for and developing geological materials for humankind including metals, hydrocarbons and non-metallic minerals, but contribute to society also by delineating natural resources including those that are essential for our basic needs, principally water, shelter and food. Geology may therefore become a constructive tool for agricultural development, especially through exploration and development of fertilizer raw materials used either directly or in modified forms for the production of one of our most basic needs, food (Straaten, 2007). “Agrogeology, the use of rocks for crops”, is the title of a recently published book, which aims at making the use of rocks and minerals to improve soil fertility for the benefits of farmers. It provides information on the geological provenance of the major plant nutrients and micronutrients, which especially in Africa are sometimes agronomically extremely effective. This book may therefore make a significant contribution towards achieving the Millenium Development Goals (MDGs) of reducing the number of hungry and poor people globally.

### 2.3 Geoenvironmental Hazards

Although natural hazards and disasters seem to be inevitable, their catastrophic impact can be considerably reduced through various methods of pre-disaster planning and post-disaster reconstruction and rehabilitation. In many developing countries, characterized by heavy concentration of population, shanty towns, slums and marginal settlements, a natural hazard or disaster can lead to grave consequences even where its initial impact is not very severe. In this context the following distinctions have to be made for future planning exercises, and it is important to distinguish between hazards, disasters and emergencies: A hazard is a rare or extreme event or process in the natural or human environment that has the potential adversely to affect human life, property or activity to the extent of causing a disaster.

A disaster is the occurrence of a sudden or major misfortune, which disrupts the basic fabric and normal functioning of a society or community. An emergency is an extraordinary situation, in which people are unable to meet their basic survival needs, or there are serious and immediate threats to human life. Disasters and emergencies are therefore the consequences of hazards and may always be taken as the potential results of hazards. The following three categories reflect the types of hazards, which are considered and addressed in the atlas:

- Geophysical hazards, including earthquakes, landslides, volcanic eruptions and mudflows
- Environmental hazards, including erosion and

desertification
- Geochemical hazards, including natural contamination of soils and human-made pollution by mining and other activities

Disaster management requires response, incident mapping, establishing priorities, developing action plans, and implementing the plan to protect lives, property and the environment. Mapping and information acquisition is therefore vital for disaster management. Preparation of risk maps is essential for planning effective preparedness and response measures. Available technologies such as GIS and Remote Sensing provide analysis of environmental factors for the identification of potential geohazards and disasters. A comprehensive inventory of the major geoenvironmental hazards of the African countries has not yet been made, and it is therefore aimed in the atlas that there should be more efforts directed towards the development of an integrated geographical information system amongst various governmental institutions and non-governmental agencies that will help to minimize the effects of hazards and disasters.

### 2.4 Geosites

Across the whole continent of Africa there are many examples of landscapes, regionally specific rocks and fossil sites that provide key evidence of a particular moment or period in Earth history. Such Earth heritage sites are important for educating the general public in environmental matters. They also serve as tools for demonstrating sustainable development and for illustrating methods of site conservation as well as remembering that rocks, minerals, fossils, soils, landforms and activities like mining form an integral part of the natural world. However, it is only since 1996 that the International Union of Geological Sciences (IUGS) and UNESCO have been sponsoring the global GEOSITES project, which is aimed at compiling a global inventory of important geological sites of both scenic and scientific value.

Why is the preservation of geosites of importance? Firstly, in some instances the significance of certain sites for aesthetic or tourism reasons is obvious. There are numerous geosites, which could contribute to effective exploitation of geotourism, often in conjunction with ecotourism. The strategy employed to such sites involves close consultation with all communities in the vicinity of the respective geosite and is not only aimed at tourism and education, but also at sustainable improvement of the infrastructure of the people of this area. Geological heritage sites, properly managed, can generate employment and new economic activities, especially in regions in need of new or additional sources of income. Secondly, geosites are a medium of education, with regard to natural sciences, but also with respect to the mining industry and to history. This aspect involves such subjects as neoarchaeological and mining geological heritage. In Africa it is only South Africa, where an active community of geoconservationists has already provided an inventory of geosites in the country, which are for instance described and well-illustrated in the book of Viljoen and Reimold (1999).

### 2.5 Geoscience Education

Geology/geoscience education in Africa is currently in a crisis (Schlüter and Davies, 2008). As the continent has been plagued in the last decades by instability, including military coups, civil wars, periods of economic stagnation and the HIV/AIDS epidemic, the stress of living in such domestic and occupational scenes has also led to deficiencies in the basic training of geology/geosciences graduates and inadequaties in teaching resources and research facilities, including staffing, fieldwork, library equipment and student attitude. Altogether there are in Africa about 100 university departments and other geoscientific institutions that offer undergraduate courses in geology/geosciences (Fig. 2), roughly meaning in average one geology/geosciences department for 10 million people. Classical mining countries like South Africa yield for a population of about 48 million people at least 13 universities with geology/geosciences departments, while some of the smaller countries do not provide an education with geoscientific background at all. Countries like Morocco, Nigeria and Egypt have quite a number of geology/geosciences departments with sometimes large personnel capacities, but are institutionally often rather poorly equipped. Political instability has contributed to the deterioration of geology/geosciences departments in Burundi, Rwanda, Liberia, Sierra Leone and Somalia.

In the midst of the training and educational crisis, however, some good research is still coming out, albeit minimal. But African research results are rarely indexed in major international databases, a problem that is further exacerbated by the inaccessibility of theses and dissertations complemented in the respective region, many of which contain local empirical data that are often not available in international literature.

Specialization in fields such as remote sensing and GIS, hydrogeology, engineering geology, micropalaeontology, etc., accompanied by some practical orientation even at the undergraduate level, will without doubt enhance the chances of African geology/geoscience graduates acquiring jobs in the mining, engineering and water sector or in other relevant areas. The establishment of regional networks linking existing institutions and other agencies is a means of upgrading the teaching of Earth science graduates and providing special training in the latest techniques and concepts. Network activities include exchange of information, organization of regional workshops and specialized training courses for staff, improvement of mechanisms to allow Earth scientists to meet on the regional and international levels, and cooperative use of the scarce resources and equipment.

## 3 Conclusions

As already outlined in the epilogue for the Gondwana 10 Symposium (Cape Town 1999) by Ashwal and De Wit (2000), much of the research work that currently takes place in Africa is done by non-Africans. The reasons for this are complex and involve sociological, political and financial elements. Africa as the focal area of Gondwana has apparently been rediscovered in recent years, and it is therefore vitally important that this interest and research effort from countries external to Africa is balanced against a growing interest from within the continent. Under ideal conditions, scientists from the first world should consider their counterparts in the south as full and equal colleagues, but this is often not the case. This is especially important in the acquisition, handling and sharing of large and frequently disparate datasets. Considerable responsibility also rests on the shoulders of geoscientists, who live in Africa, to communicate amongst themselves, not only to welcome colleagues from outside the borders of their countries, but also to maintain and enhance their passion for a collaborative effort in understanding this spectacular natural laboratory. It is therefore the aim of this atlas to contribute to capacity building and extended communication in African Earth sciences, both within the continent and outside, and to initiate new research opportunities by providing a database of basic geological background information of this continent.

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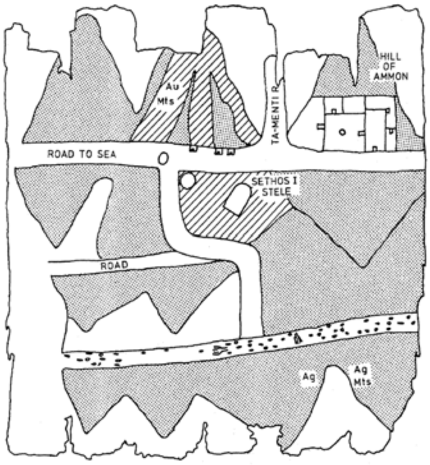
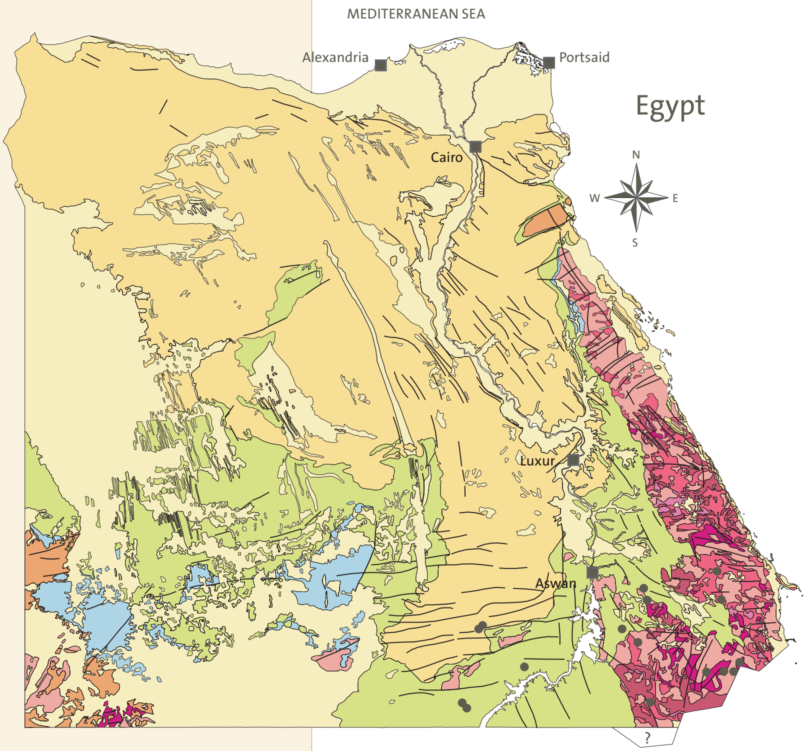
# Chapter 2

## Early Geological Maps of Africa





# Early Geological Maps of Africa

William Smith (1769–1839), an English engineer and surveyor, began at the end of the 18th century to collect fossils from successive beds, which he had observed in the course of his journeys across England. He realized that each stratum could be recognized by the fossils found in it, and that the same succession of strata could be observed wherever the rocks concerned were found. In 1815 appeared as a result of his investigations the large geological map of England and Wales with an accompanying explanation. This is the earliest large-scale geological map of any extensive area or country (Winchester, 2001), although similar efforts had already been made since the late 18th century in Saxony by A. G. Werner (Wagenbreth, 1998). A preceding attempt of these early scientific geological maps should here, however, be mentioned, because of its origin in Africa: Undoubtedly existed in ancient Egypt a highly developed surveying and engineering system, but unfortunately almost no cartographic proof of it is known – except a map drawn on a papyrus, which is currently kept in the Museo Egizio in Turin. It was apparently prepared during the 19th Dynasty under the reign of the Pharaoh Sethos I, together with his son Ramses II, who was initiating new mining operations for gold in the Eastern Desert of Egypt, because the traditional nearer accessible supplies had been exhausted. One of these areas for exploration may have been in the Wadi Hammamat and is figured on the Turin Papyrus, exhibiting apart from topographic details also the occurrence of silver and gold bearing deposits (Bowen & Jux, 1987) (Fig. 3). It is therefore a kind of a geological map, surely the oldest known attempt to draw somehow geological units. The oldest scientific geological map of Africa originates also from Egypt and was already compiled by R. Russeger in 1842 (Fig. 4). The term "Nubian Sandstone", which characterizes mainly continental and sandy deposits, and which is sometimes still in use today, is mentioned for the first time in this map. Until recently, this chronolithological unit was considered to be stratigraphically indivisible. Recent research has shown that these rock sequences comprise differentiated strata containing intercalations of marine sediments.

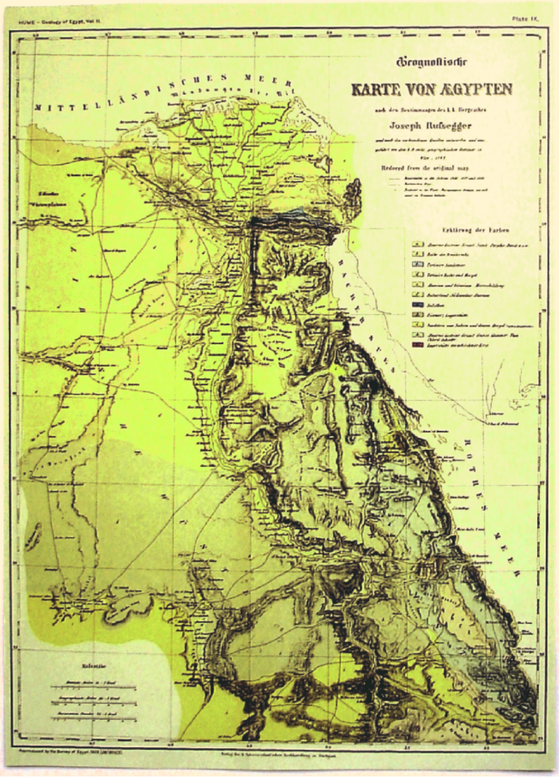


**Fig. 4** Geological map of Egypt, published by Russeger (1842)

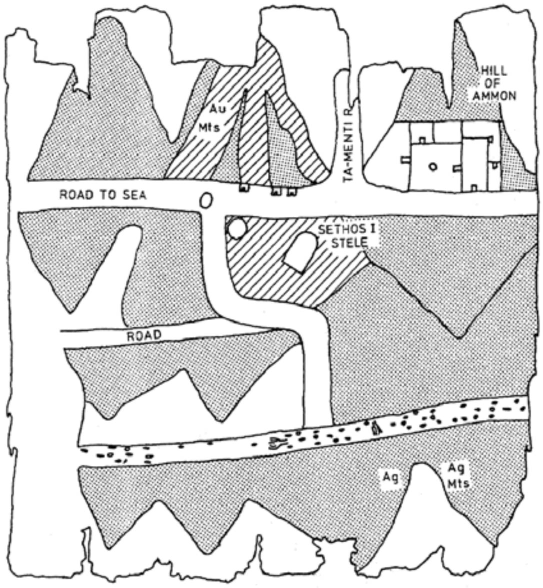


**Fig. 3** Pharaonic map of gold mining areas in Wadi Hammamat, Eastern Desert, Egypt

Geological maps have sometimes been produced without proper knowledge of the topography of the concerned area, as can be seen from the geological map published by Sadebeck (1872) on East Africa, in which the Great Lakes region of central eastern Africa is very poorly figured, but surely because the famous explorers like Livimgstone, Stanley, and von Höhnel had not yet reported about their discoveries there. In 1880 the Scotsman Joseph J. Thompson presented in the journal Nature the first geological field account of a sector of the East African Rift System, that of Nyanza, in which he included three cross sections. As a result of his traverses Thompson postulated a zone of volcanism extending from the Cape to Ethiopia, roughly parallel to the Indian Ocean. From 1883 to 1886 the German naturalist Gustav A. Fischer mapped the rift grabens of southern Kenya and northern Tanzania. Notably is a detailed geological map at a scale 1:50,000, which he included in his 1884 publication. Less than 15 years later Gregory (1896) was already able to draw a rather comprehensive and exact picture of the geology of the Kenya Colony and the northern part of the then German East Africa (Schlüter, 2001) (Fig. 5). Similarly in the grade of accuracy has also been prepared the geological map of the Karoo Basin and adjacent areas in southern Africa (Rogers, 1905) (Fig. 6). The stratigraphic sequence of the Karoo System (or Supergroup as it is termed today), subdivided into Dwyka, Ecca, Beaufort and Stormberg Series, had already been established, and their paleoenvironment carefully evaluated.

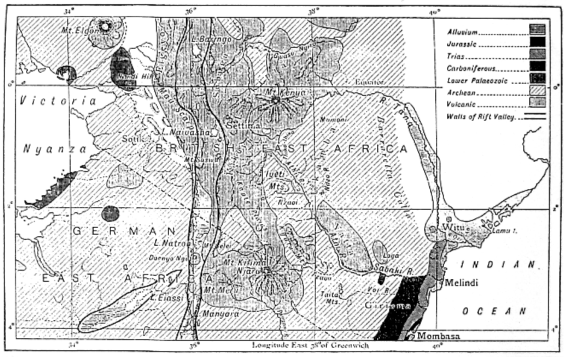


**Fig. 5** Geological sketch map of the southern part of the Kenya Colony and the northern part of former German East Africa (from Gregory, 1896)

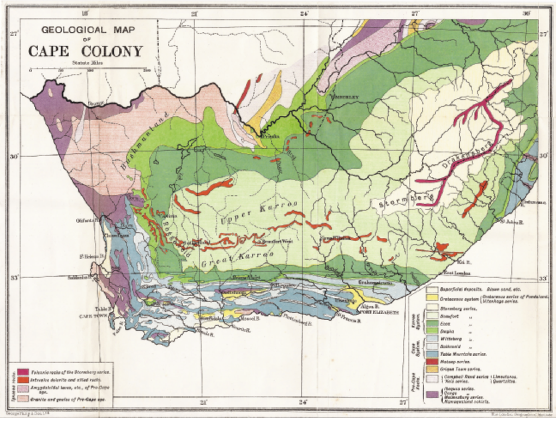


**Fig. 6** Geological map of the Cape Colony (from Rogers, 1905)

There is, however, one aspect that was largely omitted by the pioneering geologists of the late 19th century almost up to the middle of the 20th century: The Precambrian basement comprises by far the largest share of rocks on the continent, but often the monotony of its facies as well as the inability to date these formations sufficiently were probably the two striking reasons, why comparatively few publications on the Precambrian strata were then published. Geologists of this time had no other tools than lithostratigraphic comparisons, which, of course, were not sufficient to correlate these formations precisely (Furon, 1968). Arthur Holmes (1890–1965), whose book "The Age of the Earth" had already appeared in 1913, was a scientist, who devoted a major portion of his career to the application of radioactivity in the solution of geological age dating. It is remarkable that his calculations and hence resulting definition of the Mozambique Orogenic Belt were based on less than 25 radiometric ages, when he gave his memorable address to the Association of African Geological Surveys at the International Geological Congress in London in 1948 (Holmes, 1951). He provisionally dated the Mozambique Orogenic Belt to be approximately 1,300 Ma old, an age today indicative for the Kibaran Orogenic Belt, but at least much younger than the previously assumed Archean age. Therefore, when Holmes defined the Mozambique Orogenic Belt as extending from south of the Zambezi River to the extreme north of Kenya, Uganda and southern Ethiopia, the stratigraphic and structural map of equatorial and southern Africa received a new face (Fig. 7), which basically still holds today. In a compilation prepared by Arthur Holmes and Lucien Cahen (1912–1982), the latter being another father of Precambrian stratigraphy of Africa, in 1954, the number of radiometric ages in Africa had grown to approximately 100, and by 1956 the same authors were able to list about 300 ages. In their summarizing book "The Geochronology of Equatorial Africa", Cahen and Snelling (1966) considered more than 550 determinations. During the early fifties, the K:Ar and R:Sr methods had been established on a

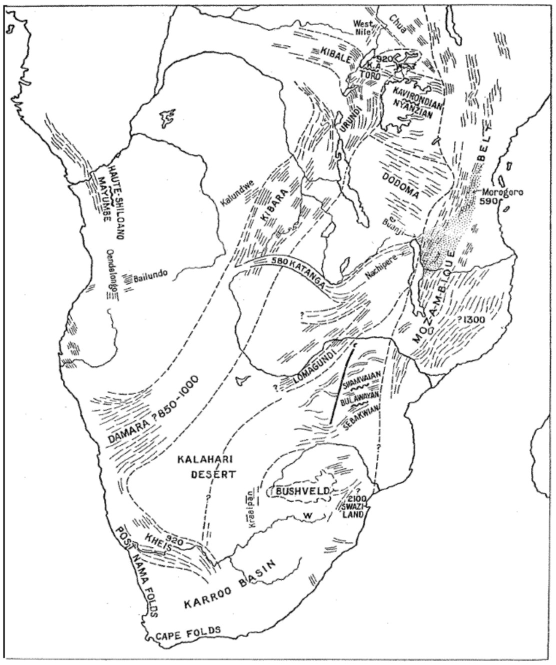


**Fig. 7** Orogenic belts in southern and central Africa as proposed by Arthur Holmes in 1948 (Holmes 1951)

virtually routine basis, while the older U-Pb method had become even more firmly entrenched.

On the other hand it has to be pointed out that Cahen et al. (1984) in their famous and, currently probably most quoted book on the Precambrian stratigraphy of Africa, are of the opinion that much of the former isotopic evidence is of relatively poor precision, and that the data obtained for the variation of initial 87Sr:86Sr ratios through place and time with respect to Africa will probably soon become only of historical interest. Accordingly, also the abundant U-Pb data achieved before 1984 should for similar reasons largely be ignored. Cahen et al. (1984) predict for future stratigraphic investigations isotopic variations of strontium, lead and neodymium, whereas they are skeptical about palaeomagnetic studies.

Publication of quarter degree sheet geological mapping at various scales began in Africa since the beginning of the 20th century, sometimes only in the 1930's, and was linked to the establishment of Geological Surveys in the respective countries. It was assumed that these institutions might provide sound and reliable geological maps as a basic prerequisite for the development of potential mineral resources. It was during the colonial administration also anticipated that private mining companies were not expected to take serious interests in initiating detailed mineral exploration projects before having at their disposal geological maps indicating the nature, distribution, composition and structural relationships of the various rocks in the respective areas. Geological maps were prepared predominantly in a scale 1:125,000, sometimes 1:100,000. Some geological maps with various aims in a smaller or a larger scale were sometimes also issued. Quarter degree sheet mapping of Africa has, however, never been completed, and it has to be pointed out that the advent of independence for most African countries in the 1960's and the cease of publication of geological maps from there are almost coincident. For example, although about 80 % of Tanzania is now geologically mapped, only 116 of the foreseen 322 map sheets have yet been published, probably because there are currently no sources for their printing available.

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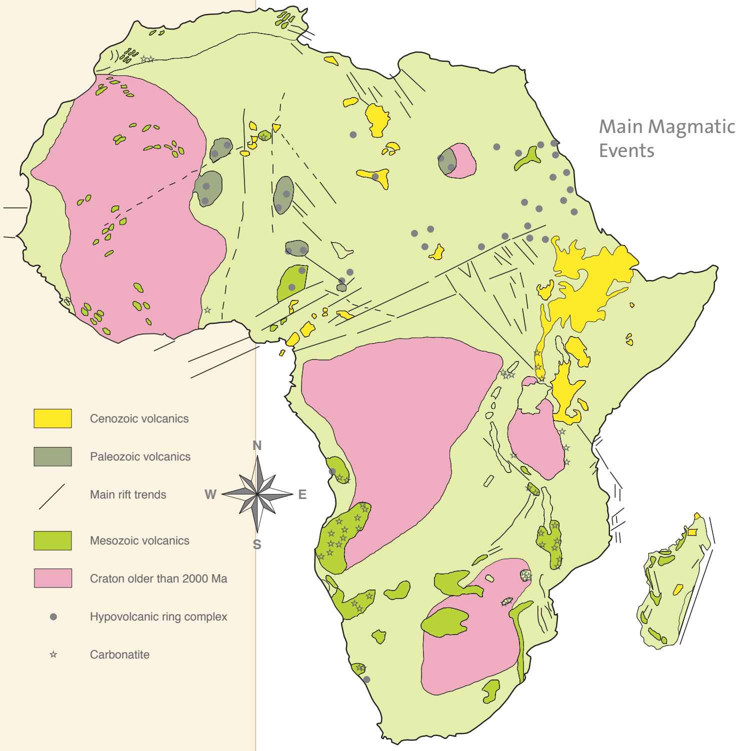
# Chapter 3

## Tectonostratigraphic Synopsis



Main Magmatic Events

# Tectonostratigraphic Synopsis

## 1 Introduction

Africa encompasses a land area of 30.3 million km$^2$, occupying about one-fifth of the land surface of the Earth. From a geological viewpoint it is a very old continent spanning at least 3,800 Ma of the Earth' history. Practically the whole of the continent is underlain by Precambrian basement. Phanerozoic cover rocks are only of limited areal extent. The following executive summary on the stratigraphy and tectonics of Africa in a comprehensive context is mainly based and adopted from papers published by R. Key (1992), A. J. Boucot (1999) and A. B. Kampunzu & M. Popoff (1991).

The crystalline basement of Africa is composed of metasedimentary, meta-igneous and igneous rocks, which vary in age from Paleoarchean to Cenozoic times. Within the Precambrian crystalline blocks, granitic-gneissic greenstone belts of the Archean cratonic nuclei are surrounded by essentially Proterozoic orogenic provinces often referred to as mobile belts. Parts of the crystalline basement are igneous intrusions associated with anorogenic magmatism. The heterogeneous basement is extensively concealed beneath a variable thickness of diverse, essentially unmetamorphosed supracrustal cover rocks. These also vary in age. The oldest cover rocks are the Archean and Paleoproterozoic sedimentary and volcanic sequences capping the Kapvaal Craton: the Pongola, Witwatersrand, Ventersdorp, Transvaal-Griqualand West and Waterberg-Soutpansberg-Matsap Supergroups. The youngest cover sequences include the Cenozoic volcano-sedimentary deposits associated with rifting, notably within the East African Rift System, and the partly consolidated sediments, such as the Kalahari Supergroup, currently infilling the major crustal depressions.

## 2 Archean Cratonic Nuclei (Fig. 8)

### 2.1 General

Large parts of the Congo Craton and of the cratonic nuclei in western and northern Africa are covered mainly by unconsolidated Cenozoic deposits. This means that their geological histories and areal limits are imperfectly known. The western part of the southern African Archean province is also concealed by up to 200 m of the Kalahari Supergroup, but geophysical studies and subsequent drilling operations have established its main geological components. Detailed geological mapping and geochronological studies have shown that all the Archean cratons have been reworked, at least marginally, during several Proterozoic orogenesis. The principal components of the Archean cratonic blocks (excluding the Limpopo Mobile Belt between the Kapvaal Craton and the Zimbabwe Craton) are predominantly low-grade greenstone belts, extensive areas of high-grade gneisses, granitic series including several phases of migmatites, and usually ending with anorogenig K-granites, and late minor intrusions.

### 2.2 Greenstone Belts

Two sequences of greenstone belts are generally recognized in the major cratonic nuclei except the Kapvaal Craton, which prematurely stabilized (at about 3,050 Ma) prior to the formation of the second generation of belts. The oldest greenstones were laid down between about 3,550 Ma and about 3,050 Ma. They commonly have precursor gneiss foundations, which include definite metasedimentary components. Within these greenstone belts there are essentially single cycles from basal, mainly basic, volcanics with diagnostic high-MgO rocks (komatiites), upwards into clastic sediment-dominated sequences. They are best preserved on the Kaapval Craton and central parts of the Zimbabwe Craton. The Barberton Greenstone Belt in northeastern South Africa and Swaziland serves as an excellent example of the lithological content of the older belts. Unusually, the older volcanics of the Tanzania Craton, referred to the Nyanzian Group, may have a higher proportion, up to 75 % of the volcanic pile, of andesites, although it is doubtful if the lower part of the Nyanzian is ever seen. The younger greenstone belts were laid down between about 2,800 Ma and about 2,600 Ma. They appear to be slightly older in the West African Craton relative to the central African cratons, although there was a minor development of greenstone belts on the Zimbabwe Craton at about 2,950 Ma. All these belts again comprise single volcanic cycles from basal basic lavas up into more felsic pyroclastics. Both bimodal and calc-alkaline volcanic sequences are recognized. Bimodal assemblages are found in the basal parts of younger belts and contain abundant mafic and ultramafic rocks with minor felsic volcanics and cherts and very little andesitic material.

Upper volcanics in younger belts have calc-alkaline affinities and vary from ultramafics through andesites to felsic rocks with associated greywackes. Mineral variations are used to distinguish up to six types of amphibolites (altered mafic volcanics). However, they have similar whole rock chemistries, which closely correspond to oceanic tholeiitic basalts.

Sedimentary sequences are important in the youngest greenstone belts, e.g. the Shamvaian Group on the Zimbabwe Craton, the Kambui Supergroup of West Africa, the Kavirondian Group of the Tanzania Craton, and the upper Congolian Group of the Congo Craton. The sediments consist of intercalated beds and lenses of chemical and clastic deposits, which form highly variable proportions of greenstone belts within individual cratons. Thus, although the average proportion of metasediments within the younger greenstone belts of the Zimbabwe Craton is about 15 %, the Vumba Greenstone Belt contains minor metasediments, while the adjacent Tati Greenstone Belt has major metasedimentary formations. Typical metasediments in the greenstone belts are Algoma-type banded iron formations (BIF), marbles, calc-silicates, metaquartzites, coarse clastic rocks (conglomerates, arkoses, etc), aluminous shales, black shales, greywackes and reworked volcaniclastics. These show wide grain-size variations and are chemically varied. The ironstones have along-strike facies variations from chert-hematite/magnetite associations into carbonates and sulphides. Typical greenstone belt mineralizations are indicated by gold dissemination in the metavolcanics or concentration in fracture-controlled veins, or by volcanogenic base metal deposits. The greenstone belt terrains have distinctive hilly landscapes controlled by the varied bedrock.

Greenstone belts are least common in the Kaapvaal Craton, where only the oldest are represented, and most common within the Zimbabwe Craton and northern half of the Tanzania Craton. The belts are broadly linear throughout the West African Craton and are of higher metamorphic grade (up to granulite facies). Within other cratonic domains, the greenstone belts have only suffered greenschist facies metamorphism apart from marginal zones at amphibolite facies. It is possible that the high-grade West African greenstone belts represent disinterred basal remnants. The varied distribution of the greenstone belts of up to 20 % by area of each craton, may be due to a combination of tectonic disruption and variable erosion. At deeper crustal levels granitoid rocks may dominate, especially if the greenstones are compressed within tight synclinal folds.

## 2.3 Granitic Series (Including Gneisses) and Late Minor Intrusions

Granites, roughly contemporaneous with spatially associated greenstone belts, are recognized in the main cratonic nuclei. Two main granitic series are recognized, one encompassing igneous activity between about 3,600 Ma and about 3,100 Ma, and the second between about 2,950 Ma and 2,450 Ma. The older series commenced with high-grade migmatites, which are certainly as old as the adjacent greenstone belts (e.g. the Ancient Gneiss Complex of Swaziland), or older as the basement in the central African cratons. Metasediments and orthogneisses are present in the early migmatites, which are recognized on all the cratonic nuclei. However, the succeeding intrusions have only been mapped and placed into a chronological order in the southern African cratons. Here various major synorogenic tonalitic and trondhemitic intrusives cut the early migmatites and older greenstone belts and were succeeded by anorogenic potassic granite plutons. The early sequence is repeated by the second granite series, characterized by calc-alkaline trends, which is much more widely recognized. The migmatites, which floor younger greenstones generally record ages of about 2,950 Ma, or they are slightly younger. The succeeding granitoid intrusives generally show progressive increases in $K_2O/Na_2O$ ratios from early tonalitic plutons to anorogenic potassic granites. These relatively sodic, early rocks underlie featureless plains, whereas the later G3 plutons form positive outcrop features, locally with a thick saprock. The relatively high potassium content and the abundance of quartz means that the saprock is not broken down into a thick soil cover. The emplacement of potassic granites generally marks the end of the Archean orogenesis. This was a diachronous process, from about 3,050 Ma (Kaapval Craton) to about 2,600 Ma for the Zimbabwe Craton and about 2,450 Ma for the central African cratons.

## 2.4 Tectonothermal Events

Complex vertically plunging structures dominate the early (3,600–3,200 Ma) African cratonic areas. However, detailed studies of the younger Archean cratonic areas have revealed polyphase tectonothermal histories similar to those established for Phanerozoic orogenic belts. Regional folding produced nappes followed by static metamorphism and emplacement of tonalitic plutons into folded metasedimentary and metavolcanic rocks. After these early

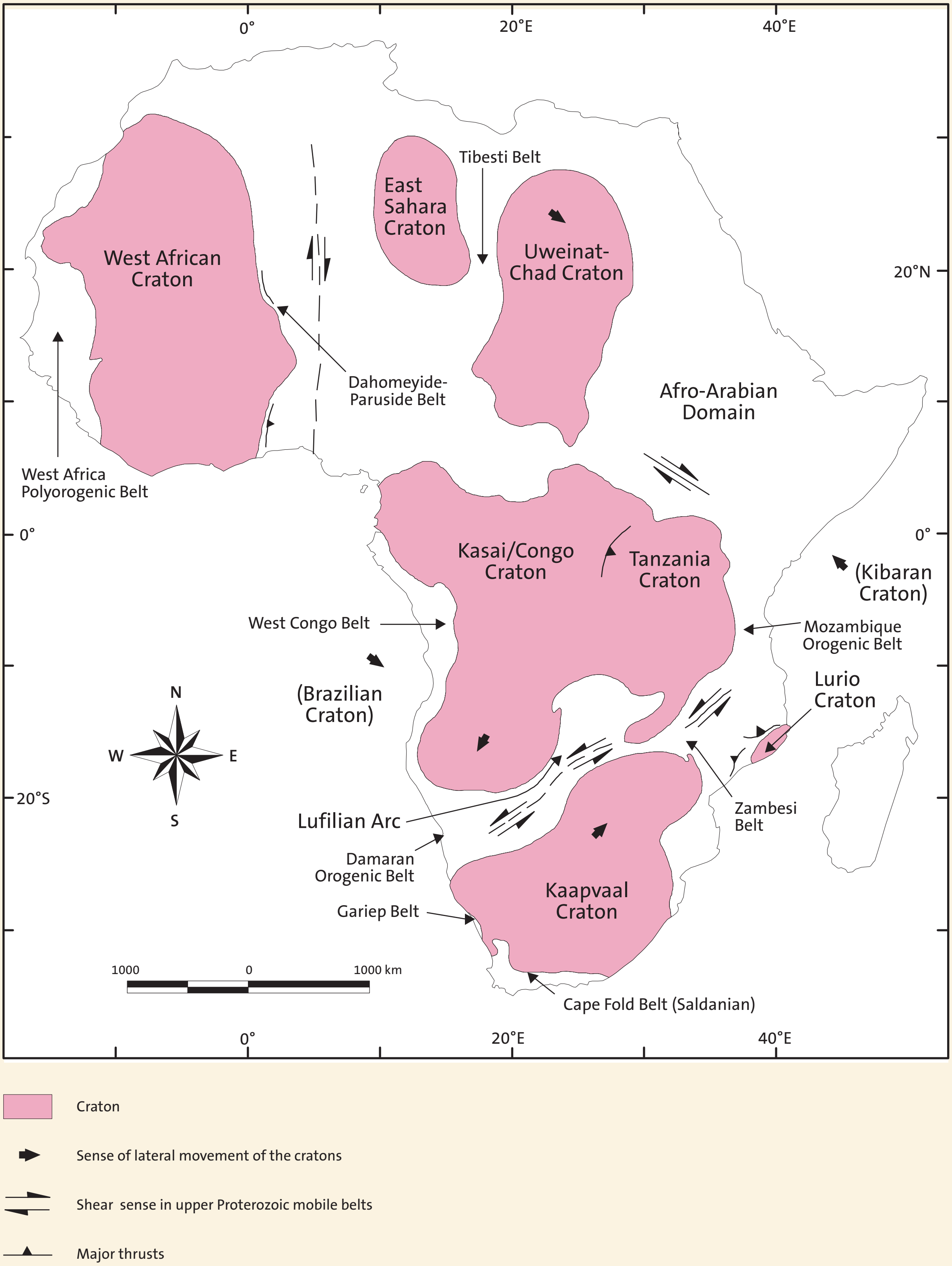


**Fig. 8** Assumed extension of the Archean cratonic nuclei (after Key, 1992)

events the greenstone belts were isolated as relatively low-grade schist relics within higher-grade gneisses. Further ductile and subsequently brittle tectonothermal events were roughly contemporaneous with the final phase of the granite series. Although the final tectonothermal events were relatively weak compared to higher-grade earlier events they have a critical influence on groundwater storage. These late events generated open folds and crenulations in addition to brittle faults and fractures, which are locally important aquifers. Retrogressive metamorphism produced hydrous mineral phases, which made the host rock more susceptible to weathering. The average regolith thickness over the Zimbabwe Craton is about 18m, and is generally from 10 to 30m in West Africa. Undoubtedly there were unique features to Archean geology caused by secular changes to the lithosphere. The older greenstone belts are thought to have originated above mantle plumes, due to the existence of hotter, thinner and more mobile crust within ensialic rifts. However, the recognition of the similarities of the geological histories of younger (post –3,200 Ma) Archean cratons and Phanerozoic orogenic belts has generally led to uniformitarian interpretation of the older provinces. For example, the youngest greenstone belts are regarded as fragments of oceanic volcanic terrains accreted to continental nuclei during orogenesis. Consequently the development of the younger Archean cratons is often likened to that of younger orogenic provinces including the Proterozoic mobile belts recognized in Africa. Tankard et al. (1982) have described an evolutionary path from mobile belt to craton with gradual lateral growth of African continental crust throughout the Precambrian. Key (1992) assumes that this is probably an oversimplification as major disruption of the Archean cratonic blocks took place during the various Proterozoic orogenies and it is still unknown, how much continental crust was present by the end of the Archean.

Strike-slip shears and transcurrent faults, over 100 km in length, are characteristic features of modern lithospheric plates. Their existence indicates relative horizontal movement between adjacent competent crustal/lithospheric segments. Therefore the presence of Archean shears of comparable length can be used as evidence for large, coherent Archean crustal blocks. In Africa, the oldest of these megashears is found in the Limpopo Mobile Belt, where they have a maximum age of 3,000 Ma. A logical follow-up of this argument is that the early greenstone belts of the Archean areas, which are older than the major shear zones, formed in environments devoid of large stable blocks of continental crust. Their generation cannot therefore be related to Wilson-cycle plate tectonic processes, but they may have originated above mantle plumes.

### 2.5 The Limpopo Mobile Belt

The Limpopo Mobile Belt trends in a WSW-ENE direction for about 690 km with a maximum width of about 200 km. It separates the Kapvaal and Zimbabwe Cratons and is dominated by high-grade gneisses and lacks the low-grade greenstone belts, tonalitic plutons and anorogenic potassic granite batholiths normally associated with Archean provinces. Orogenic development between about 3,200 Ma and about 2,500 Ma was dominated by differential (vertical/strike-slip) movement between the Kaapvaal Craton and the ancient central areas of the Zimbabwe Craton. The Limpopo Mobile Belt may be referred to as a linear buffer zone as typical for Proterozoic mobile belts. The Great Dyke in Zimbabwe (emplaced at about 2,450 Ma) cuts across the Zimbabwe Craton-Limpopo Mobile Belt boundary to provide a minimum age for the stabilization of the southern Africa Archean Province.

## 3 Paleoproterozoic Basement Development (Fig. 9)

During this period in excess of two thirds of the present African continental crust was affected by a similar sequence of events to those recorded from the Archean cratonic nuclei. However, controversy remains with regard to the proportion of Archean material adjacent to the nuclei in the surrounding Paleoproterozoic provinces. This is due mainly to a lack of detailed geological and geochronological knowledge of the Paleoproterozoic provinces, together with poor exposure in many areas, notably northern Africa. However, an increasing amount of isotopic data does imply that a significant amount of new crustal material was introduced around the Archean cratonic cores.

Low-grade supracrustal sequences are more widely preserved than in the Archean cratons. The oldest supracrustals are clastic metasediments derived from Archean cratons during the long period of uplift and weathering at the beginning of the Proterozoic. They include the altered quartzites, pelites and banded ironstones of the Luiza Supergroup of equatorial

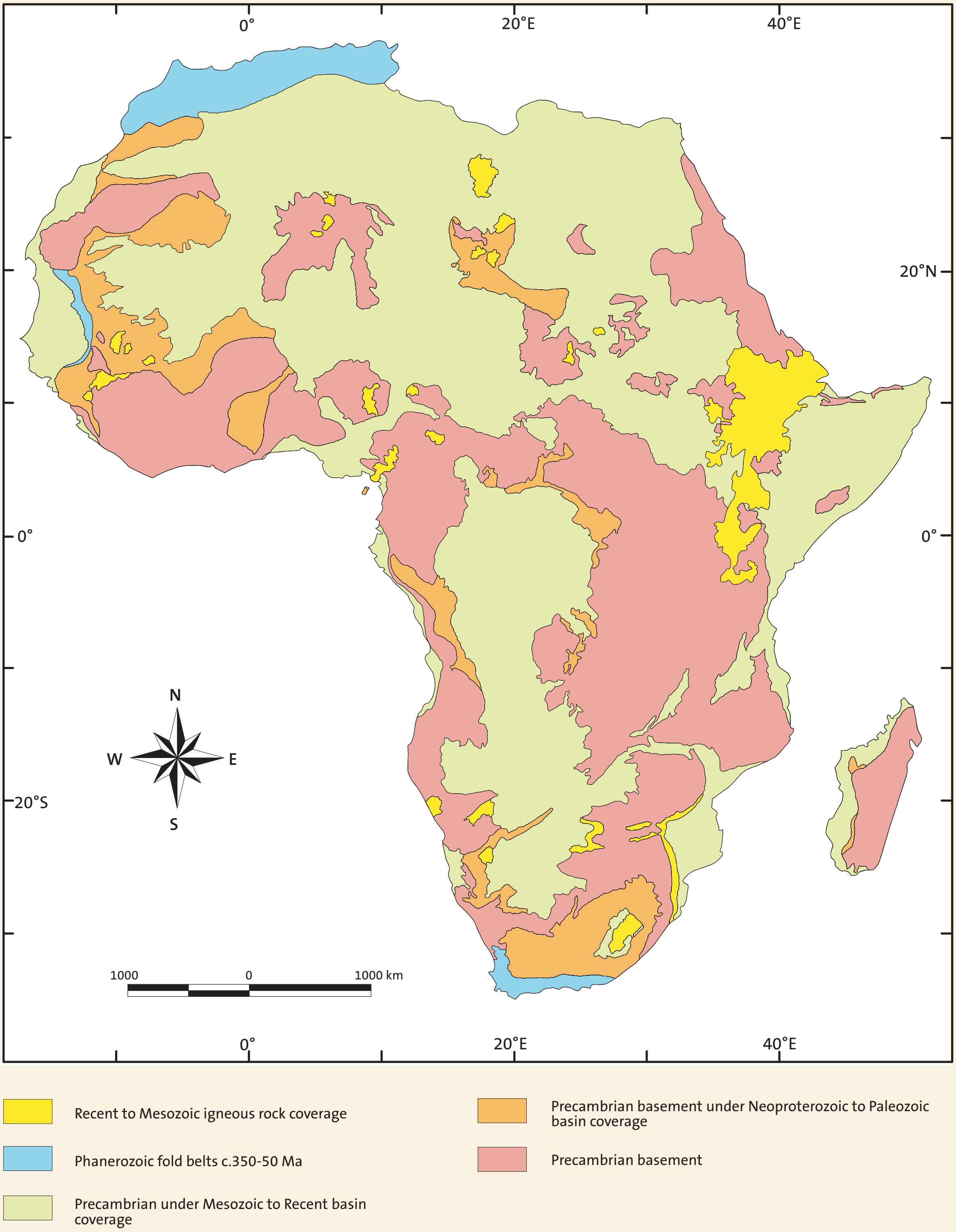


**Fig. 9** Exposure of Precambrian rocks, partly under younger coverage (after Key, 1992)

Africa and the Oendolongo System of southern Angola, which is dominated by metaconglomerates. The main supracrustal sequences in the 2,250–1,950 Ma orogenic belts are lithologically similar to those of the Archean greenstone belts. These include the Birrimian Supergroup in West Africa (up to 15,000 m thick in Ghana), the Mporokoso Group (up to 5,000 m thick) of the Bangweulu Block, and the Buganda-Toro Supergroup in eastern equatorial Africa locally interpreted from geochemical evidence, as accreted slabs of ocean crust. The Birrimian Supergroup is characterized in Ghana by five parallel, evenly spaced, several hundred kilometre-long volcanic belts, separated by basins with folded volcaniclastic and clastic sediments as well as granitoids. A lower, thick sequence dominated by alternating phyllites and greywackes with associated slates, schists and tuffs is overlain by a group of volcanics with minor sedimentary intercalations. Basic lavas and associated intrusives, and less common acidic lavas and pyroclastics, comprise the Upper Birrimian Group. The erosion of the Birrimian volcanics and sediments produced the Tarkwaian Group sediments, which were deposited in long narrow intramontane grabens, which formed by rifting in the central portions of all five Birrimian volcanic belts.

Associated with the supracrustals is a wide range of intrusions. Alkaline granite series, featuring early large syntectonic plutons are recognized within the main orogens. These include major granodiorites and potassic granites occupying antiformal zones between synforms defined by Birrimian supracrustals in the Baoule-Mossi Province of West Africa. The large gabbro-anorthosite complexes of southern Angola were also emplaced in the earliest orogenic stages. Migmatites appear to have Proterozoic sedimentary/volcanic rock and Archean components - most easily recognized in marginal zones of the Archean cratonic nuclei. Post-tectonic igneous activity in the orogenic belts is principally restricted to relatively small intrusions of mixed composition. However, contemporaneous anorogenic magmatism is important within the stable Archean provinces. Both the Great Dyke and the Bushveld Igneous Complex were emplaced during Paleoproterozoic times. Dolerite dyke swarms such as the Mashonaland dolerites of central Africa are another distinctive facet of anorogenic magmatism.

As wide a range of tectonic styles is shown in the Paleoproterozoic Eburnian provinces as well as in the Archean cratons. Some have similar sequences of events to the early cratons with initial ductile elements (folds and shears) defining regional structural trends, e. g. the SSW-NNE grain of the Baoule-Mossi Province defined by the major synforms in the supracrustal relics. Other areas record major strike-slip movements between bounding cratons. The most impressive structures in all the Eburnian provinces are steeply dipping, brittle fractures (in the intrusives) and faults. The largest faults can be traced for several hundred kilometres, notably in the Tuareg Shield. These faults may have originated as ductile shears of sutures during the early orogenic history, with repeated subsequent movement to include late brittle faulting. The faults tend to be parallel to the regional trend of the orogenic provinces, e. g. N-S to NE-SW within the Baoule-Mossi domain.

The pre-existing stable Archean provinces must have had a profound influence on the evolution of the Eburnian belts of Africa. It is thought that the Paleoproterozoic provinces resulted from either full Wilson-cycle orogenesis, involving collision of separate, relatively small Archean cratons, or ensialic disruption of a single large craton (Kröner, 1981). Post-orogenic gravitational collapse and extension of continental crust thickened by tectonic and/or magmatic processes may have produced some mid-Proterozoic sedimentary basins.

## 4 Mesoproterozoic Basement Development (Fig. 9)

Orogenic activity was not as widespread as during the preceding period. Two major orogens are recognized: the linear Kibaran Belt of central western Africa and the arcuate Namaqua Province of southern Africa. The Namaqua Province comprises the Namaqua Belt of South Africa, the Choma-Kaloma Block and possibly the NE-SW trending Irumide Belt of central southern Africa. The younger, E-W trending Zambesi Belt separates the Choma-Kaloma Block from the Irumide Block. Elsewhere in Africa, less well documented orogenesis took place in the Mozambique Orogenic Belt. All three provinces are polycyclic with superimposed Pan-African events (complete orogenic cycles).

A large proportion of the Kibaran Belt comprises metasediments, which likely exceed 10,000 m in total thickness. The supracrustals are dominated by clastic metasediments with major metaquartzite formations. Less common are limestones and greenstones (basic metavolcanics). Metamorphic grade is generally low within this base-metal mineralized belt. Intrusives include early granitic gneiss complexes as well as composite granitoids such as the Choma-Kaloma Batholith of Zambia.

The Namaqua Province is lithologically more varied with tectonic interleaving of basement gneisses, supracrustals and syntectonic sheet-like intrusions all cut by discordant post-tectonic minor intrusions. In this respect it resembles the older Proterozoic crystalline basement provinces. Variable, greenschist to granulite facies, metamorphism associated with tectonic disruption further complicated the lithological diversity. The province is extensively mantled by Neoproterozoic to Recent deposits. The Irumide Belt in Zambia generally consists of coarse clastic metasediments (Muva Supergroup) with possible felsic metavolcanics. In a western foreland zone these overlie the granitoid Bangweulu Block. Further east in Malawi a thicker cover sequence is dominated by metapelites with local carbonates and amphibolite (metagabbro) sheets. These sheets, at least in part, represent altered intrusions and not ophiolite slices. In Malawi, and possibly parts of Zambia, the metasediments are volumetrically subordinate to early granitoid intrusives.

There is geochronological evidence for a Mesoproterozoic basement to the more widespread Neoproterozoic sediments and volcanics in the Mozambique Orogenic Belt from Mozambique, Malawi, Tanzania and Kenya. This basement records a 1,100–1,200 Ma old high-grade tectonothermal event. In central Kenya it is dominated by massive migmatites, but a more extensive and varied lithological sequence is described from Mozambique. Here, four separate supracrustal sequences have been tectonically interleaved and cut by various granitoid batholiths. The oldest supracrustal formation comprises gneisses and migmatites derived from calc-alkaline volcanics. The younger units are mixed sequences of fine-grained metasediments and metavolcanics, which include disrupted ophiolites. The granitoid batholiths, which are locally porphyritic, are individually up to 500 km$^2$ in area and form about 25 % of the orogenic belt.

Two main periods of polycyclic tectonothermal activity have been defined in the main Mesoproterozoic orogenic provinces. During both periods the earliest major structures are fold and thrust belts, implying compression across the orogens. Ductile shears penetrate through the cover rocks into a crystalline basement, which largely controlled the style of deformation. The associated metamorphism locally reached the granulite facies. Subsequent events produced more upright folds and shear zones with large strike-slip movement, e. g. 200 km of dextral displacement across the Gordonia Subprovince in the Namaqua Province. Contemporaneous strike-slip faulting in adjacent reactivated older belts compensated for shortening in the main orogens, e. g. major NW-SE sinistral strike-slip faulting in the Ubendian Belt during oblique compression across the Irumide Belt.

The recognition of uplifted blocks of basement in the Kibaran Belt influenced early models for the evolution of the Mesoproterozoic mobile belts as ensialic rifts along intracratonic zones of crustal weakness. However, subsequent detailed structural studies in southern and central Africa indicate that the orogenies also involved considerable crustal shortening. Their stepwise evolution comprised:

- Crustal extension.
- Crustal shortening to produce fold and thrust belts, which tectonically interlayered sedimentary and volcanic supracrustal rocks and some sialic basement.
- Post-collision strike-slip faulting, upright folding and retrogressive metamorphism
- Uplift and erosion to commence the next orogenic cycle (of Neoproterozoic age) in parts superimposed on all the Mesoproterozoic belts.

## 5 Neoproterozoic Basement Development (Fig. 9)

By the end of the Neoproterozoic period almost all of the present African continent had been formed, and it has remained a stable cratonic area after polyorogenic activity in well-defined belts. Cahen et al. (1984) record widespread tectonothermal activity in the orogenic belts at about 950 Ma, 785 Ma, 720 Ma, 685 to 660 Ma and from 600 to 450 Ma. Four major lithological components are variably present in the main orogenic belts, as follows.

Clastic and chemical sedimentary rocks with important fluvio-glacial deposits and stromatolitic limestones (e. g. in the Voltaian and Togo Belt of West Africa, the Limestone and Quartzite Group of Morocco and the Damar metasediments of Namibia). In some cases these rocks are at very low metamorphic grades and should not strictly be regarded as part of the crystalline basement.

Volcanic rocks either as minor intercalations in thick sedimentary sequences or as important volcanosedimentary provinces tectonically interleaved with the sedimentary sequences. The major volcanic assemblages include the disrupted island arc/ophiolite sequences found in northeastern and northwestern Africa. Alkaline and calc-alkaline volcanic assemblages up to several thousand metres thick are recorded.

Intrusive rocks of the alkaline and calc-alkaline granitoid series including syn- and post-orogenic intusions. The major batholiths are mostly granodioritic, e.g. the early granodiorites of the Mozambique Orogenic Belt in Kenya. Major pegmatites are common, e.g. the Khan Pegmatite of Namibia, as are post-tectonic dolerite dykes and sheets (West Africa, Egypt). Older basement inliers occur as crystalline foundations at low tectonic levels or tectonically interleaved within cover sequences (all high-grade orogenic belts). For instance, the Mukogodo Migmatite in central Kenya is exposed in the cores of relatively late antiformal structures. There was widespread tectonic reworking of the marginal parts of the cratonic areas.

The metamorphic grade is variable within single Neoproterozoic orogens. For example, a range from greenschist to granulite facies assemblage occurs in the Mozambique Orogenic Belt of equatorial eastern Africa and in the Tibesti Belt of northern Africa. The Neoproterozoic sequences of northeastern Africa are generally at low metamorphic grades, whereas contemporaneous rocks further south in the Mozambique Orogenic Belt are in the amphibolite or granulite facies. Both terrains are related to the same oblique continent-continent collision. Eroded root zones of the orogen are presently exposed in the Mozambique Belt. Lower grade, higher level parts preserving major slivers of oceanic crust crop out in northeastern Africa, indicating a lateral change in tectonic style along the orogen. Major strike-slip faulting took place in the northeast. Consequently it is futile to generalize with regard to the lithological make-up of the Neoproterozoic orogenic belts of Africa.

The cover sequences of the orogenic belts can be traced onto the cratonic forelands, where they are not metamorphosed and are not part of the crystalline basement, e.g. the Voltaian Supergroup and the Rokel River Group of West Africa. Contemporaneous anorogenic magmatism (e.g. within the cratonic foreland to the Pharusian Belt of northern Africa) and major ductile or brittle shearing, such as the Chuan shear zones of the Tanzania Craton including the Aswa shear zone in Uganda, are also recorded within the cratonic areas between the Neoproterozoic orogens. On the cratons, the intrusions are only of local importance, but the shear zones can be traced for up to several hundred kilometres.

All recent authors interpret the development of the Neoproterozoic orogenic belts in terms of Wilson-cycle plate tectonic processes. Four stages are identified, which may be repeated within a single orogen, as follows.

- Rifting. Initial extension of continental crust (older cratonic areas) with either complete disruption to generate oceanic crust or intraplate, locally transtensional aulacogens (failed rift arms). Some aulacogens are formed by reactivation of old crustal fractures by the new stress fields, e.g. the Katangan Supergroup. Remnants of the newly formed oceanic crust are recognized, both in low- and high-grade terrains, over the whole of Africa.
- Subduction and initial collision. Initial basin closure with accretion of successive volcano-sedimentary assemblages onto the cratonic forelands are well documented from northeastern Africa. Major tectono-thermal activity gave rise to thrust and fold belts and accompanying magmatism.
- Collision between the cratonic fragments. Continuing tectono-thermal activity and magmatism extend into the cratonic forelands. Major strike-slip zones within the orogens are aligned subparallel to the trends of the orogens, e.g. in the Trans-Sahara Belt.
- Post-collision cooling and uplift. Recorded by mineral ages within the orogens and the cratonic blocks. During this period there was a change from subduction-related to within-plate magmatism.

## 6 Phanerozoic Development

### 6.1 General

Africa lay at the centre of Gondwana at the close of the Precambrian. The Pan-African orogeny had joined other continents to its eastern and western margins. Throughout most of the Paleozoic times North Africa occupied the southern seaboard of the Iapetus Ocean, whereas southern Africa was bordered by a shelf sea to the south. After the Iapetus Ocean closed during mid-Devonian times and the Hercynian orogeny had brought together in Late Carboniferous the remaining northern continental blocks into the Pangea Supercontinent, Africa assumed an even more interior location, in which position it remained until Mesozoic to Cenozoic times, when Pangea fragmented and each continent went its separate way.

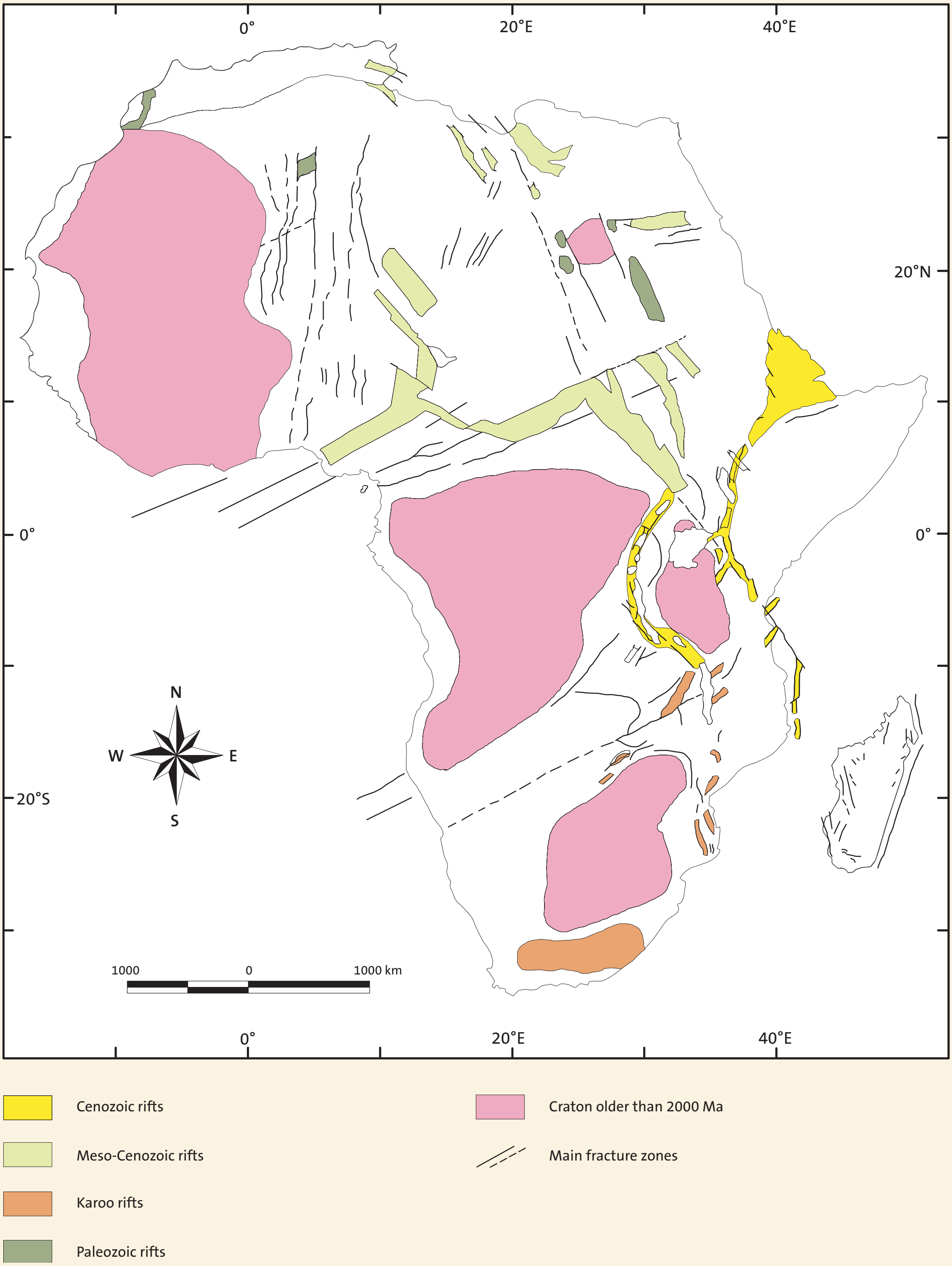


**Fig. 10** Main rift structures (after Kampunzu & Popoff 1991)

### 6.2 Orogenic Activity

The final throes of the Neoproterozoic orogenesis persisted into the lower Paleozoic until about 425 Ma. Anorogenic granitoid magmatism and uplift were widespread in the mobile belts. Low-grade tectonothermal activity was mostly localized, although epithermal alteration was ubiquitous in the orogens, facilitating subsequent weathering processes. Renewed major orogenesis in well-defined fold-thrust belts was confined to the southernmost tip and northwestern coastal zone of Africa. Elsewhere in Africa essentially unmetamorphosed major Phanerozoic basins form important components of the cover.

The beginning of Paleozoic orogenesis in northwestern Africa is marked by extrusion of alkaline volcanics at about 560 Ma. Cover sequences of clastic and chemical sediments with volcanics, cut by relatively minor granitoid intrusives, were deformed during the Caledonian-Hercynian tectono-thermal activity. This produced mountainous fold-thrust belts cut by major wrench faults. The orogeny is a product of the interaction between the North Atlantic and African Plates. Major extensional faults and rift-related magmatism during the Triassic and Jurassic preceded the Alpine orogenesis in the extreme north.

Inliers of older metasediments and a granite basement are locally present along the mountainous coastal strip, the Cape Fold Belt, which strikes roughly E-W across the southern tip of the continent. A predominantly sedimentary cover of the Middle Paleozoic Cape Supergroup and overlying mixed Karoo Supergroup dominates this late Hercynian foldthrust belt, which heralded the break-up of Pangaea.

### 6.3 Anorogenic Magmatism

Phanerozoic anorogenic magmatism is widespread and generally linked to major faulting and rifting associated with the break-up of Gondwana and subsequently since the Mesozoic with the development of the East African Rift System (EARS). Two major suites of intrusives are recognized as well as the new oceanic crust generated in the Afar area of the East African Rift System. These are the alkaline granitoid ring complexes and basic dykes and sheets.

The alkaline ring complexes are generally sited within the Neoproterozoic mobile belts. Their emplacement is related to uplift during reactivation of the major shears and transcurrent faults during fragmentation of Gondwana. Individual complexes are up to about 100 km in length, but mostly from 1 to 30 km in diameter. They tend to form positive topographic features despite extensive epithermal alterations.

The basic, commonly tholeiitic, dykes and sills are concentrated in areas that remained as stable cratons during the Neoproterozoic in contrast to the granitoid intrusions. The dyke swarms preferentially weather to control present drainage networks and consequently have important groundwater implications. Kimberlite pipes are another small-scale manifestation of anorogenic magmatism.

### 6.4 Phanerozoic Rifts and Associated Magmatism (Fig. 10 and 11)

In contrast with the Archean cratonic areas, where only kimberlite bodies are common, the successive Proterozoic mobile belts have been the sites of Phanerozoic brittle tectonics and magmatism since the end of the Pan-African Orogeny. For instance, the western branch of the East African Rift System reworked the Paleoproterozoic NW-SE trending Ubendian suture zone along the southern Lake Tanganyika region; it also cut across the Mesoproterozoic Kibaran structural trends in the northern Lake Tanganyika-Lake Kivu regions and possibly the Neoproterozoic Mozambique Belt in Lake Malawi. In western Africa, the N-S trending Pan-African suture and decollement zones, still active up to Cambrian times, were mobilized during the Paleozoic east of the West African Craton. Later on, during the Mesozoic, the Mesozoic African Rift System also reworked the NE-SW trending Pan-African ductile shear zones, which accommodated the last stages of the collision between the West African and the San Francisco-Congo Cratons.

Depending on the extensional stress applied to an individual domain, the old crustal to lithospheric discontinuities together with some neo-fractures acted as normal to oblique faults and transfer faults, observed respectively as perpendicular, oblique and parallel to the vertical sigma 1 - sigma 3 principal stress planes. In Mesozoic times, Africa was crosscut by major transfer fault systems (Fig. 10). In the earliest rift stages, for instance clearly illustrated in the western branch of the East African Rift System, and also in the Benue Trough, the magmatic provinces are mainly located at the junction of the major fracture systems (Fig. 11). Later on, these rift faults imprinted the continental marginal fracture zones, whereas transfer faults with their initial offset induced transform fault zones when in contact with an oceanic crust.