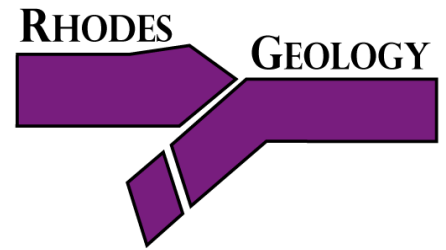


**Department
of Geology**



Field guide to geological sights in the Makhanda area

360 million years of Earth history in 5 easy steps

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The Geology of the Makhanda area

The Regional Setting

The rock sequences in the Makhanda area reflect the geological history over a very considerable period of time, from about 400 million years ago up until today.

The rocks can be grouped into three main divisions:

1. The oldest rocks belong to the **Cape Supergroup**, which constitutes the major part of the Cape Fold Belt. This is a belt of deformed rocks that runs approximately west-east across southern South Africa, from the Western Cape, through Makhanda, entering the sea to the east, near the mouth of the Fish River (east of Kleinemonnd). Table Mountain is carved out of rocks of the Cape Supergroup.

2. Rocks of the **Karoo Supergroup** overlie those of the Cape Supergroup. These rocks occur in a vast area, from Makhanda to the northeast, north and northwest. They underlie most of South Africa and are present in all of the provinces, extending even up into Namibia, Botswana and Zimbabwe.

3. On top are younger sedimentary and alteration deposits, which are found mainly along the coast, but also around Makhanda.

Intense weathering has affected many rocks of the Cape and Karoo Supergroups. Erosion specifically since the end of the Jurassic (140 million years ago) has shaped the land surface as we see it today.

The geological column for the Eastern Cape is shown as a table in Figure 1. A geological map and cross-section for the area between the Gamtoos and Fish Rivers are shown as Figures 2 and 3, respectively. The rocks of this part of the Eastern Cape are sedimentary rocks, laid down in a variety of depositional environments, and they tell geologists much about what has happened in this region over the past few hundreds of millions of years.

Cape Supergroup

In the general region of Makhanda, the Cape Supergroup comprises two main groups of rocks. The **Bokkeveld Group** is found to the south near Alexandria. It consists mainly of shale, along with sandstone, originally formed in a delta. The Bokkeveld contains a large variety of invertebrate fossils.

The **Witteberg Group** consists predominantly of quartz sandstones (also described as quartzites) with minor interbedded shales. Some of the shales are black and carbonaceous. These rarely contain tree trunks, arborescent lycopod stems, aquatic and terrestrial invertebrates, early fish fossils and trace fossils. In 1985, the new National Road (N2) bypass exposed a thick layer of black shale which has provided our most important window into Late Devonian life in southern Gondwana.

The Witteberg Group rocks were deposited in a sandy coastal setting, where barrier islands at places sheltered brackish (salty) back-barrier lagoon systems with significant fresh water input (see Figure 4). From interpreting grain-size and grain-shape changes and patterns in the rock layers ("bedforms"), geologists can tell that

the sandstones formed from shoreface deposits, passing upwards into washover, tidal channel, tidal delta and back-barrier tidal channel deposits (a trend of gradually increasing water depth, overall). The black shales near Makhanda, which host most of the fossils, represent a stagnant, back-barrier lagoon (fine-grained sediments deposited in “quiet water”, or a low-energy system).

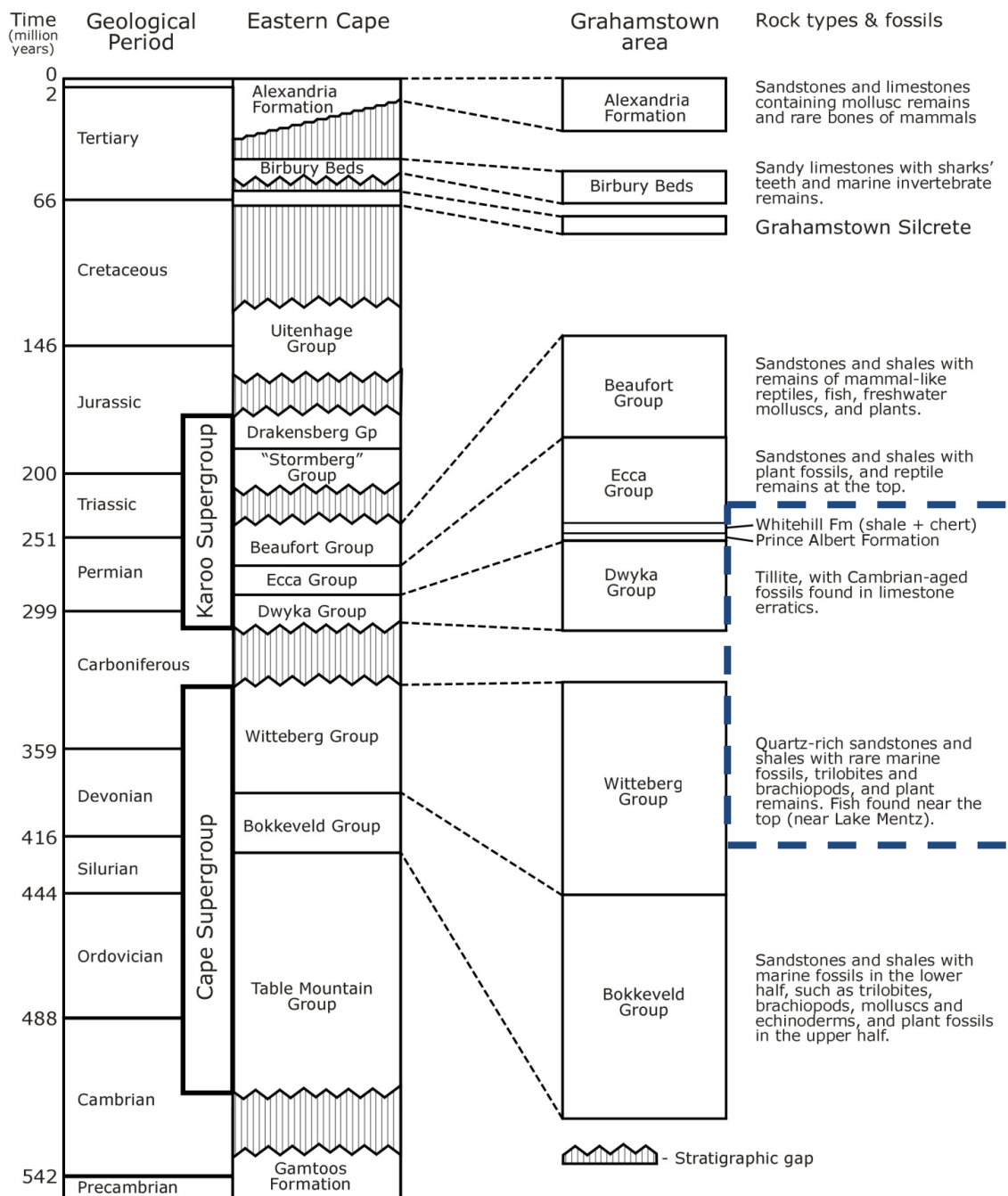


Figure 1. A geological column (stratigraphic section), showing the rock types of the Makhanda area compared to those elsewhere in the Eastern Cape (modified from Hiller, 1985). The dashed line highlights the Devonian and Permian rocks we will see on our trip. (This frequently re-quoted table needs revision as its summary of Witteberg fossils entirely predates the discovery of Waterloo Farm – the Witteberg Group’s most important fossil site).

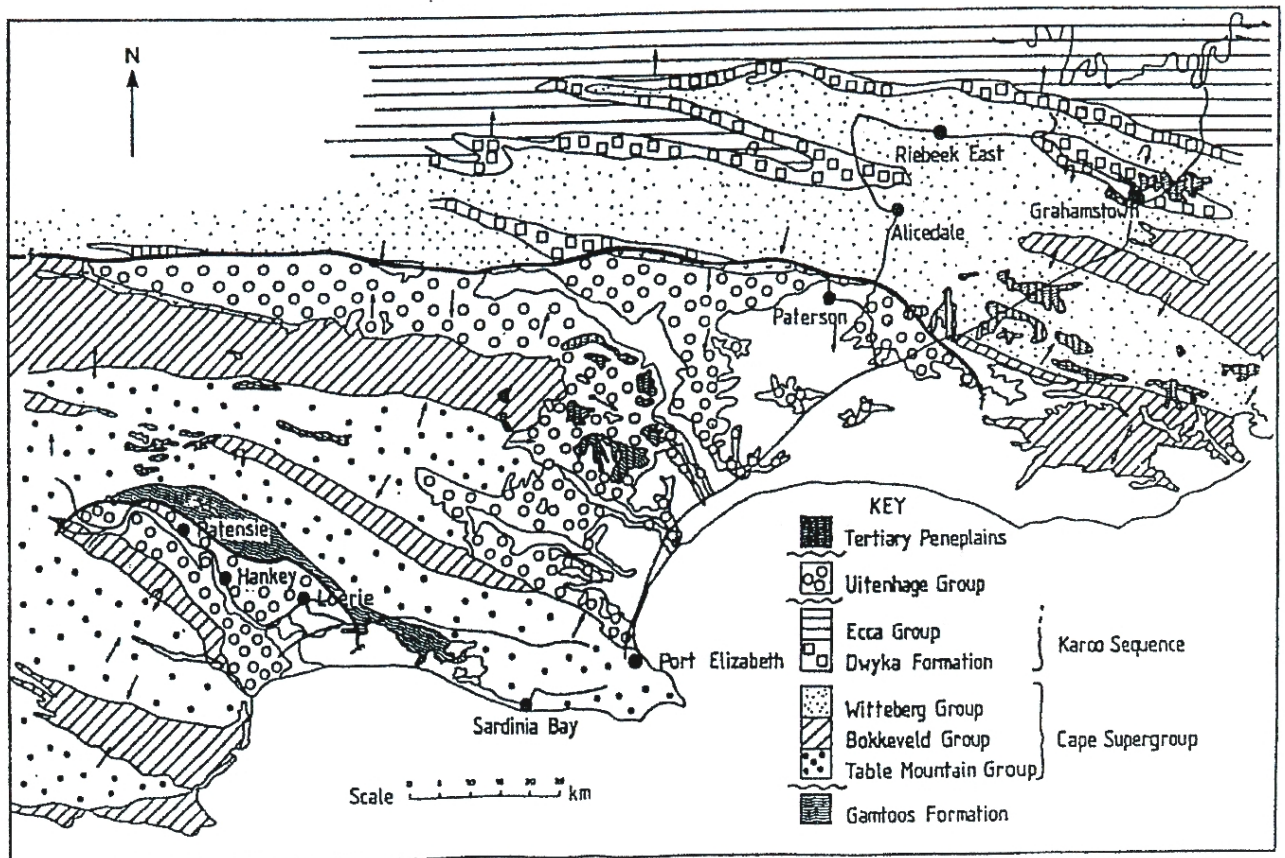


Figure 2. Simplified geological map of the Makhanda (Grahamstown) and Port Elizabeth area. *Note: rocks south of Grahamstown labelled as "Bokkeveld Group" in fact belong to the Witteberg Group.*

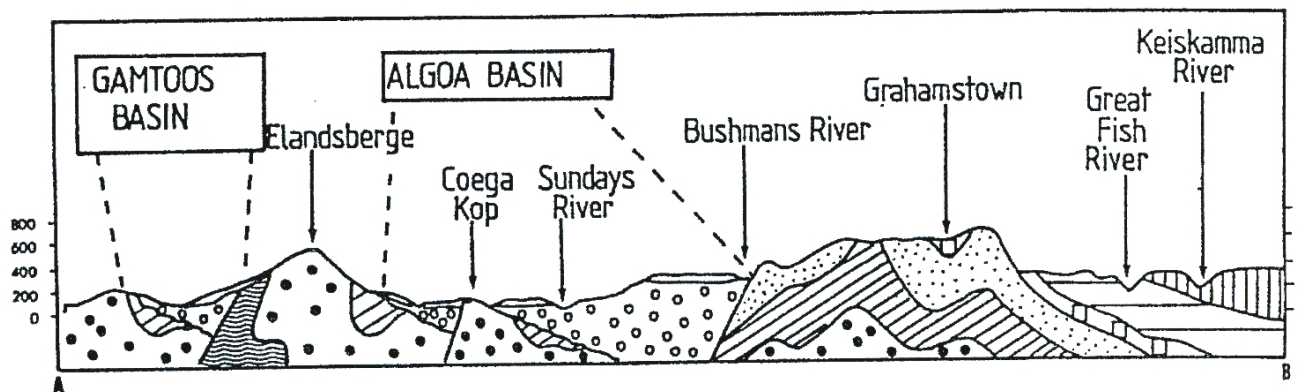
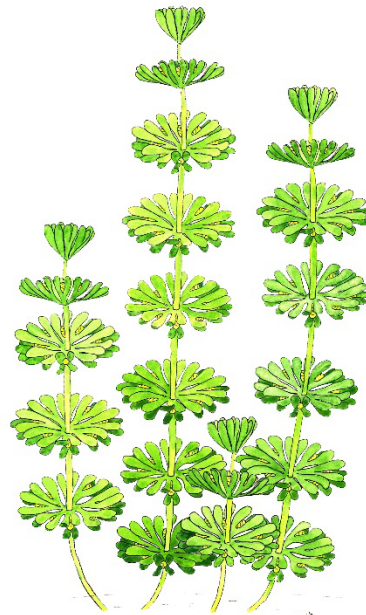


Figure 3. A geological cross-section from the Gamtoos Basin to beyond the Fish River. (see comment above)

Palaeontology of the Witteberg Group

Fossils occur to some extent in the sandstones, normally as **trace fossils** (which are markings in the rocks which indicate resting, moving, or feeding tracks, or traces, of shallow-water-dwelling organisms), although lag deposits of plant stems are also known. However, most fossils are found in the black shales. Most common are algae and plant remains of both terrestrial and aquatic origin. These include *Charophyte* and *Phaeophyte* Algae, and a diverse array of plant types, including members of the *Zosterophylloids*, *Lycopside* and *Progymno-spermopsida*. Animals represented in the fossil material include remains of invertebrates such as *Ostracoda*, *Conchostraca* (shelled *crustaceans*), *Eurypterida* (giant “sea scorpions”) and terrestrial scorpions (the oldest terrestrial animal remains from Gondwana).

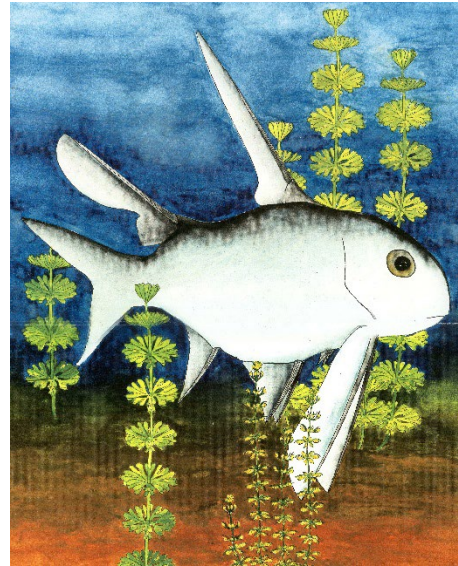
There are also various fossil fish documented. The fossils can be assigned to several groups including *Agnatha* (jawless fish represented by the world’s oldest lamprey) *Placoderms* (“plated fish”), *Acanthodians* (“Spiny sharks”) *Chondrichthyans* (sharks), *Actinopterygians* (“ray-finned fish”) and *Sarcopterygians* (including *coelacanths*, lungfish and tetrapod ancestors). Work on the various fossils continues to yield much new information to palaeontologists.



Charophyte octochaera, a plant fossil (and its likely natural appearance)



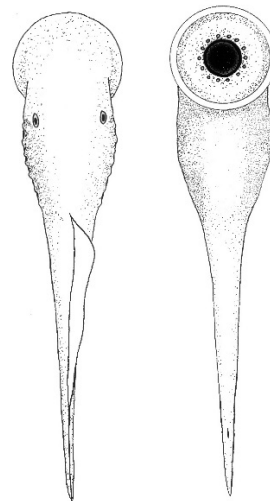
Head and trunk carapace of *Bothriolepis africana* (a placoderm fish) from Waterloo Farm (left) and its reconstruction (right).



Diplacanthus (acanthodian fish) from Waterloo Farm.



Pincers of a scorpion, as evidence for animal life on land and existence of scorpions some 360 million years ago.



Priscomyzon, a member of *lamprey* order of jawless fish. The oldest (~360 million years old) fossil of this type of fish has been found on Waterloo Farm (Gess et al. 2006).

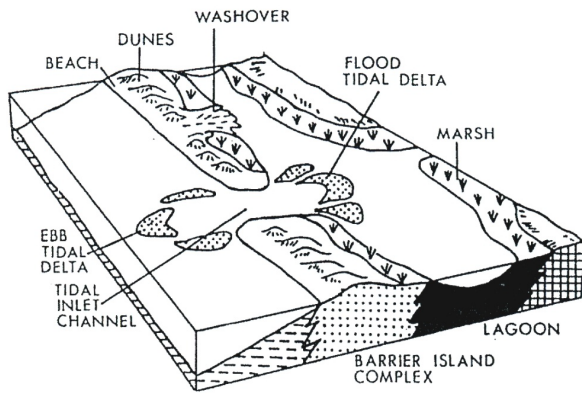


Figure 4. The probable depositional environment for the area of the fossil site on the N2 Bypass at Waterloo Farm (after Hiller, 1985).

Karoo Supergroup

The base of the Karoo Supergroup consists of sedimentary rocks of the Dwyka Group. These rocks rest directly on top of the upper Witteberg shales, and consist of boulders, cobbles and pebbles of a variety of older rocks in a very-fine-grained blue-grey matrix. The rock is a "lithic boulder-clay", and is referred to as the Dwyka Tillite. It was deposited by glaciers (see Figure 5) during a major ice age that affected the southern hemisphere supercontinent, Gondwana, during the late Carboniferous Period (around 300 million years ago). The widespread ice sheets moved over the surface of Gondwana, eroding (gouging, scratching, and otherwise wearing down) and picking up rock. When the ice eventually melted, the load of rock and clay debris was dropped, forming the tillite.

Higher in the Karoo succession and further inland from Makhanda, in the Beaufort Group, we find a large variety of vertebrate fossils, including mammal-like reptiles, preserved in fluvial (river derived) deposits.

Deformation: Folding and faulting

The rocks of the Cape and the south-western parts of the Karoo Supergroups have been deformed, in places spectacularly, as can be seen in some of the mountain ranges and passes to the west, such as Meiringspoort and Swartberge (near Oudtshoorn). Fold and fault structures can also be seen in the Witteberg Group rocks around Makhanda (Figure 6). These show that the major deformation was related to N-S crustal shortening. Common thrust and reverse faults formed during this contraction event, resulting in fracturing and displacement of rocks and injection of quartz veins. Faults and fractures in rocks have important implications for mineralisation and for the storage and movement of groundwater.

Makhanda is situated on tillites and shales within a large fold structure known as a syncline (Figure 7). The city and peneplain are flanked by ranges of easterly-trending hills composed of Witteberg quartzites.

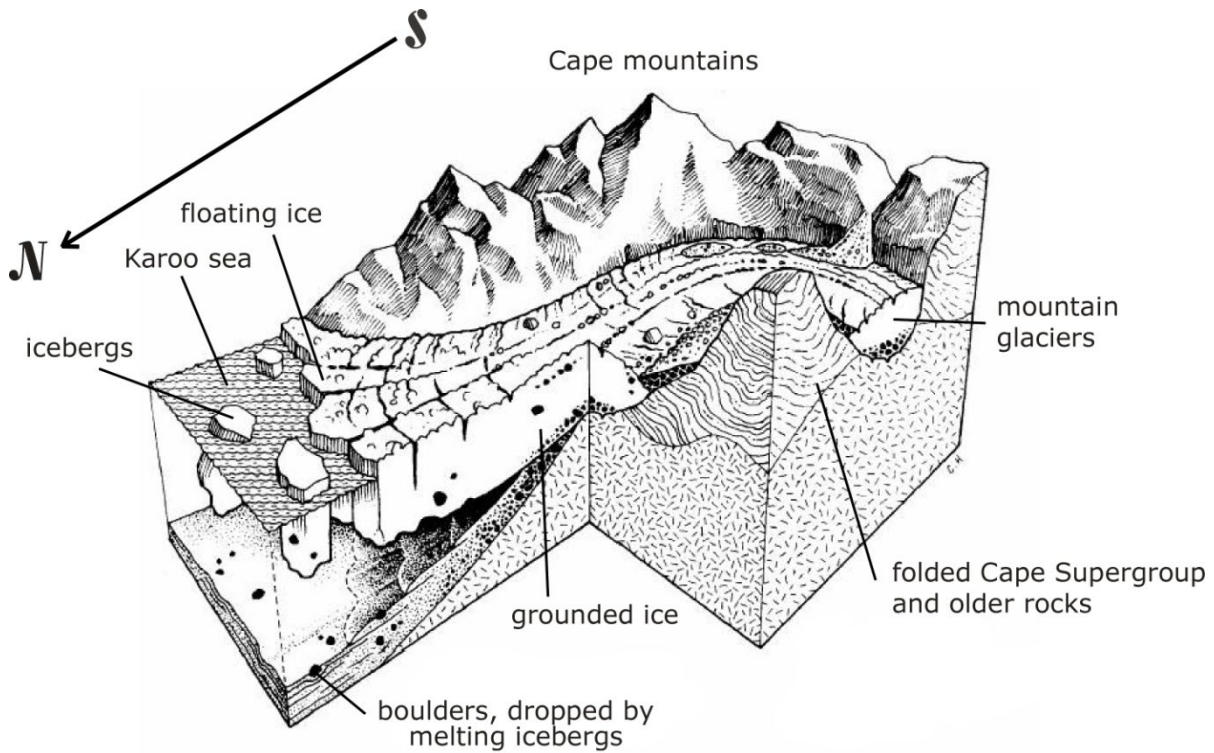


Figure 5. The probable depositional environment of the Dwyka Tillite, modified after Smith et al. (1993) and McCarthy & Rubidge (2005).

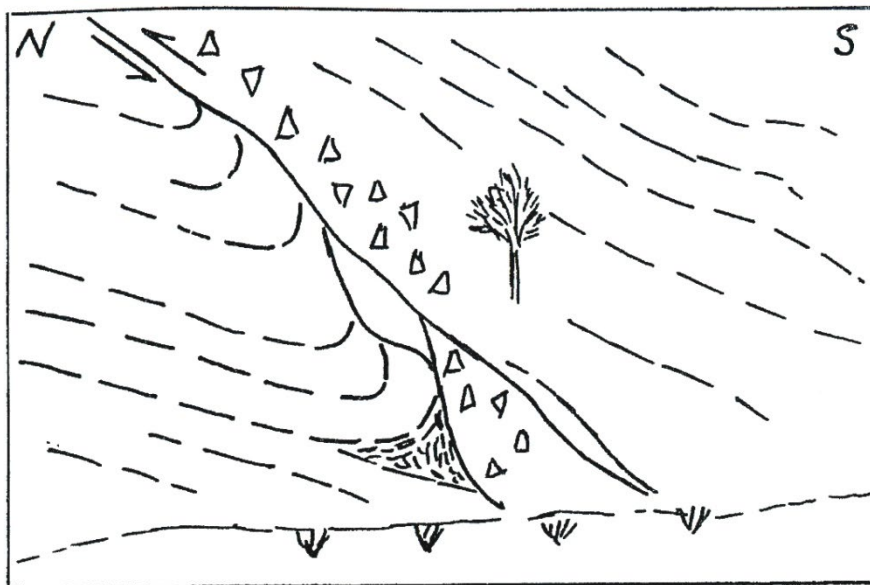


Figure 6. A cartoon illustrating a reverse fault with fault drag, from the road cut near the Caravan Park (Grey Street).

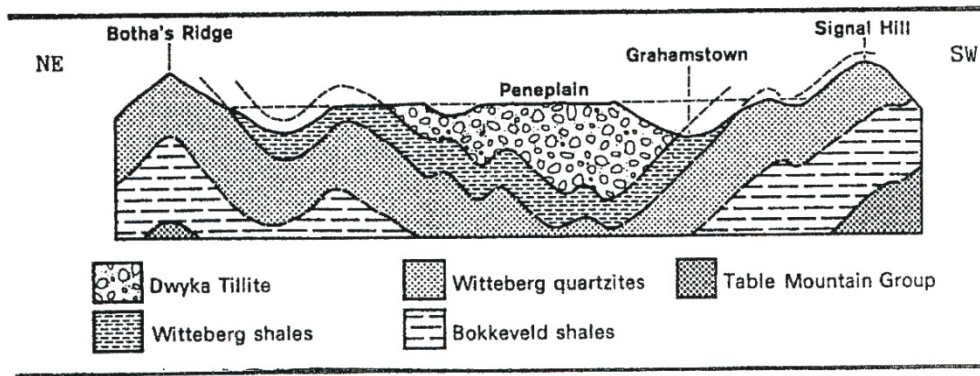


Figure 7. A geological cross-section of the Makhanda area, showing the synclinal structure between the ridges of Witteberg quartzite (after Hiller, 1985). (NOTE: "Bokkeveld shales" in fact belong to the Weltevrede Fm of the Witteberg Group).

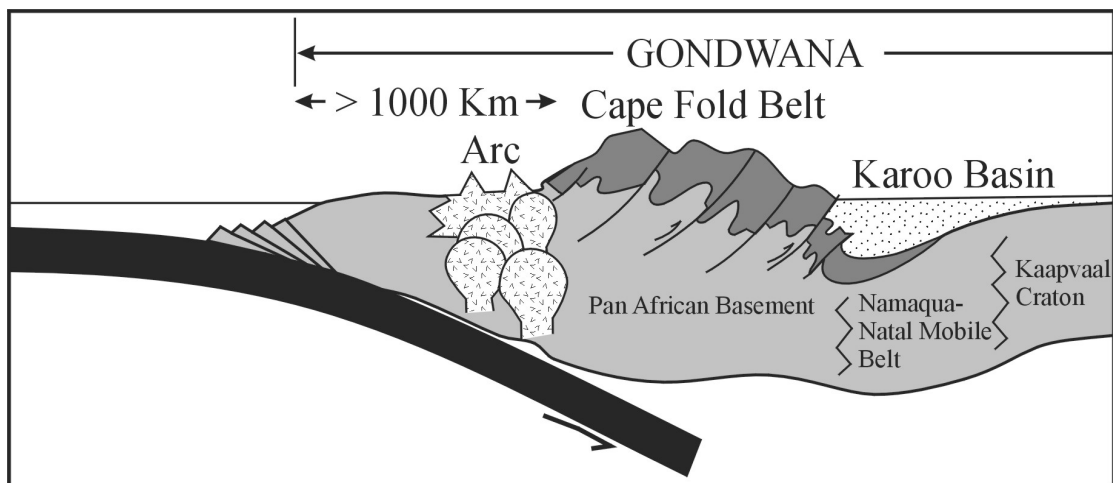


Figure 8. A cross-section illustrating the large-scale tectonic and basin-formation processes affecting the area around 300 million years ago (after Catuneanu et al., 1998).

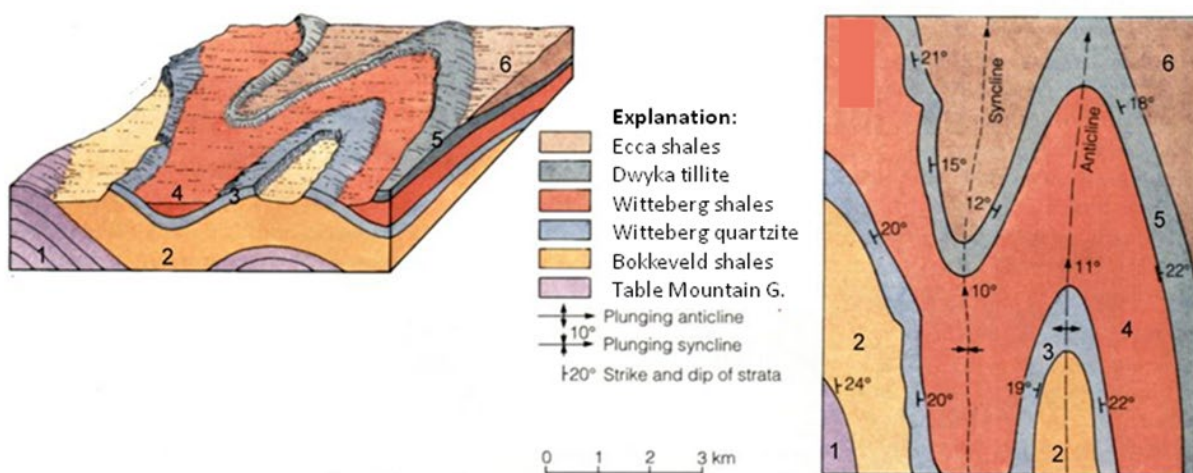


Figure 9. Block diagram and geological map in a folded terrain. Note the relationship between topography and exposed rock layer in this example which is similar to the Makhandha situation.

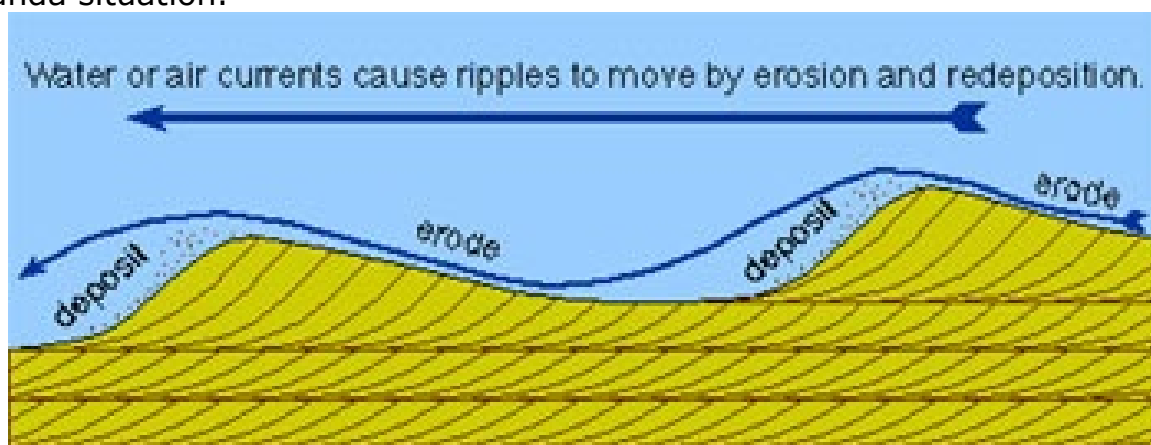


Figure 10: Cross-beddings in sand-rich sediments: note the deposition of sand as inclined foresets and their erosion at the top. The eroded surface, later covered by younger foresets, can be used as a “way-up” criterion in sandstones that have been tilted or overturned by folding or faulting.

Younger Deposits

In the area between Makhandha and the coast, a well-developed coastal plain occurs, formed as a number of wave-cut platforms. In places, remnants of Tertiary-aged (from 65 million years ago until quite recently) sandstone and limestone deposits containing marine fossils (such as shark’s teeth) are preserved. At that time, the coast was much closer to where Makhandha is today.

The main recent unit of interest around Makhandha is the so-called Grahamstown Silcrete. This unit was not formed by sediment being deposited in the usual way (that is, physically carried and dropped by moving water), but by chemical processes that operated in the soil profile during an extensive period of weathering and erosion. In the early Tertiary, when the climate was hotter and wetter, deep chemical weathering took place. This caused silica to be leached upwards from the underlying shales and tillite, leaving behind a residue of clay-rich weathered rock. The clay grades downwards into “fresh” (unweathered) rock. The silica was precipitated in the soil profile to form the dense, hard resistant silcrete.

The clay below the silcrete is bleached and whitish in colour, and it consists of a variety of clay minerals, mainly kaolinite. The deposits have been exploited, and the white scars of old workings dot the area around the city. The clay is used mainly for bricks, roof, wall and floor tiles, bathroom fixtures and pottery. It can also be used as a filler in the paint and paper industries. In addition to its industrial uses, it also has socio-cultural ornamental uses.

Clay deposits and weathered, clay-rich rocks, are of considerable environmental importance. They tend to swell when wet and to shrink when dry, so that structures (buildings) built on clay commonly tend to crack over time. Clays are impermeable and therefore can impede the flow of water, which can be undesirable in agriculture,

farming and gardening. However, it has the benefit that clay can retard the movement of polluted water, preventing it from getting into the groundwater system. For example, clay-rich rocks or clay-linings are favoured for radioactive waste-disposal sites; in Makhanda, the municipal waste dump is located in an old, disused clay pit, so that the clays have trapped and contained most of the pollutants.

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Glossary of Terms

Coelacanth	-a type of primitive lobe-finned fish thought to be extinct until relatively recently (1938), when it was rediscovered (by South Africans) off the Eastern Cape coast. It features regularly at Sasol SciFest, as well.
Delta	-triangular-shaped topographic pattern of sediments produced by river drainage into a larger reservoir (lake or sea).
Fault	-a non-elastic brittle deformation feature where rock is broken, and there has been movement of rock on either side of the fracture.
Fold	-a non-elastic ductile deformation feature where rock is bent, but not broken.
Fracture	- a non-elastic brittle deformation feature where rock is broken, or cracked. A fracture may be filled in by later minerals, or may be empty.
Gondwana	-a supercontinent which existed between about 500 and 100 million years ago, and included Africa, South America, Antarctica, India and Australia (so there was much less travel required for Tri-Nations matches then), plus Madagascar and the Falkland Islands.
Invertebrate	-animals with no skeletons ("spineless"), such as molluscs, jellyfish, cephalopods, sea urchins, insects etc.
Lungfish	-a lobe-finned fish which acquires oxygen from either or both gills and rudimentary lungs.

Peneplain	-a gently-undulating extensive land surface produced by uplift and erosion of a landscape.
Quartz	-a mineral made of silicon-dioxide, or silica, which can be found as crystals in rock, or grains, or precipitated out of hot water as veins.
Quartzite	-a metamorphic rock consisting mostly of quartz, produced by heating and compressing a sandstone.
Sandstone	-sedimentary rock, typically consisting mostly of quartz, cemented together by silica or lime (carbonate).
Shale	-a very-fine-grained sedimentary rock with a fissile character (a tendency to form flat plates which break apart easily).
Tetrapod	- a four footed beast such as a frog, cat or human. Weathering -the process of breaking down rocks by reaction with surface water and air ("weather"), contributing to erosion of the rock.

Stops:

1. At the 1820 Settler's Monument

An overview of the geology and geomorphology.

2. Faults and folds in quartzite and shale of the Witteberg Group

~250 million years old deformation structures, formed at ~10 km depth.

3. N2 Makhanda Bypass outcrop

Late-Devonian carbonaceous shales (there might be plant and fish fossils!): a former lagoon in the arctic climate zone. *Note that it is illegal to collect fossils without a permit.*

4. N2 Road cutting

Weathered Dwyka tillite: formation of clay in the Palaeogene

5. Near Ecce Pass

a) Fresh Dwyka Tillite (Carboniferous): sediments of an ice age

b) Shales of the Whitehill Fm (part of the Permian Ecce Group) with layers of volcanic ashes.

