Geology, palaeontology and evolution

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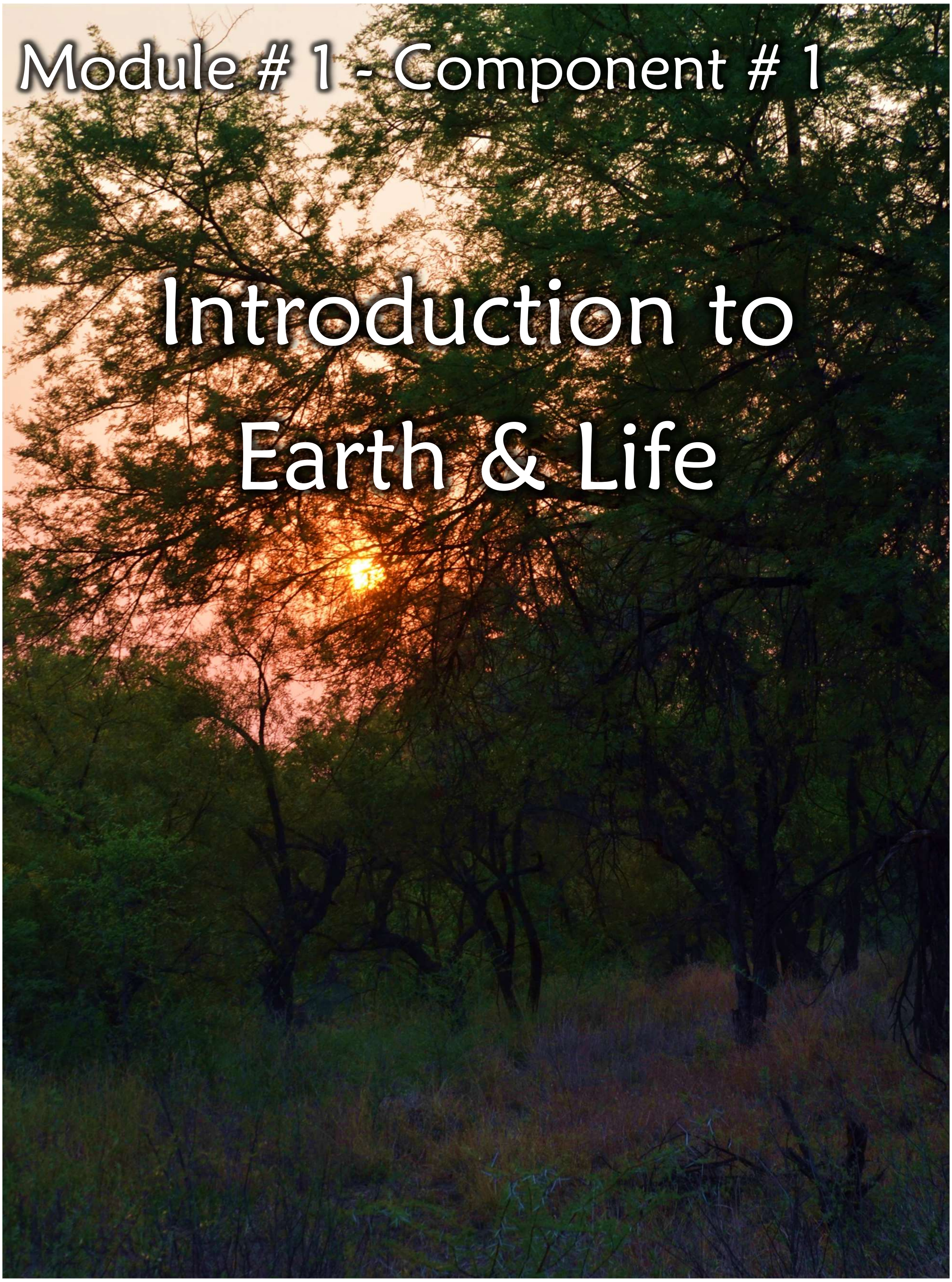

Module # 1 - Component # 1
Introduction to
Earth & Life

Introduction

The ability to reason, to **understand cause and effect**, is a uniquely human trait. Evidence for its beginnings extends back more than one and a half million years in the form of carefully selected digging tools found in cave deposits containing hominin (**human ancestors**) remains, such as at **Sterkfontein** and adjacent sites in Gauteng. Slightly younger deposits contain primitive stone tools.

In later deposits dating from just over a million years ago, we see evidence of **the ability to design and manufacture tools** to order, in the form of uniform, beautifully fashioned, symmetrical hand axes of the Acheulian period **(figure 1.1).**

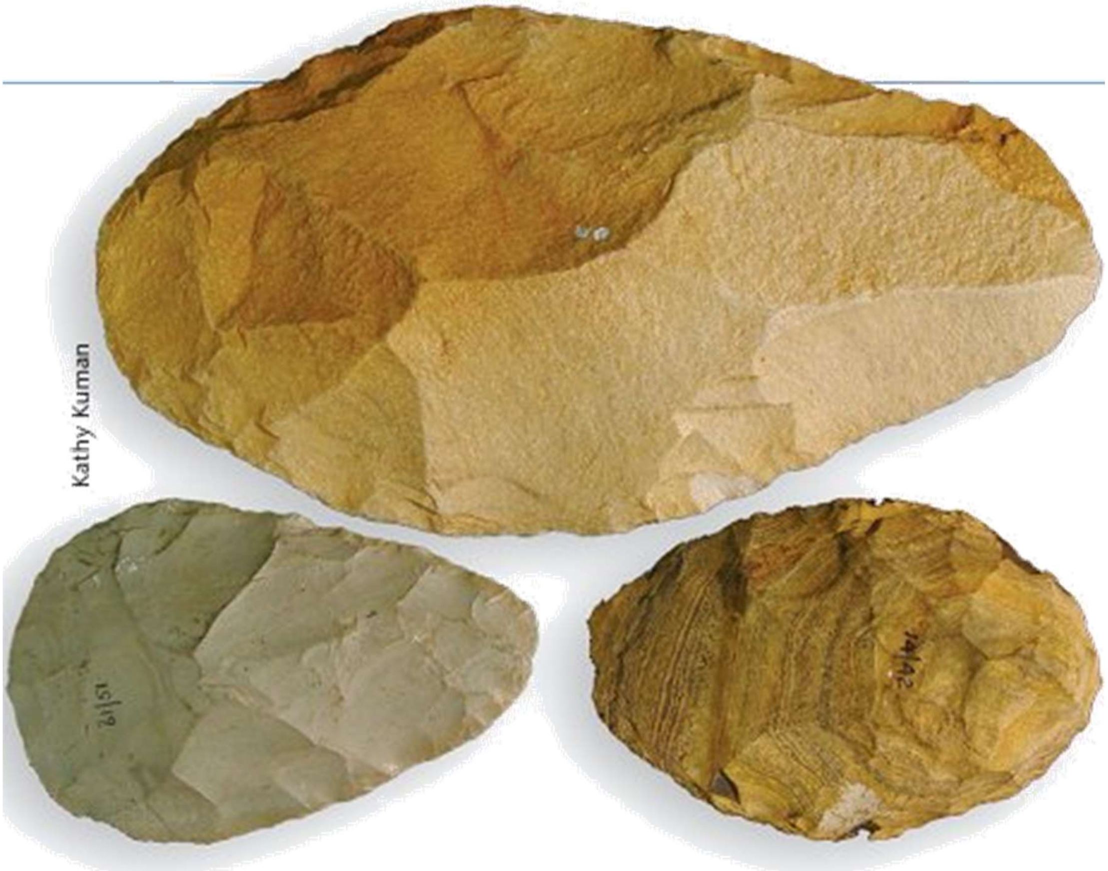


Figure 1.1 *Examples of hand axes from the Acheulian period illustrate an ability to produce a standardised tool form of varying size and from different types of rock. These tools may be more than 500 000 years old.*

Whether these ancient tool makers **possessed a true culture** is not known, and the earliest evidence of what might be called culture - the use of decorative symbolism and of ochre paint **(figure 1.2)** and shell beads - comes from deposits in Blombos cave in the Western Cape, which are about 70 000 years old.

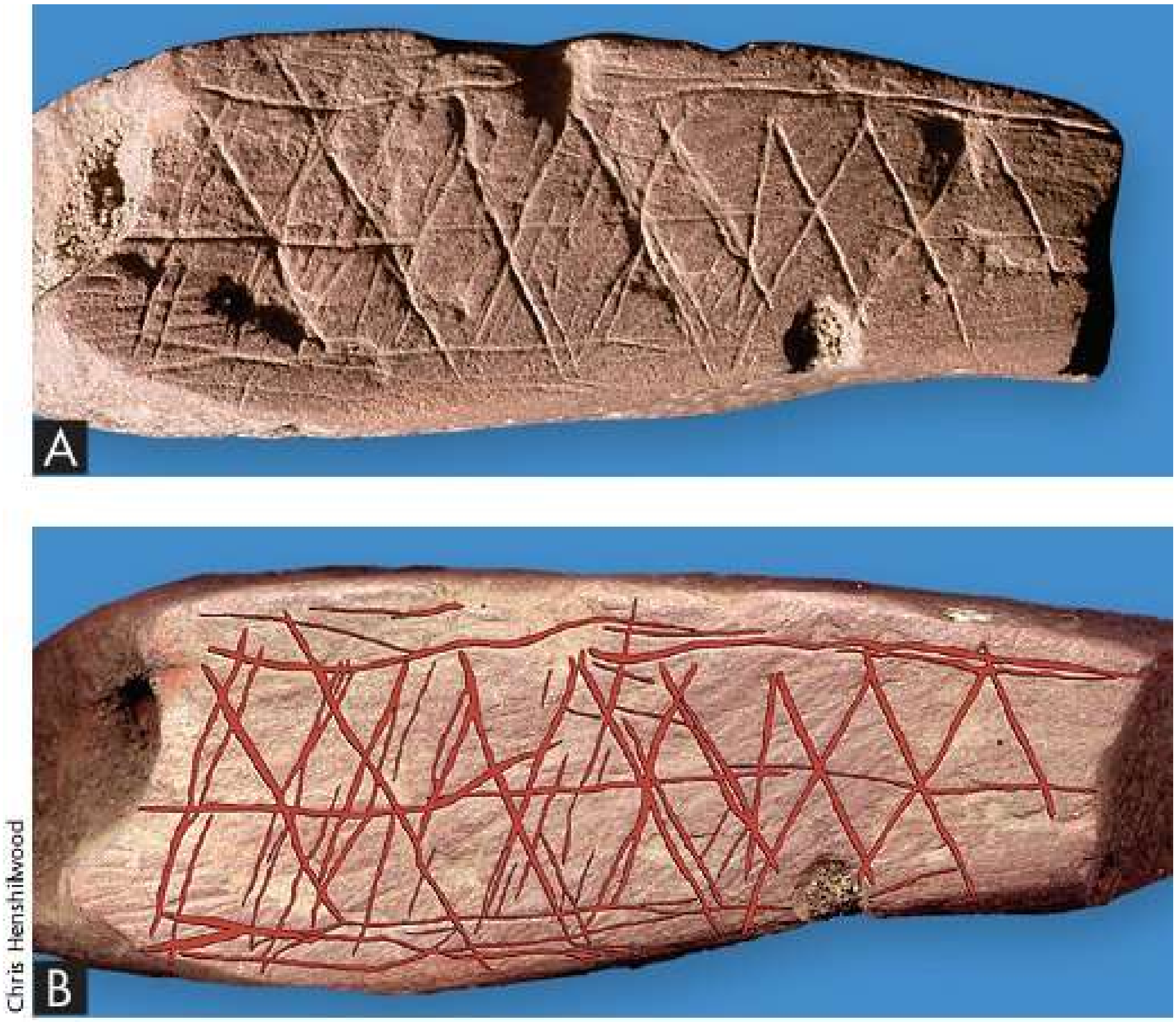


Figure 1.2 *Engraved red ochre from Blombos cave on the southern Cape coast. The specimen is 77 000 years old, and provides the earliest evidence of cognitive abilities central to modern human behaviour.* ***A*** *shows the clay tablet as it appears to the camera, while* ***B*** *emphasises the red ochre scratches.*

By about 40 000 years ago, these cultural practices had become commonplace and sophisticated both in Africa and Europe. They included **elaborate paintings** on cave walls, the use of **decorative jewellery** and even **musical instruments**. Many of the cave paintings created by these people are shamanistic (**spiritualistic**) and indicate that human thought extended well beyond the simple needs of daily living; the human mind had begun to probe spiritual questions.

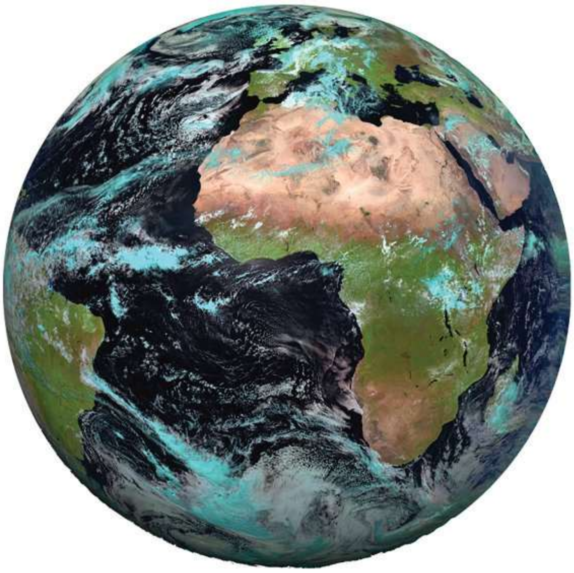
It is likely that these people had **developed some form of mythology**, perhaps seeking explanations for common events such as the rising and setting of the Sun and Moon, the passing of the seasons, and even of death. Probably later, deeper questions related to the origin of the world began to be probed. We have no idea when these appeared, but all cultures possess some form of creation mythology, usually intimately intertwined with religious beliefs.

In **Judaeo-Christian philosophy**, the **Creation** is specifically described in the opening chapter of the Book of Genesis. So specific is this description and the subsequent narrative that in 1654 the Bishop of Armagh, James Ussher, was able to use the biblical lineages to **calculate the date and time of the Creation**: 09h00 on 23 October**, 4004 BC**.

Understanding of the world throughout the Dark Ages was based on a combination of the Bible and the writings of Greek natural philosophers and Renaissance brought with it not only a revival of art and literature, but a more enquiring approach to the natural world, initially in the area of astronomy, and later in physics and chemistry.

Serious geological enquiry that addressed the question of Earth history, however, only arose in the late 1700s.

Probing Earth's History



While **matters related to the origin of the Earth fell into the realm of religious mythology**, the more practical aspects of rocks and minerals received considerable attention. Stone was used since the earliest times, initially for tool manufacture and later for building. Minerals were mined and processed to extract metals such as iron, copper, lead, tin, silver, and gold. Practical knowledge about mining and metallurgy was passed from generation to generation, and much of this accumulated knowledge was recorded in a famous book, *De Re Metallica* by Georg Agricola, published in **1556**. **Fossils**, which are common in rocks over large parts of Europe, attracted considerable attention and were the **subject of speculation** since the earliest times.

Greek and Roman scholars such as Pythagoras, Herodotus, Aristotle, Theophrastus, Strabo, and Pliny developed ideas on their origins and their implications: they attributed the occurrence of fossil marine shells and fish at high altitude to alternate depression and uplift of the land. Following the Dark Ages, writings again began to appear on geological topics. Fossils attracted the attention of theologians in particular, as they were considered to provide proof of the biblical flood.

The **rocks hosting fossils** also began to attract attention, and their regularity was noticed - so much so that in 1684 Martin Lister proposed the concept of a geological map.

During the 1700s, the study of rocks and fossils began to grow in popularity among gentleman scientists. The French made important contributions. In his 1749 book on natural history**, Georges Louis Buffon proposed that the Earth was of great antiquity and that its surface had experienced slow and gradual changes**, but he was severely censured at the Sorbonne and the Faculty of Theology in Paris, and **forced to withdraw his views**. The study of rocks continued unabated, and in 1751 Jean Etienne Guettard published possibly the earliest geological map, showing the distributions of minerals and rocks in France. The term geology was coined in 1778 by JA de Luc.

In Germany, AG Werner, Professor of Mining at Freiburg, recognised the ordering of strata and the fact that **rock strata could be characterised by the fossils they contained**. His ideas were published in 1796. Similar observations were made in the United Kingdom by William Smith, whose geological maps began to make their appearance in the 1790s. Smith went further to produce the first geological column for the United Kingdom, which characterised and described the sequences of rocks and their fossils. His great work, a geological map of England, Wales, and parts of Scotland, was published in 1815.

Meanwhile, in 1785, James Hutton published his extremely influential work A **Theory of the Earth**, which became a milestone in geological thought. Hutton argued that **sediment accumulation** that we can see taking place today, such as on mud flats and at river mouths, is very slow. Great thicknesses of sedimentary layers had been mapped by Hutton, Smith and others, and Hutton argued that these deposits must have taken immense periods of time to accumulate. The **implication was that the Earth is very much older** than suggested by the Old Testament.

These arguments were expanded by Charles Lyell in his three-volume treatise Principles of Geology (1833). **Jean Baptiste Lamarck**, a French biologist regarded as the **father of invertebrate palaeontology**, rekindled the ideas of Buffon regarding the great antiquity of the Earth in a series of books published between 1801 and 1822. From his knowledge of the changing fossil forms in successive rock layers, he **developed the notion of the evolution of life**. His idea was that life forms evolved as a consequence of changing environmental factors and that characteristics or adaptations acquired by an organism during life could be inherited by succeeding generations.

Charles Darwin and **Alfred Wallace**, who were both keen naturalists with an interest in geology, also made the **connection between changing fossil forms, the probable immense time involved**, and the diversity of life we see on the planet today, and simultaneously proposed their **Theory of Evolution in 1858**. They differed from Lamarck in that they noted there is always a range of characteristics (e.g. shorter or taller stature) within any individual species, and that **environmental pressures can favour particular variants** over others, allowing some variants to breed more successfully and therefore drive evolutionary change - a process Darwin termed natural selection.

Thus, in a brief period spanning the late 18th and early 19th centuries, the foundations of our present understanding of the Earth and its life were laid.

How Can We Know the Past?

We are a unique species. We possess the ability to manipulate natural materials to suit our purposes. We are capable of abstract thought and can communicate these thoughts to others. We can work in teams, executing complex plans. We can pass accumulated knowledge from one generation to the next. We alone among species can pose fundamental questions, **including questions about our own origins and the origins of the world** around us.

But posing such questions is one thing; providing the answers is quite another. **How can we see back into the past**, to a time before written records, before our species walked on this planet, or perhaps even to the time when our planet was born? There are some who turn to religious texts for answers, but there are others, scientists, who seek answers in the world around them, using the considerable mental abilities with which our species is endowed. We are all familiar with **archaeological methods**, at least in general terms. Archaeologists dig at a site and recover artefacts (**figure 1.3**). These artefacts have an origin - they were made by early people. The deeper the archaeologists dig, the older the artefacts must be.

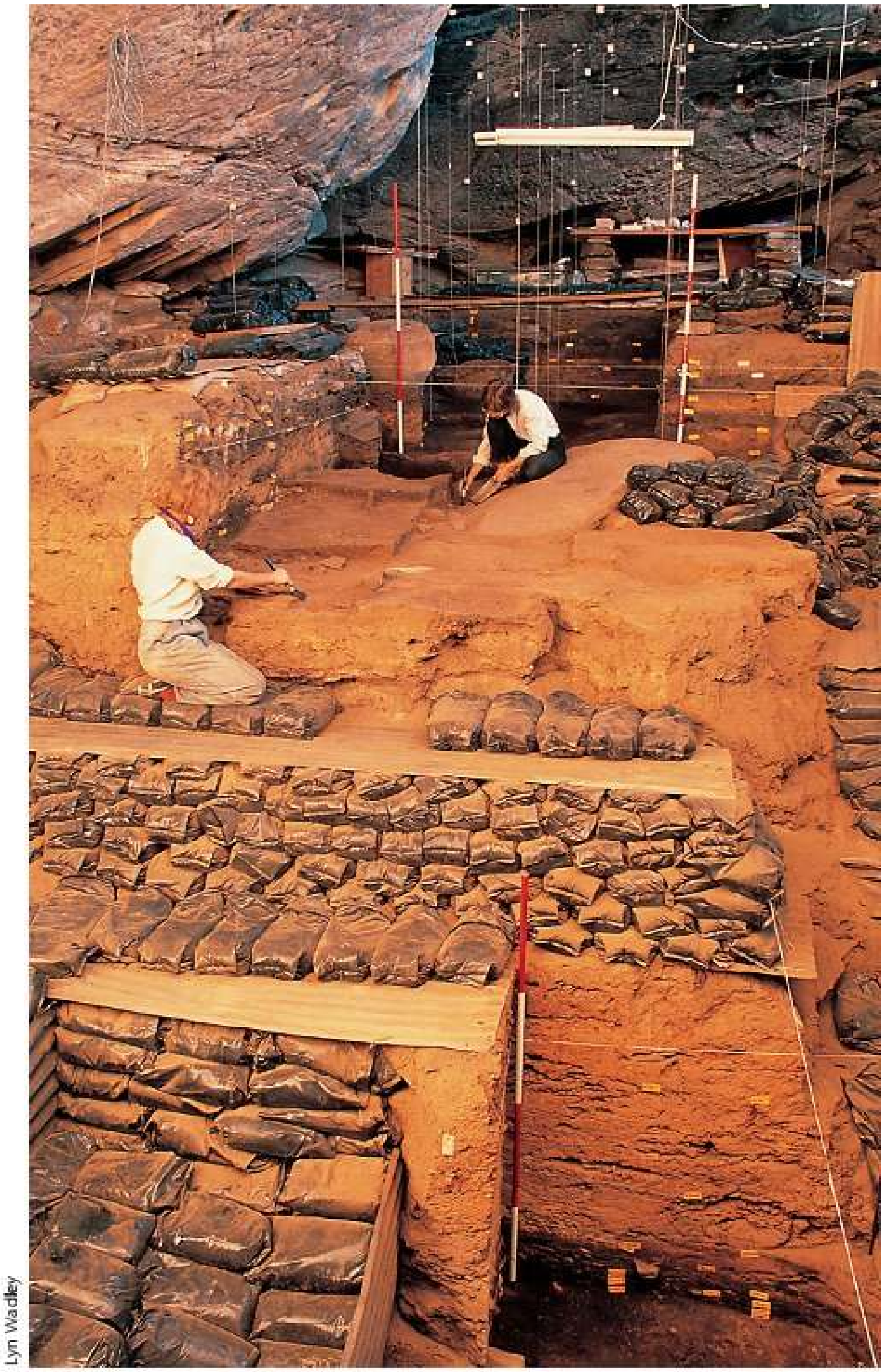


Figure 1.3 *An archaeological excavation at Rose Cottage Cave in the Free State, where the deepest layers provide information about the earliest occupants of the cave. The 6 m of cave floor deposits encapsulate a record of 100 000 years of habitation.*

Archaeologists can deduce what an artefact was used for by characteristics such as shape and wear patterns. They can also tell much about the lifestyle of its makers from the context of the artefact - how and where it was positioned in the site and what other artefacts and remains were associated with it. They can even **measure its age by dating the object** itself, or suitable material associated with it, using the radioactive decay of a kind of carbon atom present in organic matter, carbon 14 (14C).

Archaeological sites are time capsules, having frozen during some event or succession of events in the past. By excavating and studying them archaeologists can reconstruct these past events. They have been very successful in piecing together the history of mankind, especially our more recent history. But as they go **further back in time, the record becomes increasingly fragmentary** and more difficult to interpret: fragmentary because of subsequent partial destruction by natural agencies such as erosion and decay; and more difficult to interpret because the artefacts become increasingly removed from our own experience.

We now understand that rocks are perfectly analogous to the ancient artefacts excavated by archaeologists. **Rocks, too, are time capsules**. All rocks are not of the same age. Some rocks, for example, were formed by solidification from the molten state - from lava erupted from volcanoes. Others were formed by accumulation of sediment, such as gravel in a riverbed, sand on a beach, or silt and mud on a river delta. Yet others may have been transformed by heat and pressure during deep burial to produce new kinds of rocks.

From the nature of a rock we can tell how it formed; from its context - the rocks with which it is associated - **we can deduce the environment** in which it formed. In this way we **can reconstruct geographic environments and geological events of the past**. And in the same way as archaeologists date their artefacts using 14C, geologists can date rocks using not carbon but other radioactive elements. Rocks are much more common than archaeological sites; they are everywhere beneath our feet. By mapping their distribution and establishing how they formed and in what type of environment, **geologists can reconstruct the changing environmental history of a particular region**. Every region has had a unique history, and each must be individually determined, just as each country has its own, unique social and political history.

As we go further back in time, the record becomes increasingly fragmentary, **evidence having been obliterated by erosion or later geological events** that often overprint the earlier record. Very ancient rocks are therefore extremely rare and difficult to interpret.

About this Course

South Africa is, geologically speaking, a **very diverse** and in many ways unique place, without equal on the globe. There are several factors that contribute to this uniqueness. South Africa is a treasure house of valuable minerals. Despite **occupying only 1% of the Earth's land surface**, the country is or once was (before some of the mines were exhausted) the **world's largest producer of gold, chromium, diamonds, vanadium, manganese, and platinum**. It possesses very large reserves and is a world-class producer of **iron, titanium, zinc, coal, fluorspar, refractory minerals, and phosphorus**, and also produces **copper** and **lead**. It has been said that hectare for hectare, the northern half of South Africa is the **richest piece of real estate on earth**.

The table below (under the heading **South African Mineral Reserves**) shows just how spectacular the country's mineral wealth is. South Africa has a very long geological history, **its oldest rocks dating back some 3 600 million years**. Rock-forming events extend from this ancient dawn virtually to the present, providing a long, albeit punctuated, geological history. The preservation of these ancient rocks is quite remarkable and many look little different today from the equivalents formed in very recent times (**figure 1.4**). The rocks record events during many crucial periods in Earth's history.

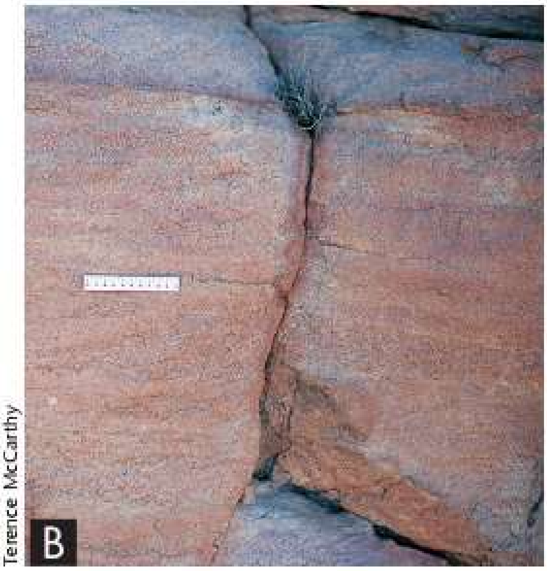


Figure 1.4 *Rocks deposited in southern Africa in ancient times are remarkably well preserved.* **A** *shows sand and gravel deposited by rivers a few thousand years ago (Rooisloot, Mokopane, Limpopo Province).* **B** *shows sand and gravel deposited 2 900 million years ago (Witwatersrand Supergroup, Gauteng).*

They also provide insight into globally important changes that took place in the past, such as the **changing composition of Earth's atmosphere** and the assembly and fragmentation of the supercontinents. Finally, South Africa's rocks contain a very special and long record of life. The very earliest life forms are preserved as fossils in the rocks; **the evolution of land plants and animals, and especially the origin of mammals and dinosaurs**, are well preserved (**figure 1.5**). South Africa also has probably the **best record of the origin of hominins**. Truly an amazing record of Earth and its life.

Figure 1.5 *Well-preserved fossils from southern Africa, such as this skull of a reptile that lived in the Karoo region, provide insight into the origins of dinosaurs and mammals.*

In this Course we will **journey through time and examine the unfolding of that remarkable history.** Although the logical place to start an historical account is at the beginning, we will begin our story at the end because it is not just an account of consecutive events, of seas that came and went, volcanoes that erupted and then became extinct. We also want to address the questions of **how and why these events occurred**. In other words, we want to put our geological history in context. To do this, it is necessary to **understand how the Earth works**. In the last few decades, earth scientists have made remarkable strides in understanding the Earth, and it is believed that many processes we see operating today have operated since the earliest times. This knowledge has radically improved our understanding of past events, as it provides a context for these events. So, our **story begins with the modern Earth**, and describes how the Earth works.

Armed with this knowledge, we will be able to **journey back in time to the birth of the Earth**. Readers unfamiliar with geology will be faced with many **new concepts and terms**, introducing essentially a new discipline that - like all disciplines - has its own **special jargon**. While we have made every effort to reduce jargon to a minimum, there are essential concepts and terms you need to know to appreciate South Africa's geological history.

For some, this may have the unfortunate effect of making what is basically a fairly simple story seem quite complicated. If you tend to forget the meanings of terms, it can be a source of immense frustration. Just as a map helps you recall place names when travelling in a foreign country, we have included **Route Maps** in our journey through time to help recall the meanings and significance of names and terms used in the text. In addition, we have added **several hundred new terms to the WildlifeCampus Online Glossary** for quick reference to the meaning of these terms

We live in a four-dimensional space-time world, and our minds are attuned to certain natural scales in both space and time. Time, we measure in seconds, minutes, and hours, and we are familiar with scales of seasons and years. As we age, we begin to appreciate time scales of a generation or two. But that is where our experience and familiarity with time ends. In the same way, we measure distance in centimetres, metres and even kilometres. We can gaze on and appreciate mountains many hundreds of metres high. We think of local places in terms of their distance from where we live. But we have no appreciation for really great distances, distances on a global scale.

We travel globally, but we express global distances not in terms of kilometres, but in terms of the travel time by jet airliner because the time is more comprehensible. Our natural, in-built space-time reference frame is **too limited to cope meaningfully with Earth history; time and distances are simply too vast**. There is no easy solution to this problem. In their training, earth scientists develop a familiarity with the numbers involved, a familiarity that makes them feel comfortable with very old or very large things. But like everyone else, earth scientists cannot really comprehend the vast time expanses or huge distances in and on Earth.

Geological Map of Southern Africa

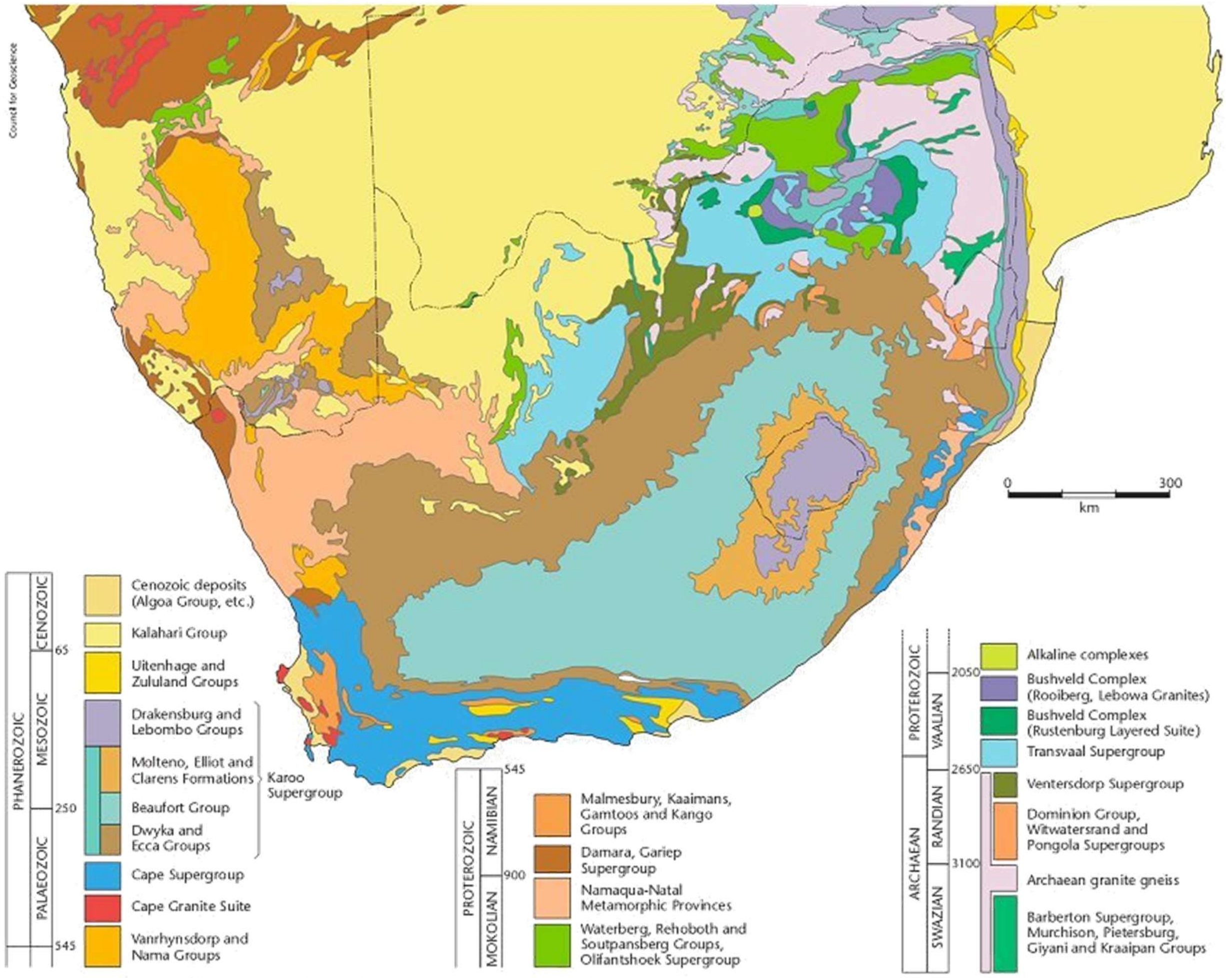


Figure 1.6 *In this geological map of southern Africa each of the colours represents a group of rocks formed during a specific period. These rocks record the geological history of the region*

It is about the Rocks

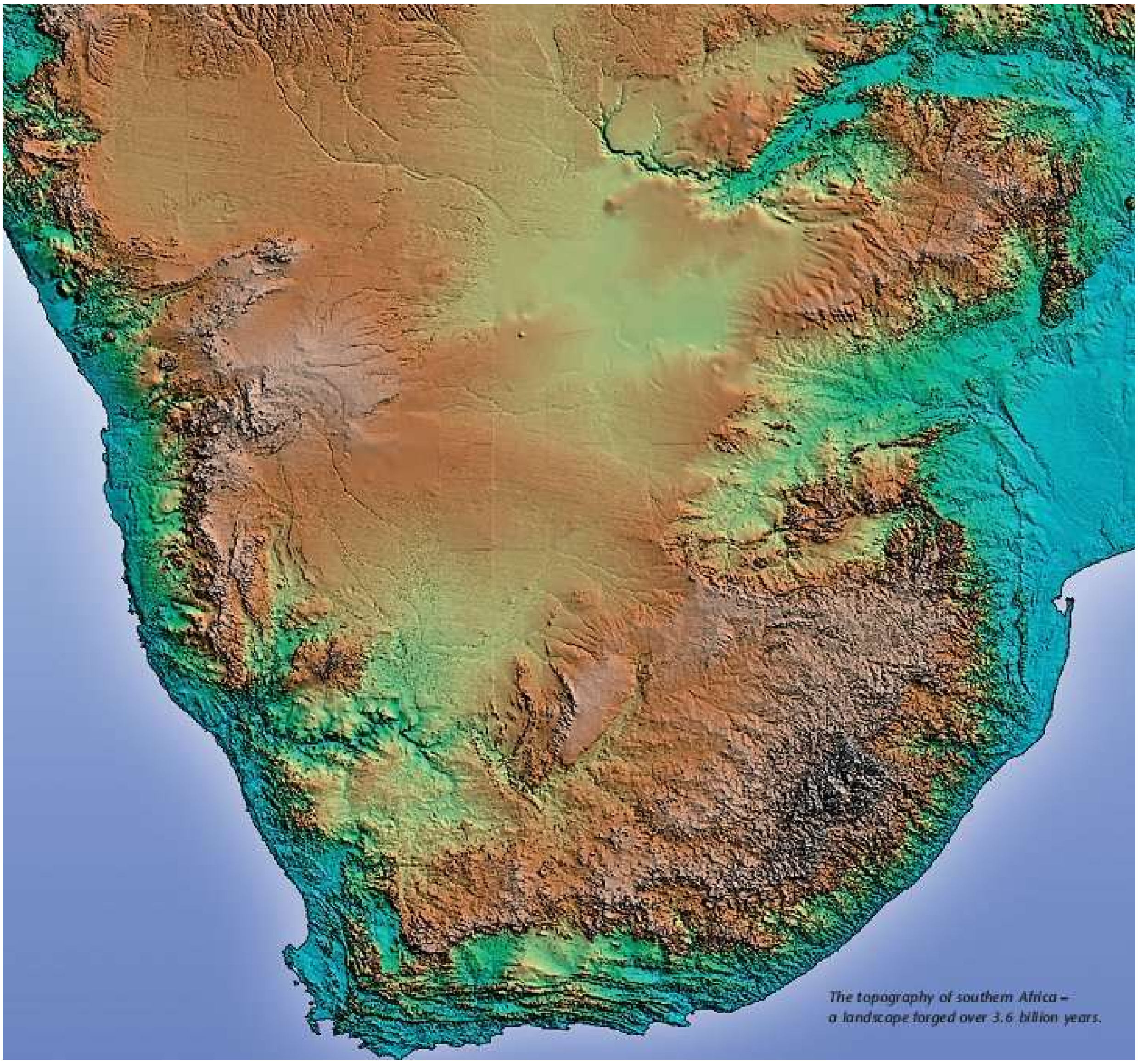
To really appreciate the story told in this Course, you too need to **develop a feeling for big numbers**. Another useful skill is sensitivity to the Earth's **three-dimensionality**. Like architects, earth scientists operate in a world where the third dimension assumes a far greater importance than is required in everyday life. The ability to visualise a three-dimensional object from a two-dimensional sketch is therefore very useful. It is inordinately difficult for most people to relate past events described by earth scientists to the world we see around us today. Reason and logic are strained when they **describe mountains that were once seas**, or seas where there were once mountains. It is hoped that this course will go some way to alleviating this kind of difficulty.

This course is about the **rocks of southern Africa**, shown in the geological map in **figure 1.6**,and the physiographic map in the next Component , as well as the fossils they contain.

Rocks are all around us, and they create the scenery we cherish - the Drakensberg, the Waterberg, the Cape mountains, the Karoo. When you gaze on these vistas, what are you seeing? Beautiful scenes to be sure, but there is another dimension to your view. **Whether you realise it or not, you are looking back in time**. This course is about that other dimension:

- How did the rocks form?
- And when?
- How did they get to be as we see them today?
- How did the mountains, valleys, and rivers we see around us form, and how old are they?
- What animals and plants lived there in the past?

Rocks in themselves are uninteresting to most people, and understandably so. But rocks are also time capsules because they encapsulate information about their surroundings when they form and preserve it. **They have a story to tell**. The story, however, is in code. Earth scientists are breaking the code and are steadily deciphering Earth's history. Study of the rocks of southern Africa has revealed the origins of the region's great mineral wealth. The most ancient rocks tell of a world very different from today, one with a crushing, toxic atmosphere, and bacterial slime as its most advanced life. Rocks and their fossils also reveal the story of Earth's slow, at times life threatening, journey to the present, and how southern Africa came to be the way it is.


The topography of southern Africa – a landscape forged over 3.6 billion years.

South Africa's Mineral Reserves

South Africa's mineral reserves and production in a global context

Reserves are minerals or metals known to exist but not yet mined; **production** is the actual amount extracted annually. Percentages refer to South Africa's share of the world's reserves or production. The units are: t = tonnes; mt = million tonnes; bt = billion tonnes; mc = million carats. PGM denotes Platinum Group Metals (platinum, palladium, ruthenium, rhodium, osmium and iridium). The value of mineral production in 2001 was approximately R100 billion (b = billion; m = million).

Commodity	Reserves		World Rank	Production		World Rank	Rand Value
	%	Units		%	Units		
Manganese	80	4 bt	1	20	3.6 mt	1	3 b
Chrome	76	5.5 bt	1	45	6.6 bt	1	7 b
PGM	56	63 000 t	1	46	207 t	1	25 b
Gold	52	40 000 t	1	17	428 t	1	30 b
Vanadium	44	12 mt	1	57	18 000 t	1	780 m
Vermiculite	40	80 mt	2	45	210 000 t	1	132 m
Refractories				36	183 000 t	1	118 m
Zirconium	22	14 mt	2	28	0.25 mt	2	7 m
Titanium	20	146 mt	2	23	1 mt	2	600 m
Fluorspar	10	36 mt	3	5	213 000 t	3	1 000 m
Diamonds					11 mc	5	
Uranium	9	0.2 bt	4	2	860 t	9	215 m
Nickel	8	12 mt	6	3	37 000 t	9	2 b
Antimony	6	8 mt	4	3	3 700 t	4	29 m
Phosphate	7	2.5 bt	3	2	2.8 mt	9	900 m
Copper	2	13 mt	14	1	0.14 mt	13	1.6 b
Zinc	3	15 mt	5	1	63 000 t	18	310 m
Lead	2	3 mt	5	2	75 000 t	9	109 m
Iron	1	1.5 bt	9	4	34 mt	8	3 b
Coal	11	55 bt	5	6	224 mt	6	20 b

Author's Foreword

Southern Africa is a mineral-producing region of global importance and has been so for more than a century. It has a record of life preserved in its fossils that is more extensive than any other region in the world, a record that preserves not only the evolution of plants and animals, but humans too. There is a growing awareness of the natural environment and in order to understand the landscape and ecosystems, a good grasp of local geology and geological history is essential because the basis of ecosystems is ultimately geological. Yet, ironically, information on the geological formations that host the region's mineral and fossil wealth, the story of life that the fossils tell, and the geological history of southern Africa are largely stashed away in technical publications that are accessible only to the specialist. With this Course we hope to rectify this situation and share with non-specialists the exciting story of how southern Africa, and to some extent the world, came to be the way it is - how its mineral deposits formed, how its life evolved, and how the landscape of southern Africa was shaped. Writing a course such as this requires a team effort, and we would like to express our appreciation to all of our contributing authors for their enthusiasm in the project, their on-time delivery and their good grace in the face of editorial reworking of their material.

We would also like to thank our many colleagues who willingly provided illustrative material, as well as Robin Cox, Stanley Duncan, Andrew Terhorst, Philip Frost, Neil McKenna, Hein Pienaar, Glen McGavigan, Lew Ashwal and Marina Rubidge for assistance in sourcing images. The subject matter of the course is extremely wide ranging, and as far as possible we wished to ensure that the content is accurate, or at least as accurate as such a work can be, given the divergent opinions that often exist in the earth sciences.

We also wanted to ensure accessibility of the writing and clarity in the general approach to this vast subject. any colleagues and associates assisted towards these ends: we thank Fernando Abdala, Carl Anhaeusser, John Begg, Bob Brain,Grant Cawthorn, Fred Daniel, Mike and Maarten De Wit, Doug Erwin, Nok Frick, Rob Gess, Roger Gibson, James Hersov, Judith Kinnaird, Pieter Kotze, Rodrigo Lacruz, Judy Maguire, Erna McCarthy, Jennifer Oppenheimer, Rose Prevec, Mike Raath, Uwe Reimold, Chris Sidor, Peter Tyson, Rob Veal, Richard Viljoen, Lyn Wadley, Lilith Wynne and Adam Yates. We nevertheless accept full responsibility for errors or omissions in the text and illustrations.

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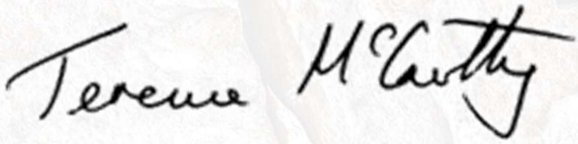

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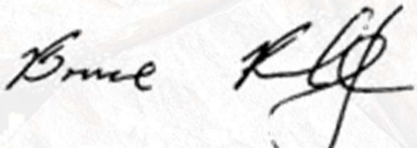

BRUCE RUBIDGE

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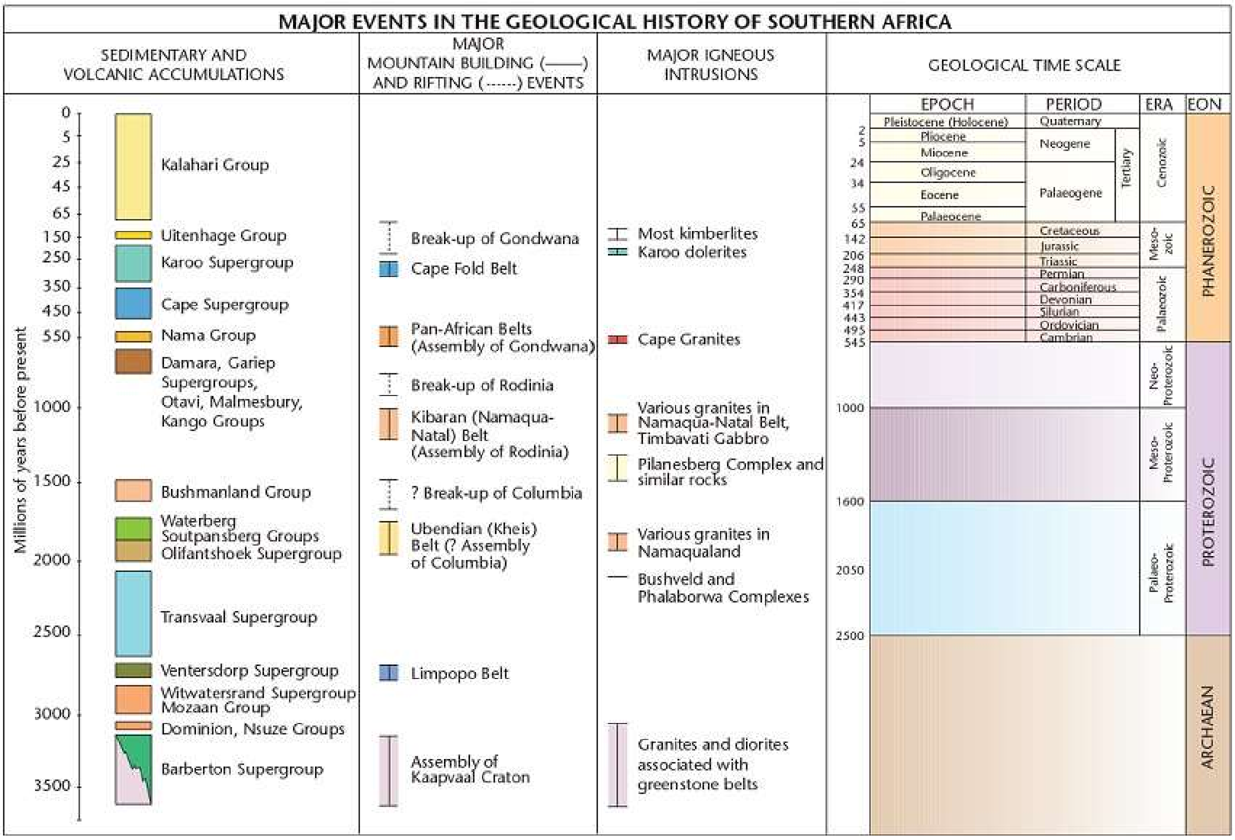
Major Events in the Geological History of Southern Africa



The Diversification of Life