Interaction of subduction and rifting on the exhumed Cretaceous convergent margin arc of Zealandia

Andy Tulloch[1], Nick Mortimer[1], Rose Turnbull[1], Keith Klepeis[2], Harold Stowell[3], Josh Schwartz[4], Jahandar Ramezani[5], Kaj Hoernle[6]

[1] GNS Science, Dunedin, NZ ; [2] University of Vermont, Burlington, VT USA; [3] University of Alabama, AL USA; [4] California State University, Northridge, CA USA, [5] Massachusetts Institute of Technology, Cambridge. MA USA, [6] IFM-GEOMAR, Kiel, Germany

a.tulloch@gns.cri.nz

Subduction and rifting are commonly spatially and temporally distinct processes, but the exhumed late Mesozoic convergent margin in New Zealand, and formerly adjacent continents of east Gondwana, is an ideal area to investigate their interaction. In particular, does intra-arc rifting affect the geochemical evolution of arcs, and can intra-arc and post subduction intra-plate rifting be distinguished?

The NZ segment of the convergent margin, extending 7000 km from Papua New Guinea via Queensland and NZ to West Antarctica, is the only location where arc (Median Batholith), forearc basin and accretionary prism are all preserved. The Median Batholith also contains one of the deepest (65 km in Fiordland[1]) arc roots available for study. Much of its exhumation is due to extensional denudation that preceded 85 Ma breakup[2] of east Gondwana, and which immediately followed (c. 102 Ma) cessation of magmatism (105 Ma). Thick sedimentary basins related to breakup also contain important repositories of information on the composition and tempo of arc and rift development. These relationships provide an unusually complete time and space section through continental crust from its base to basins that reside at the surface.

The Median Batholith[3] on a 90 Ma reconstruction is over 800 km long within Zealandia and separates a Paleozoic Western Province from the accreted Mesozoic terranes of the Eastern Province. It ranges in age from 230 to 105 Ma and is largely comprised of two margin parallel belts[4], separated by a prominent age gap at c. 135 Ma. The outboard (Pacificward) belt of 230-135 Ma plutons consists of typical low Sr/Y (LoSY[4]) plutonic and volcanic suites[5]. The inboard (wrt Gondwana) belt consists of 131-105 Ma, high Sr/Y (HiSY), TTG-like sodic plutons that dominate the deepest levels. Zircon U-Pb and garnet Sm-Nd geochronology indicate that thickening[6] and granulite facies metamorphism closely followed HiSY magmatism in Fiordland[7, 8], and corroborate interpretations from metamorphic petrology of rapid vertical motion of the crust[9] during this final phase of subduction-related magmatism. Minor but widespread A-type and peralkaline granites may indicate discrete intra-arc extensional episodes.

The Whitsunday Volcanic Province of Queensland is a likely NW extension of the Median Batholith along the Lord Howe Rise[10], but has previously been interpreted as intra-plate rifting associated with formation of the Tasman Sea[11]. Because the shallow structural level exposed in Queensland contrasts with the deeper levels in tectonically extended and exhumed NZ, the potential for each area to inform on the other, as shallow and deep levels of the same subduction system, is significant. To the SE, the Median Batholith extends across the Campbell Plateau, where arc and rift magnetic anomalies overlap, and into West Antarctica. The exposed lateral and vertical extent, and strong HiSY signature, make the Median Batholith one of best Phanerozoic subduction zone TTG-like localities available for study. Strong similarities with the Peninsular Ranges Batholith[4] suggests Median Batholith features are not unique and have global application. First order questions on the New Zealand arc and its exhumation follow:

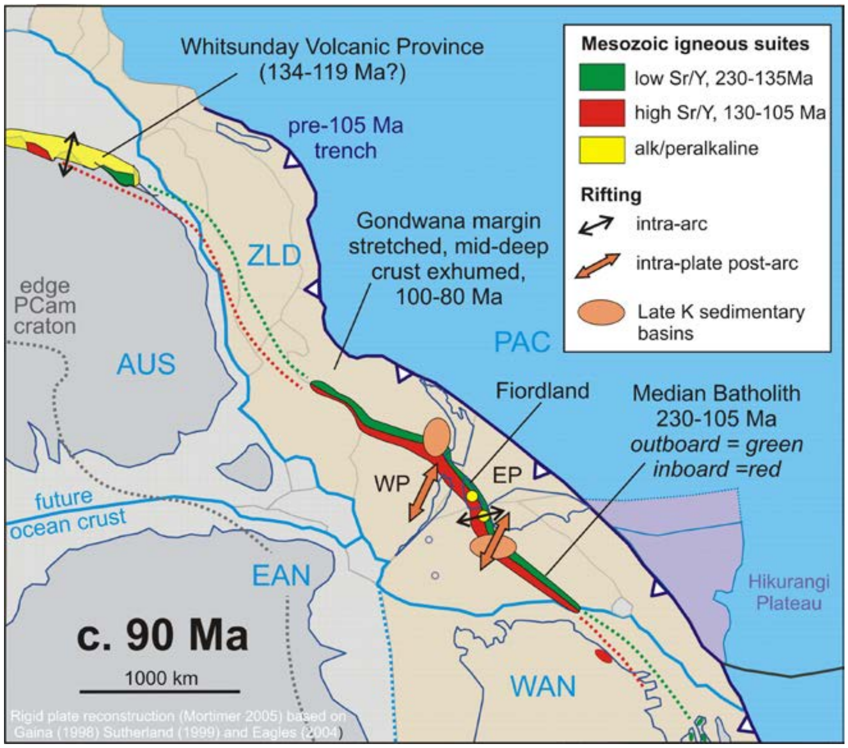
What geodynamic processes were associated with the sudden and complete switch to HiSY, TTG-like, plutonism at c. 135 Ma? Did the slab retreat, roll back or drop off, allowing hot asthenosphere to partially melt a thick basaltic crust underplated during 230-135 Ma subduction, or later underthrusting[4,12]? Were slab-derived fluids required for generation of HiSY magmas from basaltic underplate? Did asthenosphere wedge-generated magmatism cease at 135 Ma? Did episodic delamination of eclogitic residues contribute significantly to an overlying "Cordillera Zealandia"[13] by isostatic rebound (a current NZ Marsden Fund proposal)? Does peralkaline and A-type magmatism at c. 135 Ma suggest intra-arc extension was associated with the switch to HiSY magmatism? Is the geochemical rift signature observed in the Whitsunday Volcanic Province due to intra-arc rather than intra-plate, rifting? And, is it the equivalent of the 135 Ma intra-arc peralkaline magmatism in NZ?

When and where did subduction cease in NZ? Did an actively subducting slab cease to exist beneath the South Zealandia margin from 135, 105 or 85 Ma? How can this be recognised in the accretionary wedge? How can this be recognised in the Cretaceous igneous and metamorphic record? Is there still a stalled Hikurangi Plateau slab beneath South Zealandia[14,15]? Was cessation of subduction magmatism diachronous (120 Ma in Queensland, 105 Ma in Zealandia)? Did Gondwana breakup influence subduction cessation? When did intra-plate extension begin to affect Zealandia (>102 Ma?), how can it be distinguished from intra-arc rifting[16], and how might we distinguish intraplate alkaline magmas from possible A-type trends in the waning arc? Why did breakup in the central Zealandia segment occur well inboard of the arc[17]- was the lithosphere along the recently extinct arc relatively strong[18]?

References:

1. De Paoli, M.C., Clarke, G.L., Klepeis, K.A., Allibone, A.H., & Turnbull, I.M., 2009, The eclogite-granulite transition: mafic and intermediate assemblages at Breaksea Sound, New Zealand, Journal of Petrology, 50, 2307-43.
2. Kula JL, Tulloch AJ, Spell T, Wells ML, Zanetti K. 2009. Thermal evolution of the Sisters shear zone, southern New Zealand; formation of the Great South Basin and onset of Pacific-Antarctic spreading. Tectonics 20 TC5015
3. Mortimer, N, Davey, FJ, Melhuish, A, Yu, J, Godfrey, NJ, 2002. Geological interpretation of a deep seismic reflection profile across the Eastern Province and Median Batholith, New Zealand: crustal architecture of an extended Phanerozoic convergent margin, N. Z. J. Geol. Geophys., 45, 349–363.

4. Tulloch, AJ, Kimbrough, DL, 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. Geol. Soc. Am., Special Paper 374 (Gastil Volume), 275–295.
5. Turnbull, RE., Weaver, SW, Tulloch, AJ, Cole, J., Handler, M., Ireland, TR. 2010. Field and geochemical constraints on mafic–felsic interactions, and processes in high-level arc magma chambers: an example from the Halfmoon Pluton, NZ . Jl Petrol. 51, 1477-1505.
6. Scott, J.M., Cooper, A.F., Tulloch, A.J., Spell, T.L.. 2011. Crustal thickening of the Early Cretaceous paleo-Pacific Gondwana margin. Gondwana Research 20, 380-394.
7. Stowell, H.H., Parker, K.A., Gatewood, M.P., 2010a. Sequential pluton emplacement, garnet granulite metamorphism, and partial melting during construction and modification of magmatic arc crust, Fiordland, New Zealand. Geochimica et Cosmochimica Acta, 74, A997.
8. Stowell, H.H., Tulloch, A.J., Zuluaga, C.A., Koenig, A., 2010b, Timing and duration of garnet granulite metamorphism in magmatic arc crust, Fiordland, New Zealand: Chemical Geology, v. 273, p. 91-110.
9. Allibone, A.H. Milan, L.A., Daczko, N.R, Turnbull, I.M. 2009. Granulite facies thermal aureoles and metastable amphibolite facies assemblages adjacent to the Western Fiordland Orthogneiss in southwest Fiordland, NZ. Jl of Meta. Petrology 27, 349-369.
10. Tulloch AJ, Ramezani J, Faure K, Allibone AH (2010) Early Cretaceous magmatism in New Zealand and Queensland: intra-plate or intra-arc origin? In: Buckman S, Blevin PL eds) New England Orogen 2010, vol. University of New Endland, University of New England, Armidale, pp 332-335.
11. Bryan, S. E., Constantine, A. E., Stephens, C. J., Ewart, A., Scho¨n, 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.
12. Muir, R.J., Ireland, T.R., Weaver, S.D., Bradshaw, J.D., Evans, J.A., Eby, G.N. & Shelley, D., 1998. Geochronology and geochemistry of a Mesozoic magmatic arc system, Fiordland, NZ, *Jl of the Geol. Soc.*, 155, 1037–1053.
13. Tulloch, AJ. Beggs, M., Kula, J, Spell, T. 2006. Cordillera Zealandia, the Sisters Shear Zone and their influence on the early development of the Great South Basin. NZ Petroleum Conference Proceedings, http://www.nzpam.govt.nz/cms/pdf-library/petroleum-conferences-1/2006
14. Davy B, Hoernle, K., Werner R., 2008. Hikurangi Plateau: Crustal structure, rifted formation, and Gondwana subduction history, Geochem. Geophys. Geosyst., 9, Q07004, doi:10.1029/2007GC001855.
15. Reyners, M. 2012. The central role of the Hikurangi Plateau in the Cenozoic tectonics of New Zeland and the SW Pacific. Earth & Planetary Science Letters 361, 460-468.
16. Tulloch, AJ, Ramezani, J, Mortimer, N, Mortensen, J, van den Bogaard, P, Maas, R, 2009. Cretaceous felsic volcanism in New Zealand and Lord Howe Rise (Zealandia) as a precursor to final Gondwana break-up, *in* Ring, U., and Wernicke, B., eds, Extending a Continent: Architecture, Rheology and Heat Budget: Geological Society, London, Special Pub., 321, 89–118.
17. Dunbar, J.A. Sawyer, D.S. 1989. How preexisting weaknesses control the style of continental breakup. Jl Geophys. Res. 94, 7278-97.
18. Klepeis, KA, King D, De Paoli M, Clarke GL, Gehrels G, 2007. Interaction of strong lower and weak middle crust during lithospheric extension in western NZ. Tectonics 26.


Whitsunday Volcanic Province
(134-119 Ma?)
pre-105 Ma
trench
Mesozoic igneous suites
low Sr/Y, 230-135Ma
high Sr/Y, 130-105 Ma
alk/peralkaline
Rifting
intra-arc
intra-plate post-arc
Late K sedimentary
basins
ZLD
Gondwana margin
stretched, mid-deep
crust exhumed,
100-80 Ma
edge
PCam
craton
AUS
PAC
Fiordland
Median Batholith
230-105 Ma
outboard = green
inboard =red
WP
EP
future
ocean crust
EAN
Hikurangi
Plateau
c. 90 Ma
1000 km
WAN
Rigid plate reconstruction (Mortimer 2005) based on
Gaina (1998) Sutherland (1999) and Eagles (2004)