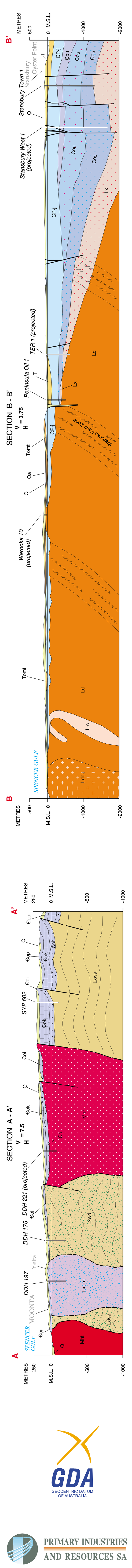
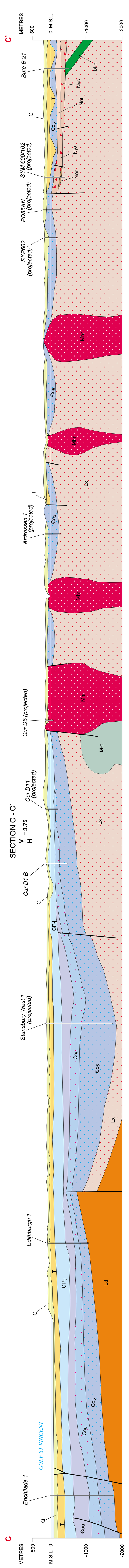
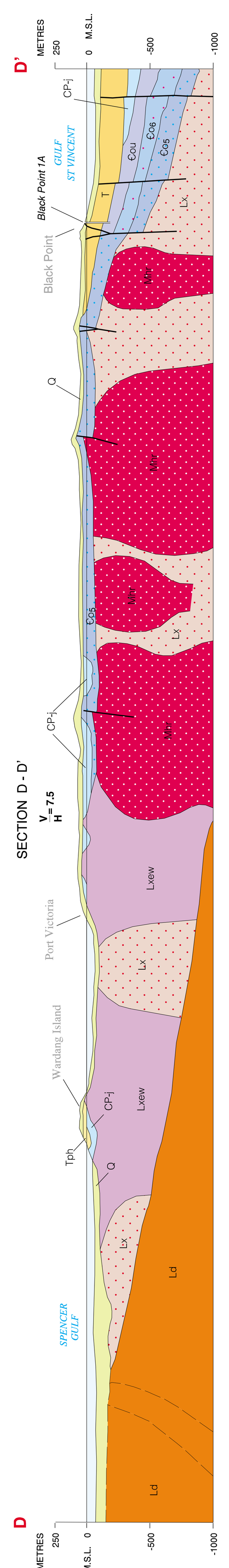
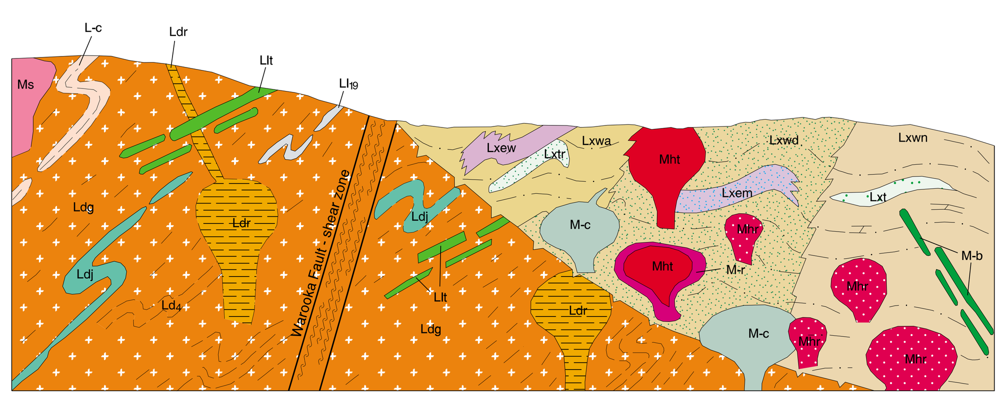
MAITLAND SPECIAL

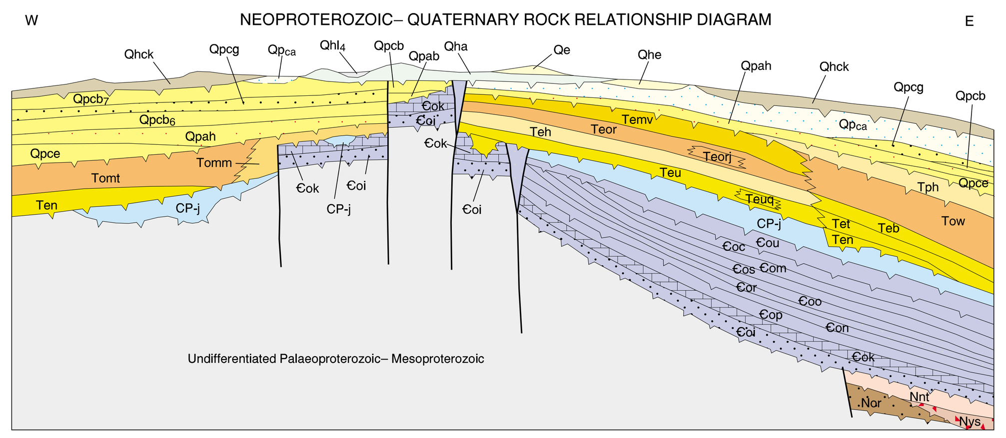
GEOLOGICAL SURVEY OF SOUTH AUSTRALIA
DEPARTMENT OF PRIMARY INDUSTRIES AND RESOURCES SA

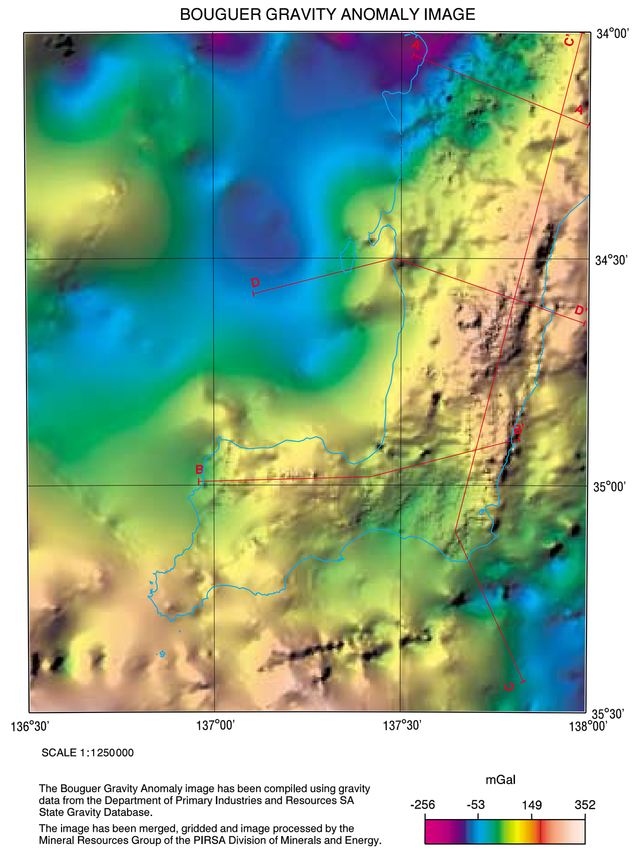


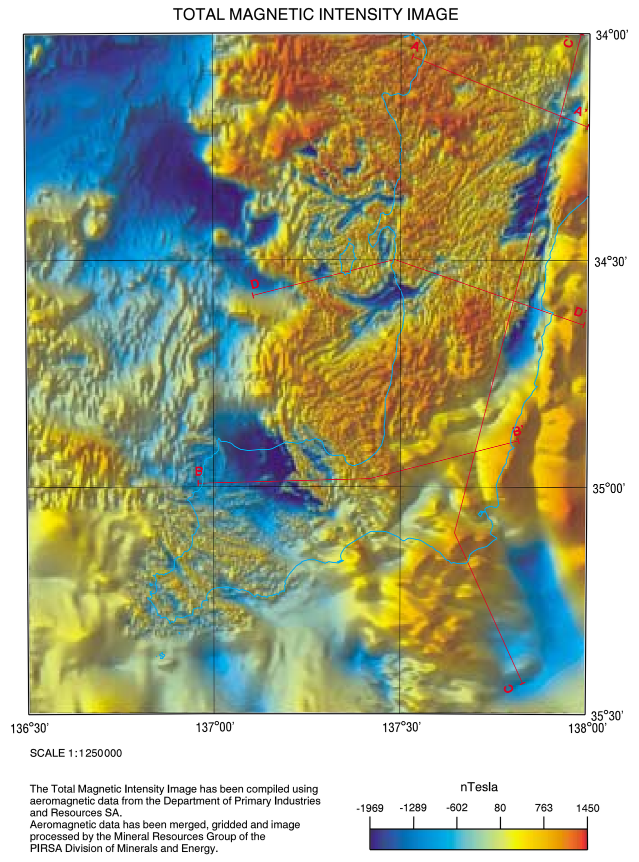


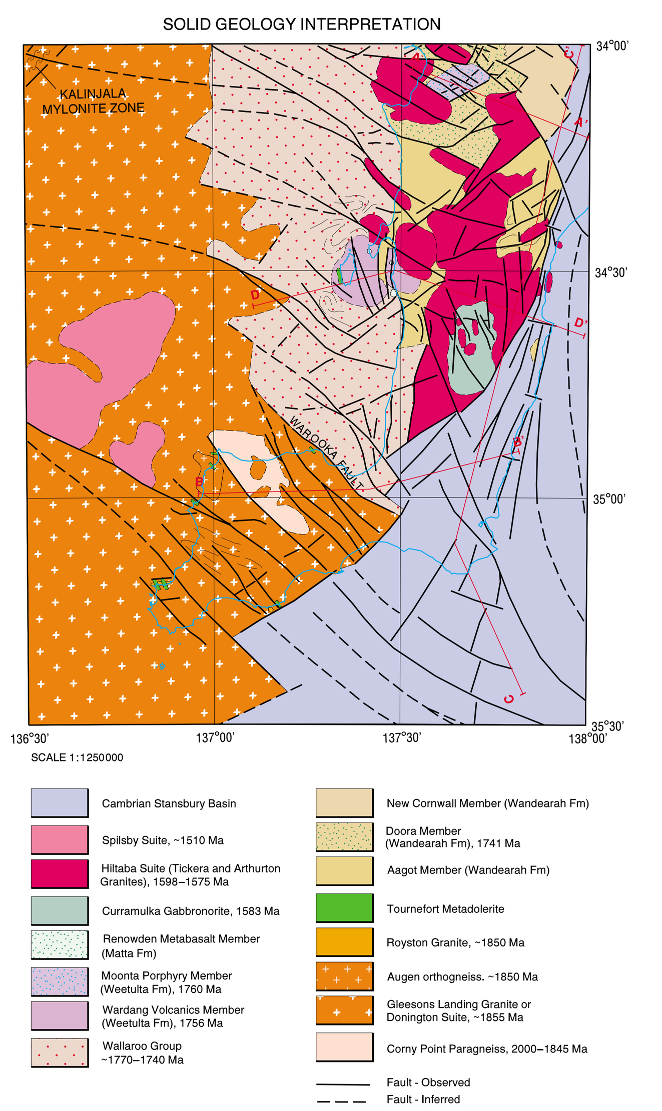












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Published 2003

GDA
GEOCENTRIC DATUM OF AUSTRALIA

PRIMARY INDUSTRIES AND RESOURCES SA

The Honourable Paul Holloway, MLC,
Minister for Agriculture, Food and Fisheries,
Minister for Mineral Resources Development.

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Transverse Mercator Projection, Geocentric Datum Australia, 1994.

Geological mapping and compilation by W. Zang Ph.D., from geological mapping by A.R. Crawford, M.Sc. (First Edition), with contributions from departmental mapping, company reports and university theses, Geological Survey Branch.

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Spatial Information Services,
Primary Industries and Resources SA.
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Digital data available from Primary Industries and Resources SA.

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Jim Hallion, Chief Executive.
Department of Primary Industries and Resources SA.

SECOND EDITION 2003

GEOLOGICAL SURVEY SOUTH AUSTRALIA

REFERENCE

CAINOZOIC – QUATERNARY (Q)

HOLOCENE

Qhck ST KILDA FORMATION: Undifferentiated Holocene coastal marine sediment. <7000 years to present.

Qhckh LE HUNTE MEMBER: Gypsiferous lacustrine sediment of coastal saline lakes. Carbonate sand with gastropod fossils, veneered by yellow siliceous sand. Stromatolites. Basal with seagrass *Posidonia.*

Qhcks SEMAPHORE SAND MEMBER: Unconsolidated, white bioclastic quartz–carbonate sand of modern beaches and transgressive dune fields.

Qhckg GANTHEAUME SAND MEMBER: Unconsolidated aeolian cliff-top dunes and sand spreads. Originates from aeolian reworking of Bridgewater Formation, particularly out of receding coastal cliffs.

Qhck6 Samphire–algal marsh facies. Mottled red-brown and grey, fossilised burrows and roots, soft organic, shelly carbonate or terrigenous mud. Common *Katelysia* and *Bembicium*.

Qhck8 Intertidal flat facies of shelly and quartz-rich muddy sand, unconsolidated, bare or *Zostera*-colonised. Veneered by cobbles and gravel.

Qha Recent undifferentiated alluvial or fluvial sediments, orange mottled sand and clay with ironstone nodules and gravels.

Qhe3 Sand spreads, inland sand dunes and their remobilised extension, unconsolidated.

Qhl4 Holocene lacustrine marl: Grey to green gypsiferous, fossiliferous marl and sandy clay with abundant fossils, including ostracods, *Coxiella,* Charophyte oogonia and small gastropods.

Qhl5 Holocene lacustrine beach lunette: Arcuate lunettes to 5 m high of grey to white fine siliceous gypsiferous sand, clay pellets, heavy mineral layers and *Coxiella* shells. Thin salt crust or marginal micritic carbonate crust.

PLEISTOCENE - HOLOCENE

Qa Undifferentiated reworked calcareous clay, weathered sandy clay, pebbles and kaolinitic debris. Mainly in creeks and low lands, related to flood reworking and wind remobilisation.

Qe Undifferentiated aeolian mantle: Reworked aeolian blanket of mottled orange-white, coarse-grained, ferruginous pisolite, breccia and calcareous sand. Also down-washed slope deposits and fault scarp debris, related to Quaternary fault activities.

Qpca Undifferentiated calcrete: White to pale-brown, nodular and massive sheet calcrete and cemented carbonate breccia; soil.

PLEISTOCENE

Qpcb BRIDGEWATER FORMATION: Medium-grained, large-scale cross-bedded calcarenite and calcareous aeolianite with numerous palaeosol horizons and capped by thick laminar to powdery or bouldery calcrete. Cavernous in places with abundant rhizomorphs and solution pipes. Preserved dune morphology.

Qpcb7 Upper member of BRIDGEWATER FORMATION: Soft, pale white to cream large-scale foreset-bedded, fine to medium-grained bioclastic calcarenite and aeolianite with soft earthy palaeosol horizons. Basal angular breccia layer. Thin sheet hardpan locally developed. Merges with Glanville Formation near sea level. ~1–0.2 Ma (Sr).

Qpcg GLANVILLE FORMATION (separates upper and lower members of Bridgewater Formation): Mottled, yellow-brown sandy marl and fossiliferous limestone. Basal conglomerate, middle fossil-poor marl and upper shelly bed. Fossils of oysters, corals, paired bivalves (*Fulvia tenuicostata, Katelysia* and *Anadara*) and turreted gastropods. Strontium isotope age 0.13–0.1 Ma.

Qpcb6 Lower member of BRIDGEWATER FORMATION: Fine to medium-grained, cream to white, large-scale foreset-bedded calcarenite and calcareous aeolianite, often traversed by red-brown palaeosol horizons. Abundant solution pipes; capped by laminar, nodular and clastic calcrete and orange loam clay. Basal tidal channel calcarenite with comminuted shell fragments.

Qpah HINDMARSH CLAY (= ARDROSSAN CLAY and SANDROCK): Basal gravel layer. Middle mottled red-brown to orange clay and upper fluvial and alluvial red-brown silty sandstone. Alluvial, fluvial and lacustrine sediments. The Brunhes-Matuyama Polarity Transition, 0.78 Ma.

ST VINCENT BASIN

Qpce POINT ELLEN FORMATION: Pinkish grey fossiliferous fine-grained laminated calcarenite or silty limestone and shelly sandstone with *Brachidontes, Elphidium, Qunqueloculina,* and *Batillaria* remains. Strontium isotope age ~1.2 Ma.

TpQr1 Tertiary–Quaternary colluvium: Mottled yellow to brown clayey sand, reworked ironstone nodules and carbonate nodules (reworked regolith).

TERTIARY (T)

T Undifferentiated Tertiary sediments.

PLIOCENE

Tph HALLETT COVE SANDSTONE: Red-brown calcareous sandstone and siltstone, sandy limestone, oyster-rich bed with gastropods and bivalves *Anodontia*

OLIGOCENE - MIOCENE

Temv PORT VINCENT LIMESTONE (Temv): Sandy bryozoal limestone and silty limestone, transitional to Port Willunga Formation.

Tow PORT WILLUNGA FORMATION (Tow): Thick-bedded bryozoan-rich limestone, silty and sandy locally. Lower sandy, skeletal limestone and calcareous sandstone; middle pink-brown massive to thick-bedded fossiliferous with minor marl layers, and upper part bleached and silty.

Tomm MELTON LIMESTONE (Tomm): Fossiliferous, including foraminifer *Lepidocyclina-howchini*, limestone and sandstone.

Tomt POINT TURTON LIMESTONE (Tomt): Red-brown, coarse-grained, trough cross-bedded sandstone, silty medium-grained sandstone and upper bryozoal limestone. Fossils, including *Victoriella.*

EOCENE

Teor ROGUE FORMATION: Silty sandstone, calcareous sandstone, sandy siltstone and sandy limestone. Abundant fossils, including *Spirocolpus (Turritella) aldingae.*

Teorj PORT JULIA GREENSLAND MEMBER: Massive glauconitic, silty quartz sandstone with numerous bivalves, gastropods, corals, foraminifera, and bryozoans.

Teh THROOKA SILT: Pale grey to light brown siltstone and basal trough cross-bedded, haematitic fine-grained sandstone. Foraminifera. Lagoonal.

Teb BLANCHE POINT FORMATION: Silty limestone and calcareous siltstone with sandy siltstone interlayers, abundant *Spirocolpus (Turritella).*

Tet TORTACHILLA LIMESTONE: Limestone to sandy marl, locally glauconitic, with foraminifera.

Teu MULOOWURTIE FORMATION: Calcareous siltstone or silty calcarenite, cross-bedded sandstone and basal conglomerate. Foraminifera *Fibularia gregata*, echinoids and crinoids. **Teuq** QUARTOO SAND MEMBER: Medium to coarse-grained cross-bedded estuarine sandstone and grit layers.

Ten NORTH MASLIN SAND: Cross-bedded fluvial sandstone, conglomerate with minor sandy siltstone, unconsolidated. Unfossiliferous, possibly middle Eocene.

TROUBRIDGE BASIN

PALAEOZOIC – PERMIAN

CP-j CAPE JERVIS FORMATION: Diamictite of unconsolidated yellow-green siltstone, sandstone, sandy limestone and grit with rounded pebbles, boulders and residual erratics of Cambrian Kanmantoo Group metasandstone and Cambro-Ordovician megacrystic granite, granite gneiss and aplite sourced from the east; includes rare silicified glaciofluvial outwash sediments. Abundant pollen and spores. Uppermost glacio-marine siltstone with foraminifers. Sakmarian.

STANSBURY BASIN

CAMBRIAN – MIDDLE CAMBRIAN

€ou YURUGA FORMATION: Red-brown, arkosic sandstone, sandy siltstone and conglomerate. Massive to cross-bedded. Fluvial–lacustrine to shoreface; trilobite tracks.

€o6 Lower Cambrian sequence set 2, mainly red-brown siliciclastics with some carbonate deposits.

€oc COOBOWIE LIMESTONE: Sandy, oolitic, fossiliferous limestone, minor calcareous siltstone and basal glauconitic sandstone. Small skeletal fossils and trilobite *Pagetia*. Middle Cambrian.

EARLY CAMBRIAN

€om MOONAN FORMATION: Massive, bedded to laminated green-grey siltstone and fine-grained sandstone, occasionally with rip-up intraclasts. Restricted marine (lagoonal) to delta, lacustrine to fluvial settings. Acritarchs and rare shelly fossils. Subsurface only.

€os STANSBURY LIMESTONE: Medium-bedded nodular to flaggy silty limestone, ooid grainstone and thin siltstone interlayers. Basal wackestone with grit. *Redlichia* and small skeletal fossils. Toyonian.

€oo CORRODGERY FORMATION: Dark grey to red-brown siltstone and fine-grained sandstone. Siltstone with bioturbation and organic debris, restricted marine, to prodelta or lagoon. Sandstone cross-bedded with rip-up intraclasts, deltaic or lacustrine settings. Acritarchs. Subsurface only.

€or RAMSAY LIMESTONE: Flaggy to nodular, thin to medium-bedded silty limestone with basal sandy oolitic grainstone and bioclastic packstone. Marginal marine, to lagoonal. Archaeocyaths and trilobites *Redlichia.* Toyonian.

€on MINLATON FORMATION: Red-brown and minor grey siltstone, sandstone, silty carbonate and basal conglomerate. Gypsum layers at the top. Marginal marine, deltaic, fluvial to lacustrine. Acritarchs and shelly fossils. Toyonian. Subsurface only.

€o5 Lower Cambrian sequence set 1, mainly carbonate deposits.

€op PARARA LIMESTONE: Nodular limestone with minor mottled argillaceous limestone and thin calcareous shale. Archaeocyaths, trilobites *Yorkella australis, Pararaia* and acritarchs. **€opk** KOOLYWURTIE LIMESTONE MEMBER: Bioherms of archaeocyaths (*S. favus* beds) and calcareous algae including *Girvanella, Epiphyton*. Late Atdabanian to Botoman.

€ok KULPARA FORMATION: Upper limestone unit (€ok1) and lower dolomite unit (€ok2). Dolomite massive to thick-bedded, vuggy and locally stromatolitic. Limestone thick-bedded, vuggy, locally oolitic with intraclasts and fossiliferous. Archaeocyaths (*Spirillicyathus tenuis*), small skeletal fossils and acritarchs. Tommotian–Atdabanian.

€oi WINULTA FORMATION: Arkosic sandstone to quartzite with minor siltstone and basal conglomerate. Uppermost part is dolomitic and silty. Hyolithids, trace fossils *Plagiogmus arcuatus, Treptichnus pedum, Diplocraterion* and acritarchs. Tommotian.

ADELAIDE GEOSYNCLINE

PROTEROZOIC – NEOPROTEROZOIC – STURTIAN

Nnt TAPLEY HILL FORMATION: Grey, thin-bedded to laminated shale and dolomitic shale with thin silty dolomite. Locally thin, fine-grained sandstone. Basal sandstone with rip-up siltstone clasts. Deep marine shelf deposit. Acritarchs. Subsurface only.

Nys STURT TILLITE: Glacial diamictite of massive green-grey claystone with boulders or angular to rounded pebbles of metamorphic rocks, granite, quartzite and chert. Subsurface only.

TORRENSIAN

Nor RHYNIE SANDSTONE: Fluvial sandstone and conglomerate with thin, red-brown siltstone interlayers. Subsurface only.

GAWLER CRATON

MESOPROTERZOIC – EARLY MESOPROTEROZOIC

Ms SPILSBY SUITE: Granite, interpreted to intrude the Donington Suite in Spencer Gulf, ~1510±12 Ma. (LINCOLN)

Mh HILTABA SUITE: Granitoid intrusives in the Gawler Craton. ~1600–~1580 Ma.

Mhr ARTHURTON GRANITE: Pink, coarse-grained, A-type adamellite with quartz, microcline, plagioclase, mica, sphene, magnetite and chlorite. Undeformed to foliated. Often pegmatitic or miarolitic. 1582±7 Ma.

Mht TICKERA GRANITE: Red-brown, medium-grained, I-type monzonite to quartz monzonite with microcline, quartz, plagioclase, biotite, ±muscovite, chlorite and magnetite. Undeformed to foliated. 1598±7–1575±7 Ma.

M-c CURRAMULKA GABBRONORITE: Medium to coarse-grained gabbronorite with plagioclase, clinopyroxene (augite), orthopyroxene, hornblende, biotite, quartz or orthoclase. Intrudes Aagot Member and intruded by Arthurton Granite. Subsurface only. 1589±5 Ma.

M-b BUTE METADOLERITE: Dolerite and diorite intrusives in the Bute region. Mainly medium to fine-grained plagioclase and hornblende, minor quartz, biotite, epidote, chlorite and opaques. Occasionally ophitic textures. Subsurface only.

M-r OORLANO METASOMATITE: Metasomatic rocks of albite, scapolite, diopside, tremolite, epidote, carbonate, quartz, mica, magnetite. Protolith unknown. Subsurface only. Latest metasomatism Hiltaba Suite age.

PALAEOPROTEROZOIC – LATE PALAEOPROTEROZOIC

Lx WALLAROO GROUP: Low-grade (greenschist to lower amphibolite facies) metasediments and metavolcanics in the eastern Gawler Craton, ~1770–1740 Ma.

Lxt MATTA FORMATION: All mafic volcanics or intrusives in the Wallaroo Group. Intrudes both Wandearah and Weetulta Formations.

Lxtr RENOWDEN METABASALT MEMBER: Fine-grained, massive, foliated basalt with hornblende, plagioclase, clinopyroxene and biotite. Quartz-rich vesicles suggest a formerly scoriaceous texture. Intrudes Wardang Volcanics. ~1750 Ma.

Lxe WEETULTA FORMATION: All felsic volcanics and intrusives in the Wallaroo Group. Intruding or interlayered with metasediments.

Lxem MOONTA PORPHYRY MEMBER: Massive, fine-grained to porphyritic rhyolite, rhyodacite to dacite (orthoclase, plagioclase, quartz, minor chlorite, biotite and sericite). Extrusive to intrusive, A-type. Glomeroporphyritic texture, foliated. 1760±7 Ma.

Lxew WARDANG VOLCANICS MEMBER: Red-brown porphyritic rhyolite, rhyodacite, dacite to latite, mainly K-feldspar, quartz, plagioclase, biotite, opaques (ilmenite and magnetite), hornblende, pyroxenes, chlorite, epidote and accessory zircon, apatite, carbonate and scapolite. Shallow intrusive and extrusive, A-type, foliated. 1756±27 Ma.

Lxw WANDEARAH FORMATION: All metasediments in the Wallaroo Group on Yorke Peninsula, including metasandstone, argillite, siltstone, carbonate, calcsilicate and occasional conglomerate, ranging from shelfal, deltaic, lacustrine to fluvial setting.

Lxwn NEW CORNWALL MEMBER: Carbonate-dominated unit. Layered limestone, dolomite, siltstone, calcareous argillite, calcsilicate, graphitic schist, locally sandstone, conglomerate and albitite. Mixed carbonate and siliciclastic platform setting. Greenschist facies.

Lxwd DOORA MEMBER: Biotite schist-dominated unit. Layered, foliated biotite-rich schist of psammitic, argillaceous, calcsilicate, iron-rich, graphitic and minor albitic meta-sediments. Siliciclastic platform setting. 1741±9 Ma (from intercalated acid volcanics).

Lxwa AAGOT MEMBER: Metasandstone-dominated unit. Layered metasandstone, sandy argillite, minor conglomerate, calcsilicate and albitic rocks. Sandstone with haematite-coated grains, cross-bedding and heavy mineral banding. Aeolian–fluvial to shallow foreshore and shelf setting. Foliated. ~1756 Ma (from intercalated Wardang Volcanics Member).

MIDDLE PALAEOPROTEROZOIC

Ll Undifferentiated Palaeoproterozoic Intrusives: Granitoid and mafic intrusive complex, emplaced during the middle Palaeoproterozoic Neill Event and late Palaeoproterozoic Kimban Orogeny. ~1855–1700 Ma.

Llt TOURNEFORT METADOLERITE: Undifferentiated dolerite, metadolerite and amphibolite dykes, with plagioclase, hornblende, clinopyroxene, biotite, sphene and opaques. Altered, occasionally foliated. Ophitic texture. ~1800 Ma.

Ll5 Pegmatite, granite and aplite dykes: Undifferentiated. Mainly quartz, microcline, plagioclase, mica, sphene and opaques. Graphic texture. Four phases recognised on Yorke Peninsula. ~1850–1500 Ma.

Ld DONINGTON SUITE: Quartz-gabbronorite, hypersthene gneissic granite, syenogranite, adamellite, granodiorite, tonalite, megacrystic granitoid gneiss. 1855–1850 Ma.

Ldr ROYSTON GRANITE: Adamellite to syenogranite, with microcline, quartz, plagioclase, biotite, hornblende, apatite and metamict zircon. Foliated to undeformed, intruding Gleesons Landing Granite and intruded by Tournefort Metadolerite, 1850±12–1849±11 Ma.

Ldj JUSSIEU METADOLERITE: Composed of hornblende, plagioclase, sphene and minor quartz. Foliated. Intrudes Gleesons Landing Granite with back-veining texture.

Ldg GLEESONS LANDING GRANITE: massive to banded I-type granitoid pluton or sill complex.

Ldg1 Syenogranite: Red-brown, fine to medium-grained alkali-feldspar-rich granite, with microcline, quartz, plagioclase and biotite–hornblende. Foliated and layered. ~1855–1850 Ma. Possibly equivalent to Ldc on LINCOLN.

Ldg2 Adamellite: Pink to pink-brown, containing quartz, microcline, plagioclase, biotite and magnetite, accessory hornblende, sphene, apatite and zircon. Foliated. Intercalated with syenogranite.

Ldg3 Granodiorite: Grey, green-grey to dark grey with quartz, plagioclase, hornblende, microcline, and sphene, accessory epidote, allanite, clinopyroxene and biotite. Transitional to tonalite. Foliated. Intrudes Corny Point Paragneiss. 1808±18 Ma (Rb–Sr). Possibly equivalent to Ld_2 on LINCOLN.

Ldg4 Augen orthogneiss: White-grey to pink-brown, strongly deformed megacrystic microcline–perthite gneissic adamellite, consisting of microcline, quartz, plagioclase, biotite and hornblende. 1850±5 Ma. Possibly equivalent to Ldw on LINCOLN.

Ld4 Hornblende micro-adamellite: Grey, layered, foliated, fine-grained hornblende–biotite adamellite with microcline, plagioclase, quartz, hornblende, biotite, sphene and opaques. Intruded by Royston Granite.

Ll19 Biotite schist: Layered, mafic rock containing dominantly biotite with some quartz and plagioclase, with accessory apatite and zircon.

L-c CORNY POINT PARAGNEISS: Migmatitic layered paragneiss, dark grey to white-grey, with coarse-grained quartz, plagioclase, biotite, alkali feldspar, garnet, sillimanite, ±orthopyroxene, ±clinopyroxene, ±cordierite, ±spinel, ±corundum. Protolith possibly Hutchison Group equivalent, deposition ~1920–1860 Ma. Metamorphic age 1845±6 Ma.

Note: Geochronological dates are U–Pb ages on zircon (unless otherwise stated).

GEOLOGICAL BOUNDARY
OBSERVED
APPROXIMATE
UNCONFORMITY
INFERRED
LIMIT OF BRIDGEWATER FORMATION (Qpcb)
FAULT
OBSERVED
APPROXIMATE
BEDDING
INCLINED 50
TECTONIC FOLIATIONS
LAYERING
INCLINED 88
EXPLORATION DRILLHOLE
STRATA SEQUENCE (THICKNESS IN METRES) Q 24.0 Topn 18.6
DIAMOND DRILL HOLE (For additional information please refer to PIRSA's Drillhole Database) DDH 207
GEOLOGICAL SECTION A A'
MINE
ABANDONED
MAJOR
MAJOR OPEN CUT
MINOR OPEN CUT
PROSPECT
PROSPECT ABANDONED
HIGHWAY
SECONDARY
MINOR ROAD
VEHICLE TRACK
ADMINISTRATIVE BOUNDARY
LANDING GROUND
HOMESTEAD "Lockwood"
BUILDING, BEACON
IDENTIFIED POINT (ELEVATION IN METRES) 25
TRIANGULATION STATION (ELEVATION IN METRES) 129
TOPOGRAPHIC CONTOUR (INTERVAL 50 METRES) 250
SAND DUNE
CLIFF
LIGHTHOUSE
ROCKS, BARE OR AWASH
BATHYMETRIC CONTOUR (INTERVAL 10 METRES) 40
TANK OR DAM
EPHEMERAL STREAM
CLAYPAN, SALTPAN, LAKE
SWAMP

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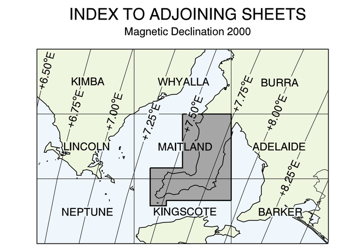

Annual Variation + 1.4 minutes

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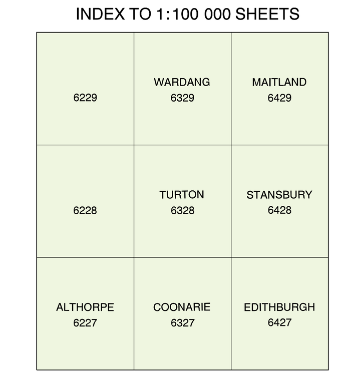

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MINERALS & ENERGY

MAITLAND
SI 53-12 & PORTION SI 53-16

EXPLANATORY NOTES

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SOUTH AUSTRALIA

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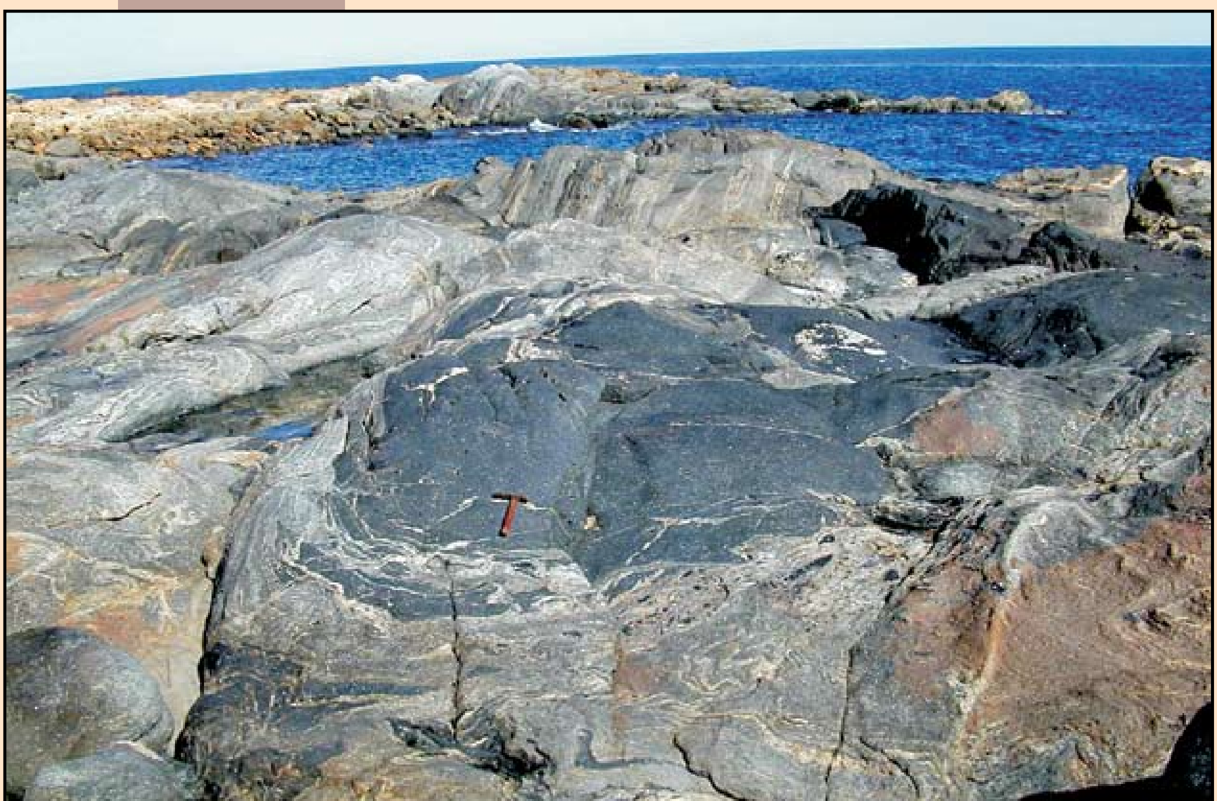

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Cover photo: Mafic Jussieu Metadolerite intruding tonalite, Corny Point, western Yorke Peninsula.
Note the brecciated contact margin. (Photo 048697)

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1:250 000 Geological Series — Explanatory Notes

MAITLAND Special

SOUTH AUSTRALIA

SHEET SI53-12 International Index

Wen-long Zang
with contributions by
Wayne M. Cowley and Martin Fairclough

Issued under the authority of

The Hon Paul Holloway MLC

Minister for Mineral Resources Development

PIRSA Geological Survey Branch

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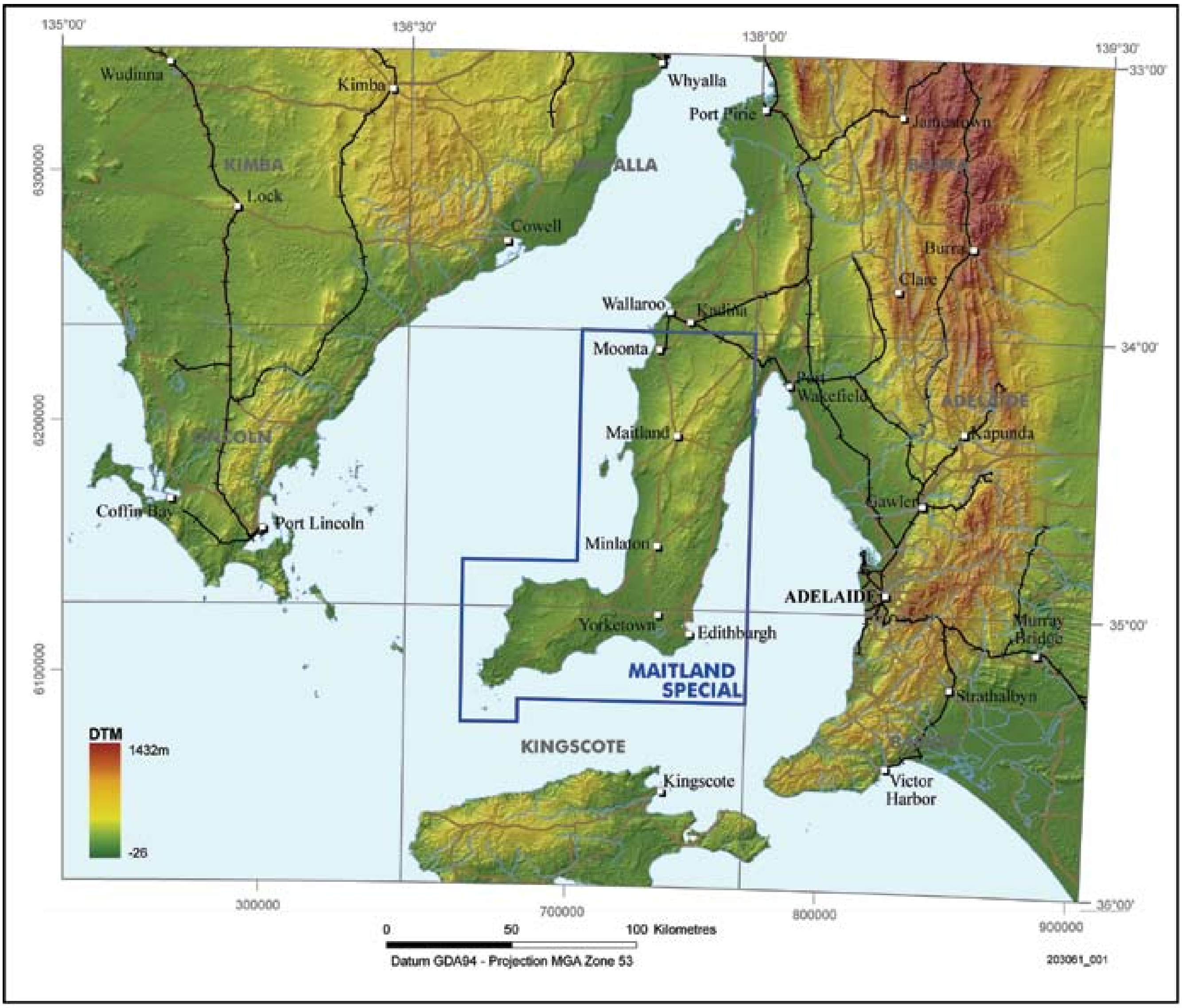


Fig. 1 *Regional locality map, MAITLAND Special 1:250 000 map area.*

Explanatory Notes for the MAITLAND Special 1:250 000 geological map

Wen-long W. Zang with contributions by Wayne M. Cowley and Martin Fairclough

ABSTRACT

The MAITLAND Special 1:250 000 geological map covers the major part of South Australia's Yorke Peninsula. The rocks in the map area comprise deformed Palaeoproterozoic and early Mesoproterozoic basement of the southeastern Gawler Craton, and undeformed Neoproterozoic to Quaternary sediments. More than 90% of the land surface of the map area is covered by Quaternary sand dunes, calcrete, aeolianite and soil.

The oldest rocks on Yorke Peninsula belong to the middle Palaeoproterozoic Corny Point Paragneiss (~1920–1845 Ma), which has a Hutchison Group equivalent protolith and was metamorphosed at ~1845 Ma. Several felsic and mafic plutonic suites, principally Gleesons Landing Granite, intrude the paragneiss on the southern part of the peninsula. The early phases of this I-type granite could be as old as ~1855 Ma, and are intruded by megacrystic augen orthogneiss (~1850 Ma). The Gleesons Landing Granite is intruded by the deformed Royston Granite (~1849.5 Ma) and mafic dykes (Tournefort Metadolerite).

The late Palaeoproterozoic Wallaroo Group (1770–1740 Ma) comprises a succession of metasediments and volcanics, and in the northern part of the map area hosts the Moonta–Wallaroo Cu–Au deposits. The Wallaroo Group is considered to have been deformed by the Kimban Orogeny (in the restricted sense of Schwarz, 2003) during 1730–1700 Ma, and later intruded by early Mesoproterozoic Tickera Granite (1598–1586 Ma), Curramulka Gabbronorite (1589 Ma) and Arthurton Granite (1582 Ma).

Neoproterozoic sediments are known only from drillhole intersections in the northeastern part of the map area, and were deposited along the Torrens Hinge Zone marginal to the Adelaide Geosyncline. The units intersected include Rhynie Sandstone, Sturt Tillite and Tapley Hill Formation.

The Cambrian Stansbury Basin on Yorke Peninsula is interpreted to have formed on a rifted continental platform on the eastern Gawler Craton; up to 2000 m of sediments are interpreted from seismic surveys. Generally, the Cambrian succession contains three sequence sets and records two local marine transgression and regression cycles. The Cambrian sediments have petroleum potential in the region.

Permian diamictite crops out on southern Yorke Peninsula and is widely intersected in drillholes. The diamictite (Cape Jervis Formation) was deposited in glacio-lacustrine, glacio-fluvial and restricted marine environments.

Tertiary sediments are exposed in the coastal cliffs of the eastern side of Yorke Peninsula and consist of siliciclastics with minor carbonates. Deposition of the Quaternary successions was probably controlled by the glacial-eustatic sea-level oscillations, resulting in deposition of several marine beds. Transgressions, evidenced by deposition of the marine Point Ellen Formation (~1.2 Ma), tidal channel deposits at the base of the Bridgewater Formation (<0.78 Ma), fossiliferous Glanville Formation (~0.125 Ma) and *Posidonia*-bearing beds of the St Kilda Formation (~6000 years), are recognised.

Tectonic development of Yorke Peninsula is relatively complicated, particularly the formation of the basement rocks, and interpretation is made especially difficult due to poor surface exposure. Generally in the region, six major depositional events can be recognised, relating to deposition of the middle Palaeoproterozoic (1920–1845 Ma Corny Point Paragneiss), late Palaeoproterozoic (1770–1740 Ma Wallaroo Group), Neoproterozoic (~770–700 Ma), Cambrian (~540–500 Ma), Permian and Tertiary sediments. Seven deformation or shear-faulting events (D_1–D_7) are recognised in this study.

INTRODUCTION

The MAITLAND Special 1:250 000 geological map includes the MAITLAND and northern part of the KINGSCOTE 1:250 000 geological map areas. The map contains the major part of Yorke Peninsula and is located between longitudes 136°30' and 138° E, and latitudes 34°°and 35°25'S. More than half of the map area lies under the waters of eastern St Vincent Gulf and western Spencer Gulf (Fig. 1).

The first edition of the MAITLAND one-inch-to-four-mile (1:253 440) geological map (mapped by A.R. Crawford) was published in 1960. The KINGSCOTE map had been previously published in 1954. These were followed by publication of 'The geology of Yorke Peninsula' (Crawford, 1965) and 'A field guide to the geology of Yorke Peninsula' (Field Geology Club of SA Inc., 1997). Over the last three decades, Yorke Peninsula has been a focus for mineral and petroleum exploration with extensive seismic, gravity and aeromagnetic surveys. More than 3000 exploration holes have been drilled and over 5000 geochemical analyses undertaken.

The current mapping project commenced on 1 July 1996. A major study, immediately preceding the mapping and involving interpretation of the basement and related mineralisation, was completed for the Moonta–Wallaroo data package (Conor, 1995). Field mapping was carried out using 1:40 000 scale colour aerial photographs and was compiled as 1:50 000 sheets. The geological data that have been compiled include local mapping carried out by exploration companies, university students and many departmental colleagues.

HISTORICAL NOTES

Yorke Peninsula was first geographically delineated by Matthew Flinders in early 1802 when he explored the southern Australian coastline. The area was named after the Right Honourable Charles Philip Yorke, First Lord of the Admiralty.

The Aboriginal Naranga tribe occupied Yorke Peninsula at this time and was estimated to comprise 500 people when Europeans began settling and farming in the region in the early 1850s. Yorke Peninsula was brought to wide attention when copper was discovered in the Kadina and Moonta region in 1859. Development of mining, smelting and shipping industries in the region led to establishment of the townships of Moonta, Kadina and Wallaroo, which are commonly known as the 'copper triangle'.

Early population numbers on Yorke Peninsula varied with the copper price and prosperity of the Moonta–Wallaroo Mines. Some 15 650 people were living in the district in 1911, of whom ~14 000 had a job related to mining (Jack, 1917). Following closure of the Moonta–Wallaroo Mines in 1923, settlement intensified across the peninsula with the expansion of grain farming and associated shipping operations.

Currently, the principal settlements include Moonta, Maitland, Ardrossan, Arthurton, Port Vincent, Minlaton, Warooka and Yorketown, many of which have recently developed as tourist centres. In 1974, the entire coast of Yorke Peninsula was proclaimed a protected area (the Yorke Coast Protection District), for preservation of areas of ecological, scientific and scenic importance (Wynne, 1980).

PREVIOUS INVESTIGATIONS

REVIEW OF GEOLOGICAL SURVEYS

The environmental and geographical features of Yorke Peninsula were well described by early investigators (e.g. Flinders, 1814; Jameson, 1838). However, the first significant regional geological map in the region, relating to mining activities in the Moonta, Kadina and Wallaroo areas, was produced by Jack (1917). He observed that calcrete and blanketing sands masked the older rocks, particularly the Precambrian complex. Patches of altered sediments, basic and igneous intrusions, feldspar porphyry and granitic intrusions were also noted to crop out along coastal cliffs, which were overlain by Cambrian sediments and Tertiary limestone.

Geological investigations on Yorke Peninsula can be divided into three stages. The early studies include reports by Tepper (1879, 1880, 1882), who described Early Cambrian fossils in the Ardrossan area when he was a teacher at the local school. Other important early works are those of Tate (1881, 1884, 1886, 1892), Fletcher (1890), Pritchard (1892), Greenway and Phillips (1902), and Howchin (1900, 1909). These were followed by two comprehensive studies of regional geology, including sediments (Howchin, 1918) and the basement and mineralisation (Jack, 1917). A second stage was marked by publication of the first edition of the MAITLAND geological map and bulletin (Crawford, 1965), and KINGSCOTE geological map (Sprigg et al., 1954) which was enhanced by the research of Stuart (1969, 1970) on the Tertiary. A third stage is represented by the study of basement rocks of the Wallaroo Group (Conor, 1995), Cambrian sediments (Gravestock, 1995) and the current mapping project.

Stratigraphically, the rocks on Yorke Peninsula range from the middle Palaeoproterozoic to Quaternary. Previous work on middle Palaeoproterozoic gneissic granites and gneisses was limited (Tate, 1890; Howchin, 1900; Greenway and Phillips, 1902; Glastonbury, 1939; Glaessner and Parkin, 1958; Crawford, 1965; Golin, 1976; Pedler, 1976; Richardson, 1978; Major, 1973; Rankin et al., 1991; Webb et al., 1986; Parker, 1993a). Crawford (1965) broadly mapped the basement rocks as Archaean but recently these rocks have been reinterpreted as middle Palaeoproterozoic Lincoln Complex as a consequence of similar metamorphism and geochronological dates to Eyre Peninsula rocks (Webb et al., 1986; Parker, 1993a; Fanning, 1997).

The late Palaeoproterozoic Wallaroo Group was first named and described in detail by Conor (1995), and published in 1998 (Daly et al., 1998). Importantly, the group is the host to the Moonta and Wallaroo copper mines. Early descriptions of local geology in the mine area include Woods (1862) and Higgs (1872). Two significant papers on the geology of the Moonta and Wallaroo Mines were published by Jack (1917) and Dickinson (1942). Regional geology and mineralisation in the Wallaroo Group was also the subject of many other studies (Parker, 1993a; Parker and Fanning, 1998; Conor, 1995; Huffadine, 1993; Wurst, 1994, Plimer, 1980; Lynch, 1977; Janz, 1990; Hafer, 1991; Both et al., 1993) and numerous company reports. The group was recently formally described and subdivided by Cowley et al. (2003).

Cambrian sediments are widely exposed or intersected on Yorke Peninsula and below Gulf St Vincent. Woodward (1884) noted the presence of the Cambrian trilobites, whereas the finding of archaeocyathid fossils in the Ardrossan area was reported several years earlier even though they were initially mistaken as Silurian corals (Tepper, 1879; Tate, 1881; Etheridge, 1890). Daily (1956, 1972, 1976, 1990) established the Cambrian sedimentary succession and proposed an initial biostratigraphic zonation. This work has been supplemented by studies of Tucker (1989), Bengtson et al. (1990), and Zhuravlev and Gravestock (1994). Gravestock (1995) summarised this knowledge and established a Cambrian sequence stratigraphy. A comprehensive study of the small skeletal fossils of the peninsula was recently published (Gravestock et al., 2001).

Late Carboniferous – Permian glacial activities and dropstones or erratics on Yorke Peninsula were noticed by many early explorers and documented by Tate et al. (1896) and Howchin (1900). The diamictite from outcrop and subcrop contains foraminifera (Ludbrook, 1957a), and pollen and spores (Foster, 1974). The regional distribution was documented by Howchin (1918), Crawford (1965) and Alley (1995). Stratigraphic drillhole TER 1, west of Minlaton, intersected 4–6 beds of sandy limestone within the diamictite, which greatly contributed to the understanding of the Late Carboniferous – Permian glacial marine and non-marine deposition (Zang and Hore, 2001, 2003).

Tertiary limestone is well exposed along coastal cliffs on the east coast of Yorke Peninsula, and lithological descriptions and fossils were documented by many early geologists (Tate, 1879, 1880, 1881, 1882, 1884, 1886, 1890, 1892; Tepper, 1879, 1880 1882; Scoular, 1882; Brown, 1884, 1899, 1902, 1908; Howchin, 1888, 1897, 1900, 1907, 1909, 1912, 1922, 1924, 1929). This was followed by studies in the 1940s–1950s (Sprigg, 1946; Glaessner, 1953a,b; Ludbrook, 1957a,b; Glaessner and Wade, 1958). Most of these early contributions were summarised in Crawford (1965), Stuart (1969, 1970), Cooper (1985), and Lindsay and Alley (1995).

An investigation of the Quaternary was included in the first research paper published on the geology of Yorke Peninsula (Tepper, 1879). The first informal lithological name 'Ardrossan Clays and Sandrock' (= Hindmarsh Clay) was proposed by Tepper (1879) from the Ardrossan area. Salt lagoons and lakes were also investigated thoroughly in the region for rapid expansion of the salt and gypsum industry (Howchin, 1900). The subsurface Quaternary geology on the peninsula is now comparatively well known despite >90% of the land surface being covered by Quaternary sand dunes, calcrete and calcarenite–aeolianite of the Bridgewater Formation (Crawford, 1965; Belperio, 1995).

REVIEW OF GEOPHYSICAL SURVEYS

The earliest geophysical surveys in the Moonta–Wallaroo district were carried out in 1929 by the Imperial Geophysical Experimental Survey. A series of geophysical surveys were also conducted by the Geological Survey of South Australia in the late 1940s to 1960s (Rayner, 1942; Mumme, 1955; Gerdes, 1983) and the Bureau of Mineral Resources in 1975. They were conducted with varying survey specification such as altitude, ground speed, sampling intervals, sensitivity of the instruments and flight-line spacing, and were combined in Crawford (1965) and Gerdes (1983). Together with new data from the former South Australian Department of Mines and Energy, all of the map area has been covered by aeromagnetic surveys (Fig. 2).

A TEISA (Targeted Exploration Initiative South Australia) aeromagnetic survey on Yorke Peninsula was undertaken in June 1999. The survey specifications were 80 m height and 400 m line spacing, with 200 m line infill by companies in their licence areas. This survey also filled two onshore TMI survey gaps on eastern (e.g. Port Vincent) and southwestern Yorke Peninsula, the last two gaps of the complete state TMI image. New aeromagnetic data integration of the surveys indicated significant tectonic differences beneath Spencer Gulf and revealed several new structures on Yorke Peninsula, which are potential new targets for mineral exploration.

Gravity surveys were conducted primarily from the 1950s to early 1980s, in association with aeromagnetic investigations. Quality is generally poor, except locally in the Moonta and northern Curramulka areas (Stuart, 1983). A regional gravity compilation has been carried out recently (Hore, 2000). Interpretation of limited seismic data was undertaken by Teasdale et al., (2001).

MODERN ENVIRONMENT OF YORKE PENINSULA

CLIMATE

Like most of coastal South Australia, the climate of Yorke Peninsula is dominated by hot, dry summers and cold wet winters (average yearly minimum 10°C and maximum 23°C). Periods of hot or dry weather occur mainly from late November to early March due to northerly winds from the inland areas of the state.

The average annual rainfall is mostly <500 mm (~300–650 mm), of which 70% falls in the period May to October. Winds are dominantly western onshore, although data are limited in the region.

TOPOGRAPHY

Yorke Peninsula is generally of subdued relief, lower about the coast and higher inland, generally <100 m above sea level in the south, gently rising to a height of ~200 m in the northern Maitland area. The highest point on the map is the Arthurton Trig Point, at 229 m above sea level.

From east of Warooka to Edithburgh, there are many saline lakes and swamps in the low lands or depressions. The water level of the lakes and swamps is almost at sea level; the lakes dry out during summer and flood on rainy days. Peesey Swamp and other lakes have been mined for salt and gypsum, and the evaporites are still being deposited.

Most of the low ridges on Yorke Peninsula are N–S orientated and were formed during Quaternary uplifting events (~800 000–120 000 years ago). Some other hills, such as the Hummocks Range and Mount Rat, were probably initiated during an earlier uplifting event ~500 million years ago (Delamerian Orogeny). Evidence of this early event and faults can also be seen in the Pine Point area.

SOIL TYPES AND DISTRIBUTION

More than 90% of Yorke Peninsula is covered by Recent aeolian sand and soil, and is suitable for agriculture. Soils on the peninsula have been broadly divided into four zones: mallee soil, calcareous sands, sand-over-clay and range country zones (Fig. 3; Webber and Matz, 1970). All zones, except the range country zone where it is too steep to be worked, are fertile lands for farming.

The mallee soil zone is the most extensive and contains four types: loamy, grey, sandy and shallow red mallee soils. The loamy mallee soil extends from Urania to Bute. The grey mallee soil is mainly in the western parts of the peninsula and has formed in unconsolidated, mobile sand spreads. The sandy mallee and shallow red mallee soils consist mainly of recent sands mixed with rock fragments, and are relatively thin. All four soils are fertile for agriculture.

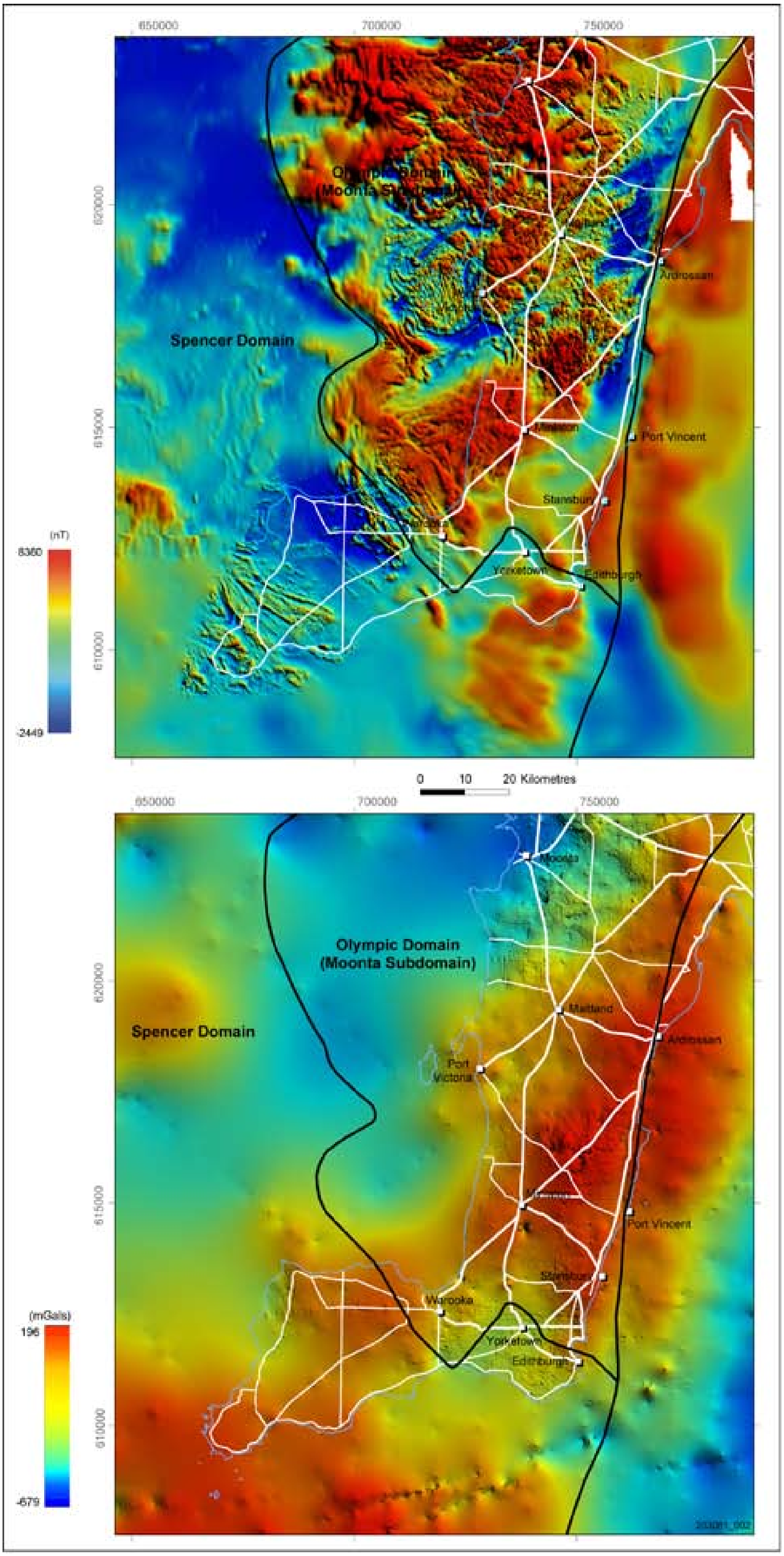


Fig. 2 *Airborne TMI and gravity image of the MAITLAND Special 1:250 000 map area.*

The calcareous sand zone is recognised along the southeastern coast and southwest of Warooka. The soils in this zone contain a significant portion of Recent sands mixed with calcareous sands.

The sand-over-clay soil zone occurs east of Minlaton and west of Arthurton, where clay soils are mixed with Cambrian carbonate and covered by Recent sands. The sandy soils are quite porous and have been developed into barley lands.

The range country zone includes the Hummocks Range and Mount Rat areas. The hill country of exposed Neoproterozoic to Cambrian rocks contains very thin topsoil.

Several low areas saturated with saline groundwater and forming saline swamps or playas occur at the foot of Yorke Peninsula. The Peesey Swamp area displays active Quaternary sedimentation and is still subsiding.

VEGETATION

The vegetation on Yorke Peninsula has been described by Laut et al. (1977). Natural vegetation consists of various mallee eucalyptus, shrubs, native pine and broom bushes, but has been extensively cleared for agriculture. Two vegetation groups can usually be distinguished. A woodland of dryland teatree (*Melaleuca lanceolata*) and drooping sheoak (*Casuarina stricta*) occurs throughout the region. In the active coastal dune area, mallee scrub (*Eucalyptus diversifolia*) is dominant. Samphire occurs around salt lakes.

To the north in the central peninsula, chenopod shrubland with *Arthrocnemum halocnemoides* and *Nitraria schoberi*, and open heath of *Olearia axillaris, Leucopogon parviflorus* and *Acacia sophorae*, are also abundant. Towards the northern part of the map area, the native vegetation includes open mallee scrub (*E. socialis, E. gracilis, E. incrassata* and *Melaleuca uncinata*), chenopod shrubland (*Arthrocnemum halocnemoides, A. arbuscules, Avicennia marina* and *Nitraria schoberi*), and open heath (*Olearia axillaris, Leucopogon parviflourus* and *Acacia sophorae*; Laut et al., 1977).

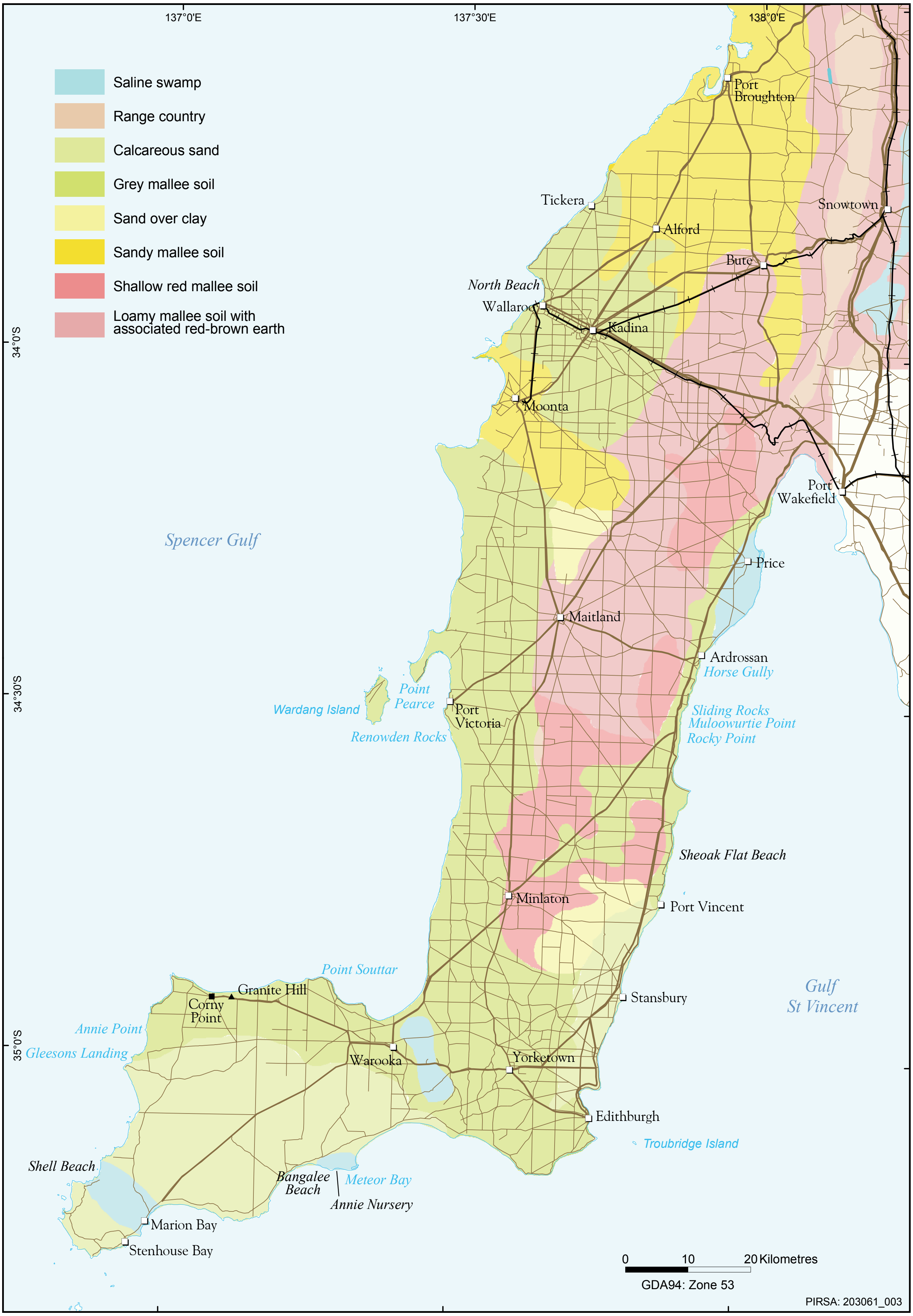


Fig. 3 *Soil types and distribution, MAITLAND Special 1:250 000 map area.*

AGRICULTURE

Pastoral development began on Yorke Peninsula in 1846, but significant expansion of farming only occurred following the cessation of major mining at the Moonta–Wallaroo Mines in 1923, with former miners relocating throughout the peninsula. Nowadays, agriculture is the stable industry of Yorke Peninsula. The diversity of its products, the reliability of its rainfall and efficiency make the peninsula a very productive region of South Australia. The relatively thick Quaternary sediment cover and fertile soil are suitable for most crops, particularly wheat and barley. Minor crops include oats and peas. Major shipping ports for farming products include Ardrossan, Wallaroo and Port Giles.

STRATIGRAPHY

The stratigraphy of Yorke Peninsula can be broadly divided into Palaeoproterozoic – early Mesoproterozoic metamorphic basement and Neoproterozoic–Quaternary sedimentary sequences. The basement rocks, which form the southeastern margin of the Gawler Craton, have suffered multiple deformations. On the southern portion of the peninsula, the basement is dominated by the middle Palaeoproterozoic Donington Suite (Spencer Domain), and to the north by the metasedimentary and metavolcanic Wallaroo Group and Hiltaba Suite plutons (Moonta Subdomain). A tectono-stratigraphy is illustrated in Figure 4.

The sedimentary sequences comprise mainly Cambrian (Stansbury Basin) and Tertiary (St Vincent Basin) successions, with limited outcrops and subcrops of Permian (Troubridge Basin) diamictite in the south, and Neoproterozoic siliciclastics in the north of the peninsula. The majority (>90%) of Yorke Peninsula is blanketed by thin Quaternary sand dunes, calcrete, alluvial, aeolian and playa sediments. Some of the mapped outcrops are under ~0.3 m of soil cover.

PALAEOPROTEROZOIC

Palaeoproterozoic rocks on Yorke Peninsula range from middle Palaeoproterozoic high-grade metamorphosed granite and gneiss to late Palaeoproterozoic low-grade metamorphosed Wallaroo Group. Some units on the peninsula have been updated (Table 1).

CORNY POINT PARAGNEISS (L-C)

The Corny Point Paragneiss (1920–1845 Ma) is a migmatitic paragneiss exposed in a low cliff north of Corny Point, consisting of dark grey to white-grey, coarse-grained, layered migmatites of quartz, plagioclase, biotite, alkali feldspar, garnet, sillimanite, ±orthopyroxene, ±clinopyroxene, ±cordierite, ±spinel, ±corundum. Fine-grained meta-argillite and calcsilicate lenses occur as boudins up to 2 m across; elongation is largely parallel to layering. The sedimentary precursor is suggested to be Hutchison Group equivalent (~1920–1860 Ma), which is widely distributed on Eyre Peninsula. At Corny Point, the paragneiss has been intruded by foliated amphibolite and the Gleesons Landing Granite, with concordant fabrics. It is interpreted that the migmatisation was prior to the deformation and probably associated with the mafic and felsic intrusions (Richardson, 1978; Zang et al., 2002).

The paragneiss displays a well-developed compositional layering which is parallel to S_1. The S_1 foliation is commonly defined by sillimanite and biotite or elongated quartz–feldspar or occasionally cordierite grains. Garnet is widespread; locally, large cracked garnet in porphyroblastic aggregates are common, particularly in migmatitic veins. Sillimanite is

Corny Point Paragneiss at Corny Point; migmatitic bands of the paragneiss and massive garnetiferous metasediments. (Photo 048735)

Table 1 *Geochronological dates on middle Palaeoproterozoic rocks in this study (C.M. Fanning, ANU, pers. comm., 1997–2001; Zang and Fanning, 2001).*

Sample No. (location)	Rock unit	SHRIMP U–Pb age* (Ma)	Comments
R215245 (southern Berry Bay)	Augen orthogneiss (Gleesons Landing Granite)	1850±5	Crystallisation age
R194507 (RH 1) (Royston Head)	Royston Granite	1850±12 1849±11	Two samples processed; crystallisation age
R392772 (Corny Point)	Migmatite (Corny Point Paragneiss)	1845±6	Metamorphic age; rounded zircon core ages ~1920 Ma, ~2400 Ma
R194506 (RH 2) (Royston Head)	Syenogranite (Gleesons Landing Granite)	~1855	Crystallisation age
R205163 (Annie Nursery)	Undeformed syenogranite (Royston Granite)	Discordant analyses	Metamict zircon; one concordia intercept ~1800 Ma
R205166 (Gleesons Landing)	Syenogranite)Gleesons Landing Granite)	Discordant analyses	Upper concordia intercept ~1835 Ma

*SHRIMP — Sensitive high resolution ion microprobe.

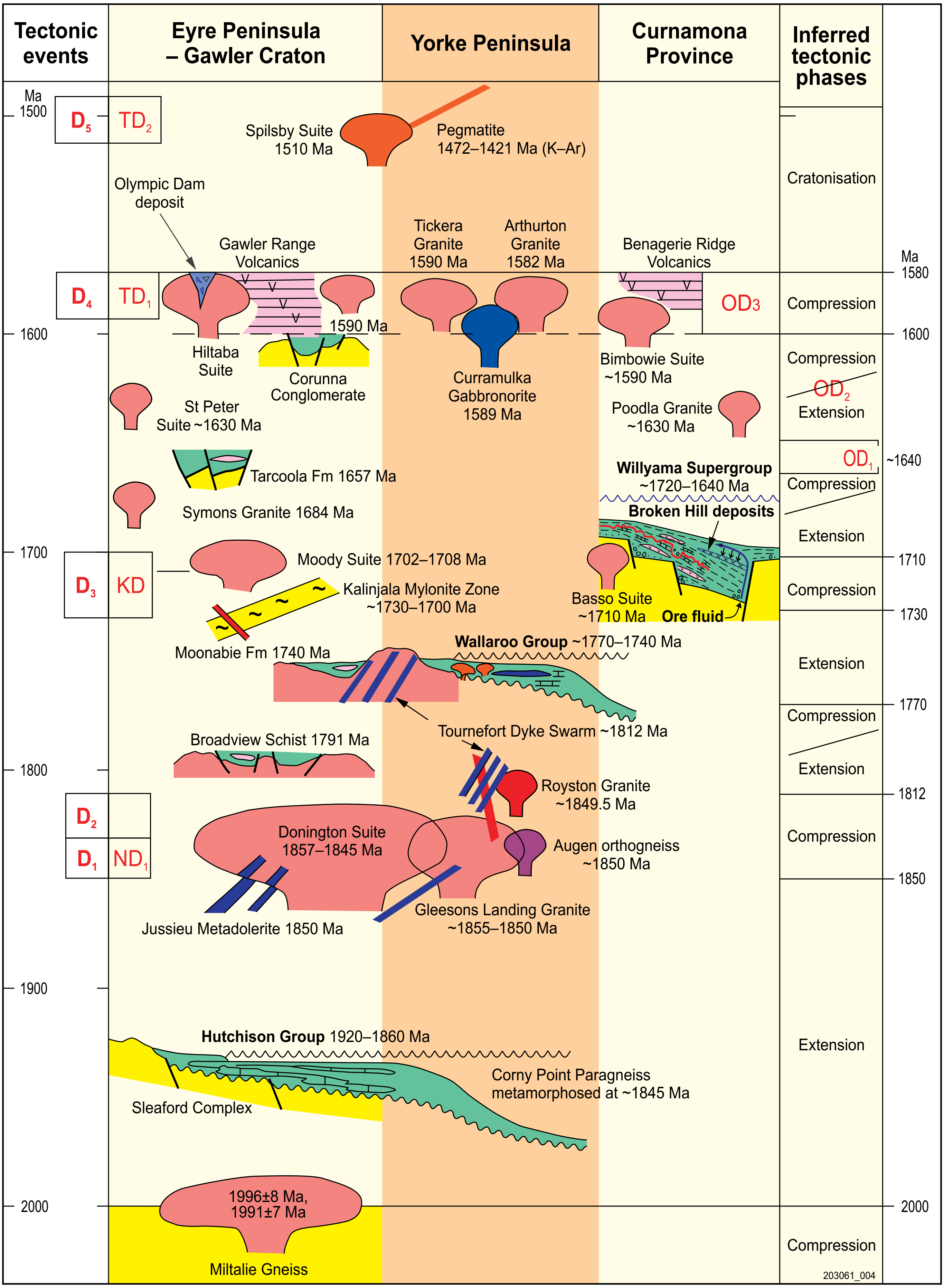


Fig. 4 *Stratigraphy of basement rocks, MAITLAND Special 1:250 000 map area.*

commonly present in mafic-rich layers and in late shear zones it can be retrogressed to muscovite (S_4). The paragneiss is intensely deformed with S_1 fabrics dominant, whereas the $S_{2–4}$ fabrics are present only in shear zones or fold hinges. Partial melting in the paragneiss and sillimanite–pyroxene–cordierite–garnet–biotite mineral assemblages suggests at least upper amphibolite metamorphism. Locally layered migmatitic samples at Corny Point (sample R408913) contain a quartz–orthoclase–garnet–biotite–sillimanite–plagioclase–cordierite assemblage, which was probably derived from a sandy pelite or an impure sandstone, and is considered to have been metamorphosed to granulite facies (Purvis, 1999). Richardson (1978) estimated that the temperature was up to 700°C during this tectonic episode (termed the Neill Event), whereas Bull (2003) suggested that the peak P-T conditions reached ~11 kbar and 750–800°C.

A migmatitic paragneiss band present on the northern part of Althorpe Island is hosted by biotite–hornblende adamellite or quartz monzonite. The paragneiss is layered with orthoclase–plagioclase-rich bands containing garnet–biotite–spinel–sillimanite–corundum assemblages (including vermiform spinel–feldspar intergrowths ±corundum) and plagioclase–orthopyroxene–quartz bands, possibly derived from a silica-deficient pelite (Purvis, 1999). The layers are parallel to the regional S_1 foliation, and mineral assemblages suggest an upper amphibolite to granulite facies.

Muscovite-bearing paragneiss is exposed in a low beach cliff at Point Souttar. The paragneiss is well foliated, defined by biotite–muscovite alignment. Quartz and feldspar grains are also elongated along layering, which is now parallel to the Warooka Fault Zone. Calcsilicate xenoliths have been intersected in drillhole TER 1 west of Minlaton (Zang and Hore, 2001), and are hosted in mafic rocks. The calcsilicate is layered, with 5–85% clinopyroxene to 1.5 mm in grainsize, and is considered to represent an endoskarn (Purvis, 2000).

Migmatitic paragneiss xenoliths, up to 2 m wide and 12 m long, occur in augen orthogneiss at northern Point Deberg. The xenoliths are generally lens shaped, veined and twisted, and were stretched along the axis parallel to regional foliation. The augen orthogneiss is dated at 1850 Ma (Table 1), which imposes a minimum age for migmatisation.

The sedimentary setting for the protolith is poorly known. Sediment boudins include both fine-grained sandstone and calcsilicate, but their original sedimentary features have been modified. The presence of zircon and rounded sedimentary quartz grains argue against a pelagic, oceanic basin setting. The boudins with interlayered sandy pelitic and calcsilicate bands suggest a depositional regime with access to a continental source. It is possible that the protolith of the Corny Point Paragneiss was deposited on a continental shelf.

UNNAMED BIOTITE SCHIST (LI_{19})

Golin (1976) described a layered biotite-dominated schist in the Bangalee Beach section as containing biotite (75%), quartz (10%), plagioclase (15%), and accessory apatite and zircon in the quartz–plagioclase layers. The schist bodies are up to 2 m thick and stretched discontinuously for up to 30 m. The layers are concordant with the foliation of the host Gleesons Landing Granite.

Biotite schist at Bangalee Beach; layered and folded schist with crenulations. (Photo 048760)

The schist has distinct dark and light layers. In petrographic thin section, the dark layers contain primarily deep-brown biotite to 4 mm grain size, with some stretched quartz and plagioclase grain-lenses up to 3 mm long between the biotite flakes. The light layers consist mainly of fine-grained plagioclase and quartz, largely 1 mm across, with minor biotite. Biotite defines a schistosity that has been folded along with the layering. Four deformation events can be interpreted in the biotite schist, including fabrics S_1 (biotite alignment), F_2 (microscopic isoclinal folds or crenulations), mesoscopic F_3 and megascopic F_4. The F_4 is a fault propagation fold adjacent to a NW–SE-trending shear-fault.

Golin (1976) interpreted the biotite schist as a metamorphosed relict of a sedimentary sequence. This study suggests it may be a thoroughly hydrated mafic body. Geochemical analysis gives a low SiO_2 (45.5%), CaO (0.23%) and Na_2O (0.3%), and high MgO (6.14%), TiO_2 (1.7%) and V (350 ppm), probably indicating an altered mafic intrusive. Purvis (1997) suggested the layered schist originated as a metasomatic zone between mafic rock and gneissic granite.

PALAEOPROTEROZOIC INTRUSIVES

DONINGTON SUITE (Ld)

The Donington Suite (= Donington Granitoid Suite; Schwarz, 2003) comprises mafic intrusives, quartz-gabbronorite, hypersthene gneissic granite, syenogranite, adamellite, granodiorite and megacrystic granitoid gneiss on Eyre Peninsula that crystallised during ~1855–1835 Ma (Fanning, 1997). The type locality of the suite is at Cape Donington, southeastern Eyre Peninsula, and the outcrops on southern Yorke Peninsula are broadly considered to be equivalents (Parker, 1993a) as they yield similar geochronological dates (Webb et al., 1986; Fanning, 1997; Zang and Fanning, 2001) and have similar metamorphic characters (Pedler, 1976).

The Donington Suite includes the newly named Gleesons Landing Granite and Royston Granite, as well as hornblende micro-adamellite and Jussieu Metadolerite on Yorke Peninsula. The geochronological dates suggest that the crystallisation of the granites ranges from ~1855 to 1835 Ma (Table 1).

Gleesons Landing Granite (Ldg)

The name Gleesons Landing Granite applies to a group of massive to banded granitoid plutons or sill complexes exposed along the southern cliffs of Yorke Peninsula, usually standing out against coastal erosion. Four phases are identified based on their field character and plagioclase–orthoclase percentages, namely syenogranite, adamellite, granodiorite and augen orthogneiss. The type locality is designated at Gleesons Landing, where the granite is well exposed and the four phases are partly intercalated. The granite is generally foliated, layered and folded, and each phase has its own geochemical features.

Recently, drillhole TER 1 west of Minlaton intersected ~9 m of layered, foliated granite gneiss to a total depth of 199 m. Purvis (2000) identified at least 11 layers from five samples, ranging from syenite, syenogranite, adamellite and tonalite to diorite. Petrographic and metamorphic character suggests that the granite gneiss is equivalent to the Gleesons Landing Granite.

Syenogranite Phase (Ldg_1)

The syenogranite phase, an alkali-feldspar granite, is red-brown, fine to medium-grained (commonly 0.2–2.5 mm) and generally foliated and banded. It consists mainly of 45–60% microcline, 20–35% quartz, 5–10% plagioclase, and <5% biotite–hornblende. In petrographic thin sections, the grains are prismatic to poikilitic and commonly occur in small lenses to 4 mm long, with a weak elongation parallel to the foliation. The granite is metamorphosed; the margins of quartz and microcline grains are often lobate or curved and inter-phase tri-points are common. Accessory grains of apatite, zircon, epidote and magnetite are present, whereas zircon is usually abundant in mafic-rich lenses. Microcline grains consist of parallel or subparallel intergrowths of sodium-rich strings (probably albite), and perthitic texture and large euhedral hornblende blades may suggest a high-grade, probably middle to upper amphibolite facies metamorphism during the initial deformation (D_1). Pedler (1976) suggested the P-T conditions of the gneissic syenogranite during deformation in the Point Yorke area were close to 2–4 kb and ~700°C.

Layered syenogranite with a chevron fold, western Point Souttar. (Photo 048748)

In the Point Yorke area, a Rb–Sr isochron from an ‘intrusive’ foliated syenogranite produced an age of 1752±66 Ma with an initial ratio of 0.7114±0.0211 (Pedler, 1976). At Royston Head, a concordia SHRIMP date from syenogranite (R194506, RH 2) gives crystallisation at ~1855 Ma. The syenogranite sample R205166 (Gleesons Landing) contains metamict zircon with thick magmatic zoning that produces discordant ages (1835+10/-11 Ma; C.M. Fanning, ANU, pers. comm., 1999). The syenogranite is considered to be equivalent to the Colbert Granite on Eyre Peninsula, which is dated at 1852.5±4.4 Ma (Schwarz, 2003).

Adamellite phase (Ldg_2)

The adamellite phase is pink to pink-brown in colour and contains more plagioclase in comparison to the syenogranite. The foliated adamellite is often megacrystic and contains compositional layering of quartz–feldspar and biotite–magnetite-bearing bands; in thin sections, biotite and hornblende blades are largely parallel to this layering. The foliation is defined by elongated quartz–plagioclase and microcline rods or aggregates and mafic blades. The petrographic study indicates that the adamellite contains quartz (30–35%), microcline (20–45%) plagioclase (15–30%), biotite (3–5%), magnetite (1–4%) and accessory hornblende, sphene, apatite and zircon, whereas locally, hornblende can be abundant, particularly in the Stenhouse Bay area.

Foliated adamellite at Stenhouse Bay. (Photo 048752)

The adamellite phase is mainly distributed in the southern coastal area and on Althorpe Island (Major, 1973; Zang, 2005). At Cape Spencer and Stenhouse Bay, medium to coarse-grained, well-foliated feldspathic quartz–biotite gneisses occur in beach exposures; Glastonbury (1939) regarded these as orthogneiss, whereas the finding of ‘spherical zircon grains’ led Crawford (1965) to suggest a possible sedimentary origin. Recent studies suggest that it is a foliated adamellite (Purvis, 1996) and that the foliation in the area is determined by orientation of hornblende–biotite and elongated quartz–feldspar augen, with E–W to NW–SE trends, dipping south to southwesterly.

A Rb–Sr date of adamellite from Althorpe Island and nearby islands suggests an age older than 1794±40 Ma (Webb et al., 1986).

Granodiorite phase (Ldg_3)

The granodiorite phase has been mapped at southern Corny Point, Gleesons Landing, Granite Hill homestead (east of Corny Point township) and Point Margaret, and possibly is intersected in drillhole Edithburgh 1. The granodiorite is grey, green–grey to dark grey in outcrop and consists of quartz (25–30%), plagioclase (45–55%), microcline (2–10%), hornblende (7%) and sphene (2–3%), with accessory epidote–allanite, clinopyroxene and biotite. The composition is apparently transitional to tonalite, particularly at Gleesons Landing and Point Margaret (Purvis, 1996). The granodiorite is intensely deformed and a foliation is defined by the alignment of hornblende and quartz–plagioclase rods. At Corny Point, augen bands are present and have been referred to informally as the Corny Point augen gneiss or grey gneiss (Webb, 1978; Webb et al., 1986). At Gleesons Landing, the contact between the granodiorite and syenogranite (Ldg_1) is banded and intercalated; the major banding trends NW–SE, with moderate to steep (20–75^o) dips towards the southwest.

Granodiorite at Corny Point; massive to layered granodiorite–tonalite hosts the light-coloured paragneiss. (Photo 048753)

Grey granodiorite is also found in a single outcrop at Granite Hill homestead. The granodiorite is dark grey in colour, veined, weakly foliated and consists mainly of plagioclase, quartz, biotite, hornblende and microcline. Geochemical data indicates that it contains 66% SiO_2, suggesting a transitional intermediate granite. Petrographic and geochemical studies suggest that it correlates with the granodiorite at Corny Point and Gleesons Landing.

In the low beach exposures south of the Corny Point lighthouse, the granodiorite contains bands and pods of migmatitic paragneiss xenoliths and mafic bodies. The paragneiss is commonly layered and boudinaged, whereas the mafic bodies are fractured and contain back-veining structures. Occasionally, hornblende-rich layers are present at the contact between the granodiorite and mafic bodies and assimilation shows migmatitic features. A geochronological age of 1808±18 Ma (Rb–Sr, initial ratio 0.7043±0.0013) was obtained from the augen bands (Webb et al., 1986), which gives a probable minimum age for the granodiorite.

Augen orthogneiss phase (Ldg_4)

The augen orthogneiss phase is a white-grey to pink-brown, strongly deformed megacrystic microcline–perthite gneissic adamellite exposed continuously along the cliffs from southern Berry Bay to Point Annie, extending ~5 km further south to a lone outcrop at Swincers Rocks. The augen are on average 15x30 mm across, usually microcline with inclusions of plagioclase, quartz and hornblende–biotite. Generally, the rock is an adamellite in composition, consisting of ~35% microcline, 25% plagioclase, 30% quartz, 7–8% foliated biotite and 2–3% clay after hornblende (Purvis, 1996). The biotite foliae wrap around the augen and are parallel to the major foliation, which mainly trends NW–SE. Minor myrmekite is also present between plagioclase and microcline.

Augen orthogneiss at Point Deberg. (Photo 048756)

The augen orthogneiss phase in the Point Deberg area contains boudins of adamellite (Ldg_2), syenogranite (Ldg_1) and migmatitic paragneiss (L-c). The composition of the augen orthogneiss and adamellite boudins is very close, but microcline in the augen orthogneiss is generally perthitic. There are some variations among those augen that display their origin of development, probably as modified primary crystals. Some boudins contain a shearing 'tail' which merges with augen bands, suggesting that the augen orthogneiss is probably a tectonite of a granite body, most likely the adamellite. The timing of the augen orthogneiss formation is considered to be syn-D_1.

Similar augen bands crop out sporadically at Gleesons Landing, Browns Beach and Shell Beach; some narrow bands are also present at Corny Point and Foul Hill. At Shell Beach, layered, megacrystic adamellite intercalates with the grey augen bands. The bands are considered to represent former shear-mylonite zones.

Recent aeromagnetic surveys indicate that the augen orthogneiss in the Point Deberg area is probably an intrusive body. The body is oval in shape, ~6 km wide and 10 km long, with distinct margins to host rocks. A SHRIMP analysis on the augen orthogneiss (southern Berry Bay) produced a concordant age of 1849.9+5.5/-4.8 Ma (crystallisation age); a weighted mean of the $^{207/206}$Pb ages gives a slightly younger mean age of 1848.3±4.1 Ma, indicating that the slight discordance results from loss of radiogenic Pb prior to the present day (C.M. Fanning, ANU, pers. comm., 1999). The host rocks (syenogranite, Ldg_1), as mentioned above, are dated at ~1855 Ma.

Geochemical data have also been collected for a detailed study of the Gleesons Landing Granite, and the discrimination diagrams and results have been described recently (Zang, 2002a).

The augen orthogneiss phase is suggested to correlate with the Wanna Megacrystic Granite Gneiss on Eyre Peninsula (Schwarz, 2003).

Unnamed hornblende micro-adamellite (Ld_4)

This hornblende micro-adamellite is a grey, layered, foliated, fine-grained hornblende–biotite adamellite body consisting primarily of microcline (30–35%), plagioclase (30–35%), quartz (25%), hornblende (3–10%), biotite (3–5%), sphene and opaques. The grain size commonly ranges from 0.1 to 0.5 mm, but is up to 1 mm in some layers. The coarser layers contain more biotite, whereas fine hornblende is the dominant mafic in finer layers. The layers comprise the banding with variable alkali feldspar and mafic biotite and hornblende, and often are intruded by aplite veins, which often show complex folding features in the field. The rock is intensely deformed, with a distinct biotite–hornblende alignment. The micro-adamellite was in early studies considered to be orthogneiss (Glastonbury, 1939), paragneiss (Crawford, 1965) or heterogenetic because of differentiated initial $^{87}Sr/^{86}Sr$ ratio values (Pedler, 1976).

Layered hornblende microadamellite, Annie Nursery. (Photo 048757)

The hornblende micro-adamellite is geochemically distinct from the Gleesons Landing Granite. Four samples indicate that SiO_2 ranges from 61.8 to 65.42% (average 63.88%), suggesting that the micro-adamellite is intermediate, whereas more than 20 samples from the Gleesons Landing Granite average 70.67% (Zang, 2002a).

Fine-grained biotite–hornblende micro-adamellite also occurs on Althorpe Island as isolated pods or dykes in the host adamellite of the Gleesons Landing Granite. The presence of orthopyroxene (~2%) suggests high igneous or metamorphic temperatures (Purvis, 1999). The foliation, defined by mafic minerals, is concordant with regional trends. Several bands of hornblende micro-adamellite also occur in the western Point Souttar area and intercalate with the syenogranite. The hornblende micro-adamellite is considered to be a syntectonic pluton associated with the Gleesons Landing Granite.

Royston Granite (Ldr)

The name Royston Granite is given to felsic plutons or dykes, mainly of adamellite to syenogranite composition, that intruded the Gleesons Landing Granite and unnamed hornblende micro-adamellite, and were probably emplaced during the D_2 event. The granite contains two phases: a porphyritic adamellite at Royston Head and an undeformed syenogranite in the Annie Nursery – Point Yorke area (Zang, 2002a). At Royston Head, the adamellite is pink to light grey and forms porphyritic dykes, up to 8 m wide, largely in an en echelon arrangement with an E–W orientation, and discontinuously for ~1.5 km along the coastal exposure. Petrographic study indicates that it contains mainly microcline (35–40%), quartz (25%) and plagioclase (20–25%), with biotite, hornblende, apatite and metamict zircon. The adamellite contains porphyroblastic augen of mainly microcline in a quartz–plagioclase–hornblende–biotite-rich matrix. It is foliated, particularly intensely, in the contact margin with the host Gleesons Landing Granite; E–W-trending fabrics are defined by hornblende–biotite and K-feldspar–quartz augen elongation, largely parallel to the dyke orientation. In petrographic thin sections, there seems to be an early fabric preserved in augen and the quartz c-axes are ~45° to the later layering and foliation (Purvis, 1999). This early fabric is probably remnant S_1 of the host rocks (now trending 320°).

Royston Granite at Royston Head, showing foliation and elongated mafic enclaves in the granite. (Photo 048762)

At Annie Nursery, an undeformed leucogranite phase intrudes the layered unnamed hornblende micro-adamellite and foliated Gleesons Landing Granite. The intrusive margin is generally sheared. The leucogranite is pink, fine-grained with microcline (50%), quartz (35–40%), plagioclase (10%), and minor biotite and opaques (Purvis, 1996). The bulk composition is similar to the syenogranite phase of the nearby Gleesons Landing Granite. The origin of the intrusive is not known, and it is tentatively assigned to the Royston Granite.

The metamorphic grade of the Royston Granite is estimated by a study of new fabrics at Royston Head. The growth of pleochroic pale to dark green, iron-rich hornblende (or ferrohastingsite) to 2 mm long, and some dark iron-rich biotite, indicate a probable middle amphibolite facies (Purvis, 1999). Regionally, the en echelon-shaped dykes might imply E–W compression during emplacement. Kinematic analyses in the field indicate that the compression induced a dextral sense of shearing movement. A hypothetical diagram was suggested for D_2 in the Royston Head area (Zang, 2002a).

SHRIMP analysis of single zircon grains produces concordant dates. Sample R194507 from an adamellite dyke at Royston Head contains abundant elongate, simple, clear magmatic zircon, whereas some grain terminations appear to have been modified by metamorphic processes. A regression line gives an upper concordia intercept of 1850+12/-11 Ma, a date similar to the crystallisation age of the host

Gleesons Landing Granite, whereas a weighted mean of the $^{207/206}$Pb ages gives a date of 1842±9 Ma, arising from loss of radiogenic Pb prior to the present day (C.M. Fanning, ANU, pers. comm., 1999). A repeat analysis in 1999 gave a concordia age of ~1849 Ma. Combined data produce an average age of ~1849.5 Ma.

MAFIC DYKES AND INTRUSIVES

Mafic dykes commonly intrude the Donington Suite and were referred to as the Tournefort Metadolerite (Parker et al., 1987). Recently, two generations of dykes have been recognised on Eyre Peninsula and the older syn-Donington Suite dykes were referred to as the Jussieu Dykes (Hoek and Schaefer, 1998; Schwarz, 2003). These two mafic units are very distinct in the field, but have only slightly different geochemical features.

Jussieu Metadolerite (Ldj)

Jussieu Metadolerite (Jussieu Dykes of Hoek and Schaefer, 1998) is syn-Gleesons Landing Granite in age in the map area and is considered a unit of the Donington Suite. The dykes and mafic intrusives are generally foliated with distinct S_1 fabrics and normally boudinaged within the host gneissic granite. At Corny Point, the dykes are boudinaged as pods in granodiorite, where back-veining textures are present at the contact margins. At Point Souttar, they are sheared or layered such that they intercalate with gneissic syenogranite, and on Althorpe Island the dykes are mylonitised in the host adamellite. The back-veining texture, in which the mafics are broken into angular fragments by injection of felsic magma (back-veining) from the host rock, suggests that emplacement and crystallisation of the mafic dykes occurred when the host rocks were at least partly in a molten state; the dykes are therefore syntectonic (Hoek and Schaefer, 1998). Similar textures are common on southern Eyre Peninsula and nearby islands (Zang, 2002a).

Jussieu Metadolerite at Corny Point, showing the contact margin between the mafics and granodiorite. (Photo 048767)

Geochemical features of the Jussieu Metadolerite are not very different from the younger Tournefort Metadolerite in the region. They contain slightly high SiO_2 (>51%), but most other data are similar, suggesting they arose from similar enriched sources.

CO-MAGMATIC MAFICS

On Althorpe Island, there are several ultramafic (SiO_2 = 39.2%; Rankin et al., 1991) enclaves composed of hornblende, clinopyroxene, plagioclase and opaques. The enclaves contain a foliation (hornblende fabric) parallel to that of the host granite. The ultramafic rocks are fine to medium-grained and granoblastic; several fragments show indications of an earlier fabric (?clinopyroxene–hornblende elongation). The rocks differ from the Jussieu Metadolerite petrographically and geochemically, and are considered to be altered co-magmatic mafics (Rankin et al., 1991).

Tournefort Metadolerite (Llt)

The Tournefort Metadolerite (Tournefort Dyke Swarm of Parker et al., 1987) includes numerous undifferentiated dolerite, metadolerite or amphibolite dykes on southern Eyre Peninsula. Similar dykes on Yorke Peninsula are generally altered, but rarely foliated; in some dykes the original igneous textures are still intact. The dolerite consists mainly of plagioclase, hornblende, clinopyroxene, biotite, sphene and opaques. The dykes intrude the Gleesons Landing and Royston Granites and are considered to correlate to the Tournefort Metadolerite on Eyre Peninsula, where some five generations of the dykes have been identified on the basis of mutual crosscutting relationships and can be as old as 1812±5 Ma (Schaefer, 1998). The dyke swarm in the map area, based on field evidence, is considered to have been emplaced during post-D_2 and pre-D_3, ranging from ~1850 to 1730 Ma.

Mafic rocks of the Tournefort Metadolerite, which intrudes the Gleesons Landing Granite at Gleesons Landing. (Photo 048769)

Mafic dykes on southern Yorke Peninsula normally contain some biotite, particularly at the contact margins, a feature that is probably related to extensive alteration. Dykes on the peninsula mainly trend NW–SE; on Althorpe Island, several conjugate dykes also trend NE–SW. At Royston Head, a swarm of NW-trending dykes crosscut both the Gleesons Landing and Royston Granites, but are displaced by younger fault-shear zones. The dykes are often boudinaged or folded in D_4 structures, and several re-folded folds are present in the Point Deberg – Berry Bay area.

The dolerite dykes in the Point Souttar and Point Deberg areas are characterised by the presence of large plagioclase phenocrysts. At Point Deberg, a dolerite body is ~0.3 m wide and intrudes augen orthogneiss with a 20 mm wide chilled margin at the contact. The mafic body is not foliated and contains mainly plagioclase (55%) and hornblende (40%), with minor biotite and opaques; some ophitic textures are present. The irregular plagioclase phenocrysts are up to 12 mm across. Some later shear-cleavages cross the dolerite, and associated biotite has grown both within groundmass and plagioclase phenocrysts.

UNNAMED PEGMATITE AND APLITE (Ll_5)

Pegmatite and aplite dykes are widely distributed in the gneissic granite and paragneiss as well as in the younger Wallaroo Group. They are generally undifferentiated, ranging from ~1850 to 1500 Ma. At least three generations of pegmatite can be recognised on southern Yorke Peninsula. The first is present in the migmatitic paragneiss and granodiorite at Corny Point, and in biotite–hornblende micro-adamellite at Meteor Bay, where they occur as pegmatite pods or boudins. Occasionally quartz and feldspar grains are stretched, forming regionally concordant fabrics. Emplacement of the first generation pegmatite is considered to be syn-D_1, arising from anatexis of the Gleesons Landing Granite.

The second generation felsic dykes are considered to be broadly post-D_1 and pre-D_4, and they are interpreted to be displaced or folded in D_3 or D_4 structures, but are not foliated. At southern Berry Bay, pegmatite and granite dykes cut the augen orthogneiss and are folded; some are terminated by dykes of the Tournefort Metadolerite. These felsic dykes are considered to be syn-D_2, and probably related to the Royston Granite. However, at Royston Head, several aplite–granite veins crosscut the Royston Granite, but are displaced by D_4 cleavages and/or faults, indicating an emplacement post-D_3 and pre-D_4.

The third generation felsic dykes intrude the Tournefort Metadolerite and cut across almost all structures in the Palaeoproterozoic basement, usually as aplite veins, but pegmatite dykes or pods up to several metres across are not uncommon in amphibolites at Point Yorke lookout. The dykes are quartz rich, often with graphic texture, and are considered to be genetically related to the early Mesoproterozoic granites, emplaced ~1580 Ma.

WALLAROO GROUP (Lx)

The Wallaroo Group (Conor, 1995; Daly et al., 1998; Zang, 2002b; Cowley et al., 2003) comprises a succession of late Palaeoproterozoic metasediments, and felsic and mafic volcanics, on Yorke Peninsula. It probably overlies the middle Palaeoproterozoic Gleesons Landing Granite and is intruded by the early Mesoproterozoic Hiltaba Suite or equivalents. Deposition of the Wallaroo Group (1763±14–1741±9 Ma; Fanning in Conor, 1995) marked an important period of crustal extension, sedimentation and continental accretion during the late Palaeoproterozoic on the eastern Gawler Craton (Daly et al., 1998; Zang, 2002b).

The group has been divided into three formations, representing metasediments, felsic and mafic volcanics respectively, on the peninsula (Conor, 1995; Cowley et al., 2003; Table 2). On northern Eyre Peninsula, equivalents include the Moonabie Formation, McGregor Volcanics and Price Metasediments (Parker, 1993a; Oliver and Fanning, 1997; Parker and Fanning, 1998; Schwarz, 2003). The Wallaroo Group in South Australia may also include similar metasediments beneath the Stuart Shelf.

Table 2 *Subdivision of the Wallaroo Group (Cowley et al., 2003).*

Wallaroo Group		
Wandearah Formation (metasediments)	Aagot Member	Mainly sandstone and argillite.
	Doora Member	Mainly biotite schist, minor calcsilicate.
	New Cornwall Member	Carbonate, graphitic siltstone and calcsilicate.
	Wokurna Member	Red–brown siltstone, calcsilicate and albitic rocks.
	Ninnes Member	Interlayered albitite, siltstone, sandstone, carbonate.
Weetulta Formation (A-type felsic volcanics)	Moonta Porphyry Member	Porphyritic rhyolite to rhyodacite.
	Wardang Volcanics Member	Rhyolite, rhyodacite, dacite.
	Mona Volcanics Member	Felsics in the Bute area.
Matta Formation (mafic volcanics, tholeiites)	Willamulka Volcanics Member	Amygdaloidal mafics.
	Renowden Metabasalt Member	Fine-grained extrusive and shallow intrusive.

Wandearah Formation (Lxw)

This formation has been proposed to include all late Palaeoproterozoic metasediments on Yorke Peninsula, and five members have been recognised, based mainly on geographic distribution, metamorphic grade and limited lithofacies study. Only the Aagot, Doora and New Cornwall Members occur in the map area. Because of regional metamorphism and lack of outcrop, the stratigraphic relationship between each member cannot be defined. Generally, they are believed to represent separated but regionally intercalated lithofacies deposited in a rift continental shelf setting. The main features are summarised in Table 3.

Aagot Member (Lxwa)

The Aagot Member (Zang, 2002a; Cowley et al., 2003) consists of layered metasandstone or psammite, sandy or tuffaceous argillite with minor calcsilicate and albitic rocks on Wardang Island and in the Port Victoria, Point Pearce, Pine Point and Parara Mine areas. At Point Pearce, ~70 m of sandstone, sandy argillite and minor calcsilicate are exposed along a low-relief beach, and are intercalated with massive Wardang Volcanics and mafic Renowden Metabasalt and,

Table 3 Summary of the lithology and type sections of Wandearah Formation sediments on MAITLAND.

Member	Major lithology and sedimentary facies	Drillholes or section
Aagot	Sandstone with minor siltstone and calcsilicate.	Point Pearce, Port Victoria, Wardang Island
Doora	Biotite argillite with calcsilicate, albitite, sandstone.	DDH 7, 52.2–502.6 m; DDH 151, 24–145 m
New Cornwall	Layered or bedded limestone or dolomite, often inter-fingering with graphitic siltstone, calcsilicate, minor sandstone.	DDH 214, 106–598.6 m; DDH 190, 8.53–54.25 m

locally, by early Mesoproterozoic granite, which also resulted in the formation of sillimanite-bearing migmatite at the contact. The sandstone contains metamorphically enhanced cross-bedding and heavy mineral banding comprising magnetite, zircon and rutile, probably suggesting beach-foreshore deposition. In petrographic thin sections, cross-bedded sandstone contains well-rounded quartz and feldspar grains coated by haematite dust, indicating an aeolian origin. In albitic and calcareous rocks, haematite-coated quartz is also present. The argillite is mainly parallel layered, with some enhanced cross-bedding, graded bedding and laminae. Calcsilicate layers are normally thin and interbanded with fine-grained argillite. Sedimentary features suggest that the Aagot Member in the Point Pearce area was deposited in an aeolian–fluvial to foreshore – shallow shelf conditions.

At the wreck of the 'Aagot' on Wardang Island, the Aagot Member contains conglomerate, tuffaceous siltstone and fine-grained sandstone interbedded with, or intruded by, porphyritic Wardang Volcanics. The conglomerate contains mainly well-rounded rhyodacite and reworked siltstone–sandstone pebbles. Some foliated granite boulders, up to 0.2 m across and similar to the syenogranite phase of the Gleesons Landing Granite, are present. In the sandy siltstone, clastic feldspar grains, derived directly from the weathering of the porphyry, are common (Bone, 1984). Fine-grained sediments occasionally contain possible graded bedding and cross-bedding. Normally the sedimentary bedding is concordant with the flow banding in the Wardang Volcanics. Hyaloclastics are not uncommon in the contact zones between the sediments and volcanics. Sedimentary features on the island suggest settings of waterlain hyaloclastics and fluvial or foreshore to nearshore deposition.

The Aagot Member consists mainly of metasiltstone with minor metasandstone and calcsilicate in the Port Victoria area. Metamorphic-enhanced cross-bedding and graded-bedding occur in fine-grained sandstone. The metasediments are intercalated with extensive felsic volcanics. Huffadine (1993) suggested that the volcanics were erupted and deposited in a subaqueous environment, probably marginal marine, in association with the sediments. This is supported by the presence of jigsaw-fit hyaloclastite breccias, which probably indicate molten igneous rock injecting into cold, unconsolidated sediments. Generally fine-grained sediments with minor calcsilicate may indicate a shelf depositional setting.

Fine-grained argillaceous metasandstone of the Aagot Member at Port Victoria, showing enhanced cross-layering. (Photo 048779)

The metasandstone and metasiltstone have been mapped west of Ardrossan and north of Pine Point along the eastern coast of Yorke Peninsula. No sedimentary features are observed in the area due to extensive metasomatism and limited outcrops. However, in a lone beach exposure at northern Pine Point, a laminated siltstone boulder (1x2 m across) is hosted by medium to coarse-grained sandstone. The sandstone is feldspar rich, with commonly rounded grains, and contains metamorphically enhanced layering and cross-bedding. Laminae in the siltstone boulder are discordant to the layering of the sandstone, and both laminae and layering are crossed by the later Delamerian microfaults or fractures. Sedimentation and tectonic history in this area is poorly understood.

Aagot Member equivalents have been intersected in drillholes in the Curramulka area, where metasandstone and metaconglomerate are intruded by the Curramulka Gabbronorite. Pebbles in the conglomerate are commonly stretched, and the inter-pebble vugs are filled by chlorite, amphiboles and biotite. The sandstone is feldspar rich and the grains are subangular to rounded, with a large proportion of scapolite grains. Some enhanced cross-bedding is present in sandstone, and is marked by heavy minerals and biotite. Sedimentary features suggest a fluvial–estuarine setting.

The Aagot Member is interpreted to have been deposited over central and southern Yorke Peninsula in marginal continental settings. At Port Victoria, Point Pearce and Wardang Island, sedimentary analysis suggests that depositional settings probably range from fluvial–aeolian to shallow shelf environments.

Sediments of the Aagot Member have been metamorphosed to lower amphibolite facies, locally up to middle amphibolite grade, indicated by the presence of perthitic or anti-perthitic feldspar and sillimanite. A concordant foliation defined by mica and amphiboles is present in sediments and associated volcanics, of which the Wardang Volcanics on Wardang Island produce a crystallisation age of 1756±27 Ma (Fanning in Conor, 1995). A study of Rb–Sr isotopes by Huffadine

(1993) suggested multiple thermal events post-sedimentation in the Aagot Member, with isochrons on whole rock yielding 1572–1513 Ma; on muscovite separates giving a date of 1296 Ma (IR = 0.73374); and on biotite returning an age of ~481 Ma.

Doora Member (Lxwd)

The Doora Member (= Doora Schist, Parker, 1980; Doora Metasediments, Conor, 1995) consists of layered, foliated, biotite-rich schistose, psammitic, pelitic, calcsilicate, iron-rich, graphitic and minor albitic metasediments in the Doora, Moonta, Kadina, Wallaroo and Weetulta areas. The sediments were metamorphosed to lower to middle amphibolite facies, locally to upper amphibolite facies (with perthitic microcline–sillimanite–biotite in DDH 103; Purvis, 1997). Biotite schist is widely intersected in the Moonta area, up to ~500 m width in subsurface (DDH 7) and isolated outcrops are found at North Beach, Wallaroo (WHYALLA 1:250 000 map area), Port Hughes, Warburto Point and Winulta. Metasediments of the member interdigitate with, and locally overlie, the Moonta Porphyry (DDH 151), and were intruded by the Tickera and Arthurton Granites. A felsic volcanic layer within the Doora Member (Devon Mine DDH 1) was dated at 1741±9 Ma (U–Pb, Fanning in Conor, 1995).

Doora Member folded biotite schist and calcsilicate slab collected from ruins near the New Cornwall Mine, Kadina. The scale bar is 10 mm for each red and white grid. (Photo 048791)

Schist of the Doora Member was recognised as the host of the copper mineralisation in the Kadina area by Jack (1917). Regionally, this stratigraphic unit has been used to encompass a number of metasediment varieties and volcanics, including hornfels, magnetite-rich amphibolite, felsic volcanics, biotite-rich calcsilicate, and poikiloblastic scapolite-rich gneiss. Plimer (1980) suggested that the Doora Member comprises at least seven mappable mineral assemblage units that were formed during three stages of deformation on northern Yorke Peninsula. Regionally, the multiple deformations in the Doora Member can be analysed in both outcrop and subcrop.

Jones (1940) studied the metasediments in the Wallaroo Mines and suggested that they were originally arkose, siltstone or calcareous siltstone, with some mafic igneous rocks, and could be divided into two groups: metamorphosed arkose and siltstone (quartz–biotite schist), and metamorphosed calcareous siltstone or calcsilicate (McBriar, 1962; Gerdes, 1983). Parker (1980), after detailed study of the schist in the Moonta–Wallaroo area, suggested that the Doora Member (= Doora Schist) was deformed and metamorphosed before the deposition of overlying lower grade metamorphic Wokurna Member (=Wandearah Metasiltstone) and intercalated Willamulka Metabasalt Member (=Willamulka Volcanics, amphibolite and amygdaloidal basalt). An alternative interpretation suggests that the two rock units represent a single succession of sediments with different facies and with regionally metamorphic transition from higher grade Doora Member to lower grade Wokurna and New Cornwall Members (Plimer, 1980; Conor, 1995). A rapid facies and metamorphic transition zone between the Doora and New Cornwall Members is present in the eastern Kadina (New Cornwall Mine) area.

New Cornwall Member (Lxwn)

The New Cornwall Member comprises a subsurface succession of metamorphosed (low amphibolite to greenschist facies), layered limestone, dolomite, laminated calcareous and graphitic argillite and locally sandy argillite in the Pridham's prospect and Paskeville areas. The member is interdigitated with minor felsic, intermediate and mafic rocks; its distribution is poorly known and it is considered to be transitional into the Doora and Aagot Members. Bedding in the carbonate rocks is generally enhanced by deformation, and is commonly interbedded with calcsilicate or siltstone; cross-bedding and rarely stylolitic bedding can be found occasionally. Calcsilicate rock with amphibole, scapolite and albitite banding is common. An interbedded siltstone and carbonate succession in the Pridham's prospect area is thin-bedded to cross-bedded with graded bedding. Few sandstone layers are present in the member. Sedimentary features suggest that the member in the Pridham's prospect area was probably deposited in an environment ranging from a carbonate platform to relatively deep water (below fair-weather wave base) settings. To the northwest near Bute (WHYALLA 1:250 000), the carbonates are fine grained and seem transitional with the siltstone and albitite units. The increase of carbonate content to the east of the New Cornwall Mine was also described by Callen (1966) as a carbonate sequence.

Pelitic and carbonate metasediments north of Pridham's prospect contain mineral assemblages varying from lower

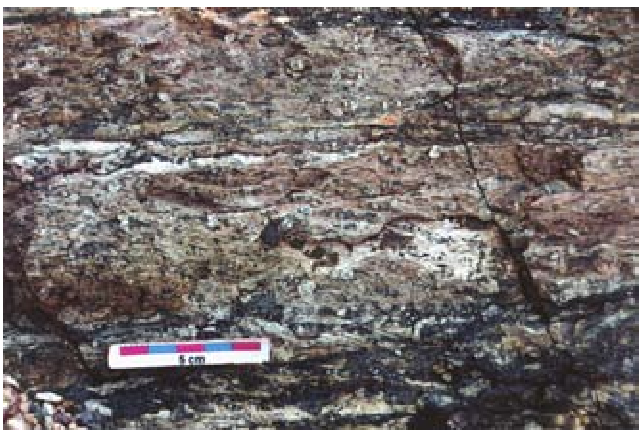
Deformed and layered marble (New Cornwall Member) in DDH 190, depth 46.5 m, west of Paskeville. The scale bar is 10 mm for each red and white grid. (Photo 048797) metamorphic grade to higher grade pelite–calcsilicate at depth, according to core data. In drillhole DDH 213 (50.9–996.1 m), pelitic calcsilicate comprises amphiboles, epidote, mica, scapolite and graphite. Magnetite and haematite are abundant locally. Plimer (1980) recognised a set of mineral assemblages in cores, including muscovite–quartz–pyrite±chlorite, andalusite–muscovite–quartz±albite, quartz–biotite–muscovite and quartz–muscovite–graphite–pyrite assemblages. Lynch (1982) undertook a detailed study of the New Cornwall Member (his East Kadina Group) and recognised a regional stratigraphy in the area: the youngest unit is feldspathic haematitic siltstone, progressively changing down section to feldspathic calcareous siltstone, albitic haematite–magnetite-rich siltstone, and chloritic, dolomitic siltstone; the oldest unit is a graphitic to pyritic siltstone with possible tuffaceous interbeds and minor albitites.

Weetulta Formation (Lxe)

The Weetulta Formation encompasses all felsic volcanics in the Wallaroo Group, including three members — Moonta Porphyry Member, Wardang Volcanics Member and Mona Volcanics Member. In the map area, these felsic rocks are widely intersected in drillholes, and occur in outcrop at Wheal Hughes and Poona Mines, Port Victoria, Point Pearce, and Wardang Island. The Weetulta Formation ranges from syndepositional extrusive to shallow intrusive volcanics.

Moonta Porphyry Member (Lxem)

The Moonta Porphyry Member (Ward and Jack, 1912; Dickinson, 1942) is applied to a subsurface feldspar-phyric rhyolite, rhyodacite to dacite body in the Moonta district, dated from 1737±5 (Parker, 1993a) to 1760±7 Ma (SHRIMP weighted mean age; Fanning et al., 1998). In the Poona and Wheal Hughes open pits near Moonta, the porphyry is massive to layered, and may be either extrusive or intrusive in nature. Phenocrysts are commonly glomeroporphyritic, mainly plagioclase-phyric, occasionally perthitic microcline or quartz-rich. The porphyry is uniform, LREE enriched with an average SiO_2 of 71.35% (range 66.23–75.74%, n = 27), and geochemically resembles A-type granites (Parker, 1993a). The Moonta Porphyry hosts the Cu–Au deposits in the Moonta area and is interdigitated with biotite schist of the Doora Member.



Moonta Porphyry in the Wheal Hughes Mine, with extensive chlorite alteration. The scale bar is 10 mm for each blue and red grid. *(Photo 048813)*

The Moonta Porphyry has been interpreted as an intrusive igneous mass (Jack, 1917; Dickinson, 1942; Whittle, 1974), extrusive rhyolite (McBriar, 1962), ash flow lavas (Lemar, 1975), or a high-level intrusive–extrusive acid igneous magma (Lynch, 1977). Callen (1966) considered the porphyry to be sediment altered by metamorphic differentiation and metasomatism. After a detailed study of regional distribution, and in particular the fragmental volcanics intercalated with sediments in DDH 151 that were interpreted to be part of a breccia pipe, Lynch (1982), Hafer (1991) and Conor (1995) interpreted the Moonta Porphyry as an intrusive and extrusive complex.

The Moonta Porphyry is foliated and recrystallised. Tabular phenocrysts of plagioclase, up to 3 mm, contain traces of sericite and epidote-group minerals as retrograde phases (Plimer, 1980). The groundmass comprises a fine-grained equigranular mosaic (average grainsize ~0.04 mm) of quartz, plagioclase and K-feldspar. At least two major fabrics can be recognised in the porphyry. The dominant fabric is defined by partially sericitised feldspar augen or glomerophenocrysts, and the orientation of biotite and green chlorite. A later, very pale green chlorite is present in veins that cut biotite, chlorite, feldspar and quartz grains in the groundmass (Plimer, 1980). On the walls of open pits at the Wheal Hughes and Poona Mines, the host Moonta Porphyry has a dominant biotite fabric, apparently orientated NE–SW, and a later, weak chlorite fabric is aligned with the major mineral lode strike, crosscutting the biotite foliation.

Wardang Volcanics Member (Lxew)

The Wardang Volcanics Member (Bone, 1984) consists of massive porphyritic rhyodacite, dacite or latite, locally rhyolite, with an average SiO_2 of 69.46% (64.7–73.3%), in the Wardang Island, Point Pearce and Port Victoria areas (Clarke and James, 1993). The phenocrysts, generally <5 mm in size, consist of either K-feldspar or calc-plagioclase with carbonate, scapolite and chlorite inclusions. The matrix contains predominantly K-feldspar plus quartz, plagioclase, biotite, opaques (ilmenite and magnetite) with or without hornblende, pyroxenes, epidote and accessory zircon, apatite, carbonate and scapolite. The volcanics are interpreted to be shallow intrusive and extrusive, or ignimbrites of ash flow bodies, with flow banding, columnar cooling structures and hyaloclastics in the Port Victoria and Wardang Island areas. A SHRIMP date suggests an age of 1756±27 Ma (magmatic crystallisation) with some dispersion and inheritance at 1800–1850 Ma (Fanning in Conor, 1995). A $^{143}Nd/^{144}Nd$ date indicates a depleted mantle model age of 2090 Ma for the provenance of the rhyodacite at Port Victoria (Huffadine, 1993).

The Wardang Volcanics at Port Victoria are light-brown to red-brown and contain Fe-stained feldspars with biotite and hornblende; groundmass, mainly microcline and plagioclase, is aphanitic to microcrystalline, and may be a product of devitrification of glass (Huffadine, 1993). Locally, the rhyodacite is chaotically flow folded, and fold axes are not consistent in orientation. Feldspar phenocrysts, mainly microcline and plagioclase 1–4 mm in size, are altered to sericite. Biotite and hornblende wrap around relict feldspar

Wardang Volcanics in coastal exposure, Port Victoria, showing flow folding structure. The hammer is ~300 mm long. (Photo 403049)

phenocrysts or rodding, defining a metamorphic foliation (Bone, 1984).

The Wardang Volcanics on Wardang Island either intercalate with or intrude conglomerate and tuffaceous siltstone of the Aagot Member. Interlayered conglomerates are locally deposited in shallow channels within the Wardang Volcanics, whereas the extrusive volcanics are often marked by hyaloclastic breccia at the contact margins. At one outcrop, along the western beach, volcanic breccia is angular and poorly sorted, with clasts 20–250 mm across and with a chilled margin, suggesting a vent breccia or peperitic deposit.

In summary, the felsic volcanics of the Wallaroo Group (Weetulta Formation) on Yorke Peninsula probably resulted from one high-temperature melting event during 1763–1741 Ma, forming A-type, shallow intrusive and extrusive deposits. The thermal event was believed to have been associated with syndepositional rifting and bi-model magmatism, leading to an important period of continental accretion within the eastern Gawler Craton.

Matta Formation (Lxt)

The Matta Formation includes all mafic rocks associated with the Wallaroo Group, mainly metabasalt, metadolerite or amphibolites, in the map area. Most mafics in the formation are metamorphosed and have a concordant foliation with those in metasediments and felsic volcanics. Two members, the Willamulka Volcanics Member and the Renowden Metabasalt Member, are present within the formation in the map area (Zang, 2002a).

Renowden Metabasalt Member (Lxtr)

The Renowden Metabasalt Member (Zang, 2002b; Cowley et al., 2003) consists mainly of fine-grained amphibolite or metabasalt along the beach exposures at Port Victoria, Point Pearce and Renowden Rocks. The mafic rocks consist of anhedral to subhedral crystals of hornblende up to 2 mm and plagioclase 0.5–3 mm (with alteration of feldspar to sericite), biotite as <1 mm laths, with occasional chlorite, sphene, opaques, quartz, apatite and rutile as accessories (Huffadine, 1993). At Renowden Rocks, the metabasalt consists of fine-grained hornblende, clinopyroxene and sericite-altered plagioclase with abundant quartz-rich vesicles, suggested to be a formerly amygdaloidal texture (Purvis, 1997). The metabasalt intrudes metasediments of the Aagot Member and Wardang Volcanics. The mafics, felsics and metasediments are all deformed and the foliations are largely concordant. They are considered to have been formed during the Kimban Orogeny, ~1730–1710 Ma (Hand et al., 1995).

Renowden Metabasalt at type section, Renowden Rocks. Metabasalt with vesicles filled by quartz, interpreted as a scoriaceous texture. (Photo 048819)

The Renowden Metabasalt Member was probably formed as a shallow intrusive. At Point Pearce, bands of metasediment breccia are present in the contact margin between the metabasalt and sediments. The breccia is subrounded to subangular and has been stretched parallel to the regional foliation. The metabasalt has been metamorphosed to lower-middle amphibolite facies, defined by the formation of NE–SW and N–S-orientated hornblende and biotite flakes. Locally, this fabric is cut or rotated by NNW–SSE-trending shear zones.

MESOPROTEROZOIC

The Mesoproterozoic rocks in the map area encompass several intrusives attributed to the Hiltaba Suite (1600–1580 Ma) and Spilsby Suite (~1510 Ma) or their equivalents. On Yorke Peninsula, granites exposed along the coast and in low relief hills are named Tickera Granite in the north and Arthurton Granite in the central area. C. Conor (PIRSA, pers. comm., 1999) suggested that these two granites should be grouped as a single unit because of similar characteristics . In the Curramulka–Yuruga area, an early Mesoproterozoic mafic body (Curramulka Gabbronorite) is present in the subsurface, and has a close relationship with the Arthurton Granite. Younger granite belonging to the Spilsby Suite has been interpreted from geophysical data below Spencer Gulf in the western part of the map area.

CURRAMULKA GABBRONORITE (M-c)

The Curramulka Gabbronorite (Zang, 2002b; Cowley et al., 2003) is a subsurface mafic intrusion in the Curramulka area; TMI and gravity interpretation suggests that it is ~10x20 km in size, and is intruded by granite, indicated by the presence of gravity lows. Seven drillholes in the area intersected the gabbronorite during the 1980s and 1990s. It consists mainly of plagioclase, clinopyroxene (augite), orthopyroxene, hornblende, biotite, ±quartz or orthoclase, and was metamorphosed to middle amphibolite facies, producing a green hornblende in contrast to the brown, primary igneous hornblende blades (Purvis, 1997). A foliation is defined by the alignment of biotite and pyroxene (often with a uralite rim) or hornblende, and later retrograde metamorphism has resulted in the formation of chlorite, albite and epidote in shear zones (Zang, 2002b).

The composition of the Curramulka Gabbronorite is variable, suggesting a high degree of crustal assimilation. The plutonic mass ranges from norite to gabbro, having possibly formed in a subvolcanic magma chamber, and its cumulate texture suggest that the gabbronorite is plagioclase-rich, possibly representing a normal to high-K calc-alkaline parental magma (Purvis, 1997), whereas the apophyses or dykes contain substantial quartz. A quartz-rich zone can be defined at the contact margins between the pluton and metasediment. These margins have most likely been sheared. In the late-formed shear zones, breccia or rock fragments are accompanied by albite, chlorite and carbonate.

Norite of the Curramulka Gabbronorite. Core slab from drillhole Cur D2, depth 58.2 m. Scale bar is 10 mm for each red and white grid. (Photo 048823)

The Curramulka Gabbronorite contains abundant irregularly shaped zircon that has been dated by SHRIMP. Sample R364682 is a gabbronorite that was collected from 320 m in MCD 1; 14 analysis points plot with an upper intercept concordia age of 1588±15 Ma (MSWD = 0.77; probability of fit = 0.68), and their weighted mean age is 1588.3±6.3 Ma with 95% confidence. Sample R364685 is a norite (Cur D2, 58.2 m); 20 analysis points (with two repeated) give an upper intercept concordia age of 1590.9±3.4 Ma and weighted mean age of 1589.1±7.4 Ma. Combining the two samples returns a weighted mean age of 1588.6±4.8 Ma, which is interpreted as the age of crystallisation of the gabbronorite (C.M. Fanning, ANU, unpublished data, 1999).

The genesis of the gabbronorite is probably related to a mantle plume or continental extension event, forming a lower crustal magma chamber. The Curramulka Gabbronorite was probably formed in a separate chamber located in the upper crust. Heat accumulation and mafic under-plating could have produced significant crustal melting and resulted in formation of the granite around the chamber. This under-plating process was also suggested by Stewart (1994) for the formation of the Hiltaba Suite and Gawler Range Volcanics in the Gawler Craton.

HILTABA SUITE (Mh)

Tickera Granite (Mht)

The Tickera Granite (Jack, 1917; Dickinson, 1942) is widely distributed in the Tickera and Wallaroo areas, and contains two phases — red-brown monzonite or quartz monzonite, and light grey tonalite (Wurst, 1994). The monzonite consists mainly of microcline and quartz with minor plagioclase, biotite, ±muscovite and magnetite, whereas plagioclase and quartz are dominant in the tonalite. The monzonite and tonalite seem to intrude each other at Wallaroo North Beach; here, the monzonite is dated at ~1575±7, 1586±5, ~1560±28 and ~1600±16 Ma, and the tonalite at 1598±7 Ma (Fanning in Conor, 1995). Jack (1917) considered the Tickera Granite to be older than the Arthurton Granite on the basis of more intense textural fabrics.

The monzonite crops out in the Moonta Bay area, and is strongly deformed by an E–W to NW-trending foliation that is cut by later NE and NW-trending shear bands. The foliation is defined by biotite alignment and elongation of quartz–feldspar grains. Perthitic texture, triple-point junctions and amphibole–mica fabric indicate at least lower amphibolite facies metamorphism.

Arthurton Granite (Mhr)

The Arthurton Granite (Jack, 1917; Dickinson, 1942) is a pink, coarse-grained adamellite consisting mainly of quartz, microcline, plagioclase, mica, sphene, tourmaline, magnetite and chlorite. Extensive subcrops are present in the Arthurton area, and limited outcrops are mapped in the Maitland, Pine Point, Parara Mine, Sandilands, Point Pearce and Mt Rat areas. Aeromagnetic survey and drilling data indicate that much of the central and northern peninsula is underlain by the granite. A U–Pb date on zircon suggests that the granite has a crystallisation age of 1582±7 Ma (Creaser and Cooper, 1993).

The Arthurton Granite is usually pegmatitic in outcrop, and miarolitic texture is common. A study of mineral assemblages suggests that the source magma was possibly undersaturated, and a significant muscovite component in the granite suggests a prominent crustal component to the melt (Wurst, 1994). Jack (1917) considered that the granite was

Arthurton Granite at Pine Point, showing foliated, pegmatitic adamellite. (Photo 048840) the top of an extensive batholithic intrusion that fractured the surrounding rocks, thus providing the plumbing system for ore-producing hydrothermal systems. Miarolitic cavities are suggested to be good evidence for this 'plumbing system' or magmatic volatile phase exsolution. The granite intrusions, particularly the Arthurton Granite, are associated with the hydrothermal systems and mineralisation elsewhere in the Moonta–Wallaroo area (Jack, 1917; Both et al., 1993; Conor, 1995; Morales-Ruano et al., 2002).

OORLANO METASOMATITE (M-r)

The Oorlano Metasomatite (Conor, 1995) is a series of metasomatic skarn-like rocks of calcsilicate, feldspar-rich and iron-rich composition that consist of varied combinations of albite, microcline, scapolite, actinolite, diopside, tremolite, epidote, carbonate, quartz, biotite, magnetite and haematite; generally its protolith cannot be identified. In the map area, the alteration is believed to be related to hydrothermal systems generated during intrusion of the Tickera Granite (Conor, 1995). In shear zones, the Oorlano Metasomatite displays distinct compositional layering of green diopside, tremolite and actinolite, and pink K-feldspar-rich layers. The metasomatite contains both Mesoproterozoic granite and Wallaroo Group protoliths, and has a monazite age of ~1585 Ma (Raymond et al., 2002) which is suggested to be the final metasomatic age.

SPILSBY SUITE (Ms)

A pluton of the Spilsby Suite is interpreted below Spencer Gulf, on the western margin of the MAITLAND map area, this unit being the youngest granite known in the Gawler Craton (Daly in Flint, 1993). On Spilsby Island (LINCOLN 1:250 000), the granite is a porphyritic, medium-grained, equigranular adamellite with magmatic layering (Flint, 1993). The granite is tilted and weakly foliated. A SHRIMP–zircon age of 1510±12 Ma has been obtained from the granite (Fanning, 1997).

NEOPROTEROZOIC (Adelaide Geosyncline)

Neoproterozoic sediments are well exposed in the Flinders and Mount Lofty Ranges to the east of the map area (Preiss, 1987), but are found only in the subsurface in the northeastern corner of the map area, adjacent to the Torrens Hinge Zone, which forms the southwestern edge of the Adelaide Geosyncline. No outcrops are found on the MAITLAND and northern KINGSCOTE, and the so-called 'shield Proterozoic' of Crawford (1965) is now mapped as Cambrian Winulta Formation.

Rhynie Sandstone (Nor)

The Rhynie Sandstone (Emeroo Subgroup, Burra Group) comprises mainly fluvial sandstone and conglomerate with thin red-brown siltstone interlayers. Six drillholes in the northeastern Yorke Peninsula intersected the sandstone. In SYM 600/102, the Rhynie Sandstone (269.2–290.4 m) unconformably overlies basement of the Wallaroo Group, and is unconformably overlain by the glacial Sturt Tillite. The sandstone in the region is normally <100 m thick, but in DDH 76 east of Moonta is >200 m thick (6.6–228.2 m TD). The Rhynie Sandstone is the basal unit in the Burra Group and was deposited at ~780 Ma (Torrensian).

Rhynie Sandstone in drillhole SYM 102, depth 283.9 m. (Photo 403050)

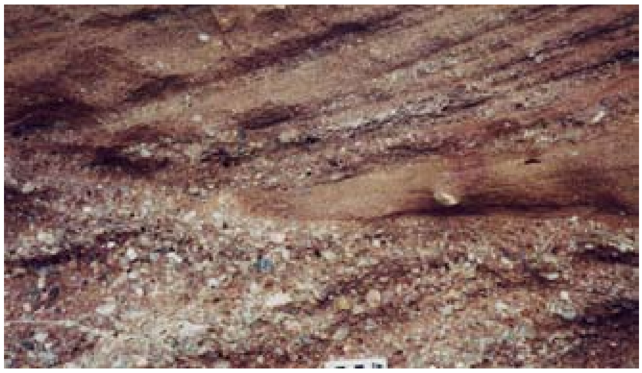
Sturt Tillite (Nus)

Sturt Tillite is a diamictite unit consisting of massive green–grey siltstone to claystone with angular to rounded boulders or pebbles of metamorphic rocks, granite, quartzite and chert. Three drillholes intersected the unit: SYM 600/102 (164–269.2 m), SYM 101 (136.1–186.6 m) and Bute B21 (404.5–406.2 m). In SYM 600/102, the diamictite unconformably overlies the Rhynie Sandstone, and in SYM 101 and Bute B21 it directly rests on the underlying Wallaroo Group. Sandstone, with cross-bedding and massive to bedded siltstone, are also present intercalated in massive diamictite. The siltstone contains some poorly preserved leiosphaeroidal acritarchs. The diamictite is considered to have been deposited in a glacio-lacustrine setting, possibly with minor marine influence indicated by carbonate composition in several layers. Powell et al. (1994) suggested that the Sturtian tillites were deposited in association with rift valley formation, during which time the Laurentia supercontinent was rifting away from Gondwana at ~700 Ma.

TAPLEY HILL FORMATION (Nft)

The Tapley Hill Formation is intersected only in Bute B21, where it is 345 m thick (depth 60–404.5 m). It comprises grey, thin-bedded to laminated shale and dolomitic shale,

Diamictite of the Sturt Tillite, drillhole SYM 101, depth 141.1–141.8 m. (Photo 403051) with thin silty dolomite layers and local, thin, fine-grained sandstone layers. At the base is sandstone or grainstone with rip-up siltstone clasts, unconformably overlying diamictite of the Sturt Tillite. The sandstone layer fines upwards into siltstone. At 399 m, another conglomeratic sandstone layer is present with a scoured base, passing up into siltstone, and fine-grained sandstone with dolomite interlayers. Cross-bedding is present in the siltstone, and some graded layers are observed in the fine-grained sandstone. Sedimentary features suggest a deep-marine shelf deposit, probably below storm-wave base. The formation is unconformably overlain by sandstone of the Winulta Formation. Two samples were processed for acritarch study and contain mainly leiosphaeroidal microfossils.



Cross-bedded sandstone and conglomerate of the Winulta Formation, Port Hughes. (Photo 403053)

CAMBRIAN (Stansbury Basin)

Cambrian sediments are widely distributed on Yorke Peninsula as outcrop and subcrop, and are assigned to the Stansbury Basin (Wopfner, 1972). The basin extends to eastern Fleurieu Peninsula and southern Kangaroo Island. The Cambrian succession in the basin has been well studied stratigraphically (Fig. 5; Daily, 1956, 1957, 1976, 1990; Gravestock, 1984; Zhuravlev and Gravestock, 1994; Gravestock et al., 2001). The sediments are considered to have potential for petroleum and MVT mineralisation.

WINULTA FORMATION (Eoi)

The Winulta Formation (Daily, 1976, 1990) consists of a basal conglomerate, sandstone and minor siltstone, >106 m thick in Stansbury Town 1. Basal conglomerate is up to 1 m thick and crops out in the Winulta, Mt Rat and Moonta areas. The conglomerate grades up into red-brown fluvial sandstone and estuarine to shoreface sandstone in the upper part. In the Wheal Hughes Mine open-pit wall section, a cross-bedded, arkosic coarse-grained sandstone of the Winulta Formation occupies a channel within the Palaeoproterozoic Moonta Porphyry Member. The upper part of the formation is generally only intersected in drillholes, and comprises quartzitic, medium-grained, cross-bedded, relatively well-sorted and fossiliferous sandstone, suggesting estuary to foreshore settings. The formation was broadly mapped as a Proterozoic unit (Crawford, 1965), but findings of trace fossils (*Plagiogmus arcuatus* Roedel, *Triptichnus pedum* Seilacher, *Diplocraterion* sp.) and small skeletal spicules of *Chancelloria* indicate a Tommotian age (Daily, 1976, 1990). Grey siltstone also contains well-preserved acritarchs. The fossils suggest a correlation between the Winulta Formation and Parachilna Formation in the Arrowie Basin (Flinders Ranges). The Winulta Formation is conformably overlain by dolomite of the Kulpara Formation. Thin bands of grey siltstone are interbedded with the sandstone and dolomite in many sections, indicating a transgressive transition.

The Winulta Formation is the most widespread Cambrian unit to crop out, and is present from Warburto Point in the northwestern corner of the map area to Mt Rat in the south. The sandstone often caps hilltops as a result of uplift events, presumably of the Delamerian Orogeny and Quaternary. The conglomerate and sandstone at Port Hughes were first recognised by Jack (1917) as Cambrian, overlying schist of the Wallaroo Group. Crawford (1965) instead mapped it as Proterozoic. This study and regional mapping indicate that the conglomerate and sandstone are representative of the basal Cambrian lowstand deposit on Yorke Peninsula. A similar sediment crops out in a quarry exposure near Winulta, where it unconformably overlies biotite schist of the Doora Member.

The Winulta Formation is intersected in several deep petroleum wells (Daily, 1990). Sandstone at least 280 m thick (1376–1656 m TD), with consistent dips, was intersected in Enchilada 1 and was originally interpreted as a Neoproterozoic Adelaidean sediment (Canyon Ltd, 1998). Examination of cuttings from the well suggests that the sandstone is quartzitic and similar to the Winulta Formation in Edithburgh 1. The sandstone is unconformably overlain by probable Early Cambrian Minlaton Formation (‘red-beds’) in Enchilada 1.

Kulpara Formation (Eok)

The Kulpara Formation (Daily, 1990) is a carbonate unit, containing an upper limestone unit (Eok_1) and a lower dolomite unit (Eok_2), up to 355 m thick in Stansbury West 1 (Fig. 6; Daily, 1990).

The dolomite (Eok_2) is massive to thick-bedded, vuggy and locally stromatolitic. Dolomitisation is considered to be secondary, whereas Daily (1990) suggested that some bands

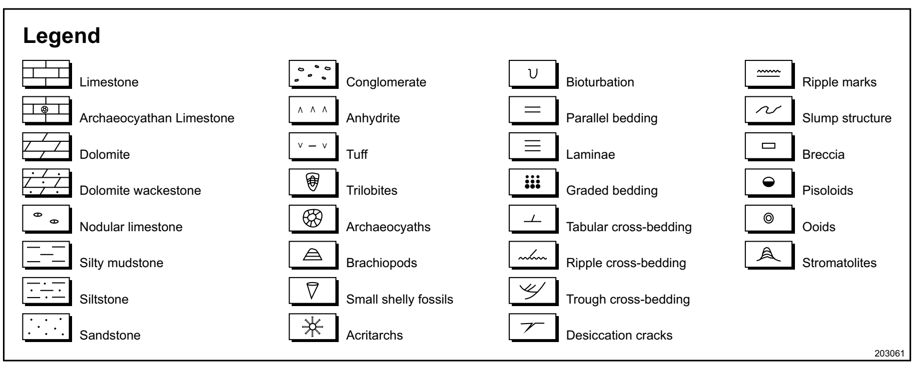


Fig. 5 *Legend.*

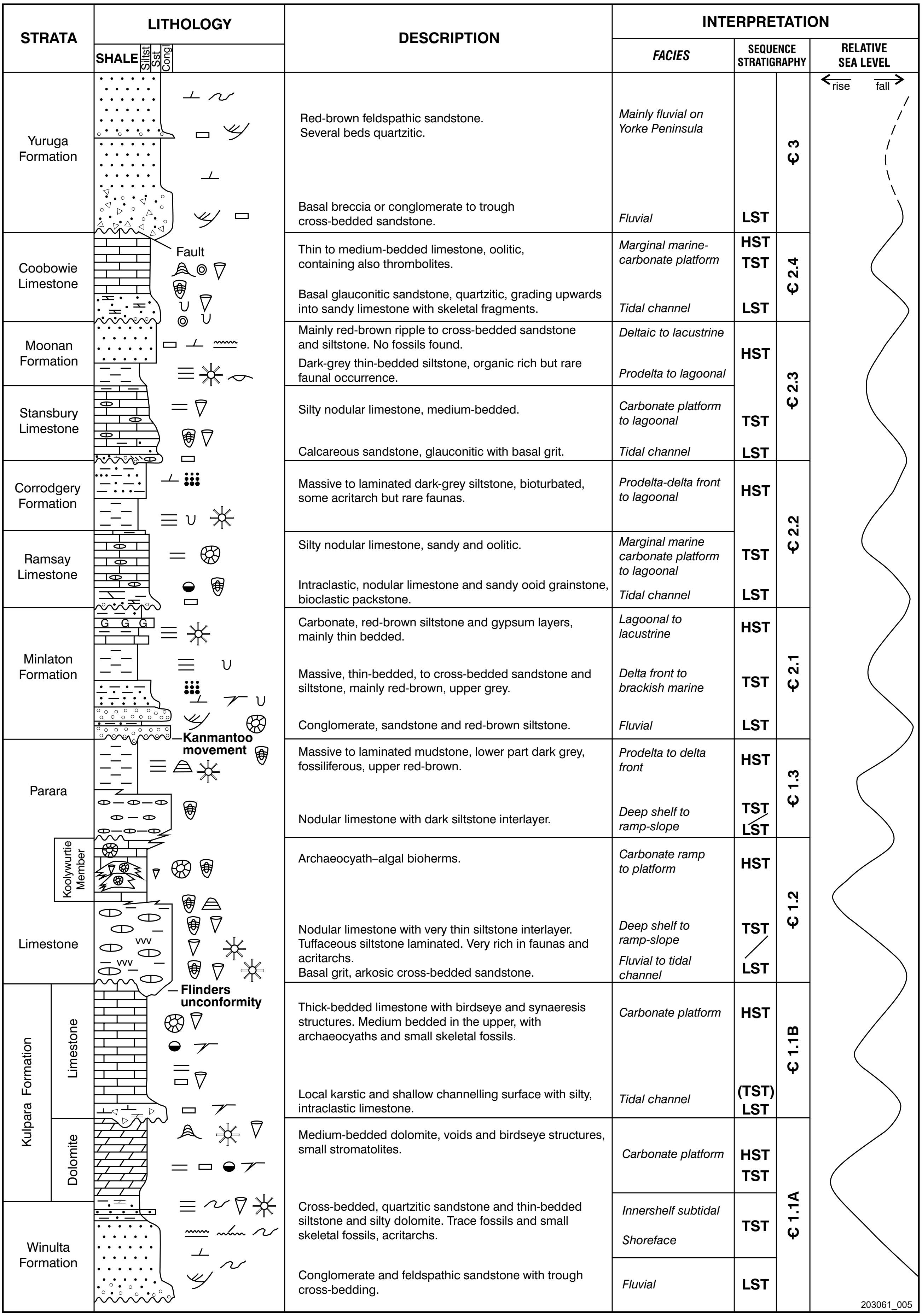


Fig. 5 *Cambrian stratigraphic column, MAITLAND Special 1:250 000 map area.*

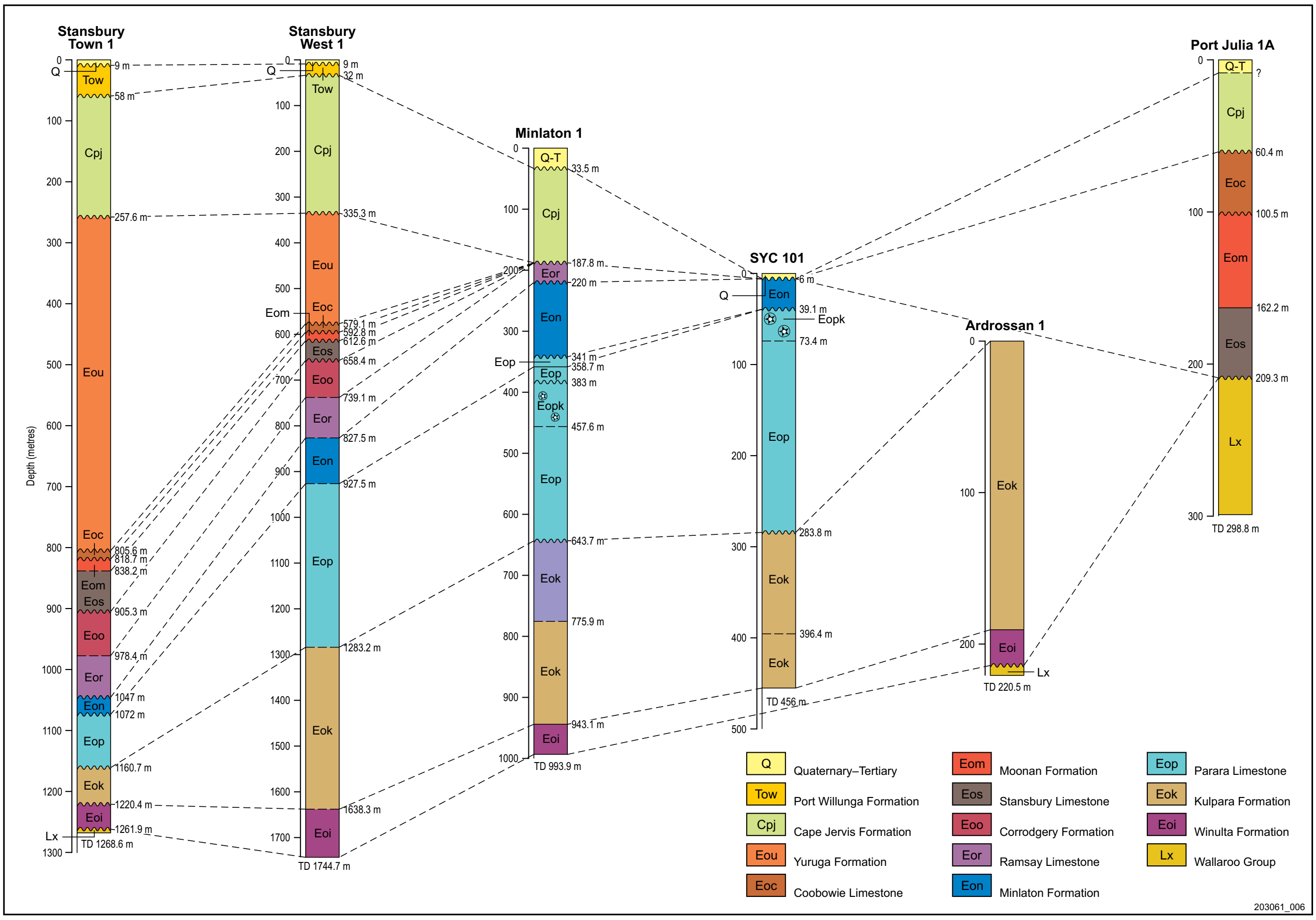


Fig. 6 *Cambrian drillhole correlation, central Yorke Peninsula.*

Dolomite of the Kulpara Formation at Sliding Rock. *(Photo 403054)*

of fine-grained dolomite were 'primary'. The dolomite is generally well exposed in quarry sections (five quarries are in the map area, either active or abandoned) and is quarried as an industrial mineral. It is less commonly exposed than the Winulta Formation and primarily occurs in the northeastern part of Yorke Peninsula, often in association with the underlying Winulta Formation. At Winulta, medium-bedded dolomite in a road exposure contains lamination and low-angle cross-bedding. In the Sliding Rocks coastal section, the dolomite is medium to thick-bedded with stromatolitic laminae. The dolomite is thought to have been deposited in tidal to nearshore subtidal carbonate platform settings.

In the Horse Gully section, the lower creek exposure of the stromatolitic dolomite grades into upper calcareous dolomite containing abundant small skeletal fossils, probably suggesting an early Atdabanian age (Zhuravlev and Gravestock, 1994). The calcareous dolomite is unconformably overlain by the Parara Limestone, and the unconformity is marked by a red ferruginous stromatolitic horizon (Wallace et al., 1991).

In the nearby section at the Ardrossan dolomite quarry, the thick-bedded upper limestone unit (Eok_1) unconformably overlies the dolomite, and the same ferruginous horizon is present at the top of the limestone. The horizon may represent the erosion surface of the so-called 'Flinders Unconformity' (Gravestock, 1995) in the Ardrossan area. An uplift event in the area might have resulted in complete erosion of the upper limestone unit in the Horse Gully section. Along the coastal cliff exposure at Sliding Rocks, the upper limestone unit is stylolitic and fossiliferous (D. Gravestock, PIRSA, pers. comm., 1999), and was probably deposited on a karstic surface of the lower dolomite.

The limestone unit has a restricted distribution, probably due to limited sedimentation and post-depositional erosion in this region. The limestone is normally thick bedded with minor thin bedding; oolitic limestone and stratiform algal mats are also present. South of Curramulka, the thick-bedded limestone is in fault contact with the Parara Limestone, and in subcrop it is vuggy, locally oolitic with intraclastic breccia, and is fossiliferous. Depositional environment of the limestone probably ranged from tidal to subtidal platform. Abundant Atdabanian archaeocyaths (*Spirillicyathus tenuis* Zone) and small skeletal fossils are found (Tate, 1892; Daily, 1990; Zhuravlev and Gravestock, 1994; Gravestock et al., 2001). A sedimentary contact is exposed in the Curramulka Quarry.

Parara Limestone (Eop)

The Parara Limestone (Tepper, 1879) consists mainly of nodular limestone with minor mottled argillaceous limestone and calcareous shale, 285 m thick in Minlaton 1, and up to 358 m thick in Stansbury West 1 (Daily, 1990). The nodular limestone is sporadically exposed in creek sections at Dowlingville (north of Ardrossan) and southeast of Kainton, and in a quarry section at Curramulka. In outcrop, the limestone consists of fossiliferous, dark grey, thin to medium-bedded, close-packed silty limestone nodules, in a black, pyritic calcareous mudstone matrix. A thin layer of calcareous clay fills the gap between each bedding break. Depositional settings of the limestone could range from shallow slope to lagoonal environments, with oscillating aerobic and anaerobic bottom conditions (Zhuravlev and Gravestock, 1994). In the Curramulka drillholes Cur D7–12, nodular limestone interbeds with thick-bedded white-grey to pink-brown limestone, and the pelite beds are up to several metres thick; the evidence suggests an open-marine, shallow carbonate shelf deposit. The limestone is fossiliferous and contains the late Atdabanian to Botoman trilobites *Yorkella australis*, *Pararaia* sp. and *Redlichia* sp. (Daily, 1956; Bengtson et al., 1990). Acritarchs are also abundant.

Nodular limestone of the Parara Limestone, Curramulka Cave. (Photo 403055)

Koolywurtie Member (Eopk)

In most outcrops and cores, nodular limestone of the Parara Limestone is capped by stacked archaeocyathan bioherms of the Koolywurtie Member. The bioherms consist of archaeocyathan and calcareous algal *Girvanella*, *Epiphyton*, *Renalcis* boundstone that have been named the *Syringocnema favus* beds (Zhuravlev and Gravestock, 1994). At the western end of Horse Gully, the Koolywurtie Member is ~50 m thick and is known as 'Tepper's Knoll' (Tucker, 1989; Zhuravlev and Gravestock, 1994). The unit in most drillholes conformably overlies nodular limestone of the Parara Limestone, and is unconformably overlain by the Minlaton Formation, whereas in Minlaton 1 it is unconformably overlain by nodular limestone of the upper Parara Limestone. The bioherms are interpreted to form a reefal complex in the Parara Limestone, and these archaeocyathan reefs and calcareous algae build-ups are considered to have been deposited in subtidal, shelf to ramp environments (Gravestock et al., 2001).

Archaeocyath-bearing limestone of the Koolywurtie Member, drillhole Cur D1B, 266.7 m. (Photo 403056)

Minlaton Formation (Eon)

Minlaton Formation (Daily, 1976) is characterised by the occurrence of red beds, and comprises red-brown and minor grey siltstone, sandstone, silty carbonate and conglomerate with several gypsum layers in the upper part. The formation is not exposed outcrop but has been widely intersected in drillholes.

The formation is common and distinct in cores, and includes mainly red-brown siltstone with a basal conglomerate, and with gypsum layers in the youngest part. In Minlaton 1, the gypsum layers are up to 12 m thick (232.6–244.8 m) and thin layers of grey siltstone or silty carbonate also occur. Thin-bedding, cross-bedding and occasional graded bedding are present in the siltstone. The basal conglomerate in the Curramulka drillholes unconformably overlies the Koolywurtie Member, and eroded boulders or pebbles with archaeocyath fossils are common. The conglomerate is interbedded with trough cross-bedded sandstone and cross-bedded siltstone, suggesting fluvial to delta-lacustrine settings; in Cur D8, the red-brown siltstone bed with gypsum is up to 20 m thick (depth 272.8–293 m). The unconformity and basal conglomerate deposition are considered to be a result of the earliest phases of the Kangarooian Movement (Daily and Forbes, 1969; Daily and Milnes, 1971; Daily, 1990).

Haematitic, gypsiferous siltstone of the Minlaton Formation, drillhole Minlaton 1, 243.5 m. (Photo 403057)

Fossils are rarely found in the Minlaton Formation, and sedimentary conditions may have ranged from marginal marine to deltaic, fluvial or lacustrine environments. Poorly preserved acritarchs in the laminated grey siltstone suggest probable restricted marine to lacustrine conditions.

In Minlaton 1, an 18 m (depth 341–358.7 m) siltstone occurs between the nodular limestone of the Parara Limestone and red-brown siltstone of the upper Minlaton Formation. This siltstone unit has been included with the Minlaton Formation in prior literature. It is mainly grey but with red-brown beds in the upper part, conformably overlies the Parara Limestone; the transition is marked by a gradational change from nodular limestone into dark grey to grey, massive to laminated siltstone. Acritarchs and shelly fossils are present in the grey siltstone, and sedimentary features suggest that the unit was deposited in a prodelta to delta front setting. As the unit is unconformably overlain by basal conglomerate of the upper Minlaton Formation, it is instead reassigned to the Parara Limestone in sequence set Є1.3 (Table 4).

Ramsay Limestone (Eor)

The Ramsay Limestone (Crawford, 1965) is flaggy to nodular, thin to medium-bedded silty limestone with basal sandy ooid grainstone and bioclastic packstone. Outcrops of the limestone south of Curramulka were reported a century ago (Pritchard, 1892) and later found to contain archaeocyaths (Ward, 1944), but these were not found in the current study. The presence of the trilobite *Redlichia nobilis* and skeletal fossils *Helcionella*, *Chancelloria*, etc. suggest a Toyonian age (Daily, 1990; Brock and Cooper, 1993). The limestone is up to 109 m thick in Cur D1B (103.9–212.5 m). In cores, the Ramsay Limestone unconformably overlies the Minlaton Formation, and basal grits and sandy limestone or grainstone are present in Cur D11. The occurrence of pisolite, skeletal fragments, red-beds and cross-bedding suggests marginal marine to lagoonal environments. The Ramsay Limestone is transitional into the overlying Corrodgery Formation. Exposures also occur 8 km east of Minlaton.

Nodular limestone of the Ramsay Limestone, drillhole Minlaton 1, 210.6–216.1 m. (Photo 403058)

Corrodgery Formation (Eoo)

The Corrodgery Formation (Daily, 1990) is a subsurface unit of mainly dark grey to chocolate-brown siltstone and fine-grained sandstone, up to 81 m thick in Stansbury West 1

Bioturbated siltstone of the Corrodgery Formation, drillhole Dur D1B, 89.2 m. (Photo 403059)

(Daily, 1990), and is fully cored in Cur D9 (187–261 m). It conformably overlies the Ramsay Limestone, and is unconformably overlain by the nodular Stansbury Limestone. The lower part of the formation is mainly massive, layered to laminated dark grey siltstone, with bioturbation and occasional debris beds; it was probably deposited in a restricted marine to lagoonal setting. The upper part is dominated by sandstone with thin red-brown siltstone interlayers; the sandstone is massive, bedded to cross-bedded, with grading, and rip-up mudstone intraclasts. The evidence suggests delta front deposition.

No skeletal fossils have been found in the Corrodgery Formation. Abundant acritarchs from the bioturbated siltstone suggest correlation with the Tempe Formation in the Amadeus Basin (Zang and Walter, 1992), and a possible Toyonian age.

Stansbury Limestone (Eos)

The Stansbury Limestone (Daily, 1969, 1972) comprises mainly medium-bedded, nodular to flaggy silty limestone, ooid grainstone and thin siltstone interlayers, up to 67 m thick in Stansbury Town 1 (Daily, 1990). No outcrops are known on Yorke Peninsula. The limestone is fully cored in Port Julia 1A (162.2–209.3 m), where it unconformably overlies the Palaeoproterozoic Wallaroo Group, and is conformably overlain by the Moonan Formation. The limestone contains basal wackes, oolitic to sandy limestone and layered silty limestone, and passes up into thin to moderate-bedded limestone. In Cur D9, the Stansbury

Stansbury Limestone, drillhole Stansbury 1, 619.6 m. (Photo 403060)

Limestone unconformably overlies the Corrodgery Formation. The lower part of the cored section contains a 3 m thick unit of calcareous sandstone or sandy calcarenite with basal grit; ribbons of limestone intraclasts are present. The sedimentary features indicate a probable tidal channel deposit. The calcarenite passes upwards into grey to mottled nodular limestone with thin calcareous siltstone interlayers, interpreted as a carbonate platform deposit. The presence of the trilobite *Redlichia* sp. and abundant small skeletal fossils indicate a latest Toyonian age.

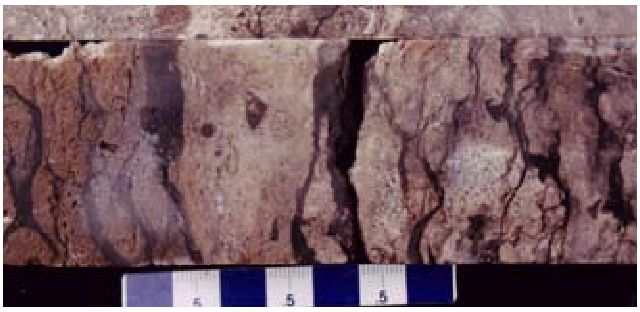
Moonan Formation (Eom)

The Moonan Formation (Daily, 1990) consists of massive, bedded to laminated siltstone and fine-grained sandstone. The formation is fully cored in Port Julia 1A (100.5–162.2 m) and here it is mainly green-grey siltstone with minor fine-grained sandstone in the lower part, and red-brown fine-grained sandstone with minor siltstone in the upper part. The siltstone of the lower unit is generally massive to laminated and the associated sandstone is thin bedded to cross-bedded with occasional rip-up intraclasts. It was probably deposited in restricted marine (lagoonal) to prodelta settings. The upper unit is dominated by massive to cross-bedded sandstone with minor red-brown siltstone; slump folds and rip-up intraclasts are also present, probably indicating a deltaic–lacustrine deposit. Rare brachiopods occur. Filamentous and coccoidal microfossils were collected from the grey laminated siltstone, suggesting a restricted marine to lagoonal environment. No outcrops are mapped on Yorke Peninsula.

Siltstone of the Moonan Formation, drillhole PJ1A, 150.9 m. (Photo 403061)

Coobowie Limestone (Eoc)

The Coobowie Limestone is an oolitic, fossiliferous limestone that is named from cuttings in Stansbury West 1 and Stansbury Town 1 (Daily, 1972), where it overlies Moonan Formation and is overlain by Yuruga Formation. The limestone is cored in Port Julia 1A (60.4–100.5 m), where it unconformably overlies the Moonan Formation, and is unconformably overlain by glacial diamictite of the Permian Cape Jervis Formation. The basal limestone is a 1 m thick glauconitic sandstone with mudstone intraclasts, which grades up into sandy, glauconitic, occasionally peloidal limestone (91.3–99.1 m), probably representing a tidal channel deposit. The upper part of the limestone is medium-bedded, oolitic to silty and contains small possible thrombolites, suggesting a shallow marine deposit. The first appearance of *Pagetia* sp. and associated small skeletal fossils at 86.15 m in Port Julia 1A suggests a Middle Cambrian age (Gravestock and Shergold, 2001).



Pisolitic limestone of the Coobowie Limestone, drillhole PJ 1A, 99.1 m. (Photo 403062)

In a low cliff exposure at Sliding Rocks, a lens ~5x1 m of sandy limestone in the fault contact with the Yuruga Formation. The limestone here is tentatively mapped as Coobowie Limestone. The lens is largely parallel to NNE–SSW-trending Delamerian faults.

Yuruga Formation (Eou)

The Yuruga Formation (Daily, 1990) comprises mainly red-brown fluvial sandstone, conglomerate and breccia, up to 548 m thick in Stansbury Town 1 (Daily, 1968). The formation is known to overlie the Coobowie Formation and represents the youngest Cambrian deposit on Yorke Peninsula. In the Muloowurtie Point, Pine Point and Rocky Point areas, the formation is in faulted contact with the early Mesoproterozoic Arthurton Granite. At Pine Point, the Yuruga Formation contains a series of fluvial cycles, starting with angular to subangular fault-generated breccia, passing upwards into coarse-grained sandstone and trough cross-bedded medium-grained sandstone, and then into cross-bedded fine-grained sandstone and siltstone. In the drillholes, angular breccias and some rip-up intraclasts are also present. The sandstone is generally haematitic and arkosic, and may be of aeolian origin; siltstone layers are minor and usually thin. Trace fossils and trilobite tracks occur (Daily, 1990), but no index fossils are present. Daily (1990) considered the formation to be late Middle Cambrian in age.

Fluvial sandstone and conglomerate of the Yuruga Formation, Pine Point. (Photo 403063)

CAMBRIAN SEQUENCE STRATIGRAPHY

The sequence stratigraphy in the Stansbury Basin is well described (Gravestock, 1995; Zang et al., 2004; Flöttman et al., 1998) and locally three sequence sets can be recognised (Table 4). In brief, sedimentary sequences on Yorke Peninsula record two local marine transgressions. The first started with marine coastal–estuarine sandstone of the Winulta Formation, reached the maximum transgression at deposition of the lowest dolomite of the Kulpara Formation (epeiric platform to ramp), and was followed by drowned ramp–slope and deep shelf deposits (Parara Limestone). The second transgression was subdued by the uplifting event of the Kanmantoo Movement and formation of a palaeo-high in the Stansbury region, which probably semi-barred a western depocentre from eastern open marine. It began with deltaic red-beds of the Minlaton Formation, reached the maximum transgression at deposition of the Ramsay Limestone, and ended with the thick fluvial sandstone of the Yuruga Formation.

LATE CARBONIFEROUS – PERMIAN (Troubridge Basin)

Cape Jervis Formation (CP-j)

The Cape Jervis Formation (Bourman and Alley, 1990), formerly Cape Jervis beds (Ludbrook, 1967), comprises a succession of diamictites, ranging from lower glacio-fluvial and glacio-lacustrine to upper fossiliferous (foraminifer) glacio-marine siltstone with minor sandstone in the lower part. The type section of the formation is at Cape Jervis on Fleurieu Peninsula to the east of the map area where five units have been recognised, ranging from glacio-fluvial, deltaic to marginal marine settings (Alley and Bourman, 1995).

Late Carboniferous – Permian diamictites are widely intersected in drillholes, but outcrops are limited to southern Yorke Peninsula, notably at Port Vincent, Waterloo Bay, Point Turton and Warooka areas, Hardwicke Bay to Port Rickaby, and Cliff Point on Wardang Island. The diamictites are massive and mainly green-grey silts with erratics of granite, sandstone, metamorphic basement and Kanmantoo Group metasediments. The Cape Jervis Formation is <20 m thick in outcrop on Yorke Peninsula, whereas up to several hundreds of metres are intersected in drillholes (e.g. 303 m in Stansbury West 1 and 412 m in Edithburgh 1), where the sediments unconformably overlie the Cambrian Yuruga Formation and are unconformably overlain by the Tertiary Port Willunga Formation. At Waterloo Bay, the diamictites are unconformably overlain by the Quaternary Hindmarsh Clay or Bridgewater Formation.

Diamictite of the Cape Jarvis Formation, Point Turton. *(Photo 403064)*

Recent drilling of TER 1, west of Minlaton, intersected 162 m (depth 9–171 m) of diamictite, in which up to six beds of sandy limestone or calcarenite are present (Zang and Hore, 2001). Sedimentary features may indicate a restricted marine shoreface environment in the area.

The depocentres of the Carboniferous–Permian sediments are interpreted to be located under Gulf St Vincent by seismic interpretation in the map area. On Yorke Peninsula, local depocentres are interpreted near Yorketown (Beach Petroleum NL, 1969), where a Carboniferous–Permian depression may exist on the Cambrian basement. On northwestern Yorke Peninsula, isolated outcrops and subcrops were probably deposited in glacial valley settings. Abundant erratics, particularly granite blocks up to several metres in diameter resembling Delamerian granite from Fleurieu Peninsula, occur in the Port Vincent and Waterloo Bay areas, and on inland saline lake floors. These suggest a west and northwestward glacial movement during deposition (Alley and Bourman, 1995).

The foraminiferal fossils in Yorke Peninsula drillholes suggest an Early Permian Sakmarian age (Ludbrook, 1957b, 1969) and palynological studies reached a similar conclusion (Harris and McGowran, 1971; Foster, 1974). However, Cooper (1981) argued, using palynology, that the Cape Jervis Formation could be correlated, at least partly, with the Late Carboniferous. Most fossils have been collected from the upper part of the Cape Jervis Formation whereas the lower diamictites contain only rare microfossils. In Troubridge Island 1, Ludbrook (in Geosurveys of Australia Pty Ltd, 1963) found foraminiferal beds only at the top of the formation. The sedimentary succession of the formation in the region records a progression from cold to warm climate for the deglaciation; sea-level rise resulted in marine incursion onto Yorke Peninsula, but only extending into the southern depocentres in the Edithburgh and Waterloo Bay areas.

Distribution of the Cape Jervis Formation in the Troubridge Basin is well documented (Alley and Bourman, 1995). Some 2000 m of Carboniferous–Permian deposits have been interpreted by seismic data in the eastern Backstairs Passage area and related to graben or depression structures (Parker, 1993b). On southern Yorke Peninsula and under Gulf St Vincent it is <1000 m thick, indicating that major syndepositional faults were reactivated from Cambrian structures. West of Point Turton, a Carboniferous–Permian graben structure can be interpreted from offshore seismic sections. It is interesting that zircon dating from the basement complex often records a Permian thermal event or loss of radiogenic lead prior to the present day (C.M. Fanning, ANU, per. comm., 1999). This may suggest that some significant crustal movements or rifting events happening in the region during the Early Permian.

Table 4 *Correlation of the Cambrian sequences in South Australia (after Gravestock, 1995).*

Age		Sequence Sets		Yorke Peninsula		Kangaroo Island		Fleurieu Peninsula		Arrowie Basin	
Middle Cambrian		Є3		MORALANA SUPERGROUP	Yuruga Formation	KANGAROO ISLAND GROUP		KANMANTOO GROUP	Middleton Sandstone	LAKE FROME GROUP	Grindstone Range Sandstone
Middle Cambrian		Є2	2.4	MORALANA SUPERGROUP	Coobowie Limestone	KANGAROO ISLAND GROUP		KANMANTOO GROUP	Petrel Cove Formation, Balquhidder Formation	LAKE FROME GROUP	Pantapinna Sandstone
Early Cambrian	Toyonian	Є2	2.3	MORALANA SUPERGROUP	Moonan Formation, Stansbury Limestone	KANGAROO ISLAND GROUP	Boxing Bay Formation	KANMANTOO GROUP	Tunkalilla Formation, Tapanappa Formation	LAKE FROME GROUP	Balcoracana Formation, Moodlatana Formation
Early Cambrian	Toyonian	Є2	2.2	MORALANA SUPERGROUP	Corrodgery Formation, Ramsay Limestone	KANGAROO ISLAND GROUP		KANMANTOO GROUP	Talisker Calc-siltstone, Backstairs		Wirrealpa Limestone
Early Cambrian	Toyonian	Є2	2.1	MORALANA SUPERGROUP	Minlaton Formation	KANGAROO ISLAND GROUP	Emu Bay Shale, White Point Conglomerate	KANMANTOO GROUP	Passage Formation, Carrickalinga Head Formation		Billy Creek Formation
Early Cambrian	Botoman	Є1	1.3	MORALANA SUPERGROUP	Parara Limestone (Koolywurtie Member)	KANGAROO ISLAND GROUP	Smith Bay Shale, Stokes Bay Sandstone	NORMANVILLE GROUP	Heatherdale Shale	HAWKER GROUP	Narina Greywacke, Oraparinna Shale, Bunkers Sandstone
Early Cambrian	Botoman	Є1	1.2	MORALANA SUPERGROUP	Parara Limestone	KANGAROO ISLAND GROUP	Mount McDonnell Formation	NORMANVILLE GROUP	Fork Tree Limestone	HAWKER GROUP	Mernmerna Formation
Early Cambrian	At.	Є1	1.1B	MORALANA SUPERGROUP	Kulpara Formation: Limestone Unit	KANGAROO ISLAND GROUP	Mount McDonnell Formation	NORMANVILLE GROUP	Sellick Hill Formation	HAWKER GROUP	Lower Wilkawillina Limestone
Early Cambrian	Tom.	Є1	1.1A	MORALANA SUPERGROUP	Kulpara Formation: Dolomite Unit; Winulta Formation	Investigator 1 intersection	Kulpara Formation, Winulta Formation	NORMANVILLE GROUP	Wangkonda Formation, Mount Terrible Formation	HAWKER GROUP	Woodendinna Dolomite, Parachilna Formation
Early Cambrian	N.		1.0							HAWKER GROUP	Uratanna Formation

TERTIARY (St Vincent Basin)

The St Vincent Basin is a semi-intracratonic depression on a rifted continental shelf with probable seaway links to the southern ocean east and west of Kangaroo Island. The basin is present below Gulf St Vincent, and parts of eastern Yorke Peninsula, western Fleurieu Peninsula and Kangaroo Island where it is defined by a series of graben – half-graben structures (Wopfner, 1972; Cooper, 1985; Birt, 1995). The Tertiary succession is well exposed on the coast of Yorke Peninsula and consists of alternating marine and non-marine siliciclastics and limestone. Two channels have been recognised on Yorke Peninsula that connect the St Vincent Basin with the Pirie Basin to the north and west. The northern channel is mapped by the distribution of palaeochannel deposits of the Eocene North Maslin Sand and Miocene Melton Limestone (Crawford, 1965; Pain et al., 1992). The major Tertiary outcrops are along the eastern coast of the peninsula and have been well studied (Fig. 7; Crawford, 1965; Stuart, 1970; Cooper, 1985; Lindsay and Alley, 1995).

North Maslin Sand (Ten)

Basal Tertiary sand and lignite are mapped in quarry exposures in the Ardrossan, Price and Correll sandpit areas (Crawford, 1965). Extensive drilling for building sand during the early 1990s confirmed that the unit correlates with the Middle Eocene North Maslin Sand of the eastern St Vincent Basin (Pain et al., 1992). No fossils occur in the sand. The unit consists mainly of cross-bedded fluvial sand and gravel; palaeocurrent analysis suggests an east-southeast stream transport (Stuart, 1970). The sand in the Ardrossan Quarry and nearby road-cut exposures is 1–10 m thick, unconformably overlies the Cambrian Kulpara Formation, and is unconformably overlain by the Hindmarsh Clay. In the Price Quarry, the sand is unconsolidated, up to 50 m thick, and displays large-scale cross-bedding and trough cross-bedding. The unit reaches ~65 m thickness in AP 8 (Stuart, 1970), and in Black Point 1A is ~20 m thick. Several road-cut exposures have been mapped near Ardrossan and west of Price.

Quarry exposure of the North Maslin Sand, west of Price.
(Photo 403065)

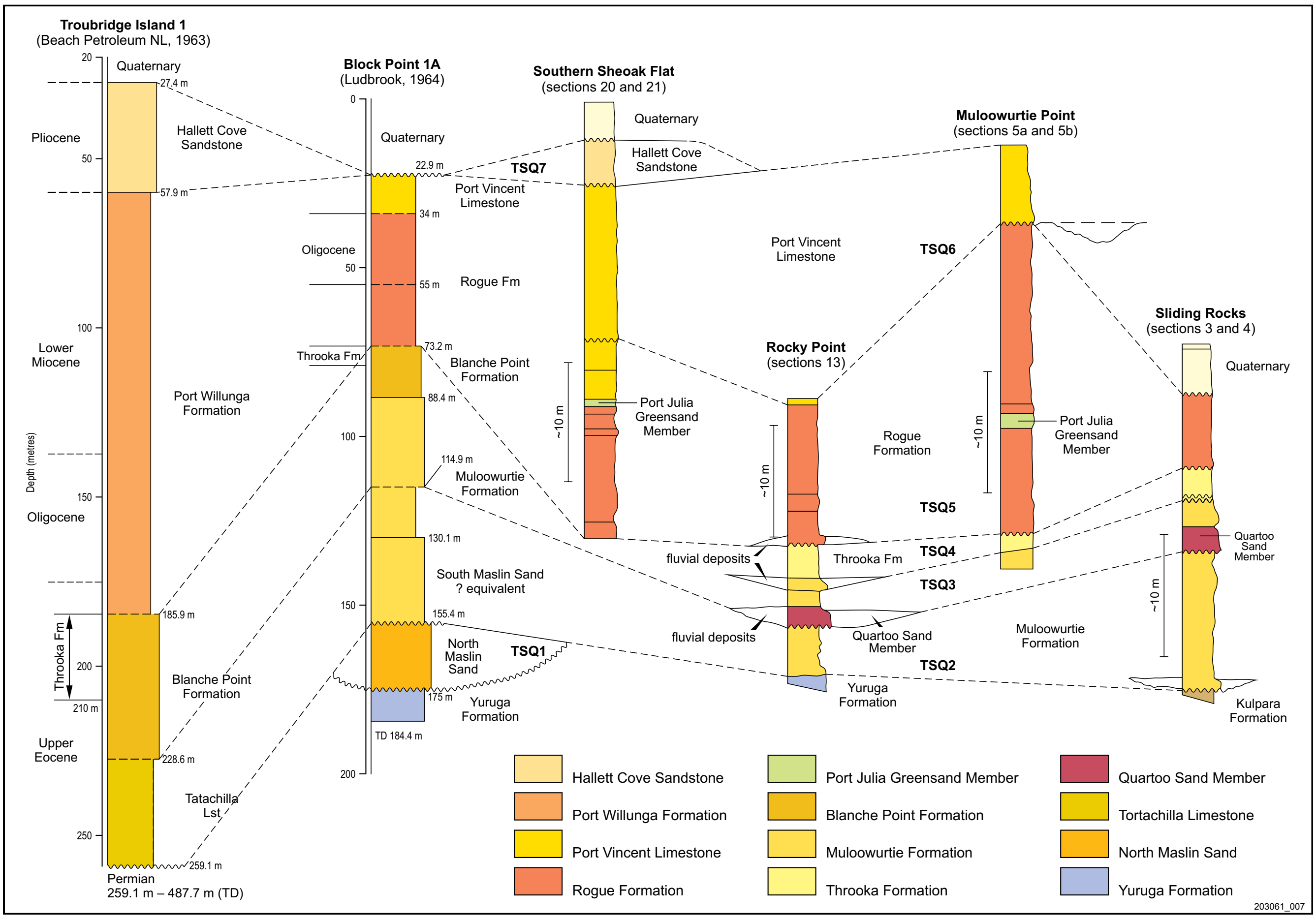


***Fig.** 7 Tertiary sections and correlation, Yorke Peninsula.*

Muloowurtie Formation (Teu)

The Muloowurtie Formation (Stuart, 1970; formerly Muloowurtie Clays, Tepper, 1879) is a succession of calcareous siltstone or silty limestone, with sandstone and conglomerate in the lower part. At the type section at Sliding Rocks, the formation is ~12 m thick (Stuart, 1970). The basal unit is an ~1.5 m thick fluvial conglomerate with large-scale cross-bedding unconformably overlying dolomite of the Kulpara Formation. The conglomerate is transitional into the overlying calcareous siltstone containing fossils or fossil fragments, including *Fibularia gregata* Tate and *Rhynchropygus*? *janchrisorum* (Stuart, 1970; Holmes, 2004). Glauconitic sandstone and silty limestone lenses occur in the upper part of the formation; the limestone is rich in foraminifers, echinoids, crinoids and other fossil groups. The formation has a maximum known thickness of 67 m in Black Point 1A, and represents fluvial-shoreface and marginal marine deposits of Late Eocene age.

Quartoo Sand Member (Teuq)

At Rocky Point, a lens up to 3 m thick of variegated quartzitic sandstone has been recognised as the Quartoo Sand Member (Stuart, 1970). It divides the Muloowurtie Formation into lower and upper parts. The member thins northwards at Pine Point, and contains medium to coarse-grained sandstone and granule layers. From Muloowurtie

Coastal exposure of the Muloowurtie Formation, Rocky Point. (Photo 403066)

Quartzitic sandstone with herringbone cross-bedding, Rocky Point, Quartoo Sand Member. (Photo 403067)

Point to Sliding Rocks, the sandstone forms a tongue in the upper Muloowurtie Formation (Stuart, 1970). The generally well-sorted sandstone is thin bedded to cross-bedded, and occasionally an erosion surface is present at the base with conglomerate or coarse-grained sandstone. The evidence suggests that the Quartoo Sand Member might have been deposited in a nearshore submarine channel or estuarine environment. The member is overlain by a 2 m thick thin-bedded to laminated calcareous siltstone of the upper Muloowurtie Formation at Rocky Point.

Tortachilla Limestone (Tet)

The Tortachilla Limestone does not crop out on Yorke Peninsula, but three drillholes intersected the unit in the map area, including 228.6–259.1 m in Troubridge Island 1, and an unknown thickness in Enchilada 1. The limestone contains foraminiferal faunas of Late Eocene age (McGowran, 1989), and fossil evidence suggests that it correlates with the lower part of the Muloowurtie Formation (Stuart, 1970).

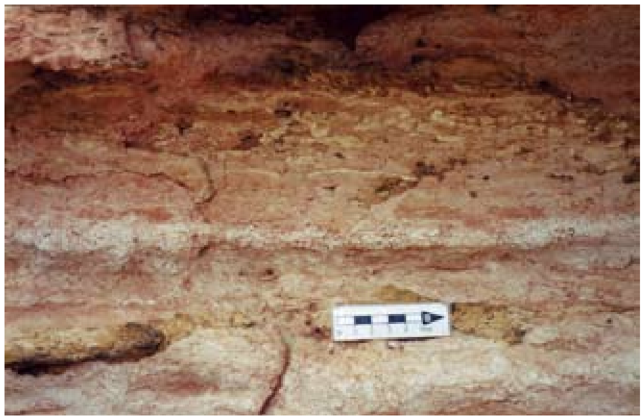
Blanche Point Formation (Teb)

The Blanche Point Formation consists of a bed of silty limestone and calcareous siltstone that conformably overlies or partly intertongues with the Muloowurtie Formation south of Rogue Point. The bed is ~4 m thick, and has been considered to be either Blanche Point Limestone (Reynolds, 1953; Crawford, 1965) or upper Muloowurtie Formation (Stuart, 1970). The bed is fossiliferous, particularly abundant in *Spirocolpus* (*Turritella*), and the fossil evidence suggests a Late Eocene age (Stuart, 1970). The limestone bed grades into calcareous siltstone of the Rogue Formation at Sliding Rocks. Fossil evidence suggests that the lower Rogue Formation and Blanche Point Formation are correlative (Morphett, 1984). The limestone is intersected in drillholes Troubridge Island 1 and possibly Enchilada 1.

Fossil-bearing marl of the Blanche Point Formation, south Rogue Point. (Photo 403068)

Throoka Silt (Teh)

The Throoka Silt (Stuart, 1970; formerly 'unfossiliferous ochreous clays', Tepper, 1879) applies to a 2.3–3.6 m thick bed (Stuart, 1970) of lagoonal pale grey to light brown siltstone and fine-grained sandstone in the Muloowurtie and Rogue Point areas. However, at Rocky Point, the silt bed overlies trough cross-bedded, haematitic sandstone, up to 1.5 m thick, considered to have been deposited in a fluvial channel.



Lacustrine deposits of the Throoka Silt, Rocky Point. (Photo 403069)

Correlative marginal swamp (black lignitic sand and lignite in Black Point 1A) and marine (calcareous siltstone in Troubridge Island 1) facies are also interpreted (Stuart, 1969, 1970).

The Throoka Silt is comparatively thin on eastern Yorke Peninsula but with a relatively uniform thickness. The basal channel deposits incise into the Muloowurtie Formation, and at Rocky Point unconformably overlie an ~0.2 m thick layer of weathered, kaolinitic claystone, indicating a significant sedimentary break.

The Throoka Silt was considered to have been deposited in a lagoonal setting (Stuart, 1970) during a sea-level fall. Sedimentary features include thin-bedding and lamination with minor cross-bedding; silicified wood and plant impressions occur on weathered surfaces (Stuart, 1970). The presence of Late Eocene foraminiferal faunas in the upper part suggests occasional marine influence. The formation probably thickens towards Gulf St Vincent and likely grades laterally into the Blanche Point Formation.

Rogue Formation (Teor)

The Rogue Formation (Stuart, 1970) is a siliciclastic unit comprising silty sandstone, calcareous sandstone, sandy siltstone and sandy limestone with numerous facies changes in the sections from south of Rogue Point to Port Vincent on eastern Yorke Peninsula (Stuart, 1970). The formation unconformably overlies the Throoka Silt or Muloowurtie Formation; near Port Vincent it unconformably overlies diamictite of the Permian Cape Jervis Formation. To the south of Stansbury, more sandy limestone occurs and it grades into the skeletal limestone of the lower unit (Aldinga Member) of the Port Willunga Formation. The formation contains abundant and diverse Oligocene fossils, including numerous *Spirocolpus* (*Turritella*) *aldingae* (Stuart, 1970).

The Rogue Formation is as thick as 30 m in outcrop (Stuart, 1970). At Muloowurtie Point, basal massive to thin-bedded silty sandstone, up to 11 m thick, unconformably overlies Throoka Silt, becoming calcareous and glauconitic upwards, with increasing abundance of bryozoans and other fossil groups. The uppermost part of the sandstone contains abundant glauconite that increases up to 20% to form 'greensand' (Port Julia Greensand Member) in the Port Julia and Port Vincent areas. The sandstone is overlain by 10–15 m thick pale grey calcareous and silty sandstone with

Coastal exposure of the Rogue Formation, Port Julia. *(Photo 403070)*

thin limestone interlayers; the silty sandstone is thin-bedded and cross-bedded with abundant fossil fragments and rip-ups, suggesting a relatively higher energy marine shelf, perhaps upper subtidal setting.

A study by Morphett (1984) suggested that the coarser grain size of the lower Rogue Formation sediments implies that the source of probable volcanogenic products, which may have contributed to the formation, was close to the Yorke Peninsula section and that much of the formation was removed by erosion.

Port Julia Greensand Member (Teorj)

The Port Julia Greensand Member is defined by a layer of glauconitic sandstone up to 0.5 m thick in the middle part of the Rogue Formation (Ludbrook, 1963; Crawford, 1965; Stuart, 1970). The member is easy to recognise in the field due to the green colour of the glauconite. The layer is lenticular, with lenses up to 200 m long, and comprises mainly massive, glauconitic, silty quartz sandstone with numerous lamellibranchs, gastropods, corals, foraminifers, bryozoans and other fossils (Stuart, 1970). The member may represent a shallow marine transgressive deposit in the Rogue Formation.

Port Willunga Formation (Tow)

The Port Willunga Formation is the name applied to a thick-bedded, bryozoan-rich, locally sandy or silty limestone in the eastern St Vincent Basin. At the type section, the formation contains three members that are also exposed in the Klein Point limestone quarry south of Stansbury. The formation, up to 128 m thick in Troubridge Island 1, unconformably overlies the Blanche Point Limestone and is unconformably overlain by calcareous sandstone of the Hallett Cove Sandstone; it ranges from Oligocene to Miocene in age.

Glauconitic sandstone of the Port Julia Greensand Member, south Rogue Point. *(Photo 403071)*

The lower Aldinga Member equivalent is ~6 m thick in the Wool Bay area and comprises sandy, skeletal limestone and calcareous sandstone that is transitional into the Rogue Formation to the north. Lenses of thin silty limestone, siltstone and glauconitic sandy layers are present. The contact with the overlying Ruwarung Member is sharp to gradational.

The middle Ruwarung Member equivalent (=Port Vincent Limestone) consists of pink-brown massive to thick-bedded skeletal limestone and minor marl or silty limestone, up to 15 m thick in the Klein Point Quarry. Bryozoans are the dominant component in the limestone, of which the voids are filled with sparry cement or calcareous sand or silt. Silty limestone contains fewer fossils and has thin bedding and occasional cross-bedding. The member is conformably overlain by a bed of silty to sandy limestone, up to 3 m thick. The bed is massive and contains many solution lenses filled with calcareous silt. The two units are considered to have been deposited in a shallow shelf setting, probably above fair-weather wave base. The uppermost part of the formation is bleached and overlain by the Hallett Cove Sandstone or Hindmarsh Clay.

The biostratigraphy of the Port Willunga Formation has been well studied, and fossils from the base of the formation are often suggested to correlate with those of the Rogue Formation. One sample of sandy limestone (basal Port Willunga Formation herein) from 2 m above the Permian Cape Jervis Formation at Waterloo Bay was found to contain a benthic foraminiferal assemblage that correlates with those from the Rogue Formation (Lindsay, 1967, 1972; Stuart, 1970).

Port Vincent Limestone (Temv)

The Port Vincent Limestone is a local name for a sandy bryozoan limestone in the Port Vincent area (Crawford, 1965). The unit is transitional into Port Willunga Formation south of Port Vincent, and is probably equivalent to the middle and upper members of the Port Willunga Formation north of Port Vincent to Muloowurtie Point, where the silty limestone overlies the Rogue Formation (Stuart, 1970). Fossils in the Port Vincent Limestone are similar to those in the middle and upper Port Willunga Formation.

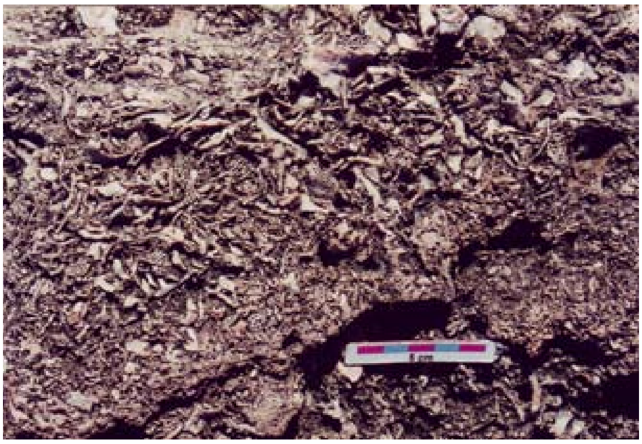
To the north of the Port Julia area, the limestone grades into the Rogue Formation. At Muloowurtie Point, an erosional remnant of bryozoan limestone occupies a small channel-shaped structure and unconformably overlies the Rogue Formation; the base is veneered by thin granular sandstone (Stuart, 1970). Stuart also demonstrated that this unconformity is angularly discordant, suggesting a probable tilting event.

Melton Limestone (Tomm)

The Melton Limestone (Lindsay, 1970) is a fossiliferous limestone and sandstone defined from the Pirie Basin. The limestone crops out north of Melton (Crawford, 1965) and has been intersected by several drillholes (Pain et al., 1992). The unit is equivalent to the middle and upper Port Willunga Formation, and ranges from Oligocene to Miocene in age.

Point Turton Limestone (Tomt)

Point Turton Limestone (Crawford, 1965) was deposited in a small graben-like structure in the Point Turton area, and has been intersected in drillholes around Warooka. In outcrop, the unit is up to 16 m thick, comprising basal coarse-grained red-brown sandstone, silty medium-grained sandstone and upper bryozoan limestone. The basal sandstone, ~3 m thick, unconformably overlies diamictite of the Cape Jervis Formation and contains tabular and trough cross-bedding. The sandstone is relatively well-sorted, thin layered, and was probably deposited in a fluvial to shoreface environment. The bryozoan limestone, correlated with the Port Willunga Formation and Melton Limestone, was deposited in a high-energy carbonate shelf, and contains abundant fossils including a diagnostic benthic foraminifer, *Victoriella* (Crawford, 1965), suggesting an Oligocene to Miocene age.

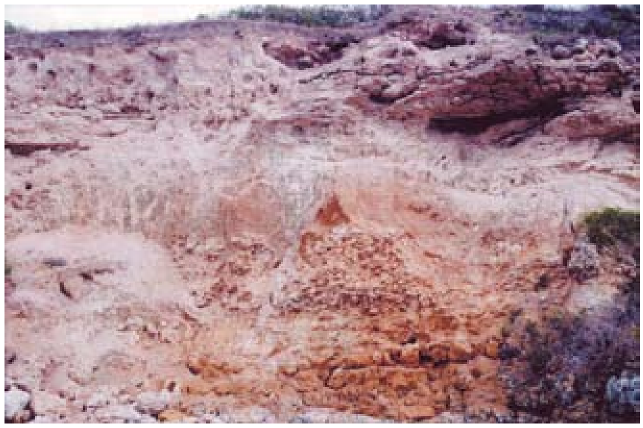


Skeletal limestone of the Point Turton Limstone, Point Turton. (Photo 403072)

A bryozoan limestone correlated with the Point Turton Limestone was mapped at Urania by Crawford (1965), but was not located in this study. A small outcrop of bryozoal limestone, of presumed Tertiary age, also overlies basement at Corny Point (Field Geology Club of SA Inc., 1997).

Hallett Cove Sandstone (Tph)

The Hallett Cove Sandstone in eastern Yorke Peninsula is a thin (<3 m thick) transgressive red-brown calcareous sandstone and siltstone and sandy limestone south of Wool Bay. Further south, in Troubridge Island 1, a similar unit is ~30.5 m thick. Near Giles Point, sandy limestone contains an oyster-rich bed with gastropods, bivalves and other fossils, suggesting a Pliocene age (Ludbrook, 1959). The Hallett Cove Sandstone equivalent on Yorke Peninsula is detailed by Crawford (1965) and generally unconformably overlies the Port Willunga Formation or equivalents. In the Adelaide region, an angular unconformity exists between the Hallett Cove Sandstone and Port Willunga Formation (Daily et al., 1976), but this has not been recognised on Yorke Peninsula.



Fossil-bearing, haematitic sandy siltstone of the Hallett Cove Sandstone, south of Giles Jetty. (Photo 403073)

The Hallett Cove Sandstone at Wool Bay and Giles Point is largely continuous in outcrop, and sedimentary features suggest that it was deposited in a nearshore subtidal to lower intertidal setting because of the good preservation of oyster shells and other fossils. The sandstone unconformably overlies the Port Willunga Formation and is in turn unconformably overlain by the Hindmarsh Clay or soil. The unit was also reported west of Edithburgh, along the western coast south of Brentwood, and at Port Rickaby by Ludbrook (1959) and Crawford (1965). In the Peesey Swamp area, Pliocene sandy limestone was also intersected in PDH 15 (7.6–10.7 m), where it directly overlies Permian diamictite (Geosurveys of Australia Pty Ltd, 1969).

At Fossil Beach on southern Wardang Island, Bone (1978) measured a fossiliferous limestone bed ~4.2 m thick, with abundant foraminifers (*Marginopora*, *Discorbis*, *Triloculina*, *Quinqueloculina*), bivalves (*Anodontia*, *Dosinia*) and large gastropods (*Cerithium)* up to 150 mm across, suggesting a correlation with the Hallett Cove Sandstone (Bone, 1978; Crawford, 1965). The limestone, sporadically exposed for several kilometres along the southern coast of the island, unconformably overlies diamictite of the Cape Jervis Formation or Palaeoproterozoic Wardang Volcanics Member, and is capped by calcrete. The limestone is considered to have been deposited in a relatively 'warm' marine environment.

Drillhole Anna 1 in Spencer Gulf (Pirie Basin) intersected moderately thick Tertiary sediments. Two palynological samples from bit samples pulled at 152 and 172 m contain abundant pollen and spores, dinoflagellates, foraminifers and bryozoan fragments. Dominant *Nothofagidites* spp. and other fossil spore-pollen indicate a Middle–Late Eocene age (Nerdlihc Inc., 1990). Middle–Late Eocene sediments are poorly known in the Pirie Basin (Parker, 1980; Alley and Lindsay, 1995).

TERTIARY SEQUENCE STRATIGRAPHY

Tertiary sequence packages (TSQ, third or fourth-order sequences) can be recognised in the siliciclastics succession along the eastern coast of Yorke Peninsula where they are distinguished by regional unconformities and their correlated conformities. The unconformities or sequence boundaries are indicated by the occurrence of fluvial channel incision and subaerial weathered surface. No basinal or slope lowstand deposits have been interpreted in the St Vincent Basin.

In brief, the Tertiary succession in the western St Vincent Basin contains seven sequence packages as a result of regional tectonic development and global sea-level changes (Table 5). The sequence boundaries are observable in outcrops, which are all preserved in the sections north of the Port Vincent structural high. Transgressive deposits contain mainly foreshore sandstone and fossiliferous sandy calcarenite, whereas highstand deposits consist largely of limestone units below Gulf St Vincent. The highstand deposits in several sequences cannot be interpreted due to post-depositional erosion and limited outcrop.

QUATERNARY

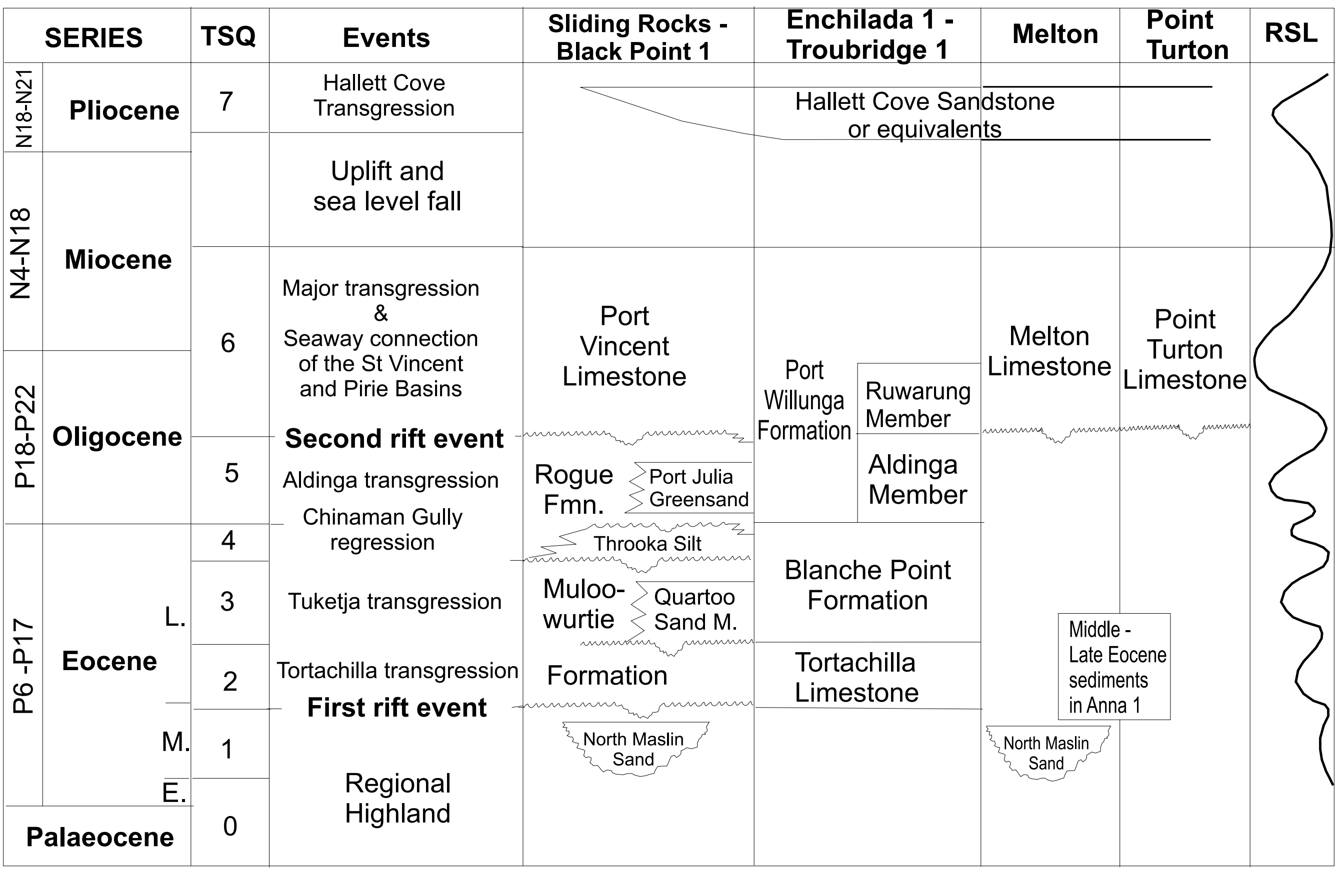
Quaternary sediments are widely distributed on Yorke Peninsula and cover almost all underlying rocks inland. Quaternary deposition in the region has been influenced by worldwide eustatic sea-level changes related to the waxing and waning of ice caps. The earliest Quaternary deposits on the peninsula are the Pleistocene fossiliferous Point Ellen Formation, Hindmarsh Clay ≡(=Ardrossan Clays and Sandrock; Tepper, 1879), and Bridgewater and Glanville Formations (Fig. 8). The Holocene St Kilda Formation comprises modern beach, coastal swamp and tidal deposits that have been actively deposited along the coast and in gulf waters.

Quaternary sedimentary environments and deposits on Yorke Peninsula received much attention because of the early development of the gypsum and salt industries. Tate (1890) first recognised most calcareous sand deposits of southern Yorke Peninsula (i.e. Bridgewater Formation) as aeolian in origin. These deposits were alternatively considered to represent deposits of a raised 'sea bed' (Howchin, 1900) or estuarine deposits (Greenway and Philips, 1902). Crocker (1946) reviewed the Tertiary and Quaternary geology in the region, suggesting that dune formation coincided with periods of glacial lowstand settings. Crawford (1965) recognised the importance of massive calcrete layers as markers of hiatus surfaces related to Late Pleistocene and Holocene aeolian and groundwater activities; this work was furthered by a detailed study of genesis related to calcarenites and aeolianites in southern Australia (Wilson, 1991).

Point Ellen Formation (Qpce)

The Point Ellen Formation (Milnes et al., 1983; Ludbrook, 1983) is a thin, sandy to silty fossiliferous limestone that crops out in isolated exposures at Browns Beach, Point Souttar and Corny Point. At Browns Beach, off the southern coast, unconsolidated skeletal limestone, ~1.5 m thick, probably occupying a tidal channel, unconformably overlies Gleesons Landing Granite, and is unconformably overlain by the Bridgewater Formation. The limestone contains abundant fragments of coral, bivalves and bryozoans, and a foraminiferal assemblage representing a brackish water environment, including *Elphidium* cf. *crispum*, *Elphidium* sp., *Qunqueloculina* sp., *Pyrgo* sp., and ?*Discorbis* sp. (sample R201334; M. White, PIRSA, pers. comm., 1997). The limestone is interpreted to be a Point Ellen Formation

Table 5 *Tertiary stratigraphy and sequence packages on Yorke Peninsula (after Stuart, 1970; McGowran, 1989; Lindsay and Alley, 1995). TSQ — Tertiary sequences, RSL — relative sea level.*



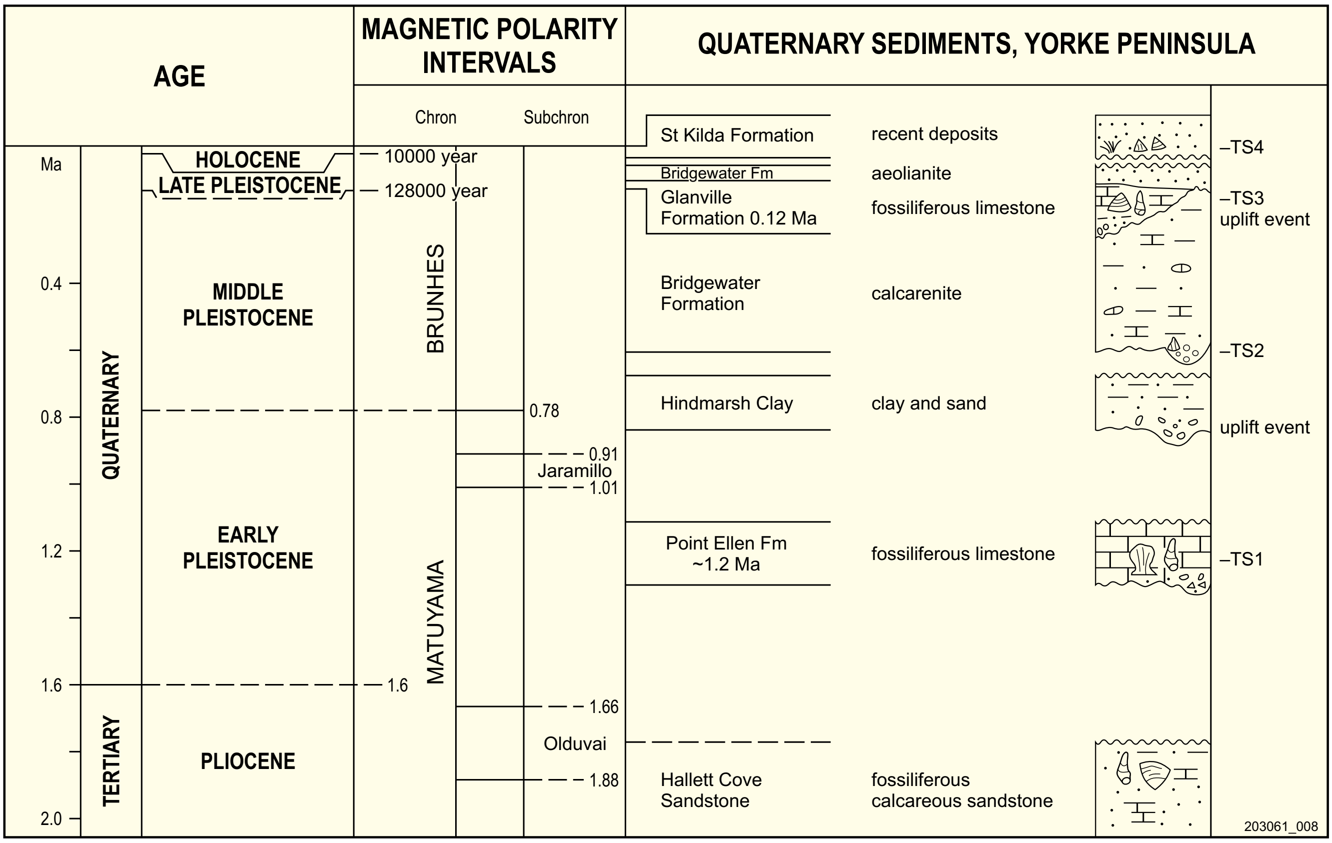


Fig. 8 *Quaternary stratigraphy on Yorke Peninsula.*

Skeletal limestone of the Point Ellen Formation, Browns Beach, Innes National Park. (Photo 403074)

Haematitic, sandy siltstone of the Hindmarsh Clay, Ardrossan. (Photo 403075)

equivalent (=Burnham Limestone), representing a marine transgressive wedge in the early Quaternary. Some 51 faunal species have been described from the Point Ellen Formation in the region, of which 15 belong to the Early Pleistocene and 36 are still living today (Ludbrook, 1983), including *Katelysia*, *Hartungia*, *Nerita*, *Brachidontes* and *Batillaria*. Using the Sr isotope method, fossil material from the unit has provided a date of 1.2 Ma (Belperio, 1995).

Hindmarsh Clay (Qpah)

Hindmarsh Clay (Firman, 1966) is an unconsolidated to semi-consolidated, mottled, mainly red-brown clay and sandy clay with granules and gravels. The type section is well studied in the Adelaide region and the unit can be correlated from Kangaroo Island to Yorke Peninsula, where it equates with the local less-known equivalent unit, the Ardrossan Clays and Sandrock (Tepper, 1879; Howchin, 1918; Crawford, 1965), Ardrossan Soil (e.g. Daily et al., 1976) or Ardrossan Clays (Wilson, 1991). This study intends to apply the name Hindmarsh Clay to all equivalent sandy clays on Yorke Peninsula, and is consistent with mapping on Kangaroo Island (A.P. Belperio, MESA, pers. comm., 1997). The clay is suggested to have been deposited in alluvial fan, valley flat, playa lake and fluvial channel settings. The occurrence of shelly fossil remains suggests correlation with the Early Pleistocene Calabrian Stage (Ludbrook, 1963), and a recent magnetic polarity study indicates that the clay contains the 0.78 Ma Brunhes–Matuyama Polarity Transition (Pillans and Bourman, 1996), suggesting that it extends to the Middle Pleistocene.

The red-brown arenaceous clay and pebbly clay of the Hindmarsh Clay, which crop out along both east and west coasts of Yorke Peninsula, is commonly 1–5 m thick, unconformably overlies Tertiary or older rocks, and is itself unconformably overlain by the Bridgewater Formation. In the Ardrossan region, particularly adjacent to the Ardrossan Fault, the Hindmarsh Clay is >30 m thick and contains at least three units: gravel, clay and uppermost sandstone. The gravel unit is exposed in the southeastern wall of the Ardrossan dolomite quarry and comprises massive, unsorted alluvial fan breccia. The breccia contains angular to subrounded sandstone and carbonate pebbles of the Cambrian Winulta and Kulpara Formations, and minor, smaller Tertiary sandstone clasts. Deposition of the gravel is thought to have been related to uplift of the Ardrossan Fault, with erosion resulting in dumping of sedimentary breccia from the western block to form an alluvial fan. Reverse faulting has resulted in the Cambrian Kulpara Formation being thrust over the gravel in the quarry exposures (Fig. 9).

To the east in the beach cliff exposure adjacent to the Ardrossan jetty, the gravel layers are not present; here, the middle unit of mottled arenaceous clay is unconformably overlain by the upper unit, a silty fluvial–aeolian sandstone. The arenaceous clay is massive and weathered, with patches of white-grey kaolinite and alunite. The mottling and kaolinite are interpreted to be related to groundwater bleaching, and the associated alunite deposits are attributed to reactions between acid groundwater and illitic clay (Wilson, 1991). The base of the upper unit is often conglomeratic, with quartzitic sandstone pebbles up to 80 mm across. It passes upwards into red-brown silty sandstone of fluvial–aeolian origin. The upper unit is up to 5 m thick and contains at least three cycles of fluvial–aeolian deposits.

The clay is well exposed along the coast at Balgowan and Moonta (Field Geology Club of SA Inc., 1997). At the Moonta Bay jetty, it contains a basal breccia up to 2 m thick, in which some shell fragments and remnants of plant roots occur. The breccia, overlying the sandstone of the Winulta Formation, is overlain by red-brown haematitic clay but the upper sandy unit is absent. The clay is also sporadically present in southeastern and southern coast sections; at Waterloo Bay, the clay unconformably overlies the Permian Cape Jervis Formation.

Bridgewater Formation (Qpcb)

The term Bridgewater Formation was first applied to Pleistocene beach-dune calcarenites (aeolianites) and underlying flaggy limestone with interbedded palaeosols near Portland in southwestern Victoria. The name has been subsequently used for a succession of regressive calcareous dunes and bioclastic barrier shoreline complexes along coastal settings in South Australia (Boutakoff and Sprigg, 1953). In South Australia's South-East as well as in adjacent Victoria, the Bridgewater Formation may range back to Early Pleistocene in age, whereas on Yorke Peninsula the formation unconformably overlies the Hindmarsh Clay and is overlain by modern St Kilda Formation. The formation on Yorke Peninsula contains three units that have been well studied by Wilson (1991). The lower unit ($Qpcb_6$) is a medium to coarse-grained, large-scale foreset bedded calcarenite, interlayered with red–brown sandy clay palaeosols. Wilson (1991) suggested that the unit can be as early as 0.7 Ma (early Middle Pleistocene). Fossiliferous Glanville Formation (Qpcg; Firman, 1966), dated by the Sr isotope method at 0.1–0.13 Ma (Belperio, 1995), frequently overlies the lower unit. The upper unit of the Bridgewater Formation ($Qpcb_7$) comprises fine to medium-grained aeolianite and bioclastic calcarenite, and probably conformably overlies the Glanville Formation. The upper unit was dated by the ^{14}C method at Gleesons Landing, southwestern Yorke Peninsula, using charcoal from a solution hole which provided an age of 22400±800 years, and further material from an underlying shell horizon which revealed a date >27000 years BP (Wilson, 1991). The dating may limit the uppermost Bridgewater Formation to ~22 000 years BP on Yorke Peninsula. The Bridgewater Formation is often capped by calcrete (Qp_{ca}).

The calcarenites or calcareous aeolianites of the lower Bridgewater Formation are interpreted to have been

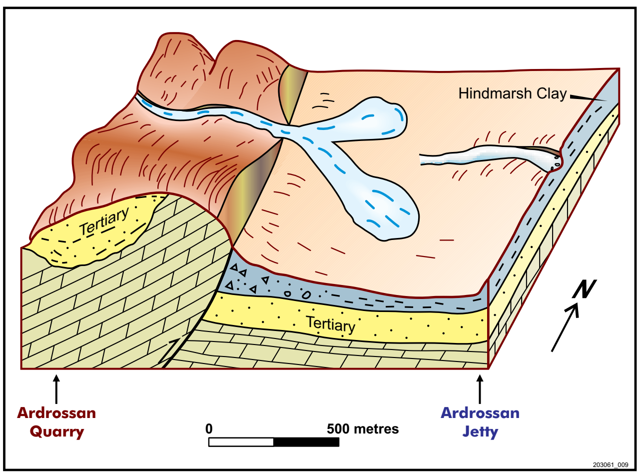


Fig. 9 *Conceptual block diagram showing Quaternary reverse fault and deposition of the Hindmarsh Clay, Yorke Peninsula.*

Coastal exposure of the Bridgewater Formation, Cape Spencer, Innes National Park. (Photo 403076) deposited as a series of spatially separated, shoreline-parallel supratidal dunes. Morphologically, individual dunes display weakly lenticular to tabular geometries and are capped by a red-brown palaeosol layer. Diagenetic alteration has been extensive, and vertical solution pipes and 'honeycomb' channel porosity (white ant nests?) are pervasive (Wilson, 1991). The calcarenites contains numerous tiny fragments of molluscan, bryozoan, foraminiferal, echinoid, algal, peloidal and lithoclast allochems (Wilson, 1991).

The Bridgewater Formation is normally thin (<10 m thick) in the MAITLAND map area, but is up to 70 m thick at southern Cape Spencer, 100 m on Althorpe Island and 200 m on southwestern Wedge Island (Major, 1973). The lower unit forms the main part in coastal cliff outcrops and contains mostly coastal barrier shoreline complexes of sandy calcarenites, transgressive dune sands and aeolian sand sheets (Milnes and Ludbrook, 1986; Belperio, 1995). The calcarenites contain some large-scale cross-bedding and weathered clay layers. In the coastal section at Cape Spencer, the lower unit contains at least 12 sedimentary cycles or parasequences of clay and calcarenite deposits. The base of the cycle is always erosive and contains haematitic clay with haematite pebbles and sand. Occasionally, some small solution pipes are present in the underlying calcarenite and are filled with haematitic clay. The clay layer is usually thin, but can be as thick as 1 m. The clay grades upwards into sandy calcarenite with increasing calcite content. The calcarenite is weakly cemented, cross-bedded, and occasionally trough cross-bedded. The clay–cross-bedded calcarenite couplets represent typical weathering–transgressive coastal dune facies cycles. Calcarenites contain some reworked Miocene fossils, and Milnes and Ludbrook (1986) suggested that deposition of the dune calcarenites might have commenced after Pleistocene regression of the sea that had left a widespread blanket of Middle Miocene marine sediments over southern South Australia.

At Kemp Bay, skeletal calcarenite of the lower Bridgewater Formation was deposited in a tidal-channel-like structure. The channel is incised into diamictite of the Cape Jervis Formation, and is filled by large-scale, cross-bedded to trough cross-bedded, calcareous, skeletal grainstone. The grains are medium to coarse and normally well rounded. Skeletal remnants include fragments of foraminifers, ostracodes, bryozoans, echinoids and molluscs that occur in several layers having similar size as the surrounding grains. The grainstone is considered to represent the first marine transgression in the area during deposition of the Bridgewater Formation. The grainstone grades upwards into silty calcarenite of the lower unit.

A palaeontological sample was collected from the grainstone (F183/72; Foster, 1974; Lindsay, 1972) and the extracted foraminiferal assemblage found to be dominated by benthic forms (19 species, including *Discorbis mira*), but to also include the planktonic species *Turborotalia inflata*, *Globigerinoides* sp. aff. *ruber*, *Globigerina bulloides* and *Orbulina universa* (Lindsay, 1972). The assemblage suggests a possible Middle Pleistocene age, and the occurrence of planktonic foraminifers indicates an open-marine environment (Lindsay, 1972).

The lower unit of the Bridgewater Formation is usually unconformably overlain by the Glanville Formation, but in several sections within the Innes National Park the unit is in direct contact with the upper Bridgewater Formation, with some roots and plant fragments on the unconformity surface. Deposition of the Glanville Formation may represent the second recognisable marine transgression in the Bridgewater Formation on Yorke Peninsula.

A few terrestrial gastropods and coralline algae were reported in aeolianites on Wardang Island (Bone, 1978). Analysis of cross-beds and dune forms suggests that wind direction for deposition of the Bridgewater Formation was dominantly from the south and southwest on Yorke Peninsula (Bone, 1978; Wilson, 1991).

The upper unit of the Bridgewater Formation is normally thin (<2 m in the Peesey Swamp, but up to 15 m at Cape Spencer) in the region and contains mainly calcareous aeolianites. The contact between the upper unit and Glanville Formation or lower Bridgewater Formation is sharp to gradational. At Swincers Rock, the basal part of the upper unit contains a 0.1–0.4 m thick angular breccia bed that is overlain by a layer of haematitic clay, and passes upwards into calcareous aeolianite. The upper unit is semi-consolidated to unconsolidated, cross-bedded, and contains rare skeletal remains. At Peesey Swamp, the calcarenitic sand contains some shells of *Katelysia*.

Glanville Formation (Qpcg)

The Glanville Formation is characterised by abundant bivalves (*Anadara*, *Katelysia*) and other fossils (Howchin, 1888, 1909, 1924, 1935; Ludbrook, 1976), and is commonly <1 m thick in the region. It crops out sporadically from Port Vincent to Wool Bay along the east coast of Yorke Peninsula, and from Peesey Swamp to Warburto Point along the west coast. North of Edithburgh, the shell bed is associated with a calcite conglomerate layer, forming a transgressive wedge; some in situ coral fossils occur at the base of the bed. Deposition of the formation is considered to be related to a Late Pleistocene interglacial marine transgression ~125 000 years ago (Murray-Wallace et al., 1988); Daily et al. (1976) indicated a minimum C^{14} age of 45 000 years. The contact between the Glanville and upper Bridgewater Formations in the Peesey Swamp area appears to be conformable.

Fossil-bearing limestone of the Glanville Formation, north Edithburgh. (Photo 403077)

In a trench exposure in the Peesey Swamp area, the Glanville Formation is ~1.5–2 m thick (Geosurveys of Australia Pty Ltd, 1969) and overlies a grey-brown sandy calcarenite, possibly the lower Bridgewater Formation. The lower part is a silty limestone, up to 0.70 m thick, with a basal grit. Shells, including gastropods, comprise only ~20% of the sediment, whereas in the upper unit, shells (mainly *Glycimeris* and *Katelysia*) can constitute as much as 85% of the rock. The lower part was probably deposited in a subtidal setting considering the fossil assemblage and abundant organic-rich layers. Shells in the upper part are well preserved and some bivalve shells are still joined. The sediments and fossil bed were probably deposited in a semi-barred marine embayment or lagoonal setting (Geosurveys of Australia Pty Ltd, 1969), with the molluscs being transported little from their living abode.

In the Stansbury and Port Vincent areas, fossiliferous limestone overlying the Port Vincent Limestone or equivalent was reported by Stuart (1969, 1970) and is correlated with the Glanville Formation. Similar fossiliferous limestone float has been found in paddocks near the two towns in this survey, but in situ beds were not mapped.

Shell beds were reported in drillholes in the Marion Lake area (Bolton, 1975); they overlie the lower Bridgewater Formation and are overlain by Holocene gypsum deposits. The beds are considered to be Glanville Formation equivalent.

Numerous isolated exposures of fossiliferous limestone have been mapped along the west coast of the peninsula. Localities include Warburto Point, Port Moonta, south of Port Victoria, Port Rickaby and northern Hardwicke Bay. Most exposures occur as erosion-resistant calcrete. No Glanville Formation has been mapped more than 10 m above the sea level on Yorke Peninsula.

Calcrete (Qpca)

Calcrete layers, up to 8 m thick, are common landscape features on Yorke Peninsula. However, following recent practice, calcrete is not considered here as a distinct stratigraphic unit but as a pedogenic feature. Calcrete, termed kunkar in Crawford (1965), and soil weathering profiles are extensively developed within the calcareous aeolianites and have played an important role in the initial stabilisation and preservation of these sediments and landforms (Bone, 1978; Wilson, 1991). Calcretes cap the Quaternary Bridgewater Formation, Tertiary Hallett Cove Sandstone and Port Willunga Formation or equivalents, Permian Cape Jervis Formation, and the Cambrian Ramsay Limestone, Parara Limestone, Kulpara Formation and Winulta Formation. They are generally considered to be related to aeolian process and groundwater recharging (carbonate dissolution and re-precipitation). Crawford (1965) recognised three calcrete layers on Yorke Peninsula with the most common layer being the most recent, probably formed after deposition of the upper Bridgewater Formation, ~22 000 years ago.

Calcretisation occurs in several pedogenic stages resulting from biochemical and physiochemical change to a variably indurated or fossilised soil profile. Wilson (1991) described a five-stage model for the pedogenesis from calcareous aeolianite to calcrete. Stage 1 commences with exposure of the aeolianite to the meteoric environment. Leaching and evaporation mobilises calcium carbonate and biogenic processes gradually increase as the weathering profile develops. Stage 2 is marked by addition of CO_2 and organic acid to the pedogenic system, with development of plants and microorganism in the aeolianites which increase the ability of pore fluids to dissolve calcium carbonate. Stage 3 is marked by the formation of a laterally continuous calcrete hardpan that forms an effective seal to downward-percolating pore fluids, and hence prohibits the continued downward development of the profile into the underlying substrate. Continued development of the pedogenic profile involves initial aggradation (stage 4) until the overlying source of calcium carbonate is depleted, followed by exposure and destruction of the hardpan (stage 5) to form a carbonate lithoclast deposit (Wilson, 1991).

A calcrete layer has been found developed on Cambrian limestone in the Curramulka area and is generally thin. The layer may contain some reworked substrate limestone and is commonly haematitic or rich in clay minerals. Calcrete overlies the Permian diamictite at Port Rickaby, and in TER 1 a calcrete layer ~6 m thick is considered to have been developed from aeolianite.

Calcrete is widely used as building stone on Yorke Peninsula and is also quarried for road rubble.

St Kilda Formation (Qhck)

The St Kilda Formation is a Holocene coastal and marine-shelf deposit formed after the last glacial transgression, starting ~7000–6000 years ago on Yorke Peninsula. More than 10 named members and unnamed litho-units have been described in the formation (Cann and Gostin, 1985; Belperio, 1988, 1995).

On Yorke Peninsula, the St Kilda Formation includes:

- **Le Hunte Member** (Qhckh), a gypsiferous lacustrine, coastal saline lake deposit
- **Semaphore Sand Member** (Qhcks), a modern beach and dune sand deposit
- **Gantheaume Sand Member** (Qhckg), aeolian cliff top dunes, particularly formed from receding coastal cliffs
- unnamed intertidal sand-flat deposits ($Qhck_8$).

Beach sand deposits of the St Kilda Formation, Waterloo Beach. *(Photo 403078)*

Deposition of modern stromatolites and gypsum in Marion Lake may reflect a progressive restriction of post-glacial transgression ~5000–6000 years ago. The formation of Marion Lake was probably related to a local fault-depression structure that produced a seaway with marine transgression ~6000 years ago, which resulted in deposition of a basal, shelly, lagoonal grainstone facies separating the gypsum units and underlying Bridgewater Formation (Bolton, 1975; von der Borch et al., 1977). The deposits in the lake were probably initiated in an open-marine embayment during the earliest Holocene, and this is supported by stable sulphur and oxygen isotope analyses in which the data are comparable to modern day sea water (Warren, 1982a,b). The loss of direct contact with the sea and semi-arid conditions during the late Holocene produced hypersaline brine and gypsum deposits in which domal stromatolites are preserved. The active fault planes may be effective seepage passageways in the Marion Lake area along with the aquifer within modern beach dunes.

Extensive drilling was conducted during the 1950s–1970s in the Marion Lake area to test the gypsum deposits and Quaternary stratigraphy (Table 6; Olliver and Warren, 1979; Warren, 1982b). This is summarised below.

The *Posidonia* bed is considered to represent the latest Quaternary transgression on Yorke Peninsula and was followed by sea-level fall during deposition of the St Kilda Formation. This regression trend (or uplift of landmass) can be seen by receding coastal dune deposits in the southern region.

Modern stromatolites in Marion Lake, Innes National Park. (Photo 403079)

Table 6 *Summary of Quaternary strata in the Marion Lake area (Olliver and Warren, 1979; Bolton, 1975).*

Sand dune and spread	Loose sand, loess and soil
Aeolian gypsum	Unconsolidated, mixed with clay and sand (Le Hunte Member)
Laminated gypsum	Rhythmically layered, up to 2 m thick, with domal stromatolites (Le Hunte Member)
Posidonia-bearing bed, shelly grainstone	Fossiliferous sandy silt with seagrass *Posidonia australis*, up to 1 m, ^{14}C dates: 5090±140 and 5860±180 years; transgressive deposits in the region
Glanville Formation?	Skeletal grainstone, up to 2 m thick, disconformably overlying the lower Bridgewater Formation, *Katelysia* etc.
Bridgewater Formation	Calcarenite and calcareous aeolianite

This latest marine transgression was also recorded in the Peesey Swamp area. Deposits of the St Kilda Formation comprise mainly fine gypseous sand, with abundant small shells (*Diaphoromactra versicolor*). They are generally sporadic and <0.6 m thick, forming a thin blanket, marshy surface or low 'lunette' dunes marginal to the swamps of black organic-rich mud (Geosurveys of Australia Pty Ltd, 1969).

Salt marsh deposits (possibly Le Hunte Member) were described by Bone (1978) on the east side of Wardang Island. The marsh is covered by salinity tolerant low shrubs and is inundated by sea water during high tides and storms, producing somewhat anastomosing tidal inlets. High evaporation results in the deposition of salt and gypsum; however, carbonaceous sediments accumulate towards the sea on the tidal flats. The seagrass *Zostera muellri* occurs in shallow waters <2 m deep, whereas *Posidonia australis* dominates the waters deeper than 1 m (Bone, 1978).

Some non-marine Recent or reworked deposits occur on Yorke Peninsula, that relate to seasonal floods or aeolian processes on topsoil. The units include one mapped as **Recent alluvium** (Qha), a red–brown clay and sand with ironstone pebbles as well as reworked **colluvium sediments** ($TpQr_1$) and **sand dune spread** (Qhe_3). These sediments are mainly deposited in low-relief gullies or seasonal creeks.

Early Holocene coastal saline lake deposits were intersected in Gulf St Vincent by vibrocoring to 4 m, and C^{14} dates suggest that they were deposited over the time interval 9460–9290 years BP (Belperio, 1995). Their equivalents on Yorke Peninsula have not been mapped.

TECTONICS AND STRUCTURAL DEVELOPMENT

Introduction

The Gawler Craton is generally considered to be part of the Rodinia supercontinent before being disassembled at ~700 Ma, and was probably adjacent to the continent of Laurentia in the east and Antarctica to the south (Powell et al., 1994). General eastward-younging tectono-sequences in the southeastern margin of the Gawler Craton suggest a significant period of continental accretion after the Sleafordian Orogeny (~2440 Ma; Daly and Fanning, 1993; Daly et al., 1998; Ferris et al., 2002). Stratigraphically, in a section from southern Eyre Peninsula to eastern Yorke Peninsula, the craton developed eastwards from Archaean rocks with the accretion of Palaeoproterozoic Hutchison Group, Donington Suite and Wallaroo Group, and Mesoproterozoic Tickera or Arthurton Granites in the east. The eastern margin of the Gawler Craton is marked by the Neoproterozoic Torrens Hinge Zone and thick sediments of the Adelaide Geosyncline that were probably deposited during the breakup of the Rodinia supercontinent.

The Gawler Craton has been divided into a number of subdomains, including the Cleve and Moonta Subdomains of Eyre and Yorke Peninsulas (Parker, 1993a). Recently, a new scheme encompassing 15 domains or belts has been proposed for subdivision of the craton (Teasdale, 1997; Ferris et al., 2002), which divided the Cleve Subdomain (Parker, 1993a) into the eastern Spencer Domain and western Cleve Domain (Ferris et al., 2002). The Kalinjala Mylonite Zone separates the two.

The tectonic history of Yorke Peninsula is relatively complicated, particularly with respect to the formation of the basement rocks. Six major extensional events can be recognised — deposition of the middle Palaeoproterozoic Hutchison Group (1920–1860 Ma), late Palaeoproterozoic Wallaroo Group (1770–1740 Ma), Sturtian (~700 Ma), Cambrian (~540–500 Ma), Late Carboniferous–Permian and Tertiary sediments, whilst Quaternary tectonics have shaped the recent landscape. Seven deformation or shearing-faulting events are recognised in this study (Table 7).

Vassallo and Wilson (2002) suggested that deposition of the Hutchison Group might be as young as ~1800 Ma, based mainly on structural interpretation, but this suggestion overlooked the geochronological evidence that felsic volcanics in the upper Hutchison Group (Bosanquet Formation) have been dated at 1859±11 or >1845±9 Ma (Rankin et al., 1988; Fanning, 1997). Occurrence of the Corny Point Paragneiss on Yorke Peninsula may support the long-held view that the Hutchison Group and equivalents are older than the Donington Suite (Parker, 1993a). The metamorphic zircon in the paragneiss was dated at 1845±6 Ma, with rounded cores at ~2400 Ma and ~1965–1920 Ma (Zang and Fanning, 2001). The ~1920 Ma date may suggest a maximum age for the sedimentary protolith, and ~1845 Ma is regarded as the metamorphic age of the Corny Point Paragneiss, probably equivalent to, or slightly younger than, the peak metamorphism of the Neill Event (= Marion Orogeny, Bull, 2003; = Neill Deformation 1, Ferris et al., 2002; = Lincoln Deformation, Vassallo and Wilson, 2002; = Kimban Deformation 1, Parker, 1993a), which might range from 1850 to 1835 Ma on Yorke Peninsula. The metamorphic age is further proven by monazite dates (Bull, 2003).

Of the deformations, D_1–D_5 are interpreted from the basement rocks; the four earlier events produced fabrics while the later two were involved in formation of the Moonta and Wallaroo mineralisation. D_6 and D_7 can be recognised in Cambrian and Quaternary sediments by field and seismic mapping. Raymond et al. (2002) also reported a monazite age of 1620 Ma in the Weetulta area. This date cannot be explained by the currently understood tectonic history.

Deformation of the Spencer Domain — Neill Event

The Cleve and Spencer Domains consist of the Archaean Sleaford Complex, and Palaeoproterozoic Hutchison Group and Lincoln Complex on Eyre Peninsula (Parker et al., 1988). The Hutchison Group unconformably overlies the Miltalie Gneiss (~2000 Ma) and contains high-grade metamorphic siliciclastics and carbonates. Sediments of the group were considered to have been deposited in a primeval rift basin (Parker and Lemon, 1982), which had been deformed during the Neill Event and Kimban Orogeny. As a result of associated magmatism or volcanism, formation of the Lincoln Complex occurred. This contains at least two suites (Donington and Moody Suites) or equivalents on southern Eyre Peninsula, and the basement rocks on southern Yorke Peninsula are broadly considered to be Donington Suite equivalents with similar isotopic dates and metamorphic grade (Webb et al., 1986; Parker, 1993a).

Four distinct deformation structures and fabrics are present in the Gleesons Landing Granite and Corny Point Paragneiss on southern Yorke Peninsula (Table 8). The first two are referred to be the Neill Event, whereas D_5 is a minor event in the area that produced conjugate faults or cleavages and displaces the major fault zones. Many of these conjugate faults and cleavages have been subsequently filled by epidote and haematite.

FOLDING AND FABRICS

Gneisses and granites of the Donington Suite and Corny Point Paragneiss are layered and strongly deformed; four

***Table** 7 Summary of the major deformations on Yorke Peninsula.*

Local event	Regional event (referred)	Vassallo and Wilson (2002)	Age (Ma)	Evidence and major characters
D_1	Neill Event	Lincoln Deformation 1 (LD_1)	~1850–1845	Deformation of the Corny Point Paragneiss and Gleesons Landing Granite
D_2		Lincoln Deformation 2 (LD_2)	1845–1812	Intrusion and deformation of the Royston Granite
D_3	Kimban Deformation (KD)	Kimban Deformation ($KD_{1–2}$)	~1730–1700	Deformation of the Wallaroo Group
D_4	Tiparra Deformation 1 (TD_1)		~1585	Intrusion and deformation of the Arthurton and Tickera Granites, and Curramulka Gabbronorite
D_5	Tiparra Deformation 2 (TD_2)	Wartakan Event 1 (WD_1)	~1500	Intrusion of the Spilsby Suite and regional thermal resetting in basement rocks
D_6	Delamerian Deformation (DD)		~500	Reverse faulting, uplifting, termination of Cambrian sedimentation, and thermal resetting in fault zones
D_7	Neotectonics		~0.8–0.1	Reverse faulting — Cambrian dolomite overlying Quaternary sediments

folding events can be recognised in the region (Richardson, 1978). F_1 folds are very tight to isoclinal, small-sized, in the 30–150 mm range, with a well-defined axial planer fabric S_1. Generally, F_1 folds are fragmented, rotated and steeply inclined, mostly to the southwest and northeast.

The second deformation was a fold-forming event that produced tight to very tight folds, in which F_1 folds were also rotated parallel to F_2 fold axial planes. The plunges of F_2 folds vary in both dip and strike direction, with rotation by D_3 or D_4 shear zones. Locally at Corny Point, some F_2 folds are found with a N–S trend (Richardson, 1978). The third deformation and folding event is relatively well known in the Point Yorke – Meteor Bay area, where F_3 folds, mainly plunging to the NE and SW, are found to associate with NE–SW-trending shear zones that have been displaced by the NW–SE-oriented D_4 fault-fracture zones. At Annie Nursery, a mesoscopic symmetrical open F_3 occurs in the hinge zone of a megascopic F_4 anticlinal fold. In the structure, the F_3 plunges to the NE, whereas F_4 plunges to the west.

The fourth folding event produced large-scale fault propagation and break-thrust folds that are often associated with thrust or reverse faults. Some sheath folds also occur in the shear zones. F_4 folds are open to tight, upright to steeply inclined or overturned, and normally plunge to the E–W or ESE–WNW.

Microstructures and fabrics in middle Palaeoproterozoic gneisses and granites on southern Yorke Peninsula are attributed to ductile deformation, recovery and recrystallisation processes of the D_1 event during high-grade metamorphism (Golin, 1976; Pedler, 1976; Richardson, 1978; Zang and Fanning, 2001). In the paragneiss, the S_1 is defined by biotite and sillimanite, and in gneissic granitoids the S_1 is delineated by biotite and hornblende blades and elongate or lobate quartz–feldspar megacrysts or rods. L_1 is observed in the gneisses and mainly plunges southwesterly. Occasionally, S_2 is present in axial planes of tight to isoclinal folds, and in the Royston Granite it is defined by alignment of biotite–hornblende blades. S_3 and S_4 are rarely preserved in the granite gneiss.

METAMORPHISM

Four metamorphic events in the gneiss and granite show a retrogressive order. The first and major M_1 was probably also associated with earlier migmatisation in the paragneiss, producing regional schistosity. The mineral assemblage of quartz–perthitic microcline–plagioclase–biotite–hornblende ±clinopyroxene, and partial melting in granites, suggest a temperature of crystallisation somewhat above the equilibrium temperature of the reaction, and medium amphibolite to granulite facies (Pedler, 1976; Golin, 1976; Richardson, 1978; Purvis, 1996; Zang and Fanning, 2001; Bull, 2003). Pedler (1976) suggested that the P–T conditions of M_1 were close to 2–4 kb and ~700°C in the Point Yorke area. In the paragneiss, the presence of orthopyroxene–sillimanite–cordierite–garnet(±spinel±corundum) assemblages indicates locally developed granulite facies.

M_2 can be estimated by the generation of well to poorly developed hornblende or biotite schistosity in the hinges of F_2 folds. Hornblende–biotite and elongated quartz–feldspar phenocrysts in the Royston Granite indicate a lower to medium-amphibolite facies. M_3 and M_4 conditions are indicated by regional epidotisation and retrogression of hornblende and biotite. Greenschist to low-amphibolite facies were suggested by the occurrence of chlorite, epidote and albite (Golin, 1976; Pedler, 1976).

TIMING OF DEFORMATIONS *N*D$_1$ AND *N*D$_2$

The time ranges of the deformations in the Spencer Domain were analysed by Parker (1993) but the precise dates are not yet fully determined. *N*D$_1$ has been recently dated from metamorphic zircon in the Corny Point Paragneiss at 1845±6 Ma (Zang and Fanning, 2001), whereas *N*D$_2$ has been estimated from the intrusion and deformation of the Royston Granite, which at Royston Head intrudes the Gleesons Landing Granite and is intruded by a mafic dyke of the Tournefort Metadolerite. The Tournefort Metadolerite, according to Schaefer (1998), is as old as 1812±5 Ma. Approximate age of the D_2 event is thus estimated at ~1845–1812 Ma.

WAROOKA FAULT ZONE

The Warooka Fault Zone is defined by a series of NW–SE-trending TMI highs and lows that extend from southern

Table 8 *Summary of deformation events in the Donington Suite and Corny Point Paragneiss on Yorke Peninsula.*

Structural event	Folding characters	Fault style	Fabric development	Metamorphism
Pre-D$_1$ ~1920–1860 Ma			Sedimentation Bedding in boudins (Hutchison Group)	Emplacement of Lincoln Batholith, migmatisation
D$_1$ ~1850–1835 Ma (peak at ~1845 Ma)	Ptygmatic, tight to isoclinal folds, rootless	Ductile	S_1, L_1, widespread	Mid-amphibolite to low-granulite facies
D$_2$ <1845–1812 Ma	Tight to isoclinal folds, often rootless	Ductile	S_2 in fold hinge and shear zones	Low to mid-amphibolite facies
D$_3$ (=KD) ~1730–1700 Ma	Open to tight folds, preserved along shear zones	Brittle to ductile	Rarely observed, only in shear zones	Low amphibolite to greenschist facies
D$_4$ (=TD$_1$) ~1580 Ma	Break-thrust and fault-propagation folds	Brittle, shear	Rarely observed, only in shear zones	Greenschist facies

Investigator Strait to the northwestern Spencer Gulf, whereas on northeastern Yorke Peninsula the major structural trends are dominated by NE–SW TMI anomalies (Lynch, 1982). Along the low coastline at Point Souttar, where foliated syenogranite is exposed within the fault zone, the banded granitoid gneiss dips SW (30°–75°) and trends NW (300°–320°), suggesting that the zone has been formed by SW–NE compression. To the east of the zone, at Point Turton, Cambrian limestone, Permian diamictite and Tertiary fossiliferous limestone are present in graben structures. To the south, TMI interpretation suggests that the Fault Zone is truncated by a TMI and gravity low in the Investigator Strait, and seismic interpretation indicates that Cambrian and younger sediments are up to 2000 m thick in a NE–SW trending trough. The Warooka Fault Zone has therefore probably been continually active since its formation.

The evidence suggests that the Warooka Fault Zone provides a tectonic limit to the late Palaeoproterozoic Wallaroo Group. The fault zone probably developed during the early Mesoproterozoic TD_1 event, with initiation likely pre-dating deposition of the Wallaroo Group. The fault zone and its related faults probably displaced the older NE–SW-trending structures, which are generally parallel to the Kalinjala Mylonite Zone in the region. The formation of the Warooka Fault Zone and its associated deformation is a pervasive event in the southeastern margin of the Gawler Craton, separating the Spencer Domain and Moonta Subdomain.

DOMAIN DEVELOPMENT

The Cleve and Spencer Domains on southern Yorke Peninsula might represent an offshore sedimentary province during deposition of the middle Palaeoproterozoic Hutchison Group, given the presence of fine-grained argillite and calcsilicate. This possible basin was likely placed across present Spencer Gulf and connected to Eyre Peninsula. This depositional regime on Yorke Peninsula is poorly known, especially as it presumes that underlying ?Archaean basement existed.

The Gleesons Landing Granite, as a product of the Lincoln batholith, is considered to have been emplaced during the initial amalgamation (Vassallo and Wilson, 2002). Concordance with the paragneiss at Corny Point and the layered hornblende microadamellite gneiss in the Point Yorke area suggests that the granite probably intruded partly as sills. The convergent event, as a part of crustal growth on the tectonic-active margin of the Gawler Craton, might have been periodic. Subsequently, it thickened the crust in the region, and on Yorke Peninsula the granite formed the basement to the late Palaeoproterozoic Wallaroo Group.

Emplacement of the Gleesons Landing Granite might have been preceded, during a short period of extension, by intrusions of both felsic granites and the mafic Jussieu Metadolerite. This crustal extension was subsequently subdued by the continental amalgamation event.

Emplacement of the Royston Granite at ~1849 Ma is considered to result from melting of the host Gleesons Landing Granite. An en echelon array of lens-shaped dykes of the granite, and E–W shear-fabrics, implies establishment of a major N–S-trending structure during the D_2 event in the region. The major structures of this event are rarely preserved on southern Yorke Peninsula due to subsequent deformations. Continuing E–W compression during the D_2–D_4 events might have resulted in the formation of the west-dipping shear zones in the upper crust (Zang, 2002a).

Deformation of the Moonta Subdomain

The Moonta Subdomain (Parker, 1993a) is outlined by the distribution of the Wallaroo Group and is suggested to be part of the Olympic Domain (Ferris et al., 2002). Its boundary with the western Spencer Domain is defined mainly by TMI interpretation, while the eastern boundary is defined by the Torrens Hinge Zone (Parker, 1993a). This subdomain was probably initiated with extensive continental rifting on the eastern Gawler Craton, indicated by emplacement of bimodal volcanics and sedimentation of the Wallaroo Group; three deformations and intrusion of early Mesoproterozoic plutons subsequently added to the subdomain (Table 9).

SEDIMENTATION OF THE WALLAROO GROUP

The Wallaroo Group is considered to have been deposited on a rifting continental margin during 1770–1740 Ma. Deposition is suggested to result from a major rifting event extending from Yorke Peninsula, through Eyre Peninsula to the Stuart Shelf, as evidenced by the occurrence of thick metasediments and bimodal volcanics (Conor, 1995; Huffadine, 1993). The metasediments consist mainly of siliciclastics with minor carbonate or carbonate-siliciclastics-mixed facies in the eastern part (e.g. New Cornwall Formation). Generally, sediments of the Wallaroo Group probably had a western provenance. Four $^{143}Nd/^{144}Nd$ dates on the sediments at Port Victoria indicate a depleted mantle model age (T_{DM}) in the 2.34–3.93 Ga range, an Archaean source, which is consistent with the Nd-dates on the Archaean Sleafordian rocks (Huffadine, 1993).

In the Port Victoria, Point Pearce and Wardang Island regions, the sandstone-dominated sediments contain haematite-coated aeolian sandstone layers with cross-bedding or enhanced trough cross-bedding; some of the bedding planes are veneered by rounded heavy minerals. Together with the deposition of a channelised conglomerate on Wardang Island (Bone, 1984), the metasandstone of the Aagot Formation suggests a fluvial–aeolian to foreshore environment. To the east and northeast, sandstone decreases with dominant fine-grained siltstone and some carbonate; sediments contain parallel layering, laminae and graded-bedding, indicating a relatively deeper shelf setting. Sedimentary analyses suggest that depocentres of the Wallaroo Group or equivalents were probably located in the east-northeast of the Gawler Craton, even though the basinal deposits of the group are not known.

DESCRIPTION OF STRUCTURES

The structure and deformation of the Wallaroo Group are relatively well studied in the Moonta and Port Victoria

Table 9 *Summary of tectonic events and mineralisation of northern Yorke Peninsula (after Cooke, 1990; Hafer, 1990; Mendis, 1992; Carthew, 1993; Both et al., 1993, 2002; Conor, 1995; Raymond et al., 2002; Zang et al., 2002).*

Tectonic event	Rift	D_3	D_4	D_5
Age	1770–1740 Ma	~1730–1700 Ma	~1580 Ma?	~1500 Ma?
Structural styles	Extensional	Ductile, dextral, NE–SW shear zones, dipping NW	Brittle, sinistral, NW–SE major compression and NE–SW en echelon shear zones, dipping SW	Compression, conjugate shearing, coupled with faulting
Volcanism/ plutons	Bi-model: mafic and felsic volcanics		Arthurton and Tickera Granites, and Curramulka Gabbronorite	Pegmatite
Metamorphic facies		Low-middle amphibolite	Greenschist (~480–265°C)	Retrogression (~250–110°C)
Foliation planes	Sedimentary bedding	050/40°–50° NW	310/40°–75°SW	None observed
Lineation on foliation plane		Distinct, amphibolite and biotite, NE –SW	Chlorite, 295–310°/55°W	
Paragenetic sequence		Quartz, magnetite, haematite, pyrite, albite, marcasite, chalcopyrite, biotite-amphiboles	Chalcopyrite, pyrite, bornite, gold, carrollite, quartz, epidote, chlorite, sericite, tourmaline (remobilised Pb and Zn in the Wallaroo Mines)	
Mineralisation styles	SEDEX–VMS: Cu, Pb, Zn	Remobilising SEDEX into foliation or axial planes.	Major hydrothermal event, Cu–Au mineralisation, metasomatism	Minor mineralisation related to later remobilisation

areas because of coastal exposure and mining activities (Jack, 1917; Dickinson, 1942; Mendis, 1992; Carthew, 1993; Conor, 1995). On Wardang Island, Bone (1984) suggested that at least two deformation events have affected the Wardang Volcanics; rhyodacite clasts in conglomerate of the Aargot Member have been rotated and some secondary biotite wraps the clasts. Plimer (1980) recognised three generations of deformation or fabrics in the biotite-rich metasediments of the Doora beds (now Doora Member) in DDH 126. In the Moonta–Wallaroo Mines district, the Wallaroo Group contains one prominent schistosity, whereas the second schistosity is less common and the third very rare and only observed in shear zones.

Carthew (1993) conducted a detailed logging of folds in the Wheal Hughes Mine exposure. Isoclinal folds are early generation and were developed along with the shear regime; these can be rootless and often boudinaged, 10–800 mm in scale within shear zones, and with the axial plane concordant with foliation (~NE 40°, dipping 40–60°W). 'Z' drag folds (S_1) were developed during mineralisation with dextral shear movement, and plunge gently (50–20° north or south). Open asymmetrical folds have 1–10 m wavelengths in the vertical plane, plunging 300°/40–60°W, the same as prominent footwall rodding. Kink folds formed after mineralisation in a coaxial regime.

Carthew's study is furthered by a recent study by Arcaro (2000), who described four different fold generations and three fabrics in outcrops at Point Riley and North Beach (Wallaroo): S_1 is defined by the alignment of biotite, quartz and feldspar aggregates, striking 030°–090° and dipping steeply; S_2 (biotite alignment) and F_2 fold axes have a shallow to steep plunge towards the northwest and S3, defined by crenulation of earlier fabrics in the fold hinges, seems to plunge in an easterly or westerly direction. In the Wallaroo Group, the initial deformation is considered to be related to the KD event (Arcaro, 2000). D_2 and D_3 may be equivalent to TD_1 and TD_2 phases. The evidence of the later two deformations is better preserved in the deformed Hiltaba Suite and Curramulka Gabbronorite.

D_3 — KIMBAN DEFORMATION (KD_1)

D_3 structures are widely recognised in the deformed Wallaroo Group metasediments and volcanics, and they are suggested to be equivalent to the Kimban Deformation (= KD_3, Parker, 1993a; Hand et al., 1995; = $KD_{1\text{-}2}$, Vassallo and Wilson, 2002) during 1730–1700 Ma. The structures and styles of the deformation on Yorke Peninsula are poorly known due to limited outcrop and subsequent overprinting by later events. Generally, D_3 on northern Yorke Peninsula was a fabric-forming event, producing a regional NE-trending foliation shown in biotite–amphibole blades. Aeromagnetic image interpretation also reveals NE-trending fabrics, which are now fragmented or displaced and are crosscut by NW-trending demagnetised zones (Gerdes, 1983). In the Wheal Hughes and Poona Mines open cuts, the shear-faults and foliation trend NE 40–60° and dipping steeply west (~70°). The foliation is cut by NE-trending mineral lodes and, in turn, displaced by conjugating faults.

Recent TEISA aeromagnetic data reveal several folding structures in the map area. In the northern Warburto Point area, a recumbent, 'S'-type fold is marked by an anomalous layer, probably magnetite-rich skarn. The fold axis plane largely trends NE–SW. The fold is obviously displaced by three sets of faults, trending NW–SE, NE–SW and E–W. To the southeast of the fold are the Moonta and Wallaroo Mines. Fold structures are also interpreted in the Wardang Island region, where several isoclinal folds form around the probable Wardang Volcanics body and are crosscut by NW-trending shear zones. Carthew (1993) found some isoclinal folds (KF) in the Wheal Hughes Mine and related these to early generation of shear zones and the associated foliation (KS).

Sediments of the Wallaroo Group have been metamorphosed to low-amphibolite facies (biotite–amphibole fabrics), locally middle to upper amphibolite grade, as indicated by the presence of perthitic or anti-perthitic feldspar and sillimanite in the Aagot Formation (Purvis, 1997). On the eastern side of Yorke Peninsula, mineral assemblages of chlorite–sericite–carbonate±biotite suggest a greenschist to sub-greenschist facies, whereas to the west, on Eyre Peninsula, the Kalinjala Mylonite Zone is a high-pressure, high-grade (to granulite facies) transpressional shear zone (Hand et al., 1995; Vassallo and Wilson, 2002). The Kimban Deformation is apparently an easterly waning event away from the centre of the Kalinjala Mylonite Zone, where two deformation events were described (Vassallo and Wilson, 2002). The current study found only one event on Yorke Peninsula and it is speculated to correlate with the initial granulite-facies metamorphism. No direct geochronological dates were collected on Yorke Peninsula relating the Kimban Deformation.

D_4 — TIPARRA DEFORMATION (TD)

The Tiparra Deformation (=Moonta Deformation, Zang et al., 2002) is proposed to group two deformational phases in the Curramulka Gabbronorite and the coeval Tickera and Arthurton Granites on Yorke Peninsula, which are apparently related to the generation of hydrothermal fluids and regional alteration. This deformation and associated initial hydrothermal event has been recently dated, by SHRIMP on monazite in the Moonta Mines area, at ~1585 Ma (Raymond et al., 2002). This deformation had a strong impact on the development of the eastern margin of the Gawler Craton and is probably equivalent to the Wartakan Event on Eyre Peninsula.

The Tiparra Deformation contains two phases. The initial deformation (=Tickera Event, Conor, 2002) seems to have resulted in formation of conjugate fault–shear zones on Yorke Peninsula. These structural features are best exposed at North Beach, Wallaroo, where the deformed Tickera Granite is well exposed in beach outcrops and contains NE and NW-trending fault–shear zones. In the Moonta–Wallaroo Mines area, the Wallaroo lodes trend NW–SE and Moonta lodes NE–SW. The Moonta–Wallaroo lodes are controlled by these conjugate fault–shear zones.

The structures in the Moonta–Wallaroo Mines were first analysed by Dickinson (1942), and are better understood after recent open-cut mining at the Poona and Wheal Hughes Mines in the Moonta area. Mendis (1992) recognised a prominent lineation (295°/55°NW) on the foliation plane, with another weak chlorite elongation in an ~NE–SW direction with a kink plane largely at 065°/40°NE in the Wheal Hughes Mine. Carthew (1993) interpreted two principal shear–mineralisation zones in the Moonta Mines region: the Main Lode Shear, with dextral reverse shear, trends parallel to the foliation at ~045°, dipping 45–50°NW with more continuous and dominant ore shoots along it. The West Lode Shear, also with dextral reverse shear sense, trends 070°, dipping 60–70° NNW with more K-feldspar alteration, greater intensity of stringer or vein mineralisation, along with more intense jointing and ground instability. It is the intersection of these two shear directions as the chief components of this complex fissure system that produces pipelike orebodies, normally pitching 80°S (see also Dickinson, 1942, 1953). The current study suggests that the Main Lode Shear is parallel to the major foliation and probably to the remnants of the KD structure, which was reactivated during the TD_1 event. The West Lode Shear was formed later, either parallel to the rotated KS or crosscutting the major foliation.

The regional structures are better interpreted by the recent TEISA aeromagnetic survey that reveals dominant NW-trending shear zones on Yorke Peninsula. In the mine area, prominent structures also include E–W and NE–SW shear zones. A synthesis of the data, different to the previous model (Carthew, 1993), indicates a sinistral wrench regime with the principal stress field being ENE–WSW and largely orthogonal to the West Lode Shear. This model suggests that the syn-West Lode Shear structures (including Leightons Lode in the Wheal Hughes Mine) were formed as en echelon tension gashes or fractures in the Moonta Mines during the compression regime (TD_1).

The initial Tiparra Deformation has produced a low-amphibolite to greenschist metamorphism in the Moonta Mines area, as indicated by the occurrence of biotite–chlorite fabrics in the orebodies. The deformation also had a major effect on the Curramulka Gabbronorite in the central peninsula, as it produced a metamorphism in which the major foliation is defined by hornblende–biotite alignment, thus suggesting low to middle-amphibolite facies. A second phase resulted in the formation of chlorite±sericite±epidote, mostly in shear zones, but no regional foliation was found to relate to this later event.

POST-MINERALISATION D_5 (=TD_2) STRUCTURES

In the Moonta–Wallaroo Mines, tectonism reactivated and offset the mineralised horizons, as exhibited at the Wheal Hughes Mine. Such faults are often barren, being filled with pegmatite or chlorite. A 'pegmatite fault' in the mine, with a reverse dextral sense of movement, trends 140°°, dips 70°W and is a complex anastomosing zone where the pegmatite has very sharp contact discordant to the foliation in the host porphyry. This pegmatite dyke is sinistrally displaced 0.2 m by a fault (70°/70°NW; Mendis, 1992). Another nearby sinistral fault is orientated 90°/55°S, with slickensides plunging 245°/5–27°SW, and also has pegmatite. In the Wallaroo Mines region, equivalent post-mineralisation cross-faults strike 30°–45°NE and dip ~70°W (Dickinson, 1942). An analysis of the fault system in the Poona and Wheal Hughes Mines suggests it is a coaxial system with NW–SE principal compression (Carthew, 1993). F_5 folds are rarely present in the field. At Port Victoria, several open folds were found in the metasediments of the Aagot Member and are related to development of the NW-trending shear zone.

Metamorphism associated with TD_2 events produced some variable fabrics in the region. In the Poona and Wheal Hughes Mines, slickensides can be chlorite, tourmaline or clay-rich grooves plunging 36–60° in the plane of the foliation towards 310°NW (Carthew, 1993). In the shear zones, some biotite blades were found with a chloritised margin. TD_2 generally does not produce fabrics in the Moonta Mines area, but chlorite and sericite can be found along the fault planes. Some narrow fracture zones, which crosscut TS_1, are present in the Curramulka Gabbronorite and are filled with chlorite and carbonate. Those fracture zones are not found in the overlying Cambrian sediments and are considered to be of pre-Cambrian age.

The TD_2 thermal event has been dated at ~1500 Ma and is consistently confirmed by K–Ar and Rb–Sr dating (Webb, 1978; Huffadine, 1993). Five K–Ar dates on muscovite or biotite in pegmatite dykes range from 1472 to 1421 Ma (Webb, 1978). To the west, in Spencer Gulf, intrusion of the weakly foliated Spilsby Suite is dated at 1510±12 Ma (crystallisation age; Fanning, 1997). It is suggested that intrusion of the Spilsby Suite or coeval dykes provided the heat source for age resetting at ~1500 Ma in the map area.

SUMMARY

Three deformation events are recognised in the Wallaroo Group, Moonta Subdomain. The first (=Kimban Deformation) is a fabric-forming event, producing regional NE-trending structures and foliation, largely parallel to the Kalinjala Mylonite Zone and producing in the metasediments of the Wandearah Formation a metamorphic grade that apparently wanes towards the east, from low to middle-amphibolite (biotite–amphibole) facies at Moonta to greenschist facies in the eastern Paskeville and Bute areas. The second deformation (=TD_1) is a mineralisation event, producing NW and NE-trending shear zones, or tensional gashes, in which the minerals were deposited in the Moonta and Wallaroo Mines areas. The third event (=TD_2) is represented by conjugate faulting that displaced the mineral lodes in the mine area.

Deformation of the Delamerian Orogeny

The Cambrian Stansbury Basin was considered to have formed on a rifted continental platform east of the Gawler Craton. The Early Cambrian succession also overlies the thick (up to 20 km) Neoproterozoic rift succession (~850–545 Ma) of the Adelaide Geosyncline in the Flinders Ranges (Preiss, 1987; Jago and Moore, 1990), which was deposited during separation of the Gondwana and Laurentia supercontinents. During the latest Neoproterozoic, the dextral shear between the northern and southern Australian cratons along the Paterson-Petermann Ranges Orogen uplifted the geosyncline and associated central Australian basins (Walter et al., 1995), and was followed by renewed rifting, reflecting the latest Neoproterozoic – Early Cambrian continental break-up that formed the western margin of Laurentia (Powell et al., 1994). The Neoproterozoic and Early Cambrian sequences in the Stansbury Basin were mainly formed on the passive margin of the Palaeo-Pacific Ocean.

The tectonic uplift and renewed Early Cambrian rifting can be recognised by seismic and field interpretation in the Stansbury Basin. Exploration drilling reveals that the Early Cambrian sediments (e.g. Winulta Formation) unconformably overlie the Gawler Craton basement rocks on southern Yorke Peninsula. To the north at Kulpara, and east under Gulf St Vincent and on Fleurieu Peninsula, the lower Cambrian succession unconformably overlies Neoproterozoic sediments. Interpretation of extensional faults from seismic lines Y82-A3, 85ST01, 92–13, 92–18, 94–1–20 etc. indicate further break-up of the eastern margin of the Gawler Craton or subsidence of the crystalline basement during the Early Cambrian, resulting in Early Cambrian sediments onlapping the basement. Most of these faults were reversed during the Delamerian Orogeny and some are active today.

The Ardrossan and Pine Point Faults on eastern Yorke Peninsula are interpreted to result from the reverse faulting initiated by the Delamerian Orogeny. The Yuruga Formation is folded adjacent to the fault zone north of Pine Point. Pop-up structures are also present at Pine Point, as fractured dolomite of the Kulpara Formation has been uplifted and surrounded by sandstone of the Yuruga Formation. Along the fault surface, quartz–feldspar rod-slicking and shear-flow bands are found. The S-C structures suggest a possible dextral movement of the Pine Point Fault.

Tertiary faulting

The Tertiary succession on eastern Yorke Peninsula and beneath Gulf St Vincent occupies palaeochannels and gently downwarped depressions that were enhanced by a rifting continental margin brought about by the further separation of Australia and Antarctica. The influence of this continental rifting and separation may be recognised as early as the Jurassic in this region, as indicated by the occurrence of Jurassic Wisanger Basalt on Kangaroo Island. Tertiary sedimentation commenced in the St Vincent Basin approximately from the Middle Eocene, suggesting an acceleration of the separation rate at this time (Cooper, 1985). The formation of the St Vincent Basin mainly involved normal faulting following pre-existing Delamerian compressional faults, forming a N–S elongated intra-continental depression. Sediments in the St Vincent Basin are generally thin on the eastern coast of Yorke Peninsula but, according to seismic interpretation, could be up to 1000 m thick in depocentres.

On eastern Yorke Peninsula, major structural trends in the western St Vincent Basin are controlled by the Cambrian Stansbury Basin or Delamerian faults. Back-stepping normal faults have been observed along the eastern coast in outcrop (Stuart, 1970) as well as interpreted in seismic sections over Gulf St Vincent (Birt, 1995). The faults are mostly vertical or dipping east to southeast towards the depocentre under Gulf St Vincent. Cooper (1985) suggested that this tensional faulting in the Tertiary was superimposed on much older Delamerian compressional structures. Seismic interpretation of offshore St Vincent Basin suggests that its eastern and southern margins beyond the map area are dominated by intensive faulting and that Tertiary sediments are generally flat-lying to gently warped in other areas (Birt, 1995).

At least two graben faulting events can be interpreted in the Tertiary sequence on Yorke Peninsula. The first probably initiated deposition of the Muloowurtie Formation during marine incursion onto Yorke Peninsula in the late-Middle Eocene to early-Late Eocene. Remnants can be found north of Port Julia, where the Muloowurtie Formation was deposited in a graben to half-graben structure in Wallaroo Group and

Arthurton Granite basement. At Sliding Rocks, a similar structure was observed in dolomite of the Cambrian Kulpara Formation. Stuart (1970) also interpreted a normal fault south of Black Point. There could be an earlier tensional faulting event if the channel accommodating the North Maslin Sand in the Ardrossan and Melton areas is interpreted to be fault controlled (Pain et al., 1992).

The second graben faulting event is associated with local marine transgression and carbonate built-ups during deposition of the upper Port Willunga Formation. Faulting in the Melton–Ardrossan area in the north and near Warooka area in the south established sea links between the St Vincent and western Pirie Basins. At Point Turton, the Point Turton Limestone unconformably overlies the Permian Cape Jervis Formation, and offshore seismic survey suggests it was deposited in a graben structure formed by reactivation of the Warooka Fault zone. At Muloowurtie Point, basal Point Vincent Limestone was deposited in a half-graben-shaped channel within the Rogue Formation.

Differential subsidence in the western St Vincent Basin created a palaeohigh in the Port Vincent area. The high, consisting of Permian Cape Jervis Formation, regionally separates northern siliciclastic deposits from carbonate-dominated sediments to the east and southeast. In the north, a depocentre in the Black Point – Muloowurtie Point area accommodated mainly sandstone and calcareous siltstone of the Muloowurtie Formation, Throoka Silt and Rogue Formation. The overlying Port Vincent Limestone is laterally transitional to the Rogue Formation to the north and the Port Willunga Formation to the south, and probably overlaps the high (Stuart, 1970), suggesting that this high was eroded during the second rift event.

The siliciclastics succession on eastern Yorke Peninsula is relatively thin and poorly fossiliferous. The correlation between the siliciclastics deposits and carbonates in the eastern St Vincent Basin is often problematic, although lithological marker horizons have proved valuable (Cooper, 1983). Generally, the biostratigraphy of the Tertiary sediments on Yorke Peninsula is relatively well studied, and standard Tertiary fossil zones are based on planktonic foraminiferal faunas in the carbonates that are often absent in the coastal siliciclastics succession studied (Ludbrook, 1959, 1963; Lindsay, 1967, 1969, 1981, 1985; Cooper, 1979, 1985; Crawford, 1965; Stuart, 1970; McGowran, 1989; Lindsay and Alley, 1995; Holmes, 2004). The biostratigraphic correlation in this study is based on a recent version (Lindsay and Alley, 1995).

Quaternary neotectonics and geomorphology

Neotectonic movements are vital to an understanding of the recent topography on Yorke Peninsula. Uplift events during late-Early Pleistocene (~0.8 Ma) and late-Middle Pleistocene (~0.125 Ma) reactivated major N–S-trending faults and formed ranges or hills. Generally, the geometry of the peninsula is probably controlled by a nearly E–W compression during the Quaternary, based on stress-field analysis. Two structures are mapped and related to neotectonics. The earlier structure is observed in the Ardrossan dolomite quarry, where uplift of the Cambrian carbonates generated the accommodation space and resulted in deposition of alluvial-fan and valley-flat sediments (e.g. Hindmarsh Clay). The compression event resulted in formation of the reversed faults in the quarry section and uplift of more than 50 m. The reverse fault, dipping ~70°W, is probably a re-activation of the Delamerian Ardrossan Fault, which thrusts the Early Cambrian Kulpara Formation over the Quaternary sandy Hindmarsh Clay (Fig. 9).

Reverse fault, with Cambrian dolomite of the Kulpara Formation overlying Quaternary Hindmarsh Clay, Ardrossan Quarry. (Photo 403080)

The second event is recognised in the Warooka area, where uplift of the Warooka high resulted in a depression in the Peesey Swamp region, with consequent deposition of fossiliferous limestone of the Glanville Formation and upper Bridgewater Formation. The temporal lagoons or depressions and hill-front downwash slope deposits and associated fault scarp debris (Qe) were formed during this event. The Peesey Swamp depression probably remains active today.

Topographic images (Fig.10), that reveal low-relief hill ridges, are consistent with field mapping and seismic data. Major faults produce ridges, valleys or creeks through subsequent weathering. On northern Yorke Peninsula, most ridges reveal outcrops of Cambrian sediments or Mesoproterozoic granite, whereas the valleys are filled by modern gravel and clay; along the southeastern coast, the Tertiary sediments and Pleistocene Bridgewater Formation stand high above sea level. From seismic interpretation of Gulf St Vincent, the most recent faulting seems to occur along ancient lines of weakness deriving from the Delamerian orogeny or older.

The Warooka earthquake (19 September 1902, estimated magnitude 5.9)

This earthquake caused major damage on southern Yorke Peninsula, particularly at Warooka and nearby areas such as Troubridge Island Lighthouse. Limited damage also occurred in Adelaide. The epicentre was initially located at Warooka, but more recent work suggests that it might have been under Gulf St Vincent (D. Love, PIRSA, pers. comm., 2002). This event resulted in at least two deaths, the first known fatalities from an earthquake in Australia. The earthquake has been attributed to tectonism along the Warooka Fault Zone.

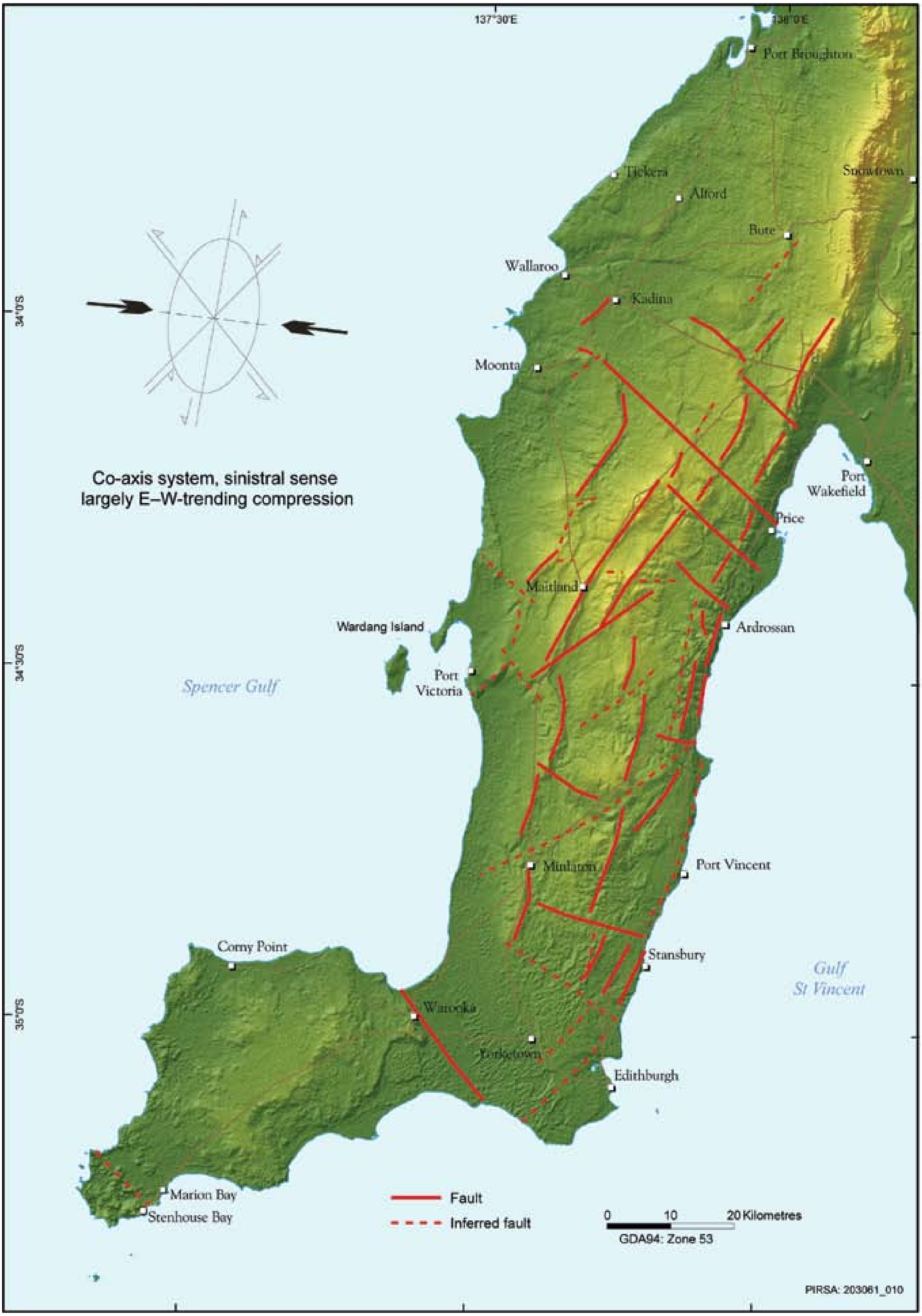


***Fig. 10** Quaternary faults and topography, MAITLAND Special 1:250 000 map area.*

ECONOMIC GEOLOGY

INTRODUCTION

Development of the Yorke Peninsula economy has closely paralleled the establishment of the Moonta and Wallaroo Mines. Mineral exploration of the peninsula can be traced back to the 1850s when the first mining lease was issued to Captain Walter Hughes. Unfortunately, most exploration data from this early period have not been recorded. PIRSA (MESA) records from 1947 list more than 70 mineral licences and nine petroleum licences in the map area.

Minerals and their occurrences on the peninsula were reviewed in detail by Brown (1908), Willington (1960), Crawford (1965), Conor (1995) and Zang et al. (2002). The following information is summarised mainly from recent exploration reports.

COPPER–GOLD

Copper exploration in this region started when Captain Walter Hughes bought the Wallaroo pastoral run (bounded by the present townships of Moonta, Paskeville and Tickera) in 1857. He suspected copper or other minerals in the area and applied for a mineral section in 1851. He secured the first mineral lease after James Boor, his shepherd, found copper oxides outside the burrow of a marsupial rat in December 1859, an event that led to development of the Wallaroo Mines at Kadina. This was followed by the finding of the Moonta mineral deposit by another shepherd, Paddy Ryan, in 1861. Two parties subsequently applied for mining leases over the Moonta discovery, but again Hughes was eventually successful (Pryor, 1962). The two mines started production almost immediately and the resulting major regional mining complex continued until 1923 when the price of copper slumped and high-grade orebodies had been largely mined out. This mining phase produced a total output of 330 000 t of copper and 54 000 ounces of gold from 6.25 Mt of ore (3.5 Mt from Wallaroo Mines and 2.75 Mt from Moonta Mines) at an average grade of 5.4% Cu during 1861–1923, which in the early days was ~30% Cu (Jack, 1917). Several other small mines also operated in the Moonta region during this period, but they were not very profitable (Jack, 1917). Exploration in 1930–31 revealed small ore shoots in the southern extension of Elder's Lode that were estimated at ~16 000 t at 6% Cu (Dickinson, 1953) or ~75 000 t at 3.75% Cu (Ward, 1940). Renewed exploration and mining of copper and gold in this region during 1989–94 produced ~450 000 t of ore averaging 4.0% Cu and 1.0 g/t Au from Wheal Hughes and the Poona deposit (Amalg Resources NL, 1993; Table 10). The area has potential for future mineral discoveries since the availability of existent orebodies can provide a reliable geological and geophysical model for application to other areas, and new technology will reveal more structures from this largely concealed region.

The Moonta–Wallaroo Mines have been well reviewed by Jack (1917) and Dickinson (1942). Cu–Au prospectivity remains high and several prospective areas have been documented north of the mined deposits by Conor (1995, 2002):

(**a**) **Moonta area.** The mines ceased production in 1923 but reopened intermittently during the 1930s and 1940s. Subsequent exploration in the area discovered many small deposits, and McBriar (1962) reported exceptionally high cobalt and nickel values associated with barite, sphalerite and pyrite in the Wallaroo and Moonta lodes. Discovery of the Poona and Wheal Hughes deposits and their subsequent development in the early 1990s brought optimism that additional Cu–Au deposits could be located. Numerous drillholes intersected zones of chalcopyrite–bornite–chalcocite–pyrite with minor molybdenum, gold, silver and uranium hosted in the Moonta Mines area. Small, rich lodes are very possible, but large deposits are unlikely.

(**b**) **Doora–Vulcan area.** Diamond drilling in the area has intersected numerous thin chalcopyrite-bearing horizons, with pyrite, magnetite, minor pyrrhotite, trace galena, sphalerite, ferberite, scheelite, molybdenite and gold, most commonly <5 m in width with 2% Cu. The best intersection was up to 8.8 m at 2.04% Cu (Plimer, 1980; Conor, 1995). Further drilling along the west Doora–Vulcan line at greater depths,

Open pit of the Wheal Hughes Mine, Moonta, now a tourist attraction. *(Photo 403081)*

Table 10 *Production from the Poona and Wheal Hughes Mines (Amalg Resources NL, 1993; Conor, 2002).*

Deposit	Tonnes	**Cu** (%)	**Au** (g/t)	**Contained Cu** (t)
Poona Mine				
Open pit	151 000	4.8	1.5	7 300
Underground	37 000	406	1.3	1 700
Wheal Hughes Mine				
Open pit	142 000	3.0	0.7	4 300
Underground	120 000	3.9	0.5	4 700
Total	450 000	4.0	1.0	18 000

or infilling of broadly spaced holes, would have to establish the presence of at least 250 000 t of contained copper at high grades (>3% Cu) or associated other commodities (e.g. Au, Ag, Zn, U; in DDH 49, up to 1.55 g/t Au and 5.27 g/t Ag) in order to confirm an economic resource (Plimer, 1980).

The WMC Moonta joint venture drilled 41 drillholes at the West Doora prospect, which delineated a resource estimated at 2.7 Mt, mainly low grade, but up to 2.1% Cu in four main lenses from 100 to 300 m below surface (Cooke, 1990).

(c) Pridham's prospect. This prospect is on the northern margin of the map area, and diamond-drillholes intersected mainly carbonate, siltstone and albitic rocks of the New Cornwall Member. Many wide but low-grade mineralisation zones have been found, consisting mainly of chalcopyrite, pyrite, trace molybdenum, galena and sphalerite, associated with metasomatic zones. DDH 213 intersected an ~213 m thick zone of ~0.25% Cu with a trace of gold (Conor, 2002). The best intersection in the area is up to 25.9 m at 0.53% Cu (Conor, 1995).

(d) Tea Tree Glen – Weetulta area. Anomalous values of copper, cobalt, nickel and minor molybdenum have been reported west of Weetulta (Lynch, 1977). The best intersection is up to 10 m at 0.4% Cu, 0.16% Ni, 0.06% Co and 0.34% Ce in CRA Exploration hole DD85WE1 (Conor, 1995).

(e) Parara Mine area. The now-abandoned Parara Mine is ~3 km west of Ardrossan. Brown (1908) reported that the mine was worked to a depth of ~60 m and a quantity of high-grade ore extracted in the early days (~1874). During re-mining in the 1900s, the ore grade was in the range of 23–46% Cu and 0.065–5 g/t Au (Brown, 1908). Some exploration (Otter Ltd, 1984) suggested that gold could be as high as 28.5 g/t and copper at 9%, but drilling was unsuccessful in intersecting mineralisation. The mineral lode of the Parara Mine strikes slightly east of north (Brown, 1908), and is largely parallel to the orientation of the Ardrossan Fault, implying that the mineralisation could be of Delamerian origin. Southwards along the fault, the Hillside and Harts Mines occur in a similar geological setting (Brown, 1908). Drilling and geochemical analyses northwest of Ardrossan revealed some sulphide mineralisation zones with values up to 1600 ppm Cu, 400 ppm Pb, 550 ppm Zn and 45 ppm Co in Cambrian dolomite (e.g. Kulpara Formation in SYM 600, depth 84 m). The best known mineralisation on eastern Yorke Peninsula, near Parara, has not been assessed utilising modern exploration technologies, and all historic mine workings in the area are now on farm lands.

(f) Curramulka Mine. The mine was mentioned by Brown (1908, p.47) as a possible copper working in the Curramulka area dating from 1864. He also stated that there were traces of copper in limestone, but no evidence has since substantiated the statement.

URANIUM

Uranium has long been known from the Moonta–Wallaroo Mines, but its potential has normally been given low priority. Radcliff (1906) detected up to 4.74% U_2O_5 in the thin black veins of Treuer's Shaft. Mawson (1944) examined the uraniferous veins in this shaft and found that the uranium occurred with covellite, quartz, and also with minor thucholite. Similar uranium-rich mineralisation was also reported in Elder's Lode (Radcliff, 1906; Mawson, 1944). Uranium exploration on northern Yorke Peninsula in the 1950s was summarised by Woodmansee (1957) and Hiern (1959), but despite the finding of many uranium anomalies, their work failed to delineate any economic Cu–U mineralisation around the Moonta–Wallaroo Mines.

Numerous uranium occurrences are known in the map area, including the Hillside, Harts and Parara Mines on eastern Yorke Peninsula, and the Taylors, Trivess and Wild Dog Mines in the Moonta–Yelta region. The mine dumps at both the Moonta and Wallaroo Mines contain minor secondary uranium minerals as well as slimes and skimps with radiometric anomalies. Two diamond-drillholes in carbonaceous rocks at Alford intersected a zone containing 42.7 m at 236 ppm U (up to 530 ppm) and 40.8 m at 130 ppm U (Plimer, 1980).

At the Hillside copper mine, uranium oxides including pitchblende occur in copper ore associated with calcite and appear to replace the copper sulphides, especially covellite (Woodmansee, 1957). Recent geochemical sampling in the area suggests highly anomalous uranium from 31 to 340 ppm (up to 600 ppm; Busuttil, 1997). The uranium occurs in limonite and haematite-stained clay, probably derived from an argillically altered granite in a major fault zone (Busuttil, 1997).

Anomalous uranium values also occur in the Price–Pine Point region, where Tertiary channels cut into late Palaeoproterozoic basement rocks. Drilling by Poseidon Ltd (1983) northeast of Ardrossan suggested that the Tertiary fluvial–deltaic facies transition (e.g. AP 8) has a significant potential for sedimentary uranium.

GOLD (Placer)

Plimer (1980) suggested that the conglomerate and sandstone of the Winulta Formation have palaeo-placer gold potential, because reworked basement would produce high concentrations; in DDH 186 at Cunliffe, gold traces are present in several layers with increasing grades towards the Precambrian–Cambrian boundary. Fluvial gold trace was also reported at the base of the Winulta Formation near the Parara Mine (Otter Ltd, 1984).

BASE METALS (Zn–Pb)

Extensive exploration for zinc on Yorke Peninsula started in the 1940s when SML 11 and 14 were issued (Zinc Corp. Ltd, 1949); anomalous values have since been frequently reported from Wallaroo Group metasediments. High Zn–Pb values are known in the ores of the Wallaroo Mines. There are also numerous Zn–Pb-bearing black shale lenses, but most of these occurrences are structure controlled (Plimer, 1980). In the West Doora – Vulcan area, 62 drillholes intersected some minor zinc occurrences, up to 6 m at 0.5% Zn (Plimer, 1980). Drilling in the Parara Mine area also revealed low-grade anomalies that can be up to 2 ppm Ag and 820 ppm combined Pb–Zn (Otter NL, 1984). At Pridham's prospect, the stratabound sulphides, some with anomalous zinc, are associated with the most complex and intensely folded and faulted part of metasomatic alteration (scapolitisation), as well as carbonate and quartz veining; the sulphides were produced by metasomatism (dewatering) and deformation, and are not an exhalative deposit (Plimer, 1980). It is possible that some sedimentary ore minerals were deposited within the Wallaroo Group and re-mobilised during post-depositional deformations and metamorphism.

Base metal exploration on Yorke Peninsula has focused on the Cambrian carbonates over many years, where mineralisation is commonly related to hydrothermal events of the Delamerian Orogeny. Crawford (1965) reported some minor copper and lead mineralisation in dolomitic limestone and at the contact zone between the Winulta and Kulpara Formations. Intense drilling of the Cambrian limestone for MVT mineralisation, in conjunction with seismic and gravity surveys in the Curramulka area during the early 1980s, found only minor galena, sphalerite and chalcopyrite mineralisation in the Parara and Ramsay Limestones (BHP Ltd, 1985).

IRON

Significant iron deposits have been located on and in the region of Yorke Peninsula. Thick BIF deposits have been intersected in drillhole PB12, ~50 km north of Moonta. In the map area, reconnaissance ground magnetics over a series of aeromagnetic anomalies immediately northwest of Agery (central-north Yorke Peninsula) have identified eight iron targets labelled Agery 1–8, and Nankivells prospect (M. Davies, PIRSA, unpublished data, 2000):

- Agery 1: drillhole MP807, 38–46 m — blue-green magnetite–amphibole
- Agery 3: drillhole MP806, 40–46 m — magnetite quartzite
- Agery 4: drillhole MP797, intersected quartz–amphibole–feldspar skarn with no magnetite
- Agery 5: drillhole MP798, 44–60 m — massive magnetite
- Agery 6: drillhole MP802, 32–54 m — magnetite (no magnetite in MP 803)
- Agery 7: drillholes MP804 and MP 805 — sporadic magnetite in both
- Agery 8: drillholes MP809 and MP 810 — quartzite, non-magnetic
- Nankivells prospect — drillholes MP 794, MP 795, MP 796 — all intersected intervals of massive, black magnetite.

The magnetite is often associated with elevated copper and there appears to be a significant linear magnetic high extending further southwest from Agery 8 for several kilometres. Most anomalies in the area are sourced from magnetite-rich metasediment, a potential host to remobilised magnetite-rich metasomatites (M. Davies, PIRSA, unpublished data, 2000).

Massive to brecciated iron formations were also reported in several drillholes near Balgowan. Fe-rich layers in cores are metasomatic deposits, probably related to intrusion of the Arthurton Granite. The magnetite in this case has been subjected to extensive late haematisation.

DOLOMITE AND LIMESTONE

The Ardrossan Quarry (OneSteel Ltd) provides dolomite from the lower dolomite unit of the Kulpara Formation. The product is shipped to Whyalla, Port Kembla and Newcastle for use as a flux in steel making.

The Curramulka Quarry provides nodular Parara Limestone mainly for road works on Yorke Peninsula. The resource in the area is huge (Johns, 1963). Another limestone quarry has recently been established near Minlaton, and supplied for the Pt Vincent Marina.

The Klein Point Quarry, owned by Adelaide Brighton Holding Ltd, commenced operations in the early 1900s to provide Tertiary fossiliferous limestone from the Port Willunga Formation. At present, the quarry and associated crushing plant operates 365 days per year and ships 7–8000 t of limestone daily to Birkenhead near Port Adelaide for cement manufacture. About 1.5 Mt/y of limestone are mined from Klein Point.

SALT

Salt produced from Yorke Peninsula was once a major source for South Australia (Jack, 1921). The industry was based in the southern Edithburgh – Yorketown region during later 1890s and early 1900s, with production from local lakes. The Peesey Swamp area also produced some salt.

During the 1930s, salt pans were established near Price on northeastern Yorke Peninsula by Ocean Salt Ltd, along with a salt works and refinery. These pans are still an important salt supply in the state, averaging ~60 000 t/y.

GYPSUM

Gypsum mining was once an important industry on southern Yorke Peninsula, commencing in the late 1870s from Marion, Snow and Spider Lakes (now within Innes National Park), and later including Lake Fowler to the east (Jack, 1921; Dickinson and King, 1951). The gypsum was used primarily for the manufacture of plaster and plaster products. Commercial production ceased in the 1970s, and the mining township and associated ruins are now one of the tourist attractions in Innes National Park. It is estimated that ~6 Mt of gypsum were mined from Marion Lake between 1905 and 1973. A small amount of the gypsum is still mined from the lake for road-building material.

PHOSPHATE

The Yararoo phosphate deposits in carbonate sections of the Kulpara Formation were quarried northwest of Clinton (Carroll, 1982). Some 10 000 t of low-grade phosphorites were produced from a 1800 m strike length of limestone, which contains cavities and enlarged pockets filled with soft yellow and grey carbonaceous marl, sand and clay (Plimer, 1980). The phosphate is present in fissures and cave-collapse structures in the Kulpara Formation and Parara Limestone southwest of Ardrossan and south of Paskeville (Plimer, 1980), but no specific exploration was conducted for phosphate deposits. Anomalous Pb–Zn values in the phosphatic layer were considered to be a target for further exploration of MVT mineralisation (Poseidon Ltd, 1983).

SAND

Tertiary fluvial sand (North Maslin Sand) is mined by CSR Sand Quarries and Southern Quarries in the Price area and north of Melton. The sand is used for concrete or building sand. Reserves in the region are relatively large (Pain et al., 1992).

KAOLIN AND OTHER CLAYS

Potential kaolin and montmorillonite clay on Yorke Peninsula were briefly reviewed by Crawford (1965), but no commercial mining has occurred. Investigations in 1960s showed that, although there are large reserves of Permian, Tertiary and Quarternary clays near Klein Point, their chemical composition or physical characteristics render them unsuitable for use in the wet process of cement manufacture (Blissett, 1970). Shale near the base of Cambrian redbeds drilled near Curramulka in 1968 proved too thin and too variable in composition, with relatively thick overburden (Blissett, 1970). Analyses of weathered Early Cambrian shale west of Ardrossan indicate that they may be satisfactory. An exploration program was outlined to test concealed beds in the Ardrossan district and north of Curramulka. Another unit worthy of examination is kaolinised aplite near Pine Point (Blissett, 1970).

HYDROCARBONS

Petroleum exploration on Yorke Peninsula commenced in the early 1930s when the first well, Peninsula Oil 1, was drilled east of Warooka. The first petroleum exploration licence, OEL 24, was issued to Geosurveys of Australia Ltd in 1960. Exploration in the region during the 1960s–1970s (Johnson, 1960b; Sprigg, 1961; Stuart and von Sanden, 1972) was spurred by reports of Cambrian oil in the southwestern Arrowie Basin (Wilkatana 1). Furthermore, Minlaton 1 stratigraphic hole drilled by the state government confirmed a thick Early Cambrian section that contains oil traces (Ludbrook, 1965). In 1962, Beach Petroleum NL began a 12-year systematic exploration program with aeromagnetic, gravity and seismic surveys together with drilling. Three deep and two shallow exploration wells were drilled and logged, discovering traces of gas accompanying saline water. Further exploration by Pan Pacific Petroleum NL, Nerdlihc Co. Inc., Wagner and Brown (Aust.) Ltd, and Canyon (Aust.) Ltd resulted in offshore seismic surveys, and the drilling of two offshore wells in waters of Gulf St Vincent (Enchilada 1 and Frijole 1, Canyon Ltd, 1998), and one in Spencer Gulf (Anna 1, Nerdlihc Inc., 1990). Enchilada 1 bottomed in the red-brown sandstone of the Winulta Formation; Frijole 1 reached the red-brown siltstone of the Yuruga Formation. Because of the complexity of the stratigraphy and structures, none of the predicted target structures or carbonates were intersected.

A total of five deep petroleum wells have been drilled in the Stansbury Basin. These are supplemented by five deep stratigraphic, and more than 20 deep mineral holes. All elements of viable petroleum systems exist in the Stansbury Basin, together with oil and gas shows. Preservation of traps and seals during later tectonism is a risk. Source rock volume

Table 11 *Petroleum data and potential in the Stansbury Basin (combined from Petroleum Group, 2006; Zang and Tucker, 2000). TOC: total organic carbon content; Type II: oil prone; Type III: gas prone.*

Reservoir rocks		
Carbonate reservoirs	Dolomitised limestone (Kulpara Formation)	Up to 500 m thick; vuggy, dissolution features and fractures; core porosity up to 13%; permeability up to 340 mD
	Koolywurtie reef complex (Parara Limestone)	Up to 73 m thick; vuggy and dissolution porosity
Sandstone reservoirs	Winulta Formation arkosic sandstone	100 m thick; fluvial to shoreface, arkosic sandstone, lowstand deposits
	Stokes Bay Sandstone	~350 m thick; shoreface sandstone; feldspar dissolution porosity
	Yuruga Formation	>500 m thick; lower part of sandstone, lowstand fluvial, arkosic with basal conglomerate
Seal		
Micritic Parara Limestone		Potential seal to dolomitised limestone of the Kulpara Formation and sandstone of the Winulta Formation
Siltstone–gypsum layers (Minlaton Formation)		Potential seal to underlying carbonate reservoirs
Upper siltstone (Yuruga Formation)		Potential seal to all underlying reservoirs
Source rocks		
Heatherdale Shale or equivalents		TOC (max. = 2.43%, mean = 0.64%), Kerogen type II
Parara Limestone		TOC (max. = 0.91%, mean =0.30%), Kerogen type II–III
Ramsay Limestone		Marine thin dark grey shale (TOC = 1.34%), ?presence of migrated hydrocarbons

and maturity are secondary risks, but the basin remains a frontier petroleum province.

COAL

Tertiary lignite or coal has been known in subcrop near Price and Clinton since exploration commenced in the early 1900s (Crawford, 1965; Parkin, 1947). Further drilling in the early 1960s did not reveal sufficient reserves (Johnson, 1960a). Several holes were drilled during the 1980s in the Curramulka area in search of Permian coal, but they only intersected massive diamictite (BHP Ltd, 1985).

GROUNDWATER

Moderate rainfall, hot summers and mild winters, coupled with particularly strong winds, result in a relatively high evaporation rate on Yorke Peninsula. No permanent streams are present, and most lakes are very saline and dry out in summer. Nearly all groundwater on the peninsula is salty and non-potable. Limited drinkable water (salinity <850 mg/L) has been found in aeolianite of the Bridgewater Formation in the Carribie and Para Wurlie Basins (Table 12). This provides a water supply for the township of Warooka (Shepherd, 1983). Along the coast, from south of Port Vincent to north of Stansbury, a number of wells have recorded good quality water (<1000 mg/L; Clarke, 1996). Most drinking water on the peninsula is piped from reservoirs at Beetaloo and Bundaleer in the southern Flinders Ranges.

Hydrogeology and groundwater distribution on Yorke Peninsula was investigated after initial European settlement in the Moonta–Wallaroo region. High salinity in the basement rocks was found to make the groundwater undrinkable. Due to the geographically low relief of the peninsula, groundwater in Tertiary, Permian and Cambrian sediments is of relatively high salinity (2000–7000 mg/L), and suitable only for stock (Shepherd, 1983; Clarke, 1996).

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Table 12 *Aquifer characteristics of some formations on Yorke Peninsula (Shepherd, 1983; Clarke, 1996).*

Formation	Yield	Salinity
Bridgewater Formation	300–1300 kL/d in the Carribie and Para Wurlie Basins, up to 2500 kL/d	Generally <850 mg/L, but as high as 3000–4000 mg/L and low as 400 mg/L
Port Willunga Formation	Unconfined aquifer in the Stansbury–Edithburgh area, <170 kL/d	2000–7000 mg/L
Minlaton Formation	Unconfined aquifer in the Minlaton–Curramulka area, 85–250 kL/d	2000–3000 mg/L
Kulpara Formation	Unconfined aquifer in the Minlaton–Curramulka area, 80–250 kL/d	2000–3000 mg/L
Not specified, probably Port Willunga Formation	South of Port Vincent to 5 km north of Stansbury, a number of wells with good quality water	Can be <1000 mg/L

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