Relationships between New Zealand, Australian and New Caledonian mineralised terranes: a regional geological framework

N. Mortimer[1], I.J. Graham[2], C.J. Adams[3], A.J. Tulloch[4] and H.J. Campbell[5]

[1]*GNS Science, Private Bag 1930, Dunedin, Telephone 0064-3-479-9686,*
Email n.mortimer@gns.cri.nz
[2]*GNS Science, PO Box 31312, Lower Hutt, Telephone 0064-4-570-4677,*
Email i.graham@gns.cri.nz
[3]*GNS Science, PO Box 30368, Lower Hutt, Telephone 0064-4-570-4630,*
Email c.adams@gns.cri.nz
[4]*GNS Science, Private Bag 1930, Dunedin, Telephone 0064-3-479-9685,*
Email a.tulloch@gns.cri.nz
[5]*GNS Science, PO Box 30368, Lower Hutt, Telephone 0064-4-570-4649,*
Email h.campbell@gns.cri.nz

Abstract

New Zealand can be regarded as a rifted part of mineral-prospective eastern Australia. Geologically credible comparisons between selected trans-Tasman and SW Pacific geological provinces and units, especially those that contain significant mineralisation in Australia, can help provide a useful exploration framework for New Zealand. As part of a six-year Mineral Wealth of NZ and its EEZ (MWE) research programme, we have targeted selected geological units in eastern Australia for comparison and contrast with their potential New Zealand counterparts. In future years, the programme will focus on geological units in New Caledonia.

Keywords: *New Zealand, Australia, New Caledonia, EEZ, geology, tectonics, mineral deposits, prospectivity*

Introduction

The large distances, and disparate sizes, between the vast landmass of Australia and the small islands of New Zealand do not, at first glance, suggest that they have much in common geologically. Australia contains some of the oldest rocks on Earth and was a key part of the ancient supercontinents of Gondwanaland and Pangea. The numerous orogenic belts and intracratonic sedimentary basins, combined with relative tectonic quiescence in the past 100-200 Ma have resulted in a country in which minerals and coal play a large part in the economy. In contrast, New Zealand, with its active volcanism and earthquakes, is a typical Pacific Rim country in which public awareness, and earth science employment, is typically focussed more on geological hazards than on geological resources.

GNS Science recently began a six-year research programme called Mineral Wealth of NZ and its EEZ (MWE). The aim of one of the objectives in the MWE programme is to improve New Zealand's attractiveness to overseas exploration companies by (1) drawing attention to the fact that New Zealand basement rocks are continuations of the mineralised orogenic belts of eastern Australia and (2) providing credible geological correlations between specific rock units in both countries, particularly those in prospective areas in eastern Australia.

The purpose of this short paper is to provide a broad overview of the presently understood geological framework of the New Zealand-Australia-New Caledonia region in both a Gondwanaland and Pacific rim context. Results from our targeted research work, that may well demand changes to this framework and that will be of direct relevance to mineral prospectivity, will be presented in the coming years.

Present day geological setting

Australia & New Guinea

The geology of Australia is well described by state surveys (e.g. Queensland) and Geoscience Australia has developed national digital databases. East of the Precambrian cratons, Australia can be divided into three first-order units: Kanmantoo, Lachlan-Thomson and New England Orogens (NEO) (Fig.1; Coney et al. 1990; Powell et al., 1990; Scheibner & Veevers, 2000; Betts et al., 2002). In general, the age of sedimentary rocks in each orogenic belt decreases east (from Late Precambrian to Early Paleozoic to mid-Paleozoic), though there is overlap e.g. both the Lachlan and New England Orogens contain Ordovician-Devonian strata.

Continental geological trends, including the Tasman Line and a Triassic magmatic belt, have been extended north from Australia into New Guinea (Fig. 1; Hill & Hall, 2003; Crowhurst et al., 2004). New Guinea is also a place where Cenozoic volcanic rocks of the west end of the Melanesian arc impinge on continental crust.

New Zealand and Zealandia

No Precambrian crust is exposed in on-land New Zealand. The Cambrian to Early Cretaceous basement comprises at least nine major volcano-sedimentary terranes, three composite regional batholiths, and three regional metamorphic-tectonic belts that overprint the terranes and batholiths (Mortimer, 2004 and references therein).

The Early Paleozoic Buller and Takaka terranes are the westernmost terranes in New Zealand and are grouped into the Western Province. The Eastern Province consists of the Brook Street, Murihiku, Maitai, Caples, Bay of Islands (part of former Waipapa), Rakaia (older Torlesse) and Pahau (younger Torlesse) terranes, which range in age from Permian to Early Cretaceous. These two provinces are shown in Fig. 1. The terranes are intruded by three composite batholith (>100 km^2) sized belts of plutons: Karamea-Paparoa, Hohonu and Median, as well as numerous smaller plutons. Median Batholith (including the Median Tectonic Zone) is a recently-recognised Cordilleran batholith between the Eastern and Western Province terranes that represents the site of subduction-related magmatism from c. 360-110 Ma (Mortimer et al., 1999; Tulloch and Kimbrough, 2003). The terranes and batholiths are variably metamorphosed and deformed into Devonian-Carboniferous and Cretaceous amphibolite-granulite facies gneisses, Jurassic-Cretaceous subgreenschist-amphibolite facies Haast Schist and Cretaceous subgreenschist facies Esk Head and Whakatane Melanges (not shown at the scale of Fig. 1).

In the North Island, an active volcanic arc, Taupo Volcanic Zone (TVZ), is continuous with the Kermadec Arc. An extinct Miocene-Pliocene arc trends northwest from TVZ and, prior to back arc basin formation, probably linked with the Eocene-Pliocene Vitiaz arc to the north (Fig. 1).

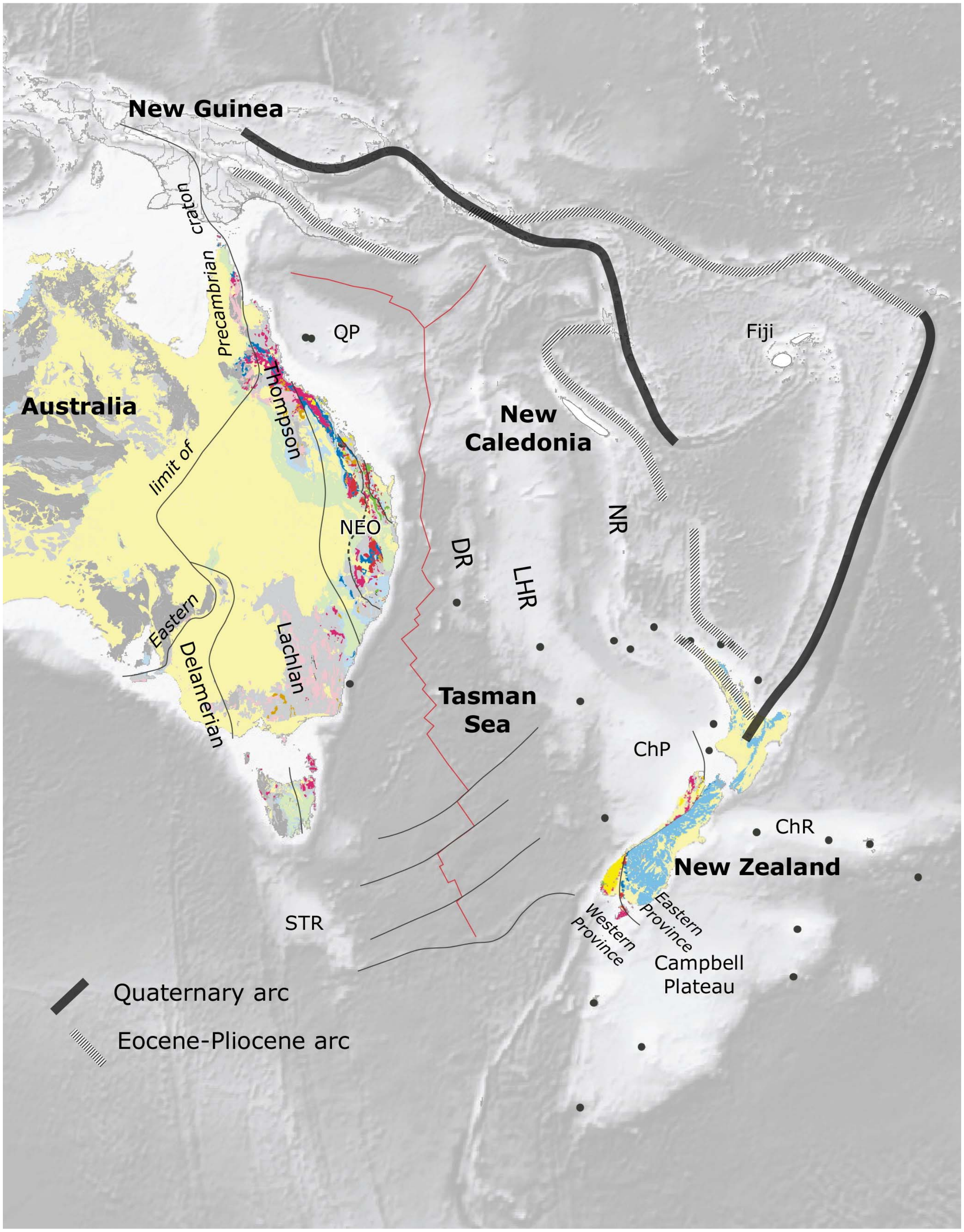

Figure 1. Geology and bathymetry of the Australia-New Zealand-New Caledonia area, including Tasman Sea spreading ridge and major fracture zones. Bathymetry is from the dataset of Sandwell and Smith (1997); abyssal plains are dark grey, plateaux, ridges and rises are white. The onland geological legend is intentionally not defined at this scale. Black dots represent offshore island, dredge and drillcore sites at which continental basement samples have been sampled. QP=Queensland Plateau, LHR=Lord Howe Rise, NR=Norfolk Ridge, DR=Dampier Ridge, ChP=Challenger Plateau, ChR=Chatham Rise, STR=South Tasman Rise.

New Zealand's excellent series of digital geological maps at 1:250 000 scale (e.g. Turnbull and Allibone, 2003) is nearly completed. Several public domain digital databases can be accessed (see http://www.gsnz.org.nz/gslinks.htm). One of these, the PETLAB database is a rock catalogue and geoanalytical database with more than 130 000 sample records. As an example of its utility, K-Ar age data extracted from PETLAB can be used to circumscribe regions affected by different geological events and thermal overprints (Fig. 2).

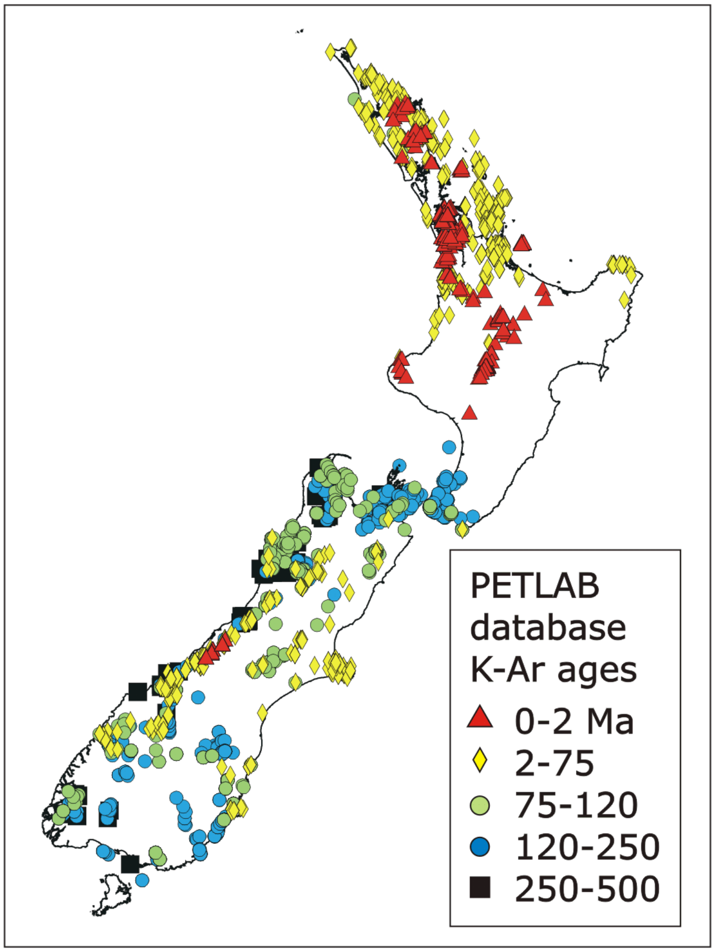

Figure 2. Summary plot of 2390 K-Ar whole rock and mineral ages from the PETLAB database (http://data.gns.cri.nz/pet) revealing patterns that are relevant to mineral exploration. In the North Island, 0-2 Ma volcanism is superimposed on an older Cenozoic arc. In the South Island the 0-2 Ma ages show the area of maximum exhumation in the Haast Schist of the Southern Alps near Mount Cook, while 2-75 Ma ages outline the broader Cenozoic exhumation of schist, and of intraplate volcanic complexes along the east coast. 75-120 Ma ages show Cretaceous extension and core complex-related tectonism and magmatism. 120-250 Ma ages are from the Mesozoic arc and mesothermal levels of the accretionary prism of the Eastern Province. 250-500 Ma ages are thermally unreset domains in the Western Province.

New Caledonia

New Caledonia is an emergent part of the northern part of the Norfolk Ridge. The geology of New Caledonia has been summarised by Paris (1981), and more recent accounts, focussing on aspects of Mesozoic stratigraphy and Cenozoic tectonics and petrology have been given by Campbell (1984), Aitchison et al. (1995) and Nicholson et al. (2000). Beneath an allochthonous ultramafic nappe, New Caledonian rock units comprise Late Paleozoic-Mesozoic volcanosedimentary terranes that, in terms of biostratigraphy, structural coherence and east-west order resemble the Murihiku and Caples Terranes of New Zealand's Eastern Province. These similarities suggest the Norfolk Ridge is the eastern limit of clearly defined Gondwanaland continental crust.

Offshore region

The continental shelf edge of greater New Zealand lies close to the 2000 m isobath. Basement schists, greywackes and granitoids are exposed on scattered islands and have been sparsely sampled in dredges on the Challenger Plateau, Chatham Rise, Campbell Plateau, Dampier Ridge and Norfolk Ridge (e.g. Challis et al., 1982; Beggs et al. 1990; Tulloch et al., 1991; McDougall et al., 1994; Mortimer et al. 1998; Sutherland 1999).

The term Zealandia is used to describe the continental mass of greater New Zealand. Zealandia thus includes the Campbell Plateau, Chatham Rise, Challenger Plateau, Norfolk Ridge and Dampier Ridge (Fig. 1). Although Zealandia is about one third the area of Australia, only 10% is emergent above sea level as the North and South Islands (Fig. 1). This emergence is consequent upon Neogene continental collision between the Australian and Pacific plates. Most of Zealandia is a rifted continental borderland and has been submerged since the Late Cretaceous. The oceanic crust in the Tasman Sea ranges in age from c. 85 Ma adjacent to Australia and Zealandia, to c. 55 Ma at the fossil spreading ridge.

Paleogeographic reconstruction

Closing the Tasman Sea

It is obvious from Fig. 1 that the orogenic belts of eastern Australia strike out eastward into the Tasman Sea. Thus the continental geology of Queensland, New South Wales and Tasmania does not stop at the low water mark. Similarly the terranes and batholiths of New Zealand strike out westward into the Tasman Sea.

Early continental fits were made by bathymetric matching of continent-ocean margins (e.g. Griffiths, 1971). The satellite gravity datasets that have emerged in the past 10 years (Sandwell and Smith, 1997) provide a clear view of oceanic fracture zones (Fig. 1). For the continental geologist, fracture zones offer a geometrically unambiguous means to close ocean basins, for example, Fig. 3 which is based on Gaina et al. (1998) and Sutherland (1999). In such reconstructions, the shape of the modern New Zealand coastline is grossly distorted because of Cenozoic strike slip motion on, and oroclinal bending about, the Alpine Fault. Zealandia restores to a position south of Tasmania.

Fig. 3 and similar reconstructions make no attempt to account for the aforementioned intracontinental stretching that affected much of Zealandia in the interval 125-85 Ma. Adequate indicators of the directions and amounts of strain needed to make a palinspastic reconstruction are lacking. However, at 125 Ma, the continent-ocean margin may have been up to 50% closer to Australia and Antarctica than it was at 85 Ma.

Geological correlations

In the opening sentence of their paper, Grindley and Davey (1982) stated “It is now widely accepted that New Zealand, Antarctica, and Australia were once joined as part of the supercontinent of Gondwanaland.” There have, of course, been many papers dealing with general and specific Australia-New Zealand geological correlations in the past. General treatments include those by Griffiths (1971), Grindley and Davey (1982), Cawood (1984) and Sutherland (1999). Papers specifically on relationships between Early-Middle Paleozoic rocks of the Lachlan Orogen and New Zealand’s Western Province include those by Cooper and Tulloch (1992) and Muir et al., (1996). Papers comparing the Permian strata of the Gympie area of the New England Orogen with those of New Zealand’s Eastern Province include those of Harrington (1983, 1987, 1998), Waterhouse and Sivell (1987) and Aitchison (1993). Identification of Permian-Jurassic Gondwana sequences in New Zealand and a comparison with their east Australian counterparts has been made by Mortimer et al., (1995), Mortimer and Smale (1996) and Campbell et al. (1998). This list is not comprehensive.

There are at least three reasons why it is timely to compare New Zealand and Australian geology again: (1) increased knowledge of seafloor geology resulting in better continental fits; (2) larger number of dredged rocks, recovered during the past 10 years, that can be used for interpolation; (3) better quality New Zealand geological datasets with which to make comparisons, particularly in regard to zircon dating and petrology.

Targeted studies

Initially, our focus is on the New England Orogen. Work in Queensland on the Permian and Triassic sequences of the Gympie Au province, and adjacent Paleozoic Yarrol, Shoalwater and Wandilla Terranes near Rockhampton, is well advanced. Sampling of the Cu-Mo-Au Cretaceous Whitsunday Volcanic Province (Bryan et al., 1997) has just been completed and results will be integrated with a broader assessment of the Queensland-New Zealand plutonic record. Fig. 3 illustrates one potential correlation, of the Cretaceous Whitsunday Province with coeval igneous rocks in the Median Batholith (Tulloch et al., 2005).

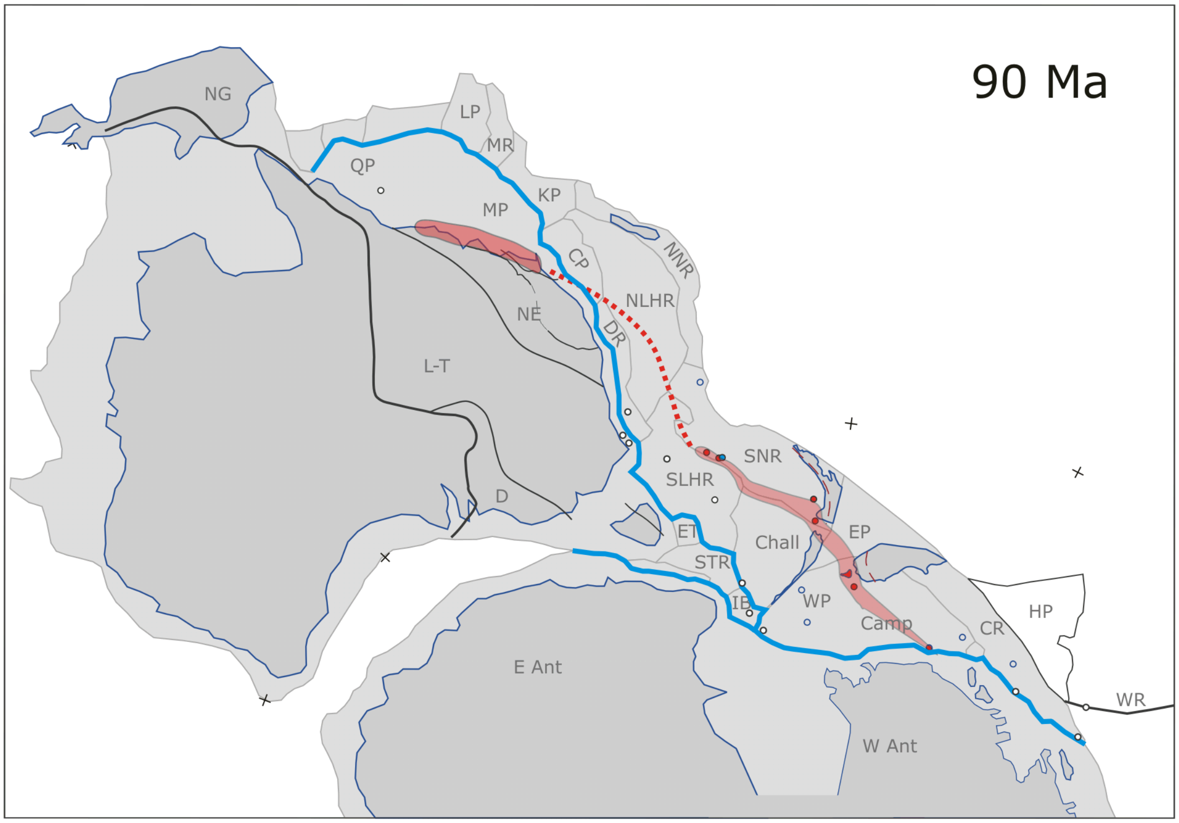

Figure 3. An “untightened” reconstruction of the continental blocks of Australia, Zealandia and Antarctica showing possible along-strike correlation between Median Batholith of New Zealand and Early Cretaceous Whitsunday Province of Queensland (Tulloch et al., 2005). Ocean basins have been closed but no attempt has been made to unstretch continental crust beneath Cretaceous sedimentary basins or beneath Cretaceous core complexes. Reconstruction is based on Gaina et al. (1998) and Sutherland (1999). Thick lines show the places where the major Tasman Sea and Southern Ocean oceanic crust spreading eventually took place, and circles are restored locations of offshore samples and islands. Geographic/bathymetric features: NG=New Guinea, QP=Queensland Plateau, MP=Marion Plateau, LP=Louisiade Plateau, MR=Mellish Rise, KP=Kenn Plateau, CP=Chesterfield Plateau, DR=Dampier Ridge, LHR=Lord Howe Rise (N & S), NR=Norfolk Ridge (N & S), ET=East Tasman Rise, STR=South Tasman Rise, Chall=Challenger Plateau, Camp=Campbell Plateau, CR=Chatham Rise, HP=Hikurangi Plateau, WR=Wishbone Ridge, Ant=Antarctica (W & E). Geological features: D=Delamerian Orogen, L-T=Lachlan-Thomson Orogen, NE=New England Orogen, EP=Eastern Province, WP=Western Province.

The paleogeographic reconstruction of Fig. 3 shows that, even with the Tasman Sea closed, New Zealand terranes are 1500 km distant along strike from their Australian counterparts. In this context, geological differences as well as similarities should reveal important first-order information about processes and geological events along the Paleozoic-Mesozoic Gondwana margin.

Conclusions

New Zealand is a piece of rifted Gondwanaland that, before Late Cretaceous sea floor spreading, was contiguous with Australia and Antarctica. On a Late Cretaceous reconstruction, orogenic trends in Queensland, New South Wales, Victoria and Tasmania strike along the Lord Howe Rise towards New Zealand. In terms of basement geology, New Zealand is as geologically prospective for mineral deposits as eastern Australia. Additional geological events that have affected New Zealand include more widespread 125-85 Ma magmatism and extensional deformation, superposition of Cenozoic volcanic arcs in the North Island, and localised Cenozoic exhumation in the South Island.

Acknowledgements

Funding for this work is provided by the New Zealand Public Good Science Fund.

References

Aitchison, J.C. 1993. Evolution of the eastern margin of Australian plate: possible correlatives in Australia, New Caledonia and New Zealand. NEO '93 Conference Proceedings: 665-669.

Aitchison, J.C., Clarke, G.L., Meffre, S. and Cluzel, D. 1995. Eocene arc-continent collision in New Caledonia and implications for regional southwest Pacific tectonic evolution. Geology 23: 161-164.

Beggs, J.M., Challis, G.A. and Cook, R.A. 1990. Basement geology of the Campbell Plateau: implications for correlation of the Campbell Magnetic Anomaly System. New Zealand Journal of Geology and Geophysics 33: 401-404.

Betts, P.G., Giles, D., Lister, G.S. and Frick, L.R. 2002. Evolution of the Australian lithosphere. Australian Journal of Earth Sciences 49: 661-695.

Bryan, S.E., Constantine, A.E., Stephens, C.J., Ewart, A., Schön, R.W. and Parianos, J. 1997. Early Cretaceous volcano-sedimentary successions along the eastern Australian continental margin: implications for the break-up of eastern Gondwana. Earth and Planetary Science Letters 153: 85-102.

Campbell, H.J. 1984. Petrography and metamorphism of the Téremba Group (Permian-Lower Triassic) and Baie de St.-Vincent Group (Upper Triassic-Lower Jurassic), New Caledonia. Journal Royal Society of New Zealand 14: 335-348.

Campbell, H.J., Smale, D., Grapes, R., Hoke, L., Gibson, G.M. and Landis, C.A. 1998. Parapara Group: Permian-Triassic rocks in the Western Province, New Zealand. New Zealand Journal of Geology and Geophysics 41: 281-296.

Cawood, P.A. 1984. The development of the SW Pacific margin of Gondwana: correlations between the Rangitata and New England orogens. Tectonics 3: 539-553.

Challis, G.A. Gabites, J. and Davey, F.J. 1982. Precambrian granite and manganese nodules dredged from southwestern Campbell Plateau, New Zealand. New Zealand Journal of Geology and Geophysics, 25: 493-497.

Coney, P.J., Edwards, A., Hine, R., Morrison, F. and Windrim, D. 1990. The regional tectonics of the Tasman orogenic system, eastern Australia. Journal of Structural Geology 12: 519-543.

Cooper, R.A. and Tulloch, A.J. 1992. Early Palaeozoic terranes in New Zealand and their relationship to the Lachlan Fold Belt. Tectonophysics 214: 129-144.

Crowhurst, P.V., Maas, R., Hill, K.C., Foster, D.A. and Fanning, C.M. 2004. Isotopic constraints on crustal architecture and Permo-Triassic tectonics in New Guinea: possible links with eastern Australia. Australian Journal Earth Sciences 51: 107-122.

Gaina, C., Müller, R.D., Royer, J.-Y., Stock, J., Hardebeck, J. and Symonds, P. 1998. The tectonic history of the Tasman Sea: a puzzle with 13 pieces. Journal of Geophysical Research 103: 12413-12433.

Griffiths, J.R. 1971. Reconstruction of the south-west Pacific margin of Gondwanaland. Nature 234: 203-207.

Grindley, G.W. and Davey, F.J. 1982. The reconstruction of New Zealand, Australia, and Antarctica. In: Craddock, C. (ed.) (University of Wisconsin. Madison) Antarctic geoscience p. 423-443

Harrington, H.J. 1983. Correlation of the Permian and Triassic Gympie terrane of Queensland with the Brook Street and Maitai terranes of New Zealand. In Permian Geology of Queensland: 431-436. Geological Society of Australia, Queensland Division, Brisbane.

Harrington, H.J. 1987. Geological units common to eastern Australia and New Zealand. Proceedings of the PACRIM Congress 87: 801-804. AUSIMM, Victoria.

Harrington, H.J. 1998. The basement geology of Lord Howe Rise and Norfolk Ridge predicted by projections from Australia, New Zealand and New Caledonia. South Pacific Technology Conference Abstracts, pp. 33-36. South Pacific Commission, Suva.

Hill, K.C. and Hall, R. 2003. Mesozoic-Cenozoic evolution of Australia's New Guinea margin in a west Pacific context. Geological Society of America Special Paper 372: 259-283.

McDougall, I., Maboko, M.A.H., Symonds, P.A., McCulloch, M.T.,; Williams, I.S, and Kudrass, H.R. 1994. Dampier Ridge, Tasman Sea, as a stranded continental fragment. Australian Journal of Earth Sciences 41: 395-406.

Mortimer, N. 2004. New Zealand's geological foundations. Gondwana Research 7: 261-272.

Mortimer, N. and Smale, D. 1996. Petrology of the Topfer Formation: first Triassic Gondwana sequence from New Zealand. Australian Journal Earth Sciences 43: 467-477.

Mortimer, N., Parkinson, D., Raine, J.I., Adams, C.J., Graham, I.J., Oliver, P.J. and Palmer, K. 1995. Ferrar magmatic province rocks discovered in New Zealand: implications for Mesozoic Gondwana geology. Geology 23: 185-188.

Mortimer, N., Herzer, R.H., Gans, P.B., Parkinson, D.L. and, Seward, D. 1998. Basement geology from Three Kings Ridge to West Norfolk Ridge, southwest Pacific Ocean: evidence from petrology, geochemistry and isotopic dating of dredge samples. Marine Geology 148: 135-162.

Mortimer, N., Tulloch, A.J., Spark, R.N., Walker, N.W., Ladley, E., Allibone, A. and Kimbrough, D.L. 1999. Overview of the Median Batholith, New Zealand: a new interpretation of the geology of the Median Tectonic Zone and adjacent rocks. Journal of African Earth Sciences 29: 257-268.

Muir R.J., Weaver S.D., Bradshaw J.D., Eby G.N. and Evans J.A. 1996. Geochemistry of the Karamea Batholith, New Zealand and comparisons with the Lachlan Fold Belt granites in SE Australia. Lithos 39: 1-20.

Nicholson, K.N., Picard, C. and Black, P.M. 2000. A comparative study of Late Cretaceous ophiolitic basalts from New Zealand and New Caledonia : implications for the tectonic evolution of the SW Pacific. Tectonophysics 327: 157-171.

Paris, J.P. 1981. Geologie de la Nouvelle-Calédonie. Bureau de Recherches Géologiques et Minières Memoire 113.

Powell, C. McA., Li, Z.X. and Thrupp, G.A. 1990. Australian Palaeozoic palaeomagnetism and tectonics-I. Tectonostratigraphic terrane constraints from the Tasman Fold Belt. Journal of Structural Geology 12: 553-565.

Sandwell, D.T. and Smith, W.H.F. 1997. Marine gravity anomaly from ERS-1, Geosat and satellite altimetry. Journal of Geophysical Research 102: 10039-10045.

Scheibner, E. and Veevers, J.J. 2000. Tasman Fold Belt System. In *Billion-year earth history of Australia and neighbours in Gondwanaland,* Veevers, J.J., ed., pp. 154-234, GEMOC Press, Sydney.

Sutherland, R. 1999. Basement geology and tectonic development of the greater New Zealand region: an interpretation from regional magnetic data. Tectonophysics 308: 341-362.

Tulloch, A.J. and Kimbrough, D.L. 2003. Paired plutonic belts in convergent margins and the development of high Sr/Y magmatism: Peninsular Ranges batholith of Baja-California and Median batholith of New Zealand. Geological Society of America Special Paper 374: 275-295.

Tulloch, A.J., Kimbrough, D.L. and Wood, R.A. 1991. Carboniferous granite basement dredged from a site on the southwest margin of the Challenger Plateau. New Zealand Journal of Geology and Geophysics 34: 121-126.

Tulloch, A.J., Ramezani, J., Allibone, A. and Mortimer, N. 2005. Early Cretaceous large volume silicic magmatism in New Zealand and Queensland: similarities between the Median Batholith and the Whitsunday Volcanic Province. Structure Tectonics Ore Mineralisation Processes 2005 Abstracts. Economic Geology Research Unit, James Cook University Contribution 64: 136.

Turnbull, I.M. and Allibone, A.H. 2003. Geology of the Murihiku area. Institute of Geological and Nuclear Sciences 1:250 000 Geological Map 20.

Waterhouse, J.B. and Sivell, W.J. 1987. Permian evidence for trans-Tasman relationships between east Australia, New Caledonia and New Zealand. Tectonophysics 142: 227-240.

Authors

Nick Mortimer is a geologist at the Dunedin office of GNS Science. He obtained a B.Sc. from Imperial College London in 1980 and a Ph.D. from Stanford University in 1984. After a postdoc at the University of British Columbia he joined the New Zealand Geological Survey. Nick is interested in all aspects of onland and offshore New Zealand basement geology and has also worked in Queensland, New Caledonia and Antarctica. He is curator of PETLAB, the New Zealand rock and geoanalytical database.

Ian Graham is an isotope geochemist at the Wellington office of GNS Science. He obtained a B.Sc. (Hons.) from Otago University in 1978, an M. Min. Tech. from Otago University in 1979, and a Ph.D. from Victoria University in 1985. Ian is Leader of GNS's Mineral Wealth of New Zealand's EEZ Programme (MWE). Ian's interests include cosmogenic and radiometric dating, and massive sulphide mineralisation along the Kermadec arc.

Chris Adams is a geochronologist at the Wellington office of GNS Science. He has a D. Phil. from Oxford University. Chris is interested in geochronology, particularly its application to detrital mineral provenance studies and tectonic problems.

Andy Tulloch is a petrologist at the Dunedin office of GNS Science. He obtained a B.Sc. from Canterbury University in 1974 and a Ph.D. from Otago University in 1979. After work with several mining companies, including Kennecott, he joined the New Zealand Geological Survey. Andy's interests include granitoids, granite-hosted mineralisation, and U-Pb geochronology.

Hamish Campbell is a paleontologist at GNS Science, Wellington and at Te Papa. He obtained a B.Sc. from Otago University in 1975, an M.Sc. from Auckland University in 1979 and a Ph.D. from Cambridge University in 1985. Hamish's interests include paleontology, stratigraphy, regional geology and science communication.