# GEOLOGICAL HISTORY AND LANDSCAPE OF THE COASTAL WINEGROWING REGION, SOUTH AFRICA

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**Abstract**
The geology of the Western Cape testifies to the former existence of a late Precambrian supercontinent, its fragmentation, the closure of an ocean between the South African and South American continental precursors (Kalahari and Rio de la Plata cratons), the accumulation of marine sediments and limestones, and their compression during a collision between these cratons. This event took place during assembly of the southern supercontinent of Gondwana, over 500 million years ago. During the Cambrian the landscape of the western and southern parts of the Cape was eroded to form an alluvial plain with granite hills. From the Ordovician to the Carboniferous this plain intermittently subsided. The resultant Agulhas Sea, which at times extended from Vanrhynsdorp in the north to beyond Port Elizabeth in the east, and which was bordered by mountains to the west and north, received considerable volumes of sediment. These sediments were lifted and folded during the Permo-Triassic Cape Orogeny to form the mountains of the Cape Fold Belt, which are capped with erosion-resistant sandstones, whilst softer shales are locally preserved in downfolds.

After Gondwana rifted, a remnant of the Rio de la Plata craton remained attached to South Africa where it underlies the vineyards of the Coastal Region. Erosion was rapid under the warm, wet conditions which prevailed through much of the Cretaceous. By the end of the Cretaceous the main topographic features of the Coastal Region had already been roughed-out. Sculpting of the landscape into its modern form took place during the Tertiary and Quaternary, a time of sub-aerial erosion, pronounced changes in sea level and climatic variation, tending toward increasing aridity. The form of the modern landscape reflects the abilities of the rock structures and materials to resist protracted weathering and erosion.

## INTRODUCTION
That natural environmental factors (or criteria, Laville, 1990) influence wine style and quality is central to the terroir concept. Some of these factors, notably mesoclimate, the physical and chemical characteristics of the soil profile, drainage, aspect, slope angle and insolation, are linked to landscape and soil parent material (Wooldridge, 2003). In the Western Cape, where rejuvenation through glacial action last took place in the Carboniferous, and where multiple cycles of sub aerial erosion and weathering have acted on the bedrock over a time period greater than that of the Tertiary, both landforms and soils reflect the underlying geological structures and materials. In the western Cape, the Cape Fold Belt and the Coastal Foreland form two distinct subregions, based on geology, soils and terrain morphology (Lambrechts, 1979). Geology is thus a factor, albeit indirect, in terroir and demarcation (Saayman, 1992; Wooldridge, 2003). Certainly, vine performance and wine style in Sauvignon blanc are affected by geological and topographic factors, including mineralogy (van Schoor, 2001), and potassium supplying power is affected by mineral assemblage which, in turn, is related to parent rock type (Wooldridge, 1990).

This article presents an overview of the geology and geological history of the Western Cape, with particular reference to the Coastal Region. Its objective is to provide a palaeo environmental framework within the context of which present landscapes, their soils and terroirs may be interpreted, and demarcated.

MATERIALS AND METHODS

This article is a summary of the published work of several noted authorities on Western Cape Geology. Notable amongst these are maps and descriptions by Gresse, 1988; Theron, 1990; Gresse & Theron, 1992 and Theron *et al.,* 1992). These should be studied in their original form. Note that geological concepts and dates change frequently as new discoveries are made.

/ insert figure 1 /

DISCUSSION

**Landscape**

Satellite imagery (Fig. 1) shows that the landscape of the south-western Cape consists of coastal forelands (Lambrechts, 1979) or plains, with rounded granite hills and sandstone-capped inselbergs. Inland, the plains are backed by intersecting mountain ranges. To the north-east the land rises to an escarpment-rimmed plateau. Reddish image colours are indicative of vineyards and orchards, of which most are concentrated toward the inland margin of the western coastal plain, on mountain slopes, in valleys cut back into or through the mountain ranges, or in intermontane basins. Few vineyards have yet been planted on or around the southern coastal plain. The coastal lowlands mainly produce winter wheat. Though apparently simple, this landscape is the product an extended evolutionary history of which the main stages are indicated in block diagrammatic form in Fig. 2. This account begins with the deposition of the oldest rocks of the area, then progresses to more recent events.

/ insert figure 2 /

**Oldest rocks**

In the Western Cape the oldest known rock formations are a range of altered sediments belonging to the Malmesbury Group of the Namibian era of the late Precambrian period (Fig. 2, stage 1). These were apparently deposited in a subsiding trough (later a marine basin) during fragmentation of the late Precambrian supercontinental assemblage of Rodinia, which existed between about 1050 and 750 million years ago (Weil *et al*., 1998; Rozendaal *et al.,* 1999). The materials, which were deposited between about 750 and 780 mya, consisted mainly of immature sandstones (greywackes). These could have been deposited at delta margins or from deep-water turbidity currents. Limestones and quartzites are also present. These are more indicative of a shallow shelf, probably bordering the Kalahari craton (the continental precourser of South Africa). The Kalahari craton seems to have drifted between 700 and 600 mya. The Adamastor (Proto Atlantic) Ocean that then separated the Rio de le Plata (South America) and Kalahari cratons, then began to close. Plate consumption along a westward-sloping subduction zone began around 570 mya, by which time an oblique collision was taking place, the eastern edge of the Rio de la Plata craton over-riding the western edge of the Kalahari Craton. By about 545 mya, a poorly developed collision orogen (mountain range) was in existence. Intrusion of granites took place beginning around 550 mya (Rozendaal *et al.,* 1999; Siegfried, 1999).

Th collision between the Rio de la Plata and Kalahari cratons was part of the greater Pan-African Thermotectonic Event which accompanied the assembly of Gondwana, a southern supercontinent that, in addition to South America and South Africa, included the continental precursors of Antarctica, Australia, India and Madagascar. After subduction ended the subcrustal forces which had previously pressed the plates together, waned. Relaxation followed, accompanied by the intrusion of a second, phase of granites, mainly along earlier-formed, north-west orientated, zones of crustal weakness. This accounts for the north-westerly elongation of the features visible on the western coastal plain. (Fig. 2, 2). Locally, heat from the granite baked the sediment to hornfels, a hard, erosion resistant rock. Hornfels now underlies the prime vineyards of the Durbanville Hills (Mabbutt, 1950). Less altered Malmesbury metasediments form the undulating western coastal plain, as around Bottelary, and are also found in some valley floor situations in the mountain belts. Granites typically form dome-shaped or elongated hills, as at Paarl, but may also be deeply weathered and kaolinised, as around Stellenbosch, Kuils River and Somerset West. Breakdown of granite appears to be a function of the degree to which the crystal structure underwent crushing after emplacement.

When suturing ended, about 500 mya, the Western Cape landscape was underlain by three north-west orientated fault blocks, or terranes (Tygerberg, Swartland and Boland), each with a distinctive character. Erosion was rapid, and coarse erosion products were carried by short, fast-flowing rivers into fault troughs and depressions, forming the Klipheuwel (stony hills) Group. Although the lower members of the Klipheuwel Group were deformed during the final stages of the Pan-African Event, the upper components are undeformed and locally grade into the basal elements of the overlying Cape Supergroup.

**Cape Supergroup**

Sub aerial erosion continued through Cambrian (543 to 490 mya) into early Ordovician times (Fig. 2, 3). Then, subsidence began, following two lines of crustal weakness, apparently in an abortive attempt at rifting. One of the arms coincided with the northerly axis of Klipheuwel Group deposition, extending north into an embayment which included Calvinia, Vanrhynsdorp, Clanwilliam, Citrusdal and Ceres, whilst the second, west-east axis, ran parallel to the present south coast line, from Cape Town eastward through Prince Albert to Port Elizabeth and beyond (Rust, 1973; Truswell, 1977). Initially, this lowland area was traversed by braided rivers and streams from the Bushman, Kamdeboo and Winterberg mountains to the north and from the Atlantic mountains to the west. This resulting undulating landscape, with its shale derived lowlands and low granite hills, may have resembled the coastal lowlands of the present day, except for a total lack of vegetation cover.

About 490 mya, in the early Ordovician, the lowermost materials of the Table Mountain Group began to spread across the landscape (Fig. 2, 4). These coarse, conglomeratic deposits (the Piekeneerskloof Formation) were deposited by braided rivers on a broad flood plain, and were locally continuous with the underlying Klipheuwel. As time progressed the area became a wide coastal plain with tidal estuaries on, and in which, accumulated the muds and shales of the 150 m thick Graafwater Formation. Further subsidence led to the deposition of clean sandstones. These Peninsula Sandstones spread across the former landscape, overtopping the granite hills and eventually reaching a thickness of over 1500 metres. Subsidence and deposition in what is now called the Agulhas sea was to continue intermittently for some 200 million years, during which the shoreline moved progressively further north. The lower, older formations of the Cape Supergroup (the Table Mountain Group) mainly consist of quartzitic sandstones deposited either by rivers on a wide floodplain adjacent to the shoreline, or in a high-energy near-shore marine environment. In contrast, the 40 m thick, late Ordovician Pakhuis Formation, which occupies the top of Table Mountain at MacLear's Beacon, was deposited from floating ice calved from glaciers at the edge of an ice cap. This covered much of Gondwana in late Ordovician to early Silurian times, at which stage the South Pole was located in south eastern Nigeria. Melting of the ice sheet led to reworking by rivers of materials dumped by the glaciers (moraines) and to transport of the finer materials to glacial lakes and shallow bays of the Agulhas sea. Both the Soom and Disa (siltstone) Members of the Cedarberg Formation are fossiliferous, the Disa Member containing spore tetrads that have been interpreted as representing the earliest plants to colonise the land (MacRae, 1999).

After the glacial interlude represented by the Pakhuis and Cedarberg Formations, conditions returned to a semblance of those of the mid Ordovician. These conditions prevailed throughout the Silurian, into the early Devonian, during which period some 480 m of sandstones (the Nardouw Subgroup) were laid down. These materials were transported from granitic highlands to the west, north and east, and deposited under shallow, open-sea conditions.

In contrast to the predominantly sandy Table Mountain Group, the overlying Bokkeveld Group consists of alternating sandstones and shales. Times of rapid subsidence, leading to deepening of the Agulhas sea and migration of the shore line toward the north, are represented in the stratigraphic record by muddy deposits (shales), of which six Formations are recognised (Gydo, Voorstehoek, Tra-Tra, Waboomberg, Klipbokkop and Karoopoort). Five sandstone formations (Gamka, Hex River, Boplaas, Wuppertal and Osberg) separate the shale formations. The sandstones represent periods with little or no subsidence when shorelines advanced and sandstones built out across the basin.

The Bokkeveld Group grades into the Witteberg Group, which spans the Devonian-Carboniferous boundary. Like the Bokkeveld, the Witteberg consists of alternating shale (Wagen Drift, Swartguggens, Kweekvlei and Waaipoort) and sandstone (Blinkberg, Witpoort, and Floriskraal) formations, although there is evidence of increasing river action leading to infilling, marshlands, formation of lagoons and deltas, sorting of sediments into fine and coarse fractions by currents, and reworking of river deposits to form offshore sand bars. Evidence of a return to glacial conditions is present in the uppermost units. In the Western Cape the transition between Witteberg and the overlying Dwyka is nevertheless marked by an unconformity. This period of zero deposition may have lasted 30 my.

**Carboniferous to Permian Glaciation, and the Karoo Supergroup**

Deposition of the Cape Supergroup finally ended in the Carboniferous with the onset of the Dwyka Ice Age (Fig. 2, 5), an episode which lasted around 50 million years, from 320 to 270 mya. Though of geological interest, the sediments of the Dwyka, and of the early Permian Ecca group are of limited occurrence in the Western Cape winelands, although they are represented in the Worcester-Robertson section of the Breede River Valley. Concerning the succeeding Karoo Supergroup (Fig. 2, 6), which lies north-east of the Winelands, it is sufficient to note that the vast Karoo basin contains a 75-million year (late Carboniferous to mid Jurassic) fossil record. This begins with the expansion of life into lands vacated by the Dwyka ice sheet, records the effects of hot-house temperatures which soared in the late Triassic, and bears witness to events surrounding the mass extinction at the Permo-Trias boundary (Ward, *et al*., 2000).

**Cape Fold Belt**

The Karoo basin was created after the axis of subsidence that had previously created the Agulhas Sea migrated north. The mountains of the Cape Fold Belt form the southern rim of the Karoo basin. Northward migration of the axis of subsidence was probably caused by compression of the southern margin of Gondwana by a north-directed subduction zone / magmatic arc complex (Johnson, 1991; Johnson *et al*., 1997) which operated from the late Permian (290-245mya) to the late Triassic (245-208 mya. The Cape Fold Belt (Fig. 2, 6a) was created by a series of orogenic events during Permo-Triassic times with major compressional episodes at 278, 258, 247 and 230 mya, and with uplift and horizontal tension at 215 mya. These events were associated with erosion and northward transport of the eroded materials into the Karoo basin. Folding of the Cape Supergroup was simultaneous in the western and southern arms of the Cape Fold Belt although, to the south-west, the granite-intruded basement protected the Palaeozoic (Cambrian to Permian) cover against buckling. Across the fold belt, crustal shortening ranged from 25% to 40%, but exceeded 70% in some areas (Hälbich, 1983).

**Gondwana fragmentation**

By the end of the Jurassic (145.6 mya) the Ecca of the Karoo Basin lay beneath a sedimentary cover consisting of the Beaufort shales and sandstones, the Molteno, Elliot (red beds) and the Clarens (Cave Sandstone) formations of the Stormberg Group (Truswell, 1977). Sedimentation ended about 187 mya when the Karoo Basin was capped by the Drakensberg Volcanics, an early stage in the process by which Gondwana fragmented (Fig. 2, 7). Continents seem to form supercontinental assemblages, then break apart in repeated cycles (Hatton, 1997). Once formed, hot mantle plumes seem to be implicated in their fragmentation (White, 1997), probably by doming the crust upward until rifting occurs, usually along pre-existing lines of weakness and accompanied by volcanism (Storey & Kyle, 1997). Gondwana fragmentation took place over an extended period. During the late Jurassic (before 154 mya) the Western Cape developed a horst and graben (elongated fault block) structure with lakes and short rivers, and the Berg River established itself along the eastern side of an upfold that occupied the present position of the Swartland. The northern Mozambique basin formed between 142 and 133 mya, but separation along the west coast did not occur until the early Cretaceous (135 to about 127 mya) with the initiation of drift between 129 and 121 mya. As the Atlantic Ocean opened, South America drifted westward, taking with it the Falklands Plateau. This plateau separated from the Mozambique Ridge along a right lateral transcurrant fault and finally cleared the southern tip of South Africa around 100 mya (Partridge & Maud, 1987).

Rifting and continental separation generated tensional forces that were released by downward rock slippage on the coastal side of faults which themselves ran broadly parallel to the coastline. Along the Worcester-Pletmos basin line, displacement varied from zero to 6 000 m. Further south, downthrow along faults led to the submergence of the Agulhas bank. Other fault (half-rift graben) basins opened to the sea (Bredasdorp, Pletmos, Gamtoos and Algoa). Sediments which accumulated in these basins were of marine origin but, in inland settings such as the valley created by the Worcester Fault, they included the mid Jurassic to lower Cretaceous Uitenhage Group Enon Formation. The

Enon consisted of coarse reddish conglomeratic material eroded from the fault scarps to the north, and of lenses of mudstone and sandstone, possibly laid down in playa lakes (MacRae, 1999).

Although continental separation was followed by cooling and subsidence of the continental margins, the continental landmass of South Africa retained a high altitude, particularly inland of its southern and eastern margins. Under the prevailing warm, humid and possibly wet climatic conditions of the Cretaceous erosion was rapid, and dominated by scarp retreat (Fig. 2, 8). Slope form evidently adjusted itself to compensate for differences in rock strength and erodability, with the result that resistant structures remained behind as the scarp retreated into the hinterland (Moon & Selby, 1983). Eroded materials were carried by rivers to the coast, and deposited on the continental shelves and slopes. By the late Cretaceous the Great Escarpment had moved inland, to within a few kilometres of its present position, and offshore sedimentation had virtually ceased due to a dryer climate and to a world wide sea level regression which exposed the continental shelves to sub aerial weathering.

When South America and South Africa separated they did not do so along the original line of suture but well to the west of it, the rift (which became the Atlantic Ocean) apparently skirting around the granite-underpinned crust of the Western Cape. The Western Cape winelands are therefore located on a microplate that, in pre Gondwana times, was part of the Rio de la Plata craton.

**Weathering and the African surface**

After vertical movements associated with continental separation had ceased, the South African continent became tectonically stable. Work by Söhnge (1991) and Partridge & Maud (1987) suggests that this stability lasted until the mid to late Miocene, about 14.5 mya, when the continent was slightly uplifted and tilted. Since the Western Cape landscape had already been culpted into a broad semblance of its present form during scarp retreat, the effect of this Cretaceous to Miocene weathering was that of modifying the pre-existing surface, mainly through down cutting, and deflation (Fig. 2, 9). The sea level regression of 96 mya was followed in Palaeocene to Eocene times by a transgression, accompanied by humid, wet conditions and decreasing temperatures. These conditions led to the widespread development of red, structureless soils. These are mostly found on dissected footslopes and pediments between 200 and 300 m altitude, or higher. The Schoogezicht surface at 500-415 m altitude probably dates back to Palaeocene / Eocene times when the coastal plain was partly submerged, with islands. During the Eocene, Australia and Antarctica were still linked. Following their separation in the late Oligocene Australia moved to polar latitudes and a cold circum Antarctic current developed. The Oligocene (around 34 mya) was a period of sea level regression. The continental shelf was exposed over a width of 200 km in some areas, and the climate was warm and wet with temperate to subtropical forests. This persisted into the Miocene (23.3-5.2 mya), when sea levels again rose. The Higher Swartland surface (200-150 m altitude) was probably formed early in the Micene, by which stage the Table Mountain Group covering of Bottelaryberg had probably been stripped away. By early Miocene times offshore sedimentation had diminished to a level which suggests that substantial areas of the African surface, both above and below the Great Escarpment, had been reduced to undulating plains. Highlands, such as the Cape Fold mountain belt nevertheless persisted, mainly because of the erosion resistance of the sandstone formations.

The cycles of weathering and erosion that created the African surface ended when uplift and tilting in mid Miocene times (about 14.5 mya) rejuvenated the drainage system, leading to dissection of the African surface. A characteristic of the African surface was the extreme depth to which susceptible rock types, notably granite and shale, were affected (etched, Twidale, 1988) by the protracted chemical weathering. Significantly, the erosion which created the Higher Swartland surface did not cut through the previously weathered material into the fresher material beneath.

**Mid Miocene to Recent**

The Post African I cycle was initiated by the mid Miocene uplift, and by regression, which lead to the deepening of the Eerste River palaeovalley. The Antarctic ice sheet reached its present thickness by the late Miocene, by which time a cold north-flowing current had established off the west coast of southern Africa. By 5.3 mya (early Pliocene) sea levels had risen once more. Further, the Benguela current had begun to exert a cooling influence. By creating an atmospheric temperature / pressure barrier which deflected rain bearing winds from the south west around the southern tip of the continent, the Benguela current also caused increasing aridity. Cutting of the Lower Swartland surface at 140-80 m altitude locally removed much or all of the preweathered material from the African cycle. Extensive areas of residual soil, and some duricrusts, were formed (Fig. 2, 10).

By the mid Pliocene, 4.2 mya, regression had taken place and the sea level was at a stillstand. The climate was cool and dry with summer rainfall. The Katarra surface (100-80 m) was cut, and the Eeerste River was about 55 m above its present bed. Some duricrust formation continued.

The Post African 1 cycle ended in the late Pliocene, about 3.8 mya, with uplift of about 100 m on the west coast. The effects of this uplift were small in the Western Cape, relative to the interior and eastern side of the continent, where elevation ranged from 600 to 900 m. The elevation was nevertheless sufficient to cause regression and rejuvenate drainage, resulting in the deposition of the Higher Terrace and Older Gravels along the Eerste River, at which stage the Eerste River was 23 to 36 m above its present level. A temperate, Mediterranean climate prevailed. Between 2.8 and 2.6 mya a global period of cooling and aridification occurred.

The early Pleistocene (1.65 mya) saw the sea level rise to its present level, the Lower Terraces cut and the Younger Gravel deposited. The climate was periodically cooler and warmer than at present, although aridity was increasing. Changes in sea level were frequent during the ensuing Pleistocene (1.64 to 0.01 mya) as ice ages came and went, alternately creating conditions for water courses to cut deep gorges, draining previously wet valley bottom sites, and at other times causing the incised drainage channels to infill.

**Cenozoic deposits**

Although various sedimentary deposits were laid down during the marine incursions of the Cenozoic, these generally lie at low altitude, close to the coast, where conditions are unsuitable for grape vines. In contrast the scree deposits of the upper footslopes, which vary in stone content but usually contain abundant coarse sand, make excellent vineyard soils, as do uncemented terrace gravels and the better drained alluvial deposits (Fig. 2, 11). Since the Tertiary and Quaternary were glaciation-free in the Western Cape, the landscapes and soils did not undergo glacial rejuvenation.

**Evidence of early human activity**

Stone artefacts, typically large, bifacially-flaked cleavers, and hand axes, some weighing over 2.8 kg, are found in vineyards around Stellenbosch, and elsewhere, usually on hillslopes above river valleys. Once attributed to the Stellenbosch Culture, these artifacts are now ascribed to the Acheulian Industrial Complex (Du Toit, 1954). The Acheulian artisans, who apparently preferred rounded cobbles from river gravels to unrounded rock fragments, probably arrived in the Stellenbosch area after the Younger Gravels had been deposited, possibly around 0.5 mya (Söhnge, 1991).

**The modern landscape**

Formation of he Coastal Region landscape began with the removal in post Gondwana times of the Palaeozoic Cape Supergroup. This exposed the underlying Precambrian to Cambrian metasediments and granites. Outliers of Cape Supergroup sandstones (Table Mountain, Simonsberg, Riebeek Kasteel and Piketberg) overlook the coastal plain. The plain is backed by mountains created by folding and uplift of the Cape Supergroup in Permo-Triassic times. Between the sandstone peaks of these mountains, clay-rich soils have developed from shales preserved in downfolds. Although the valleys in the Fold Belt tend to follow fold axes, others, such as the viticulturally significant Franschoek and Worcester-Robertson (Breede River) valleys, are controlled by basement faults which may date back to the assembly of Gondwana. The altered and locally hornfelsed Precambrian sediments and granite hills of the coastal plain, together with the granite and sandstone slopes, and the sandstone and shale-floored valleys and upland plateaux of the mountains of the Cape Fold Belt, provide the Coastal Region and its mountainous hinterland with a variety of landforms, aspects, associated mesoclimates (notably exposure to sea breezes) and soil parent materials.

CONCLUSIONS

Jointly, this summary, and the maps and articles cited in the introduction, provide both a physical structure, and a temporal framework, for the study of Western Cape terroirs. The significance of this framework and structure in terms of viticulture, terroir, demarcation and marketing remains to be determined.

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LIST OF FIGURES

FIGURE 1

Satellite image of the south-west Cape showing the coastal plains and Cape Fold Mountain Belts. Since the Great Escarpment lies off this image to the north east, the visible structures are residuals, having resisted the protracted erosion of post-Gondwana times.

FIGURE 2

Block diagrammatic representation of a hypothetical west-east section from the coast to the mountains of the north-south limb of the Cape Fold Belt, showing the main geological formations and indicating the principal stages in the evolution of the modern landscape.

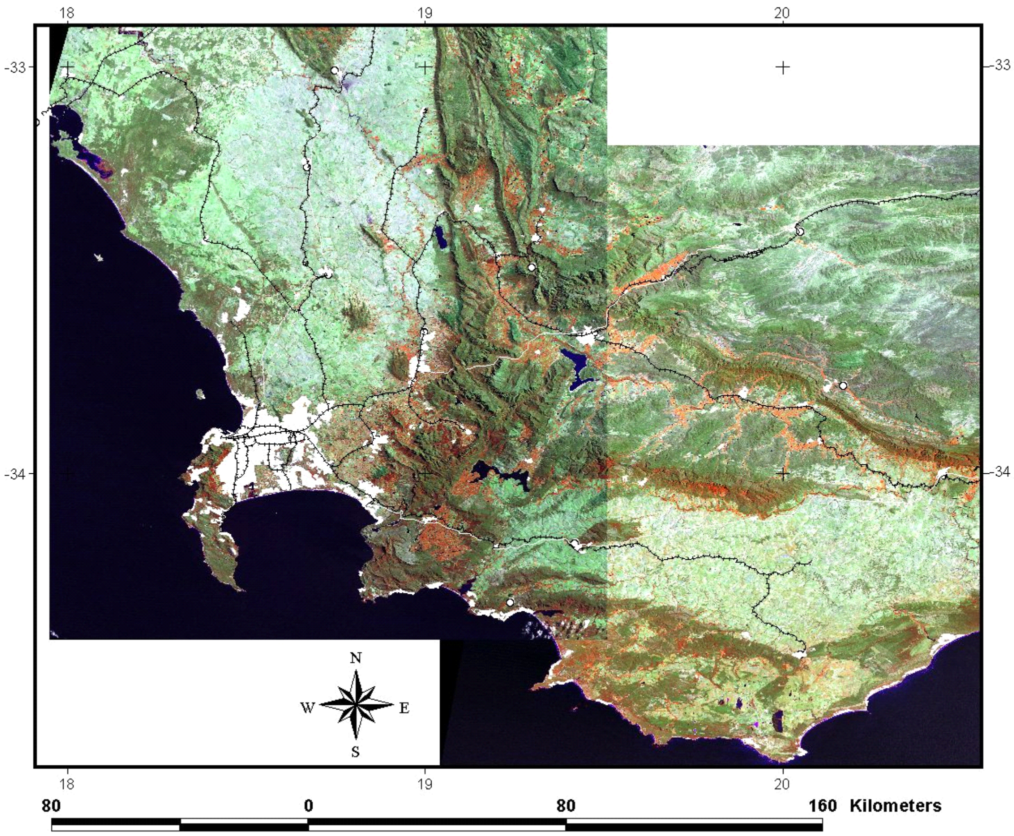


FIGURE 1

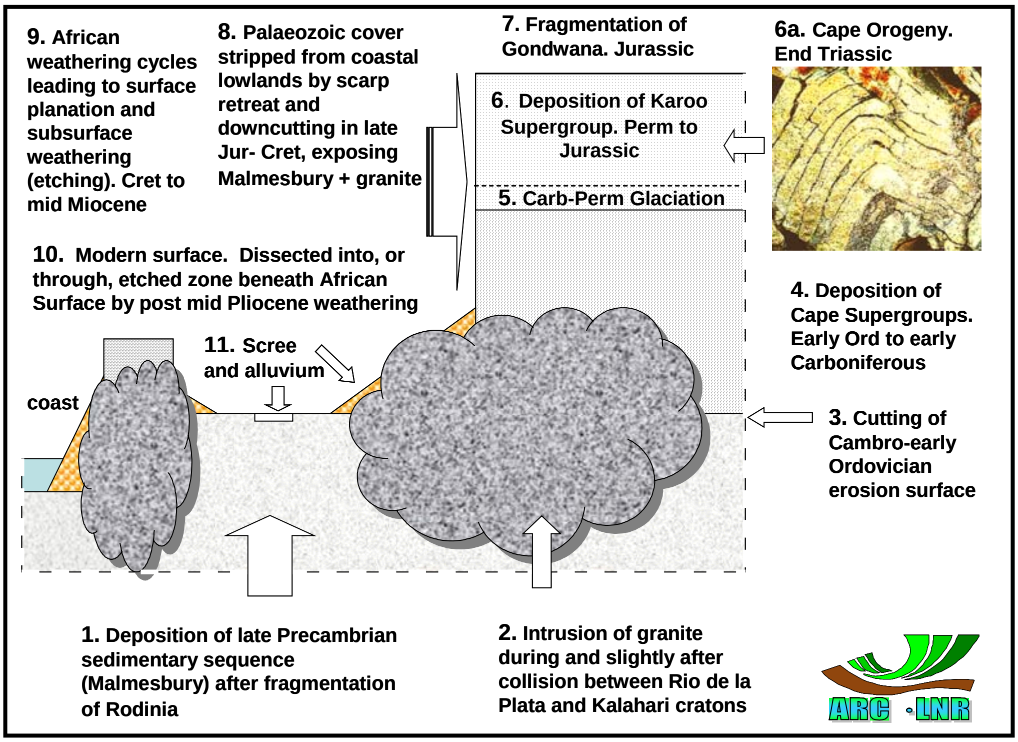


FIGURE 2