GEOLOGICAL FRAMEWORK

The geological framework outlined here provides a basic overview of the geology of Queensland and draws particularly on work completed by the Australian Geological Survey Organisation and the Queensland Geological Survey Office.

Queensland contains rocks ranging in age from Proterozoic (~1880Ma) to Recent, with world-class mineral deposits as diverse as Proterozoic sediment-hosted base metals and Recent dune silica sand. Potential exists for significant mineral discoveries in a range of deposit styles, particularly from exploration under shallow sedimentary cover fringing prospective terranes.

The geology of Queensland is divided into three main structural divisions: the Proterozoic shield in the north west and north, the Palaeozoic-Mesozoic Tasman Orogenic Zone in the east, and the interposing and overlapping Mesozoic Great Australian Basin (Figure 1).

Proterozoic Shield

Proterozoic rocks crop out in the Mount Isa and Murphy Inliers as well as the McArthur and South Nicholson Basins in the north-west and the Georgetown, Yambo and Coen Inliers in the north. In addition, Neoproterozoic – Early Palaeozoic rocks crop out in the Georgina Basin in north-west Queensland, Anakie Province in central Queensland, Cape River Province in the Charters Towers area and Barnard Province in the Innisfail coastal area.

NORTH-WEST QUEENSLAND

Mount Isa Orogen

Rocks of the Mount Isa Orogen crop out over an area in excess of 50 000km^2 in north-west Queensland, roughly centred on the township of Mount Isa (Figure 1).

Rocks of the Mount Isa Orogen have been subdivided into three broad north-trending Provinces - the **Western Fold Belt Province**, the **Kalkadoon-Ewen Province** and the **Eastern Fold Belt Province** (Figure 1).

The Western Fold Belt Province is subdivided into the Lawn Hill Subprovince in the west and the Leichhardt River Subprovince in the east separated by the Mount Gordon Fault Zone (Figure 2). The Eastern Fold Belt Province is subdivided from west to east into the Wonga Subprovince, Quamby-Malbon Subprovince and Cloncurry Subprovince (Figure 2).

Detailed summaries of the geology of the Mount Isa area were given by Blake (1987), Blake & others (1990) and Blake & Stewart (1992). Recent dating of basin phases in the Western part of the Mount Isa Orogen and their implication for basin development were reported by Page & Sweet (1998) whilst recent dating of rocks in the Eastern Fold Belt Province and their implications for crustal evolution is reported in Page & Sun (1998).

Two major Proterozoic tectonostratigraphic cycles have been recognised. The early cycle is a basement sequence of sedimentary, volcanic and intrusive rocks deformed and metamorphosed at around 1870Ma during the Barramundi Orogeny. The second cycle is represented by three cover sequences, as defined by Blake (1987), that were deposited during extensional tectonism and terminated by the compressional 1620 to1520Ma Isan Orogeny. Recent work, for example Page & Sweet (1998), has thrown doubt on the concept of discrete cover sequences occurring over the entire Mount Isa Orogen. However, for the purposes of this summary this terminology is maintained with some minor adjustments to take into account recent age dating results.

The three cover sequences are major volcano-sedimentary packages separated by regional unconformities. Cover sequence 1 consists predominantly of 1870 to 1850Ma felsic volcanic rocks related to the Barramundi Orogeny and largely confined to the Kalkadoon-Ewen Province. Cover sequence 2 consists of widely distributed shallow water sedimentary rocks and bimodal volcanic rocks. Recent work (Page & Sweet, 1998) indicates that rocks of cover sequence 2 range in age from about 1790Ma to as young as 1705Ma. Cover sequence 3 contains mainly finer grained sedimentary and carbonate rocks with subordinate volcanic rocks, dated at 1675 to 1590Ma. Cover sequence 3 occurs predominantly within the Western Fold Belt Province and the western part of the Kalkadoon-Ewen Province. Most sedimentary rocks of the cover sequences were deposited in shallow marine and fluvial environments and most of the volcanic rocks were subaerial indicating the presence of pre-existing continental basement.

Granites and mafic intrusions were emplaced at various times before about 1100Ma; those older than 1550Ma are metamorphosed and generally deformed. From west to east the main batholiths exposed are the Sybella (1670Ma) in the Western Fold Belt, the Kalkadoon and Ewen (1870 to 1850Ma) in the Kalkadoon-Ewen Province, the Wonga (1760 to 1720Ma) in the Wonga Subprovince, and the post-orogenic Williams and Naraku Batholiths, in the Quamby-Malbon and Cloncurry Subprovinces. Intrusives of the Williams and Naraku Batholiths are known to be of at least three different ages (1750 to 1730Ma, 1545 to 1530Ma and 1520 to 1490Ma).

The Mount Isa Orogen has had a complex history of deformation dominated at different periods by extension, shortening and transcurrent faulting (Blake & Stewart, 1992). The earliest deformation is recorded in basement units that were tightly folded and in places partially melted before the onset of volcanism of cover sequence 1. This early shortening is attributed to the Barramundi Orogeny. The Barramundi compressional event was followed by extension, leading to basin formation and deposition of rocks of cover sequence 2. Extensional structures also postdated cover sequence 2, possibly coeval with the emplacement of the Wonga Batholith and hence older than 1700Ma. Rocks of cover sequence 3 are thought to have been deposited in an extensional basin. At approximately 1620Ma an early phase of thrusting and folding resulting from north-south compression took place and was followed at about 1520Ma by east-west compression of the Isan Orogeny. This event formed the major north-trending upright folds that characterise much of the Mount Isa Orogen. Later extension is implied by the intrusion of the Williams and Naraku Batholiths at around 1500Ma. The main faults mapped in the Mount Isa Orogen have kilometre-scale, predominantly strike-slip displacements, and are thought to have been active largely during the Proterozoic, although some may have been active during the Phanerozoic.

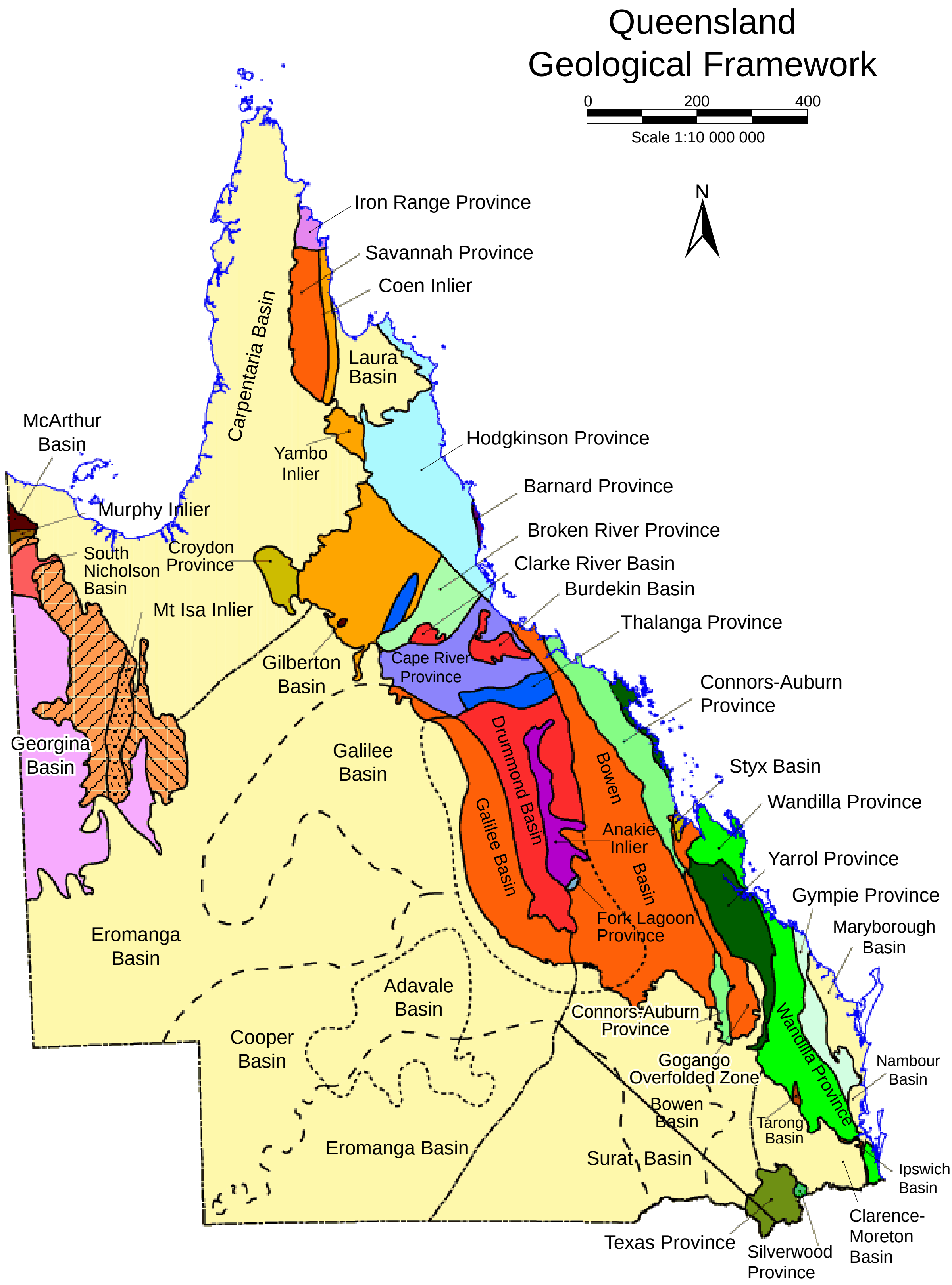
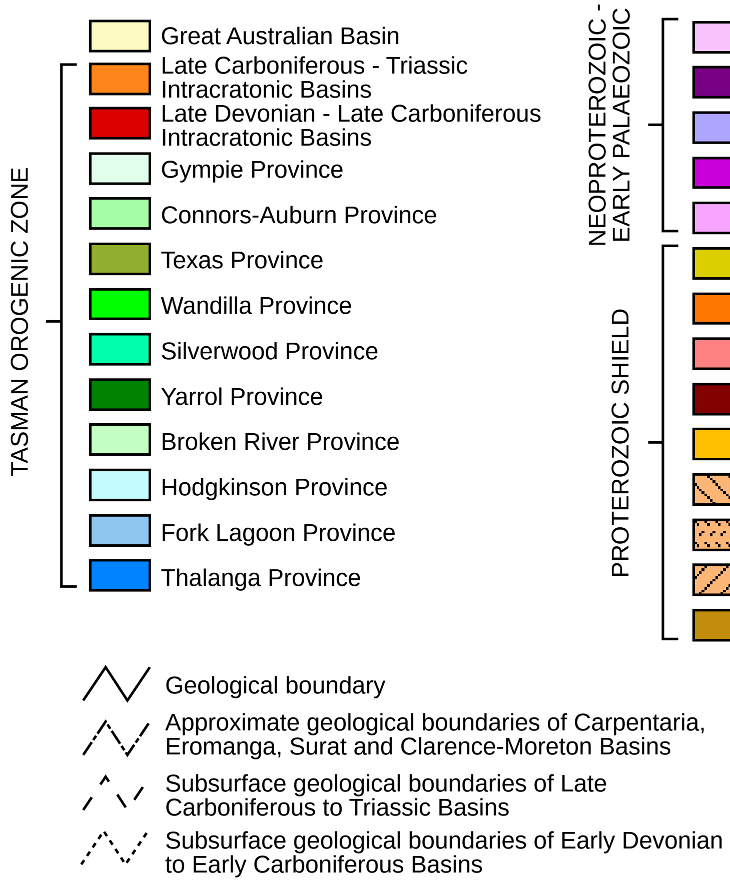


Figure 1. Queensland Geological Framework

Queensland Geological Framework Legend



Since the discovery of copper and gold near Cloncurry in the 1860s the rocks of the Mount Isa Orogen have been significant producers of copper, lead, zinc and silver. Significant resources remain, with rocks of the Mount Isa Orogen containing 11% of the world's lead and zinc resources, 5% of the world's silver resources and 1% of the world's copper resources (Wallis & others, 1998).

Four main styles of mineralisation account for the majority of the mineral resources within the rocks of the Mount Isa Orogen.

1) Sediment-hosted Silver-Lead-Zinc

Sediment-hosted silver-lead-zinc accounts for the majority of lead-zinc and a large proportion of the silver resources within Queensland. These deposits occur mainly within the fine-grained sedimentary rocks of cover sequence 3 in the Western Fold Belt Province and include the Mount Isa Pb-Zn, Century, Hilton, George Fisher and Lady Loretta deposits. Sediment-hosted base metal deposits also occur within cover sequence 2 rocks, the largest occurrence being the Dugald River lead-zinc mineralisation which is hosted by carbonaceous shale of the Eastern Fold Belt Province.

2) Brecciated Sediment-hosted Copper

Brecciated sediment-hosted copper deposits occur predominantly within rocks of cover sequences 2 and 3 of the Western Fold Belt Province and include the Mount Isa copper orebodies and the Esperanza/Mammoth mineralisation. The mineralisation is commonly hosted by brecciated dolomitic, pyritic and carbonaceous sedimentary rocks or brecciated sandstone proximal to regional fault/shear zones.

3) Iron-Oxide Related Copper-Gold

Iron-oxide related copper-gold deposits occur within high-grade cover sequence 2 rocks of the Eastern Fold Belt Province and consist predominantly of chalcopyrite-pyrite-magnetite mineralisation. Deposits of this type include Ernest Henry, Osborne and Selwyn. The Ernest Henry deposit, however, differs from the Osborne and Selwyn deposits in that it is distinctly breccia-hosted.

4) Broken Hill Type Silver-Lead-Zinc

Broken Hill type silver-lead-zinc deposits occur within high-grade metamorphic rocks in the Eastern Fold Belt Province. Cannington is the only major example.

Gold has been produced mainly as a by-product of copper from the iron-oxide related deposits of the Eastern Fold Belt Province. However, a significant exception, occurs at the now mined-out Tick Hill deposit where high-grade gold mineralisation occurred within quartz-feldspar 'laminite' bands within a broader strongly strained zone in the Corella Formation of the Eastern Fold Belt Province (Forrestal & others, 1998). This deposit forms a remarkable and important exception in that it produced 15 900kg of gold at an extraordinary average grade of

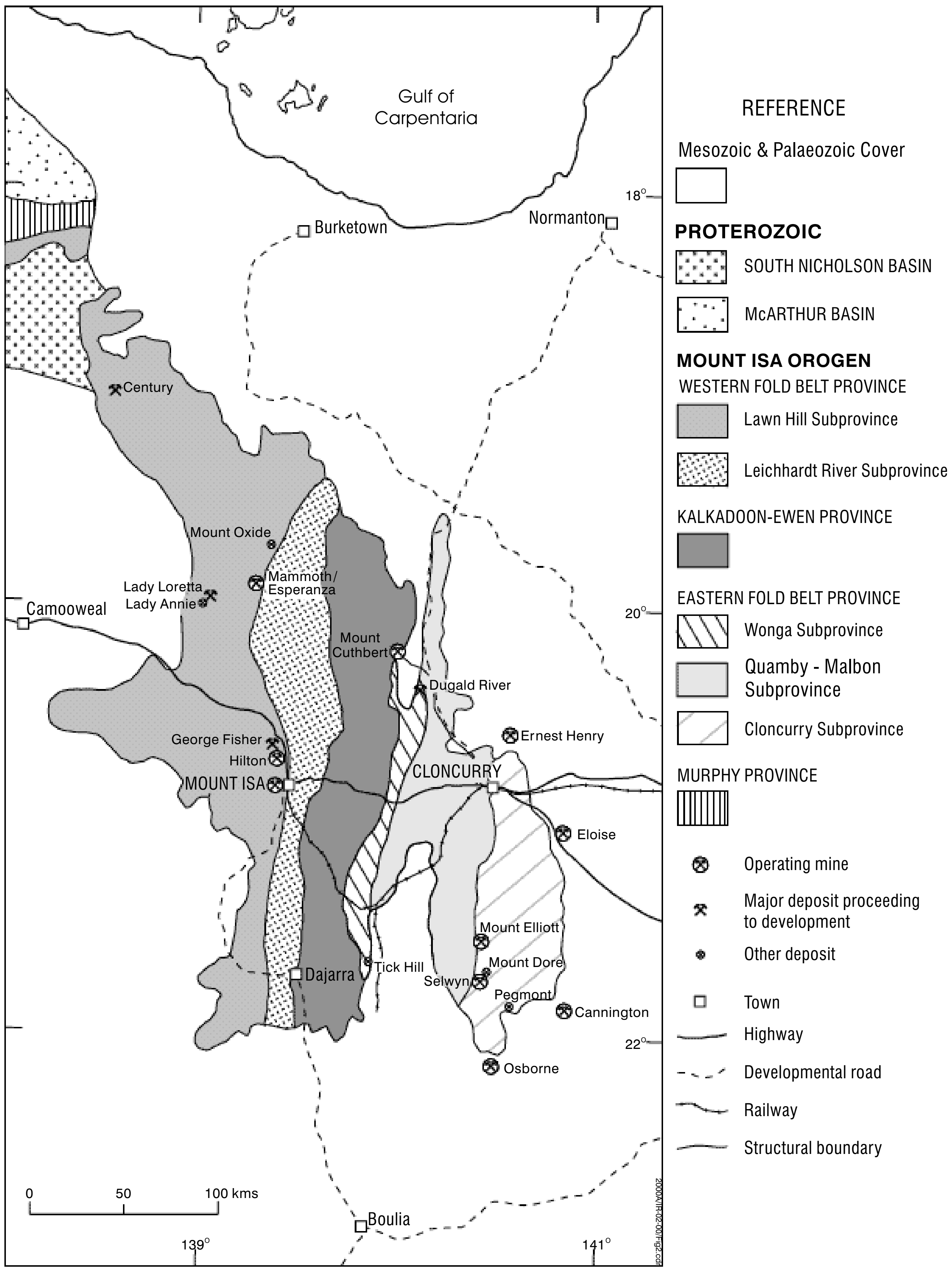


Figure 2. Geological framework of the Proterozoic shield in north-west Queensland

22.5g/t and forms a unique but poorly understood deposit style.

Murphy Province

The Murphy Province is an east-trending basement high that separates the McArthur Basin to the north from the Mount Isa Orogen to the south (Figure 1). It straddles the Queensland-Northern Territory border some 300km north-west of Mount Isa. A detailed description of the geology of the Province was given in Ahmad & Wygralak (1990) and is summarised below.

The Murphy Province is made up of the Palaeoproterozoic Murphy Metamorphics and the comagmatic Cliffdale Volcanics and Nicholson Granite Complex. The Murphy Metamorphics consist of shale, siltstone, sandstone and felsic volcanic rocks converted to schist and gneiss by greenschist facies metamorphism. These rocks are isoclinally folded along east-west axes and are unconformably overlain by the Cliffdale Volcanics. Their upper age limit is constrained by the older phases of the Nicholson Granite Complex at 1820±103Ma. The lower part of the Cliffdale Volcanics is dominated by ignimbrite whilst the upper part consists essentially of flow-banded alkali rhyolite and minor tuff dated at 1730±20Ma. The Nicholson Granite Complex intrudes both the Murphy Metamorphics and Cliffdale Volcanics and consists of granodiorite and granite.

The Murphy Inlier contains minor to moderate copper, uranium and tin-tungsten mineralisation.

McArthur Basin

Rocks of the McArthur Basin unconformably overlie the Murphy Province along its northern margin, crossing the Queensland-Northern Territory border (Figure 1). The basin fill consists essentially of sedimentary and volcanic rocks (Tawallah Group) unconformably overlain by sandstone and minor conglomerate (McArthur Group) (Ahmad & Wygralak, 1990). Age constraints on the McArthur Basin include dates of approximnately 1725Ma from volcanic rocks in the upper Tawallah Group and 1740Ma for tuffaceous units within the McArthur Group (Page & Sweet, 1998).

Within Queensland the McArthur Basin hosts only small U, Au and Cu deposits. However, in the Northern Territory, it also hosts the major stratiform McArthur River (HYC) lead-zinc-silver deposit.

South Nicholson Basin

The South Nicholson Basin unconformably overlies rocks of the Lawn Hill Subprovince of the Western Fold Belt Province, across the Queensland-Northern Territory border (Figure 1). The basin fill consists predominantly of sandstone, siltstone and shale of the South Nicholson Group. The only significant mineralisation recorded within the rocks of the basin is sedimentary ironstone in the Constance Range area (Harms, 1965) where oolitic hematite, siderite and chamosite beds occur within the Train Range Ironstone Member.

NORTH QUEENSLAND

Etheridge Province

The Etheridge Province crops out over a significant proportion of north Queensland extending from Woolgar in the south to Lockhart River in the north (Figure 1). The Province is divided into the Forsayth and Yambo Subprovinces. The geology of the Etheridge Province was outlined by Withnall & others (*in* Bain & Draper, 1997, pages 449-454) with details on the Forsayth Subprovince given in Withnall & others (*in* Bain & Draper, 1997, Chapter 3) and Yambo Subprovince in Blewett & Knutson (*in* Bain & Draper, 1997, pages 18-122).

Rocks of the Forsayth Subprovince crop out in the Georgetown area and constitute a metasedimentary sequence deposited in an intracratonic rift setting between 1700Ma and at least 1650Ma. A major metamorphic and deformational event at about 1550Ma was accompanied by S-type granite emplacement. Two major Proterozoic folding events have affected the rocks of the Forsayth Subprovince with the second corresponding to the peak of metamorphism at about 1550-1555Ma. At least four additional episodes of folding have been recognised.

Rocks of the Yambo Subprovince crop out in the northern part of the Etheridge Province within the Yambo Inlier and eastern Coen Inlier. They consist of high-grade metasedimentary and meta-igneous rocks that were probably deposited after 1640Ma and locally metamorphosed to granulite facies. Dating has indicated major I and S type granite emplacement at about 1580Ma and metamorphism at about 1575Ma. Six regional deformation events have been recognised, but these do not appear to correlate directly to those recognised within the Forsayth Subprovince.

A belt of metamorphic rocks in the extreme east of the Georgetown Orogen (west of the Broken River Province) consists of mica schist and mafic/ultramafic complexes. These have an uncertain relationship with rocks of the Etheridge Province but have been tentatively included within it. The ultramafic complexes are associated with lateritic nickel deposits such as the Greenvale deposit.

Rocks of the Forsayth Subprovince host important gold mineralisation which includes the Etheridge Goldfield (historic production of >19 500 kg Au bullion and an additional ~3 400 kg fine Au and ~5 500 kg Ag). This mineralisation, however, is thought to be genetically related to Siluro-Devonian and Permo-Carboniferous intrusives of the Pama and Kennedy Provinces (Bain, 1985). Small massive stratabound concentrations of iron and base metal sulphides are known from the base of the Etheridge Group within the Forsayth Subprovince. Denaro & others (1997) published a resource assessment of the Georgetown-Croydon area and this provides a useful overview of the mineralisation within the Forsayth Subprovince. The Yambo Subprovince has no significant defined mineral resources.

Savannah Province

The Savannah Province is an elongate north-south trending belt of metasediments and lesser metadolerite and amphibolite cropping out in the Coen Inlier in Cape York Peninsula (Figure 1). The geology of the Savannah Province was summarised by Blewett (*in* Bain & Draper, 1997, pages 454-455) with details of the constituent units described in Blewett & others (*in* Bain & Draper, 1997, Chapter 4).

The Savannah Province consists primarily of greenschist to upper amphibolite facies metasediments intruded by metadolerite and amphibolite. The metasediments are mainly slate, phyllite, schist and gneiss interbedded with massive quartzite and are thought to have been deposited between 1585Ma and 1550Ma in a shallow water environment within an intracontinental setting. Six penetrative regional deformation events have been recognised with the climax event associated with a prograde low-P high-T metamorphism and largely S-type magmatism at 407Ma.

Rocks of the Savannah Province host small gold-quartz vein deposits thought to be related to late Palaeozoic I-type magmatism. Small stratiform/stratabound massive and disseminated sulphide mineralisation is also recorded.

Croydon Province

A Mesoproterozoic sequence of S-type volcanic rocks and related granites in the Croydon area in the western part of the Georgetown Inlier is assigned to the Croydon Province (Figure 1). The overall geology of the Croydon Province was outlined by Mackenzie (*in* Bain & Draper, 1997, pages 455-458) and the component units described by Withnall & others (*in* Bain & Draper, 1997, Chapter 3). Denaro & others (1997) provide an overview of the mineralisation.

Exposed rocks of the Croydon Province are the rhyolitic to dacitic ignimbrite, rhyolite and rare andesite of the Croydon Volcanic Group, granites of the Esmeralda Supersuite and shallow-water quartzose, mainly arenaceous sedimentary rocks of the Inorunie Group which unconformably overlie the Croydon Volcanic Group. The Croydon Volcanic Group and Esmeralda Supersuite are contained within a cauldron subsidence structure and are thought to have been emplaced at about 1550Ma, probably at the close of the main deformation event in the Forsayth Subprovince.

Significant mesothermal gold deposits which form the Croydon Goldfield (historic production of ~60 000 kg Au bullion) are hosted by rocks of the Croydon Province. This mineralisation was regarded by Denaro & others (1997) as being related to Proterozoic volcanism, but dating of alteration suggests a Permo-Carboniferous age (Henderson, 1989).

NEOPROTEROZOIC-EARLY PALAEOZOIC

Several areas of Neoproterozoic – Early Palaeozoic rocks crop out in central and northern Queensland. These rocks are assigned to the Iron Range, Cape River, Barnard and Anakie Provinces and the Georgina Basin.

Iron Range Province

Rocks of the Iron Range Province are exposed over about 450km^2 in the northern part of the Coen Inlier in Cape York Peninsula (Figure 1). The overall geology of the Iron Range Province was outlined by Blewett (*in* Bain & Draper, 1997, pages 458-459) with the component units described by Blewett & others (*in* Bain & Draper, 1997, Chapter 4).

The Iron Range Province contains only one mapped unit, the Sefton Metamorphics, which are composed of a variety of rock types, including schist, quartzite, greenstone, limestone, marble and calc-silicate of predominantly sub-greenschist to greenschist facies. The age of the Iron Range Province is interpreted as younger than detrital zircons dated at about 1130Ma, the age of metamorphism being unknown. Little significant mineralisation is associated with these rocks.

Cape River Province

The Cape River Province forms several widely spaced outcrop areas, in the Charters Towers region, each given separate stratigraphic names (Cape River, Running River, Argentine and Charters Towers Metamorphics). The overall geology of the Cape River Province was outlined by Withnall & Hutton (*in* Bain & Draper, 1997, pages 459-462) and the geology of the component units described by Hutton & others (*in* Bain & Draper, 1997, Chapter 6).

All of the units within the Cape River Province consist predominantly of psammo-pelitic metamorphic rocks and subordinate mafic volcanic rocks and probably formed a single terrane before being dismembered by granite emplacement in the Palaeozoic and overlain by younger basin fill. Although the age of the rocks in the Cape River Province is uncertain, SHRIMP U-Pb zircon ages ranging from 469±12Ma to 493±10Ma from magmatic zircons in granites intruding Cape River Metamorphics provide a minimum Late Cambrian or early Ordovician age constraint. A maximum age is constrained by dates of 1145±21Ma for detrital zircons within the Caper River Metamorphics. The structure of the Cape River Province is poorly understood with the main fabric manifest as a spaced differentiated foliation interpreted as a second-generation fabric possibly correlatable with the main deformation in the Anakie Province, thought to be about 510Ma. Little significant mineralisation is genetically associated with the rocks of the Cape River Province although minor magnetite is recorded in banded iron formations.

Barnard Province

Rocks of the Barnard Province crop out along the coast and on several islands in the Innisfail area in north Queensland (Figure 1). The overall geology of the Barnard Province is given in Bultitude & others (*in* Bain & Draper, 1997, pages 462-464 and Chapter 7) and Garrad & Bultitude (1999).

The Barnard Metamorphic Province is made up of the Barnard Metamorphics and Babalangee Amphibolite, which form a narrow north-trending belt east of the Russell -Mulgrave Shear Zone in north Queensland. Rock types consist predominantly of phyllite, meta-arenite, quartzite, 'greenstone', schist and gneiss. Metamorphic grades are mainly of greenschist facies but are locally up to hornblende granulite facies. The high grade zones are commonly spatially associated with areas of Ordovician granite which intrude the metamorphic rocks. Three main regional deformation events are recognised. The second generation fabric, consisting of an intense crenulation cleavage or schistosity, is the main foliation in most outcrops. The Ordovician granites contain a pervasive fabric correlated with the second generation foliation in the metamorphic rocks, thus implying a maximum age of late Ordovician for the second deformation. The metamorphic rocks of the Barnard Province are thought to be an uplifted basement assemblage on the south-eastern margin of the Hodgkinson Province, the presence of anomalously high grade rocks implying that the unit may consist of several discrete fault blocks. No significant mineral resources are known within the rocks of the Barnard Province.

Anakie Inlier

Rocks of the Anakie Inlier are made up predominantly of Neoproterozoic-early Palaeozoic metamorphic rocks, assigned to the Anakie Metamorphic Group of the Anakie Province (Figure 1). The geology of the Anakie Province was outlined by Withnall & others (1995).

The Anakie Metamorphic Group (Figure 3) includes mica schist, quartzite, meta-arenite and greenstones. Three major deformations and subsequent minor folding events have affected the metamorphic rocks. The first deformation produced a strong foliation parallel to relict bedding that is best preserved in the quartzite units where it is observed deformed by tight asymmetric second generation folds. Within the metapelites the first generation fabric is strongly overprinted by the second-generation layer differentiated crenulation cleavage that is axial planar to tight second-generation folds. The third deformation produced north-east trending upright folds, which are overprinted by later more open east trending regional folds and some south-east trending folds. Metamorphism accompanied the first and second deformations and ranged from greenschist to amphibolite facies and was of the low pressure-high temperature type. The depositional age of the Anakie Metamorphic Group is uncertain although K-Ar age dating suggests that the rocks were deformed and metamorphosed at around 510Ma (Withnall & others, 1996).

The only significant resource within the Anakie Province is that of the Peak Downs deposit in which copper is associated with ironstone, muscovite-quartz schist and chlorite-quartz schist.

Ordovician sedimentary rocks outcropping along the south-eastern margin of the Anakie Inlier are assigned to the Fork Lagoons Province (Figure 1 and Figure 3). The contact of rocks of the **Fork Lagoons Province** with the Anakie Metamorphic Group to the north-west is a steeply dipping thrust zone. The geology of the Fork Lagoon Province (beds) was described by Withnall & others, 1995.

The metamorphic rocks of the Anakie Province are intruded by intrusives of the **Retreat Batholith** which is a large composite assemblage of Middle-Late Devonian mainly I-type granitoids (Figure 3). Rock types range in composition from diorite through monzodiorite and granodiorite to granite. Rb-Sr ages are in the range 366Ma to 385Ma. The geology of the Retreat Batholith was described in detail in Withnall & others (1995).

Volcanic rocks consisting predominantly of mafic lavas and lesser volcaniclastics unconformably overlying the Anakie Metamorphic Group south-west of Clermont are assigned to the Theresa Creek Volcanics (Figure 3). They are unconformably overlain by the Silver Hills Volcanics (basal sequence of the Drummond Basin). Geochemical studies of the Theresa Creek Volcanics and Retreat Batholith indicate that they are genetically related.

No significant mineral resources are associated with the Retreat Batholith or Theresa Creek Volcanics.

Georgina Basin

The Georgina Basin is a large intracratonic basin lying across the Queensland/Northern Territory border in north-west Queensland flanking the western and south western margins of the Mount Isa Inlier. It occupies an area of approximately 325 000km^2 of which about 90 000km^2 are in Queensland (Figure 1). The geology of the Georgina Basin was outlined by Smith (1972) and Shergold & Druce (1980).

The basin fill consists mainly of Cambrian to Middle Ordovician marine sedimentary rocks with the Cambrian and Early Ordovician rocks essentially marine carbonate rocks with minor sandstone and siltstone and the Middle Ordovician rocks dominated by siltstone and sandstone. Silurian(?) to Devonian freshwater sandstone and Permian boulder beds overlie the early Palaeozoic Georgina Basin succession and are thought to represent younger successions laid down in superimposed basins (Allen, 1975). The basin was deformed by minor to moderate folding and faulting throughout with moderate to strong folding, faulting and overthrusting along the southern margin.

Phosphatic marine sediment (phosphorite) occurs in the Middle Cambrian and Middle Ordovician rocks of the basin. The Middle Cambrian rocks host significant phosphate resources that include the Phosphate Hill deposit.

TASMAN OROGENIC ZONE

Rocks of the Tasman Orogenic Zone crop out throughout eastern Australia, from the islands of Torres Strait south to Tasmania. Within Queensland the zone can be subdivided into the Northern Tasman and Northern New England Orogenic Zones. The Northern Tasman Orogenic Zone consists predominantly of fairly deep-marine early Palaeozoic quartz-rich sandstone and mudstone intercalated with submarine mafic and felsic volcanic rocks. The Northern New England Orogen consists of middle Palaeozoic to early Mesozoic marine to continental sedimentary and volcanic rocks. Details on the subdivision of the Tasman Orogenic Zone were given by Day & others (1978) and the tectonic development and metallogeny of the zone was outlined by Murray (1986).

The tectonic history of the Tasman Orogenic Zone can be summarised as early Palaeozoic generally deep marine turbiditic sedimentation with juxtaposition of diverse facies, local mostly submarine volcanic belts and local deformation, magmatism and metamorphism. This was followed in the mid-Silurian to Late Devonian by deformation and progressive termination of the deep-marine conditions, magmatism, crustal thickening and extensional collapse and a major accretionary phase which culminated in the mid-Carboniferous although the convergent plate boundary continued migrating eastwards into the early Mesozoic (Coney & others, 1990). Numerous distinct geological provinces have been assigned for the rocks of the Tasman Orogenic Zone. Those within Queensland are summarised below.

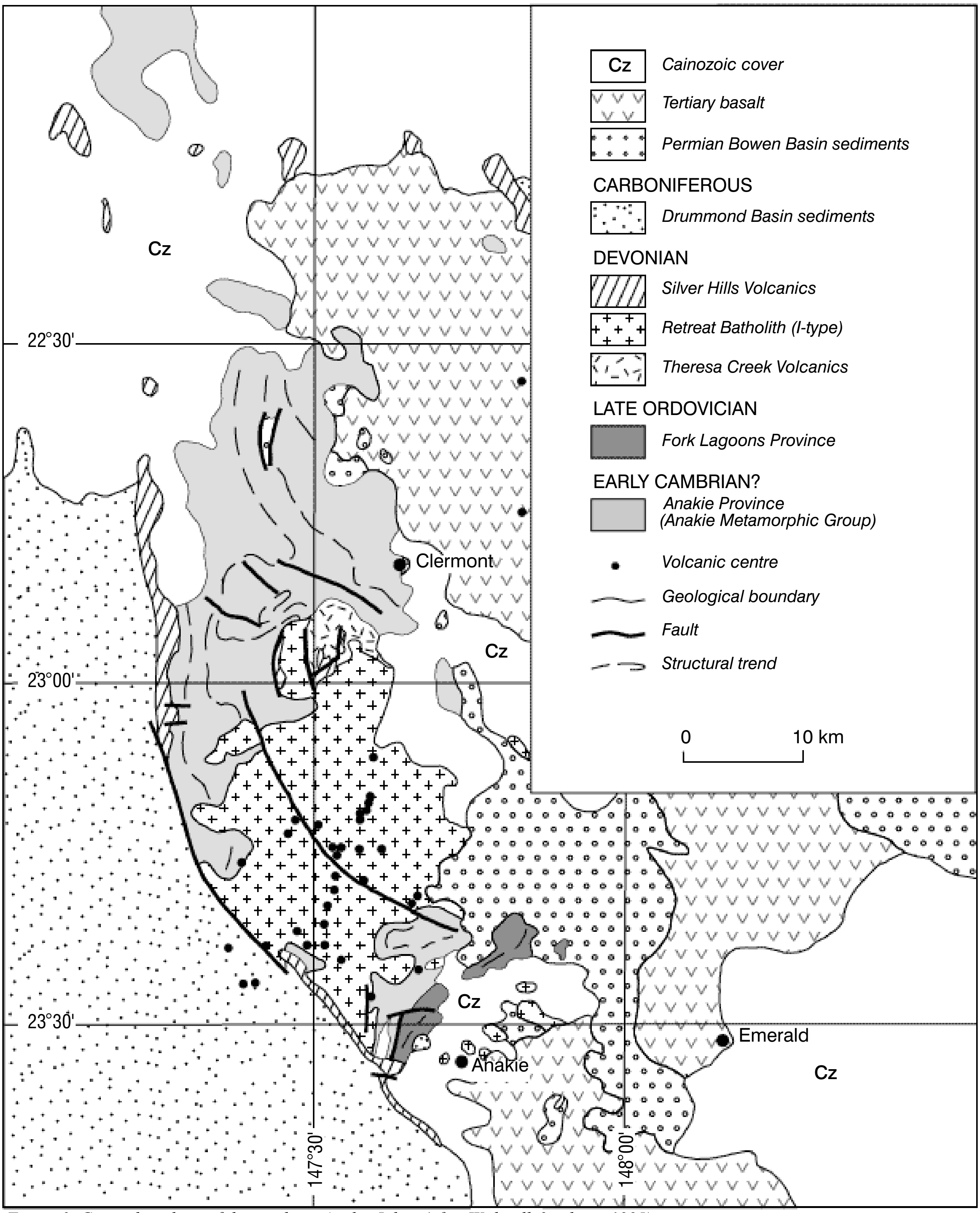


Figure 3. General geology of the southern Anakie Inlier (after Withnall & others, 1995)

NORTHERN TASMAN OROGENIC ZONE

Rocks of the Northern Tasman Orogenic Zone outcrop in north Queensland and have been subdivided into a number of geological provinces based on age and geological setting (Thalanga, Hodgkinson and Broken River provinces). In addition to these a number of interregional igneous and volcanic provinces have also been defined (Macrossan, Pama and Kennedy provinces).

Thalanga Province

The geology of the Thalanga Province was outlined by Hutton & Withnall (*in* Bain & Draper, 1997, pages 469-471) and the geology of its component units was summarised in Hutton & others (1997).

The Thalanga Province includes two belts of Late Cambrian to early Ordovician volcanic rocks and volcanogenic sediments (Figure 1). The main belt is south of the Ravenswood Batholith in the Charters Towers area and consists of deep water sedimentary rocks and subaqueous felsic and mafic to intermediate volcanic rocks assigned to the Seventy Mile Range Group. These rocks have been metamorphosed to mainly sub-greenschist to greenschist facies. The other occurs in the eastern part of the Georgetown Inlier and consists of marine or possibly subaerial rhyolitic metavolcanics, metasediments and minor mafic volcaniclastics and lava assigned to the Balcooma Metavolcanics, and leucogneiss, quartzite, amphibolite, phyllite, andesitic meta-volcanics, and minor marble assigned to the Lucky Creek Metamorphic Group. The Balcooma Metavolcanics were metamorphosed to lower to middle amphibolite facies and the Lucky Creek Metamorphic Group to upper greenschist to lower amphibolite facies. Three major deformations are recognised within the Seventy Mile Range Group whilst the Balcooma Metavolcanics preserve a steep non-domainal schistosity thought to be a first generation fabric. The Lucky Creek Metamorphic Group contains a relatively pervasive shallowly dipping mylonitic foliation.

The Balcooma Metavolcanics and Seventy Mile Range Group host significant volcanic-hosted massive sulphide (VHMS) resources including the Balcooma, Highway-Reward and Thalanga deposits.

Hodgkinson Province

The Hodgkinson Province consists of early to middle Palaeozoic turbiditic sedimentary rocks with subordinate limestone, chert and basic volcanic rocks extending for ~500km from south of Innisfail to Cape Melville and inland for ~150km from the coast to the Palmerville Fault (Figure 1). Detailed descriptions of the geology of the Hodgkinson Province were given by Bultitude & others (*in* Bain & Draper, 1997, pages 225–326, 471–476) and Garrad & Bultitude (1999).

The dominant rock types are quartzo-feldspathic arenite and mudstone, which represent deep-water density current deposits interlayered with subordinate conglomerate, chert, metabasalt and minor shallow-water limestone. Older siliciclastic rocks of probable early Ordovician age are preserved in fault bounded lenses adjacent to the Palmerville Fault along the western margin of the province. Within the Hodgkinson Province the rocks form distinct mainly fault bounded belts each of which is disrupted extensively by numerous thrust faults. The province has undergone generally sub-greenschist facies metamorphism with localised higher grade zones associated with contact aureoles around late Palaeozoic intrusives. The Hodgkinson Province has been affected by several significant deformational events of both regional and local extent.

The tectonic setting for the Hodgkinson Province remains controversial. Some previous workers (eg. Henderson, 1980) have interpreted the Hodgkinson Province succession to have accumulated in a fore-arc-accretionary prism setting located to the east of an active continental magmatic arc. Recent work by the Queensland Geological Survey Office, however, favours an extensional rather than compressional regime with a possible rifted continental margin or back-arc basin setting (e.g. Garrad & Bultitude, 1999).

Rocks of the Hodgkinson Province (Hodgkinson Formation) host significant mesothermal quartz vein-hosted gold mineralisation, which includes the Hodgkinson/Palmer goldfields. A detailed study of the Hodgkinson Goldfield is given in Peters (1987). This mineralisation is thought to have formed from metamorphic fluids produced during the devolatilisation of the sedimentary pile (slate-belt style) with the distribution of fluids controlled by major shear zones (Phillips & Powell, 1992). Quartz-stibnite veins locally crosscut these gold-only veins and are thought to be sourced from separate fluids with separate flow paths, although a metamorphic source is still envisaged (Garrad & Bultitude, 1999). The Hodgkinson Province locally hosts significant skarn mineralisation such as that at Red Dome where Permian-Carboniferous intrusives of the Kennedy Province intrude carbonate-rich rocks of the Chillagoe Formation. The Chillagoe Formation is also host to significant limestone resources.

Broken River Province

The Broken River Province consists of Ordovician to Devonian marine sedimentary rocks with subordinate, mainly mafic volcanic rocks and Late Devonian to Early Carboniferous fluviatile and minor shallow marine sedimentary rocks. These crop out over an area of approximately 7000km^2 in the Clarke River area (Figure 1). The geology of the Broken River Province is given by Withnall & Lang (1993), Withnall (*in* Bain & Draper, 1997, pages 476-479) and Withnall & others (*in* Bain & Draper, 1997, Chapter 8).

The Province has been divided into the Camel Creek Subprovince and Graveyard Creek Subprovince, which are separated by the Gray Creek Fault (Arnold & Henderson, 1976).

The Camel Creek Subprovince is more complexly deformed than the Graveyard Creek Subprovince and consists predominantly of alternating, fault-bounded packages of Ordovician to Early Devonian quartz-rich and quartz-intermediate turbidites, tholeiitic basalt and calc-alkaline lavas and volcaniclastic rocks. It is overlain by the Late Devonian to Carboniferous Clarke River Basin which contains continental sedimentary rocks and subordinate felsic volcanic rocks.

In the Graveyard Creek Subprovince a basal unit of tholeiitic basalt, quartz keratophyre and quartz-rich turbidites is overlain unconformably by Silurian to Middle Devonian shallow marine conglomerate, feldspathic and lithofeldspathic sandstone, volcaniclastics, mudstones and limestone. In the Late Devonian a pull-apart basin (Bundock Basin) developed in the south-west of the subprovince and received a thick sequence of fluviatile and some shallow marine sedimentary rocks.

The Broken River Province hosts significant limestone resources. In addition podiform chromite resources (eg. Gray Creek South) as well as lateritic nickel/cobalt resources (eg. Lucknow) are hosted by the Graveyard Creek Subprovince. Small slate-belt style gold occurrences have also been recognised.

Macrossan Province

Ordovician plutonic rocks in North Queensland are assigned to the Macrossan Province (Hutton & others, *in* Bain & Draper, 1997, pages 479–482). They are principally found as I-type granites and mafic intrusives in the Ravenswood Batholith, in the Charters Towers area, and as S-type and hornblende-bearing granites of the Fat Hen Complex adjacent to the Lolworth Batholith

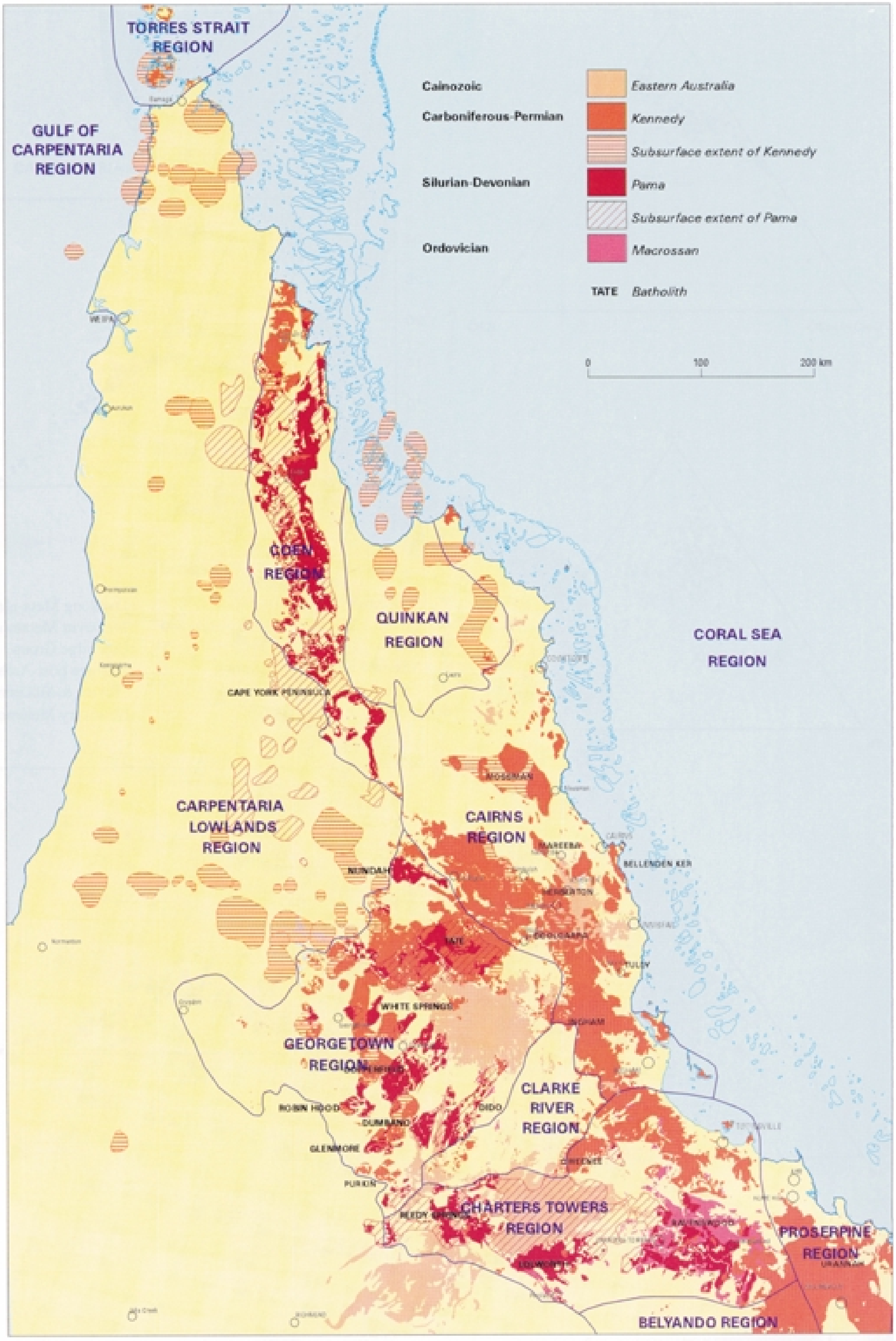


Figure 4. Interregional Igneous Provinces of North Queensland (after Bain & Draper, 1997)

(Figure 4). A small area of Ordovician S-type granites also intrudes rocks of the Barnard Province along the coastline near Innisfail.

No significant mineralisation is attributed to rocks of the Macrossan Province, although Ordovician granites in the Charters Towers area do host significant gold mineralisation thought to be associated with Devonian intrusive activity of the Pama Province.

Pama Province

Silurian-Devonian granitic rocks in North Queensland are assigned to the Pama Province (Hutton & others, *in* Bain & Draper, 1997, pages 482–488). It extends as a discontinuous belt from the Coen Region in Cape York, southwards to the Georgetown and Charters Towers regions (Figure 4). Pama Province rocks make up a large proportion of the Cape York Peninsula Batholith in Cape York, the Nundah, Tate, Robin Hood, Copperfield, White Springs, Glenmore, Dumbano and Dido Batholiths in the Georgetown region and the Ravenswood, Lolworth and Reedy Springs Batholiths in the Charters Towers region. The Pama Province rocks of Cape York comprise mostly S-type granite and leucogranite and some I-type granodiorite, whereas in the Georgetown and Charters Towers regions they are mostly I-type granitic rocks.

Alteration associated with mesothermal quartz-gold-base metal sulphide vein deposits of the Etheridge Goldfield has given Silurian-Devonian isotopic ages (Bain & others, 1998). It is thought that these deposits are genetically linked to fluid circulation systems associated with emplacement of the Silurian-Devonian granites in the area. Dating of alteration associated with mesothermal quartz vein mineralisation in the Charters Towers area also indicates a Devonian age (Carr & others, 1988; Morrison, 1988). This mineralisation may be related to igneous activity associated with the Pama Province although a metamorphic origin has also been postulated (Hutton & others, 1994).

Kennedy Province

Early Carboniferous to Early Permian igneous rocks extending throughout north Queensland are assigned to the Kennedy Province (Mackenzie & Wellman, *in* Bain & Draper, 1997, pages 488-500). It extends from south of Bowen north-west through Cape York Peninsula and across Torres Strait (Figure 4). Most of these igneous rocks are concentrated in two belts, the Townsville-Mornington Island Belt and the Badu-Weymouth Belt. The Townsville-Mornington Island Belt extends parallel to the coast from near Home Hill, south-east of Townsville to the Atherton area and then west to the limit of pre-Mesozoic exposure north of Georgetown. The Badu-Weymouth Belt extends from the Mount Carter-Cape Weymouth are in eastern Cape York Peninsula to Badu Island in southern Torres Strait and into Papua New Guinea. The Kennedy Province has been subdivided into several subprovinces, the boundaries of which largely reflect the underlying/enclosing basement provinces as outlined in Table 1.

Rocks of the Kennedy Province are largely I-type intrusives and extrusives occurring in both major batholiths and volcanic ‘fields’. A-type extrusives occur mainly in the Herberton Subprovince whilst A-type intrusives occur largely within the Kidston Subprovince. S-type intrusives occur within the Daintree Subprovince. The rocks commonly occur in large cauldron subsidence structures and are interpreted to have formed as the result of crustal melting in an extensional (or transtensional), possibly back-arc, tectonic environment.

Rocks of the Kennedy Province have been responsible for a diverse group of mineral deposit styles throughout north Queensland. These include porphyry-related breccia gold deposits (of which Kidston and Mt Leyshon are examples), vein and greisen type tin deposits (including those of the Herberton and Cooktown tinfields) and skarn deposits such as Red Dome.

NORTHERN NEW ENGLAND OROGEN

Within Queensland the Northern New England Orogen forms the eastern part of the Tasman Orogenic Zone and is subdivided into a number of geological provinces.

Table 1. Subprovinces of the Kennedy Province (after Mackenzie & Wellman, 1997)

Igneous Subprovince	Corresponding Basement Province
Jardine	Northern Savannah Province; Iron Range Province
Lakefield (concealed)	Lakefield Basin
Daintree	Hodgkinson Province (northern)
Herberton	Hodgkinson Province (southern)
Tate	(Northeastern Forsayth Subprovince), Etheridge Province
Kidston	(Main part of Forsayth Subprovince), Etheridge Province
Kangaroo Hills	Broken River Province
Paluma	Cape River Province; Thalanga Province
Connors	Drummond Basin; northern New England Province

Silverwood Province and older blocks within the Yarrol Province

The oldest tectonostratigraphic sequences of the northern New England Orogen range in age from mid-Ordovician to Middle Devonian. They occur in the **Silverwood Province** (van Noord, 1999), and in inliers and structural blocks within the **Yarrol Province** (the Stanage, Craigilee, Calliope and Philpott Blocks of Day & others, 1983), and comprise volcaniclastic sediments, coralline limestone lenses, and some primary volcanic rocks. Their submarine environment of deposition, the lack of quartz in sedimentary units, and the geochemistry of volcanic and related intrusive rocks support an island arc origin. Day & others (1978, 1983) interpreted all the component blocks in this linear belt as part of a single arc, the Calliope Volcanic Arc. However, the recent recognition that individual structural blocks contain lithologically distinct but coeval sequences suggests that they may not have been directly related, but in fact represent a number of separate exotic terranes (Yarrol Project Team, 1997; Simpson & others, 1998).

By far the most important metalliferous deposit within this Ordovician to Middle Devonian island arc assemblage is the world class Mount Morgan gold-copper deposit. It occurs within a belt of Middle Devonian volcanic and sedimentary rocks forming a roof pendant in a Late Devonian tonalite intrusion. Two main theories have been proposed for the genesis of the Mount Morgan mineralisation. The mineralisation has been proposed as a Devonian volcanogenic massive sulphide pipe deposit (eg. Taube, 1986) and as a structurally controlled Devonian replacement body related to the Mount Morgan Tonalite (eg. Arnold & Sillitoe, 1989). Recent work, however, indicates it forms an end member of the volcanic-hosted massive sulphide type (Messenger & others, 1997). These rocks also contain substantial resources of high grade limestone.

Wandilla, Texas, Yarrol and Connors-Auburn Provinces and Gogango Overfolded Zone

The basic tectonostratigraphic framework of the New England Orogen was established as a Late Devonian-Carboniferous convergent continental plate margin above a west-dipping subduction zone (Day & others, 1978). Three parallel belts representing accretionary wedge (east), fore-arc basin (centre), and continental margin magmatic arc (west) have been described.

Rocks of the accretionary wedge form the **Wandilla** and **Texas Provinces**. They consist of a stack of deep water sedimentary and volcanic rocks which in general are steeply dipping, structurally complex, and sparsely fossiliferous (Fergusson & others, 1993). In the Wandilla Province, a gross regional stratigraphy is preserved, with a western (oldest) assemblage characterised by radiolarian jasper and chert, a central belt of volcaniclastic greywacke and argillite, and an enigmatic eastern (youngest) sequence of quartzose sandstone and argillite. Limited age control is provided by radiolarians and conodonts from chert, conodonts from sparse limestone lenses, and by the occurrence in the central belt of a persistent horizon of greywacke beds containing ooliths which must have been sourced from Lower Carboniferous limestones of the fore-arc basin to the west. The accretionary wedge assemblage in the Texas Province has been folded into a large scale orocline (Murray & others, 1987), and contains numerous allochthonous lenses of Lower Carboniferous coralline limestone (Flood, 1999). Overall, the accretionary wedge is sparsely mineralised, but it does contain some slate belt type gold bearing veins and stockworks (Warwick area and at Kingston south of Brisbane), and small high grade manganese deposits.

The accretionary wedge is separated from the fore-arc basin sequence to the west by a major fault, the Yarrol Fault System, marked by serpentinite lenses. In the Marlborough area, these ultramafic rocks form an extensive flat-lying thrust sheet of early Palaeozoic ocean floor and upper mantle material. Significant lateritic nickel-cobalt deposits have been developed on the ultramafics during a Cenozoic deep weathering event.

The **Yarrol Province** consists mainly of a fore-arc basin sequence of Late Devonian to Carboniferous age. The basin fill mainly comprises volcaniclastic sedimentary rocks deposited on a marine shelf that shallowed to the west and became progressively more emergent with time. The Lower Carboniferous part of the sequence is characterised by the widespread development of oolitic limestone beds. The fore-arc basin succession overlies the Middle Devonian and older rocks unconformably (Kirkegaard & others, 1970; Leitch & others, 1992). They are only sparsely mineralised except in the vicinity of later intrusives.

The **Connors-Auburn Province** was interpreted as the Late Devonian to Carboniferous magmatic arc (Day & others, 1978). However, recent re-mapping and dating demonstrate that the most extensive plutonic and volcanic rocks are of Late Carboniferous and Early Permian age (Holcombe & others, 1997; Hutton & others, 1999; Allen & others, 1998). It now appears that these felsic rocks, if they are associated with the arc at all, represent only the final products of subduction-related magmatism. No representatives of the Late Devonian arc are present, and this appears to have been located in the western part of what was previously regarded as the fore-arc basin sequence (Blake & others, 1998). If so, the Late Devonian arc was not a typical continental margin arc, because much of the Upper Devonian sequence containing primary volcanic rocks is marine. The upper age limit of the Late Devonian-Carboniferous convergent margin tectonism is uncertain, but it appears to have persisted through much of the Carboniferous. Surprisingly little mineralisation is associated with this western belt of magmatic rocks.

Lower Permian strata that overlie the Upper Devonian-Carboniferous fore-arc basin and accretionary wedge sequences have recently been interpreted as the fill of a series of extensional basins which developed at the same time as the Bowen Basin to the west. This interpretation is consistent with the fact that many of the Permian outcrops overlie Lower Carboniferous or older rocks, implying removal or non-deposition of a substantial part of the stratigraphic section. Opposed to this concept of extensional basin formation at the beginning of the Permian is the existence of continuous and uniform Carboniferous - Permian marine sequences in some areas and the calculation of tectonic subsidence rates for the Lower Permian sequences. These calculations provide little if any evidence for significant crustal thinning caused by pull-apart or rift histories. Some Lower Permian rocks are prospective for volcanic hosted massive sulphide (VHMS) style mineralisation. The Mount Chalmers gold-copper deposit is a classic Kuroko-type deposit, and the nearby Develin Creek prospect and the Silver Spur silver-lead deposit in the Texas area are also considered to represent VHMS mineralisation. Lower Permian volcanic rocks along the western side of the Connors-Auburn Province, related to the extensional event that formed the Bowen Basin, host the Cracow epithermal gold deposit.

The Late Permian Hunter-Bowen Orogeny deformed the rocks of the New England Orogen, producing WNW directed thrusting and associated folding.

The **Gogango Overfolded Zone** is a belt of strongly cleaved sandstone, mudstone, and deformed mafic to felsic volcanic rocks that separates the Connors-Auburn Province into northern and southern sections. Stratigraphic, sedimentological and structural studies (Fergusson, 1991; Fergusson & others, 1994; Fielding & others, 1994) have led to the conclusion that the Gogango Overfolded Zone is simply a part of the Bowen Basin that was more intensely deformed by thrusting during the Hunter-Bowen Orogeny.

Gympie Province

The geology of the Gympie Province was outlined by Cranfield & others (1997)and Cranfield (1999).

The province comprises Early Permian to Early Triassic arc-related mafic to felsic volcanic, volcaniclastic and marine sedimentary rocks in a north-north westerly trending belt extending from Nambour to west of Bundaberg in southern Queensland.

The rocks have long been considered to represent a unique stratotectonic unit, which does not fit into the overall palaeogeographic pattern of the Tasman Orogenic Zone (Day & others, 1978). It has therefore been proposed as an exotic terrane which collided with the continent in the Triassic (eg. Harrington, 1983; Cawood, 1984; Waterhouse & Sivell, 1987).

Mineralisation of the Gympie Province is dominated by gold associated with the emplacement of Early to Middle Triassic and Late Triassic plutonic and volcanic rocks of the South East Queensland Volcanic and Plutonic Province. The most significant mineralisation is within the Gympie Goldfield (historic production in excess of 108 000 kg fine Au) in which structurally controlled mesothermal low-sulphide quartz reefs, are thought to be associated with Early Triassic diorite and the north-west trending Inglewood Structure. Although the fluid source is thought to be primarily related to diorite intrusives the composition of the host rocks, in particular the presence of carbonaceous shales has played a significant role in concentrating the gold mineralisation within the quartz lodes (Kitch & Murphy, 1990).

South-East Queensland Volcanic and Plutonic Province

The South-East Queensland Volcanic and Plutonic Province is a grouping used for volcanic and plutonic rocks of Late Permian-Triassic age within south-east Queensland. Rock types consist mainly of I-type intrusives and comagmatic continental volcanic rocks. Intrusive compositions range from layered gabbro to granite with granodiorite the most common composition. Gust & others (1993) proposed that active subduction produced the voluminous Late Permian and Early Triassic plutonism, and was replaced by an extensional phase marked by bimodal and alkalic magmatism in the Late Triassic.

Early-middle Triassic intrusives of the South-East Queensland Volcanic and Plutonic Province are associated with gold mineralisation within the Gympie Province including that of the Gympie Goldfield. In addition porphyry-style mineralisation such as that at Coalstoun Lakes is associated with intrusions of the South-East Queensland Volcanic and Plutonic Province. Late Triassic skarn-related deposits include that of Mount Biggenden.

Intracratonic Basins

Palaeozoic-early Mesozoic sedimentary basins overlying the ‘basement’ rocks within the state are also assigned to the Tasman Orogenic Zone. These are listed in Table 2.

The Early Devonian to Early Carboniferous basins are largely unmineralised with the important exception of the Drummond Basin (Figure 1) which developed between the Late Devonian and early Carboniferous and contains a thick succession of continental sedimentary and volcanic rocks with sporadic marine beds near its base. Olgers (1972) subdivided the basin fill into three cycles. Cycle 1 comprises the volcanic and sedimentary rock at the base of the basin, which are unconformably overlain by a sequence of quartzose and feldspathic, dominantly fluvial sedimentary rocks (Cycle 2). Cycle 3 records a return to volcanic and volcanolithic-rich sedimentary rocks. The basin hosts significant epithermal gold mineralisation such as the Pajingo Vera Nancy deposit within early Carboniferous volcanic rocks currently thought to be part of the Cycle 1 group of rocks.

The Gilberton Basin type sedimentary rocks are known to host stratabound fluorite-uranium-molybdenum mineralisation such as the Maureen deposit where mineralisation is apparently confined to relatively coarse, fluviatile arkosic sediments of the Gilberton Formation. Mineralisation, however, is thought to be genetically related to igneous activity of the Kennedy Province, although strongly controlled by sedimentary and diagenetic features (O’Rourke, 1975). Limestone resources are known from the Burdekin Basin and oil shale occurs within the Galilee Basin.

The Late Carboniferous to Triassic Basins are also poorly mineralised with the exception of the Permian Miclere Basin, in which the basal conglomeritic unit hosts the Miclere gold deposit. Basins such as Ipswich, Tarong, Callide and Bowen, however, contain significant coal resources.

GREAT AUSTRALIAN BASIN

Rocks of the Great Australian Basin occur predominantly in western Queensland with several isolated basins in the east (Figure 1). The Great Artesian Basin includes the Eromanga, Carpentaria, Surat, Laura, Mulgildie, Nambour, Maryborough and Clarence-Moreton Basins.

The Mesozoic dominantly continental sediments of the Great Australian Basin were deposited in huge sags in the early Mesozoic surface of Queensland. Deformation is characteristically mild and the structural trends are generally inherited from the older basement rocks.

On the whole the Great Australian Basin is poorly mineralised. However, the basin hosts significant hydrocarbon and artesian water resources, and significant oil shale and vanadium resources occur with the Toolebuc Formation of the Eromanga Basin.

CAINOZOIC VOLCANICS, SEDIMENTS AND WEATHERING

During the Cainozoic tectonism was generally mild with western areas experiencing rejuvenation of existing fault and fold structures and a continuation of crustal sagging over the sites of older basins forming features such as the Karumba Basin in the states north-west. Tectonic activity was more pronounced in eastern regions where epeirogenic uplift, block faulting and extensive basaltic eruptions occurred. Onshore numerous, narrow fault controlled basins were formed, including the significant oil shale deposits within the Nagoorin, Narrows and

Table 2. Intracratonic Basins of the Tasman Orogenic Zone

Age	Northern Queensland	Central Queensland	Western Queensland	Southern Queensland
Late Carboniferous to Triassic	Ngarrabullan; Olive River	Bowen; Callide; Galilee; Miclere	Cooper	Ipswich; Tarong
Early Devonian to Early Carboniferous	Bundock; Burdekin; Clarke River; Gilberton; Pascoe River	Drummond	Adavale	

Table 3. Cainozoic Basins of Queensland

Northern Queensland	Central Queensland	Western Queensland	Southern Queensland
Karumba	Biloela; Casuarina; Duaringa; Herbert Creek; Hillsborough; Lowmead; Nagoorin; Narrows; Water Park; Yaamba;	Marion; Noranside; Old Cork; Springvale	Amberley; Booval; Elliott Oxley; Petrie; Pomona

Yaamba basins. Table 3 lists the Cainozoic basins of Queensland.

Predominantly basaltic volcanic rocks are irregularly distributed along the whole length of the continental margin of Queensland and assigned to the Eastern Australian Cainozoic Igneous Province.

Repeated deep-weathering within the Cainozoic produced significant bauxite and kaolin resources such as the Weipa deposit on Cape York and magnesite resources such as the Kunwarrara deposit near Rockhampton. In addition significant heavy mineral and silica sand resources are found within the dune systems located along the coast. Significant alluvial deposits of gold and tin occur within Cainozoic alluvium particularly in North Queensland and alluvial sapphires at Anakie are worked in the Central Queensland gemfields.

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