Laurentia, Australia, and Antarctica as a Late Proterozoic supercontinent: Constraints from isotopic mapping

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ABSTRACT

The reconstruction of Laurentia, Australia, and Antarctica into a Proterozoic supercontinent is evaluated by analyzing the fit of Precambrian provinces defined by isotopic and geochronologic mapping. The analysis is complicated by allochthonous segments of the Antarctic and eastern Australian margins. Removal of the allochthonous provinces produces a closer fit of the continents; there is a match of Early Proterozoic basement between southwestern Laurentia and the only exposure of craton known from the paleo-Pacific margin of Antarctica. In addition, western Laurentia is brought closer to the Australian Gawler block, consistent with provenance interpretations of the Belt Supergroup. Removal of the allochthonous provinces by right-lateral translation relative to the Antarctic craton margin places them in a pre-750 Ma position where they could be southwestward extensions of the Yavapai-Mazatzal and Grenville provinces of southern Laurentia. This modified reconstruction leads to a prediction of extensive Archean basement in Antarctica between the South Pole and Victoria Land, a prediction partly borne out by Archean rocks in the Miller Range of the Transantarctic Mountains; it also predicts the presence of 1.4 Ga rapakivi granites in the Transantarctic Mountains basement. This configuration implies assembly of the Australia-Antarctica Gondwana margin by terrane accretion following, or accompanied by, left-lateral translation. This is compatible with a tectonic regime of clockwise rotation of Laurentia relative to Australia and Antarctica after rifting. Thus, the proposed supercontinent, with some modifications, has potential for explaining several aspects of the pattern of Precambrian provinces in the three continents.

INTRODUCTION

The concept of a Late Proterozoic Laurentia-Australia-Antarctica supercontinent is derived from the rifted nature of the continental margins in question, the approximate age equivalence of the passive margin sedimentary rocks, and correlation of the Grenville belt with rocks of similar age in Antarctica (Moores, 1991; Dalziel, 1991; Hoffman, 1991). In support of this idea, Stump (1992) noted similarities in the Late Proterozoic geology of the southwestern United States and the Transantarctic Mountains, Young (1992) discussed similarities in Late Proterozoic sedimentary rocks of Canada and Australia, and Ross et al. (1992) suggested south-central Australia as the source of zircons in the Belt Supergroup of western Laurentia.

One test of this supercontinent is the compatibility of Precambrian basement near the margins of the three continents. Moores (1991) and Dalziel (1991) focused on Grenville-age rocks of Laurentia and Antarctica, but other information on age provinces has not yet been evaluated. We refer particularly to isotope studies that used combinations of Nd, Sr, Pb, and O on granitic rocks, and extensive U-Pb geochronology, to characterize continental provinces of western North America (Bennett and DePaolo, 1987; Hoffman and Bowring, 1984; Bowring and Podosek, 1989; Bowring et al., 1989), eastern Australia (McCulloch, 1987; Gray, 1990), and the Transantarctic Mountains (Borg et al., 1990; Borg and DePaolo, 1991).

The approach used to map age provinces was described by Bennett and DePaolo (1987) and Borg et al. (1990). The "ages" used are Sm-Nd model ages (DePaolo et al., 1991) and are a measure of average crustal residence time. These are generally slightly older than the oldest crystallization ages of the Precambrian basement rocks, but are comparable to crust-formation ages inferred from U-Pb work. Ages have been calculated in a consistent fashion to allow intercontinental comparisons. We do not defend the methods here, nor do we focus on interpretation of the ages; rather, we discuss where this mapping approach leads in evaluating paleocontinental configurations. This approach is particularly valuable in this case because the Precambrian basement rocks of interest are generally not exposed. Their existence and characteristics are inferred from isotope studies of younger granites that formed by melting of Precambrian crust at depth followed by emplacement high in the crust.

ISOTOPIC PROVINCES OF THE TRANSANTARCTIC MOUNTAINS

Isotopic provinces in the Transantarctic Mountains (Fig. 1) are based on Nd, Sr, and O studies of granitic rocks, prebatholithic metamorphic rocks, and lower crustal xenoliths in Cenozoic volcanic rocks (Armienti et al., 1990; Borg et al., 1987, 1990; Borg and DePaolo, 1991; Table 1) and are labeled in terms of Sm-Nd model ages (T_{DM}). With the exception of the new data in Table 1, most of the data used here[1] were considered by Borg and DePaolo (1991) in a discussion of the tectonic evolution of the Australia-Antarctica segment of Gondwana.

New data from Antarctica (Table 1, Fig. 1) allow extension of the basement province mapping of Borg and DePaolo (1991) and provide important information relating to the proposed supercontinent. The observation that T_{DM} ages for granites in the Horlick Mountains (1.26–1.44 Ga) are substantially younger than those of most of the Transantarctic Mountains (1.6–1.9 Ga) is particularly significant. New data from Darwin Glacier area granites (T_{DM} 1.72–1.94 Ga) and granulite xenoliths from the Transantarctic Mountains near McMurdo (T_{DM} 1.6–1.8 Ga) add to the geographic extent of the 1.6–1.9 Ga province. Amphibolite at Spear Nunatak, at the south end of the Horlick Mountains, has a Nd isotopic signature indicative of mid-ocean ridge basalt (ε_{Nd} = +8.6 to +7.7 at 0.5 to 1.0 Ga), and is inferred to locate a Precambrian suture. Further data on Miller Range metamorphic rocks confirm that the Miller Formation is Archean material and that the lower grade metasedimentary rocks on the eastern side of the Miller Range (Argosy Formation [?]) contain elements having both Archean and Proterozoic provenances

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[1]GSA Data Repository item 9418, Tables A1, A2, Element Concentrations and Ratios, and Table B, Sample Locations, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

Data Repository item 9418 contains additional material related to this article.

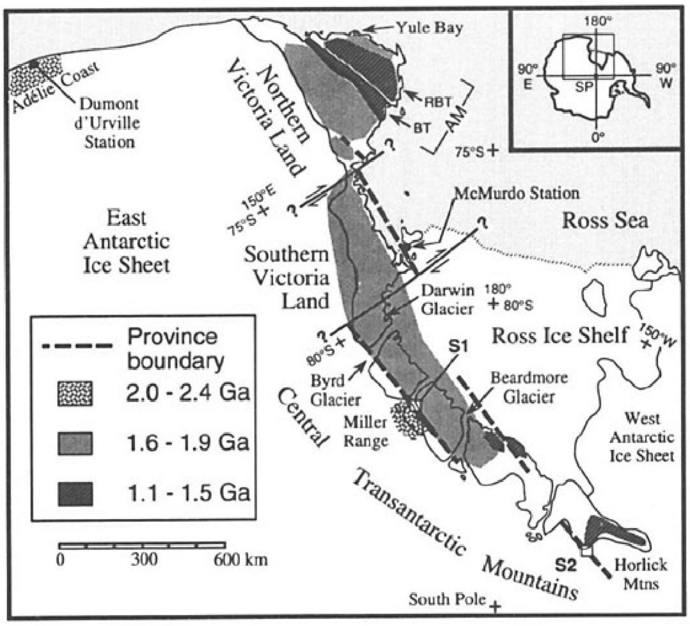

Figure 1. Map of Transantarctic Mountains region showing generalized distribution of Sm-Nd model ages (T_{DM}) of granitic rocks and inferred basement age-province boundaries. SP—South Pole; BT—Bowers terrane; RBT—Robertson Bay terrane; AM—Admiralty microcontinent. S1 (Cotton Plateau) and S2 (Spear Nunatak) are locations of rocks interpreted as oceanic sutures separating basement provinces. Strike-slip faults are speculative. Note that there is no evidence from basement provinces for large strike-slip faults under major glaciers of Transantarctic Mountains.

TABLE 1. SM-ND ISOTOPIC DATA AND MODEL AGES

Sample no.	Nd ppm	$^{147}Sm/^{144}Nd$	ε_{Nd} measured	ε_{Nd} 500 Ma	T_{DM}*
ADÉLIE COAST	Granite dike at Dumont d'Urville (T_C unknown)				
89 DDU 4	41.76	0.10614	-23.23	-17.46	2.36
SOUTH VICTORIA LAND					
	Granulite xenoliths in Cenozoic volcanic rocks (T_C set, 500 Ma)				
A83-82	17.00	0.1611	-7.09	-4.82	1.59
A82-182	23.56	0.1365	-6.55	-2.70	1.43
A84-239	34.10	0.1504	-10.82	-7.87	1.81
A84-256	18.67	0.1261	-9.96	-5.45	1.64
DARWIN GLACIER	Carlyon granodiorite (T_C = 0.568 Ga)				
89 BBG 101A	47.27	0.10241	-15.43	-9.41	1.91
89 DBG 4	27.16	0.13110	-11.80	-7.61	1.80
89 BBG 113	47.47	0.10164	-12.78	-6.70	1.72
	Horney Formation (gneiss)				
89 BBG 101B	44.43	0.11989	-14.11	-9.20	1.94
MILLER RANGE	Miller Formation (1 greenschist and 2 gneisses)				
86 BMR M36A	13.37	0.16863	-10.55	-8.77	3.48
86 BMR M37†	70.16	0.10281	-30.81	-24.83	2.83
86 BMR M39	25.74	0.10577	-33.33	-27.55	3.10
	Argosy Formation (?) (schist)				
86 BMR M24†	31.74	0.10575	-28.15	-22.36	2.72
85 DCT M2	45.99	0.10625	-15.81	-10.03	1.81
	Camp Ridge granodiorite (T_C ~ 1.7 Ga)				
86 BMR M28†	38.72	0.11817	-26.03	-21.03	2.74
HORLICK MTNS.	Granites (T_C ~ 500 Ma)				
HM 1	50.44	0.12901	-4.83	-0.49	1.26
HM 3	30.67	0.10554	-7.80	-1.96	1.38
HM 4B	39.10	0.10278	-8.77	-2.77	1.44
HM 5	17.25	0.13240	-6.55	-2.43	1.41
HM 16	6.61	0.18058	-3.29	-2.25	1.40
HM 33	28.54	0.14269	-5.69	-2.23	1.40
	Beardmore Group (?)				
HM 9A (wacke)	34.17	0.12280	-8.64	-3.91	1.52
HM 9B (shale)	47.67	0.12318	-8.71	-4.01	1.53
SPEAR NUNATAK	Mafic gneiss				
HM 14A	10.81	0.21131	9.53	8.61	
WHITMORE MTNS.	Granite (T_C ~ 120 Ma)				
WM 1	34.38	0.12282	-4.12	0.61	1.19

Note: Analytical procedures in Borg et al. (1990). $^{143}Nd/^{144}Nd$ normalized to $^{146}Nd/^{142}Nd$ = 0.63613. Values for ε_{Nd} are calculated with respect to a chondritic reservoir with present $^{143}Nd/^{144}Nd$ = 0.511836 and $^{147}Sm/^{144}Nd$ = 0.1967; λ_{Sm} = 6.54×10^{-12} yr^{-1}. Uncertainties: $^{147}Sm/^{144}Nd$, ± 0.1%; ε_{Nd}, ± 0.4.
J. Berg and R. Kalamarides provided the granulite xenoliths.
* Calculated relative to a model depleted mantle: for granites and granulite xenoliths, a time-dependent function for f(Sm/Nd) of the granite source (DePaolo et al., 1991) is used with the crystallization ages (T_C); for metamorphic rocks, measured Sm/Nd ratios are used.
† Values from Borg et al. (1990).

(Table 1). A single granitic dike from Dumont d'Urville indicates the presence there of Early Proterozoic crust.

In general, T_{DM} ages of 1.6–1.9 Ga are predominant in the Transantarctic Mountains, and form a nearly continuous north-south–trending belt extending ~2000 km from northern Victoria Land to south of the Beardmore Glacier (Fig. 1). Southeast of this region, the basement is younger—T_{DM} 1.1–1.5 Ga. Comparison of T_{DM} between Antarctica and western Laurentia suggests that basement in the Horlick Mountains region (Fig. 1) is Grenville type, whereas the basement farther north in the Transantarctic Mountains is mostly of Yavapai-Mazatzal type (cf. Bennett and DePaolo, 1987, Fig. 7; Patchett and Ruiz, 1989; Moores, 1991, Fig. 3). A granite sample from the Whitmore Mountains, northeast of the Horlick Mountains, also indicates Grenville affinity for the crust there. All of this basement material is inferred to be allochthonous to the remainder of the East Antarctic craton (Borg et al., 1990). This inference is based on the presence of basalt and metabasalt with mid-ocean ridge isotopic affinity at Cotton Plateau and Spear Nunatak (Fig. 1), which is interpreted to indicate sutures, and by the fact that the supracrustal clastic sedimentary rocks in the central Transantarctic Mountains, on Yavapai-Mazatzal-type crust, cannot be derived from known Antarctic sources and are inferred to have had an eastern source. Allochthonous blocks of the Transantarctic Mountains are inferred to have accreted to the preexisting Antarctic cratonic margin between 750 and 510 Ma. The preexisting cratonic margin, exposed only in the Miller Range area, consists of Proterozoic basement (T_{DM} 2.0–2.2 Ga, based on ca. 510 Ma granites) beneath metamorphic rocks having Archean T_{DM} ages (2.7–3.5 Ga; Borg et al., 1990).

Outboard of the Late Proterozoic accreted crust of the Transantarctic Mountains, in northeastern northern Victoria Land, are terranes inferred to have been accreted more recently (cf. Bowers and Robertson Bay terranes of Flöttmann et al., 1993; Admiralty microcontinent of Borg and DePaolo, 1991) (Fig. 1). This region contains Proterozoic Yavapai-Mazatzal–type crust (T_{DM} 1.7–2.0 Ga) in its extreme northeastern part and a Cambrian island-arc complex on its western margin (Weaver et al., 1984). These terranes extend northward into the Lachlan fold belt of southeastern Australia (Stump et al., 1986), and they were among the last terranes to be accreted to this margin (Borg and DePaolo, 1991; Flöttmann et al., 1993).

ISOTOPIC PROVINCES IN THE LAURENTIA-AUSTRALIA-ANTARCTICA RECONSTRUCTION

The extension of the Grenville province from Texas to Antarctica was a key element in Moores's (1991) reconstruction (Fig. 2A). However, without adjustments for the allochthonous terranes along

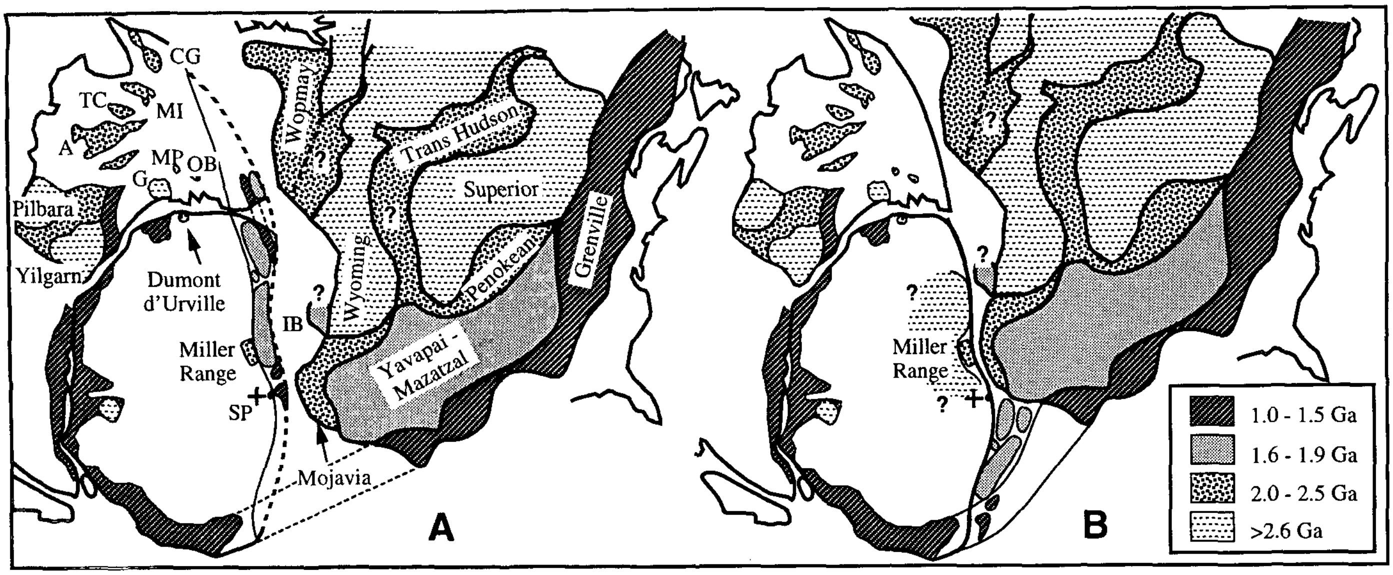

Figure 2. A: Reconstruction of Laurentia-Australia-Antarctica after Moores (1991) showing Precambrian basement provinces where known or inferred. North American provinces after Hoffman (1989), with modifications from Bennett and DePaolo (1987); T_{DM} ages of provinces extrapolated from Bennett and DePaolo (1987) and Bowring and Podosek (1989); Idaho batholith province (IB) based on our unpublished data. Australian provinces from McCulloch (1987), with modifications in southeast Australia based on data of McCulloch and Chappell (1982): A—Arunta; CG—Coen-Georgetown; G—Gawler; MI—Mt. Isa; MP—Mt. Painter; OB—Olary-Broken Hill; TC—Tennant Creek. SP is South Pole. Thin dashed lines show correlation of terranes from northern Victoria Land to southeastern Australia. Heavy dashed line approximates mid-Paleozoic boundary of Australian-Antarctic region; subparallel solid line represents pre–750 Ma edge of continents. All provinces near Australian-Antarctic margin, with exception of Miller Range, are inferred to have been accreted after 750 Ma, and must be removed to evaluate fit with Laurentia. B: Modified reconstruction in which allochthonous provinces of Transantarctic Mountains and southeastern Australia were translated about 3000 km in a right-lateral sense relative to Australian-Antarctic margin. Mojavia has been modified to compensate for Tertiary extension. In this configuration, Early Proterozoic basement of Miller Range matches with Mojavia province of southwestern Laurentia, and translated allochthonous terranes of Australia and Antarctica appear as extensions of the Yavapai-Mazatzal and Grenville provinces. In comparison to that of Moores (1991), this reconstruction places Belt Supergroup closer to Gawler block and Dumont d'Urville, consistent with provenance interpretations by Ross et al. (1992). This configuration predicts that Archean crust should exist in East Antarctica, bordering the Mojavia–Miller Range province, and that 1.6–1.9 Ga allochthonous terranes of Antarctica should contain extension of ca. 1.4 Ga rapakivi granite belt of Yavapai-Mazatzal province.

the Antarctic margin, there is not a good overall match of basement provinces. For example, the only possible match to the 1.6–1.9 Ga Antarctic provinces is the Idaho batholith region, but the general pattern of 1.6–1.9 and 1.1–1.5 Ga provinces in Antarctica and southeastern Australia disrupts the pattern of Early Proterozoic and Archean provinces in North America.

Lateral movements associated with terrane-accretion events have been mentioned in tectonic models (Rowell and Rees, 1989; Borg and DePaolo, 1991), but the only kinematic indicators that possibly bear on the style of accretion are from the Miller Range and were described by Goodge et al. (1991). The age of these structural fabrics is not well determined, but they are compatible with left-lateral oblique subduction prior to emplacement of the ca. 510 Ma granites. If these fabrics record terrane accretion in the central Transantarctic Mountains, then removal of these terranes to yield an earlier configuration requires right-lateral translation relative to the craton margin. This results in a reconstruction (Fig. 2B) that offers more possibilities for consistency and raises some potential tests of the hypothesis. In this configuration the basement of the Miller Range is adjacent to basement of similar age in Laurentia, and the allochthonous blocks of the Transantarctic Mountains are positioned so they could be extensions of the Yavapai-Mazatzal and Grenville provinces of Laurentia. The Australian allochthonous provinces could also be extensions of the Yavapai-Mazatzal province. This configuration also places the Belt Supergroup of Laurentia close to the Gawler block of Australia and the isotopically similar Dumont d'Urville area of Antarctica, consistent with the interpretation of Ross et al. (1992).

An interesting prediction is generated by this reconstruction and the configuration of Mojavia in southwestern Laurentia. As noted by Bennett and DePaolo (1987), basement provinces with T_{DM} ages of 2.0–2.4 Ga are normally adjacent to Archean cratons, as in the Trans-Hudson and Penokean provinces. However, there is no adjoining Archean craton for the westernmost part of the Mojavia province. Bennett and DePaolo (1987) hypothesized that originally adjacent Archean craton(s) had been carried away during rifting in late Precambrian time and should be found in some other continent. This reconstruction leads to the prediction of Archean crust in Antarctica adjacent to the Miller Range, as shown in Figure 2B. Evidence for Archean crust northwest of the Miller Range exists, in that Archean rocks (intruded by ca. 1.7 Ga granite) have been thrust to the southeast over 2.0–2.2 Ga crust (Goodge et al., 1991; Borg et al., 1990). In addition, metasedimentary rocks in the Miller Range, inferred to be Late Proterozoic in age, have Archean provenance ages (Table 1; Argosy Formation [?]). There is no other evidence bearing on the extent of this inferred Archean craton.

Another aspect of Laurentian geology leads to a second prediction. The belt of ca. 1.4 Ga rapakivi granites of North America (Anderson, 1983) follows the trend of the Yavapai-Mazatzal province. If the Antarctic allochthonous provinces are correctly placed in our reconstruction, then they should contain the extension of the 1.4 Ga granite belt. This could be tested by studies of inherited zircons in the early Paleozoic granites of the allochthonous Antarctic provinces.

In order to produce the present configuration from that shown in Figure 2B, Laurentia must have broken away from the Australia-

Antarctica cratons so that parts of the Yavapai-Mazatzal and Grenville provinces broke into fragments. If Laurentia rotated away in a clockwise fashion as suggested by Dalziel (1991), then fragments of these provinces could have been translated along the Antarctic margin in a dominantly left-lateral regime prior to accretion to this margin. Structures in the Miller Range are consistent with left-lateral transpression, but final accretion events need not conform to this style (cf. Flöttmann et al., 1993). Most of the material in the Transantarctic Mountains accreted between ~750 Ma and ~550 Ma (Borg and DePaolo, 1991), requiring that Australia-Antarctica split from Laurentia before 750 Ma. The Bowers and related terranes of northern Victoria Land and the Lachlan fold belt in southeastern Australia accreted later, so it is permissible, even in the context of this model, that fragments were removed from western Laurentia more recently than 750 Ma. This model is consistent with both the time of rifting in western Laurentia (Hoffman, 1989) and the concept that this rifting was protracted until, or perhaps renewed in, Early Cambrian time (Levy and Christie-Blick, 1991).

CONCLUSIONS

The Laurentia-Australia-Antarctica supercontinent proposed by Moores (1991) and Dalziel (1991) is difficult to test definitively, but one reasonable expectation is that continental basement provinces should form a consistent pattern in the reconstruction. Our analysis indicates that most of the basement in the Transantarctic Mountains is allochthonous to the East Antarctic craton and therefore must be removed to evaluate the match to Laurentia. By translating provinces of the Transantarctic Mountains in a right-lateral sense relative to the Antarctic cratonic margin, we obtain a configuration that is a reasonably good match to the western margin of Laurentia in a reconstruction similar to that of Moores (1991). Further implications of this reconstruction are that Archean crust should be prominent in the southernmost part of the present East Antarctic craton, and that the 1.6–1.9 Ga provinces of Antarctica should contain 1.4 Ga rapakivi granites. Overall, our analysis suggests that the Moores (1991) reconstruction has potential for explaining several features of the Antarctic and Laurentian Precambrian basement.

ACKNOWLEDGMENTS

Supported by National Science Foundation grants DPP-8846171 and DPP-8816925. We thank Tom Owens for assistance in the lab; I. Dalziel, C. Frost, J. Patchett, G. Ross, E. Stump, and an anonymous reviewer for helpful comments on the manuscript; and J. Berg and R. Kalamarides for granulite xenoliths from the McMurdo region.

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Manuscript received August 11, 1993
Revised manuscript received January 6, 1994
Manuscript accepted January 11, 1994