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Lost Terranes of Zealandia: possible development of late Paleozoic and early Mesozoic sedimentary basins at the southwest Pacific margin of Gondwanaland, and their destination as terranes in southern South America

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ABSTRACT. Latest Precambrian to Ordovician metasedimentary successions and Cambrian-Ordovician and Devonian-Carboniferous granitoids form the major part of the basement of southern Zealandia and adjacent sectors of Antarctica and southeast Australia. Uplift/cooling ages of these rocks, and local Devonian shallow-water cover sequences suggest that final consolidation of the basement occurred through Late Paleozoic time. A necessary consequence of this process would have been contemporaneous erosion and the substantial development of marine sedimentary basins at the Pacific margin of Zealandia. These are found nowhere at the present day, suggesting that the basins have been lost by tectonic erosion, perhaps in a margin-parallel dextral translation similar to late Paleozoic-Mesozoic suspect terranes of New Zealand. A probable detrital zircon age pattern is assembled for these lost Zealandia sediments, and then compared with those of pre-Jurassic (probable Triassic to Devonian) metasedimentary rocks in the Chilean archipelago. Significant Mesoproterozoic, latest Neoproterozoic-Cambrian and Devonian-Carboniferous detrital zircon age components are common to both, thus supporting a possible Chilean terrane destination for these 'lost terranes of Zealandia'.

Keywords: Zealandia, Detrital zircon ages, Paleozoic, Terranes, Chile.

RESUMEN. Terrenos perdidos de Zealandia: posible desarrollo de cuencas sedimentarias del Paleozoico tardío y Mesozoico temprano en el margen suroccidental del Pacífico de Gondwana y su destino como terrenos en el sur de América del Sur. Las sucesiones metasedimentarias del Precámbrico tardío al Ordovícico y granitoides del Cámbrico-Ordovícico y Devónico-Carbonífero constituyen la mayor parte del basamento del sur de Zealandia y sectores adyacentes de la Antártica y el sudeste de Australia. Las edades de enfriamiento/alzamiento de estas rocas y la cobertura local de secuencias de aguas someras del Devónico, sugieren que la consolidación definitiva del basamento se produjo durante el Paleozoico tardío. Una consecuencia necesaria de este proceso habría sido la erosión contemporánea y el desarrollo sustancial de cuencas sedimentarias marinas en el margen del Pacífico de Zealandia. Estas no se encuentran en ninguna parte en la actualidad, lo que sugiere que las cuencas se han perdido por erosión tectónica, tal vez en una traslación dextral paralela al margen similar a los terrenos del Paleozoico tardío-Mesozoico de Nueva Zelanda. Hay una agrupación que da un probable patrón de edad de circones detríticos para estos sedimentos de la perdida Zealandia, comparables con aquellos de rocas metasedimentarias del pre-Jurásico (probable Triásico a Devónico) del archipiélago chileno. Importantes componentes de edades de circones detríticos del Mesoproterozoicos, Neoproterozoico tardío-Cámbrico y Devónico-Carbonífero son comunes a ambas regiones, favoreciendo así un posible destino chileno para estos 'terrenos perdidos de Zealandia'.

Palabras clave: Zealandia, Edades de circones detríticos, Paleozoico, Terrenos, Chile.

1. Introduction

Zealandia is that part of the greater New Zealand region underlain by continental crust (Sutherland, 1999) and which formerly constituted a sector of the Pacific margin of the Gondwanaland supercontinent. A fit of Zealandia with the adjacent continental components of Gondwanaland can be made against eastern Australia by closing the Tasman Sea, and the Ross Sea regions of Antarctica by closing the south-west Pacific Ocean. This then reveals the original continuity of several late Precambrian and early Paleozoic fold belts as demonstrated for example by common sedimentary basins, plutonic arcs and metamorphic belts (Adams, 1981; Bradshaw *et al.*, 1983; Glen 2005). Despite a large proportion (95%) of Zealandia being below sea-level and unavailable for study, its geological history compares well with its Australian and Antarctic continental neighbours, but an important difference is that Silurian and Devonian sedimentary rocks are very local and limited and, apart from a single, tiny (100 m^2) seamount limestone occurrence (Jenkins and Jenkins, 1971), the Carboniferous is absent.

This paper examines this striking paucity of Silurian, Devonian and Carboniferous sedimentary rocks, and proposes that they were in fact developed in quite extensive sedimentary basins along the Zealandia Pacific margin, but were then translated, as suspect terranes, to southern South America.

2. The Zealandia continental basement: a geological outline

The pre-100 Ma basement of the Zealandia continent has three main components:

- An inboard early Paleozoic, Western Province comprises, in the Buller Terrane, extensive sandstone-dominated, turbiditic rocks of Ordovician age and minor Devonian, shallow-water successions and, in the Takaka Terrane, Cambrian to Devonian, shallow-water limestones and quartzites (Cooper and Tulloch, 1992). The province probably continues southwards on to the Campbell Plateau (Adams, 2007) and into Marie Byrd Land, West Antarctica (Bradshaw *et al.*, 1997; Pankhurst *et al.*, 1998), and also westwards into the early Paleozoic, Lachlan Fold Belt of southeast Australia (Foster and Gray, 2000; VandenBerg *et al.*, 2000; Veevers *et al.*, 2000), and more distantly, to the Late Precambrian-Cambrian, Ross and Delamerian Fold Belts of Antarctica and Australia respectively (Tessensohn *et al.*, 1981; Adams, 1997; Adams and Ireland, 2007). Undoubted Precambrian basement intrusive igneous rocks within this region are very rare (Fioretti *et al.*, 2005), but Cambrian-Ordovician granitoid complexes within the Ross/Delamerian Fold Belts are extensive in Northern Victoria Land (Tessensohn *et al.*, 1981) and South Australia. Devonian-Early Carboniferous granitoids occur in Northern Victoria Land (Tessensohn *et al.*, 1981; Tonarini and Rocchi, 1994), Marie Byrd Land (Adams, 1987), Zealandia (Muir *et al.*, 1996) and southeast Australia (Birch, 2008). Regional deformation and metamorphism throughout is late Ordovician-Silurian (Adams *et al.*, 1975; Adams and Kreuzer, 1984; Kreuzer *et al.*, 1987; Adams, 1986; Foster and Gray, 2000). In general, the fold belts represent an outward accretion in late Neoproterozoic to Ordovician times of Ross-Delamerian marginal basins in the Transantarctic Mountains and South Australia. These basins derived their sediment inputs from the immediately adjacent Australian and Antarctic Precambrian cratons. Subsequently, in southeast Australia, Zealandia and West Antarctica, Ordovician sandstone-dominated successions of the Lachlan Fold Belt (and equivalents) developed very extensively (5,000 km) at the contemporary margin of Gondwanaland (Ireland *et al.*, 1998), with reworking from both the Australian-Antarctic Precambrian cratons and the Ross-Delamerian Fold Belts. Although all these successions appear autochthonous with respect to their proposed sediment sources inboard, to harmonise their geological history in a spatial sense, Glen (2005) has nonetheless proposed major strike-slip displacement of several early Paleozoic tectonic blocks within southeast Australia and the adjacent Ross Sea regions of Antarctica.
- An outboard, Eastern Province of Late Paleozoic-Mesozoic, tectonostratigraphic terranes (Fig. 1), several of which have been regarded as allochthonous (Bishop *et al.*, 1985). Within this province there is a western terrane group represented by island-arc, volcaniclastic-dominated (mainly acid-intermediate), forearc sedimentary basins of the Brook Street, Murihiku and Dun Mountain-Maitai Terranes (Coombs *et al.*, 1976; Ballance and Campbell 1993; Landis *et al.*, 1999; Rattenbury *et al.*, 1998). Volcanic successions are

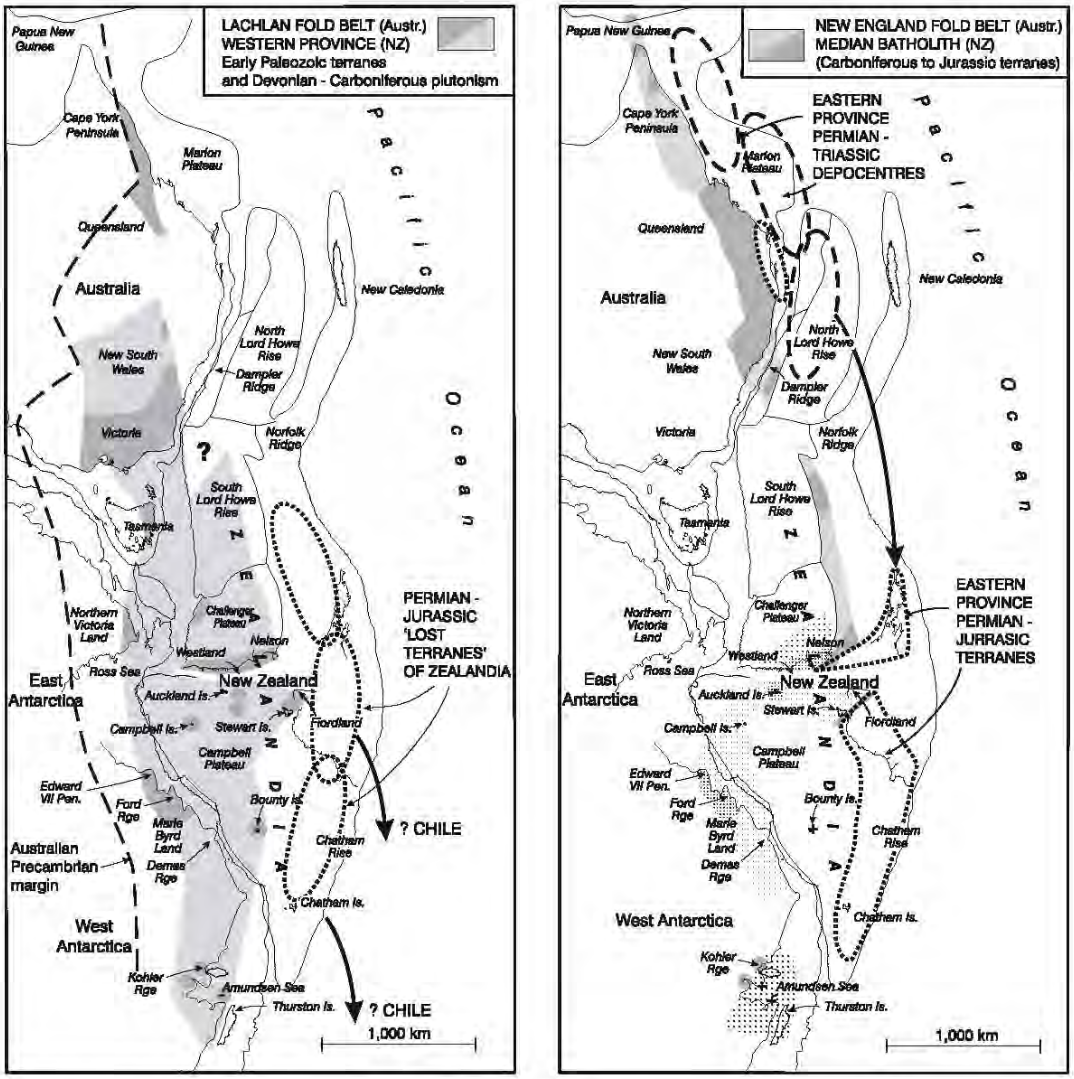

FIG. 1. The Pacific margin of Gondwanaland in a Late Triassic reconstruction showing: **left diagram:** late Neoproterozoic-early Paleozoic basement outcrop (dark grey shading) and possible geographic continuations (light grey shading) and the Precambrian craton margin (bold broken line). The bold dotted ellipses represent probable areas of late Paleozoic-Mesozoic sediment depocentres, that might now form lost terranes of Zealandia, destined for Chile (suggested tectonic transport direction shown as bold arrows); **right diagram:** late Paleozoic-Mesozoic outcrop (dark grey shading) and possible geographic continuations (light grey shading). Areas of Jurassic-Cretaceous plutonism are shown as stipple. The bold dashed ellipses represent probable areas of late Paleozoic-Mesozoic sediment depocentres that now form suspect terranes in the Eastern Province, New Zealand (bold dotted envelopes).

well represented in the Permian, Brook Street Terrane, but are rare throughout the Late Permian to Late Jurassic, Murihiku Terrane. The Dun Mountain-Maitai Terrane is dominated by the Early Permian, Dun Mountain Ophiolite Belt (serpentinites, spilites and ultramafites) (Coombs *et al.*, 1976), which is overlain by Permian-Early Triassic turbidite successions of the Maitai Group. An eastern terrane group, comprising the Torlesse (composite), Waipapa and Caples Terranes (Mackinnon, 1983; Adams *et al.*, 2009), forms accretionary complexes (Permian to Cretaceous) with extensive sandstone-dominated turbiditic rocks mainly derived from an adjacent continental margin including plutonic and metamorphic rocks. Acid-intermediate, volcaniclastic sediment inputs are pervasive in the Caples Terrane, less so in the Waipapa Terrane and rare in the Torlesse Terrane. Volcanic horizons are rare in all three terranes. Regional deformation and low-grade metamorphism within the developing accretionary wedge are recorded throughout the Triassic, Jurassic and (mainly) Cretaceous (Adams *et al.*, 1985; Adams, 2003; Adams and Maas, 2004).

- A Late Permian-Early Cretaceous, Median Batholith (Kimbrough *et al.*, 1994; Mortimer *et al.*, 1999), which separates the Western and Eastern Provinces.

In the Eastern Province, the Torlesse Terrane rocks in particular show petrographic characteristics (Mackinnon, 1983), geochemical compositions (Roser and Korsch, 1999) and radiogenic isotope patterns (Pickett and Wasserburg, 1989; Frost and Coombs, 1989; Wandres *et al.* (2004a, b); Adams *et al.*, 2005) that do not match with possible sources at the immediate Gondwanaland margin in the Western Province (Adams, 1997, 2007; Gray, 1990; Adams, 2004). Furthermore, whilst they lend support to some alternative provenances, for example within the northeast Australia or Antarctic sectors, these features do not unequivocally confirm such proposals. Attention has therefore been concentrated instead upon their detrital mica and zircon age populations. These similarly exclude any likely source areas at the adjacent margin of the Western Province of New Zealand (which are mainly Cambrian-Devonian sedimentary rocks, and Devonian-Carboniferous plutonic rocks) or their equivalents in Australia and Antarctica (Ireland, 1992a; Ireland *et al.*, 1994, Adams and Kelley, 1998; Pickard *et al.*, 2000; Cawood *et al.*, 2002; Wandres *et al.*, 2004a; Adams *et al.*, 2007) (Fig. 1). However, there is disagreement about any alternative provenances. For example, Cawood *et al.* (2002) suggested that Permian sandstones in the Akatarawa microterrane (within the Torlesse Terrane) had a distant Tethyan origin. On a comparison of petrographic, geochemical, and age information, Wandres *et al.* (2004a) suggested a West Antarctic (Amundsen Sea) source for Cambrian boulders in Torlesse conglomerates. However, these source regions remain unsatisfactory, because rocks of the appropriate extent (>100 km scale), composition (acid-intermediate), and age (Permian-Triassic) are only very locally developed (km-scale) or absent in these regions. Except for some acid volcanic rocks in Tasmania, Cambrian (and late Precambrian) igneous rocks are similarly rare or absent. No rocks of this age are known on the Campbell Plateau. Also it cannot be satisfactorily explained how Cambrian igneous rocks, occurring as clasts in rare Torlesse conglomerates (<0.01% total) have been transported large distances (>1,000 km) from tiny occurrences in West Antarctica (Amundsen Sea), whilst there is no evidence of sand-size detritus travelling similar distances from the widespread Devonian granitoids in this same sector of the Gondwanaland margin.

Alternatively, on the basis of detrital U-Pb zircon and $^{40}Ar/^{39}Ar$ mica age patterns, Adams and Kelley (1998); Pickard *et al.* (2000) and Adams *et al.* (2007) preferred Torlesse (and Waipapa) terrane sediment provenances within the Carboniferous-Triassic plutonic and volcanic complexes of the New England Fold Belt of northeast Australia, and to a lesser degree their hinterland consisting of Precambrian-early Paleozoic rocks within the Thomson and Delamerian) fold belts (Veevers, 2000; Glen, 2005). A similar preference was given for rocks within the Caples Terrane (Adams *et al.*, 2009). Features such as euhedral rather than rounded zircon mineral grains (Pickard *et al.*, 2000), conglomerate horizons (Andrews *et al.*, 1976; Smale, 1980; Wandres *et al.*, 2004b), gritstones and coarse estuarine sandstones (Andrews, 1974; Retallack, 1983), and plant material (Retallack and Ryburn, 1982) all suggest that the sandstone successions formed relatively close to a contemporary active continental margin, and the resultant sedimentary basins were subsequently transported tectonically, as suspect terranes, along the Gondwanaland margin southwards to their present New Zealand position (Adams *et al.*, 2007) (Fig. 1). This model raises the possibility that equivalent rocks were originally present at the Zealandia margin and also underwent similar tectonic transport elsewhere.

3. Late Paleozoic uplift and erosion in southern Zealandia

Throughout Zealandia and neighbouring southeast Australia and Antarctica, the K-Ar and $^{40}Ar/^{39}Ar$ cooling age patterns of the early Paleozoic metasedimentary terranes and early and late Paleozoic plutonic complexes are all in the range 440 to *ca.* 340 Ma (Adams, 1981, 1986, 1987; Adams and Kreuzer, 1984; Adams *et al.*, 1975, 1979; Foster and Gray, 2000; Kreuzer *et al.*, 1987; Vita *et al.*, 1991; Wright *et al.*, 1991; Tonarini and Rocchi, 1994). These data suggest that substantial basement uplift and erosion continued from Silurian to at least mid-Carboniferous times. This could explain the absence of Carboniferous clastic sedimentary rocks in New Zealand.

Such exhumation must have been considerable (5-15 km), to bring greenschist facies metasediments and granitoids to the surface by the Devonian in the Buller Terrane of New Zealand (Bradshaw, 1995), in Northern Victoria Land (Tessensohn *et al.*, 1981), Marie Byrd Land, Antarctica (Grindley and Mildenhall, 1981), and in Tasmania and Victoria, Australia (VandenBerg *et al.*, 2000; Birch, 2008), but later, by Late Permian time, in the Takaka Terrane of New Zealand (Rattenbury *et al.*, 1998; Bradshaw, 2000). Throughout this broad region, Devonian sedimentary cover rocks are invariably local (km-scale), and indicate prevailing shallow-water, passive margin environments. Devonian granitoids were also emplaced in all these areas too, and minor associated volcanics are recorded in Antarctica (Northern Victoria Land, and Marie Byrd Land). Thus, throughout late Paleozoic time, the Zealandia region was relatively stable, with restricted shallow-water sedimentation, and undergoing steady regional uplift.

The substantial exhumation of such a large basement region (1,000 km-scale) necessarily implies commensurate erosion and development of sedimentary basins along the contemporary Zealandia continental margin. Surprisingly, no such basins have ever been discovered. It must be concluded that they have either been completely removed by Mesozoic subaerial erosion, or, like the Eastern Province sedimentary basins, they have undergone some form of 'tectonic' erosion, and as 'Lost Terranes of Zealandia', have been transported elsewhere.

4. Sediment inputs into postulated basins at the Zealandia margin

Any late Paleozoic basins developed at the Zealandia margin would have derived their sediment inputs from an exposed basement hinterland that included:

1. Medium-high-grade metamorphic rocks (from late Neoproterozoic to Cambrian protoliths).
2. Cambrian-Ordovician granitoid complexes of the Ross and Delamerian Fold Belts.
3. Low-medium-grade Late Cambrian-Ordovician metasediments of the Lachlan Fold Belt and correlatives in Zealandia and Antarctica.
4. Devonian to Carboniferous granitoid complexes, also within the Lachlan Fold Belt and its correlatives, *e.g.*, Karamea Batholith of New Zealand.
5. Late Permian igneous rocks of the Median Batholith or sedimentary rocks of the Brook Street and Murihiku Terranes (Fig. 1).

Today, the crucial continental basement in southern Zealandia (Campbell Plateau) and West Antarctica (Marie Byrd Land) is hidden beneath sea and ice. Since proven outcrop areas are extremely limited, estimates of the extent of sources (1)-(5) are very uncertain. Bradshaw *et al.* (1997) speculated that Permian-Jurassic rocks of source (5) did indeed continue, as terranes, across the Campbell Plateau into Marie Byrd Land. In contrast, Adams (2007), citing uniform regional magnetic anomaly patterns (Sutherland, 1999), suggested the basement in this region comprised almost entirely pre-Permian sources (3) and (4), perhaps >70%.

The very extensive sandstone-dominated successions of sources (1) and (3) have plutonic, mostly granitoid, provenances, and thus, when reworked into contemporary late Paleozoic sediments, would contribute these characteristics. To this would be added similar detritus from granitoid sources (2) and (4). Thus, late Paleozoic sediments would be dominated by sands and silts with relatively quartzose compositions, more potassic than calcic, and with elevated initial Sr isotopic ratios, >0.708 (Gray, 1990; Adams, 1997). There is, however, a complication closer to the Zealandia margin (and present-day New Zealand) where Late Permian sediment contributions from source (5), such as the Median Batholith, and Brook Street and Dun Mountain-Maitai Terranes, might become important. The extension of none of these on to the Campbell Plateau is proven, although a linear magnetic anomaly extending 400 km southeast of New Zealand might be related to the Dun Mountain Ophiolite Belt (Sutherland 1999; Mortimer *et al.*, 2002). If source (5) was originally far larger, *i.e*, a large proportion has been removed by erosion, or if substantial extensions are in fact hidden on the Campbell Plateau and in Marie Byrd Land (Bradshaw *et al.*, 1997), then sediments contributed from this source would be less quartzose, more volcaniclastic and with lower bulk initial $^{87}Sr/^{86}Sr$ values <0.706.

5. Detrital zircon age patterns in late Paleozoic sediments at the Zealandia margin

The sediment sources (1)-(5) would deliver detrital zircon age characteristics to the Zealandia margin as follows:

Source **(1)**, late Neoproterozoic-Cambrian metasedimentary rocks, having two main, and roughly equal, groups: late Mesoproterozoic, *ca.* 1,000-1,100 Ma, and late Neoproterozoic to Cambrian, *ca.* 600-500 Ma.

Source **(2)**, Ross-Delamerian granitoids having primary zircons, *ca.* 460-500 Ma.

Source **(3)**, early Paleozoic metasedimentary rocks of the Lachlan Fold Belt (and its continuations) having a combined age signature made up from sources (1) and (2).

Source **(4)**, Devonian-Carboniferous, granitoids and/or associated volcanic rocks, having primary zircons, 430-330 Ma.

Source **(5)**, granodiorites and diorites of the Median Batholith (Mortimer *et al.*, 1999) or older, intermediate volcaniclastic rocks in the Brook Street Terrane (Landis *et al.*, 1999), Murihiku Terrane (Ballance and Campbell, 1993) or Dun Mountain-Maitai Terrane, having mostly Late Permian (260-250 Ma) zircons.

An estimate of their relative extent would suggest that sources (1)-(3) would be major zircon contributors to any Zealandia sedimentary basins, perhaps comprising 60-70% of total, with an important but minor contribution, perhaps 20-30%, from source (4), and an uncertain, but smallest input from source (5). This contrasts markedly with zircons delivered to the northeastern Australian Gondwanaland margin to form the Torlesse, Waipapa and Caples sedimentary basins, which were dominated by source (5), often 40-50%, with only a minor contribution, 30-40%, from sources (1)-(3), and very little from source (4). These patterns are exemplified in figure 2 (upper) by zircon age distributions in Rakaia Terrane rocks of the Torlesse Composite Terrane.

6. Lost terranes of Zealandia in Chilean Patagonia

If the postulated late Paleozoic sedimentary basins at the Zealandia margin did undergo a margin-parallel translation (*ca.* 2,000 km) as suspect terranes, similar to that of the Eastern Province terranes, then possible destination terranes might be represented in the Chilean archipelago of southern South America, as the Chonos, Eastern Andes, and Duque de York Metamorphic Complexes (Faúndez *et al.*, 2002; Hervé and Fanning, 2003; Hervé *et al.*, 2003; Lacassie *et al.*, 2006). These comprise poorly fossiliferous or unfossiliferous, low-grade siliciclastic metasediments, with exception of the Duque de York Complex, which has significant Permian limestones. In general, their age range is only poorly estimated as post-Early Permian, pre-Early Cretaceous. Faúndez *et al.* (2002) and Lacassie *et al.* (2006) compared Permian (and possible Triassic) rocks in Chilean Patagonia and southern New Zealand, and they noted that the Eastern Province terranes also have poorly fossiliferous low-grade, metasediments (post-Early Permian to pre-Late Cretaceous) which include important Late Permian limestones in the Brook Street and Dun Mountain-Maitai Terranes (Rattenbury *et al.*, 1998; Landis *et al.*, 1999).

Zircon age data from the Chilean complexes cited above are summarised in figure 2 (lower) in a similar manner to the equivalent data from the Permian-Triassic Rakaia Terrane of New Zealand displayed in figure 2 (upper). The Chilean zircon age patterns are seen to contrast with those from New Zealand. Since the Rakaia Terrane is allochthonous with respect to the southern Zealandia margin, it has zircon age data that do not match the possible basement sources there. However, the Chilean zircon data do conform to that expected of a Zealandia margin sedimentary basin. In particular there is a large zircon component (early Paleozoic and Precambrian) compatible with source-types (1)-(3), and a significant minor component (Devonian and Carboniferous) compatible with source-type (4). Permian zircon contributions of source-type (5) are more significant than predicted, but are highly variable, 10-70%, suggesting that their influence is more local, and perhaps related to volcanic sources.

7. Discussion

With the exception of the Duque de York Complex discussed below, Hervé and Fanning (2003) and Hervé *et al.* (2003) inferred from detrital zircon age data in the metamorphic complexes of the Chilean

DETRITAL ZIRCON AGE DATA FOR NEW ZEALAND EASTERN PROVINCE TERRANES: PERCENTAGE PROPORTIONS IN GEOLOGICAL PERIODS

				Cret.	Juras.	Trias.	Per.	Carb.	Dev-Sil	Ord-Cam	Precam	
	TORLESSE COMPOSITE TERRANE											
	Rakaia Terrane											
4	RBW1	205	220			33	19	6	2	16	24	RBW1
2	OTQ1	220	230			30	16	9	4	13	27	OTQ1
2	HERM2	220	230			29	18	5	5	15	29	HERM2
4	NGQ2	220	230		1	32	19	4	1	14	29	NGQ2
4	NGQ2	220	230			39	10	4	1	20	26	NGQ2
4	PUD1	220	230			33	23	7	1	12	23	PUD1
5	Balmacaan	235	242			14	31	9	5	11	30	Balmacaan
9	SEL4	251	260			5	55	7	5	15	13	SEL4
4	PAR2	251	260			3	68	1	6	10	13	PAR2
1	Aviemore					4	40	4		16	36	Aviemore
5	KUROW	251	260			7	38	25	7	13	10	KUROW
6	BMQX35					2	20	21	16	24	16	BMQX35
	Kakahu Terrane											
4	KAK35	251					66	14	7		14	KAK35
	Akatarawa Terrane											
4	TAKA10	251		6			18	19	22	7	28	TAKA10
3	te94	251				4	27	19	22	4	22	te94

DETRITAL ZIRCON AGE DATA FOR METAMORPHIC COMPLEXES OF CHILEAN PATAGONIA: PERCENTAGE PROPORTIONS IN GEOLOGICAL PERIODS

Data	Sample	Location	Strat. range (Ma)					Zircon percentages in selected age ranges					Sample
Source	Name/No.		young	old	Cret.	Juras.	Trias.	Per.	Carb.	Dev-Sil	Ord-Cam	Precam	Name/No.
	CHONOS METAMORPHIC COMPLEX												
7	CE96-03					2	16	16	8	18	24	16	CE96-03
7	FO96-06						12	42	15	12	5	15	FO96-06
7	CE96-25						12	20	28	15	4	22	CE96-25
7	FO96-40								5	4	16	75	FO96-40
	EASTERN ANDES METAMORPHIC COMPLEX												
7	PE99-32A					35	5	15	5	15	15	[illegible]	PE99-32A
7	FO98-P17						2	20	17	13	22	27	FO98-P17
7	FF99-01						4	10	8	12	10	56	FF99-01
7	FF99-05					4		22	16	12	24	27	FF99-05
7	S199-28C						2	6		12	24	56	S199-28C
7	SE99-08						2	18	2	10	40	28	SE99-08
7	VS11A								2	2	21	73	VS11A
7	PS98-01								2		11	86	PS98-01
	MAIN RANGE METAMORPHIC COMPLEX												
7	CE96-29						2	46	10	20	10	12	CE96-29
7	MA21									12	29	59	MA21
	DUQUE DE YORK METAMORPHIC COMPLEX												
	AL1						63	18	9	11	5	13	AL1
8	MD3						4	68	12	8	2	6	MD3
8	MD32							59	11	15	2	13	MD32

References

1. Ireland, 1992b
2. Adams *et al*., 1998
3. Cawood *et al.,* 2002
4. Pickard *et al*., 2000
5. Wandres *et al*., 2004a
6. Adams *et al*., 2007
7. Hervé *et al.,* 2003
8. Herve and Fanning, 2003

Percentage abundance categories

accessory	1-4%
minor	5-19%
major	20-49%
large	50-79%
dominant	80-100%

FIG. 2. $^{206}Pb/^{238}U$ detrital zircon ages for late Paleozoic-Mesozoic metasedimentary rocks of the Torlesse Composite Terrane in New Zealand (upper), compiled from Adams *et al.* (2007), and metamorphic complexes in Patagonian Chile (lower), compiled from Hervé and Fanning (2003), Hervé *et al.* (2003). Age data are divided into selected geological periods, and categorised as percentages of the total zircon set.

archipelago, autochthonous, passive-margin settings for the original sedimentary basins (see also Faúndez *et al.*, 2002). In this respect, Augustsson *et al.* (2006) reached a similar conclusion for the provenance of detrital zircons in higher-grade metasediments, of probable original Carboniferous age, in the mainland part of Chilean Patagonia. Considering only the magmatic zircons in their datasets (of which age subsets are consequently often rather small), significant proportions are Mesoproterozoic (>10%), early Paleozoic (>10%), and Devonian-Carboniferous (>15%) in age, all of which are compatible, in reasonable combinations, with a Zealandia origin. However, it must be conceded that detrital zircon age patterns in comparable late Paleozoic rocks having similar Mesoproterozoic, early Paleozoic and Devonian-Carboniferous components, are widely recognised along the south-central Andes (Chew *et al.*, 2007, 2008; Willner *et al.*, 2008; Bahlburg *et al.*, 2009). Indeed, the Mesoproterozoic and early Paleozoic-late Neoproterozoic detrital zircon components in particular are also commonly seen over thousands of kilometres, throughout East and West Antarctica and Australia, often in regions where possible source areas are surprisingly scarce or apparently absent. The examples along the South American Pacific margin cited above are usually within accretionary complexes where an autochthonous relationship at the Gondwana margin appears straightforward and probable. Comparing the U-Pb ages and Hf-isotope compositions of the detrital zircons from these complexes with possible Gondwanaland primary sources, the authors cited above all suggested sediment provenances in Paleozoic fold belts to the northeast and east, and more distantly in the Precambrian cratonic cores of Western Gondwanaland (southern Africa, East Antarctica, and central South America). There are abundant sources for the observed Mesoproterozoic and late Neoproterozoic zircons, admittedly by long (2,000 km) river transport, in southern Brazil, Uruguay, and northern Argentina. Closer sources of more limited outcrop, or known from drill-hole occurrences, of the required appropriate Paleozoic ages (Pankhurst *et al.*, 2003), were suggested in southern Argentina. However, the extensive Mesozoic-Cenozoic sedimentary cover there, and subsequent emplacement of voluminous Jurassic-Cretaceous igneous complexes in southern South America, makes the original extent and contemporary exposure of these primary source areas very difficult to assess. The authors did not consider any western provenances as suggested in this work, and in any case, the important additional contribution from zircon Hf-isotope data is unavailable to assess its validity. Although a Zealandia provenance seems distant, it can be seen from figure 3, that these sources are no more distant than some alternatives in eastern South America, for example Brazil, Uruguay, or East Antarctica. Thus the well-developed Mesoproterozoic, early Paleozoic and Devonian-Carboniferous zircon age patterns in Chilean Patagonian metasedi-

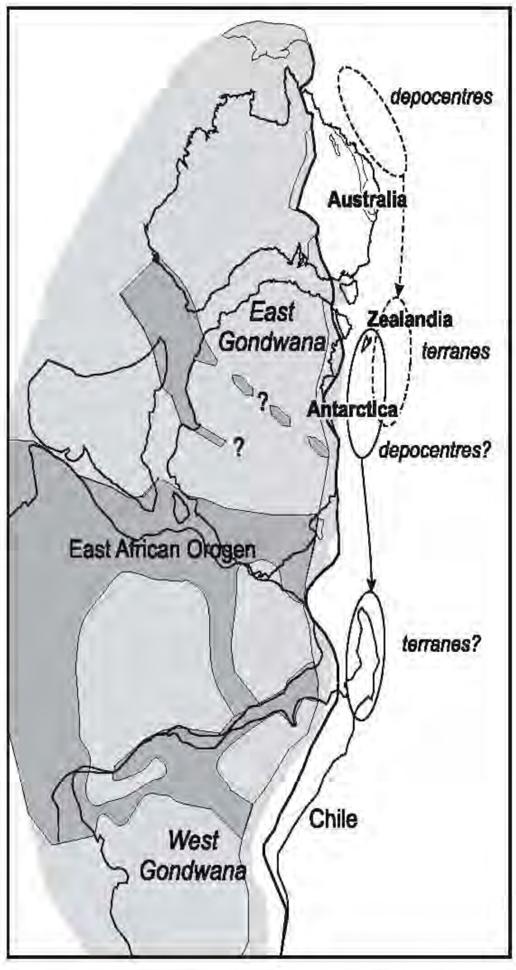

FIG. 3. The Pacific margin of Gondwanaland in the late Paleozoic-Mesozoic showing the development of major contemporary depocentres at the Australia-Zealandia margin, and their subsequent, margin-parallel, dextral displacement as suspect terranes.

ments recommend further evaluation of a western, Zealandia, provenance.

The dominant Carboniferous, Permian and Triassic zircon proportions (>70%) in the Duque de York complex (Faúndez *et al.*, 2002; Lacassie *et al.*, 2006), and significant proportions (>20%) in the Chonos and Eastern Andean complexes (Hervé and Fanning, 2003; Hervé *et al.*, 2003) must indicate the proximity (although not seen) of contemporary volcanic arcs, nearer to the Patagonian margin of Gondwanaland, that effectively blocked the input of detrital zircons from older sources to the east. The nearest examples of such a magmatic arc would be in northern Patagonia (Augustsson *et al.*, 2006).

8. Conclusions

The basement of southern Zealandia was consolidated by Carboniferous times, and constituted extensive tracts latest Precambrian-Ordovician deep-marine turbiditic metasediments, intruded by Cambrian-Ordovician and Devonian-Carboniferous granitoids. A limited sedimentary cover comprised shallow-water Devonian rocks. There may have been local, but uncertain, extension of the Median Batholith (and several Permian-Triassic terranes) in New Zealand southeastwards along the Zealandia margin.

Substantial uplift of this basement progressed through late Paleozoic time (at least Silurian to Carboniferous), and the consequent erosion and river transport should have provided voluminous sediments, of mainly granitoid compositions, to postulated marine sedimentary basins at the Pacific margin of Zealandia. These sediments would have carried detrital zircon populations dominated by Mesoproterozoic, late Neoproterozoic-Cambrian-Ordovician, and Devonian-Carboniferous age components.

The present-day absence of any such late Paleozoic sedimentary basins at the southern Zealandia continental margin suggests that they may have been tectonically transported elsewhere during the Mesozoic, as suspect terranes in a dextral, margin-parallel sense, similar to that of the Eastern Province (Permian to Cretaceous) terranes of New Zealand. A possible destination for these terranes would be in the metamorphic complexes of Chilean Patagonia. Detrital zircon age populations in their metasediments compare well with those that might be expected in Zealandia sedimentary basins, and thus a suspect terrane interpretation is permissible.

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