CHALLENGER GOLD DEPOSIT AREA, SOUTH AUSTRALIA

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INTRODUCTION

The Challenger Gold Deposit area lies in the northern Gawler Craton, and is centred at 363500mE, 6693700mN (Figure 1) within the southwestern corner of the COOBER PEDY 1:250 000 (SH53-5) map sheet. The gold deposit and surrounding area exemplify regolith–landform relationships of the northern Gawler Craton.

The Challenger Gold Deposit is one of the few sites in the Gawler Craton that has been extensively studied with respect to regolith geology and geochemistry. The deposit has been extensively drilled with published Au reserves of ~500 000 oz. The following interpretation is largely derived from studies of the Challenger Gold Deposit (Lintern and Sheard, 1998; Craig *et al*., 1998) supplemented by observations and studies from adjacent areas.

PHYSICAL SETTING

Geology

The northern Gawler Craton has been affected by extensive and prolonged tectonism, but a significant proportion of the region retains Archaean to earliest Proterozoic radiometric ages (Daly *et al*., 1998). Archaean metasediments of the Mulgathing Complex (Daly, 1985) were derived at least in part from pre-existing continental basement, and include banded iron-formation (BIF), chert, carbonate, calc-silicate, quartzite and aluminous sediments (Figure 1). Komatiite and tholeiitic basalt flows are inferred to be contemporaneous with sedimentation. Together with other types of mafic rocks intersected in the subsurface (Robertson *et al*., 1992; Daly and Van der Stelt, 1992; Morris *et al*., 1994), these metamorphosed mafic and ultramafic rocks are inferred to represent regional attenuation of the Archaean crust and may indicate the presence of oceanic crust during sedimentation.

The Challenger area consists predominantly of the Christie Gneiss, which is a compositionally layered granulite facies metasediment. The most prominent and persistent type of outcrop in the region is BIF, which, in places, has been complexly folded and oxidised to haematite–goethite gneiss. The BIF has a typical composition of quartz–magnetite–diopside plus hypersthene, with accessory apatite and Fe sulphide. The gneiss also contains bands of pink microcline–quartz–plagioclase-garnet and layers of carbonate with accessory garnet, clinopyroxene and olivine (Daly and Fanning, 1993).

Geomorphology

The Challenger Deposit is located in an upland area within a region of very little overall relief (<50 m). On a regional scale, subdued upland areas form low hills or ridges that are separated by broad depositional plains hosting narrow, shallow ephemeral drainage systems in their lowermost parts (Figure 2). The uplands are mostly composed of weathered Archaean rocks obscured by a cover of colluvial and aeolian sediments. To the southwest of the Challenger area, two large (>100 m high) Eocene dune systems form near parallel ridges several hundred kilometres in length (Ooldea and Barton Ranges).

Beneath the depositional plains lie numerous small palaeochannels that have been largely in-filled by Cenozoic and possibly Mesozoic and Palaeozoic sediments (Figure 2). These form regional palaeochannel systems, which are partly filled with older sediments (e.g. Permian), and that eventually drain to the Eucla Basin located to the SW. On a local scale, the depositional plains

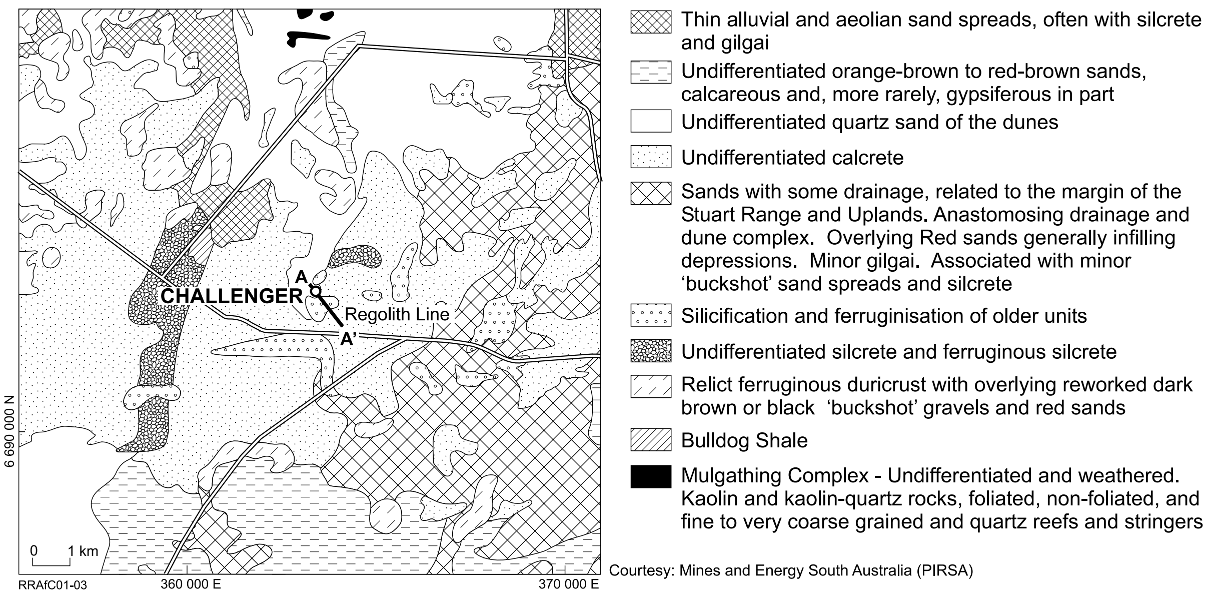

Figure 1. Geology of the Challenger area. Transect A–A' shown in Figure 2.

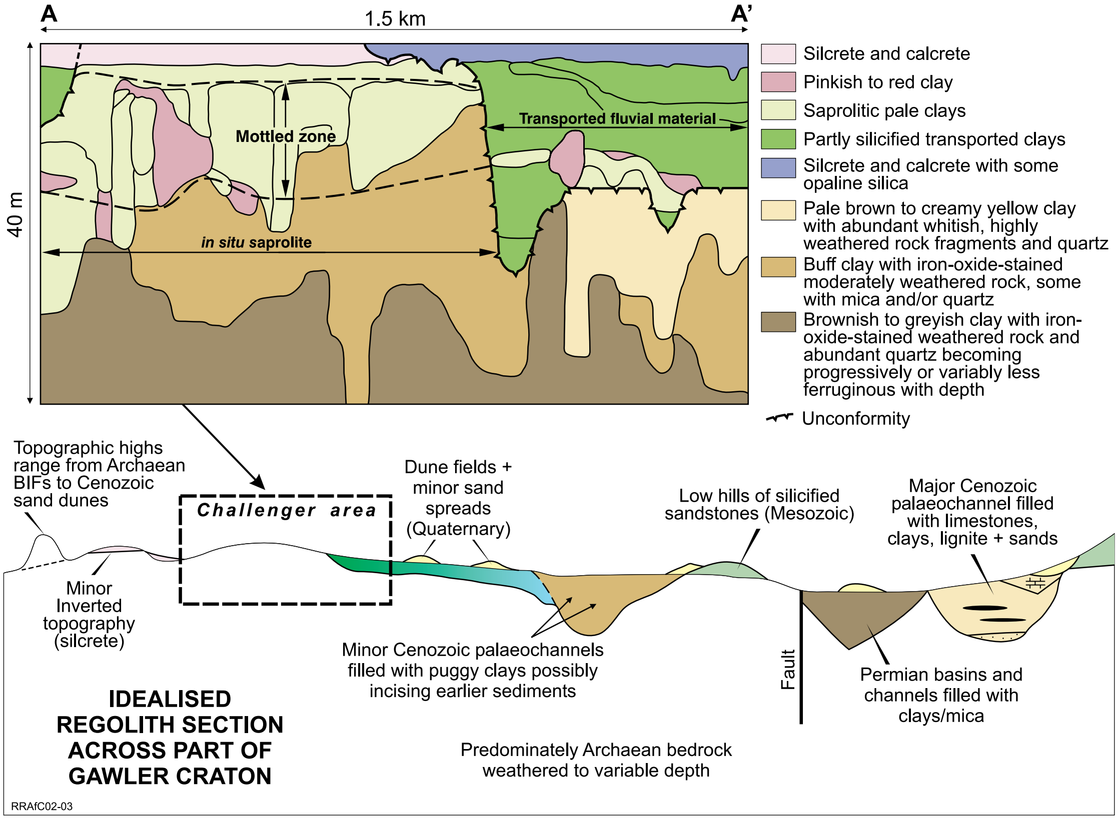

Figure 2. Idealised section through northern Gawler Craton (not to scale). Location of transect shown in Figure 1. (After Lintern and Sheard, 1998; Benbow and Pitt, 1978)

are dominated by sand spreads (Figure 1) with clay and salt pans occurring in the lower areas. The uplands are dominated by low sand spreads with sand dunes of moderate relief (up to 5 m). Outcrops of bouldery "grey billy" or massive silcrete punctuate the monotonous landscape (Figure 1) and are particularly common on the edges of the upland areas where they locally form breakaways.

Climate and vegetation

The Challenger area is semi-arid where average annual maximum and minimum temperatures vary from ~27 to 12 C. Annual rainfall (falling mainly in the winter) is 100–200 mm.

The vegetation consists of chenopod-dominated shrublands, with open woodland groves of *Acacia* (mostly *aneura*) restricted to the sandy areas. The shrubland is represented by members of the Chenopodiaceae (*Maireana sedifolia*, *Sclerolaena divaricata*, *Salsola kali*, ?*Enchylaena tomentosa*), Myoporaceae (*Eremophila* spp. including *latrobei*, *glabra* and ?*serrulata*), Amaranthaceae (*Ptilotus obovatus*), Caesalpiniaceae (*Senna* spp. including *cardiosperma* ssp *gawlerensis*, *artemisioides* and *helmsii*), Mimosaceae (*Acacia tetragonophylla*), Sapindaceae (*Dodonaea microzyga*), Loranthaceae (*Lysiana murrayi*) and Poaceae (*Aristida contorta*). In the extensive sand dunes to the south west, taller vegetation of *Casuarina*, *Callitris* and *Eucalyptus* is found.

REGOLITH–LANDFORM RELATIONSHIPS

The Challenger area and surrounding region are almost entirely covered by aeolian, fluvial and colluvial sediments (Figure 1). This extensive sedimentary cover coupled with minimal regolith exposure (either natural or man made) and drilling information, makes the task of determining regolith–landform relationships difficult. The problem has been tackled at two levels: firstly a detailed study of the southwest quadrant of the JUMBUCK 1:100 000 (5638) map sheet containing the Challenger Deposit, and secondly in a largely interpretive regolith–landform study of the Half Moon Lake area (Wilford *et al*., 1998) located to the southwest of Challenger.

The regolith–landform unit proportions for the Half Moon Lake and Jumbuck areas are shown in Table 1. Colluvial sediments account for between 50–60% of the total area. Craig *et al.* (1998) report that the colluvial sediments occur on erosional plains, pediments, depositional plains and minor footslopes, and consist of unconsolidated polymictic gravel with varying proportions of sand and clay. Aeolian sediments (31% of the area) form dunefields and modified sandplains, particularly in the southwest corner of the Half Moon Lake area, where numerous east–west trending longitudinal dunes are to have been supplied by sand from the Eocene Ooldea and Barton Ranges. The dunes probably drape over basement highs since windows through the cover occur in the swales. The aeolian sediments consist of fine-grained reddish quartz sand with variable amounts of clay.

Nearly 20% of the Jumbuck map sheet is covered by the "lags" regolith–landform unit. The lag, with clasts of up to 10 cm in diameter, is locally abundant (particularly where basement is close to the surface) and forms a conspicuous gibber surface. Finer lag appears to be locally re-worked by fluvial action into broad sheetwash deposits. The lag is polymictic, consisting of silcrete, quartz, calcrete, ferruginous material, well-rounded exotic clasts and occasionally weathered rock (saprolite). Other units such as alluvial and lacustrine sediments are only minor components of the regolith–landform composition (Table 1).

Table 1. Regolith landform units by percentage in the two study areas. (from Craig *et al*., 1998)

Regolith-landform unit	Half Moon Lake	Jumbuck
Colluvial sediments	50%	59%
Aeolian sediments	31%	12%
Lags	13%	19%
Alluvial sediments	2%	3%
Lacustrine sediments	2%	1%
Saprolite	2%	6%

REGOLITH CHARACTERISATION

Weathering profiles

The regolith was studied in detail along a traverse across the Challenger Deposit (Figure 1, 2). Two major regolith units were encountered: an *in situ* unit consisting of weathered Archaean Christie Gneiss; and a transported unit consisting of fluvial deposits of Tertiary or earlier age.

In situ regolith unit

The *in situ* regolith unit typically consists of a calcareous and siliceous hardpan (0–3 m thick), in part underlain by mottled clays, which in turn overlie variably coloured clays (mainly yellows and reds) and partly ferruginous weathered rocks, often with abundant quartz, which grade to less ferruginous weathered rock with abundant quartz at depth (Figure 2). Micas are common throughout and associated with both the highly weathered and moderately weathered bedrock. The boundary between highly weathered bedrock (mostly clay) and moderately weathered bedrock (containing appreciable quantities of partly weathered rock) is variable but generally lies at 20–40 m depth.

In the upper regolith (0–6 m), deep weathering of the crystalline basement in the Challenger region has yielded a generally pale coloured clay-rich saprolite composed predominantly of kaolinite and smectite, with residual quartz fragments and clasts. The saprolite has been stained by Fe and Mn oxides and variably cemented by silica, carbonate and rarely gypsum. Concretions of ferruginous material, such as pisoliths, are rare. Within the top 6 m there is saprolitic material of relict weathered crystalline basement gneiss. Resistant minerals, such as quartz, zircon, ilmenite, graphite, tourmaline, rare garnet and some biotite, occur in the saprolite fragments. Drill core from the surface to fresh bedrock reveals that the garnets (possibly almandine) present in the gneiss become weathered to brown ferruginous mottle-like brownish features.

Mineralogical studies of selected samples from the saprolite above mineralization indicate the presence of quartz, kaolinite and sericite, with accessory graphite, rutile, ilmenite and smectite. The rutile and sericite are alteration products, as are the clay minerals. Some of the clay-rich saprolite displays features consistent with surficial mechanical break-up and dislodgment, to form locally derived scree-talus breccias. The breccias contain resistate mineral grains that exhibit a low to moderate degree of mechanical rounding. Some of these rounded resistate minerals have been incorporated, via surficial shrinkage cracks, deeper into the *in situ* regolith profile.

Transported regolith unit

The transported regolith occurs principally in the southeastern part of the section (Figure 1) and consists, from the surface to ~3 m depth, of calcrete, silcrete and/or hardpan; and from ~3 to ~16 m depth, of white and pink variably silicified clays and silt (Figure 2). Underlying some of the lower portions of the silicified unit are brightly-coloured yellow and red clays of up to 3 m in thickness. Incising the weathered basement at the base of the transported unit are small channels, one extending to ~25 m depth and the other to ~21 m depth (Figure 2). The western (deeper) channel is filled with partly silicified white clay becoming silcrete with depth. This silcrete differs from that found near or on the land surface because it contains few quartz clasts. The location of the silcrete at the base of the channel suggests it to be of groundwater origin. The eastern (shallower) channel is largely filled with clay.

Sediments within the upper part of the transported unit (0–6 m) consist of interdigitating lenses of gravel, sand, silt and clay. The coarser-grained clasts are characteristically subrounded to well rounded, in contrast to the quartz fragments present within saprolitic material, which are angular. Sedimentary structures including, planar bedding and cross-bedding, are preserved in "grey billy" silcrete outcrop. Similar features are preserved in sub-surface silcrete blocks and corestones. Grains within the silcrete are dominantly quartz. The quartz grains are dominantly well-rounded to subangular and clear-white-milky to greyish-blue coloured, mostly similar to the quartz varieties occurring in the weathered basement. Rare silicified wood (occasionally opalised) consisting of branch and twig fragments, occurs within this palaeochannel sand sequence. Several cycles of chemical over-printing of this fluvial sequence has occurred with the introduction of silica to form silcrete, porcelanite and opaline forms (potch and hyaline). Carbonate, minor gypsum, and minor Fe and Mn oxides/oxyhydroxides have also been introduced.

Soils

Soils in the vicinity of the regolith line are predominantly of late Quaternary age. Younger sandy-textured soils, occurring mostly with sand spreads, dominate the area and have only a small to moderate horizontal texture contrast and minimal pedogenic differentiation. Older and more pedogenically-organised soils are developed on or near weathering substrates or clay pans. Many soils away from the sand spreads and dunes are gibber-clad primitive lithic-rich lithosols that are related to erosional areas or alluvial deposits. Clay-rich soils are of limited extent along the traverse and they tend to be restricted to drainage sinks (clay pans). Most of the clayey soils of this region are classified as having an alkaline reaction trend and are strongly sodic to sodic with sandy to loamy surface textures (Northcote and Skene, 1972).

REGOLITH EVOLUTION

The present relatively flat topography underlain by Quaternary formations that covers much of the northern Gawler Craton obscures a more undulating and complex palaeorelief dating back to the early Tertiary or Mesozoic and earlier. Evidence to date indicates that following Archaean to Proterozoic deformation and intrusion, this area was exhumed by erosion during the Neoproterozoic to late Palaeozoic. Permian glaciation stripped away any pre-existing weathering profiles (Drexel *et al*., 1993, Drexel and Preiss, 1995). Thus, all regolith preserved in the area will post date that glaciation.

A widely distributed weathering event that probably equates to the deeply-weathered basement profile at Challenger is the Bopeechee Regolith, a palaeo-landsurface of deep (kaolinitic) weathering, defined and mapped by Krieg *et al*. (1991). The Bopeechee Regolith weathering event, yielding the Mount Margaret Surface, has been shown by Rogers and Freeman (1996) to have affected the latest Permian sediments in the Peake and Denison Ranges within the WARRINA 1:250 000 map sheet area. Stratigraphic relationships from the edge of the Eromanga Basin at the northern end of the Flinders Ranges indicate that this deep weathering continued into the latest Jurassic and even possibly into the earliest Cretaceous (Sheard *et al.*, 1996; Preiss *et al*., in prep.). Therefore a significant period of landscape stability occurred throughout much of continental Australia during the Mesozoic; deep chemical weathering predominated, yielding leached kaolinitic profiles to depths of >50 m. Thick sedimentary units, such as the kaolin-rich Jurassic Algebuckina Sandstone, are principally derived from this regionally weathered landscape. The Jurassic was largely a cool arid time when Australia and Antarctica were near latitudes 75-50^{o}S (White, 1993, 1994; Krieg, 1995) and terrigenous sediments were dominated by aeolian and to a lesser extent fluvial processes. Cretaceous times were cool, wetter and dominated by fluvial–paludal sedimentation (Sheard, 1990; Frakes and Francis, 1988), culminating with a series of marine transgressions and deposition of the Early Cretaceous Cadna-Owie Formation followed by the Bulldog Shale. The Bulldog Shale has been mapped in outcrop 3.5 km west of the Challenger Deposit (Figure 1).

Early Tertiary times were warm and initially wet, with terrigenous fluvial deposits dominating and palaeochannels being established across large parts the continent including South Australia (Alley and Lindsay, 1995; White, 1994). Australia was at that time separating or had separated from Antarctica and was moving north to latitudes ~60–40^{o}S. A characteristic of the fluvial deposits is quartz-rich gravels and sands with minimal silt and clay fines. These deposits range in age from Palaeocene to Pliocene. Rowett (1997) identified a silicified tree branch collected from an outcrop of silicified palaeochannel sands on the Challenger regolith line, as being from a conifer (Podocarpaceae), with a possible affinity to the genus *Phyllocladus*. A time range for this genus along with other palynological evidence in the region suggests a latest Eocene to Late Miocene age for deposition of the palaeochannel sands.

Two major silicification events are recognised in South Australia. The older Cordillo Silcrete has affected Eocene and older sediments, while the younger silcrete has affected Miocene to Pliocene and older sediments. At Challenger, there is evidence that the first (Cordillo) silcrete has been disrupted by mechanical (colluvial) surface processes and some minor fluvial activity. The second (Miocene to Pliocene) silicification event then re-cemented the scree-talus and colluvium of first generation silcrete into complex breccias. Another consequence of this event may have been to promote further weathering and leaching of the regolith and deepen the silicification front of the Cordillo Silcrete. Restricted erosion with limited colluvial to alluvial deposition followed Tertiary silicification, and this has continued sporadically through to today. Deposits relating to this activity form stony alluvial plains that consist of thin surficial to near-surface pebbly clays and pebbly sandy clays. During the mid- to late Quaternary, orange siliceous sand was blown eastwards from the Eucla Basin to form a large dune field containing a myriad of approximately east-west oriented linear dunes (Great Victoria Desert). Some of these cross the Challenger area where they form thin sand spreads.

The introduction of carbonate, leading to the development of calcretes, appears to be a late feature in the Gawler Craton, although there is some carbonate cementation of palaeochannel materials and silicified equivalents below the main Quaternary calcrete front at the eastern end of the regolith line. The calcrete forms a near continuous blanket over much of the Gawler Craton. An older translucent crystalline carbonate has been recognised nearby (50 km east) at the Birthday Prospect (Lintern and Sheard, 1997) and probably formed during the late Tertiary or early Quaternary. Stratigraphic evidence from elsewhere in South Australia suggests that the latest introduction of carbonate has occurred in cycles relating to a series of glacial maxima (low sea levels) during the late Quaternary (Crocker, 1946; Belperio, 1995; Sheard, 1995). These carbonates originated as continental shelf sourced air-borne dusts, later transformed by meteoric water and pedogenesis into a variety of widespread calcrete forms (Sheard and Lintern, 1998). Most still retain marine isotopic signatures with terrestrial biogenic isotopic overprints (Chivas *et al.*, 1991). Calcrete development within the dune sands is less widespread than in the substrate on which they sit. This could be ascribed to porosity-texture contrasts, to the late Quaternary carbonate flux being swamped by aeolian sand, or to cyclic carbonate flux variations where the last cycle was relatively weak. Alternatively, it may be because the dunes are relatively young.

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