IOCGs – Where it all began
The Moonta-Wallaroo region of the eastern Gawler Craton

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Acknowledgements

It would not be possible in brief to list contributions to the understanding of the geology of Yorke Peninsula since completion of the guidebook of Zang, Raymond and Conor (2002) for the 16th AGC. Needless to say geological investigations, mainly by mineral exploration companies, but also by universities and government agencies have continued to add new information. However it is appropriate that the contribution of the talented late Dr Wen-Long Zang be recognised, and it is fitting that the Maitland Special, 1:250 000 Geological Map Series and Explanatory Notes places his name in the history of Yorke Peninsula.

Of course the greatest spur to new knowledge came with the discovery of the Hillside copper-gold-magnetite deposit by Rex Minerals in 2009, and it is hoped, firstly that the technical data will soon become publically available, secondly that the project will have a successful outcome in the near future.

Thanks are also due to the staff of the Department of State Development for bringing this field guidebook to its present operational state.

Cover

South looking view along Wallaroo North Beach of Pudding Rock, a feature well known locally. Pudding rock is a body of skarn-like calcsilicate (mined nearby as the colourful Harlequin Stone), which is contained within an extensive argillic alteration zone, manifestations of which are visible as white kaolinite bodies amongst the seaweed. The kaolinite offered easy digging, and thus was a benefit for the development of the Wallaroo Marina sited in the vicinity of the former Wallaroo smelter where ore from both the Moonta and Wallaroo Mines was processed. A century ago this scene would have included more than a dozen chimneys pumping-out noxious material, now as a reminder only one remains (see back cover). Also visible on the back cover is a strip of dark rock about 100 m further along Wallaroo North Beach than Pudding Rock. This is an outcrop of geologically critical importance because it places IOCG-related alteration in the structural context, of the two obvious fold events, the earlier pre-dates and the later post-dates metasomatic alteration.

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Geological Field Excursion Guide

IOCGs – Where it all began
The Moonta-Wallaroo region of the eastern Gawler Craton

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Contents

Introduction

Northern Yorke Peninsula (NYP) is within the southern portion of the Olympic Domain of the eastern Gawler Craton, which is arguably the world's most fertile IOCG belt (Fig. 1). That such a belt existed was only realised, when Western Mining Corporation (WMC) stepped northward in 1975 after many years of exploration with North Broken Hill Ltd in the the Moonta-Wallaroo Cu-Au Mining Field area. WMC's discovery was the Olympic Dam deposit, thus the NYP represents a major step on the path to the recognition of the IOCG-U system, and definition of the Olympic Domain.

A number of conditions need to be met in order that an IOCG prone environment can exist. These include a suitable brine-prone host succession, a major thermal event including significant magmatism, and deeply penetrating fractures as channel-ways and sites for ore deposition (e.g. Hunt et al. 2007; Skirrow et al. 2007; Groves et al. 2010). These conditions are met in the Olympic Domain, and therefore also in NYP.

The intention of this field trip, brief as it is, is to provide an understanding of the Palaeoproterozoic and Mesoproterozoic geology of the part of the Olympic Domain that includes the historic Moonta-Wallaroo mining area and the coastal exposure of Rex Minerals Hillside Cu-Au Project (Fig. 2). Portions of this field guidebook are reproduced from the 2012 GSA guidebook 'Metasomatism, Metamorphism and Mineralisation (IOCG), Northern Yorke Peninsula' (Conor and Forbes, 2012).

Donington Suite and Corny Point Paragneiss

The granites of the ~1850 Ma Donington Suite, which intrude the Corny Point Paragneiss are considered to provide the extensive basement upon which the sediments of ~1750 Ma Wallaroo Group were deposited. The Donington Suite, forming the foot of Yorke Peninsula, was deformed by the ~1850 Ma Cornian Orogeny (Reid et al. 2008).

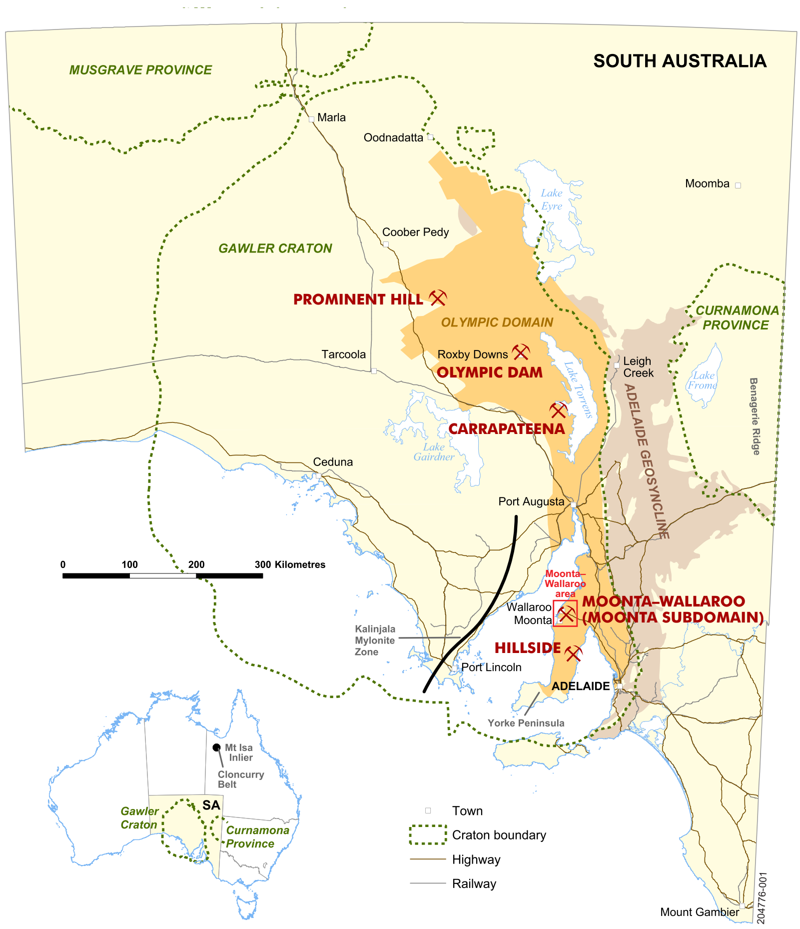


Figure 1 *Map of South Australia showing the footprint of the Olympic IOCG Domain with which the Wallaroo Group partly corresponds. Also shown are the locations of major Cu-Au deposits.*

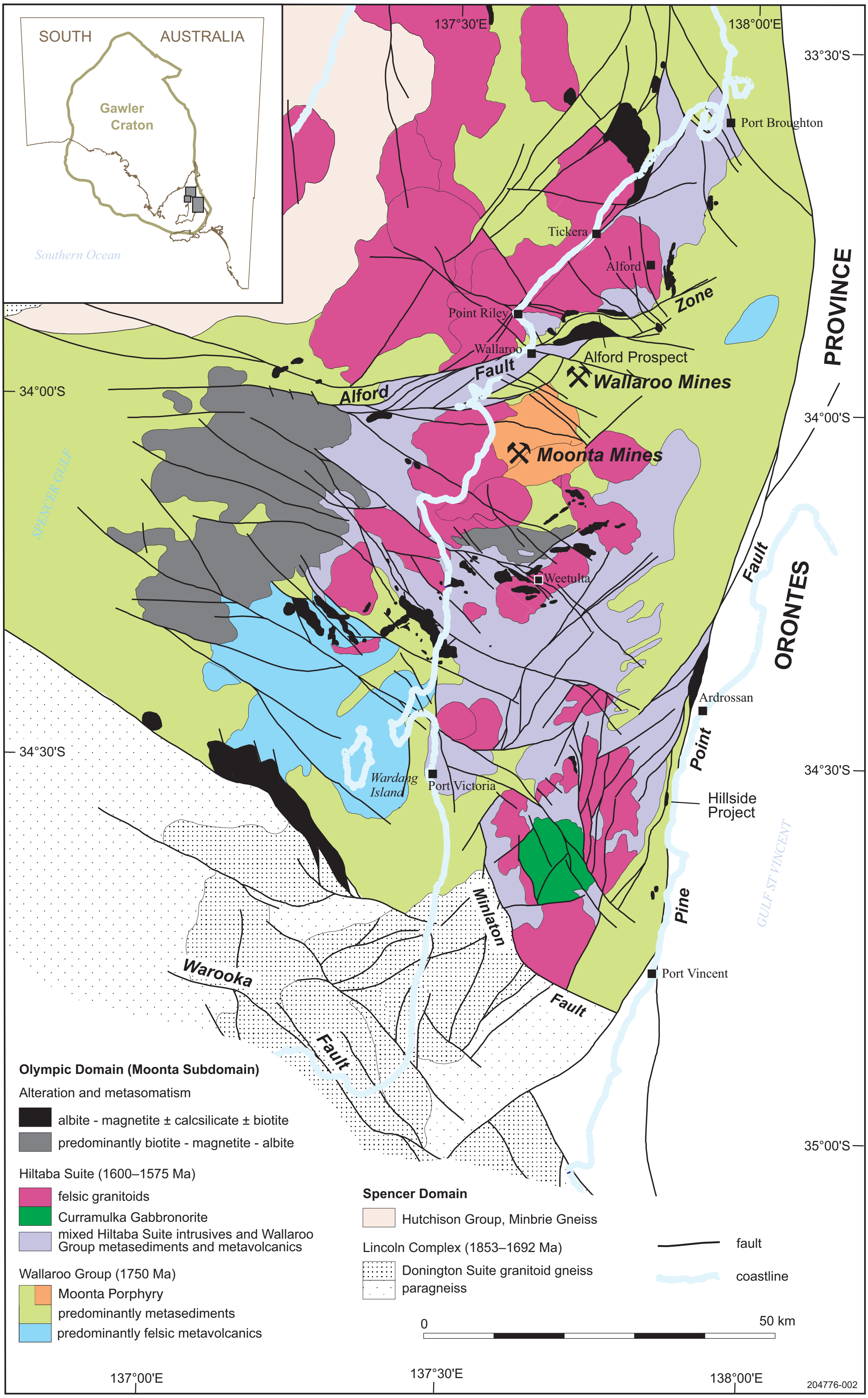


Figure 2 Geology of the northern Yorke Peninsula showing the location of the Hillside Project (from Raymond in Conor et al. 2010).

Wallaroo Group

The ~1750 Ma volcano-sedimentary Wallaroo Group is the host succession to most of the alteration and mineralisation on NYP, it was intruded by mafic and felsic magmatic rocks of the Hiltaba Suite.

The current stratigraphic system for the Wallaroo Group is available from Cowley, Conor and Zang (2003) (Fig. 3). This group is known to extend to Punt Hill and possibly to as far north as Prominent Hill (Freeman and Tomkinson, 2010) (Fig. 1). The Wallaroo Group includes a variable succession of dominantly fine-grained clastic and chemical sediments, including laminated alkali feldspar rocks ('albitite') and 'iron formations'. These are collectively referred to as the Wandearah Formation (Cowley et al. 2003). The sourcing and timing of alkali and iron deposition is open to conjecture, however with the abundance of scapolite it is likely that conditions of deposition were at least partly evaporitic. Metamorphism, locally to amphibolite facies, and intense metasomatism has caused confusion as to the genesis of some mineral phases, including iron oxides and sulphides included.

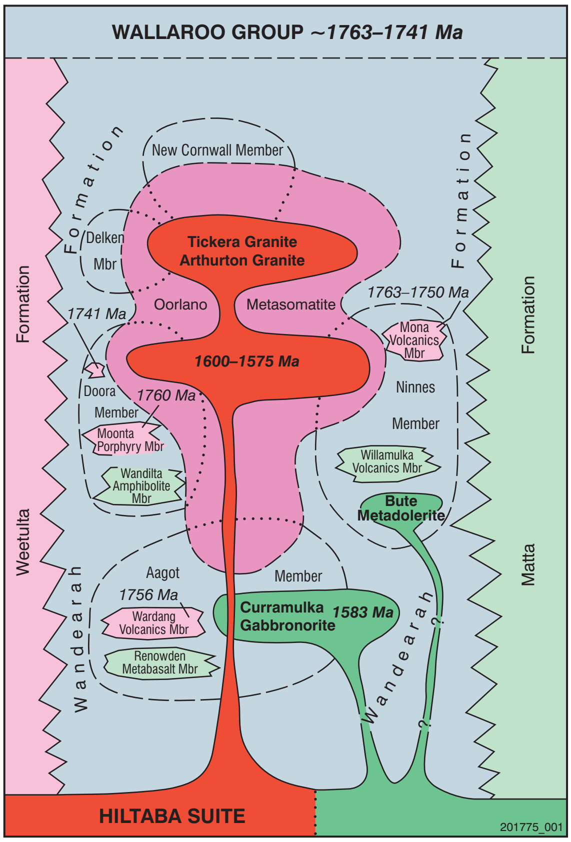


Figure 3 Rock relationship diagram for Paleo- and Mesoproterozoic units of the Yorke Peninsula including the Wallaroo Group and intrusive magmatic rocks of the Hiltaba Suite. Modified from Cowley et al. (2003).

Also included within the Wallaroo Group are felsic volcanics (Weetulta Formation) and mafic volcanics and intrusions (Matta Formation). U-Pb dating of the Weetulta Formation has provided the age range ~1770-~1740 Ma for the Wallaroo Group. The felsic volcanics have a rhyodacitic composition and A-type affinity, suggesting extrusion into rifting environment and thus crustal attenuation. Field evidence indicates that the felsic rocks were erupted in the vicinity of a shallow seafloor with cryptodomes and tuffs being interpreted. There is some evidence for syngenetic copper mineralisation. The mafic rocks of the Matta Formation are more equivocal in their field relationships, dominantly units appear to be intrusive, however there are occasional extrusive examples.

To the east, across the Adelaide Geosyncline rift complex, the Willyama Supergroup of the Curnamona Province bears similarity to the Wallaroo Group, the main difference being a younger age of deposition, i.e. ~1720-~1640 Ma (Conor 1995, Conor and Preiss 2008. The inference is that extension and rift basin formation developed eastward from the Gawler Craton to the Curnamona Province, and perhaps beyond.

Hiltaba Suite

The occurrence of a major thermal event during the interval ~1600-~1575 Ma (e.g. Cooper et al. 1985; Fanning et al. 1988; Fanning in Conor 1995) was responsible for melting of the lower crust and the generation of the felsic magma from which Hiltaba Suite granites and Gawler Ranges Volcanics were derived. Like the earlier Weetulta Formation the Hiltaba Suite is also A-type in nature, and also includes an associated mafic component of magmatism. Stocks of Hiltaba Suite are common throughout NYP. Granite compositions are not homogeneous, but show considerable variation. Regional gravity imagery shows that the largest body of granite extends from Moonta Bay to the Tickera Granite 'complex' north of Wallaroo. There is good evidence of uplift during the period that the Hiltaba Suite intruded, as evidenced by some granites having a metamorphic foliation, and others being non-foliated, cross-cutting and containing miarolitic cavities.

Olarian Orogeny

Intrusion of the Hiltaba Suite into the NYP region broadly coincided with the ca. 1.60-1.58 Ga Olarian Orogeny (Page et al. 2000) and emplacement of the Ninnerie Supersuite and Benagerie Volcanics (Wade, 2012) in the Curnamona Province. Timing is confirmed by geochronological investigations on NYP (Conor1995; Conor et al. 2010), and in the Fleurieu Peninsula further south (Szpunar et al. 2008). It would appear from drill information and aeromagnetic imagery that the Wallaroo Group is deformed into a set of long limbed, upright, tight to isoclinal folds. Such a style of deformation is consistent with observed metamorphic textures which show a distinctive steeply plunging mineral lineation, within a possible axial planar foliation. These structural elements are observed in the Wallaroo Group. Some bodies of the Hiltaba Suite, i.e. the Tickera Granite are locally intensely foliated (Jack, 1917), thus matching at least some of the deformation to the timing of the Olarian Orogeny.

Exposed at Wallaroo North Beach are 'flat-lying' isoclines that are overprinted by more brittle upright folds, which coincide with a period of metasomatism (Wurst, 1994; Arcaro, 2000; Conor, 2002). This is similar to the scenario recorded in the Willyama Supergroup of the Olary region (Curnamona Province). Current evidence suggests that NYP underwent at least two phases of folding during the Olarian Orogeny, however it is unclear as to whether any of the deformation in the NYP is related to the earlier ca. 1.73-1.69 Ga Kimban Orogeny (e.g. Hoek and Schaefer, 1998). It is possible that either affects of the Kimban Orogeny have not been proven due to limited exposure and geochronological data, or that the NYP was separated from the main mass of the Gawler Craton by the Kalinjala Shear Zone and therefore escaped Kimban deformation. The temporal discrimination of deformational stages in the NYP is currently unresolved, thus the tectonic event to which the earliest folding can be attributed is still open to conjecture.

Late during the Olarian Orogeny, or shortly after, the Curnamona Province was subjected to a period when deformation is registered by the formation of a network of sheared zones (e.g. 'retrograde shears' of Broken Hill). Such a stage is also registered in NYP, although elsewhere in the Gawler Craton a number of shear-related events dating from 1650 Ma to 1540 Ma are collectively grouped as the Kararan Orogeny (as with the Kimban Orogeny, whether the effects of the Kararan Orogeny extended to the east across the Kalinjala Shear Zone is at present open to speculation). In NYP at least some shearing was imposed synchronously with intrusion of the Hiltaba Suite (i.e. ~1600 Ma to 1575 Ma), mylonitic and schist zones resulted, but also with brecciation perhaps developed in fault jogs (Conor 1995, Conor et al. 2010). The east coast of the Peninsula owes its N-S shape to the Pine Point Fault zone, which hosts the Hillside skarn-related mineralisation. It would appear that there, and further south near Port Vincent, Mesoproterozoic magmatism and structuring were in part at least coincident.

The lineation in some mylonitic zones (e.g. the Moonta Porphyry at Wheal Hughes, and in the Wallaroo Mines area) appears similar to the regional metamorphic fabric mentioned above, and much of the western coast of NYP is controlled by the regional NE-striking foliation or large parallel structures. Dickinson (1942) indicated that the Moonta lodes were controlled by northwest dipping thrust faults, with uplift directed from the northwest. The steeply plunging, regional metamorphic lineation is supportive of such displacement, although it is possible that more than one generation of movement was involved. Evidence from the Poona Mine and Wheal Hughes indicates that the mylonitic deformation was a precursor for a more brittle style of vein networking, hence supporting the notion of uplift during this part of the Olarian orogeny.

Metasomatism

Coincident with intrusion of the Hiltaba Suite, metamorphism and deformation, the rocks of the Wallaroo Group underwent intensive metasomatism. This is particularly obvious in the aureoles to some of the granite bodies, and along some sheared zones. There was also significant pervasive alteration that either totally replaced the precursor or infiltrated via selected strata. At the outcrop and hand-specimen scale, alteration is seen to be controlled by penetrating structures such as foliations and the axial planes of folds. In some cases alteration assemblages are present along susceptible beds bordering cross-cutting structures, and in others the alteration assemblages form the supporting matrices of breccia bodies. Plainly fluids permeated the rock mass by any discontinuity, and in cases there is evidence of the filling of an original porosity. Some granitic bodies commonly show incipient alteration, and less commonly endoskarn-type replacement and alteration-associated brecciation have been observed.

The list of minerals formed by alteration is long, but includes: alkali feldspars, scapolite, amphiboles, epidote, carbonate, biotite, chlorite, magnetite and haematite. These comprise a variety of alteration assemblages, some of which co-exist with mineralisation (Zang et al. 2002). Raymond in Conor et al. (2010) names three critical alteration assemblages which are: calcsilicate-albite-magnetite, biotite-magnetite-albite, and chlorite-quartz-hematite-K feldspar-pyrite ± chalcopyrite, and maintained that copper mineralisation related strongly to the latter. Alteration, especially where the precursor has been obliterated has been given the quasi-stratigraphic name 'Oorlano Metasomatite' (Fig. 3) (Conor, 1995; Cowley et al. 2003). Unlike the northern part of the Olympic Domain, where iron oxide commonly dominates, alteration in the Moonta region relates more to calcsilicate. 'Skarn' is the word that is commonly used, although 'sodic-calcic alteration' (P. Williams pers comm. 2012) is possibly more appropriate. This is because at least some of the metasomatic calcsilicates of NYP are not true skarns in the sense of replacement of carbonate precursors, but instead the calcsilicate elements have been introduced to replace precursor lithologies, including psammopelites.

Mineralisation

Hunt, Baker and Thorkelson (2007) suggest that the variations shown by the environments of IOCG mineralisation represent a spectrum of deposits, with true magmatic versions at one end and sediment related ones at the other. Most deposits appear to be hybrids (including Olympic Dam). The main overriding controls are thermal energy, tectonism creating penetrative structures, and a fertile crust. With this in mind the associated sedimentary package is as important as the magmatic suite, thus in the case of IOCG mineralisation of NYP (and perhaps the whole eastern Gawler Craton) the Wallaroo Group (and similar sedimentary packages) and the Hiltaba Suite are paired.

To date all economic mineralisation in NYP is known to have been structurally controlled. This applies, not only to the Moonta Mines (Jack 1917) and Wallaroo Mines (Dickinson 1942), but also to the historic Poona Mine, Wheal Hughes and the Hillside Prospect (Conor e al. 2010). Although the economic metals are copper and gold, some deposits are polymetallic containing such minerals as molybdenite, galena and sphalerite. Rare earth elements are commonly elevated, especially cerium. Uranium is locally distinctly anomalous.

Although no longer confirmable, the Wallaroo lodes appear to have been formed at some depth in shear zones associated with biotite and magnetite alteration and quartz-rich pegmatite veining. Pegmatites are report in some of the Moonta workings to be associated with mineralisation, but the mineralisation at Poona Mine and Wheal Hughes appears to have taken place nearer the surface along structures previously prepared by mylonitisation. The mineralisation at the Hillside Prospect is associated with garnet-bearing 'skarn-type' alteration overprinting the Wallaroo Group, granite and mafic rocks. It is important to note that the evidence in NYP for rapid change in crustal levels from the amphibolite facies environment to near surface gives a wide range of physical and chemical conditions for the deposition of economic minerals.

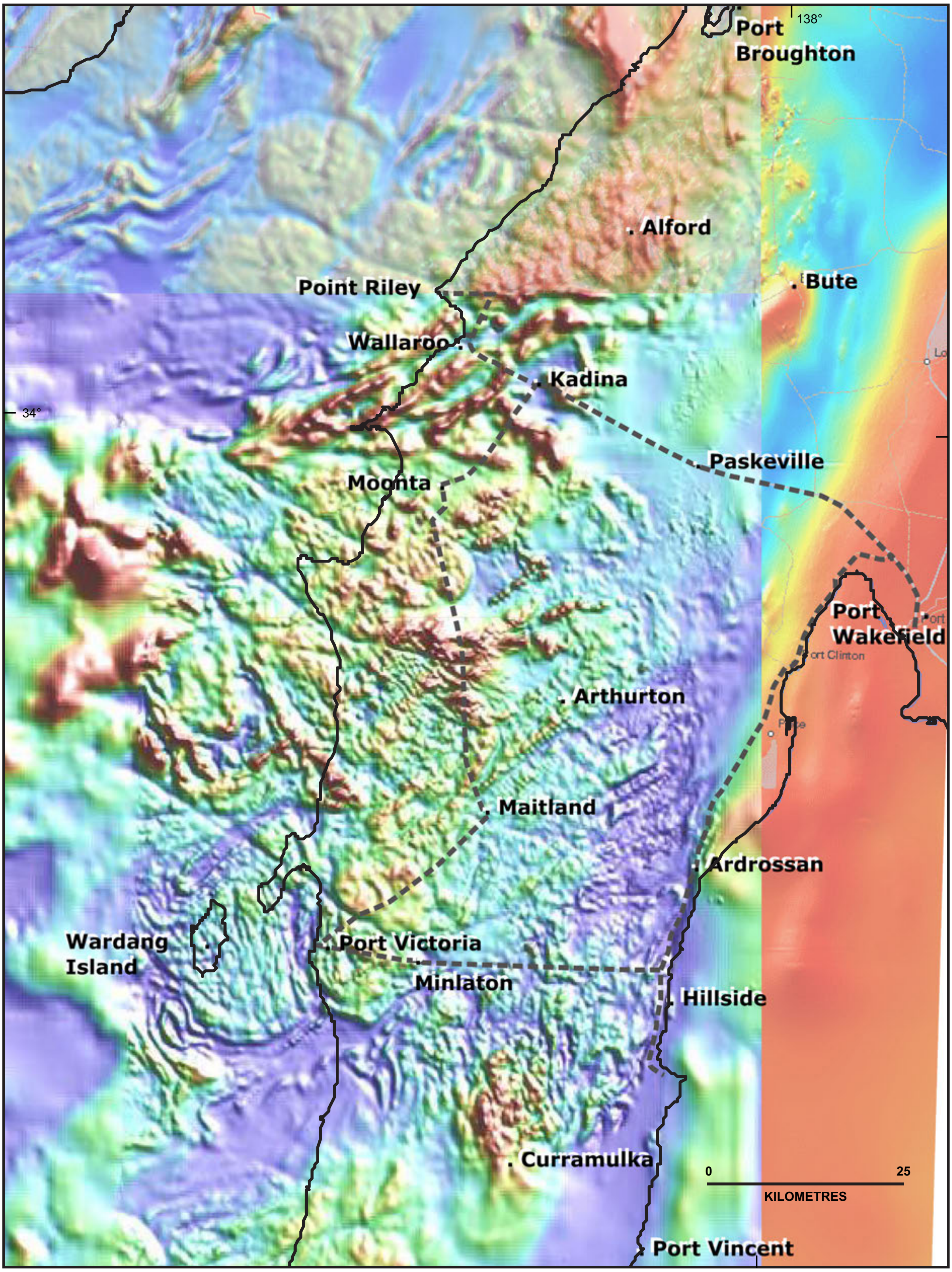


Figure 4 Routes and sites of the AESC 2016 field excursion (aeromagnetic image from MIM Exploration Ltd).

Hillside coastal section, Site H

The coastal strip east of the Hillside Project lodes is magnificent in that it provides near 100% 3D exposure of a structurally-related IOCG alteration system. This is probably the best natural exposure showing IOCG-related alteration and mineralisation in the whole of the eastern Gawler Craton. The other two, the Wallaroo to Tickera coast, and the Cultana coastline show interesting structuring and a variety of Hiltaba Suite granites. Only two years after the Whenan Shaft entered mineralized basement at Olympic Dam, two parts of the coast near the historic Hillside Mine were described in useful detail and incorporated into the Geological Heritage system of the GSA (SA Branch) (Geological Monuments YK 5 and YK 6, C. Giles 1982), the location map of these is appended.

The Cu-Au-magnetite Hillside deposit of Rex Minerals is essentially an extension of the mineralisation exposed in the original Hillside Mine workings. It is interesting to note in retrospect that, even after the discovery of Olympic Dam, indications of mineralisation had been established by the investigations of several exploration companies (e.g. CRAE, WMC, MIM), but these had not been followed up. Certainly one reason for lack of interest was that regional aeromagnetic imagery and processing power were not of the standard that they are now.

The coast itself is largely controlled by the Pine Point Fault, a significant long-lived N-S sheared zone. This structure is part of a system that has been sporadically active from at least the Mesoproterozoic (Hillside mineralisation), and it s possible that the granite that is exposed at the coast, the eastern Granite of Rex Minerals, was intruded after initiation of faulting. Evidence for later movement is provided by observations derived from the Neoproterozoic (Adelaidean rifting, Preiss, 1987) and the mid-Cambrian, the latter being highlighted by onlapping sandstones and channel-fill, locally polymict channel conglomerates of the Yuruga Formation in which angular granite clasts indicate derivation from a proximal basement source (i.e. Hiltaba Suite granite along the fault scarp).

The Pine Point Fault is in reality a very wide structural system with the western limit defined by the drilling of Rex Minerals approximately one kilometre distant from the coast, the linear shape of which suggests the possibility that the eastern limit may be buried below Cambrian and Neoproterozoic sediments under the waters of Gulf St Vincent. It is only the coastal cliffs and beach platform that provide exposure. The cliff section shows occasional structures parallel to the main trend as well as numerous steep and low angle faults and sheared zones striking at high angles to the overall N-S trend, with northerly dips appearing dominant.

Offshore, but paralleling the eastern coast of Yorke Peninsula is a major extensive magnetic-gravity feature which has been named the Orontes Province (Gerdes, in Conor, 1992). It is possible that the deeply buried source of the feature is a large linear mafic (?ultramafic) body, and it is temping to consider that it had influence upon mineralisation along the fault system (i.e. Rex Minerals' Pine Point Copper Belt). Certainly there is evidence of mafic input as such rocks are visible along the Hillside coast and were liberally encountered in the drilling of the Hillside Cu-Au deposit.

Low cliffs and beach exposures show a major fault breccia zone with brecciated pink pegmatitic granite being the dominant rock. The granite is not foliated and is considered to be a part of the Arthurton Granite (Jack, 1917). Jack, in recognizing that components of the granite complex north of Wallaroo were foliated distinguished them with the separate name, the Tickera Granite. Subsequently Wurst (1994) showed that the Tickera and Arthurton Granites could be separated by geochemical characteristics. In spite of the afore mentioned differences both the Tickera and Arthurton Granites are components of the early Mesoproterozoic Hiltaba Suite. Contained within the granite are enclaves, perhaps intrusions or co-magmatic bodies, of highly altered (weathered) mafic rock. Additionally there is a variety of metasedimentary xenoliths derived from the Wallaroo Group (for description of the Wallaroo Group see Cowley et al. 2003). Apart from being intensely brecciated the granite is variably ferruginised, including ironstone bodies apparently related from veining. Detrital non-magnetic iron oxide in places on the beach was presumably sourced from the basement rocks.

The small historic Harts Mine was presumably developed on malachite showings in the coastal cliffs approximately one kilometre east of the current Hillside deposit (Brown, 1908). The gossan exposed nearby on the shore platform shows minor visible copper carbonate mineralisation, and is associated with a band of calcsilicate rock, the result of skarn alteration of a large xenolith of Wandearah Formation. Uranium is sporadically anomalous as indicated by the Dead Horse Bay Uranium Prospect (Hiern, 1957, and MIMEX pers comm., 1995). At White Clay Bay intense kaolinite alteration of Hiltaba Suite pegmatitic granite infers weathering, but was possibly enhanced by acid derived by decomposition of sulphide from a relatively proximal source.

Well exposed along the cliffs of the northern part of the section is the basal Tertiary unconformity, with the Tertiary sediments being capped by calcrete-bearing regolith. This geology is the subject of a recent informal guidebook (Hill, 2013).

Hillside coastal sites

The Hillside coast provides a rare section through the Mesoproterozoic IOCG-related system. The dominant lithology is pink pegmatitic granite, but with a significant quantity of mafic material, and occasional xenoliths of the hosting Wallaroo Group. There are examples of the skarn-type alteration that is typical of the southern part of the Olympic Cu-Au Domain, and also mineralisation is exposed at the old Harts Mine, and minor uranium mineralisation is known locally, e.g. Dead Horse Bay. The structural style of this part of the Pine Point Fault zone is well displayed, as well as the overall brecciation of the granite.

Two unconformities are exposed overlying the Mesoproterozoic basement, the mid-Cambrian Yuruga Formation along the shore platform, and Tertiary and later sediments along the cliff-top. The Mesoproterozoic rocks are variably weathered, the extremes being visible as clay alteration of the mafic rocks, and the intense kaolinisation of the granite at White Clay Bay.

The northernmost outcrop of Mesoproterozoic granite is at WGS84 Zone 53H 0764920 6175078.

A word of warning, the cliffs are unstable and subject to collapse, so please **be aware of overhead dangers** (see Plate 16).

Site H1
(764860mE 6174750mN)

Intensely metasomatically altered metasediment, with granite cropping out to north and south this is possibly a large xenolith. In generality this is a messy patchy green to brown rock, i.e. 'calcsilicate', locally cherty, but showing crude layering, locally transposed folds, the more competent layers are disrupted (undulating layering 30-45°/230-240°). While the layering was probably influenced by metamorphism, it is likely to reflect original bedding. The precursor metasediment is not known, but may have had a calcareous component.

Plate 1 *Calcsilicate altered (alkali-feldspar, clinopyroxene, amphibole, epidote, magnetite) Wandearah Formation metasediment.*

Site H2
(764866mE 6174425mN)

Brecciated pink pegmatitic granite is the dominant Mesoproterozoic rock-type that is exposed in the Hillside coastal cliffs. Here a major north dipping structure juxtaposes pink brecciated granite in the north from ferruginised granite. Variations in ferruginous alteration, pegmatite content, brecciation and weathering can be observed along the coast. Notably, unlike the Tickera Granite at Point Riley, this, the 'Hillside eastern granite' of Rex Minerals, is not foliated, therefore it might have been intruded after the early stages of shearing in the Pine Point Fault zone.

Plate 2 *Brecciated pink pegmatitic Arthurton Granite of the Hiltaba Suite.*

Plate 3 Faulted variably altered granite.

Site H3
(764850mE 6174265mN)

A xenolith of dark grey weathered finely planar layered metasediment that is similar to the Delkin Member of the Wandearah Formation (Cowley, Conor and Zang, 20003) (Plates 4 and 5). The resistant layers of the Delkin Member are mainly composed of alkali feldspar, commonly albite, but locally with calcsilicate or iron oxide interbeds (the latter possibly introduce metasomatically). Sodic (or locally possibly potassic) composition suggests a hypersaline environment of deposition.

Plate 4a Ferruginised planar bedded metasediment as a xenolith within Arthurton Granite (Delkin Formation)

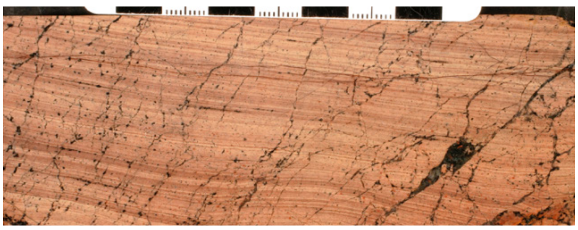


Plate 4b for comparison an example of 'fresh' Delkin Formation from drill hole PB12.

Plate 5 Wandearah Formation xenolith in Arthurton Granite.

Site H4 – Harts Mine and surrounding area
(764860mE 6174200mN and 764845mE 6174234mN)

Worked in 1847 the short-lived Harts Mine has the significance of being the first copper deposit exploited on Yorke Peninsula. The name comes from a Captain Hart, who with Mr A. Weaver, bought the adjoining sections to establish a sheep run and whaling station, the latter indicating the once presence of whales in Gulf St Vincent and how times have changed. Appended is the excellent description by of this area, which is contained within Geological Heritage Site YK. 5 (C.W. Giles, 1982a). Giles (1982b) also described a strip of the same coastline further south, i.e. Geological Heritage Site YK. 6, this is also appended. As well as copper mineralisation, uranium minerals have also been reported (Hiern, 1957). Items of interest include:

- Delkin Member xenolith-granite contact (Plate 6)
- Harts Mine excavations. Two shallow shafts in the cliffs. Recorded as an occurrence by H.Y.L. Brown (1908). The following summary comes via (Mindat.org) : "A Copper mine with mineralisation (*carbonates and chalcocite*) in quartz-iron oxide lodes in host Oorlano Metasomatite. Low-angle, west-dipping shear was exposed in cliffs to the south. It was worked periodically from 1847-48, 1889-91, and 1899. No production records recorded".
- Unusual calcsilicate rock, probably skarn-altered metasediment (Plate 7)
- Ferruginous material exposed on the coastal pavement, which is a malachite-mineralised gossan (Plate 8). Ii is interesting to speculate to how far east mineralisation could extend!

Plate 6. *Harts Mine area showing spoil from one of the two shallow shafts in the cliff face and the locally copper and uranium mineralised, dark brown calcsilicate-altered and gossanous metasediment xenolith.*

Plate 7 *Calcsilicate altered metasediment, Harts Mine mullock in the background.*

Plate 8 *Malachite-stained gossan on the beach platform at Harts Mine.*

Site H5 – Ferruginous zone (6173995-6173940mN)

Sporadically along the base of the cliffs is a brown iron-rich zone with an indistinct margin with the host kaolinised granite. At the south the zone is complicated by a cross-cutting ferruginous structure orientated ~20°/340° (strike 250º) (Plate 9).

Plate 9 *Intense ferruginisation associated with a N-S coast parallel structure.*

Site H6 – Cambrian and overlying fossiliferous ?Eocene (764850mE 6173740mN)

Cambrian sediments are exposed from here southwards to near Pine Point. The Cambrian lithology, assigned to the Yuruga Formation (Gravestock and Gatehouse, 1995) comprises near flat-lying brown bedded medium grained sandstone with local lenses of channel-fill polymict conglomerate (Plate 10). Clasts are angular to subrounded, with the dominance of granite clasts attesting to local derivation, possibly due to contemporary activity of the Pine Point Fault. Yuruga Formation is not recorded above the cliffs to the west, although there is a tilted outcrop of sandstone on the face of the cliff (McBriar and Giles 1984). The Yuruga Formation continues to off-shore near Site 7, but reappears further south continuing toward Pine Point near where the measured section is located (Gravestock and Alexander pers comm., Appendix 3). Of note, although the platform outcrop is heavily iron-stained, the sandstone of the easternmost part contains shelly fossil material (pecten), and so is likely to be Paleogene in age. Thus at this location there exists the following unconformable relationships: Yuruga Formation on Mesoproterozoic granite, Paleogene on Yuruga Formation and possibly Paleogene on the cliff top overlying weathered Mesoproterozoic granite.

Plate 10 *Channel-fill conglomerate and fluviatile sandstone beds of the Cambrian Yuruga Formation (Photo K. Wills).*

Site H7 – Alteration or weathered mafic

(764830mE 6173605mN)

At the base of the cliff of brecciated ferruginised granite varicoloured dark brown-red-green material is exposed, alteration of the granite or altered mafic?

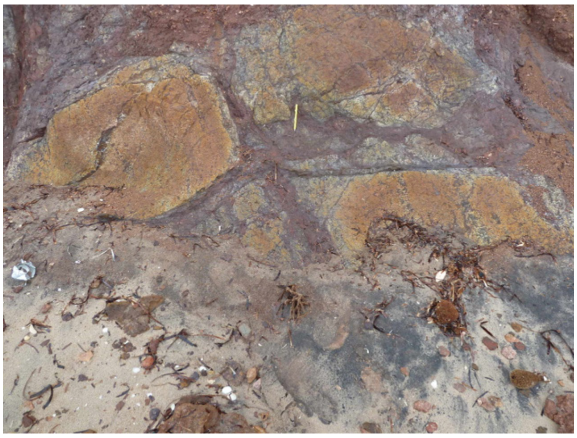


Plate 11 *Example of the 'mafic' rock, here highly weathered and disrupted by a network of ferruginous veins.*

Site H8 – Structural control of granite – 'mafic' contact

(764800mE 6173570mN)

While the obvious trend of the Pine Point Fault zone is north-south, structures of that orientation are not commonly visible along the cliff face (Plate 12). Better displayed instead are fractures at a high angle, with the majority appearing to dip northerly. At Site 8 a complex array of structures, both north and south dipping, control the contact between weathered granite to the north and a massive green clay-rich rock to the south, this latter is considered to be weathered 'mafic' rock.

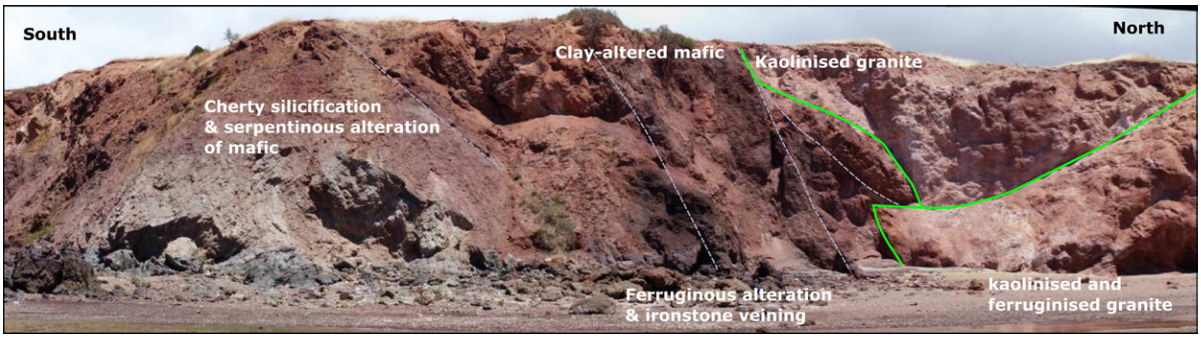


Plate 12 *Fault complex (green lines) separating kaolinised brecciated granite to the north from highly weathered mafic green clay rock. Intense alteration exposed in the promontory (left) includes serpentine-like rock, which is partly silicified to honey-coloured chert.*

The Moonta-Wallaroo region of the eastern Gawler Craton

Site H9 – Ironstone veins, serpentine-like alteration of 'mafic' and cherty silicification (764810mE 6173560mN to 764805nE 6173515mN)

Site 9 adjoins to the south of Site 8 and includes a small promontory. Two NE-striking (75/330) ironstone veins core a zone of intense ferruginisation, perhaps a common structural trend. The promontory exposes a variety of weathered materials including a N-S striking (75/080) network-veined green serpentine-like body that can be seen in places to be separated from the green 'mafic' by a thin zone showing shear foliation (Plate 13). Both the 'serpentine' and green clay 'mafic' have chemistry supportive of a mafic origin (See appendix for Niton analyses of mafic green clay rock and the serpentine-like rock). It has been suggested that the precursor of the serpentinous rock was a 'clinopyroxenite', similar to examples encountered by Rex Minerals' drilling (M. Twining, 2014). In places the 'serpentinite' can be seen to be partly silicified to form a honey-coloured cherty quartzite, blocks of which are common along the shore platform.

Plate 13 *Serpentine-like alteration of mafic or alteration product of a mafic.*

Site H10 – Alteration and faulting of 'mafic' (764800mE 6173505mN)

In this area the mafic body is affected by intense fracturing with faults or shear zones trending in a variety of directions. Structures are ferruginised and the host clay-rock locally silicified to form vuggy quartzite (75/310) (Plate 14).

Plate 14 *Alteration of a fault in the 'mafic' rock, siliceous alteration of wall-rock.*

Site H11 (764760mE 6173410mN)

Ferruginous alteration of the clay-altered 'mafic'. Siliceous veining and a N-S structure exhibiting a sheared fabric (Plate 15).

Plate 15 *Evidence for N-S shearing shown in limited exposure. Note ferruginous debris.*

Site H12 – Structurally controlled southern boundary of the 'mafic' body (764752mE 6173360mN)

N.B. Take care here as the cliff is known to be unstable.

To the south is the highly kaolinised granite of White Clay Bay, the contact with the 'mafic' body to the north is obscured by a debris fan. However exposed in the cliff is a very impressive bifurcated shallow northerly dipping shear structure (Plate 16).

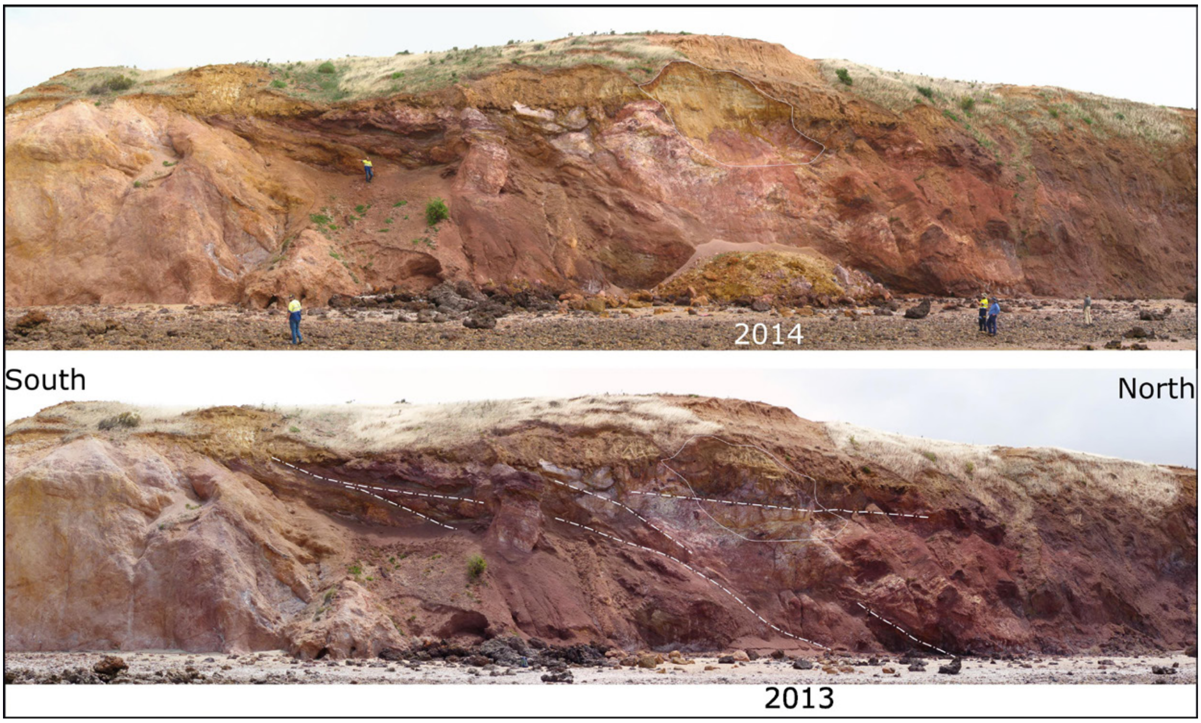


Plate 16 A substantial bifurcated northward dipping structure is in the vicinity of the rock change from kaolinised Mesoproterozoic granite to mafic to the north. Cainozoic sediments are unconformable. The two panoramas taken a year apart illustrate the risk from cliff instability due sea erosion along the cliff base.

Site H13 – White Clay Bay, weathered granite profile and overlying Tertiary cover (764710mE 6173290mN to 764700m 6173080mN)

Plate 17 White Clay Bay viewed from the north. Paleogene sediments overlie kaolinised and ferruginised granite. Black sand on the beach is non-magnetic iron oxide, possibly eroded from ironstone veins such as that shown as a ragged black mass on the beach in the far distance.

The cliff at White Clay Bay exposes a striking unconformity of kaolinised Mesoproterozoic Arthurton Granite and overlying thing Paleogene sediments (Plate 17). The profile shows about 10m of saprolite overlying kaolinised saprock, that in places is ferruginised (Plate 18). The saprolite in this area is restricted to White Clay Bay where it is unusually thick. It is notable that the Cambrian Yuruga Formation is not present in the cliff section, but is offshore, this presumably being due to the influence of the variable displacement within the Pine Point Fault zone.

S. Hill (pers comm. 2013) indicates that the overlying Cenozoic section could include the following:

Youngest

- ~1.0 m discontinuous nodular calcrete largely derived from weathering of the Port Vincent Limestone (Oligocene-Miocene)
- <7 m of Rogue Formation sands and silts, interpreted to be late Eocene to early Oligocene marginal marine and marine sediments
- ~3 m Throoka Silts interpreted to be Eocene lagoonal-esturine facies
- <6 m Quartoo Sand Member of the Muloowurtie Formation, these sands and silts are associated with an Eocene marine transgression
- <1 m discontinuous basal gravels of the Quartoo Sand Member

Unconformity

- ~10 m saprolite derived from the weathering of the Arthurton Granite
- Saprolite of Arthurton Granite

Although mineral development is no longer possible within 40om of coasts, the kaolinite body has been considered as a clay resource in the past (Ridgeway, 1952; Jackson, 1952; Smith, 1957; Crawford, 1957). More recently this profile was studied as a part of the Australia-wide push aimed at better understanding regolith processes (Keeling et al., 2000), then following the discovery by Rex Minerals of the extension to the historic Hillside Mine, a significant regolith sampling and research program was undertaken by the University of Adelaide.

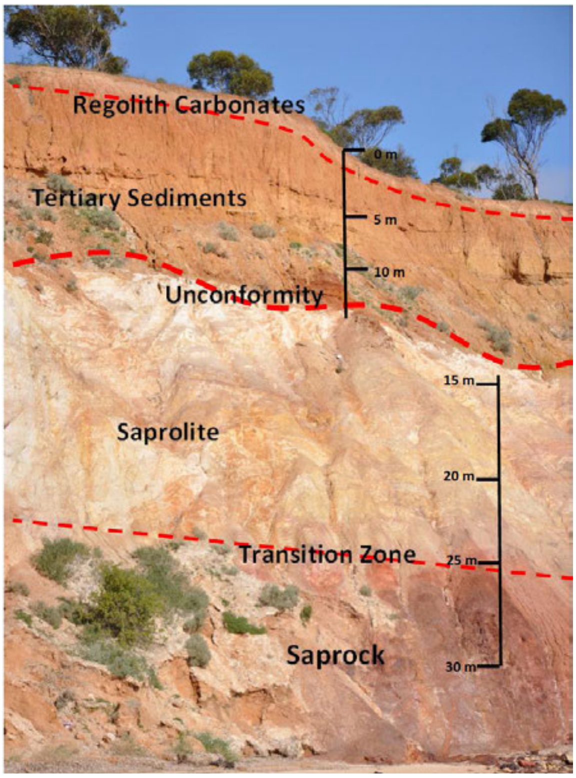


Plate 18 Measured profile through the section at White Clay Bay showing the weathered Arthurton Granite overlain by unconsolidated Tertiary (Paleogene)sediments (Figure S. Hill pers comm.).

Site H14 – Ironstone veining (764695mE 6173115mN)

Standing up on the shore platform at the southern end of White Clay Bay is a ragged dark brown mass of ironstone (Plate 17), in the distance, to the left). It is the remnant of an extensive vein stockwork preserved by hydrated iron oxide. The deformed host is not exposed. Similar material is present around the promontory to the south (Plates 20 and 21).

Site H15 – Blocks of slumped silicified ?Tertiary sediment (764730mF 6173070mN)

The promontory is marked by three metre high ragged masses of light coloured siliceous rock, which contains rare rounded pebbles (Plate 19). The lithology is interpreted as silcrete derived from silicification of parts of the overlying Paleogene cover succession. The northernmost block overlies Cambrian Yuruga Formation which becomes the dominant pre-Paleogene unit further south towards Pine Point.

Plate 19 *'Silcrete' block possibly slumped from the cliff immediately to the west. A polymict assemblage of angular to rounded clasts is visible. This possibly represents a silicified portion of the basal part of the Quartoo Sand Member.*

Site H16 – Uranium mineralisation hosted by ironstone veining
(764670mE 6172880mN)

An ironstone mass is the vicinity of the Dead Horse Bay uranium occurrence gave a detectable reading indicating sporadic uranium or thorium mineralisation (Plates 20 and 21). Hiern (1957) describes the hosting geology as: '.. the contact between a soft pale green clay rock (to the west) and a hard rusty-brown jasparoid rock (to the east) can be traced for over 100' in a north-south direction. Green clay samples were interpreted to have been derived by weathering or alteration of granite or pegmatite with the colour being due to chlorite. An assay reported 0.9 lbs U_3O_8 / ton.

Plate 20 *Dead Horse Bay, general view of the outcrop of ferruginous rock that is measurably radioactive. View looking south with Pine Point visible in the distance. Also in the distance, the dark line below the sandy beach marks extensively outcropping Cambrian Yuruga Formation.*

Plate 21 *Detail of the outcrop shown in Plate 20. The rock is composed of brecciated honey coloured cherty material with a dark brown ironstone network-veined matrix, using a radioactivity monitoring instrument it returned readings as high as 4 µSv/hr. Other ironstone outcrops and veins in this bay are not obviously radioactive.*

Plate 22 *Northerly trending ironstone vein in Dead Horse Bay developed in Arthurton Granite. View looks northwards to the sites shown in Figs. 19 and 20). While this vein was not obviously radioactive, it is possible that its formation does relate to the Dead Horse Bay uranium anomaly. The shore platform is covered by a thin veneer of highly organic silty sediment.*

Site H17 – Yuruga Formation (764550mE 6172270mN)

From Site 14 south the cliffs, where not soil or scree covered, exposes kaolinised granite (Plate 10). Running along the shore platform is discontinuous outcrop of Cambrian Yuruga Formation that shows striking examples of channel-fill conglomerate lenses. Site 16 marks the entrance to the gully from which a measured section of the Yuruga was derived (Gravestock and Alexander pers comm. 1987, see Appendix 2).

Rex Minerals Ltd Hillside Project

Due to difficulties, commercial and social, the Hillside Project of Rex Minerals is temporarily on hold. In addition the company is in the process of compiling material for publication. The result therefore is that no information can be included in this guidebook. However Rex Minerals has supplied a short summary for the exclusive use of participants of the AESC 2016 Yorke Peninsula excursion. A figure in Appendix 2 shows the location of the Hillside Cu-Au deposit relative to this coastal section, and interested parties are directed to Conor et al. (2010), and the various ASX submissions.

Rocky Point, Site R

(Information credit - S. Hill pers comm. 2013)

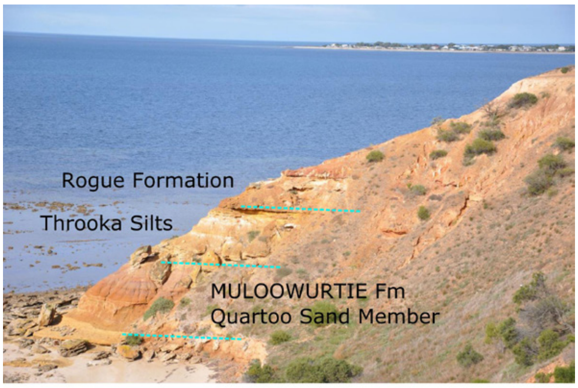
Rocky (Quartoo) Point provides an exposure of largely Eocene, St Vincent Basin sediments.
N.B. The cliff is unstable, please take care.

The cliff sequence includes (from base upwards):

- 5 m of Eocene Muloowurtie Formation sands and silts;
- 4 m of Eocene Quartoo Sand Member of the Muloowurtie Formation;
- 2 m of silicified, cross-bedded quartz sands, interpreted as an Eocene palaeochannel;
- 4 m of Eocene Throoka Silts;
- 15 m of variably silicified red sands of the late Eocene – early Oligocene Rogue Formation; and,
- 1 m of nodular regolith carbonate derived from transport of weathered Oligocene-Miocene Pt Vincent Limestone.

Three key points from this site:

1. Silcrete development within palaeo-aquifer systems (e.g. palaeochannel sands)
2. Palaeoredox interfaces, particularly leisegang banding and "roll-front" morphologies within Throoka Silts as well as large regional palaeo-redox front within Quartoo Sand Member (associated with goethite/hematite transition)
3. Acid-sulphate, redox controlled weathering largely derived from ferrolysis, oxidation of organic materials and oxidation of secondary pyrite. Resulting in Al mobility and Si redistribution that produces authigenic clays and alunite as well as phreatic silcretes.



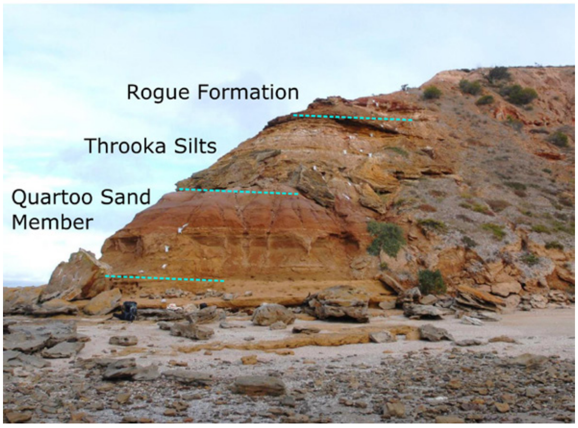


Plate 23a and b Paleogene units of Rocky Point, Yorke Peninsula, and sampling sites.

Port Victoria, Site V

The 5.5 km of very clean coastal exposures at Port Victoria (Fig. 5) , and the western coast of Wardang Island show examples of all three formations of the Wallaroo Group, that is a complex of metasediments, mafic and felsic volcanics of the Wardang Volcanics (Bone, 1984; Huffadine, 1993). The volcanics are of variable composition dominantly rhyodacitic but with rhyolite, dacitic and latitic volcanics and hyaloclastites, and originally dated using Rb-Sr (Bone, 1984; Lang et al., 2002) and more recently by zircon U-Pb at 1772 ±14Ma (Fanning et al.,2007). Intercalated metasediments of the Aagot Member include muscovite-bearing metasiltstone, fine-grained metasandstone and minor calc-silicate. The equivalent sediments on Wardang Island and Point Pearce include volcaniclastic conglomerate, cross-bedded fluvial aeolian metasandstone (Zang et al., 2002). The sedimentary evidence suggests terrestrial fluvial to shallowmarine settings for deposition of the Aagot Member (Zang, 2002a).

Figure 5 *The coast at Port Victoria with the seas of Spencer Gulf to the west. This section of coast beautifully exposes all three formations of the Wallaroo Group (i.e. Wandearah, Weetulta and Matta).*

Three deformation fabrics have been interpreted in the metasediments and volcanics (Bone, 1984). However a consistent feature of homogeneous felsic and mafic rocks, here and elsewhere (e.g. locally the Moonta Porphyry) is a steeply inclined mineral lineation. It is not known to which major structures this relates, but perhaps to the large long-limbed isoclinal folds that are visible in aeromagnetic imagery. Bone (1984) suggested that the metamorphic grade on Wardang Island had reached amphibolite facies.

In Figure 5 three localities are marked to show such features as lithological variation, flow layering and folding, possible hyaloclastic brecciation, deformation and incipient high temperature calcsilicate alteration. Bronze plaques are present at intervals along the shore, which represent localities along the Port Victoria Geological Trail (Sites PGVT of Clarke and James, 1993).

Site V1

Layered, folded muscovite-bearing metasiltstone – calcsilicate (Aagot Member), feldspar-phyric rhydacitic volcanics, and mafic dykes or volcanics (Fig. 6). The Aagot Member consists mainly of bedded and homogeneous metasiltstone with minor metasandstone, and layered calc-silicate (Plates 24 and 25), the calcsilicate material was possibly metasomatically introduced. Locally cross-bedding and graded-bedding are visible, consistent with a shelf depositional setting. There is an approximate N-S contact following the shoreline where metasediments (to the west) co-exist with felsic volcanics with variable contact relationships, in places undisturbed at others hyaloclastic (Plate 26). Huffadine (1993) suggested that the volcanics were erupted and deposited as a crytodome in a subaqueous environment, probably marginal marine in association with the sediments. Mafic rocks of the Matta Formation were intruded semi-parallel to layering but locally cutting across bedding, and in one place is crudely layered and contains what appears to be felsic clasts. There is evidence for acute folding.

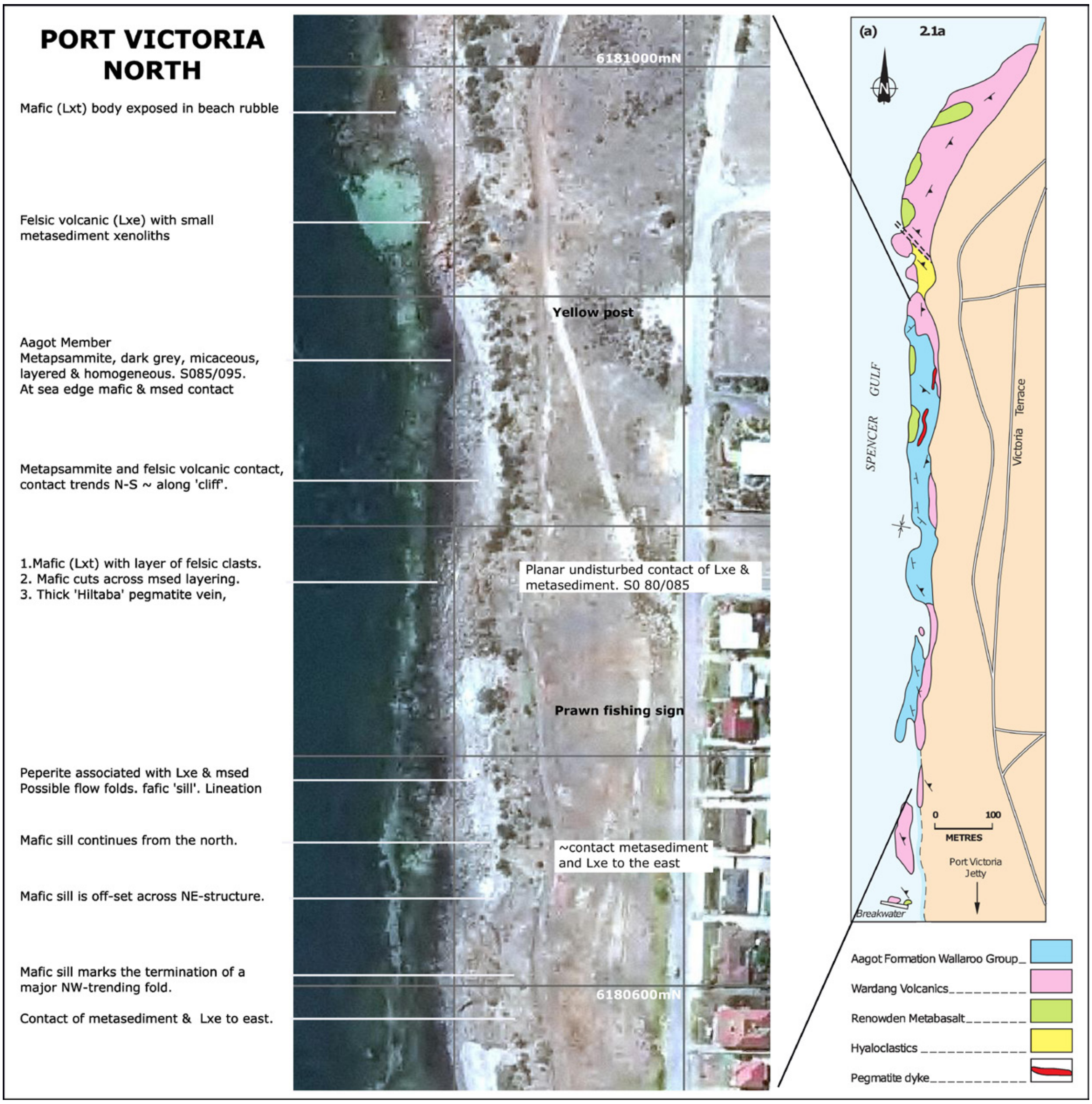


Figure 6 *Port Victoria, Site V-1. The site includes the contact between felsic volcanics and psammite. Calcsilicate layering in places appears to be the result of metasomatic alteration, but possibly is remobilisation from primary beds. Locally peparite is visible. A mafic sill is well exposed and is acutely folded. Thick pegmatite veins related to the Hiltaba Suite intrude cleanly. The geological map is derived from Huffadine (1993).*

Site V2 – Port Victoria Jetty

Below the jetty is the contact between felsic volcanics (Wardang Volcanics Member) and a mafic body (Matta Formation), which shows a metamorphic rodding.

Site V3

Magnificent flow folding is displayed by a flow-banded meta-rhyolite (Plate 27). There is incipient calc-silicate alteration associated with pegmatite veins, and small lenticular bodies controlled by the foliation. Calcsilicate alteration is indicated by amphibole and epidote-bearing clots. The volcanics comprise massive porphyritic rhyodacite, dacite or latite, and locally rhyolite (Zang, 2002).

The phenocrysts, generally less than 5 mm in diameter, consist of either K-felspar or calcic-plagioclase, with carbonate, scapolite and chlorite inclusions. The matrix consist predominantly of K-feldspar, quartz and plagioclase, and accessory zircon, with what are presumably meyamorphic biotite, opaques (ilmenite and magnetite) with or without hornblende, pyroxenes, epidote, , apatite, carbonate and scapolite. The volcanics are considered to be shallow intrusive and extrusive, or ignimbrites of ash-flow bodies, with flow banding and columnar cooling structures on Wardang Island. Several amphibolite pods intrude massive felsic volcanics. Along this coast and on Wardang Island the steeply plunging mineral lineation is visible in both felsic and mafic rocks.

Plate 24 *Aagot Member, layered psammite at Site V1 (Photo: W-L Zang).*

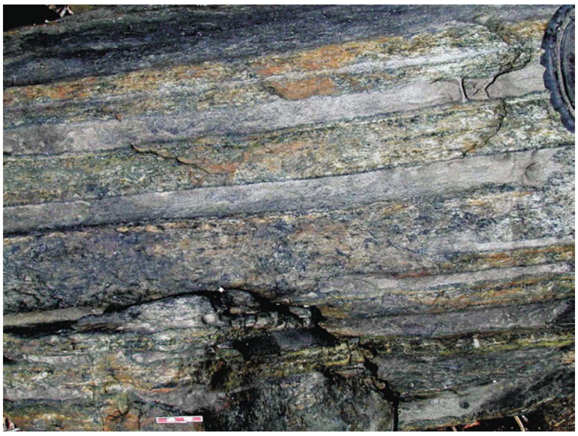


Plate 25 *Site V1. Planar-bedded interlayered psammite and calcsilicate of the Aagot Member. Some calcsilicate is metasomatic, was all the calcsilicate in these rocks introduced metasomatically? (Photo: W-L Zang)*

Plate 26 *Hyaloclastic developed at the interface of Aagot Member and felsic volcanic (Wardang Volcanic Member) (Photo: W-L Zang).*

Plate 27 *Site V3. Flow fold in rhyodacite lava (Photo: W-L Zang).*

At Renowden Rock, ~5 km south of Port Victoria, the amphibolite of the Renowden Metabasalt Member contains probable amygdaloidal vesicles.

Poona Mine, Site P

The Poona Mine (a faulted off-set of the ~1861 discovery) and the Wheal Hughes (and Leighton Lode) were discovered by WMC in 1986, using SIROTEM. EL 1394, which included the two deposits, was bought by the Moonta Mining joint venture in December 1987. A treatment plant for upgrading the ore was installed at Kadina using water from the old Wallaroo Mines Taylor's Shaft. The production was sold to Electrolytic Refining and Smelting (Port Kembla) and Mount Isa Mines (Mount Isa) (Cooke, 1990). See Table 3 for production and grade. Poona Mine and Wheal Hughes represent members of the Moonta Porphyry-hosted Cu–Au deposits. All of the mined deposits in the Moonta Mining Field were formed by the filling of relatively late-stage fractures; fractures which Jack (1917) considered to be developed in three concentric arcs (Fig. 7). As mentioned previously 355 000 t of copper and 2 t of gold were extracted from the two mining fields of the northern Yorke Peninsula, with approximately half coming from the Moonta Field. Dickinson (1942, 1953) described the ore bearing structures as follows:

...the structural features produced in the Moonta Porphyry can be summarised as west dipping, high angle, northeast–southwest striking thrust faults with right-handed displacements.

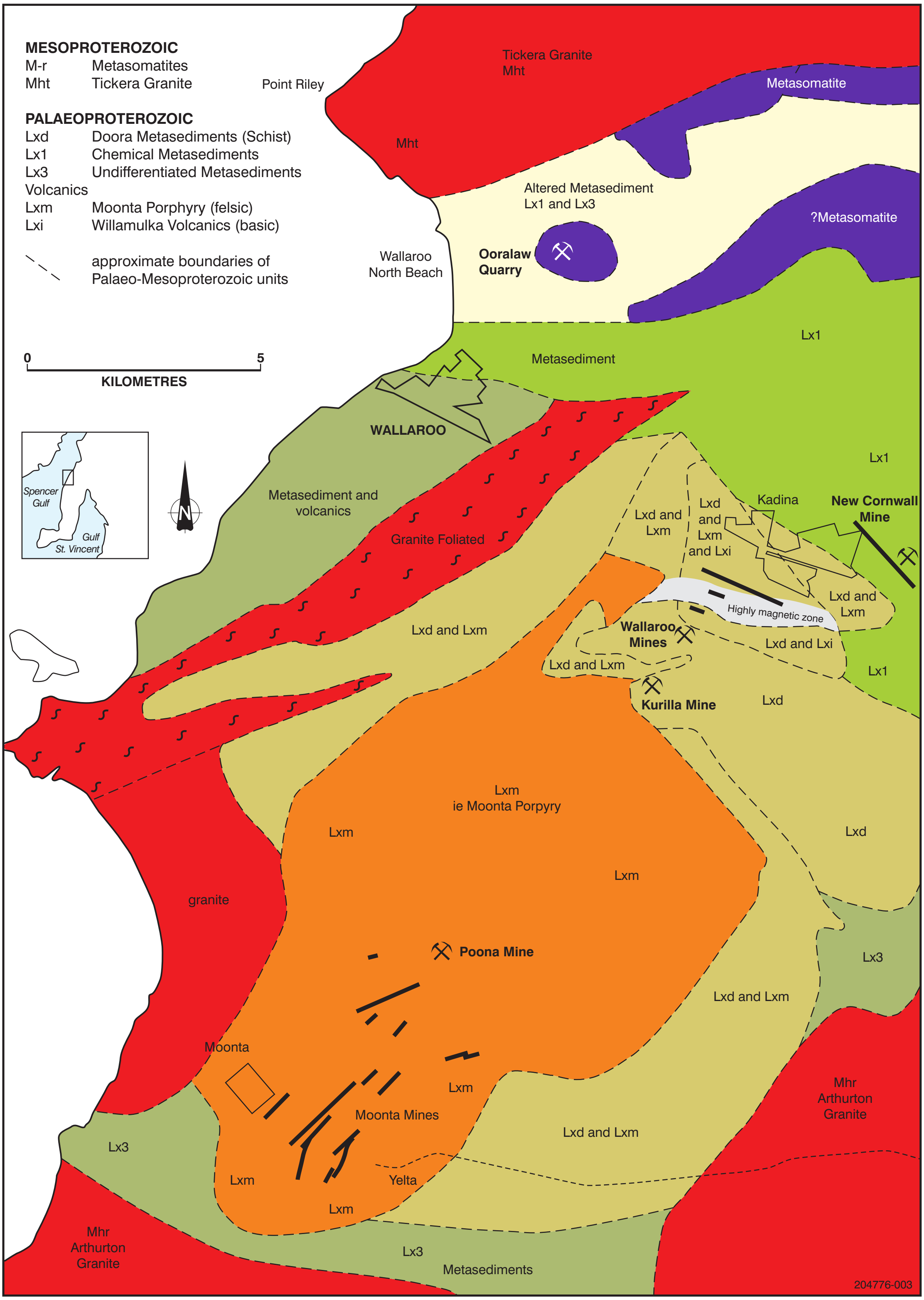


Figure 7 *Solid geological interpretation extending from Point Riley to Moonta. (From Jack 1917 and Conor, 1995)*

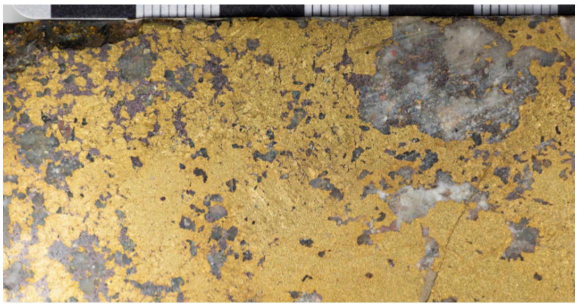


Plate 28 Massive ore from Poona Mine, mainly chalcopyrite, minor bornite, with ragged fragments of vein quartz gangue.

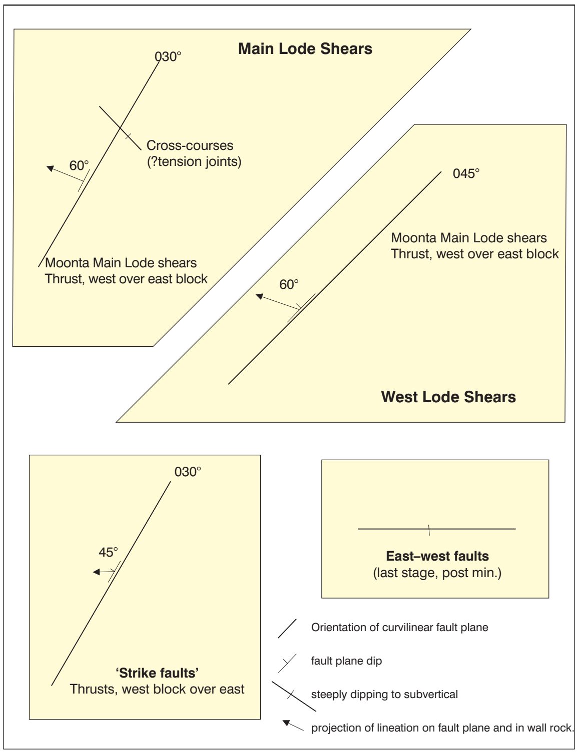


Figure 8 'Exploded' plan showing the strikes of the main structures related to the Moonta Lodes.

He summarised fault elements in the main Moonta field as follows:

a. 'Main lode shears'. Arcuate but ~60°/030° (extensive ore shoots).

b. 'West lode shears'. Arcuate but ~60°/045° (more continuous in strike but less mineralised).

c. Strike faults. ~45°/030° (parallel strike to the 'main lode shears', not mineralised).

d. Northwest–southeast cross-courses. Vertical or steep southwest (off-set the lodes, generally not mineralised, but separate segments of the mineralized structures into distinctly higher or lower grade portions).

e. East–west transverse faults. Near vertical. (limited distribution, non-mineralised, off- set the lodes).

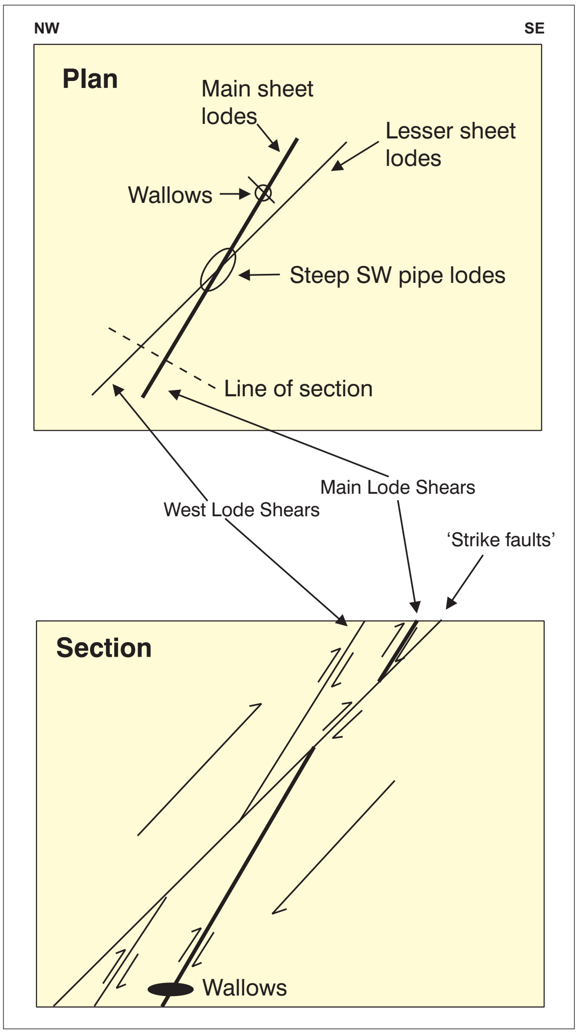


Figure 9 Plan and section summarizing relationships of mineralized thrust faults of the Moonta Mines.

The Poona Mine and Wheal Hughes are fairly typical of the Moonta-style lodes, although, whereas the southern Moonta lodes are commonly associated with mineralised pegmatites, the chalcopyrite dominated mineralisation of Poona and Wheal Hughes is not (Plate 28).

Wheal Hughes also is tourmaline-rich and shows a high degree of kaolinisation. Both deposits show, with little variation, a similar mineralogy and paragenesis, i.e.:

- Stage 1 Magnetite converting to hematite.
- Stage 2 Pyrite +marcasite (at Poona also hematite).
- Stage 3 Introduction of the ore elements (Cu, Au and Mo, Co), producing chalcopyrite and some bornite.

The reader is referred to a number of studies for details (Janz, 1990; Hafer, 1993; Both et al., 1993). There was significant, near surface, supergene enrichment. Cooke (1990) reported the following at Poona:

- soil and calcrete
- green, fibrous atacamite-bearing alunite
- covellite, chalcocite and native copper in a body 20 m long, 6 m wide and 3 m deep running between 2–25% Cu.

The gangue includes quartz, feldspar, hematite, chlorite, tourmaline, trace fluorite, epidote, alunite and kaolinite.

Janz (1990) recognised, in the vicinity of Poona Mine, complex alteration involving the following classes:

- propylitic (epidote, chlorite)
- argillic (kaolinite, alunite)
- sericitic (alteration of feldspar and release of silica)
- silicic (deposition of silica immediately adjacent to the Poona ore body, but patchy)
- tourmalinic (in veins, shear zones, and replacement of enclaves in the shears).

Hafer (1991) proposed a similar alteration paragenesis at Wheal Hughes. No complete structural study has been completed of these two mines, although a number of workers have carried out limited studies (e.g. Cooke, 1990; Mendis, 1992). Carthew (1993), while working for Moonta Mining Joint Venture, produced the only set of underground geological maps for either the Moonta or Wallaroo fields. While there are structural elements common to both Poona and Wheal Hughes, the detail is complicated and requires further work, it is without doubt that any such study would have been rewarding.

The Moonta Porphyry, while commonly being undeformed, locally shows the development of an intense foliation. The foliation is macroscopically manifested by biotite (chlorite where altered) pressure shadows around, potassic-altered, plagioclase phenocrysts. The fact that biotite is the mineral forming the shadows possibly indicates early iron-metasomatism. In the vicinity of the mines these shadows exhibit a steeply inclined lineation. Evidence of evolving strain is indicated by deformation of the foliation. The ore at both Poona and Wheal Hughes is contained partly by structures, which are sub-parallel to the foliation and partly by structures, which are acutely oblique. The main pit parallels the local regional northeasterly structural trend (Plate 29).

The main ore plane at Poona dipped ~50°/340° (strike 070°); there is an oblique set of fractures–

Plate 29 *Southerly looking oblique aerial view showing the historic Moonta Mines waste in the distance, the village of North Yelta, and the open cuts of Wheal Hughes in the middle distance and the flooded Poona Mine in the foreground. Both deposits were discovered by Western Mining (WMC) and successfully mined by AMALG until the early 1990s. The NNW dipping footwall thrust is plainly visible in Poona Mine, and a remnant of the copper-gold lode is still accessible in the SW corner (near where the track approaches from Wheal Hughes). The waste rock at Poona is a current aggregate resource.*

veins striking ~040° (Fig. 10, from Cooke, 1990). The ore body was terminated to the west-southwest and east-northeast by steeply dipping faults striking to ~320°. The western fault (O'Callaghan Fault) shifted the ore six metres sinistrally, the eastern fault (Greenhill Fault) displaced the trend 100 m dextrally.

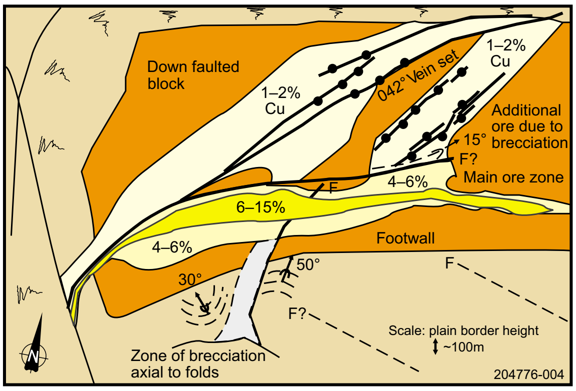


Figure 10 *Sketch of Poona Mine showing copper grades relative to fracture sets (Cooke, 1990).*

Cooke (1990) recognised at Poona that in plan the footwall showed a district corrugation; this corrugation has an amplitude of ~0.3 m and a wavelength of ~3–5 m. The corrugation caused the ore body to pinch and swell. The corrugation parallels the main stretching lineation of the hanging and footwalls. A second set of structures also caused pinching and swelling of the ore, this set is represented by kinks affecting the foliation; kink axes plunge at shallow angles within the envelope of the foliation. Mendis (1992) and Carthew (1993) recognised both the steep corrugations and the shallow plunging kinks at Wheal Hughes. Additionally, in places the ore lode is visibly folded.

Site P – Poona Mine

The Poona Mine open-cut and surrounding area is privately owned with mullock being an aggregate resource. It is the only site where mineralisation of either the Moonta or Wallaroo types are exposed, therefore permission to enter and view the rocks is highly appreciated. Although the underground workings and lower part of the pit are submerged there still remains much to see.

Features of interest include:

1. overall shape and trend of the pit reflecting the ore body
2. Soil profile including calcrete/?Hindmarsh Clay equivalent
3. Lateritic regolith profile in the hangingwall above more solid Moonta Porphyry
4. Eastern tail of the mineralised zone, where the mylonitic foliation and lode are folded.
5. Corrugated fabric of the footwall, possibly due to a conjugate fracture or foliation set.

New Cornwall Mine, Site C

New Cornwall Mine is one of the many smaller workings in the vicinity of the main Wallaroo and Moonta Mines (Fig. 11). It was considered to represent an extension of the Wandilta lode, these trending about 315º. As will be seen from the extracts below it attracted much interest, and apparently is of worldly significant for the excellence of atacamite specimens (Plate 30). The workings here at 'East Kadina' are in barely deformed finely layered metasiltstone, that at depth are partly graphitic and magnetite and hematite-bearing. Mineralised rock in mullock shows sulphide and carbonate in brittle crackle veins, a style very different to that of

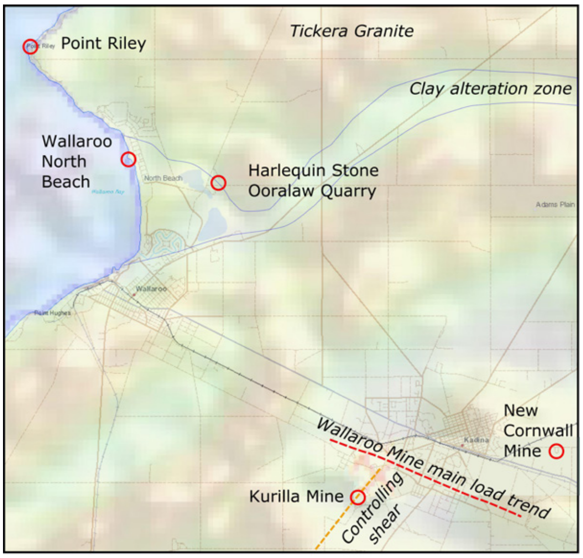


Figure 11 *Field stops in the Wallaroo region, TMI background with mag-highs commonly representing magnetite-bearing calcsilicate alteration assemblages. The late kaolinite alteration zone, which overprinted calcsilicate 'skarny' alteration is shown.*

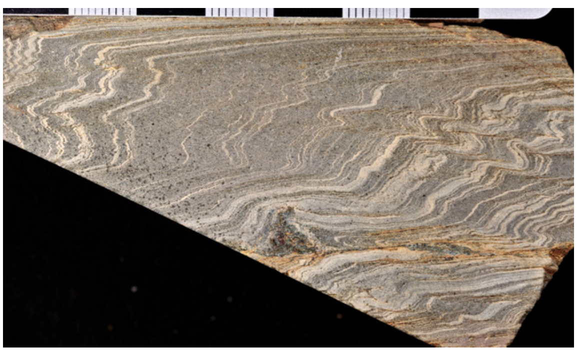


Plate 30 *Wandilta – New Cornwall Mines area, deformed New Cornwall Member, possibly a transitional stage to the Doora Member schistose metamorphic style (compare with Plate 32).*

the nearby Wallaroo Mines where conditions were highly ductile. The appearance of rock from these two adjoining areas resulted in controversy where on the one hand the Wallaroo rocks were considered be primarily related but with the difference being due to deformation, metamorphism and metasomatic alteration (Lynch, 1982; Conor, 1995). On the other hand it was proposed that the East Kadina rocks, called the Wandearah Metasiltstone, were a younger supercrustal succession overlying a metamorphosed succession called the Doora Schist (Parker in Drexel, 1993). Eventually the first suggestion proved the more correct due to the matching geochronology of contained felsic volcanics in both set of rocks. Therefore all are now included in the Wandearah Formation of the Wallaroo Group.

Samples of rock spoil in a nearby to the west, perhaps from the historic Wandilta Mine, showed fine grained layered metasediments being transformed into foliated metamorphic rock. So it is tempting to consider a transitional zone nearby (Plate 30). Sadly, the advance of progress has smeared this dump and incorporated it into domestic housing foundations.

Plate 31 *The world's best atacamite specimen, this from the New Cornwall Mine (credit; Mindat,org)*

The following, including the photograph of atacamite ($Cu_2(OH)_3Cl$ is taken from the web site 'Mindat':

"This mine is renowned for producing the largest and the best atacamite specimens in the world. Many of its early specimens are now in museums around the world.

This mine started its life as the Cornwall Mine, but quickly changed to the New Cornwall Mine. Why and exactly when this name change occurred seems to be lost in history. So much so that almost all records available, only have the New Cornwall name on them.

It was originally believed that it may be a continuation of the two lodes being worked at the nearby Wandilta Mine.

Since the mine's closure the property has been used primarily for farming, at one point as a pig farm, thus the use of the names 'Pig Pen Mine' and 'Piggery Mine', although these have never been official names."

The mine was recorded in the publication of H.Y.L. Brown (1908) and the description is included below.

CORNWALL (NEW CORNWALL).—This is a mining property near Kadina which was believed to carry a continuation of two lodes that had been worked in the Wandilta Mine, near the Wallaroo Mines. As usual in discoveries in that locality, there was a show of green carbonates mixed with the nodular and loose gravelly limestone, and the adventurers were rewarded by lighting upon a fine deposit of grey ore and green carbonate of copper not far from the surface, and a large and beautiful specimen was sent for public exhibition. The adventurers went to great expense, importing a large engine direct from Cornwall, and sinking to a considerable depth for prospecting at that period and that locality. Operations ceased after a while, and nothing in the way of practical working was attempted on the property for some years. The Government Geologist reported, on September 15th, 1898, that no information could be gained respecting this property except from the surface workings. There are apparently two lodes, running more or less parallel in a N.W. direction. These are strong formations of considerable width. The deepest shaft is said to be 360ft., and the water-level is about 50ft. from the surface. The underlie is slight and to the S.W.

In April, 1907, the Inspector of Mines reports that the main shaft was said to have been sunk to a depth of 420ft.; but little or no reliable information can now be obtained as to the results, or why operations were discontinued. During the last two years the mine has been held and worked by Paull and party, who have confined their operations to the ground above water-level, with, so far as can be ascertained, satisfactory results. The surface workings have, apparently, disclosed a very wide belt of mineral-bearing country, consisting principally of decomposed gritty sandstone, containing bunches and seams of ore of exceedingly good value, chiefly in the form of green carbonates. Sample taken from these seams returned 47 per cent. copper. It is generally supposed that this belt of metal-bearing country is traversed by at least two or three lodes, running parallel, and probably are continuations of the same lodes that have been worked in the Wandilta Mine in the early days. Owing to the water, which stands about 50ft. from the surface, none of the lower workings could be examined; but, judging from the appearance of the waste dumps, which came from the deep shaft, there is no doubt that the workings had reached the sulphide zone, as yellow ore can be freely seen in the waste material. Recently there has been dispatched to the smelters 12 tons of crude ore, yielding an average value of 20 per cent. copper. Work in this mineral belt should be continued, when doubtless other valuable shoots or deposits of ore will be discovered. (I.M.R., 23-4-07.)

Kurilla Mine, Site K

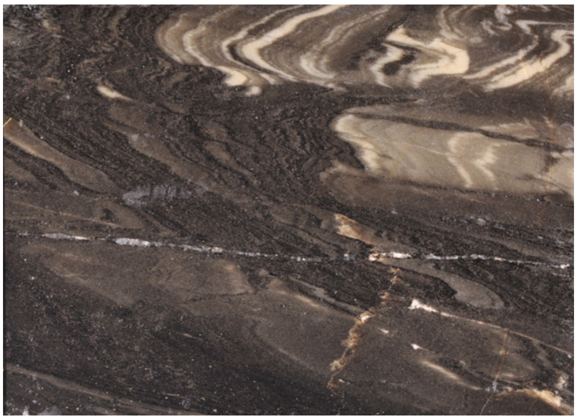


Plate 32 *Hand specimen from Kurilla Mine illustrating deformation and alkali-feldspar and biotite alteration (comp. Plate 30).*

The waste dumps of the Kurilla Mine are easily accessable (providing that there is inaction at the pistol club) (Fig. 11). The Kurilla Mine was developed on W-E lodes cross-cutting the main northeasterly controlling structure. The main Wallaroo Mine Lodes to the north were similar, but had greater lateral extent. The Kurilla Lodes are described as being less contaminated by country-rock gangue, and hence might represent dilatant structures. The material in the mine waste dump is very different to that at the New Cornwall Mine, and is generally a medium-grained biotite schist. The is enough sample to see that biotite is metasomatic and has overprinted the finely laminated bedding (Plate 32). In drill core the alteration is commonly most intense in areas of greater strain. There are disrupted sulphide-bearing quartz veins and also amphibole-alkali feldspar veins and segregations. These rocks are included within the Doora Member (formerly Doora Schist).

Quote from Mindat.org: 'A copper mine consisting of a series of EW-trending quartz-iron oxide veins with shallow secondary Cu mineralisation, chalcopyrite at depth in host altered quartz-biotite schist. Production ~20,500t dressed ore ~25%Cu from 1863-1905'.

Description of the Kurilla Mine from H.Y.L. Brown (1908)

Kurilla Mine.—Situated a little to the S.W. of the Wallaroo Mines. It contains three lodes underlying N., with an E. and W. bearing, and having an underlie ranging from 1ft. 8in. to 2ft. 3in. in the fathom. The width of the lodes varies from 1ft. to 9ft., and the ore they contain is chiefly chalcopyrite. Sometimes, indeed, it is pure chalcopyrite, but in other instances it contains from 3 per cent. to 15 per cent. of copper. The veinstone associated with the metallic minerals is iron pyrites, portions of the bedrock, &c., while the country rock is talcose schist. Twenty-six shafts, including the trial shafts, have been sunk, the deepest of which is 498ft. The length of drives put in at various levels in 1886 equalled 3¼ miles. The water-level was :eached at 30ft. The deposits of copper ore are chiefly along the lead of the lodes, associated with "gangue," the present supplies being mostly chalcopyrite. In many ways this mine is similar to the Wallaroo Mines, the chief difference being that the veinstone is not so mixed with "gangue," so that the chalcopyrite is of a higher percentage. Accurate information with regard to the total amount of ore raised and its money value has not been obtainable; but during the 10 years from 1874 to 1884, the ore sold from this mine equalled 19,397 tons, of the value of £155,068. Of the ore raised prior to 1874 no record was kept, and of that obtained since 1884 it is probable that at least 1,000 tons have been sold, valued at £5,000. (1886.) (1899 edition.)

Ooralaw Quarry, Site O

Harlequin Stone, the original rock representing South Australia at the National Rock Garden, Canberra.

Plate 33 *Harlequin Stone, South Australia's icon at the National Rock Garden, Canberra (at this stage partly polished (photo: W. Harvey).*

The source of Harlequin Stone are two quarries developed in a belt of magnetic calcsilicate rocks that follows the southern margin of the Tickera Granite body north of Wallaroo (Fig. 11). The subcropping part containing the Ooralaw Quarry and Wallaroo Quarry (formerly Hill's Quarry, and Kelly's Farm Quarry) is essentially the type locality for the Oorlano Metasomatite. Oorlano Metasomatite is the quasi-stratigraphic name given to alkali-carbonate replacement of pre-existing metasediment of unknown composition. Such replacement is usually referred to as 'skarn', which is typically contact alteration of a carbonate-rich unit. Cut surfaces clearly show that replacement was imposed following one or more fold events (Plate 34). This is possibly the case at the Wallaroo Quarry, but drilling information nearby demonstrates that the precursor need not be carbonate bearing, because the calcsilicate suite of elements can be introduced from elsewhere. 'Alkali-carbonate alteration' is an alternative term. The colour of the rock is striking, varying from black to red to green, these colours relate to the proportions of the various minerals in the assemblage assemblage that includes alkali-feldspar (hematite-stained albite), actinolite, clinopyroxene, epidote, quartz, dolomite, magnetite, sphene (titanite), pyrite and a trace of chalcopyrite. What is considered relict bedding is recognizable, although what the original sediment composition was is an open topic. Irregular pink and white crystal shapes, now plagioclase, were likely to have been scapolite, so some of the original sediments might have been saline calcareous muds. Owen (2015) demonstrated that the detrital zircon population was clearly derived from the Donington Suite basement, possibly locally.

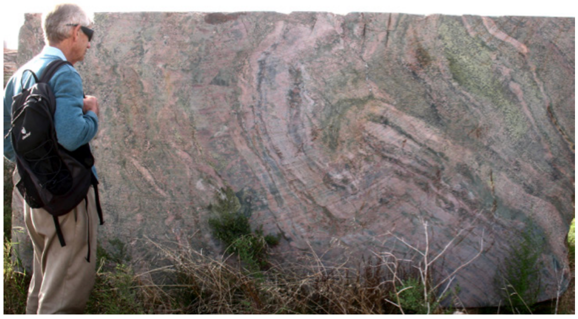


Plate 34 *A sawn block in the Ooralaw Quarry displaying a structure reminiscent of fold interference. Metasomatism postdates the folding.*

From 2001 to the 'global financial crisis' the rock was a popular export, being sold under the apt name of Harlequin Stone. Currently the quarry appears to be 'mothballed' and awaiting the return to more financially favourable conditions. The northern Ooralaw quarry is owned and operated by a local farming family, whereas the operator for the southern quarry is AustralAsian Granite Ltd. Details concerning the quarrying and physical properties of Harlequin Stone are illustrated via a poster in Appendix 1 (J. Hough).

Formerly the extent of the Harlequin Stone-type alteration would have been much greater, but a later generation of kaolinite-dominated alteration was responsible for the obliteration much of it. The low marshy valley to the south of the quarry is the geomorphic reflection of the extensive zone of kaolinisation, and provided a site of easy digging for the Wallaroo Marina. Alteration is suggested to extend to considerable depth because the kaolinite zone is prominent as a linear low in regional magnetic imagery. Wallaroo North Beach exposes the kaolinite alteration zone as well as remnants of early high-temperature Oorlano Metasomatite at Pudding Rock and its surrounds.

Wallaroo North Beach, Site W

(Figs 11 and 12)

The following descriptions are derived from Conor (2002), Zang et al. (2002) and Conor and Forbes (2012).

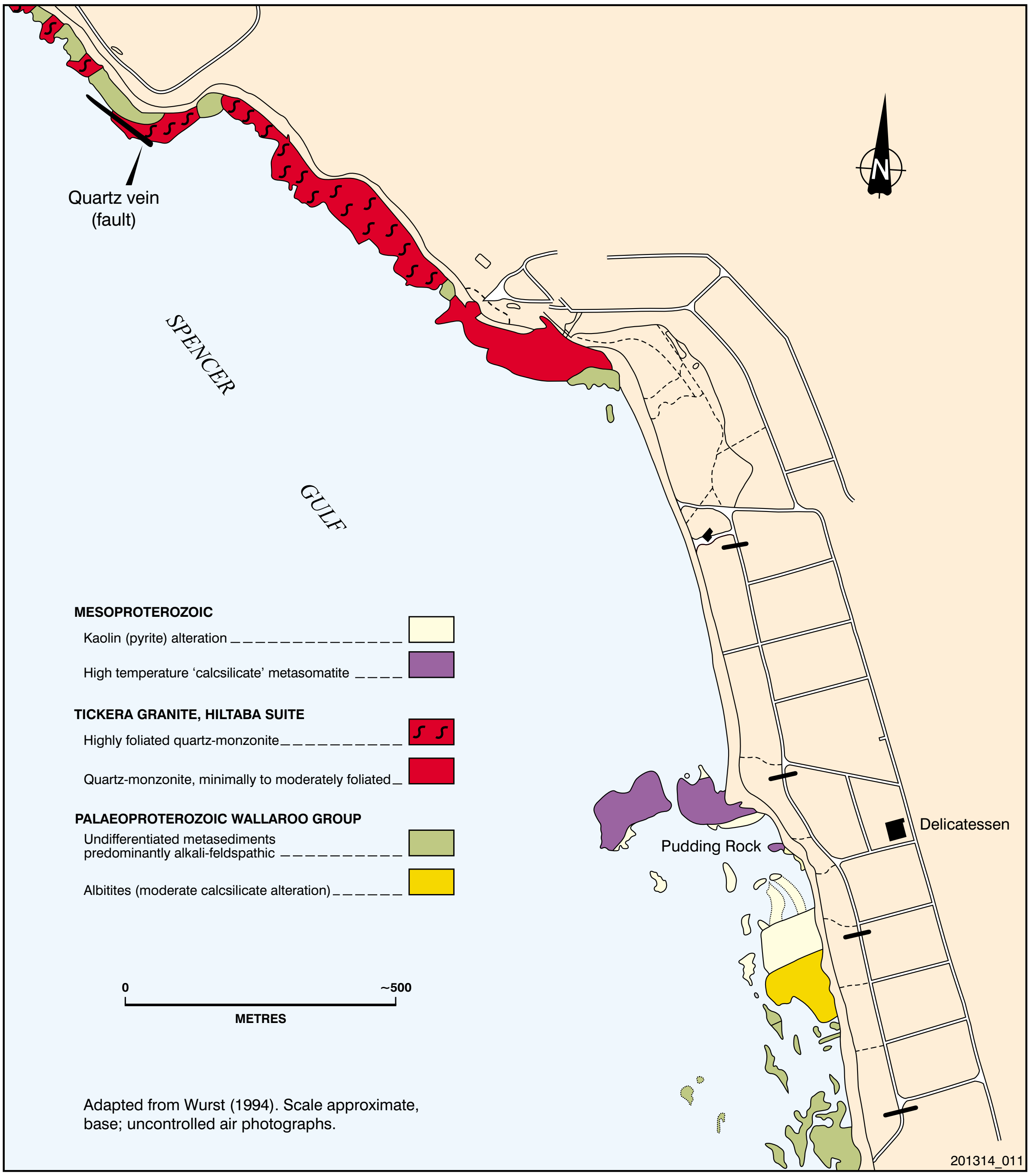


Figure 12 *Geological map of the Wallaroo North Beach area (derived from Wurst, 1994). The Pudding Rock Geological Heritage Site is at the lower right. It appears to be within the metasomatic aureole of the Tickera Granite (to the north). Wallaroo Group metasediments are albitised, then converted to calcsilicate skarn, and this then replaced at a later date by a kaolin-dominated argillic assemblage.*

Geological interest and significance of the Pudding Rock Geological Site

The Pudding Rock Geological Site is of significance as a reference and teaching locality because it encapsulates aspects of the evolution of the Palaeo-Mesoproterozoic iron-oxide copper gold uranium (IOCGU) system that is so economically important to Australia. IOCGU deposits form a broad class that includes much variation, and evidence displayed by the Pudding Rock site is representative of the situation on northern Yorke Peninsula in that it demonstrates the structural control of IOCGU-related metasomatic alteration, and also in this case relates it to a particular point in the structural history. Elsewhere in the region evidence indicates that alteration and shear-dominated deformation are broadly coeval with the introduction of 1600-1575 Ma Hiltaba Suite intrusives bordering which there are intense skarn-like alteration zones. The Wallaroo North Beach site is within the aureole of one such pluton, that of the Tickera Granite, variants of which are beautifully exposed at the north of Wallaroo North Beach and from there around the coast past Point Riley (Figs 12 and 13). Additionally a later kaolinite forming event largely obliterates all precursors, and evidence of this too is visible on Wallaroo North Beach.

The Pudding Rock site can be considered in the following three parts (Fig. 12 and Plate 35):

- Pudding Rock; a hogsback outcrop of sodic calcsilicate altered rock,
- Southern Outcrop; a low-lying W-E strip of folded Palaeoproterozoic Wallaroo Group metasediments
- Intermediate Area; surrounding the above two areas and extending out to sea where there are sporadic outcrops of white-veined kaolinite.

Pudding Rock

Pudding rock is the local name for a small hogsback outcrop that projects through the beach sand (Plate 35). It is crudely layered and composed of an highly inhomogeneous mixture of skarn-like masses of white and pink feldspar-rich rock and light and dark green calcsilicate minerals such as amphibole and epidote. The rock is considered by some to be similar to the semi-precious unakite of the Unakas Mountains of North Carolina. In this South Australian case the rock's formation is attributed to the same calcsilicate alteration seen in the 'Southern Outcrop', but with the process going to the extreme. A house, 100m to the northwest of Pudding Rock, is founded on a promontory composed of similar material, and nearby the same material is mined for export as the prized Harlequin Stone (Plates 33 and 34). Harlequin Stone is classified commercially as an ornamental dimension stone, and is extracted by AustralAsian Granite Pty Ltd (Extractive Mining Leases 5793, 6155), 2 km ESE of Pudding Rock, where, with permission for access, cut faces provide clean displays of this spectacular rock.

These calcsilicate altered rocks of Yorke Peninsula have been given the quasi-stratigraphic name of Oorlano Metasomatite (Conor, 1995), and are mappable as 'highs' in aeromagnetic imagery due to contained magnetite (Fig. 13), and appear to relate to high density areas in gravity imagery (Fig. 14).

Plate 35 General view, looking south. Pudding Rock in the right foreground, the left to right dark-coloured strip in the middle distance is the 'Southern Outcrop', and the area in-between is the 'Intermediate Area'.

Plate 36 *Oorlano Metasomatite at Pudding Rock. A calcsilicate skarn replacement of a siliceous metasediment associated with the aureole of the Tickera Granite. (Photo. W-L Zang)*

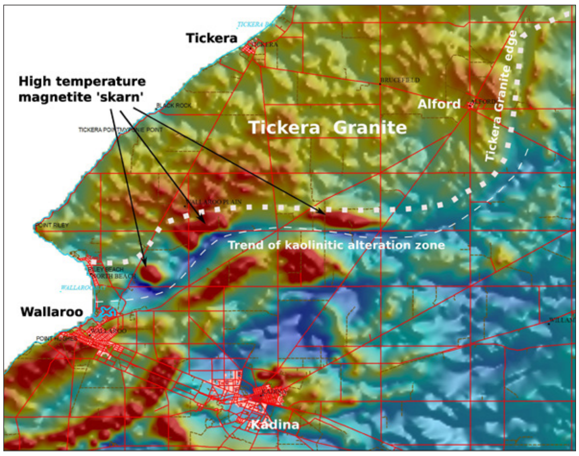


Figure 13 *Regional TMI magnetic image showing, within the aureole of the Tickera Granite, corridors of high intensity areas of magnetite-bearing calcsilicate 'skarn' (red), and low intensity kaolinite-dominated argillic alteration (blue).*

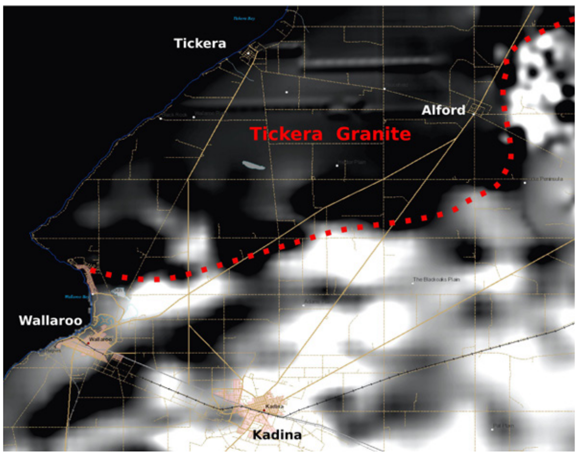


Figure 14 *Regional gravity image showing the approximate pluton boundary (red), the white patches proximal to the margins represent remnants of high density magnetite-bearing calcsilicate metasomatite.*

Southern Outcrop

Thinly planar-bedded metasediments have been largely albitised (i.e. metasomatically converted into sodic feldspar). Prior to albitisation these sediments were perhaps fine-grained sandstone, siltstone and calc-siltstone. The broad fabric of the outcrop is controlled by west-southwesterly trending, upright, open to chevron folds, with fold axes tending to shallowly plunge in the same direction, i.e. WSW. The vertical axial cleavage planes are commonly picked out by calcsilicate minerals such as dark green amphibole, and in places form the loci of small breccia bodies (Plate 37).

Plate 37 *Detail from the 'Southern Outcrop' of calcsilicate alteration assemblage emplaced along the cleavage (parallel to the knife) of the second fold event mentioned in the text.*

The same calcsilicate mineral assemblage invades particular layers adjacent to the cleavage planes giving rise to classic 'Christmas tree' alteration features, where susceptibly replaced 'horizontal' beds mimic branches extending from a central 'vertical' mineralising trunk structure. Locally it can be seen that the upright fold-set has deformed an earlier generation of flatter-lying long-limbed isoclinal folds (Wurst, 1994) (Plates 37-39). Arcaro (2000) studied this locality in detail and interpreted four deformation events, the first being the metamorphic layering, which is likely to relate to bedding.

Plate 38 *The 'Southern Outcrop' view looking west-southwesterly along the axis of the second generation open upright fold set. The yellow drawing below the scale highlights a refolded isoclinal mesofold set.*

Plate 40 *Kaolinised ground in the 'Intermediate Area', partly overlain by pebbles, the smooth elongate body in the foreground is composed of veined kaolinite rock. View looking inshore, southeasterly towards Wallaroo North Beach with the 'Southern Outcrop' appearing on the right hand side just this side of the dunes.*

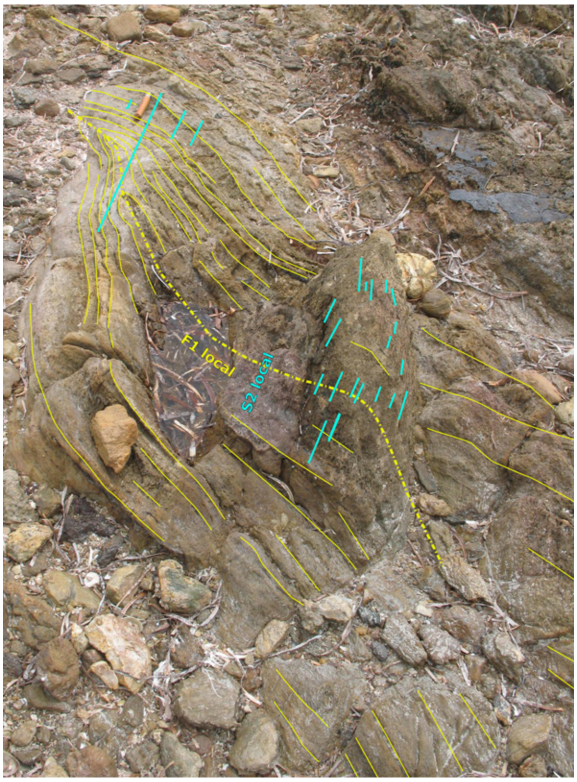


Plate 39 *Refolded fold, another example of an early fold (S0 and IF1 axis yellow, later S2 cleavage cross-cutting).*

Intermediate area

The bedding of the metasediments of the Southern Outcrop loses its layered characteristic at the edge of outcrop, this is due to kaolinisation caused by a third generation of alteration. The same is true of the margins of the promontory to the north, and would probably be true of Pudding Rock if the beach sand was to be stripped away. Low outcrops of white-veined kaolinite of the Intermediate Area are visible in the vicinity of the Southern Outcrop and also northwards towards Pudding Rock (Plate 40).

The kaolinite is developed in a broad W-E zone stretching for several kilometres to the east of Wallaroo North Beach and curving to follow the Tickera Granite contact. Being readily eroded this zone of argillic alteration is geomorphically marked by the broad valley mentioned above, and nearer the Wallaroo township the Copper Cove Marina was excavated by easy digging of the kaolinite rock. Pudding Rock, the mass comprising the northern promontory, and the Southern Outcrop are now but relicts of hard rock embedded in a mass of soft kaolinite. Aeromagnetic imagery clearly defines and contrasts areas of magnetite-bearing sodic calcsilicate alteration with the zone that underwent argillic alteration. This is because the magnetite, formed during the former high temperature event, was obliterated during the later low temperature kaolinisation (Fig. 13).

The Wallaroo North Beach Geological Site not only displays examples of rock formed by the metasomatic alteration associated with IOCGU mineralisation of Yorke Peninsula, but also provides some insight into the timing and evolution of this important geological event. The bulleted passage below shows stages of the geological history in this part of Olympic Domain, with text in bold indicating evidence provided by the Pudding Rock site.

Summary of the geological history — Palaeoproterozoic to Adelaidean

- c.1750 to 1730 Ma. **Deposition of sediments into a basin** formed by extension and attenuation of the earth's crust, these processes being evidenced by coeval A-type felsic and mafic magmatism, e.g. Moonta Porphyry.
- **Burial of the volcano-sedimentary pile, isoclinal folding and metamorphism**, possibly associated with the 1730 to 1690 Ma Kimban Orogeny.
- c.1600 to 1575 Ma. Tectono-thermal event including partial melting, Hiltaba Granite intrusion, shear-dominated deformation, overthrusting, **albitic alteration, upright folding, high temperature calcsilicate alteration,** copper-gold mineralisation.
- **Low temperature kaolinite alteration**, faulting, possibly copper-gold mineralisation.
- **Uplift and erosion**, followed by deposition of the sediments of the Adelaide Geosyncline and Stuart Shelf.

State of preservation and protection of site

The site is of State significance. Preservation is very good, but, comprising outcrops on a popular beach in an area undergoing development, the site requires protection. It is recommended that informative signs be erected, and that the Southern Outcrop and Pudding Rock be protected against damage and destruction or burial. Sampling for improving scientific understanding should be strongly controlled to avoid the loss of critical features.

Site W1

Oorlano Metasomatite forms a promontory, upon which a house is built marginally above the current high water mark. This calcsilicate lithology is well washed and so is cleanly exposed, and is similar to that viewed at Stop 1.

Along the southern edge of the promontory, hopefully not obscured by sea grass, is a ferruginous kaolinite-rock. This is interpreted as an extension of the large kaolinite ± siderite±pyrite (±chalcocite) body which was intersected by the drilling of the NBH/WMC Alford Prospect 5 km to the east.

Sites W1–W2

It is presumed that much of the beach over this section is underlain by kaolinite-rock. At low tide some small pavements of the kaolinite-rock show dendritic clay veining. Such textures, the presence of siderite and pyrite below the limit of surface oxidation, and the unplumbed vertical extent of the body, suggest that its origin is arguably due to hydrothermal processes rather than weathering. Pudding Rock (Plate 35) is a remnant mass of calcsilicate metasomatite in which possible primary layering is still vaguely visible.

Site W2

The southern margin of the kaolinite-body is well exposed and contains remnant enclaves of the precursor metasediment. The bulk of the exposure at Stop 2.2 comprises laminated albitite metasediment (albite > magnetite or actinolite > quartz, biotite). There are prominent shallow, southwesterly plunging upright folds with an obvious axial planar cleavage (local F2, S2). These upright folds deform a set of apparently sub-horizontal isoclines (local F1).

Calcsilicate metasomatism is constrained to syn- to post F2 development as evidenced by amphibole veining forming a network controlled by the local S2 cleavage and bedding (Christmas tree structuring).

Point Riley – Wallaroo North Beach, Site R

This section from Point Riley to Wallaroo North Beach is one of the few good coastal traverses, not only of northern Yorke Peninsula, but also of the entire Olympic Domain. This is a true section of about two kilometres normal to the structural trend, it displays the contact relationships cleanly between the Hiltaba Suite Tickera Granite complex and metasediments of the Wallaroo Group. Andrew Wurst (1994) completed a very useful Honours study in the area, including mapping this coastal strip and the maps are his.

One would require days to look at this section properly, therefore time allows only brief stops at certain salient points (i.e. Stops 3.1–3.10; Fig. 15).

Features of interest:

Various phases of the Tickera Granite (quartz monzonite, leucotonalite and pegmatites).

The varying deformation of the Tickera Granite.

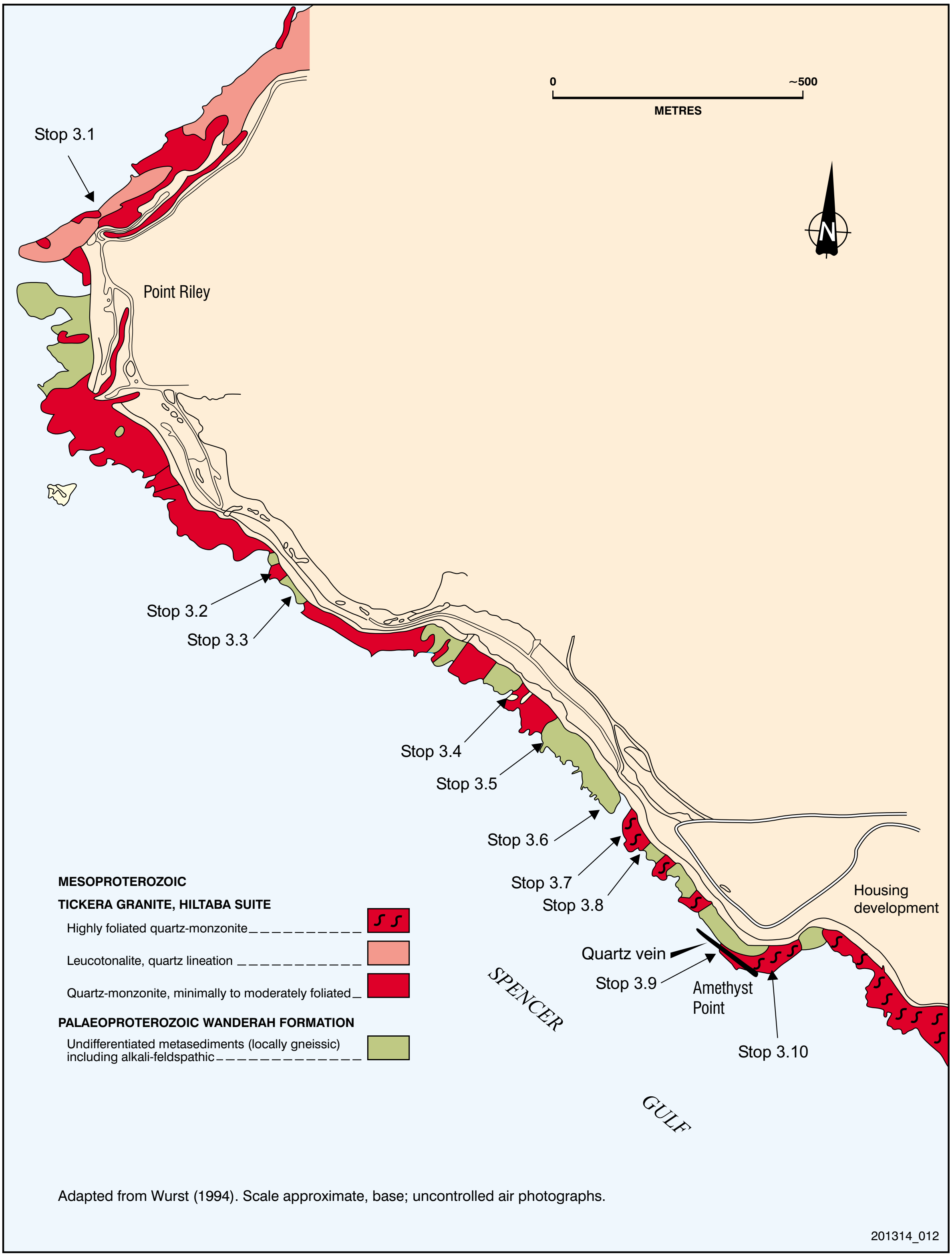


Figure 15 *Site R 3.1 -3.10. Coastal section from Point Riley to Wallaroo North Beach exposing a structural cross section of the Tickera Granite complex with large enclaves of altered Wandearah Formation metasediments. (Adapted after Wurst, 1994; Conor, 2002; Zang et al., 2002).*

Pegmatites, again showing various states of deformation, partly related to timing.

A foliation, shared by the granite and contained metasediments which controls the orientation of the northeast-trending portion of the coast (Fig. 15). All the main penetrative fabrics (including primary layering and the schistosity within metasediment enclaves) faithfully parallel this trend.

Fold axes plunging at various orientations within the plane of the foliation.

An orthogonal, laminated, quartz-filled fracture set which controls the orientation of the southeast-trending portion of the coast.

A variety of metasediments are exhibited by variably sized enclaves. There are two main types of layered metasediment: the more common, pale brown 'planar banded', leucocratic feldspathic metasediment, and the less common, bluish-grey calcsilicate metasediment. Xenoliths also preserve evidence for polyphase folding. Extremely high modal proportions of alkali–feldspar, and in some cases biotite, indicates metasomatic activity. As at Cloncurry in the Mount Isa District the timing of feldspar formation is complex.

Site R3.1

North, northeasterly-trending coast of Point Riley (Fig. 15). Three or more phases of the Tickera Granite are exposed. Two spatially dominant ones are a coarse grained, red-brown highly weathered quartz–monzonite (microcline = plagioclase > quartz >> biotite = opaques) and a finer grained, white leucotonalite (plagioclase > quartz >> opaques >> biotite) (Plate 41). The boundaries between the two phases are not sharp, and there is no clear-cut temporal difference between the two and both are foliated. (Plate 42) Harder less weathered granite nodules contained within in quartz-monzonite either represent parts that were less effectively strained, or another phase that was disrupted during intrusion (Plate 42).

The leucotonalite is marginally S-type rather than I-type (Wurst 1994), quartz aggregates show a definite but subtle foliation, i.e. it is a meta-leucotonalite. A sample from this locality produced a U–Pb age of 1598 ± 7 Ma (Fanning in Conor, 1995). The quartz-monzonite has more I-type characteristics (Wurst, 1994) and the weathered surface highlights the pervasive northeasterly trending foliation.

Plate 41 Three granite phases of the Tickera Granite complex. The quartz-monzonite in the foreground and the white leucotonalite are both foliated, the upstanding red pegmatitic granite in the background is not foliated and bears miarolitic cavities.

Plate 42 The three phase of granites (tonalite represented by a piece of float). The pencil marks transecting of foliation in the quartz-monzonite by the late red granite. A 'knot' (lower left) perhaps represents an earlier disrupted granite phase.

The third phase is an elongate red coarsely crystalline body, 'sill-like' because it approximately conforms to the trend of the foliation in the host quartz-monzonite, which it appears to postdate. The rock itself is not obviously foliated, and contains miarolitic cavities (A. White pers comm., 1996) (Plate 43), which could be interpreted as indicating crystallisation at shallower crustal levels of lessened hydrostatic pressure. No geochronological information is available (as yet).

Jack (1917) named two sets of granites on Yorke Peninsula, the Arthurton and Tickera Granites. The basis of differentiation related to the effects of deformation, the Arthurton Granite is not obviously foliated, but the Ticker Granite, as exemplified at Point Riley, is. Wurst (1994) showed too that there

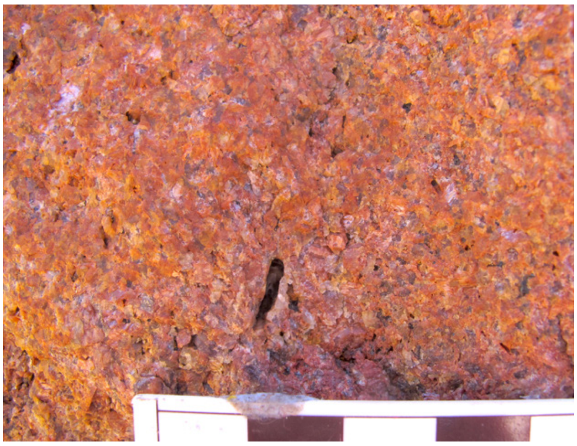


Plate 43 *Miarolitic cavities in the red pegmatitic granite 'sill', (Photo: R. Dart).*

Plate 44 *One of the many deformed metasediment xenoliths contained within the quartz-monzonite (Wandearah Formation) (Photo W-L. Zang).*

geochemical differences separating the Arthurton and Tickera Granites. It is tempting to suggest that since the Arthurton Granite, where exposed near Hillside, is non-foliated and pegmatitic, and the late red granite at Point Riley is similarly undeformed and pegmatitic that the two are genetically related.

Based upon observations at this stop, Conor et al. (2010) suggested that during the 'Hiltaba event' the NYP crust was uplifted from considerable depth (i.e. lower amphibolite facies) to near surface. Aeromagnetic imagery suggests the presence of a major northeasterly-trending structure nearby off-shore, so that the foliation visible along the coast possibly represents a proximal expression. The obvious steeply down-foliation lineations, suggest vertical movement. Kinematic indicators and evidence for boiling accompanying mineralisation at the Poona Mine and Wheal Hughes (Janz, 1990; Morales et al. 2002), are supportive of this structure having accommodated uplift during the 'Hiltaba event' (Conor et al. 2010).

One hundred metres or so the south there is a west-facing beach with a couple of shacks, here are good examples of xenoliths of Wandearah Formation (Plate 44). Such xenoliths are common (Fig. 15) and show a spectacular examples of granitic metasomatism, and deformation. Conor (1995) attributed the more obvious folding to compression coeval with the development of foliation in the containing quartz-monzonite. Arcaro (2000) was of opinion that there was evidence for three deformational events.

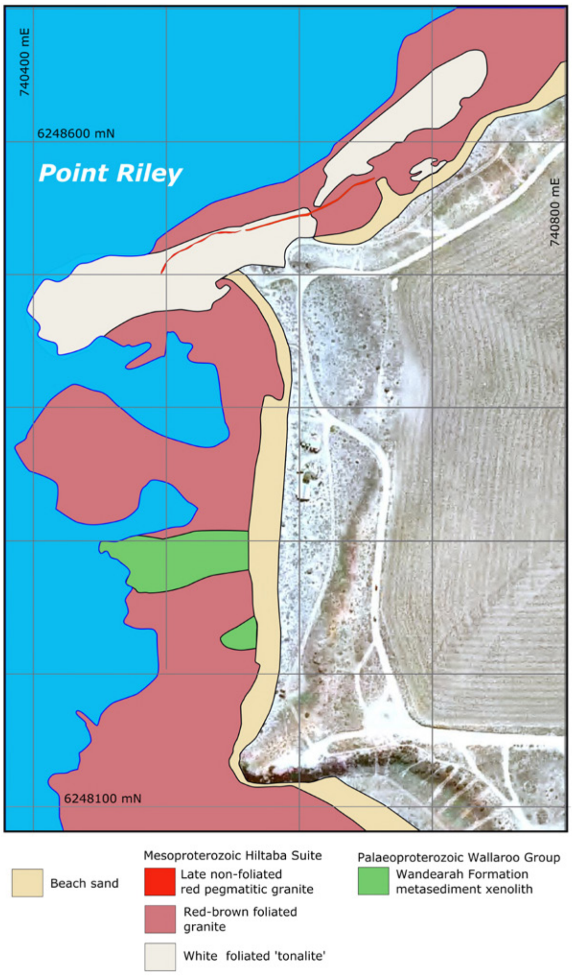


Figure 16 *Geology of Point Riley.*

Site R3.2

Dark greenish-gray alteration of the quartz–monzonite. The principal alteration phases are chlorite and sericite, with hematite and goethite; quartz aggregates and earthy hematite or goethite are obvious in the most altered portions (Plate 45). Prismatic bodies of sericite possibly represent pseudomorphed scapolite.

Plate 45 *Chlorite altered granite at site R3.2 from which a sample was taken for dating (Conor, 1995). This style of alteration is spectacularly displayed further north at Black Rock where it is associated with quartz-veining of the Amethyst Point type.*

Zircons from a chlorite-altered sample taken from this locality gave a U–Pb age of 1583±10 Ma (Fanning in Conor, 1995; Fanning et al., 2007).

At Black Rock, some 8 km to the north-northeast, much of the granite has this grey colour, suggesting a similar style of alteration. At that locality there is extensive veining, infilled by layered extensional quartz veins and earthy hematite (also stop 3.9). A genetic connection between veins and alteration is suggested because locally the grey alteration intensifies towards the veins.

As mentioned above, this part of the coast is orientated parallel to a southeast-trending vein set; the veins are of similar style to those at Black Rock and possibly genetically related to the chloritic alteration at this locality. Elements of the set become increasingly common along the coast to the southeast.

Site R3.3

Layered, alkali–feldspar > biotite metasediment (plagioclase + microcline = quartz > biotite > opaques). The layering is deformed by at least two styles of folding; the earlier is apparently near isoclinal, acute chevron in plan view. The later less regular, asymmetric, dextral vergence folds locally show a link with the intrusive episode by having granitic or pegmatitic veins sub-parallel to the axial planes.

Site R3.4

At this locality a gneissosity has evolved during deformation by the injection of granitic material as veins into the metasediment, the veins have been subsequently folded and boudinaged during northwest–southeast compression (perhaps transpression). The axial planes of some folded veins are intruded by later generations of pegmatite, thus indicating active intrusion into stressed rocks. Amphibole + feldspar clots are suggestive of metasomatic activity (this is a similar assemblage to that seen at Stop 2, Pudding Rock), as is apparent lithification by alkali–feldspar, i.e. 'granitisation'.

Features of interest are:

- Highly deformed calcsilicate metasediment
- Microgranite and pegmatite veins, deformed parallel to S0/S1, intensely folded and boudinaged, with axial plane structures repeatedly intruded
- Amphibole clots formed during the intrusive event
- Indistinct, subvertical rodding of granitic and amphibole boudins
- Apparent patchy lithification of the migmatitic fabric by feldspar (this 'granitisation' process can be studied in further detail at locality 3.5)
- The 'planar' migmatitic fabric is cut by pegmatites and by pink quartz–monzonite, which is essentially undeformed but contains large amphibole clots

Site R3.5

Apart from later granitic dykes, there are two dominant lithologies at this stop; one is leucocratic and feldspar-rich, the other mesocratic and biotite- and amphibole-rich.

Despite obvious layering, veining, and folding, the pale brown feldspathic rock has an overall 'cherty' appearance. Pegmatite veins in the mesocratic lithology show a higher degree of crenulated folding. It is suggested that the felsic body presents a relatively late stage of syn-deformational, feldspathisation restricted to roughly lenticular masses of the country-rock.

It can also be argued that the higher mafic content of the mesocratic lithology represents local chemical differentiation, with alkalis moving from one part (now more mafic) and being redeposited to form the felsic parts. Such a process would also explain the derivation of other biotite-rich bodies exposed along this shore.

Site R3.6

Wurst (1994) recognised that some pegmatite veins were folded while others were not. At this locality there are a number of folded pegmatite sheets with a foliation present at the apices. The degree of plunge of the fold axes is considered to be controlled by the original crack orientation; e.g. original horizontal sheets have low angle fold axes, vertical sheets show steep axes. The folding suggests significant shortening even at the relatively late stage represented by these pegmatites.

Site R3.7

The purpose of this stop is to view a highly deformed, medium-grained, porphyritic quartz–monzonite (plagioclase > microcline = quartz > biotite > opaques) (Plate 46). This lithology, with little variation, continues southeast to the end of this portion of the shore (i.e. Amethyst Point). Zircon U–Pb data from this granitoid gave an age of 1577±7 Ma (Fanning in Conor, 1995; Fanning et al. 2007).

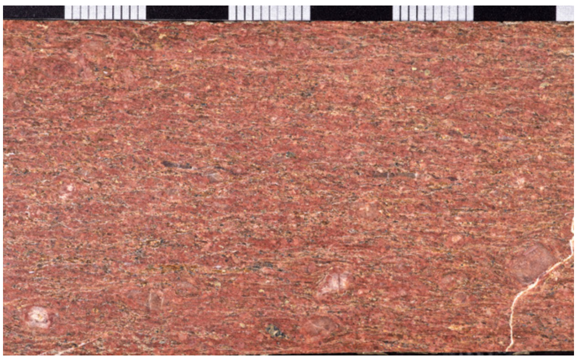


Plate 46 Protomylonite, a highly deformed granite, perhaps originally porphyritic. A few meters to the west of Amethyst Point this granite is visibly coeval with a deformed quartz-monzonite phase.

Site R3.8

This portion of the coast exposes many examples of the southeast-trending Amethyst Point vein set. While both apparent dextral and sinistral displacements are observed, it is possible that bulk sense of movement was dextral.

Sites R3.8-3.9

Deformed granite, albitic metasediment enclaves, southeast-trending quartz veins and locally hematite-bearing matrix breccias.

Site R3.9

Amethyst Point. A large extensional quartz±carbonate±hematite vein cross-cuts the foliation of the quartz–monzonite (Plate 47). This vein, as is typical for all members of a late-stage regional set, shows signs of repeated dilation, e.g. internal brecciation, layered and coliform quartz, and the wall-rocks are brecciated and ferruginised. This vein-set is very similar to that described above at Black Rock where chloritic alteration is intense.

The relative age of veining is equivocal. It is certainly younger than intrusion and deformation of the Hiltaba Suite granites, but being orthogonal to the foliation it may represent late-stage A–C type fracturing. Intriguingly, a case can be made from aeromagnetic imagery for this structure to continue southeasterly to the Wallaroo Mines area at Kadina. Thus was this structure, or a precursor of it, influential in mineralisation? Certainly the late quartz-haematite-chlorite association has been shown to be an important factor in the IOCG mineralisation of NYP (Conor et al. 2010). However it has been suggested (e.g. J. Parker, Geosurveys Australia, pers. comm., 1996; Wurst, 1994) that the vein could be as late as the Cambrian or the Ordovician-Delamerian Orogeny, and Arcaro (2000), who described the fault in detail, considered that it juxtaposes two distinct structural domains.

(The informal name of 'Amethyst Point' relates this vein to findings of amethyst pebbles along the Wallaroo North Beach; elsewhere veins of this type are known to bear amethyst.)

Plate 47 The late-stage complex vein and breccia zone at Amethyst Point (Conor, 1995). This was studied in detail by Arcaro (2000) who suggested that it separated two very different structural domains.

Site R3.10

The contact of the medium-grained quartz–monzonite and a coarser grained variant is exposed. The contact is not seriously disrupted, although both lithologies contain the same coarse L-S fabric. The metasediment enclave at this locality contains transposed mesofolds with sub-horizontal axes.

Site R3.11 to Wallaroo North Beach.

The southeastern margin of the main Tickera Granite mass is situated a further 400 m to the southeast; the rock is foliated for all this distance, apart from the final 50 m which comprises an undeformed, tourmaline-rich granite (Wurst, 1994).

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Appendixes

Appendix 1. Harlequin Stone poster (J. Hough)

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HARLEQUIN STONE
Oorlano Metasomatite

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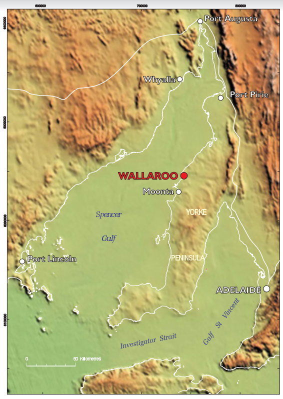
INTRODUCTION

Harlequin Stone is an 'ornamental granite' building stone currently produced by AustralAsian Granite Pty Ltd from Kelly's Farm Quarry, 3 km north of Wallaroo on northern Yorke Peninsula. Wallaroo, 160 km northwest of Adelaide, is the key shipping port for the peninsula and is a thriving town with a history of copper smelting dating from the 1860s.

Kelly's Farm Quarry



Digital Terrain Model of Yorke Peninsula and surrounding region

BACKGROUND

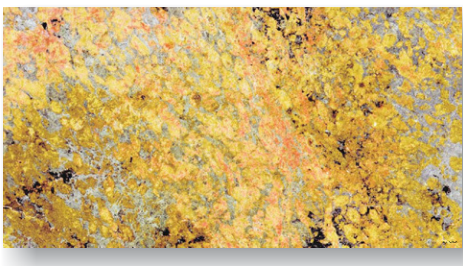
The Oorlano Metasomatite (Harlequin Stone) was first intersected in drillholes during the early 1950s by the Department of Mines whilst exploring the area for iron ore deposits, and it was then that the beautiful greens and pinks of this enigmatic rock were noticed. The stone was 're-discovered' during quarrying operations in the late 1990s on Extractive Mineral Lease (EML) 5793 granted to Aldeford Pty Ltd. The EML was originally granted for the mining of calcrete during construction of the Wallaroo marina. Once the surface calcrete was removed, the Oorlano Metasomatite was exposed and it was then that its potential as a building stone was realised.

The quarry is now operated and being developed to its full potential by AustralAsian Granite Pty Ltd. Harlequin Stone from this quarry is currently the state's most popular 'granite' building stone. The stone can also be seen at the Port Hughes jetty breakwater.

The quarry has now produced about 5500 t of the metasomatite. Production of Harlequin Stone has steadily increased since 2001, with the quarry producing an average of 2500 t/y. Continued demand for the stone from international buyers has seen record production in the six-month period to June 2003.

Kelly's Farm Quarry, showing newly cut faces of the Harlequin Stone

Sawn slab of Harlequin Stone



GEOLOGY

Oorlano Metasomatite (Conor, 1995) was originally a layered, calcareous sedimentary rock of Palaeoproterozoic age that has had its composition altered by interaction with hot fluids produced at the same time as the nearby intrusion of granite. These granites are part of the widespread Mesoproterozoic Hiltaba Suite on the Gawler Craton.

The metosomatite is a medium-grained, green and pink mottled rock dominated by a calcsilicate and iron-rich mineral assemblage. Its distinctive green and pink colouring is due to the minerals actinolite, epidote and feldspar. Accessory minerals include pyroxene, plagioclase feldspar, amphibole, dolomite, magnetite, quartz, sphene and pyrite, with traces of chalcopyrite and apatite. Adelford Pty Ltd reported that drilling of three holes to a depth of 12 m on EML 5793 had demonstrated a resource of 200 000 m^3 (PIRSA, 1999).

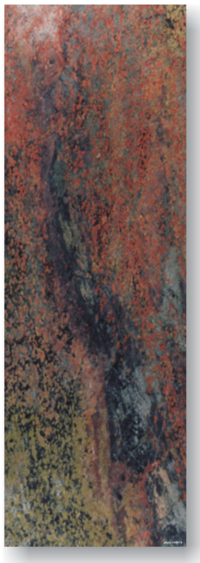
Outside of the quarry, the Oorlano Metasomatite has limited outcrop and can only be seen at Wallaroo North Beach just above the high water mark where it occurs as the foundation to a house built, somewhat unusually, out to sea. It occurs below the surface as a number of small lozenge-shaped features north of the Wallaroo marina (Fig. 1). The subcrop extent of the metasomatite has been determined by drillhole data only. Scattered fragments of the rock can be seen in the soil in some paddocks to the north of the quarry. Figure 1 shows the inferred boundary where the metasomatite may occur close to the surface.

GEOTECHNICAL SPECIFICATIONS

Geotechnical testing of Harlequin Stone by AMDEL (Amdel, 1998) produced the following results from a sample obtained from Kelly's Farm Quarry.

Compressive Strength (Mpa)	
Mean dried strength	206.3
Mean soaked strength	218.0
Flexural Strength (Mpa) Loaded parallel	
Mean dried strength	7.2
Mean soaked strength	13.3
Flexural Strength (Mpa) Loaded perpendicular	
Mean dried strength	18.7
Mean soaked strength	23.6
Water Absorption	
% by weight	0.16
% by volume	0.47
Bulk Density	2.96 tm^3
Index of Abrasion Resistance	87
Accelerated Weathering	No sign of sulphide staining
Dimensional Stability (% line change) after 10 wet/dry cycles	
Vertical	-0.001
Horizontal	+0.001

NB: Igneous rocks may display a natural variation in geological and technical characteristics.



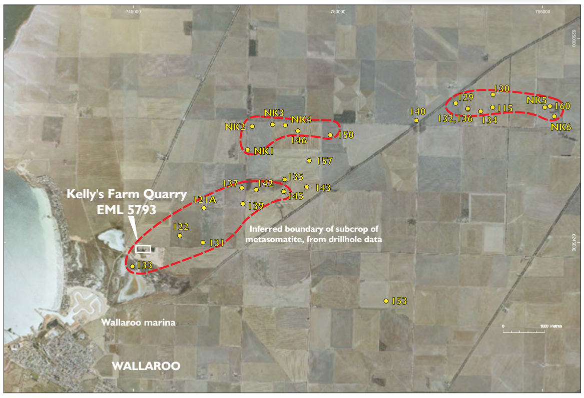


Fig. 1 Aerial photograph of the Wallaroo area showing drillhole locations and inferred metasomatite boundary

APPLICATIONS AND FINISHES

The physical testing by AMDEL has shown that Harlequin Stone has high abrasion resistance, high bulk density, low water absorption, and is dimensionally stable. The stone would comply with most specifications where used for paving and veneer cladding. Harlequin Stone has proved very popular for use in monuments, bench tops and ornamental tables. Large blocks of the stone are quarried for domestic and international markets.

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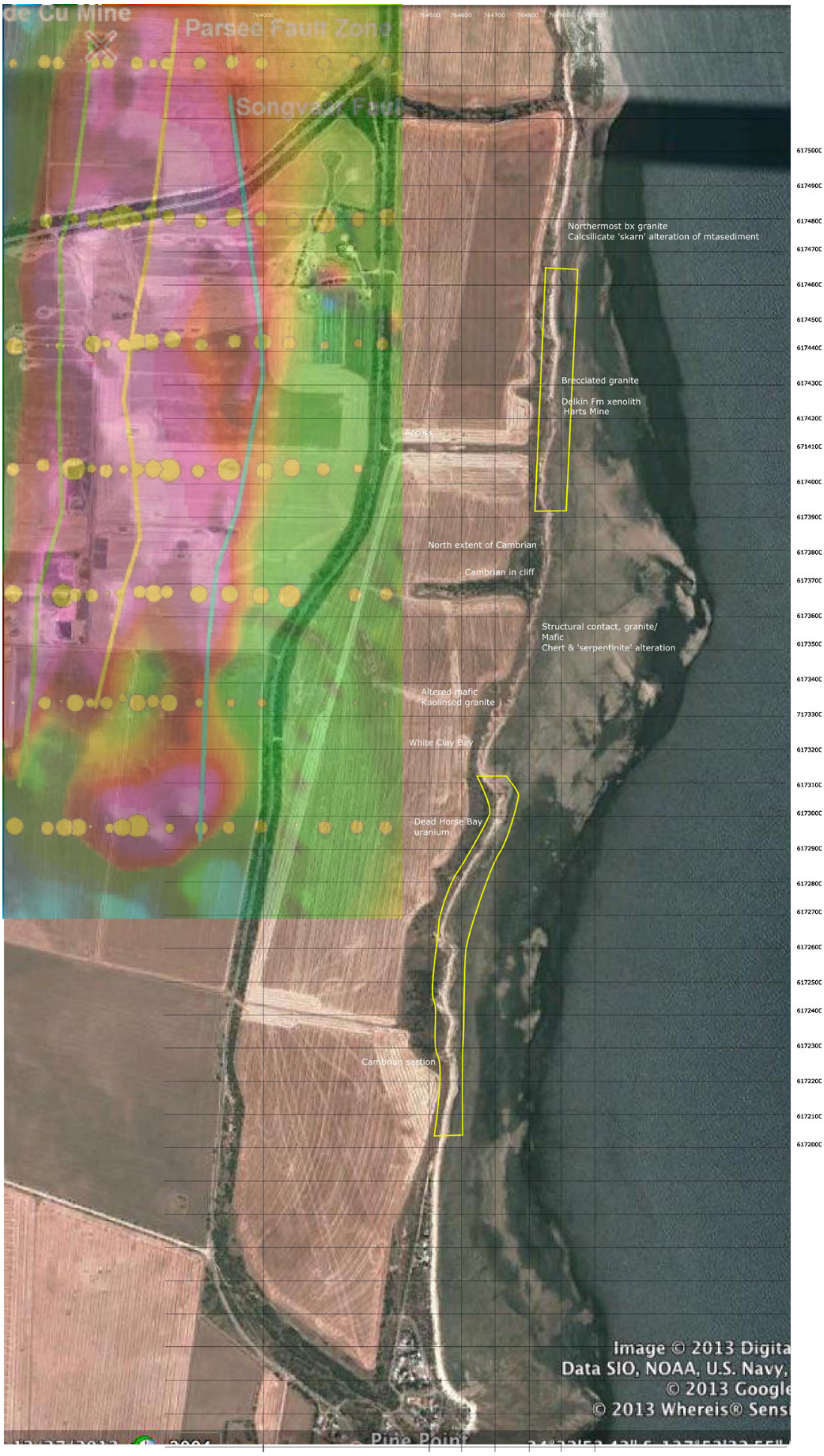
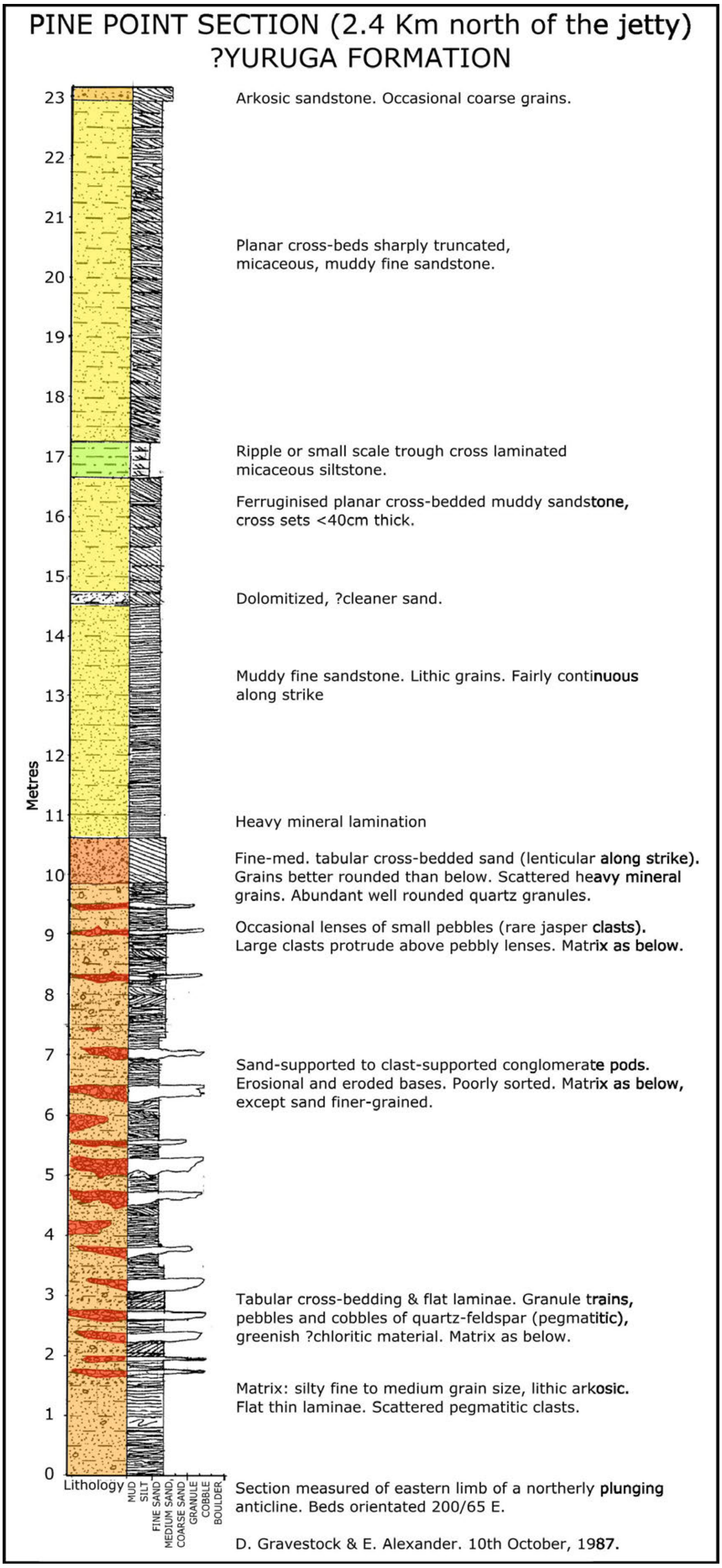
Appendix 2. Locations of Geological Monuments YK4 and YK5, Hillside coastal area (McBriar and Giles, 1984). The magnetic anomaly representing the Hillside Project mineralisation is also shown.



Appendix 3. Geological section of the Yuruga Formation near Pine Point.



The mid-Cambrian Yuruga Formation was named from drilling by Daily (1976, 1990). However these sands and conglomerates that crop out north of Point Riley give a broader picture of this exposed part of the Yuruga Formation. The quantity of locally derived granite in the channel-fill gravels suggest tectonic activity at the time of deposition. The section measured by Gravestock and Alexander (1987) and the figure displayed here has not been previously published.

Appendix 4. Geochemical analyses of three rocks from the Hillside Project coast.

Chemical analyses (Niton) of three samples from the coast near the Hillside Project area, contributed by Rex Minerals Ltd
Mafic and ultramafic in the vicinity of 53 764810mE 6173530mN. Harts Mine 764870mE 6174160mN

Date	Time	Instrument SN	Model	Tube Anode	Unit	Mode	Reading	Elapsed Time 1	Elapsed Time 2	Elapsed Time 3	Elapsed Time Total	LOD Sigma	SAMPLE ID	Comment	Cu	Cu +/-	P	P +/-
9/04/14	8:35:56	510106	Delta Premium	Ta	PPM	Soil	#2	29.74	29.32	29.92	88.98	3	UM1	Ultra mafic outcrop	60	4	<LOD	1350
9/04/14	8:38:41	510106	Delta Premium	Ta	PPM	Soil	#3	29.61	29.39	29.91	88.91	3	UM1	Ultra mafic outcrop	101	6	<LOD	1464
9/04/14	8:40:38	510106	Delta Premium	Ta	PPM	Soil	#4	29.44	29.14	29.83	88.41	3	UM1	Ultra mafic outcrop	198	6	<LOD	1546
9/04/14	8:42:27	510106	Delta Premium	Ta	PPM	Soil	#5	29.38	29.07	29.87	88.32	3	UM2	Ultra mafic outcrop	189	6	<LOD	1295
9/04/14	8:44:58	510106	Delta Premium	Ta	PPM	Soil	#7	29.45	29.17	29.91	88.53	3	UM2	Ultra mafic outcrop	49	4	<LOD	1217
9/04/14	8:47:25	510106	Delta Premium	Ta	PPM	Soil	#9	29.52	29.16	29.86	88.54	3	UM2	Ultra mafic outcrop	62	4	<LOD	1375
9/04/14	8:49:17	510106	Delta Premium	Ta	PPM	Soil	#10	29.59	29.35	29.86	88.8	3	HM1	Shore platform - Harts Mine	144	7	<LOD	1741
9/04/14	8:51:08	510106	Delta Premium	Ta	PPM	Soil	#11	29.49	29.25	29.74	88.48	3	HM1	Shore platform - Harts Mine	135	7	<LOD	1430
9/04/14	8:53:05	510106	Delta Premium	Ta	PPM	Soil	#12	29.69	29.5	29.87	89.06	3	HM1	Shore platform - Harts Mine	20	5	<LOD	1922

Comment	S	S +/-	Cl	Cl +/-	K	K +/-	Ca	Ca +/-	Ti	Ti +/-	V	V +/-	Cr	Cr +/-	Mn	Mn +/-	Fe	Fe +/-
Ultra mafic outcrop	3352	220	864	169	370	78	81878	989	278	17	7	2	<LOD	19	776	15	18154	142
Ultra mafic outcrop	4704	278	1517	209	963	99	71175	974	2367	50	26	4	<LOD	25	1257	23	29051	232
Ultra mafic outcrop	3318	239	2941	222	1276	97	102894	1262	173	20	50	3	49	9	3463	47	46225	318
Ultra mafic outcrop	3397	201	<LOD	447	433	71	108489	1137	182	14	8.5	1.9	<LOD	17	1257	18	17505	129
Ultra mafic outcrop	464	141	580	149	1414	85	83103	935	253	15	<LOD	5.6	<LOD	17	733	13	14584	114
Ultra mafic outcrop	6364	271	1368	177	1266	87	90135	1040	184	17	11	2	<LOD	21	1571	23	29076	205
Shore platform - Harts Mine	3442	292	8290	351	56247	827	100270	1351	2701	55	260	7	117	12	842	18	50573	396
Shore platform - Harts Mine	<LOD	629	2015	231	49123	734	43897	630	1998	48	261	7	109	14	12177	164	88028	653
Shore platform - Harts Mine	6425	375	20210	552	45484	739	101231	1463	1492	43	206	7	44	12	1129	23	83501	707

Comment	Co	Co +/-	Ni	Ni +/-	Zn	Zn +/-	As	As +/-	Se	Se +/-	Rb	Rb +/-	Sr	Sr +/-	Zr	Zr +/-	Mo	Mo +/-
Ultra mafic outcrop	<LOD	87	<LOD	12	39	3	<LOD	3.8	<LOD	2.3	<LOD	2.4	15.6	0.9	46.2	1.4	<LOD	2.9
Ultra mafic outcrop	<LOD	117	<LOD	13	60	4	<LOD	4.4	<LOD	2.6	5.1	1	67	2	202	4	<LOD	4.1
Ultra mafic outcrop	<LOD	132	14	5	49	3	<LOD	4	<LOD	2.5	2.9	0.9	33.9	1.2	52.8	1.5	<LOD	3
Ultra mafic outcrop	<LOD	79	<LOD	11	40	3	<LOD	3.5	<LOD	2.4	<LOD	2.3	37.1	1.2	12.7	0.9	<LOD	2.5
Ultra mafic outcrop	<LOD	74	<LOD	11	30	3	<LOD	3.6	<LOD	2.3	<LOD	2.4	45.4	1.4	78.9	1.8	<LOD	2.9
Ultra mafic outcrop	<LOD	104	14	4	53	3	<LOD	3.8	<LOD	2.3	4.4	0.8	93	2	10.7	1	<LOD	2.6
Shore platform - Harts Mine	<LOD	156	<LOD	15	9	3	11.7	2	<LOD	3.2	369	4	237	5	49	2	<LOD	4.1
Shore platform - Harts Mine	<LOD	200	47	7	53	4	12	2	<LOD	3.3	377	4	165	3	70	2	<LOD	4
Shore platform - Harts Mine	<LOD	225	<LOD	18	16	3	8	2	<LOD	3.2	365	5	200	5	21	2	<LOD	4.2

Comment	Ag	Ag +/-	Cd	Cd +/-	Sn	Sn +/-	Sb	Sb +/-	W	W +/-	Hg	Hg +/-	Pb	Pb +/-	Bi	Bi +/-	Th	Th +/-	U	U +/-
Ultra mafic outcrop	<LOD	11	<LOD	17	<LOD	29	<LOD	37	<LOD	18	<LOD	7	<LOD	4.3	29	7	<LOD	4.3	<LOD	4.3
Ultra mafic outcrop	<LOD	13	<LOD	19	<LOD	33	<LOD	42	<LOD	21	<LOD	7	<LOD	5.1	<LOD	24	<LOD	5.4	<LOD	5.8
Ultra mafic outcrop	<LOD	11	<LOD	17	<LOD	29	<LOD	37	<LOD	19	<LOD	7	<LOD	5	<LOD	21	<LOD	4.4	8.7	1.9
Ultra mafic outcrop	<LOD	11	<LOD	16	<LOD	27	<LOD	34	<LOD	17	<LOD	6	<LOD	4.1	21	6	<LOD	4	<LOD	4.1
Ultra mafic outcrop	<LOD	11	<LOD	17	<LOD	28	<LOD	36	<LOD	17	<LOD	6	<LOD	4.3	30	7	<LOD	4.3	<LOD	4.6
Ultra mafic outcrop	<LOD	11	<LOD	16	<LOD	27	<LOD	35	<LOD	18	<LOD	7	<LOD	4.5	<LOD	21	<LOD	4.4	<LOD	5.1
Shore platform - Harts Mine	<LOD	13	<LOD	20	<LOD	34	<LOD	44	<LOD	24	<LOD	9	13	2	<LOD	28	37	3	<LOD	12
Shore platform - Harts Mine	<LOD	12	<LOD	19	<LOD	32	<LOD	41	<LOD	23	<LOD	8	10	3	<LOD	28	38	3	13	4
Shore platform - Harts Mine	<LOD	14	<LOD	22	<LOD	37	<LOD	47	<LOD	24	<LOD	9	9	2	<LOD	29	<LOD	7	18	4

Niton XRF analyses for the Hillside Coast (credit: Rex Minerals)