A COMPOSITE REGOLITH PROFILE AT CEDUNA, SOUTH AUSTRALIA.

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Summary

A composite regolith profile has been exposed by coastal erosion on a headland 1 km south of the Ceduna town jetty. The 4.2 m high profile consists of kaolinised and iron mottled Precambrian granitic rocks at the base, overlain successively by a metre of kaolinised siltstone, a 30 cm thick layer of ferruginous fine sand containing clasts of ferruginised sandstone and silcrete, and two calcrete layers developed on marl. The section is interpreted essentially as a local sequence: the siltstone was derived from the underlying weathered granitic rocks and the ferruginous horizon with numerous clasts is interpreted as a lag formed on a palaeo-shore platform later covered with sand. Iron was introduced by ground waters. A regional climatic change towards increased aridity is associated with the formation of the two overlying horizontal calcrete layers. Weathering of the basement rocks has been tentatively assigned to the late Tertiary and calcrete formation has been associated with the Pleistocene.

KEY WORDS: Regolith, calcrete, ferricrete, silcrete, ‘laterite’

Introduction

A weathered regolith profile occurs in the sea cliffs on the eastern margins of the town of Ceduna on Eyre Peninsula, South Australia, within Murat Bay (Fig.1) at 32° 8’ 6.4” S latitude and 132° 14’ 13.0” E longitude. The cliff section (Figs 2 & 3) occurs on a headland approximately 1 km south of the Ceduna town jetty. The section is 4.2 m high from the ground surface to approximately mean high tide level. The author’s attention was drawn to this section because of the dramatic variegated colours of the regolith materials, which ranged through shades of white, red, orange and yellow. Superficially the profile might be interpreted as a ferruginous ‘laterite’ underlain by a pallid zone that rests on mottled, weathered crystalline rocks, with the profile being mantled by calcareous sediments in which two prominent calcrete horizons have developed.

Weathered regolith exposed by coastal erosion, has been described from various locations around the Eyre Peninsula coastline, often, but not always capped with Pleistocene aeolianite and/or calcrete horizons. For example, at Point Labatt, Milnes et al. (1985) described remnants of ferruginous regolith at the base of high cliffs of Bridgewater Formation. Here a kaolinised, mottled zone, developed in granite, is overlain by an iron-rich sediment at the modern shoreline. The ironstone crust overlying the mottled material is a gravelly ferricrete formed of nodules and pisoliths with poorly developed rinds set in a sandy matrix, which is less iron-rich than the nodules, and contains some clay and fine silt. Titanium is present in the matrix, which may be silicified. The above provides an example of a weathered profile developed in bedrock and overlain by a sedimentary ferricrete close to present sea level.

Other relicts of deep weathering occur in the coastal cliffs of Sleaford Bay where Precambrian metasediments and granites have been weathered and ferruginised with strong lithological controls imposed on weathering and the development of hematite-rich mottles, Bourman1. The bleached part of the weathering contains high concentrations of titanium and the overlying calcrete abundant ferruginous pisoliths dominated by hematite and maghemite with typically high Fe₂O₃ (42.69%). The pisoliths are sometimes overlain by a thin sandy soil, which superficially might be interpreted

1 (BOURMAN, R.P. (1989) Investigations of ferricretes and weathered zones in parts of southern and southeastern Australia - A reassessment of the laterite Concept. Ph.D. thesis, The University of Adelaide (unpubl.) 495 pp.)
as a fossil 'lateritic' A-horizon. However, the sand is a wind blown deposit derived from the nearby beach. Cliff-top dunes occur in the area, and in one locality sand can be traced continuously from the back beach up the cliff face to the cliff top. A small valley cut into the weathered zone that has been filled with pisoliths, which are hardening to form a detrital pisolitic crust of recent age much younger than the underlying weathered zone. There is, thus, evidence of complex reworking and modification of the weathered substrate.

Molina Ballesteros et al. (1995) described an 18 m thick weathering profile, developed on crystalline rocks of the Sleaford Complex, 2,700 to 2,300 Ma in age, beneath dune calcarenite at Point Drummond, 80 km northwest of Port Lincoln. Five stages in weathering transformations were described with original rock structures being preserved in the lowest three units. The weathering was tentatively assigned a Plio-Pleistocene age.

Many other mottled and weathered bedrock exposures occur at the shore zone. At Redbanks, on Whalers Way, for example, ferruginised and mottled sediments, which resemble the “Hindmarsh Clay” (Firman 1967a, 1967b) overlie Precambrian granitic rocks, and are overlain in turn by horizontally bedded goethitic sediments and aeolianite. A younger, vertical weathering pattern transgresses both the goethite-rich horizon and the underlying hematite-rich Hindmarsh Clay, suggesting that weathering of the profile has been ongoing. Weathering of Precambrian rocks occurs at Port Neill, Tumby Island, Redcliffs at Massena Bay, Peake Point, Louth Bay, near
Lincoln Cove, Point Brown and numerous other sites. All of these sites have been examined, but none of them closely resembles the Ceduna Profile, the focus of this paper.

Figure 2  Long distance view of the headland 1 km south of Ceduna town jetty. The Thevenard silos are visible in the right/centre of the photograph. Note the flat lying nature of the land surface and the underlying stratigraphy.

Figure 3  Diagrammatic sketch of the described section
Objectives

At first sight the lower part of the profile appeared to be a relict “lateritic” weathering profile in which unweathered bedrock is successively overlain by a kaolinised pallid zone, an iron-rich mottled zone and a ferricrete horizon. The objectives of this paper are to:

i. present sedimentological, weathering and mineralogical data from a complex regolith profile exposed in an actively eroding headland near Ceduna and, based on the interpretation of this data,

ii. develop a conceptual model that best explains the evolution of the profile, thereby testing the hypothesis that it developed as a result of “lateritic” weathering.

iii. determine whether the profile has regional or only local significance.

Methodology

In assessing the regional significance of the profile, the coastal cliffs around much of the Eyre Peninsula coastline were examined in order to map the lateral extent of the full profile. The weathered profile was carefully examined, which revealed changes in the character of the regolith materials including bedding, structures and textures as well as the presence of at least three unconformities. The calcareous nature of the upper part of the profile was determined by effervescence, following the application of hydrochloric acid. Halite in the profile was identified both by taste and X-ray diffraction. The thicknesses of discrete horizons were measured and samples from the different zones, related to colour variability, were collected for mineralogical analysis. The samples were also assigned Munsell colours for their descriptions.

In the laboratory, ground powders of the samples were pressed on filter paper into aluminium holders to produce randomly oriented powder samples for X-ray diffraction. All samples were analysed in a Philips PW/710 diffractometer using cobalt radiation, automatic divergence slits and a graphite monochromator. For the majority of samples analysed, the scan speeds were 1°2θ per minute through an angular range of 2°2θ to 75°2θ. Mineral identification was carried out using powder diffraction data given in Brindley & Brown (1980) or in the JDPCS Powder Diffraction File cards and books.

Results

The base of the section (Fig. 2) comprises 1.2 m of weathered, kaolinised and mottled crystalline Precambrian bedrock, which is more strongly ferruginised within the intertidal zone than in supratidal zone. The weathered rocks have been assigned to the St Peter Suite of the Lincoln Complex with a probable age of 1620 ± 4 Ma (Flint et al., 1990). The bleached basement rocks contain both red and yellow mottles. A shore platform has been cut across the Precambrian rocks, which, although extensively kaolinised, retain their original granitic fabrics. Samples collected for mineralogical analysis from this part of the profile include:

Base of section: Weathered Precambrian crystalline rock (mean sea level to 1.2 m above sea level - asl)

Sample 1 White kaolinised bedrock 10YR 8/1 with flecks of mottles 10YR 7/1
0.5 m asl Mineralogy: kaolinite, quartz, felspar, halite, possible smectite, possible halloysite and anatase(?)

Sample 2 Red mottle 10R 4/8
0.7 m asl Mineralogy: kaolinite, quartz, hematite, felspar, possible smectite
Sample 3  Yellow mottle  10YR 7/8
0.9 m asl  Mineralogy: kaolinite, quartz, goethite, felspar, possible smectite

**Siltstone layer (1.2 m to 2.2 m asl)**

Overlying the 1.2 m of weathered crystalline rocks are 1 m of bedded silty fine sandy sediments, off-white in colour, that are also mottled, with some strong red mottles but in the upper section are dominantly weak yellow in colour. A lens of halite occurs at the contact between the Precambrian bedrock and the overlying siltstone layer. Samples collected from the siltstone unit of the profile include:

Sample 4  Off-white siltstone  10YR 7/1
1.7 m asl  Mineralogy: quartz, kaolinite, felspars, smectite

Sample 5  Dark red zones in siltstone  10R 4/8
1.8 m asl

Sample 6  Yellow mottles in siltstone  10YR 7/6
1.9 m asl

**Ferruginous zone**

In turn, the siltstone is overlain by a 30-40 cm reddish to yellow, ferruginous zone. This matrix material is a fine, silty sand, containing a jumble of rounded and angular clasts. These clasts are dominantly iron-impregnated sandstone, but a slabby block of silcrete as well as smaller silcrete pebbles also occur. A large slabby block of silcrete (Fig 7) was observed on 17/9/2000 but is now gone, as is a large boulder of ferruginised sandstone from near the base of the ferruginous zone. Some of the material in the ferruginous zone appears to be pyritic. No pyrite was identified by X-ray diffraction, but parts of the matrix material resemble pyritic materials observed elsewhere. In the upper part of this unit there are pods of alunite within the ferruginous horizon, immediately below the calcrete layers.

**Ferruginous zone (2.2 m to 2.6 m asl)**

Sample 7  Matrix material – silty, fine sand - dominant colour  (2.5 YR 5/8) with some
darker red mottles (10R 4/8)
2.4 m asl  Mineralogy: quartz, kaolinite, felspars, hematite, smectite, halite.

Sample 8  Inclusions – Dark red-coloured clasts  (5YR 2.5/2 to 10R 3/4) with yellow
rinds around some clasts (10YR 6/6)
2.3 m asl  Mineralogy: quartz, goethite, hematite, muscovite, halite, felspars

Sample 9  Weak yellow mottles in matrix  (10YR 6/6)
2.4 m asl  Mineralogy: quartz, kaolinite, goethite, felspars, anatase(?), smectite.

Sample 10  White coloured pods
2.6 m asl  Mineralogy: alunite, quartz, kaolinite, micas, halite, possible halloysite

**Calcareous horizon (2.6 m to 4.2 m asl)**

Overlying the ferruginous layer, in the top 1.6 m are two calcrete layers formed on calcareous marl. The calcrete varies through rubbly, pisolithic to massive in character.
Figure 4. (left) View of studied section across intertidal shore platform, which is cut across weathered (kaolinised) and mottled Precambrian crystalline bedrock (St Peters Suite). The platform is strewn with boulders and clasts derived from erosion of the section. Clasts include calcrete with surficial iron coatings and blocks of ferruginous sandstone. Small caves in the upper part of the section separate the two calcrete layers and the ferruginous layer occurs within the central part of the section.

Figure 5. (right) Photo of measured section. At the base is horizontally bedded siltstone overlain successively by a ferruginous horizon and two layers of calcrete.

Figure 6. (left) Mixed boulders and clasts of ferruginous sandstone and calcrete on the shore platform. The geological hammer is 30 cm long.

Figure 7. (right) Close up of slabby silcrete boulder incorporated into the ferruginous layer.

**Discussion**

Despite having only a total thickness of 4.2 m, the profile displays considerable variability in the development of regolith materials, which include kaolinitic bedrock, ferruginous mottles, ferricrete, silcrete and calcrete (Figs 2, - 6).

The section is interpreted as a stratigraphic sequence that includes remnants of *in situ* weathering as well as reworked weathering products. The crystalline, granitic rocks that form the base of the section have been extensively weathered, with much of the felspar content altered to kaolinite, although some felspar minerals remain intact. There is no doubt that these weathering transformations have occurred *in situ* as the original rock structure has been preserved. Goethite-rich and hematite-rich mottles in this weathered rock suggest that local mineral transformations and redistribution have resulted in concentrations of iron oxides as mottles as past water tables fluctuated.

A clear unconformable contact separates the kaolinised crystalline bedrock from overlying horizontally bedded silty sediments, which were probably deposited in very quiet waters, possibly in a lagoonal setting. Mineralogical affinities of these sediments to those of the underlying
weathered bedrock suggest derivation of the siltstone from the underlying unit. Ferruginous mottles, both goethite and hematite-rich suggest local mobilisation and reprecipitation of iron oxides within the siltstone.

The succeeding ferruginous unit in the section displays a marked contrast to that of the off-white siltstone horizon in that it contains variably sized ferruginous and siliceous clasts, set in a matrix of fine silty sand with prominent red, orange and yellow colours. The coarse, bouldery texture suggests a dramatically different environment of deposition for this unit from the underlying siltstone. Pebbles and boulders of silcrete together with lumps of ferruginised sandstone, some of which have yellowish surface coatings, suggest at least localised transport of sediments into this unit, as goethitic rinds often result from near surface pedogenic processes (McFarlane 1976).

The reworked clasts within this ferruginous layer resemble the jumble of boulders and clasts on the modern shore platform and could represent an old shore platform during a sea stand a couple of metres higher than at present. Ferruginous sandstone boulders and pebbles occur on the modern shore platform in the intertidal zone (Fig 6) along with calcrete clasts, many of which have ferruginous surface coatings. These boulders have derived from the erosion of the weathered shore platform and the backing cliff, isolating hardened ferruginous mottles, sediments and calcrete boulders and pebbles. In situ silcrete occurs locally in the Ceduna area (Gary Ferris – pers. comm., 2004), and the boulders and pebbles of silcrete may have derived from along shore sources. A slabby, sub-angular silcrete boulder in the section had not been transported very far. It is suggested that the lag on the modern beach is an analogue of the ferruginous zone preserved in the section, representing a series of reworking of previously existing materials, and subsequently buried by fine silty sand.

If the lag on the modern beach is an analogue of the ferruginous zone preserved in the section then the unconformity between the ferruginous zone and the underlying siltstone layer could represent an old shore platform during a relatively higher sea stand of one of the Pleistocene interglacial episodes. The lateral distribution of the section is not great and it could have been a palaeo-headland with a shore platform similar to that of today. This model would explain the jumbled mass of clasts and boulders in the ferruginous zone and the general level bedding within the section.

Halite is present in many of the samples analysed and it has almost certainly been derived from salt spray from the sea. In one location between the ferruginous layer and the underlying siltstone there is a large pod of massive halite.

The two layers of calcrete are interpreted as having formed on material transported into the area as there is no large source of calcium carbonate in the underlying materials. Aeolianite or dune calcarenite has a widespread distribution along the western coast of Eyre Peninsula, but the sediments associated with the calcretes of the study site are much finer than sand, there are no prominent cross-beds and the calcretes and associated sediments are flat lying. Some surface reworking of the calcretes has given them a rubbly, pisolitic, fragmented upper surface. The calcareous sediments on which the calcretes have developed is a marl and is interpreted either as a lacustrine or aeolian sediment.

Pillans and Bourman (2001) presented evidence of a marked change from an iron oxide-dominated weathering regime to a carbonate-dominated regime approximately 500 to 600 ka ago across southern Australia. This change was interpreted as representing a major shift to aridity in regional climates, leading to drying out of lakes and increased aeolian dust accessions, possibly during glacial episodes in the Pleistocene with increased dryness and windiness (Pillans & Bourman, 2001). It is suggested that this dramatic change is reflected in the coastal section at Ceduna, with the superimposition of calcareous horizons over iron oxide impregnated rocks and sediments. Working in the St Vincent Basin, Phillips and Milnes (1988) concluded that a calcareous sediment blanket, associated with calcrete, mantles terrestrial Pleistocene sediments and was also dominantly of aeolian origin. The widespread distribution of calcareous materials on Eyre Peninsula is also
reported by Wright (1985). The suggested evolution of the coastal section at Ceduna is summarised in Table 1.

The section described above appears to have a very limited distribution, with preservation restricted to the headland. Similar weathering and motting of ancient crystalline rocks does occur at the Pinky Point headland at Thevenard and there are vestiges of similar weathering on other headlands. At Pinky Point a reddish coloured clayey sand occurs between the weathered Precambrian rocks and the underlying calcrete, but unlike the study site, the reddish sand contains no clasts. Occasional ferruginous clasts or reddish coloured sands occur near the base of coastal sections to the north of the study site, and two upper calcrete horizons are quite common.

However, a search along the coast reveals that the complete, described section is restricted to the headland 1 km south of the Ceduna jetty. Iron could have been introduced into the porous ferruginous layer from groundwater. Although no pyrite was unequivocally identified in the mineralogical analyses undertaken from the ferruginous layer, some of the ferruginous materials closely resemble known pyritic materials observed elsewhere and may have provided an iron source.

Table 1 Suggested evolution of the Composite regolith section

| o | Weathering, kaolinisation, iron-rich motting of the crystalline rocks of the St Peter Suite of the Lincoln Complex, which has a probable age of 1,620 ± 4 Ma. |
| o | Erosion of the above weathered rocks, forming an unconformity with the overlying sediments. |
| o | Deposition of a finely-bedded siltstone above the weathered crystalline basement rocks, from which the siltstone may have derived as the two layers bear close mineralogical affinities. The siltstone layer was probably deposited in very quiet waters such as a lake. |
| o | Iron motting of the sedimentary siltstone layer. |
| o | Erosion of the siltstone layer producing another unconformity, possibly as ashore platform. |
| o | Accumulation of pebbles and boulders on the shore platform, including clasts of sandstone, ferricrete, ferruginous nodules and silcrete boulders. |
| o | Deposition of fine-grained aeolian sand on shore platform providing matrix material for the clasts. |
| o | Introduction of iron by iron-rich groundwaters or weathering of pyritic materials |
| o | Burial of the above sediments by fine calcareous aeolian sediments later transformed into calcrete. |
| o | Aeolian deposition of calcareous marl over the previously subaerially exposed calcrete layer. |
| o | Formation of a second calcrete layer by weathering transformation of the calcareous marl. |
| o | Alunite (Potassium, aluminium sulphate) introduced to the profile by groundwater, forming pods of alunite between the base of the lower calcrete and the upper part of the ferruginous layer into which the alunite extends. |

Age of section

Without additional dating data, the numerical ages of the weathered composite section are unknown. Weathering features on the Palaeoproterozoic St Peter Suite of rocks superficially resemble Late Tertiary weathering signatures described from other localities (Bourman 1993). The ferruginous horizon may be related to the late Tertiary Pantoulbie Formation (Barnett 1978; Parker et al. 1985), but the preferred interpretation of the section at Ceduna is that it is a localised occurrence rather than of regional significance. The dramatic change from a ferruginous to a calcareous environment suggests that the calcretes are equivalent in age to the Pleistocene.
Bridgewater Formation and may relate to the major climatic change towards increasing aridity suggested by Pillans and Bourman (2001). The occurrence of silcrete boulders in the ferruginous horizon clearly indicates that this horizon postdates silcrete development in the area.

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