3.3. ALGOA GROUP

The greater part of the Coega IDZ area, both along the coast and across the Coega and Grassridge Plateaux in the interior, is underlain by aeolian, coastal and shallow marine sediments of the Algoa Group (See map Fig. 2). In the study area this Late Caenozoic succession comprises five successive formations ranging in age from the Late Miocene, roughly 7 million years ago, through to the Recent (Fig. 35). The Algoa Group rocks unconformably or paraconformably overlie much older sediments of the Table Mountain Group and Uitenhage Group (Fig. 1). Predominant sediment types include calcareous sandstones (both marine and aeolian), sandy and shelly clastic limestones, conglomerates and coquinite (*ie* gritty to gravelly "shell hash"). Due to their high content of finely comminuted (ground-up) shell material of marine origin, many of these units are very lime-rich. Since deposition, they have frequently been modified to form well-consolidated calcareous rocks ("coastal limestones"). These include tough, white surface calcretes (pedogenic limestones) that have been formed through the solution and reprecipitation of carbonate minerals by groundwaters and that are typical of semi-arid climates.

The complex overlapping distribution of the various Algoa Group formations reflects the pattern of continental uplift and global changes in sea levels during the late Caenozoic Era. Useful summaries of Algoa Group geology have been given by Le Roux (1990a), Maud & Botha (2000) and Roberts *et al.* (2006), while data pertinent to the Coega region is provided by Engelbrecht *et al.* (1962), Toerien and Hill (1989), Goedhart and Hattingh (1997) and Le Roux (2000). Note that important revisions to the Algoa Group geology of the Coega IDZ shown on the 1: 250 000 map (Fig. 2) were made for the later maps published at 1: 50 000 scale. The present study suggests that further small revisions may be necessary with respect to the distribution and identification of some coastal formations (*eg* the Nahoon Formation outcrop is much more extensive than indicated). However, this requires detailed mapping by geologists familiar with these challenging sediments, and for the most part the scheme shown in the published 1: 50 000 maps is followed here.

The estuarine, coastal and shallow marine successions within the Algoa Group – *ie* the Alexandria and Salnova Formations – are often characterized by abundant and diverse invertebrate faunas that are dominated by various groups of mollusks (notably bivalves and gastropods). These important Miocene to Pleistocene shelly faunas have been reviewed in key papers by Barnard (1962) and Le Roux (1987a, 1993) (See also MacRae 1999 for a well-illustrated, less technical account). In contrast, the terrestrial aeolianites (wind-blown dune sands) of the Nanaga, Nahoon and Schelm Hoek Formations, generally contain only a sparse fossil to subfossil biota. The most obvious groups here are a small range of land snails as well as calcretized rhizoliths (root casts) and possible termitaria.

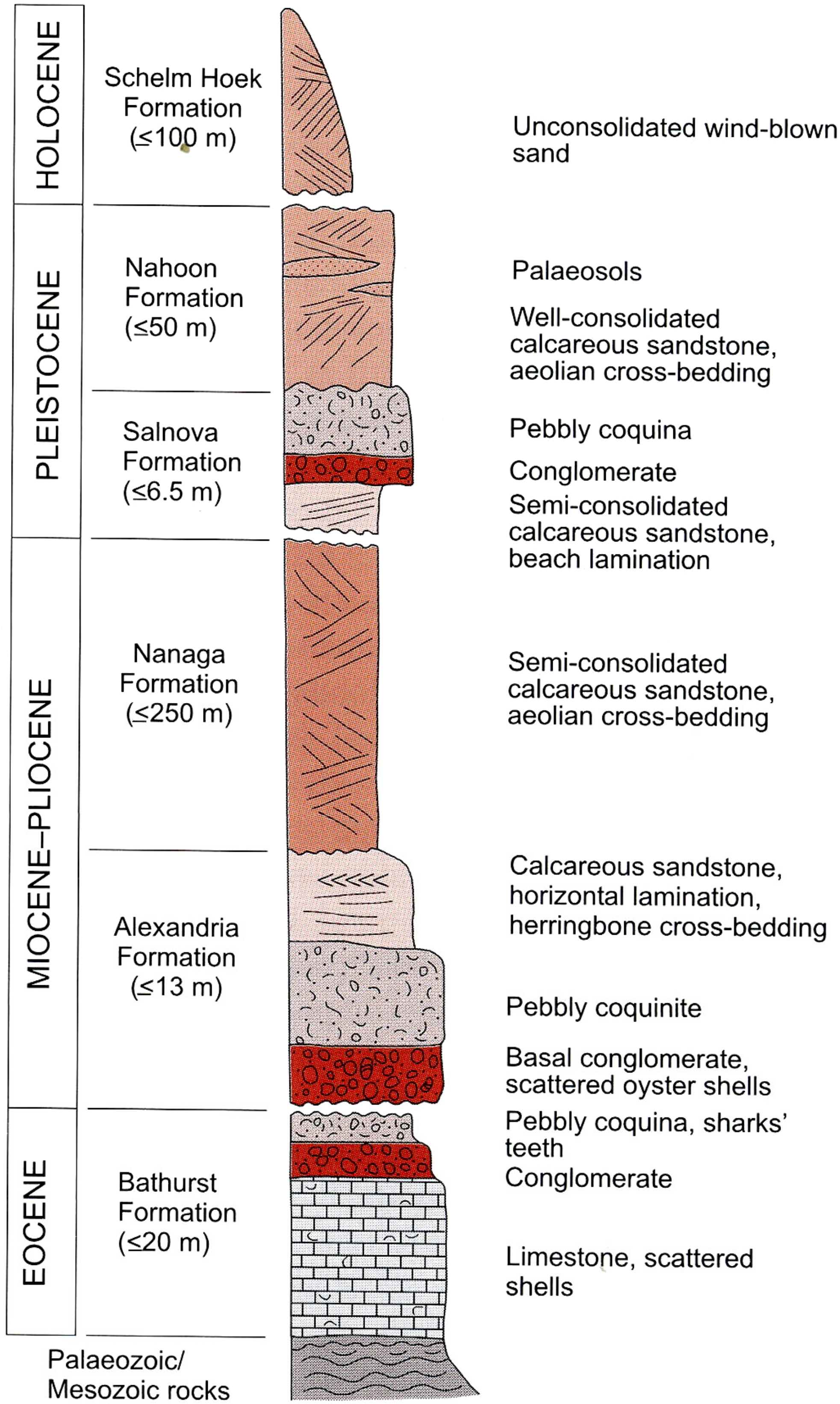


Fig. 35. Schematic stratigraphic column for the Algoa Group along the southeastern Cape coast (Roberts *et al.*, 2006). Note this scheme is highly simplified. For example, the Alexandria and Nanaga Formations partially overlap in age, while the Salnova Formation interdigitates with the Nahoon and Schelm Hoek successions.

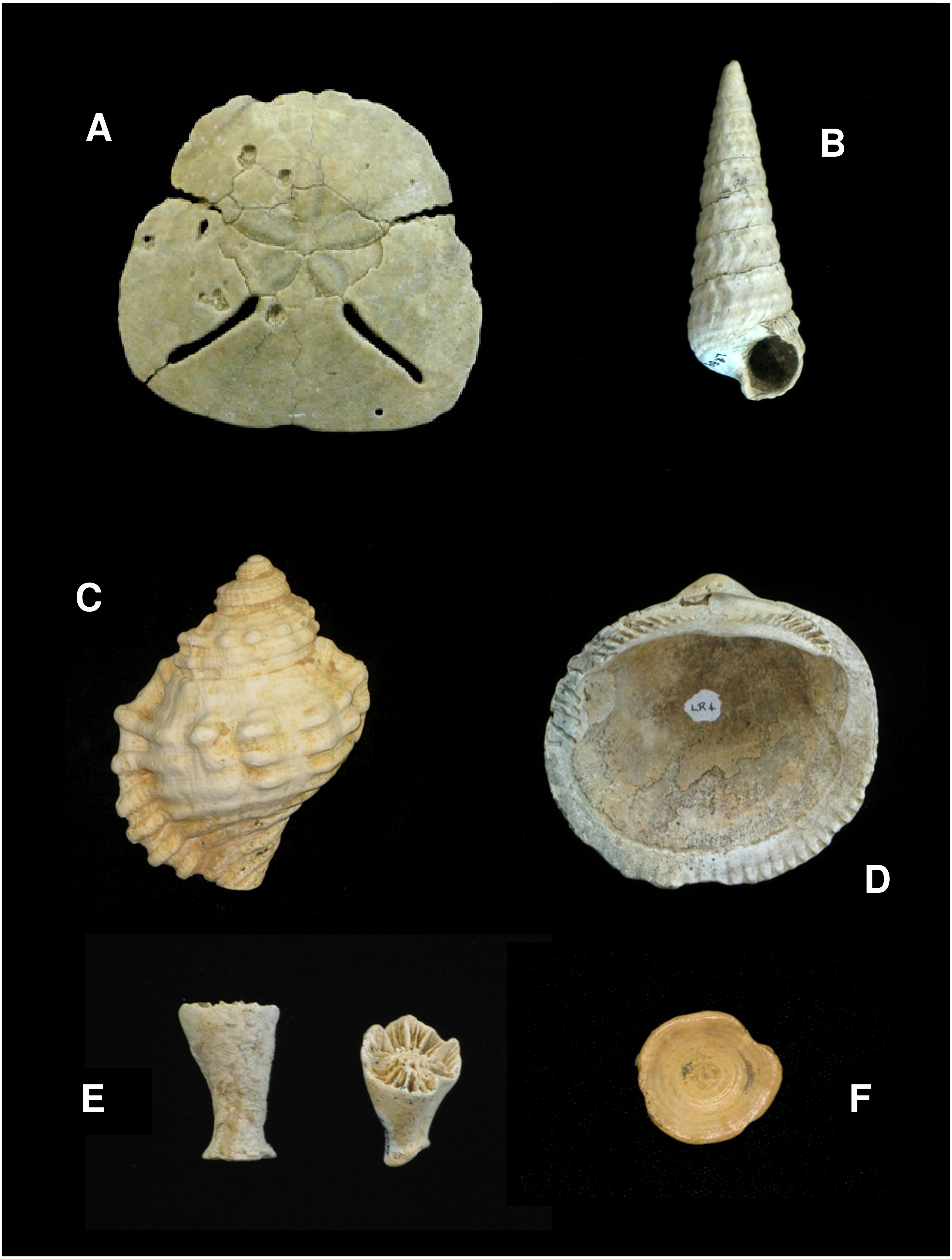
3.3.1. Alexandria Formation (Ta)

This estuarine to coastal marine formation consists of a basal conglomerate rich in oyster shells overlain by calcareous sandstones, shelly coquinas and thin conglomerates (See idealized section provided by Le Roux 1987; Fig. 38 herein). It represents a composite product of several marine transgression (invasion) / regression (retreat) cycles across the Algoa coastal plain in Late Miocene-Pliocene times, *ie* roughly around 7-5 Ma ago (Maud & Botha 2000, Roberts *et al.* 2006). The Alexandria Formation overlies a series of marine terraces incised into older (mainly Cretaceous) rocks in the hinterland of the Algoa Basin - the lower seawards Coega Plateau and the higher, landwards Grassridge Plateau (Ruddock 1968, Goedhart and Hattingh (1997). The Alexandria Bay Formation ranges from three to 13m in thickness, with an average of 9 to 10m (Le Roux 1987b, Goedhart and Hattingh, 1997). It reaches its greatest thickness between the Swartkops and Sundays Rivers. Maud & Botha (2000) record a maximum thickness of 18m. One of the reference stratotype sections for the Alexandria Formation (Stratotype D of Le Roux 1987; Fig. 46 herein), a road cutting situated close to the main Coega brick pit, has probably been obliterated by recent road development. Here the unit was some 7-8m thick and rich in fossil remains.

3.3.1.1. Palaeontological record of the Alexandria Formation

The Alexandria Formation limestones as a whole are highly fossiliferous. However, good exposures in the interior are usually limited by cover of younger sediments of the Algoa Group (*eg* Nanaga Formation aeolianites), weathered surface material of the "Bluewater Bay" facies (Section 3.3.1.3. below), extensive development of surface calcretes and thicket vegetation. A wide range of shelly marine fossils are recorded from the Alexandria Formation (Newton 1913, Du Toit 1954, Barnard 1962, Engelbrecht *et al*. 1962, King 1973, Dingle *et al*., 1983, Le Roux 1987a, 1987b, 1990b, 1993, McMillan 1990). These are mainly molluscs (bivalves, gastropods, scaphopods), but also include serpulid worm tubes, sea urchins (the "sea pansy" *Echinodiscus*), solitary and colonial corals, bryozoans, brachiopods, barnacles and crab claws and benthic foraminifera (*e.g.* Figs. 36, 43, 44, 45, 61). Sharks' teeth and rare fish vertebrae are also known. Robert Gess (undated heritage report for Coega development) mentions mammal bones found in this unit but this may be a reference to the later, Pleistocene fauna briefly described by W. H. Gess (1951/1952) from Aloes. Diverse trace fossil assemblages (*eg* pellet-walled burrows of *Ophiomorpha*, bivalve borings *Gastrochaeonolites*, and a wide range of shell borings) occur in the Alexandria sediments but have not yet been described in detail in the palaeontological literature.

Fig. 36 (following page). Selected fossils from the Miocene / Pliocene Alexandria Formation (Collections of the Albany Museum, Grahamstown). A – an irregular echinoid *Echinodiscus*, the "sea pansy" (7cm wide) B - *Pirenella*, a gastropod (5.5cm tall) C – *Cymatium*, a gastropod (10cm tall) D – *Glycimeris*, a bivalve (10cm wide) E – *Balanophyllia*, solitary corals (2.5cm tall) F – fish vertebra (2.25cm across). *NB* These images are not at the same maginification.


A
B
C
D
E
F

3.3.1.2. Alexandria Formation in the Coega IDZ

The limestone-rich Alexandria Formation (Ta) and its reddish, pebbly surface weathering products, the "Blue Water Bay Formation" (T-Qb) mantle the greater part of the Coega IDZ (Fig. 2). Arcuate ridges and troughs crossing the Coega Plateau subparallel to the modern coastline are clearly visible on satellite images where they are emphasized by vegetation contrasts (*eg* in IDZ Zone 6). These are beach ridges and swales generated by intermittent stillstands of sea level as the Alexandria coastline gradually retreated seawards in late Pliocene times (Goedhart & Hattingh 1997, their fig. 3.3). The ridges are characterized by thick storm gravel deposits while lines of solution hollows (*dolines*) have developed along the swales that are also picked out by denser thicket vegetation.

Numerous recent excavations have cut through the Alexandria Formation in the Coega IDZ – notably several deep stormwater trenches and reservoirs as well as new roadcuts in Zones 6, 11. This formation has also been exposed in several small limestone quarries in the area, most of which are no longer active, but is best seen in the main limestone quarry east of Coega (Fig. 37). Thin cliffs or *kranzes* of Alexandria Formation sediments fringe the low escarpment along the northern edge of the Coega River Valley (*eg* on Bontrug 301 and the Brakrivier Valley).

Fig. 37. Excellent vertical sections through the upper Alexandria Formation in the main Coega limestone quarry, showing cross-bedding and channel infilling by conglomeratic facies. Note also flat-bedded coquinites towards the base and calcretes on top. This freshly exposed quarry face has already been partially covered by backfilling.

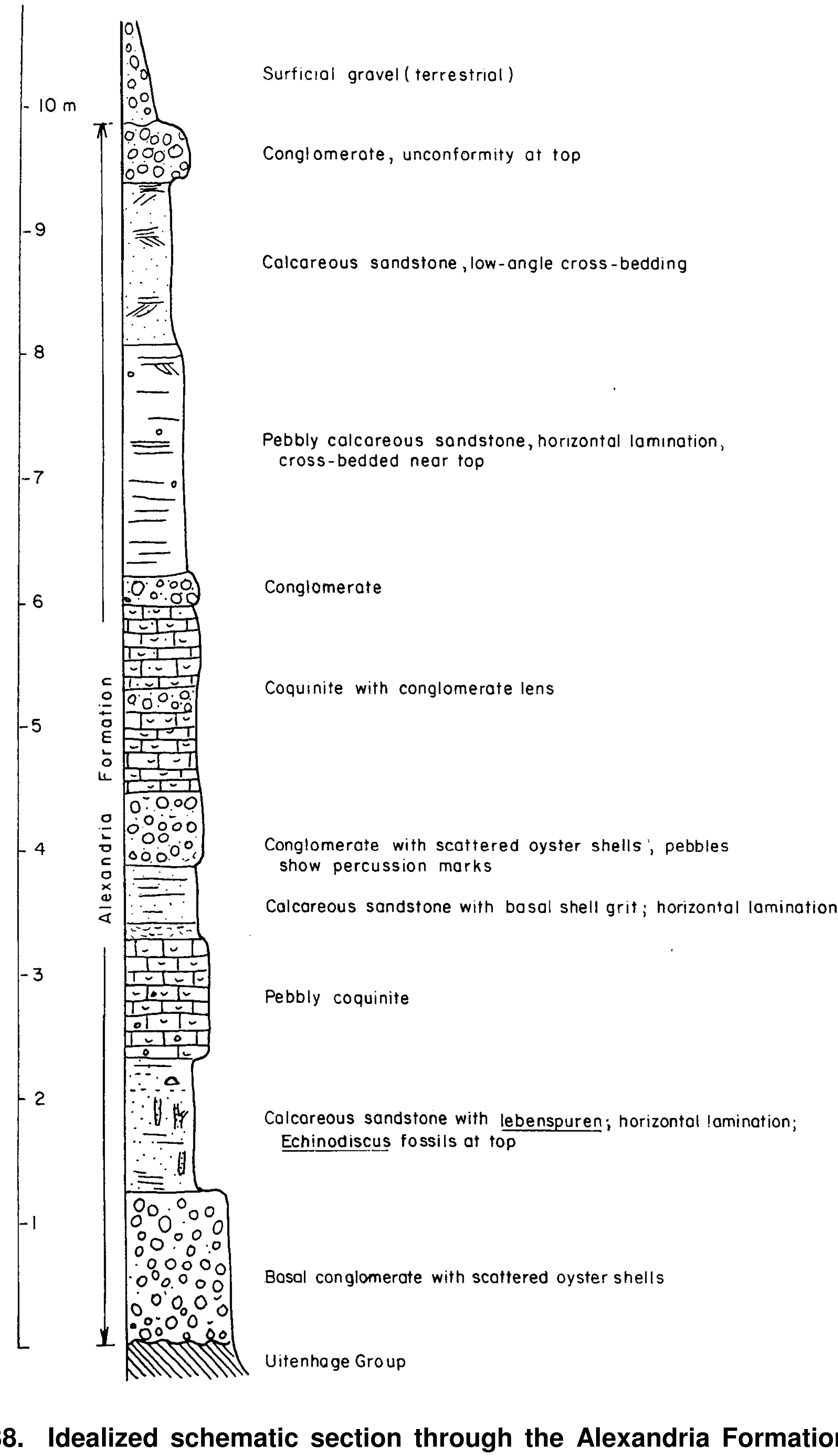


Fig. 38. Idealized schematic section through the Alexandria Formation showing the variety and sequence of sedimentary facies (Le Roux 1987a).

Fig. 39. Conglomeratic facies of the Alexandria Formation, Coega limestone quarry, showing scattered broken shell remains between the pebbles (Hammer = 30cm).

Fig. 40. Thick-shelled bivalves (*Glycimeris*) and comminuted shell debris within coarse-grained coquinas of the Alexandria Formation (Transported block, Zone 5).

Fig. 41. Detail of Alexandria Formation shelly coquinite showing finely comminuted shell hash and extensive borings within larger shell fragments.

Fig. 42. Leached shelly limestone within the Alexandria Formation showing preservation of many shells as moulds ("impressions").

Fig. 43. Robust-shelled bivalves (two specimens of *Glycimeris* and an oyster) *plus* a large gastropod (possibly *Cymatium*) from the Alexandria Formation at the main Coega limestone quarry.

Fig. 44. Two-knobbed shells of an extinct cowrie species (*Cypraea zietsmani*) from the Alexandria Formation of the Coega area.

Fig. 45. Large gastropod shell (*Thais*) embedded in coquinite, Alexandria Formation, main Coega limestone quarry (Shell is 7.5cm tall).

By far the most extensive, geologically informative and freshest exposures of the formation are seen in the faces of the upper limestone quarry at Coega (Locs 52-57; Figs. 37, 93). Most of the sedimentary facies (rock types) and fossils shown in the idealized stratigraphic section through the Alexandria Formation of Le Roux (1978a; Fig. 38) can be seen here. From a geological as well as palaeontological viewpoint, it would be highly advantageous to keep the upper Coega quarry faces open for future research and fossil collection (See Geosite GS2, Section 4). This would replace the nearby Stratotype D roadcut section designated by Le Roux (1987b) that has since been destroyed by development of the new tar road (Fig. 46). Unfortunately, part of the Coega limestone quarry has already been back-filled and some of the older faces are partially degraded by material washed from above and the growth of weeds.

The important stratigraphic contact between the pale, limestone-rich base of the Alexandria Formation and the much older mudrocks and thin sandstones of the Sundays River Formation is well seen along the eastern face of the main Coega quarry (Fig. 92). An angular discordance between the gently-dipping Sundays River beds and the subhorizontal Alexandria beds is clear here. The contact is technically an *unconformable* one, reflecting uplift, tilting and erosion of the Uitenhage Group before deposition of the Algoa Group cover rocks. An equally clear, but less accessible, Algoa / Uitenhage Group contact on the back face of the main Offit clay quarry shows a vertical section through an unusual, deeply-incised channel feature that is several meters wide and deep (Loc 27, Fig. 58a).

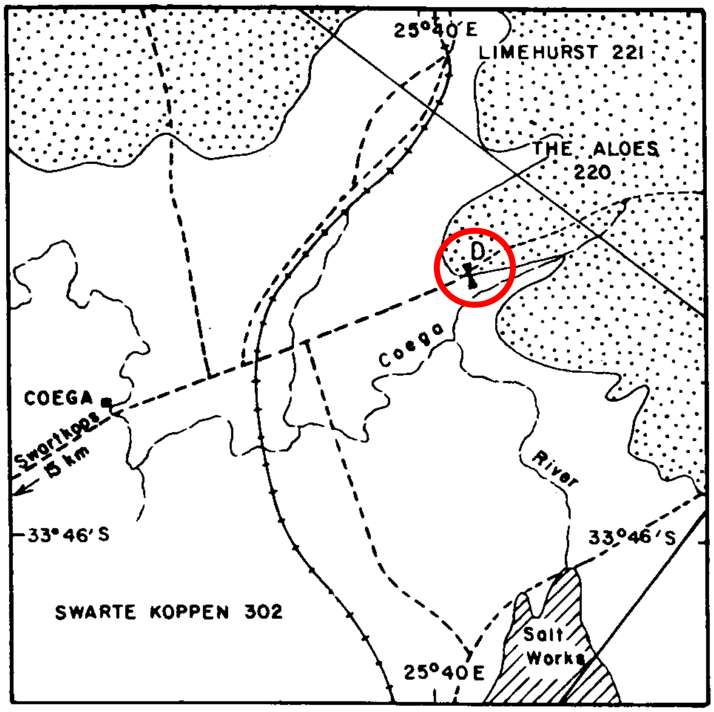


Fig. 46. Map showing original position of stratotype D roadcut section through the Alexandria Formation designated by Le Roux (1987b). This section has since been destroyed by road development.

Fig. 47. Cross-section through a 25cm wide block of brown Uitenhage Group sandstone embedded within the basal Alexandria Formation showing typical surface borings constructed by bivalves.

The basal Alexandria beds are typically conglomeratic, with especially abundant well-rounded pebbles and clasts of Table Mountain Group quartzites. Other megaclasts include angular to subrounded blocks of darker sandstones that were eroded from the Uitenhage Group during the initial Miocene marine transgression. Typically, many of these brown to buff Uitenhage sandstone clasts have been intensively bored by mollusks and other animals (Fig. 47). Rarer clasts are "cannibalized" or reworked blocks of Alexandria Formation calcareous sandstones and coquinites (well-cemented, gritty shell hash).

The lime-rich matrix of the basal Alexandria conglomerates is usually heavily calcretized and contains abundant shell remains, most belonging to thick shelled bivalves (*eg* oysters, *Glycimeris*) and gastropods. Typically, many of the shells were broken and extensively bored by sponges, polychaetes and other invertebrates prior to their final burial; intact fossil shells are therefore uncommon. Very rare Early Cretaceous fossils reworked from the underlying Sundays Formation beds also occur within the basal Alexandria Formation beds – these are known as *derived* fossils. For example, a specimen of the straight-shelled ammonite *Bochianites* was found within Alexandria limestones at Coega quarry (Fig. 49). The actual contact surface between the Alexandria Formation and underlying Uitenhage Group, which represented a firm rocky seabed (*hardground*) in Miocene times, was extensively bored by bivalve mollusks. Their petrified flask-shaped burrow-infills are referred to the ichnogenus *Gastrochaenolites*. These can be seen *in situ* at the Algoa / Uitenhage Group contact (*e.g.* Locs 8, 60) and are also commonly found as weathered-out calcified, drop-shaped casts (Figs. 48, 56, 57).

Fig. 48. Broken-off infills of flask-shaped borings (*Gastrochaenolites*) from the contact between the Alexandria and Sundays River Formations at the main Coega quarry (Loc 60). These borings were drilled by specialized bivalves colonizing the firm seafloor or "hardground" when this was flooded by seas in the Late Miocene.

Fig. 49. Reworked Cretaceous ammonite fossil (*Bochianites*, *c*. 5mm wide) embedded in basal limestones of the Miocene Alexandria Formation (Loc 60) – an example of a derived fossil.

Shell-rich conglomerates occur at a several points higher in the Alexandria succession (Figs. 37, 38, 39). Large blocks of disturbed Alexandria shelly conglomerate situated close to the western lip of the upper quarry at Coega contain moulds of shells displaying a wonderful array of fine-scale borings; there are currently being studied by Dr W. de Klerk (Albany Museum, Grahamstown) and colleagues and should be safeguarded. Pebbly beds towards the top of the Alexandria Formation succession show well-developed channel-fill structures and cross-bedding (Fig. 37).

Other common facies within the Alexandria Formation are horizontally bedded gritty coquinites (shell hash) and finer-grained calcareous sandstones that were deposited in high energy shoreface and foreshore settings. They contain sparse larger clasts such as pebbles and the odd shell (Figs. 40, 41, 45). The thin-bedded to laminated sandstones often show a small range of infaunal vertical to oblique burrows, including the well-known pellet-lined burrow *Ophiomorpha* that reached 4-5cm in diameter (Figs. 51, 52, 54, 55). During the Caenozoic Era *Ophiomorpha*-type pellet burrows characterize a variety of subtidal shoreface to intertidal sandy facies, including estuaries. They are attributed to sediment-feeing callianassid crustaceans (sand prawns), a group that thrives in estuaries along the South Coast today. *Ophiomorpha* burrow systems into shallow marine carbonates in the Bahamas and Florida extend up to 2m below the seafloor (Pollard *et al*., 1993, Allen 2010).

Lenses and beds of darker-hued siltstones towards the base of the cut faces in the upper quarry contain sinuous, rusty-coloured burrows and may reflect sedimentation within quiet-water lagoonal settings. Flat-bedded, 20-30cm thick fining-upwards cycles of massive calcareous sandstones and siltstones are characterized by dense networks of fine, vertical root casts towards the base of each cycle (Fig. 50).

Fig. 50. Cycles of dense, fine rhizoliths within the Alexandria Formation, Coega limestone quarry (Loc 54).

Fig. 51. Thin-bedded calcarenites within the lower Alexandria Formation, Coega limestone quarry, showing abundant vertical burrows, some of which are crustacean burrows *Ophiomorpha*.

Many of the larger, irregular, sometimes branching trace fossils seen in the uppermost parts of the quarry succession are probably *rhizoliths* (petrified root casts) of land plants that developed within semi-consolidated Alexandria Formation sands after these were exposed on land by marine regression, for example in Plio-Pleistocene times (*cf* Nanaga Formation rhizoliths, Section 3.3.2.). A similar palimpsest or superimposed origin is suggested for possible rounded termitaria and associated tubular burrow systems, both of which are infilled with fine grey or reddish sediment that contrasts with the Alexandria Formation limestones (Fig. 53). Similar termitaria-like structures are seen within the limestone krans running along the western side of the Brakrivier Valley (Loc 31). Irregular solution hollows developed as part of karstic weathering of the Alexandria Formation limestone plateau are seen in section in various parts of the quarry face. Sometimes these are empty, but in many cases where they were in open contact with the land surface above they are infilled with ferruginised silty and pebbly material of the "Blue Water Bay" facies (Section 3.3.1.3. and Fig. 65).

Only a very brief review of sedimentary and palaeontological observations made at numerous other Alexandria Formation exposures examined in this study is given here. This is because: (a) most of these features are best seen at the upper Coega quarry described above, and (b) these older limestones have usually been extensively weathered and calcretised. As a result, finer-scale sedimentary features and shelly fossils have often been obliterated.

Good exposures of Alexandria Formation conglomerates and limestones unconformably overlying colourful, reddish and greenish mudrocks and sandstones of the Kirkwood Formation are seen in the railway cuttings and stormwater excavations in Zone 5. Well-preserved *Ophiomorpha* pellet burrows are present in laminated calcareous Alexandria sandstones at Locs 4 to 6 (Figs. 54, 55). Abundant *in situ Gastrochaeolites* mollusk borings are exposed in vertical section at Loc 8 (Figs. 56, 57). The Cretaceous mudrocks beneath the Algoa Group unconformity have frequently been extensively disrupted and shot through by secondary calcrete veins.

The contact between the base of the Alexandria Formation and mudrocks of the Sundays River Formation is still accessible at Tossies Quarry South, though partially obscured by backfill (Loc 37, Figs. 58b, 96; see Goesite GS5 in Section 4)). Here the conglomeratic basal Alexandria beds contain abundant reworked clasts of Uitenhage Group sandstones (many bored), oyster shells, as well as cannibalized coquinite and calcareous sandstone. Much of the Alexandria Formation succession has been strongly calcretised, however. Oyster-rich basal beds are well-seen just north of Tossies Quarry North (Loc 41, Fig. 60) and, especially, in the Grassridge area in the northern IZD where pebbles and cobbles of Table Mountain Group quartzites are less prevalent (*eg* Bontrug 301, Locs 102, 104, Fig. 59). Where the basal beds are calcretised, the shells may be preserved primarily as moulds (Fig. 42), but often a scree of well-preserved oyster shells mantles the slopes beneath the low Alexandria Formation cliffs here (Fig. 61). Le Roux (2000) illustrates a basal Alexandria unit dominated by fossil oyster shells on Keerweder, Grassridge 190. Extensive communities of oysters must have thrived in the shallow, turbulent waters that covered a major part of the Algoa Basin in Miocene times. Frequent storms ripped up living and dead oyster shells and piled them onshore to form the concentrated coquinas seen in the Grassridge area.

Figs. 52. Abundant oblique burrows within finely-laminated shoreface or foreshore sands, Alexandria Formation, Coega limestone quarry.

Fig. 53. Possible palimpsest termitaria constructed within the upper Alexandria Formation, Coega limestone quarry (Loc 56).

Fig. 54. Vertical, pellet-lined tubes of the ichnogenus *Ophiomorpha* penetrating fairly flat-bedded intertidal sands of the Alexandria Formation in Zone 5 (Loc 6). These burrows were probably constructed by deposit-feeding callianassid crustaceans (sand prawns).

Fig. 55. Close-up view of pellet-lined *Ophiomorpha* burrows from Zone 5 (Loc 4).

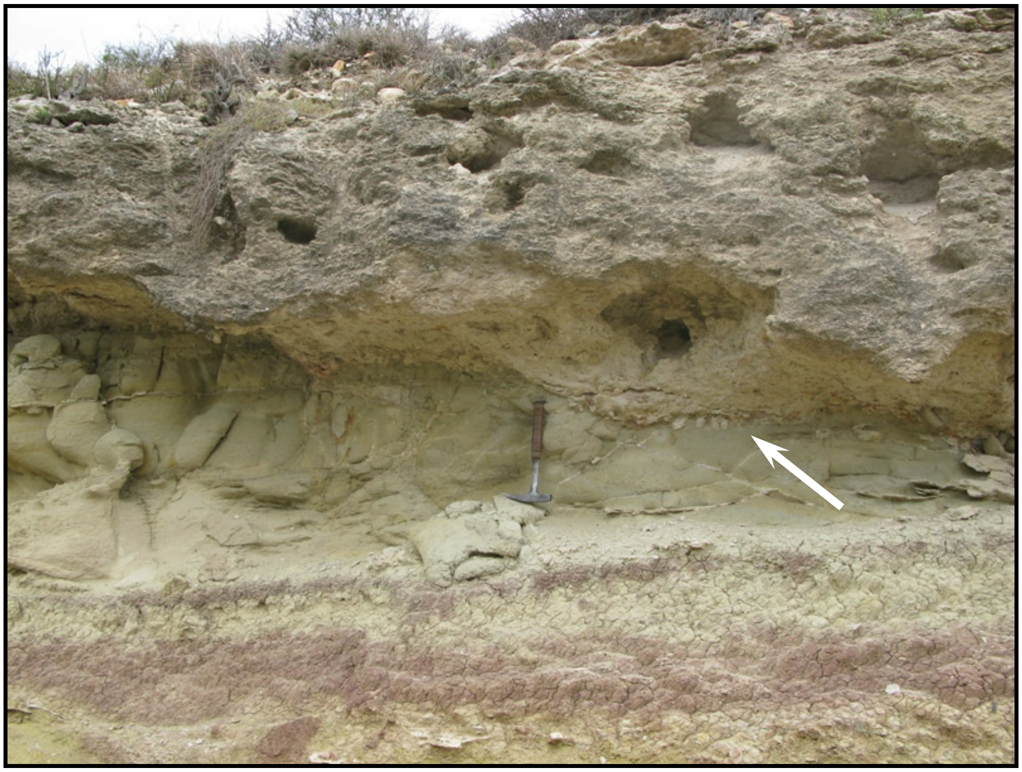


Fig. 56. Extensive bivalve boring into sandstones of the Kirkwood Formation along the unconformable contact with the Alexandria Formation (arrow) (Loc 8).

Fig. 57. Detail of bored contact in preceding figure. The *Gastrochaeonolites* bivalve borings here are *c.* 5cm deep.

Fig. 58a. Deeply-incised erosional channel at the contact of Alexandria and Sundays River Formations, Offit clay pit (Loc 27). The base of the channel infill is markedly conglomeratic.

Fig. 58b. Erosional contact of basal Alexandria shelly conglomerate and Sundays River Formation mudrocks in the upper part of Tossies Quarry South (Loc 37). This is Geosite locality GS5 (See also Fig. 96).

Fig. 59. Oyster-rich basal conglomerate of the Alexandria Formation in the Grassridge area (Loc. 104).

Fig. 60. Detail of shell-rich basal Alexandria conglomerate near Tossies Quarry North (Loc. 41). The flat oyster shells are 10-15cm across.

Fig. 61 . Robust oyster shells that occur prolifically within the basal Alexandria Formation in the Grassridge area (Zone 14, Loc 104).

Huge volumes of Alexandria Formation limestones have been quarried during recent and ongoing excavation of an extensive system of stormwater drainage channels, reservoirs and road cuts within the Coega IDZ (*e.g.* Locs 3-5, 47, 50-51, 64-65, 68, 72-75, 113). However, inspection of the exposed sediments shows that for the most part they have been heavily calcretised and contain little or no well-preserved fossil material. Many of the shells originally present have been dissolved and are preserved as moulds. Occasional coquinite and pebbly conglomerate beds with fragmentary to intact fossil shells – mainly oysters or large, thick-shelled gastropods - are seen, however. Well-developed surface calcretes are usually present at the top of the succession.

Just to the northeast of the new Cerebos salt factory an unusually deep (*c.* 7m), rectangular stormwater reservoir cuts down through the entire Alexandria Formation (Locs 72-75). Test pits excavated into the floor of the reservoir expose grayish-green mudrocks of the Sundays River Formation. The walls of the main reservoir expose an interesting rubbly or breccio-conglomeratic facies of the basal Alexandria Formation (Fig. 62). Scattered, well-rounded pebbles of Table Mountain Group quartzites are interspersed with abundant blocks of reworked greyish mudrocks and buff-brown sandstones of the Uitenhage Group, as well as reworked calcareous sandstones of the Algoa Group. As usual, the angular to subrounded Uitenhage Group sandstones are intensely bored and must therefore have been exposed on the sea bed for a considerable period before burial. These basal diamictites have an abundant clay-rich matrix and have usually been deeply weathered and partially calcretised. A blackish patina of manganese minerals has locally developed on the surface of the quartzite pebbles. Shells are not preserved. The sedimentological origin of this rubbly basal facies of the Alexandria Formation is unclear; they may represent submarine debris flows.

Fig. 62. Curious rubbly facies within basal Alexandria Formation near Cerebos factory (close to Loc 73). Note angular blocks of greenish-brown Uitenhage Group mudrocks and large boulder of pale, reworked calcarenite on RHS.

Le Roux (2000, p. 25) mentions that on Coega Kop a conglomerate of the Alexandria Formation consisting of large boulders overlain by a very coarse-grained sandstone can be seen. This represents a fossil storm beach from Miocene – Pliocene times when the Algoa Basin was flooded by shallow seas and Coega Kop formed an island of tough Table Mountain Group rocks. The ancient beach conglomerate could not be relocated during the present field study. It may have been destroyed, at least in part, by quarrying operations. However, several huge meter-scale boulders of Table Mountain quartzite with numerous impact crescents on their surfaces can still be seen between the two main quarries on the SE side of Coega Kop (Loc 110, Fig. 63).

Fig. 63. Relict large boulders of Table Mountain quartzite from a Miocene / Pliocene storm beach on the southeastern slopes of Coega Kop (Loc 110).

Many of the key fossil collecting localities from the Alexandria Formation mapped during the latest detailed palaeontological study by Le Roux (1987, his fig. 1.1) are actually situated within the external boundaries of the Coega IDZ. These are briefly listed here, with comments on their present status. It is notable that, with the obvious exception of No. 8, most of these localities are apparently no longer productive of fossil material.

Le Roux Loc. 7 – Limestone quarry at Butterfly Reserve on Offit land NE of Coega (Abandoned, now largely overgrown and partially infilled). Shelly basal conglomerates of the Alexandria Formation are well-exposed here (= Locs 29-30 herein).
Le Roux Loc. 8 – Upper limestone quarry (above brick pit) east of Coega (Since considerably enlarged. Still a productive fossil locality for shells and trace fossils. = Locs 52-60 herein).
Le Roux Loc. 9 – Stratotype D section of le Roux (1987) along old tar road (Since obliterated by new road development; Fig. 46).
Le Roux Loc. 10 – Limestone quarry near Irene on farm The Aloes 220, north of old road 334 (Since abandoned and overgrown).
Le Roux Loc. 11 – Limestone quarry just east of the N2 near St George's Strand (Since abandoned and overgrown; close to proposed fuel station development, Loc 98 herein).
Le Roux Loc. 12 – Limestone quarry, Hougham Park II (Not relocated).
Le Roux Loc. 6 - Brickworks, Webedachtsfontein, lies just north of the Coega IDZ.

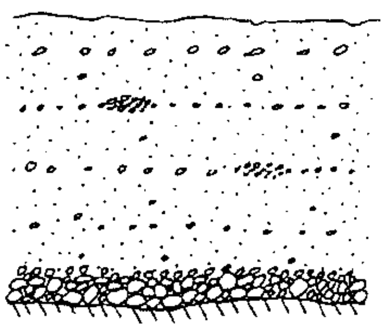
3.3.1.3. The "Blue Water Bay" Formation (T-Qb)

Geologically recent karstic (*ie* solution) weathering of the lime-rich Alexandria Formation has led to the development of pebbly, reddish-brown residual soils over much of the inland outcrop area of the Alexandria Formation (Maud & Botha 2000). This was formerly identified as a separate, bipartite *fluvial* unit of Plio-Pleistocene age with calcrete horizons that was named the Bluewater Bay Formation (Le Roux 1987c, 1989). This unit is mapped as such (T-Qb) on the 1: 250 000 Port Elizabeth geology sheet but not on the later 1: 50 000 scale geological maps where it is indicated as pedogenic gravels overlying the Alexandria Formation (circular symbols). Incised "channels" cutting into the Alexandria Formation and infilled with cross-bedded coarse "Bluewater Bay" gravels are illustrated by Le Roux (1989). Maud and Botha (2000) suggest that these surface deposits comprise a composite of *in situ* karstic weathering products (including coarse solution-hollow infills) as well as fluvial sediments of late Neogene age. Goedhart and Hattingh (1997) have developed an explanatory scheme showing how residual pebbly and sandy weathering products of the Alexandria Formation infill solution cavities within the calcretised limestones following periods of humid climate leaching (Fig. 64). The superficial "Bluewater Bay" deposits average 1.2m in thickness, but this varies greatly due to the presence of numerous incised channel-fill and solution pipe structures up to 7m deep (Le Roux 1987c, 1989, 2000).

The most prominent and widely occurring solution structures in the Alexandria Formation outcrop area are *dolines*. They stand out clearly on aerial and satellite images as rounded or oval grassy patches within darker zones of thicket. These shallow but large depressions are caused by karstic solution of the underlying limestone and may reach diameters of 100m or more. Centripetal drainage causes the build-up of fine-grained sediment and pebbles within the doline. The surface depression often develops into a pan where rainwater may accumulate unless the doline is drained by a subsurface outlet (*ie* swallow hole). The distribution of dolines in the Coega area has been mapped in detail by Goedhart and Hattingh (1997) who note that they generally occur in well-defined NE-SW zones that correspond to furrows between fossil beach ridges developed in the underlying shallow marine Alexandria Formation (*ibid.*, fig. 3.3).

The "Bluewater Bay" residual soils are largely unfossiliferous, although they may be expected to contain occasional robust marine shells weathered-out from the underlying Alexandria Formation bedrock with an admixture of terrestrial snail shells. Le Roux (1989) records sparse freshwater mussels as well as land snails from these sediments. Doline infill sediments might likewise contain the bones and teeth of mammals and other animals attracted to intermittently wet, grassy microhabitats, but this has not been observed.

Fig. 64. (Following page). Model explaining the development of Bluewater Bay - type residual soils over the Alexandria Formation under the influence of successive arid and pluvial climates (From Goedhart & Hattingh 1997).



A. **Unaltered Alexandria Formation:**

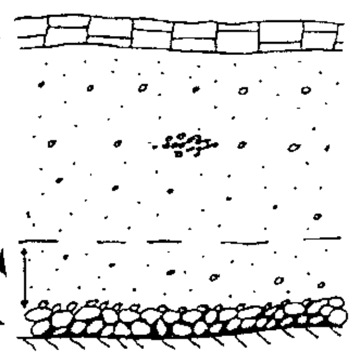
- Consisting of calcarenite with scattered pebbles and shells as a ± 10 m thick top facies overlaying
- a basal open framework boulder lag deposit formed on Cretaceous shale or mudstone

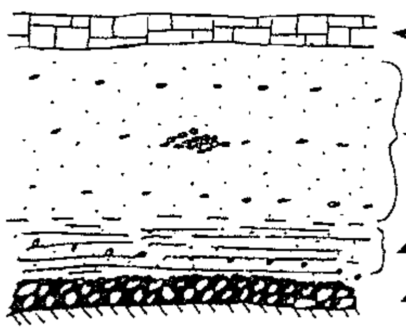
B. **Pedogenesis under arid conditions:**

-Hardpan formed due to evaporation of rain water.

-Zone of pharaetic surface oscillation where $CaCO_3$ is precipitated.

-Colloidal clay deposited as secondary matrix within boulder lag layer.





C. **Result of pedogenisis under arid conditions:**

-Surface hardpan.

-Relatively unaltered Alexandria formation calcarenite.

-Very well-indurated layer with $CaCO_3$ cement.

-Basal boulder bed with clay matrix preventing pedogenesis.

D. **Leaching and modification under humid conditions**

-Dissolution of hardpan and possible precipitation at lower levels.

-Lowering of calcrete hardpan due to leaching.

-Resistant residue on surface (pebbles + sand).

-Sand gets washed out or blown away.

-End result: clast supported residual gravel.

-Pseudo sinkholes develop where hardpan gets breached.

-Acidic waters flow through the vadose zone and drain in the bedrock.

-Net result: dissolution of shell fragments in the unaltered calcarenite.

-A cavity forms and pebbles gravitates into the cavity.

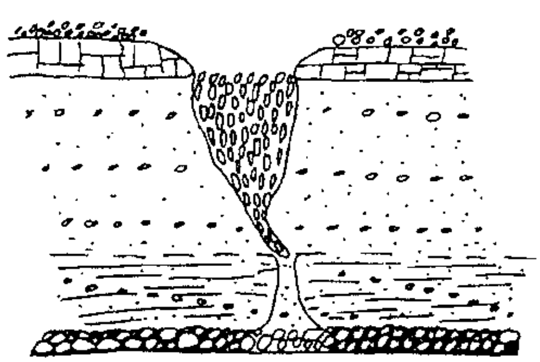


Fig. 65. Vertical section through a turnip-shaped solution hollow within the top of the Alexandria Formation limestones showing bright orange-brown infill of Bluewater Bay facies, main limestone quarry, Coega.

Fig. 66. Artificial trench into calcretised Alexandria Formation limestones showing solution hollows infilled with Bluewater Bay pebbly facies, Coega IDZ Zone 5.

Fig. 67. Typical orange-brown residual soils of the Bluewater Bay facies overlying Alexandria Formation limestones near Dedisa substation (Loc 46).

Bluewater Bay residual soils are extensively exposed along the margins of new trenches and roadcuts in Zone 6 and 11 of the IDZ, for example. Reddish-brown silts with brown-stained, well-rounded quartzite pebbles can be clearly seen infilling solution hollows in the upper part of the Alexandria Formation limestones at many sites. During this study good examples were seen in the faces of the upper limestone quarry at Coega (Fig. 65), within several deep test trenches in IDZ Zone 5 (Fig. 66), on the edge of shallow scrapings into Alexandria Formation limestones near Dedisa substation (Fig. 67) and in cuttings alongside the new tar road in IDZ Zone 6. Vertical orientation of the pebbles within the solution cavities is often marked, indicating viscous flow of pebbly sediment from the surface. Some of the fine reddish-brown sandy matrix may be originally derived from Nanaga Formation dune sands that once widely mantled near-coastal areas of the Alexandria Formation Plateau. Relict patches of Nanaga sands may locally overlie Bluewater Bay conglomeratic facies (*e.g.* Locs 62-63, Fig. 72). No fossils were observed within the Bluewater Bay facies sediments during the present study.

NE-SW trending zones of larger-scale (*c*. 100m) *doline* depressions are clearly seen in aerial and satellite images of the Coega IDZ as rounded grassy patches within darker thicket vegetation. On the ground they are floored by dark, silty soils with patches or lenses of unconsolidated Bluewater Bay type pebbles towards the centre. New road construction in Coega Zone 6 has transected one of these deep doline infills which here comprises several meters of dark, mottled soil with carbonaceous and rusty-oxidized traces of plant rootlets (Loc 49, Figs. 68a, 68b). It has been suggested that these clay-rich patches may have served as wallows for elephants and other large game animals (Paul Martin, pers. comm., 2010). However, no mammal bones or teeth were observed within the exposed doline infill.

Fig. 68a. Deeply-excavated, clay-rich doline infill in Zone 6 of the Coega IDZ.

Fig. 68b. Detail of doline infill muds showing mottled appearance as well as carbonaceous root casts indicative of waterlogged soils.

3.3.2. Nanaga Formation (T-Qn)

Coastal aeolianites (ancient, wind-blown dune sands) of the **Nanaga Formation** of Pliocene to Early Pleistocene age crop out extensively to the west and east of Port Elizabeth (Le Roux 1992). They have recently been mapped along the coast of the Coega region (not shown in earlier 1: 250 000 maps, Fig. 2). The Nanaga beds comprise calcareous sandstones and sandy limestones that often display large scale aeolian cross-bedding - well seen, for example, in deep N2 roadcuts between Colchester and Grahamstown. They may reach thicknesses of 150m or more (Maud & Botha 2000). The Nanaga aeolianites are normally partially to well-consolidated, although unconsolidated sands also occur west of Port Elizabeth (Le Roux 2000). The upper surface of the aeolianites weathers to calcrete and red, clay-rich soil, and the dune sands themselves may be profoundly reddened. The age of the palaeodunes decreases towards the modern coastline, reflecting marine regression (relative sea level fall) during the period of deposition. The oldest outcrops located furthest from the modern coast are the most elevated, having experienced some 30m of uplift in the Pliocene, and may even be Miocene in age (Roberts *et al*., 2006). Typically the ancient dunes are preserved as undulating ridges of rounded hills trending parallel to the modern shoreline (Le Roux 1992).

3.3.2.1. Palaeontological record of the Nanaga Formation

The sparse palaeontological record of the Pliocene to Early Pleistocene Nanaga Formation is summarised by Le Roux (1992). The fossil biota consists of fragmentary marine shells, foraminifera (shelled protozoans *cf* McMillan 1990), and a small range of terrestrial snails (*eg Achatina, Tropidophora, Trigonephrus, Natalina*). Dense arrays of calcretised rhizoliths (root casts) commonly occur in these and contemporary Plio-Pleistocene aeolianites along the southern and southwestern coast (Roberts *et al*., 2009). A wider range of terrestrial fossils might be found here in future, albeit only rarely due to extensive post-depositional diagenesis (*eg* solution and repreciptation of carbonate by groundwater). They might include mammal remains from hyaena lairs, such as are recorded from contemporary Langebaan Formation aeolianites in the SW Cape (Roberts *et al.*, 2006 and refs therein).

3.3.2.2. Nanaga Formation in the Coega IDZ

As mapped on the 1: 50 000 geological maps, the Nanaga Formation aeolinites (T-Qn) form an approximately 1km wide belt inland of the younger Schelm Hoek dune sands to the northeast of the Coega estuary. Here they overlie Alexandria Formation limestones and are likewise extensively calcretised. Goedhart and Hattingh (1997) record maximum thicknesses of 50-100m for the Nanaga Formation in the Coega area, where it is typically associated with undulating topography in the coastal interior. Surface soils formed by extensive weathering of the Nanaga sands are typically reddish brown due to oxidation of iron-rich impurities such as magnetite and ilmenite (*ibid*., p. 11).

A spectacular array of narrow vertical rhizoliths (both solid and hollow) that amalgamate locally to form prominent-weathering calcrete "pillars" (*megarhizoliths*) are well exposed on the margins of a long east-west trench excavated to the north of Hougham Park homestead

(IDZ Zone 7, Loc 69-70, Figs 69, 70,100. This is Geosite GS9 listed in Section 4). Recent studies of dune plant root systems by Cramer and Hawkins (2009) suggest that these calcareous rhizoliths form around living roots due to the precipitation of excess calcium carbonate that has been drawn to the roots by mass flow, itself driven by evaporative transpiration from the aerial parts of the plant. Pillar-like *megarhizoliths* ("pinnacles") are well known from the Plio-Pleistocene Langebaan Formation (*eg* along the Langebaan Lagoon and False Bay coast) and are also recorded in SW Australia and Gran Canaria. They have occasionally been mistaken for corals or petrified trees. At Hougham Park the megarhizoliths are embedded in semi-consolidated, pale grayish-brown sands that occasionally preserve relict low angle dune bedding and are overlain by dark brown soils (Fig. 69). The fossil dune sands here lie at approximately 60m above sea level and 2-3km from the coast. They are rich in fossil land snail shells, notably small specimens of *Achatina* (many with a calcrete patina and subdued or no colour markings) together with common *Tropidophora* and rarer *Natalina* (Fig. 71). Faint vertical burrows and possible calcretised termite nests with a spongy fabric are also seen here, and are also known from the contemporary Langebaan Formation. No embedded stone artifacts were observed.

Fig. 69. Pillar-like calcretized megarhizoliths within well-laminated aeoliantes of the Nanaga Formation, Hougham Park (See also following figure and Fig. 100 of Geosite GS9).

Fig 70. Calcretized megarhizoliths, smaller individual rhizoliths and isolated calcrete nodules within pale brown Nanaga Formation aeolianites, Hougham Park.

Fig. 71. Fossils of three genera of land snails - *Natalina*, *Tropidophora* and *Achatina*, from left to right - collected from the Nanaga aeolianites at Hougham Park (Locs 76-77). The largest shell seen here is about 7cm tall.

Relict patches of more typical, orange-red Nanaga aeolianites are scattered further inland across the Alexandria Formation and older rocks. A good example is seen near the western entrance to the main Coega brick quarry, over 5km from the coast (Locs 62-63). Here, at around 60m asl, irregularly calcretised and apparently unfossiliferous orange- to greyish-hued, semi-consolidated aeolianites overlie pebbly conglomerates of "Bluewater Bay" – type facies (Fig. 72). Alternatively, this occurrence may be related to the Kinkelbos Formation that unconformably overlies the Alexandria Formation limestones east of Colchester (Toerien & Hill 1989, pl. 6.2; Le Roux 1989c SACS, Johnson 1994). This apparently unfossiliferous unit is described by the last author as comprising "reddish-brown silt and fine sand with light-grey calc-tufa beds and lenses and minor gravel; 6-37m thick". These sediments are interpreted as Plio-Pleistocene marine or lagoonal deposits, but this may have been revised by later work.

Fig. 72. Bright orange-brown, partially calcretised sands overlying the Sundays River Formation at the entrance to the main Coega brick pit (Locs 62-63). These sediments are provisionally assigned here to the Nanaga Formation.

W.H.R. Gess (1951 or 1952) reported a species-rich assemblage of mammal bones, teeth and horn cores from an inferred palaeovlei site *c*. 40m asl at Aloes, between St George's Strand and Coega Kop. The fossils were embedded some 2-5m deep within clayey sand or sandy clay as well as in a thick overlying calcrete horizon and apparently extended over a considerable area. The bones and teeth were identified as pig, warthog, leopard, bovids, hyaena and rhino together with horn cores of ten antelope species. Shells of the land snail *Achatina zebra* but no stone artifacts were found in association with the bone deposit which was dated as beyond C^{14} range (*i.e.* > 40 000 years old). The stratigraphic context of this important fossil biota is unclear; it might be referable to the heavily calcretised Plio-Pleistocene Nanaga succession or perhaps to younger aeolianites. A hyaena accumulation does not appear to be involved here. The fossil material and associated documentation was deposited at the Port Elizabeth Museum and should repay detailed study (*cf* Klein 1983).

3.3.3. Salnova Formation (Qs)

The Salnova Formation in the study area comprises a spectrum of well-indurated intertidal deposits, including beach sands, coquinites, shell-rich gravels and pebbly to bouldery conglomerates. These marine rocks typically crop out along the modern coast at low elevations - less than 18m amsl according to Le Roux (1991). Intraformational clasts of older Algoa Group coquinite and conglomerate are much commoner than in the older Alexandria Formation. Finer-grained estuarine and lagoonal sediments are also found, such as the stratotype D locality designated by Le Roux (1991) near Salnova saltworks in the Coega estuary area (Portnet land outside the present study area). The Salnova sediments were formed during a series of several Mid to Late Pleistocene transgressions. Some authors now extend the scope of this formation to include shoreline sediments of post-Pleistocene (Holocene) age. These include shell-rich cobbly and bouldery beds up to 2-3m amsl that may reflect the Mid Holocene highstand (= sea level peak) of 4000 to 3000 BP. Along the Coega IDZ coast the Salnova beds overlie the Uitenhage Group and are generally overlain by aeolianites of the Nahoon and / or Schelm Hoek Formations.

Fig. 73. Lenticular pebbly conglomerates and flat-bedded calcarenites of the coastal marine Salnova Formation near Marine Growers (Loc 92).

3.3.3.1. The palaeontological record of the Salnova Formation

The Salnova Formation is characterized by the rich, shallow marine to estuarine "Swartkops" fossil biota that comprises over three hundred taxa (Le Roux 1990b, 1991, 1993 and references therein). Fossil assemblages are dominated by a wide range of molluscs (especially gastropods and bivalves). However, many of these taxa are mainly found in finer-grained, estuarine facies that are not well exposed in the Coega IDZ itself. Some are seen at the important stratotype D locality for this formation located near the Salnova saltworks within the Portnet area. Note that the majority of mollusc species in these Pleistocene fossil faunas are still alive today, though they are sometimes represented by different subspecies and not all of them are still native to the south coast. A good example is the gigantic bivalve *Panopea glycimeris* or "geoduck", a warm water - loving bivalve that is found today along the coast of West Africa (Fig. 74; Pether 1987, 1988). Compared with the older, Miocene / Pliocene Alexandria Formation of the Algoa Group, crab and sea urchin remains are more abundant in the Salnova Formation, while corals, brachiopods (lamp shells) and sharks' teeth are generally absent (Le Roux 1991). Trace fossils include pellet-walled crustacean burrow systems of the ichnogenus *Ophiomorpha* and bivalve burrows. Vertebrate remains such as the bones and teeth of marine mammals or fish may also be present but are not well recorded. The overall palaeontological sensitivity of the Salnova Formation is judged to be high, although many occurrences – especially the coarser-grained facies - are not especially shell-rich, or mainly contain fragmentary fossil remains.

Fig. 74. *Panopea glycimeris*, a large warm water - loving bivalve from the Salnova Formation that today lives off the West African coast. This specimen is about 20cm long (Collections of the Albany Museum, Grahamstown)

3.3.3.2. Salnova Formation in the Coega IDZ

Dark, fine-grained sediments directly underlying modern dune sands at the small sand quarry near Sea Arc (Locs 79-80) probably belong to estuarine or lagoonal facies of the Salnova Formation and could well prove highly fossiliferous if they were ever excavated. Small outcrops of coarser-grained nearshore facies of the Salnova Formation (Qs) occur intermittently along the coastline of Coega IDZ Zone 10, from the Marine Growers abalone farm near the Portnet area northeastwards to Mellville. Goedhart and Hattingh (1997) record thicknesses of 1.5 to 6.5m for this stratigraphjc unit. The formation comprises a spectrum of well-indurated sandy and conglomeratic beach deposits that form low rocky benches close to modern sea level. Outcrops are locally rich in marine shell remains but most of these are damaged or high comminuted. According to Le Roux (2000, p. 48) shell grits from a quarry in the Salnova Formation at Hougham Park were exploited until 1987 for chicken feed. This quarry was not located during the present study (A limestone quarry is indicated northeast of Hougham Park II on the 1: 250 000 geological map, but this is too far inland to belong to the Salnova Formation).

The most accessible Salnova outcrops are seen on the shore just east of Marine Growers (Loc 82). Tough bouldery, cobbly and pebbly coastal conglomerates of lenticular geometry overlie and are interbedded here with cross-bedded and flat-bedded calcarenites (Fig. 73). The conglomerates are well- to poorly-sorted. Most of the clasts are well-rounded Table Mountain quartzites, but there are also bored and oyster-encrusted Uitenhage sandstones and reworked blocks of Algoa Group calcarenites. The matrix is of calcareous calcarenite and grits, with numerous shelly remains. However, most of the fossil shells are damaged or unrecognizable due to the high energy depositional setting (Fig. 76). Occasional conglomerate-infilled channels cutting down through bedded calcarenites are present. Overlying the Salnova conglomerates are found a few meters of horizontally bedded, finely-laminated coquinites and finer calcarenites, dipping gently seawards and displaying well-developed primary current lineation; some of these are probably beach deposits and they contain scattered mollusks shells (large gastropods, bivalves), some of which are quite well preserved (Fig. 75). The Salnova beds are truncated by a pronounced Early Pleistocene wave-cut platform that is overlain by well-consolidated, thinly-calcretised aeolianites with land snails of the Mid to Late Nahoon Formation (see below).

A stratigraphically important exposure of the Salnova Formation has been identified at Hougham Park – the stratotype E locality of Le Roux (1991; Locs 84-85, Figs. 34, 77, 78, 101. This is Geosite GS10 in Section 4). Many of the same sedimentological features described near Marine Growers are well-displayed here and few collectable fossils are present in these high-energy sediments. There is a clear angular unconformity between the conglomeratic basal Salnova beds and the underlying, gently dipping, dark grey-green Sundays River mudrocks and sandstones (Figs. 34, 77). The latter are extensively riddled with secondary calcrete veins. The basal Salnova sediments contain some sizeable rounded boulders of Table Mountain quartzites as well as numerous angular blocks up to a meter or so across of dark Sundays River lithologies. The tabular-bedded beach facies of the Salnova Formation, dipping gently seawards, is well exposed in vertical section and contains sparsely scattered pebbles (Fig. 78). These beds are terminated by a well-developed Early Pleistocene wave-cut platform, locally overlain by storm beach conglomerates and well-consolidated aeolianites of the Mid to Late Pleistocene Nahoon Formation (Fig. 77 and Section 3.3.4. below).

Fig. 75. Abraded specimen of a large gastropod embedded within coquinites of the upper Salnova Formation, near Marine Growers (Loc. 82).

Fig. 76. Close-up of beach conglomerates of the Salnova Formation at Hougham Park showing abundant broken shell fragments in the matrix between the pebbles.

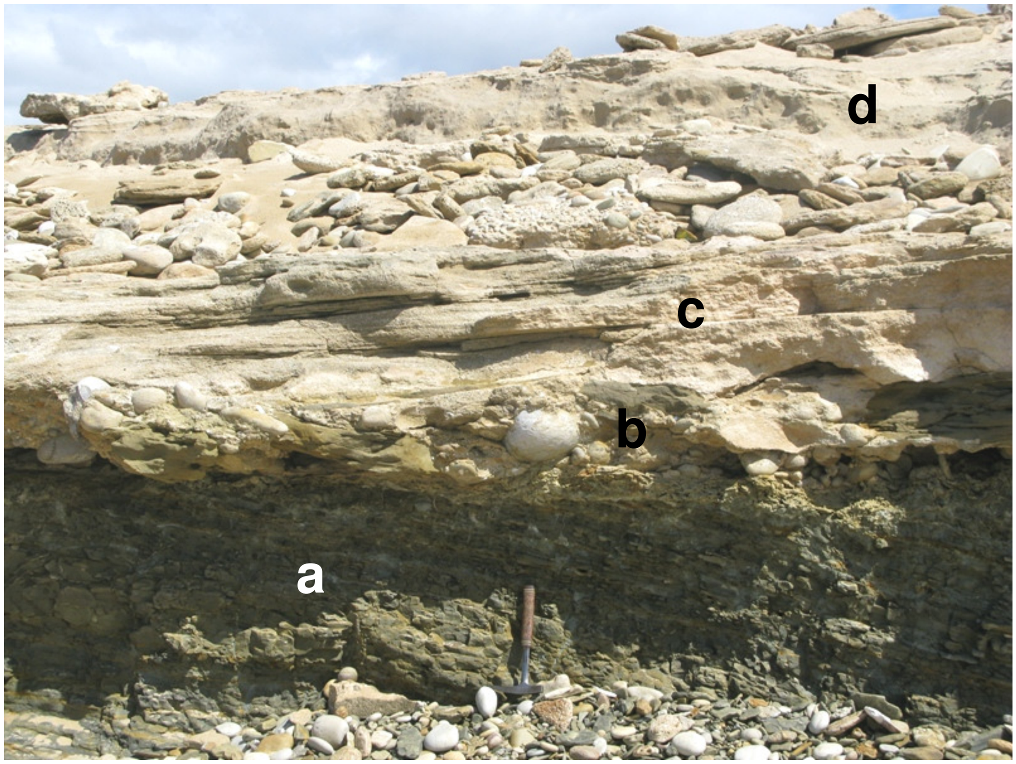


Fig. 77. The clear unconformable contact between strongly dipping beds of Sunday River Formation mudrocks (a) and the basal conglomerates of the Salnova Formation (b) at its coastal stratotype E locality on Hougham Park (Loc 84). Flat-bedded Salnova shelly sandstones (c) above the conglomerates dip seawards and are overlain by well-consolidated dune sands of the Nahoon Formation (d).

Fig. 78. Flat-bedded calcarenites and coquinites overlying beach conglomerates, Salnova Formation at the Hougham Park stratotype (Loc. 85).

3.3.4. Nahoon Formation (Qn)

This near-coastal formation consists of well-consolidated calcareous aeolianites with sporadic, thin calcretes and palaeosols (ancient soil horizons) that are assigned a Mid to Late Pleistocene age (Le Roux 1989b). Several cycles of dune deposition separated by palaeosols may be represented and large scale aeolian cross-bedding is preserved in some areas. The high level of cementation contrasts with generally poorly-consolidated older and younger dune sands of the Nanaga and Schelm Hoek Formations respectively, while deep orange-red hues as often displayed by the Nanaga sands are not present here. The Nahoon Formation usually overlies a wave-planed surface that cuts across bedrock of the Cape Supergroup or Uitenhage Group. The Nahoon beds may in turn be cut by a Late Pleistocene (Eemian, *c* 120 000 BP) wave-cut platform and overlain by unconsolidated Holocene dune sands.

3.3.4.1. Palaeontological record of the Nahoon Formation

The palaeontology of the Nahoon Formation has been summarised by Le Roux (1989b). The biota is dominated by terrestrial gastropods such as *Achatina*, *Tropidophora*, *Trigonephrus* and *Phortion* that are most abundant within palaeosol horizons. Comminuted shell debris, foraminiferans and rhizocretions (plant root casts) are also common (*ibid.,* and McMillan 1990). Near East London mammal and bird trackways, including early human footprints, occur in Nahoon aeolianites dated to 200 000 BP (Roberts *et al*. 2006, Roberts, 2006, 2008). Middle Stone Age stone tools embedded in Nahoon rocks have been recorded from several localities (Le Roux 1989b) and comparable MSA artifacts from Mid Pleistocene aeolianites of the Langebaan Formation are noted by Roberts *et al*. (2009). Occasional bone accumulations are attributed to much younger hyaena dens, as seen within contemporary ancient aeolianites at Swartklip on the False Bay coast. Peat horizons are also recorded in the Nahoon Formation (Le Roux 1989b) and should yield useful data on contemporary vegetation and palaeoclimates (*cf* Carr *et al*., 2006).

3.3.4.2. Nahoon Formation in the Coega IDZ

On the published 1: 50 000 scale geological maps of the Coega area only very small exposures of Mid to Late Pleistocene aeolianites of the Nahoon Formation (Qn) are indicated. These outcrops are situated within the Portnet area just east of the Coega River mouth and may well have been obliterated by later development at the Ngqura Port. Much more extensive outcrops of the Nahoon Formation were identified along the coast of IDZ Zone 10 during this study. These lie in the Sea Arc / Marine Growers region (Locs 81-82) as well as directly overlying the Salnova Formation stratotype E succession at Hougham Park (Locs 84-85) and further northeastwards along the coast (Locs 86-97). Here pale greyish-brown to buff, well-consolidated aeolian sands situated within a few meters above modern sea level contain sparse, irregular and thin calcrete layers, as well as abundant terrestrial snail shells (*Achatina*, *Tropidophora*) and small wind-blown marine shell fragments (Fig. 79). There are also occasional blocks of storm-tossed coquinite, breccias of consolidated aeolianite intraclasts, and occasional marine shells (*eg Turbo*, oysters). Embedded within the cemented aeolianites are sparse human artifacts of quartzite (Fig. 80). These are referable to the Middle Stone Age (Dr L. Webley, UCT pers. comm., 2010).

The Nahoon beds are planed-off by a well-developed wave-cut platform whose upper surface displays amalgamated coquinite clasts, marine and terrestrial mollusks and thin lenticles of beach conglomerate (Loc 88, Figs. 81, 82). This surface probably relates to the Eemian highstand (last interglacial sea level rise) of around 120 000 BP (*cf* Roberts *et al*., 2006, p. 613). Inland extensions of this erosional surface into well-consolidated Nahoon aeolianites can be seen in modern dune slacks. The Nahoon aeolianites at Hougham Park are overlain near the coast by ancient storm beach gravels and by younger dune sands of the Schelm Hoek Formation further inland.

Low coastal cliffs in the Mellville area, close to the eastern boundary of IDZ Zone 10, display several superimposed cycles of aeolianites separated by palaeosols, with the extensive development of calcretized rhizoliths (Fig. 83). Locally the aeolianites are slightly reddened and preserve low-angle dune lamination. Dune snails, including large specimens of *Achatina* that preserve clear colour markings, are abundant and are often concentrated along palaeosol horizons (Figs. 84, 85).

Fig. 79. Well-consolidated buff-coloured aeoliantes of the Mid to Late Pleistocene Nahoon Formation at Hougham Park overlying marine sandstones and conglomerates of the Salnova Formation. Note abundance of land snail shells (mainly *Achatina* and *Tropidophora*) in the Nahoon sands. Sparse stone tools are also found embedded with this unit nearby (See Fig. 80 below).

Fig. 80. Middle Stone Age quartzite flake (*c.* 2.5cm across) embedded in well-consolidated aeolianites of the Nahoon Formation, Hougham Park (Loc. 88). Note abundant small shell fragments in matrix.

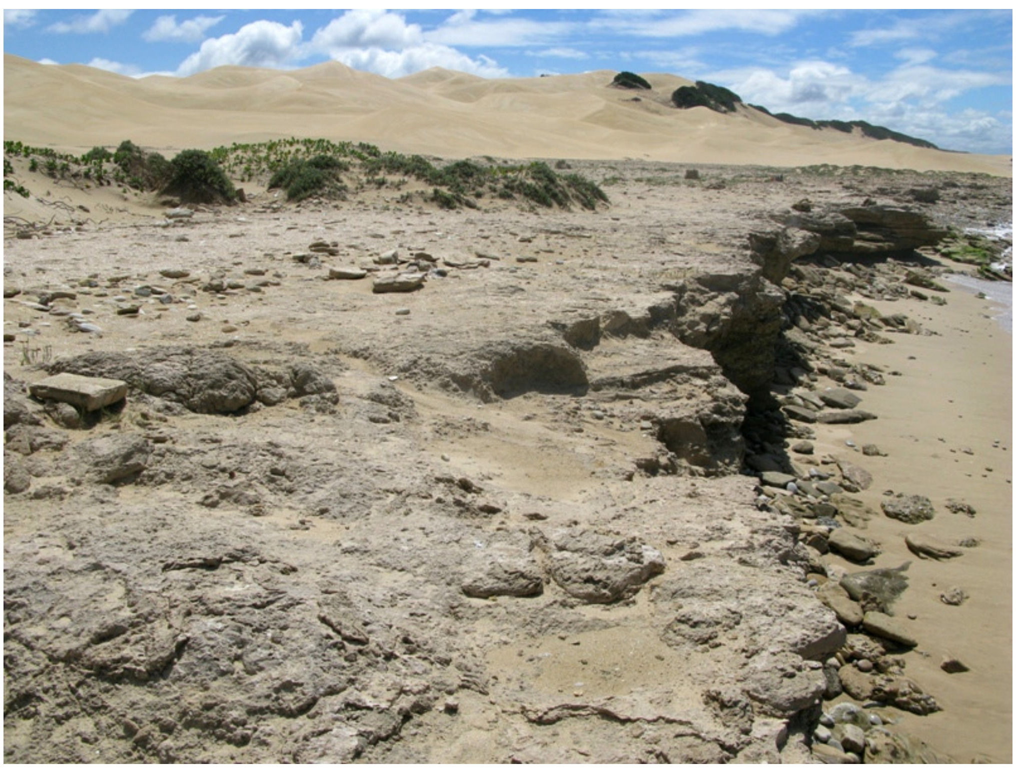


Fig. 81. Well-developed wave-cut bench truncating thin aeolianites of the Nahoon Formation (overlying Salnova and Sundays River beds) at Hougham Park.

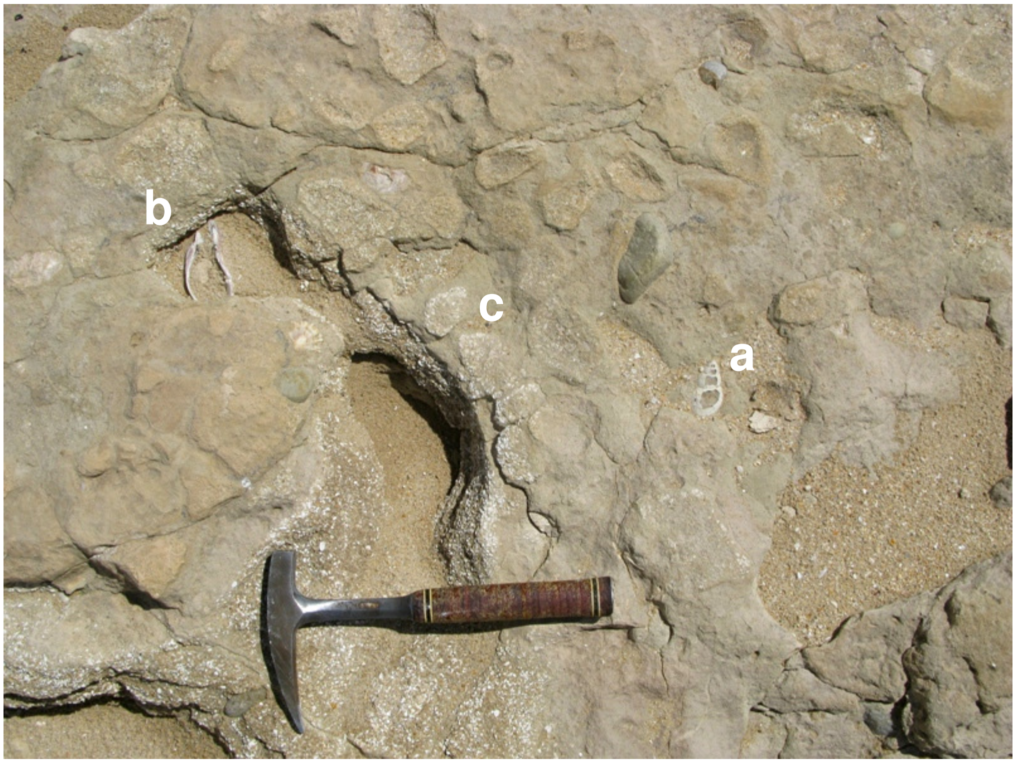


Fig. 82. Upper surface of wave-cut platform incised into Nahoon aeolianites at Hougham Park (Loc 85) showing embedded land snails (a), marine shells (b) and reworked coquinite clasts.

Fig. 83. Low cliff of well-consolidated aeolianites of the Nahoon Formation near Mellville showing relict dune lamination and pervasive rhizoliths.

Fig. 84. Slightly-reddened and calcretised Nahoon aeolianites at Hougham Park containing abundant large *Achatina* snail shells.

Fig. 85. Typical large shells of the land snail *Achatina* from the Nahoon Formation at Hougham Park (Loc. 94). Note good preservation of colour banding.

3.3.5. Schelm Hoek Formation (Qw)

Modern aeolian calcareous sands of the Schelm Hoek Formation build still-active dune sands of Holocene age along the South Coast (Illenberger 1992, Le Roux 2000). Deposition probably started during regression from the Mid Holocene transgressive maximum (*i.e.* the Flandrian transgression of 2-3m amsl at 4000-3000 BP). The dune sands may be up to 140m thick with an average of 30m, and extend up to 6km from the coast. Active sand dunes near the coast are unvegetated while those further inland are stabilized by dense dune thicket. In addition to unconsolidated, well-sorted, calcareous aeolian sands the Schelm Hoek Formation contains abundant shell middens of the Late Stone Age (Roberts *et al.*, 2006, Webley & Hall, 1998). Palaeosols (ancient soil horizons) and peats are absent according to Le Roux (2000, Table 3) whereas Illenberger (1992) as well as Goedhart and Hattingh (1997) record the presence of fossil soils. These Holocene dune deposits may be semi-consolidated at depth, and difficult to distinguish from the generally better cemented Nahoon Formation aeolianites.

Fig. 86. Modern calcareous sand dunes of the Schelm Hoek Formation, Hougham Park. Note storm beach conglomerates in foreground and middle distance. These may be of Eemian (*c.* 120 000 BP) or Mid Holocene age.

3.3.5.1. Palaeontological record of the Schelm Hoek Formation

An authoritative review of the palaeontological potential of Quaternary coastal sands of the Cape region is provided by Pether (2008). Categories of scientifically valuable fossils mentioned by Pether (*ibid.*) and others that may be preserved in these sands include:

- rare fossil bones, teeth and other remains of mammals (*e.g.* rhino, elephant, bovids, moles), reptiles (*e.g.* tortoises, lizards), and ostriches (*e.g.* egg shells)
- terrestrial gastropods
- plant remains such as charcoal, decayed plant roots
- calcareous and siliceous microfossils (foraminiferans, ostracods, diatoms, shell fragments, calcareous algae, echinoid spines)
- organic-walled microfossils (pollen, spores) from mudrocks deposited in interdune ponds and vleis, which may also contain fossil frogs, fish, aquatic snails and plant macrofossils (reeds, leaves, seeds, roots *etc*)
- trace fossils (*eg* mole and arthropod burrows, vertebrate tracks)

Illenberger (1992) records fragmentary remains of molluscs, calcareous algae, and sea urchins as well as foraminiferans, terrestrial snails (*eg Achatina, Trigonephrus*) and root casts (rhizoliths) from the Schelm Hoek Formation in particular. Shell middens close to open beaches are dominated by white sand mussels (*Donax serra*) but also contain remains of marine and terrestrial mammals, stone artifacts, bone tools and occasionally pottery (Webley & Hall 1998).

3.3.5.2. Schelm Hoek Formation in the Coega IDZ

Unconsolidated and vegetated dunes extend up to 3km from the shore along the Coega IDZ coastline, with two small, northeast-directed dune plumes clearly visible on satellite images (*cf* Roberts *et al.*, 2009). Good examples of vertically sectioned dunes showing large scale aeolian cross-bedding are seen in the active sand quarries near the Sea Arc factory site and at Sonop (Locs 76, 114, Coega Zone 10; Fig. 87).

Apart from the usual concentrations of wind-deflated dune snails - notably superabundant *Tropidophora* and *Natalina* here (Figs. 88, 89a, 89b) - a range of subfossil remains can be seen, especially in deflation hollows between the dunes. Among these are millipede exoskeletons, small mammal and reptile bones (often sand-blasted), fragments of charcoal, and buried mats of plant roots, some of which are covered in thin carbonate crusts (incipient rhizocretions; Fig. 89b). Peaty soils as well as inferred *vlei* deposits associated with large land snails, bird and mammal (antelope, seal) bones and Late Stone Age artefacts were recorded in a recent impact study by Robert Gess for a proposed Chlor-Alkali and Salt Plant at Coega. Shell middens of oysters and other edible marine shells situated close to the shoreline are attributable to Late Stone Age (and later) humans and will be considered in more detail under archaeological heritage (Dr J. Binneman, Albany Museum, Grahamstown).

Fig. 87. High-angle dune cross-lamination in modern unvegetated calcareous aeolianites of the Schelm Hoek Formation, Hougham Park (Loc. 76).

Fig. 88. Extensive scatters of wind-deflated land snail shells (mainly *Tropidophora* and *Natalina*) in unconsolidated Holocene dune sands of the Schelm Hoek Formation at the sand quarry near Sea Arc (Loc 76).

Fig. 89a. Close-up views of *Natalina* (left) and *Tropidophora* (right) from the Schelm Hoek Formation (Loc. 76).

89b. Partially buried plant material in modern sand dunes showing incipient development of calcretised crusts (Loc. 76).

3.4. Late Caenozoic fluvial deposits (T-Qk *etc*)

A variety of Late Tertiary to recent fluvial deposits is preserved along the margins of the Coega and Sundays Rivers in the study area. Detailed accounts have been provided by Hattingh (1994, 1996), Goedhart and Hattingh (1997) and Hattingh and Goedhart (1997). The fluvial sediments range from “High Level Gravels” of Miocene / Late Pliocene age situated on elevated terraces (60-15m asl) through to finer-grained alluvial sands and silts of Pleistocene / Holocene age close to modern river levels (10-2m asl; Goedhart & Hattingh 1997, Le Roux 2000). In the Coega Valley terrace sediments are up to 4m thick, but may reach 12m in the Sundays River area. The highest of the river terrace gravels on the western side of the lower Coega River valley, at +60m asl and 2km to the west of the present river course, has been correlated with the +90m sea level highstand and thereby dated to the Late Pliocene (Goedhart & Hatting 1997, p. 23). This suggests that the Coega River is quite a young drainage system that has developed quickly in the recent geological past due to the low weathering resistance of the Uitenhage Group rocks in the drainage basin.

In the Coega IDZ region relict patches of ancient fluvial terrace gravels (T-Qk) are mapped overlying Uitenhage Group rocks along the western edge of the lower Coega River Valley (east of Coega Kop) as well as on the eastern side of the river (Welbedachtsfontein 300). A patch of disturbed high level gravels (*c*. 86m asl) of probable Late Pliocene age was examined just north of the new road cutting between Coega Kop and Coega village (Loc 24). These unconsolidated conglomerates consist mainly of well-rounded pebbles and cobbles of Table Mountain quartzite. The clast surfaces are often stained brown and show impact crescents indicative of highly turbulent river flow. A few small abandoned quarries into the Kirkwood Formation in the low escarpment south of Coega village show sections through lenticular bodies of alluvial gravels at 22-27m amsl (Loc 25, Fig. 90). The one to two meter - thick gravels here are moderately well-sorted pebbles and cobbles of pale Table Mountain quartzite showing well-developed imbrication (*i.e.* down-stream dipping of platy clasts) and surface impact crescents. They are incised into Uitenhage mudrocks and overlain by pale brown silty alluvium with thin pebbly lenticles. Colluvial debris flow deposits comprising a slurry of reworked silty alluvium and scattered quartzite clasts are also seen in some nearby quarry faces (Loc 26). No fossils were observed within any of these older river terrace deposits. At most, rolled bones and teeth of vertebrates and perhaps freshwater mollusk shells might be expected in the conglomeratic facies.

Younger (possibly Pleistocene) alluvial deposits close to the level of the modern drainage systems are well-exposed in a small quarry on the eastern banks of the Coega River north of the N2 (Loc 67, Fig. 91). Here a succession of several meters of vaguely-bedded, greenish-brown silts contain thin stringers of quartzite gravels. The silts are partially consolidated, showing cavernous weathering, and are capped by reddish soils. Patches of cobbly gravels crop out in the river valley close to their base. Apart from occasional reworked Early Cretaceous shelly fossils weathered out from the Sundays River beds upstream, no fossils were seen in these younger alluvial siltstones. However, a careful search of finer-grained facies might well yield well-preserved skeletal remains of mammals, reptiles, fish, mollusks, crabs as well as plant material (wood, lignites, roots) and trace fossils (*eg* termitaria, ostrich egg shells).

Fig. 90. Ancient fluvial conglomerates ("High Level Gravels") at *c*. 25m amsl showing well-developed imbrication, small quarry on the eastern edge of the Coega River Valley (Loc 25).

Fig. 91. Geologically young (probably Pleistocene), fine-grained alluvium close to modern river levels, quarry on the western banks of the Coega River (Loc 67).

6. Conclusions and recommendations

The fossil heritage of each of the ten main stratigraphic units occurring in the Coega IDZ has been assessed on the basis of (a) the scientific literature and (b) fieldwork carried out for the present study. The palaeontological sensitivity of each unit as it occurs in the Coega IDZ has been estimated and is summarized below in Table 1. This table also outlines the specialist palaeontological mitigation that is recommended in the case of future developments that involve excavations into these stratigraphic units. Palaeontological mitigation generally concerns the construction phase rather than the operational phase of a development, unless this development involves ongoing excavation of bedrock (*eg* mining).

Future developments within the Coega IDZ will have to be individually assessed beforehand in terms of their likely impact on palaeontological heritage. The impact of these developments and the need, if any, for palaeontological mitigation can now be quicky assessed on the basis of this palaeontological report when used in conjunction with the relevant geological maps (These maps are listed in Section 2 and are available from the offices of the Council for Geoscience, Port Elizabeth). The key factors to consider here are (a) the location of the proposed development, (b) the extent (depth, volume) of the bedrock excavations involved, and (c) the palaeontological sensitivity of the stratigraphic units affected.

As shown in Table 1, specialist palaeontological mitigation is especially recommended for substantial excavations into the Kirkwood, Sundays River and Salnova Formations which all have a proven fossil record of high scientific importance. The Alexandria Formation is also known to be richly fossiliferous, and a substantial number of the key fossil localities within this unit are indeed situated in the Coega region. However, field evidence suggests that much of this lime-rich succession here has been diagenetically altered (*e.g.* by post-depositional leaching and calcretization) so that most new excavations expose few or no fossils of value. Unless rich fossil remains are encountered during excavation, palaeontological mitigation is not automatically recommended in the case of the Alexandria Formation (Note that this unit covers a large percentage of the Coega IDZ).

Where it is recommended, mitigation by a qualified palaeontologist should entail (a) the field examination of new bedrock excavations, (b) the recording of sedimentological and palaeontological data, (c) the judicious sampling of fossil material and (d) recommendations for any further action required to safeguard fossil heritage. It is important that the opportunity to mitigate is given while the bedrock excavations are fresh and *before* they are infilled, covered over or degraded by weathering and plant growth. Before development starts a realistic programme of mitigation should therefore be negotiated between the developer and the palaeontologist contracted for the project to maximize the scientific and conservation benefits of the work while minimizing disruption of the construction programme.

Environmental control officers responsible for developments within the Coega IDZ should:
(a) be alerted to the palaeontological sensitivity of several geological units in the area,
(b) familiarize themselves with the sort of fossils that might be encountered during development through museum displays and using this report, and
(c) alert SAHRA and a professional palaeontologist should significant fossil remains be exposed during excavations.

Ten localities of exceptional geological or palaeontological interest within or very close to the Coega IDZ - Geosites GS1 to GS10 - have been listed in Table 2 below and are illustrated in Figs. 92-101. The table outlines their scientific interest and makes more or less specific recommendations for action in each case. In general, these sites should be safeguarded from development as far as possible. Any unavoidable development directly affecting these sites will require palaeontological mitigation which should be commissioned in the planning stage before development commences.

Several of the proposed Geosites are naturally protected by their geographic isolation. Two of them (GS4, GS8) are on Offit or Spoornet land outside the Coega IDZ proper and are included for information only. It may be noted here that at least one further geosite (not listed here) – the stratotype section D of the Salnova Formation designated by Le Roux (1991) which is richly fossiliferous – is situated in the Coega estuary on Portnet land and also warrants special protection. One of the officially designated stratotype sections of the Alexandria Formation situated to the east of Coega has already been destroyed by recent road development. Fortunately, the recently expanded limestone quarry nearby largely compensates for this loss – *provided that* it isn't completely backfilled.

It must emphasized that management and conservation of palaeontological heritage within the Coega IDZ must extend beyond the protection of the handful of geosites listed in Table 2. Palaeontological heritage is not site-specific but related to entire geological units (*eg* formations). The distribution of these formations is indicated on published geological maps (*eg* 1: 50 000 scale maps) and these must be consulted in conjunction with the present report in order to assess the necessity for palaeontological mitigation for a particular development.

Given the palaeontological interest of the Coega region and the number of large scale bedrock excavations being carried out within the Coega IDZ, or envisaged for the future, it is recommended that a palaeontologist be commissioned by the Coega Development Corporation to briefly review potential or actual impacts on palaeontological heritage here once a year. This work would probably entail a one- to two-day site visit, a review of relevant background documentation for future projects and written report for the Coega Development Corporation and SAHRA.

The main Coega quarries have long been used by local universities for educational and research purposes. There is also considerable interest among the educated public in fossils while the topics of palaeontology and evolution now feature significantly on the new school biology syllabus. However, there is a dearth of display and well-illustrated educational materials relevant to our wealth of fossil heritage. It is therefore recommended that the Coega Development Corporation consider establishing a small, informative display of local fossils backed up with colourful geological maps, a time chart and reconstructions of past wildlife, perhaps with an accompanying leaflet. This educational project would also provide a useful resource for training ECOs involved in development in the Coega IDZ and would benefit from collaboration with concerns outside the Coega IDZ such as nearby brick pits.

TABLE 1: SENSITIVITY OF FOSSIL HERITAGE OF SEDIMENTARY FORMATIONS OCCURRING WITHIN THE COEGA IDZ, THE EASTERN CAPE (For use with 1: 50 000 scale geological maps)			
FORMATION & AGE	**FOSSIL HERITAGE**	**PALAEONTOLOGICAL SENSITIVITY**	**RECOMMENDED MITIGATION FOR NEW DEVELOPMENTS**
RIVER TERRACE GRAVELS (T-Qk) & ALLUVIUM Miocene to Recent river deposits	possibly rare rolled bones, freshwater molluscs, plant remains	LOW	mitigation not required - *unless* rich fossil accumulations exposed during excavation
SCHELM HOEK FORMATION (Qsc) Holocene – Recent calcareous dune sands	land snails, land vertebrate bones, peats & root casts, shell middens, LSA stone tools	LOW	mitigation not required - *unless* rich fossil accumulations exposed during excavation
NAHOON FORMATION (Qn) Mid to Late Pleistocene calcareous dune sands	common land snails, calcretised root casts, peats, termitaria, sparse MSA stone tools	LOW	mitigation not required - *unless* rich fossil accumulations exposed during excavation
SALNOVA FORMATION (Qs) Mid Pleistocene to Recent coastal and estuarine sediments	very rich shelly invertebrate faunas, especially molluscs but also several other groups, such as crustaceans & echinoids, possible rare vertebrate bones	HIGH	**excavations (especially those into fine-grained mudrocks) to be examined and sampled by professional palaeontologist while fresh bedrock is still exposed**
NANAGA FORMATION (T-Qn) Pliocene – Early Pleistocene calcareous dune sands	common land snails, calcretised root casts, possible termitaria	LOW	mitigation not required - *unless* rich fossil accumulations exposed during excavation
"BLUEWATER BAY FORMATION" residual weathering product of Alexandria Fm	rare fossil shells weathered out from underlying limestones *plus* land snails, freshwater mussels	LOW	mitigation not required - *unless* rich fossil accumulations exposed during excavation

TABLE 1 continued: SENSITIVITY OF FOSSIL HERITAGE OF SEDIMENTARY FORMATIONS OCCURRING WITHIN THE COEGA IDZ, THE EASTERN CAPE (For use with 1: 50 000 scale geological maps)			
FORMATION & AGE	**FOSSIL HERITAGE**	**PALAEONTOLOGICAL SENSITIVITY**	**RECOMMENDED MITIGATION FOR NEW DEVELOPMENTS**
ALEXANDRIA FORMATION (Ta) Miocene – Pliocene shallow marine to estuarine sediments	very rich shelly invertebrate faunas, especially molluscs but also several other groups, sharks teeth, possible rare vertebrate bones	LOW TO HIGH rich shelly faunas only found at some localities fossil shells often destroyed by deep weathering, calcrete formation, especially in near-surface sections	mitigation not required - *unless* rich fossil accumulations exposed during excavation
SUNDAYS RIVER FORMATION (Ks) Early Cretaceous marine to estuarine / intertidal mudrocks and sandstones	rich variety of marine molluscs (bivalves, ammonites *etc*) and other invertebrates v. rare marine reptiles (plesiosaurs)	MODERATE TO HIGH most shelly fossils associated with thin sandstones	**substantial (high volume) excavations to be examined and sampled by professional palaeontologist while fresh bedrock is still exposed**
KIRKWOOD FORMATION (J-Kk) Early Cretaceous fluvial to estuarine mudrocks and sandstones	rare dinosaurs, petrified wood, plants (esp. gymnosperms), charcoal, freshwater crustaceans & molluscs	MODERATE TO HIGH fossils generally sparse but may be concentrated at certain horizons (*eg* ancient soils, flood deposits)	**substantial (high volume) excavations to be examined and sampled by professional palaeontologist while fresh bedrock is still exposed**
PENINSULA FORMATION (Op) Mid to Late Ordovician fluvial quartzites	rare trace fossils microfossils in mudrock units	LOW	mitigation not required - *unless* rich fossil accumulations exposed during excavation

TABLE 2 COEGA IDZ: PROPOSED PROTECTED GEOSITES			
NO.	**LOCATION**	**SPECIAL FEATURES**	**COMMENTS & RECOMMENDED ACTION**
GS1 **Fig. 92**	Main clay quarry, Coega (IDZ Zone 9) 33.755 S, 26.670 E	Important site for fossils from the Sundays River Formation, also much used for student education and palaeontological groups East face shows unconformable stratigraphic contact between the Alexandria and Sundays River Formations	Abandoned quarry. Current research project on fossil crabs here by Dr W. de Klerk (Albany Museum) **Safeguard and keep clear eastern face of quarry**
GS2 **Fig. 93**	Main limestone quarry, Coega (IDZ Zone 9) 33.756 S, 25.643 E	Excellent vertical sections through marine sediments of Alexandria Formation. Important site for Miocene shelly and trace fossils from Alexandria Formation Good replacement for officially designated stratotype D for the Alexandria Formation (Le Roux 1987b) that has now been destroyed by recent roadworks	Active quarry site. Fossil collecting site of Le Roux (1987a) Current research project on trace fossils here by Dr W. de Klerk (Albany Museum) **Keep quarry faces clear and safeguard large blocks at western edge**
GS3 **Fig. 94**	Deep erosion gully at edge of escarpment, SW portion of Bontrug 301 (IDZ Zone 14) 33.749 S, 25.613 E	Richly fossiliferous sandstones within Sundays River Formation (small bivalves, scaphopods, corals) First and only known record of scaphopod mollusks (tusk shells) from Sundays River Formation	Small site that is vulnerable to disturbance (e.g. illicit fossil collection) **Protect gully from development or disturbance**
GS4 **Fig. 95**	Abandoned clay pit, (Offit land within IDZ Zone 14) 33.748 S, 25.643 E	Richly fossiliferous sandstones within Sundays River Formation (*Gervillella*, trigoniids *etc*) East face shows stratigraphic contact between the Alexandria and Sundays River Formations	Abandoned quarry. *NB* Not within current boundaries of IDZ. **Protect fossils in quarry from development or disturbance.**

GS5 **Fig. 96**	Tossies quarry South (IDZ Zone 13) 33.753 S, 25.667 E	Excellent exposure of contact between Alexandria and Sundays River Formations in upper eastern face of quarry	Abandoned quarry. Site already partially infilled. **Clear upper eastern face of quarry to ensure stratigraphic contact is accessible.**
GS6 **Fig. 97**	Erosion gully immediately N of Tossies Quarry North (IDZ Zone 13) 33.746 S, 25.670 E	Richly fossiliferous sandstones within Sundays River Formation (*Aetostreon*, trigoniids, rare limpets *etc*) Shell-rich basal Alexandria Formation above	Small site that is vulnerable to disturbance (*e.g*. illicit fossil collection) **Protect gully from development or disturbance**
GS7 **Fig. 98**	Cliff section at W end of paired stormwater tunnels beneath N2 (IDZ Zone 5) 33.782 S, 25.665 E	Sedimentary contact between Alexandria and Kirkwood Formations Well-exposed crustacean burrows (*Ophiomorpha*) within lower Alexandria Formation	Trace fossils are easily degraded **Protect cliff face from development or disturbance**
GS8 **Fig. 99**	Deep railway cutting running along W of N2 to south of marshalling yard (Spoornet ground adjacent to IDZ Zone 5) 33.781 S, 25.665 E	Sedimentary contact between Alexandria and Kirkwood Formations Vertical sections through trace fossils (bivalve burrows) at contact	*NB* dangerous access (trains!) **Protect railway cutting from development or disturbance**

GS9 **Fig. 100**	Long trench into surface limestones on E side of dust road, north of Hougham Park farmstead (IDZ Zone 7) 33.764 S, 25.712 E	Excellent exposures of large fossilized root systems (megarhizoliths) in ancient dune sands of Nanaga Formation Abundant shells of Plio-Pleistocene land snails	Trace fossils are easily degraded (Therefore they should be studied soon) **Protect northern face of trench from damage or development**
GS10 **Fig. 101**	Low coastal rock platform (Southern border of IDZ Zone 10) 33.765 S, 25.749 E	Officially designated stratotype E locality of Salnova Formation (Le Roux, 1991) Good exposure of contact between Salnova and Sundays River Formation Fossiliferous ancient dune sands of Nahoon Formation	**Protect coastal outcrop from development or disturbance**

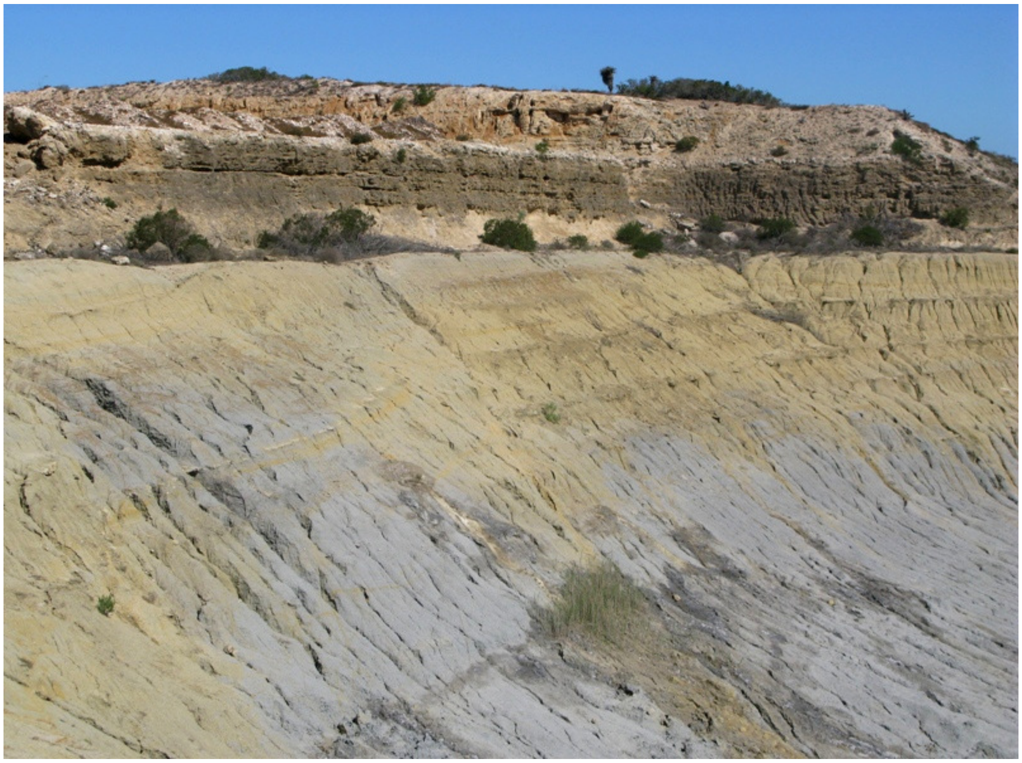


Fig. 92. GS1 - East face of main Coega clay pit: unconformable contact between Sundays River Formation mudrocks capped by Alexandria Formation limestones; rich record of shelly and trace fossils in both formations.

Fig. 93. GS2 - Main limestone quarry, Coega: excellent exposures of sediments and fossils in Alexandria Formation.

Fig. 94. GS3 - Erosion gully on Bontrug 301: fossiliferous sandstones, Sundays River Formation; only recorded site for Cretaceous tusk shells from this formation.

Fig. 95. GS4 - Abandoned clay pit, Offit land: fossiliferous sandstones, Sundays River Formation; well-exposed contact between Alexandria and Sundays River Formations.

Fig. 96. GS5 - Tossies Quarry South (east face): well-exposed contact of Alexandria and Sundays River Formation.

Fig. 97. GS6 - Erosion gully north of Tossies Quarry North: highly fossiliferous sandstones, Sundays River Formation (also shell-rich Alexandria beds in background).

Fig. 98. GS7 - Stormwater drainage cut adjacent to N2: contact of Alexandria and Kirkwood Formations; trace fossils (*Ophiomorpha*) in lower Alexandria Formation.

Fig. 99. GS8 - Railway cutting adjacent to N2: contact of Alexandria and Kirkwood Formations, boring bivalve trace fossils (*Gastrochaenolites*) along contact.

Fig. 100. GS9 - Trench north of Hougham Park farmstead: megarhizoliths (fossilized plant roots) in dune sands of Nanaga Formation; abundant fossil land snails.

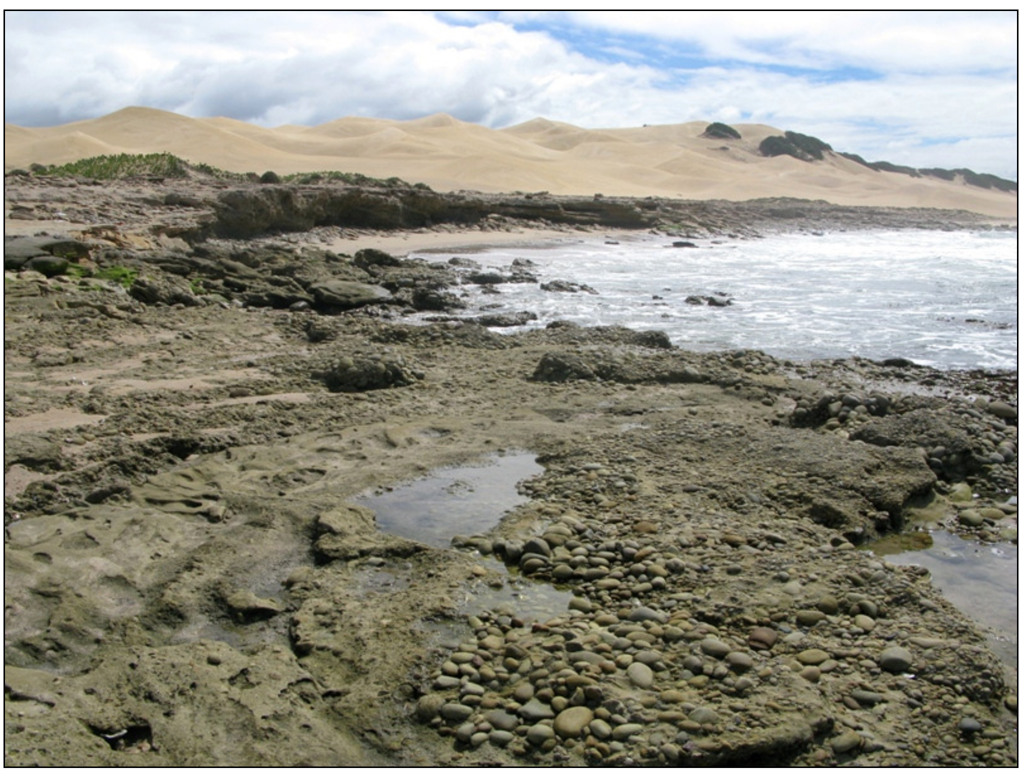


Fig. 101. GS10 - Rocky coastline at Hougham Park: stratotype section of Pleistocene Salnova Formation, fossiliferous dune sands of Nahoon Formation.

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