GSA REPOSITORY ITEM 2002040 TO ACCOMPANY PRE-NEOPROTEROZOIC (PRE-RODINIAN) OPHIOLITES: THEIR TECTONIC AND ENVIRONMENTAL IMPLICATIONS

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(Note to reader: the figure and citations are given in the main article in the Bulletin)

DETAILED INFORMATION ON PRE-RODINIAN OPHIOLITES

For reasons of clarity, complexes are discussed with respect to their position on the various modern recognized cratons, although it is clear from Figure 2 that the configuration of these cratons used to be very different. Figure 4 shows columnar sections for representative ophiolites.

BALTICA

Jormua complex (Symbol **JO** on figures 2 and 3; see also Figure 4B).

The Jormua complex (Kontinen, 1987, Peltonen et al. 1996) lies in the Baltic shield within the thrust complex of the Svecofennian orogen along the margin of the Archean rocks. It is the best preserved body in a 200 km long chain of ophiolite complexes exposed in the Kainuu schist belt between two rigid Archean blocks. Deformation includes early thrusting to the E (present coordinates) followed by multistage deformation and late N-striking strike slip faults. The sequence includes serpentinized peridotite, thought to be mantle peridotite intruded by gabbro, well-developed gabbro and plagiogranite, basaltic sheeted dikes and extrusive rocks, the latter deposited in places directly on serpentinite. Overlying sediments include mafic hyaloclastite, carbonate, and turbidites. Estimated thicknesses include 100-400 m of extrusives, more than one km of sheeted dikes, and about one km of peridotite and gabbro (see figure 4B. Using the discriminant diagrams of Pearce (1983), Peltonen et al., (1996) report the presence of two geochemical: an early fractionated ocean island basalt (OIB)-like suite, and a main suite similar to enriched mid oceanic ridge basalts (E-MORB), possibly representing a mixing of a depleted source with the OIB. There is no evidence of a "subduction" component. The magmatic age, based upon Pb-U dating of a gabbro, is 1954 ± 2 Ma. (Peltonen et al, 1996, p. 1359). The emplacement age may be that of the regional deformation about 50 m.y. later. This complex contains one of the few well-documented sheeted dike complexes in the Proterozoic. The incomplete thin sequence is reminiscent of a slow-spreading modern ridge or a transform fault. The Svecofennian has been correlated with the "Barramundi Orogeny" of Australia and referred to as "ensialic (O'Dea et al, 1997). A schematic columnar section of the Jormua complex is shown in Figure 4B.

LAURENTIA

ARCHEAN

Slave Province (SL)

Three described ophiolitic examples are included in this region. In the Cameron-Beaulieu River region of the Slave province, Kusky (1990) described a sequence of gabbro, sheeted dikes, pillow lavas with compositions similar to modern MORBs, and associated iron formation, with an Rb-Sr age on volcanic rocks of 2574 ±200 Ma.. The contacts with adjacent rocks are mylonite zones (cf Sylvester et al., 1997). Near Yellowknife, Helmstaedt et al. (1986) described a sequence of gabbro, sheeted mafic dikes, pillow lavas, and associated tuffaceous sediments, chert, and iron formation, approximately 12 km thick that they suggested was part of an ophiolite complex (Figure 4F). The nature of the basal contact is unclear but is probably tectonic. In the Pont Lake region, Kusky (1991) described a sequence, approximately 7 km thick and 2660-2667 Ma, of highly sheared cumulate ultramafic rocks, gabbro, sheeted diabase, silicic volcanic, pillow basalts, and associated iron formation, overlain unconformably by a turbidite sequence.

Wind River (WR)

In the Wind River Range, Wyoming, USA, the Diamond Springs formation consists of a complexly deformed suite of rocks including metamorphosed ultramafic rocks, gabbroic rocks, metadiabase dikes, and pillow lava with associated mica schist and banded iron formation. Harper (1985, 1986) intrepreted these rocks as part of a dismembered ophiolitic sequence. Geochemical data (Wilks and Harper, 1997) suggest compositions transitional between modern MORBs and island arc tholeiites. The dismembered ophiolite is intruded by a 2.63. ± 0.02 Ga granite pluton (Stuckless et al, 1985, in Wilks and Harper, 1997).

TRANS-HUDSON OROGENIC BELT & CORRELATIVES:

Purtuniq ophiolite (PU)

This well-developed ophiolite is located in the Cape Smith belt, Ungava Peninsula, where a series of S-vergent thrusts involve a thick ophiolitic sequence that forms the structurally highest thrust sheets of the orogenic belt (Scott et al, 1992; see figure 4B). Two suites are present: an older suite, more than 5 km thick, of pillowed/massive volcanic rocks, sheeted dikes, gabbroic layered cumulates with subordinate ultramafic cumulates and rare plagiogranite; and a younger sequence, more than 4 km thick, of sheeted mafic dikes, layered ultramafic-mafic cumulates similar to those of modern oceanic islands. Associated sediments include graphitic pelites and sandstones interpreted as deepwater turbidites.

Rare earth and Nd-Sm values indicate that the older and younger suites are similar to modern MORB s and OIBs, respectively (Scott et al., 1991). The magmatic (spreading age) is 1,998 ±2 Ma (Scott et al, 1992). The thickness of the composite section (Figure 4E) and the OIB compositions in the younger suite suggest that magmatic crust was thick, and that a mantle plume was operating during the formation of the complex. (ibid).

Flin Flon Belt/Amisk collage (Symbol *FF*).

This belt of rocks lies in the Trans-Hudson orogen, N. Manitoba. It consists of a multiply deformed and metamorphosed "collage" of distinct tectonostratigraphic assemblages including isotopically juvenile oceanic arc, ocean floor, oceanic plateau/ocean island, and isotopically evolved arc rocks, and basaltic turbidites, exposed over about 50 km across strike (Stern et al, 1995). The rocks include subaerial and submarine basalt associated with a mafic-ultramafic layered complexes. The largest body--the Elbow-Athapuscow assemblage--is up to 60 km long and approximately 3 km thick. The oceanic plateau--basalt sequence is also approximately 3 km. thick. The subaerially erupted basalts resemble OIB compositions, whereas the submarine basalts exhibit both N-MORB and E-MORB--transitional & plume basalts compositions (Stern, et al., 1995). The magmatic/spreading ages include 1.90-1.88 for the oceanic island arc, 1.92-1.90 Ga for the oceanic plateau and evolved arc, and 1.90 Ga for oceanic floor (1.90 Ga), with a presumed emplacement age of 1.87-1.88 Ga for formation of the collage (Lucas et al, 1996). Lucas et al. (1996) did not refer to these rocks as "ophiolitic", but they are clearly oceanic and would fit into that category. O'Dea et al (1997) correlate the Trans-Hudson with the "Barramundi" orogeny in Australia. Both orogenies are possibly parts of the global "Nuna" orogeny, possibly a supercontinent development (Hoffman, 1997).

New Québec (Labrador Trough; *NQ*)

In this region on the eastern side of the Superior province between the Churchill (Rae) and Superior provinces, the Willbob (Hellancourt) formation consists of tholeiitic basalt and turbidites associated with the Montagnais mafic-ultramafic intrusions (Rohon et al, 1993; Skulski et al, 1993). Geologically, these rocks are the tectonic equivalent of Ungava/Cape Smith zone but along the eastern margin of the Superior province, although heretofore, these rocks have not been described as ophiolitic. The sequence consists of a series of sills intruding into the volcanosedimentary sequence. The basalts, about 5.5 km.

thick, comprise three sequences separated by sediments. The basement of the sediments is older continental crust to west, but in east is it is unknown. The rocks are deformed in a decollement-style fold-thrust belt. Although the basalts may be autochthonous to the west, the degree of metamorphism & deformation increases to east, and the rocks may be truly allochthonous. The magmatic age of the volcanics is 1.87-1.88 Ga (Skulski et al, 1993). Geochemically the volcanic rocks consist of early primitive melts, followed by derivative melts, similar to transitional mid-ocean-ridge basalts (Skulski et al, 1993), picrites and basalts in the southern part of the exposure. Sills exhibit ultramafic-mafic cumulates; rock types include dunite, wehrlite, lherzolitic, olivine hornblende pyroxenite. The gabbros and volcanic rocks appear to be comagmatic. No sheeted dikes have been reported. The interlayered lavas and sediments are reminiscent of modern pull-apart basins, such as the Gulf of California (Skulski et al, 1993), or of modern sedimented ridges, such as the Juan de Fuca Ridge (Morton, et al., 1994).

Fox River /Thompson Nickel Belt (FT)

This extensive series of mafic-ultramafic rocks extends for hundreds of km along the Trans-Hudson Orogen along the northern margin of the Superior province (Baragar and Scoates, 1981, Scoates, 1981). The Thompson Nickel belt exhibits a series of interlayered metasedimentary, metavolcanic & ultramafic rocks as folded sequences within overprinted Archean migmatites. Volcanic flows are ultramafic to basaltic in composition. Sedimentary rocks include laminated siltstone, sandstone, quartzite, shale, phyllite, iron formation, minor chert and greywacke. Ultramafic rocks form pods and sill-like masses concentrated along western margin of the Thompson Nickel belt.

The Fox River belt consists of rocks similar to the Thompson Nickel belt, but which are relatively unmetamorphosed and deformed. It may be faulted against higher grade rocks of the Churchill as well as against Superior province rocks (Baragar & Scoates, 1981, pp. 313-314). The Fox River belt is about 300 km. long and includes sedimentary rocks, large differentiated sills, and ultramafic to mafic volcanic rocks exposed in a 15-20 km wide N-facing homoclinal sequence. The sequence is assumed to have been deposited upon Superior province gneiss, but the contact relations are obscure, and they could be tectonic. Metamorphism ranges from top to bottom from sub greenschist (top) to greenschist (bottom). Sedimentary rocks are present in three stratigraphic positions--lower, middle, upper, aggregating about 5 to 7 km thickness; they consist of siltstone, argillite, shale, sandstone, quartzite, dolomite, and locally developed hematite-magnetite-pyrite iron formation. Volcanic rocks are present as a 3 km thick lower and a 2 km thick upper sequences, intercalated with the sedimentary rocks. The lower volcanics consist from bottom to top of a 750 m thick massive zone of basalt, komatiitic basalt, and komatiite with pyroxene spinifex textures and layered flows, a 1150 m thick middle zone of pillow basalt and komatiitic basalt with some massive and composite flows, and a 400 m thick upper massive zone of homogeneous massive basaltic flows. Sills are abundant in the upper part of the lower sedimentary sequence. They range in length from 1.5 to 20 km, and average about 800 m. in thickness. Rocks include peridotite, clinopyroxenite, gabbro, and a granophyre-bearing roof zone. The Fox River sill is in the middle sedimentary unit; it is 2 km. thick, about 100 km. long, and exhibits 4 zones: marginal, lower central layered, upper central layered, and hybrid roof zone. . Cyclic units are present and range from dunite to mafic granophyre. The Fox River belt as a whole. may be fault-bounded homocline representing the upper part of thick oceanic crustal sequence

Long considered to be coeval, the two belts now appear to be quite different in age. Cumming et al (1982) report a Pb isochron model age of 2320 ± 20 Ma for the Thompson belt nickel ores and presumably also the including ultramafic rocks, whereas Heaman et al (1986) report an age of 1882.9 ±1.5 Ma for the Fox River sill. They are shown as the same symbol (**FT**), but are plotted separately on Figures 3 and 4.

MAZATZAL-YAVAPAI BLOCKS

Payson ophiolite (PA)

This body consists of a pseudostratiform sequence of mafic-silicic plutons, dike swarms, sheeted dikes, and submarine volcanic rocks overlain by dacite breccies with jasper lenses and a thick turbidite sequence (Dann, 1991, Dann and Bowring 1997; see Figure 4A). The 1.73 Ga rocks contain xenoliths and roof pendants of a slightly older sequence of granitic intrusives and felsic volcanic rocks. The rocks may be the remnant of an incipient rift within older crust. Chemically the ophiolitic rocks exhibit compositions similar to those of modern island arcs and back-arc basins.

Prescott complex (*PR*)

This complex consists of a multiply deformed sequence of serpentinized peridotite, gabbro, hypabyssal mafic volcanics, pillow lava, and turbidite sediments exposed in the Yavapai block of central Arizona. No chemical data are available for these rocks. (Anderson, C.A. 1972, Anderson, 1989, Moores, 1976). Anderson et al. (1971) report zircon Pb-U dates indicating that the rocks range in age from 1770 ± 10 to 1820 ± 10 for rocks apparently overlying the mafic-ultramafic complex

GRENVILLE OROGENIC BELT

Queensborough complex (QU)

This complex, located within the Grimsthorpe terrane of the Central Metamorphic belt of Grenville province, eastern Ontario, is exposed over an L-shaped area about 10 km wide and 50 km long, and includes the Greensborough, Kalada, and Caniff complexes (Smith and Harris, 1996). Bordered by mylonite zones, it consists of a sequence of cumulate peridotites and pyroxenites, structurally overlain by massive to highly sheared gabbros, mafic dikes, and a few enclaves of pillow lavas. Pyroclastic volcanics and siliceous clastic metasediments apparently overly the lavas. Rocks are metamorphosed to amphibolite facies and folded at least once. The complex is older than the Elzevir batholith (≈1.25 Ga). The thickness of mafic rocks about 5 km, but the structural effects on thickness have not been worked out. The tholeiitic and ultramafic rocks are thought to be cogenetic and chemically similar to the Vavilov basin in Tyrrhenian sea (Smith and Harris, 1996).

Coal Creek Domain (CC)

These rocks are located in the Grenville rocks of the Llano uplift, Texas. There Roback (1996) reported that the domain represents a series of intrusions with no identifiable sequence. They include the "structurally emplaced" Coal Creek serpentinite, as well as associated tonalitic & amphibolitic gneisses, foliated gabbroic, tonalitic, and granodioritic intrusions,. Igneous textures have been modified by shearing. The ages of the tonalitic and amphibolitic gneisses range from 1301 to 1326 Ma; those of the mafic-intermediate intrusions from 1275 to 1286 Ma. High-temp metamorphism is dated at about 1292 and 1256 Ma in mafic rocks. The map width of the "ophiolite" is about 5-10 km, with the 2.5 x 6 km Coal Creek serpentinite in the middle. The Coal Creek serpentinite contains Al-poor lizardite w/ subordinate magnetite, talc, chlorite, tremolite, anthophyllite, and olivine (Fo_{94}) and Ca-poor pyroxene (En_{93}); it is thought to represent metamorphosed cumulates. The abundance of intrusive bodies suggests an island arc environment. The relationship of the serpentinite to other rocks is unclear, but overall geology is reminiscent of some bodies in the Sierra Nevada (Mosher, 1998). (Smartville-type sequence; figure 1C).

AFRICA

Proterozoic

Kibaran complexes (*KI*)

The Mesoproterozoic Kibaran belt of eastern Africa is a zone of deformation containing a 350 km long long belt of mafic-ultramafic rocks, called the Kabanga-Musongati complexes. These complexes comprise layered intrusive bodies lying along the 10-35 km. wide boundary zone (suture?) between the "Western Internal Domain" and the "Eastern External Domain" of the Mesoproterozoic Kibaran mobile belt. The latter consists of the Archean Tanzanian Craton overlain by Mesoproterozoic foreland deposits

(Deblond & Tack 1999). The Western Belt contains terrigenous detrital sediments with intercalations of mafic-intermediate-acidic volcanics, intruded by abundant peraluminous 2-mica granites with subordinate mafic rocks (Deblond, 1994). Rumvegeri (1991) reported three "cycles" of basic magmatism, which he related to multiple deformational phases, as follows: 1. Metagabbro, metatuffites, amphibolitic sills--thought to represent initial rifting tholeiites, which are pre-D1 isoclinal folding; 2. pre 1400 Ma, silicic-intermediate "oceanic tholeiites", thought to be post D1 but pre D2 deformation and representing a "suprasubduction zone" environment; and 3. Mafic-ultramafic intrusive masses as much as 10 km thick--the layered intrusive bodies of Deblond (1994) and Deblond and Tack (1999). Associated sediments include metamorphosed turbidites, iron formation, quartzites, and calcareous rocks. Ages of younger granites are 1330-1260 Ma (5 Rb-Sr and 1 Pb-U determinations; Deblond, 1994, p. 8). Metamorphism in the western belt comprises exhibits a series of metamorphic isograds--biotite-garnet, staurolite, kyanite, and sillimanite (Rumvegeri, 1991). Tack & Deblond (1990) report the presence of at least one "thermal aureole" around one body, and report the presence of intrusive breccias and chilled margins. Most contacts on the most detailed maps (e.g. Deblond, 1994, p. 13, 21) are faulted, however.

Geochemical data on the intrusive complexes include: $Sr_{initial} = 0.708$, $\varepsilon_{ND} = -8$. There is little crustal contamination (Tack et al, 1994, in Deblond & Tack, 1999). The same authors argue that there is a major difference between ultramafic-noritic, and "gabbro-noritic" rocks. Both are derived from a tholeiitic magma source, but with different degrees of partial melting.

This belt of rocks is difficult to interpret. Rumvegeri (1991) argued for the existence of a suture and fragments of ophiolites. Deblond & Tack (1999) argued that the Kibaran orogeny is “ensialic” and thus that the Kabanga-Musongati intrusive complexes are intracratonic and intruded during an episode of sinistral transpression. However, I agree with Burke et al., (1977) that the Kibaran is not an ensialic orogen, but represents a true tectonic suture. The orogen lies along a separation of major blocks, and the mafic-ultramafic complexes need to be re-interpreted in that light. Yet the intrusive evidence seems also convincing, with magmas metamorphosing metasedimentary rocks. Three possibilities can be suggested: that these rocks represent remnants of subduction of a ridge as in Japan (Shiki & Misawa, 1982) or possibly a sedimented ridge, such as the Juan de Fuca Ridge (e.g Morton et al, 1994). They are included in the list of complexes as inferred ophiolites, but it is clear that much work remains to be done to document the basic field relations of this important belt.

KALAHARI-CONGO SUTURE

Chewore Ophiolite (CH)

The "Chewore inliers" lie along the boundary between the Zimbabwe and Congo cratons and constitute a 100 km long ENE trending belt of deformed ophiolitic and associated rocks (Johnson and Oliver, 2000). The Chewore ophiolite crops out as a SE dipping sequence along a 800 m long section along the Maunde River. The rocks are metamorphosed to low amphibolite facies, and some primary structures are preserved. Rocks from bottom to top include: a 25 m thick unit of highly altered, variably serpentinized, attenuated ultramafic rocks, interpreted as metacumulates; meta-mafic cumulates; metagabbro with sheets and anastomosing networks of plagiogranite; a 250 m thick sequence of sheeted dikes; a volcanic sequence, approximately 100 m thick, of 95% homogeneous metabasalt flows and 5% overlying pillow lavas. Metagreywackes and interbedded metapelites overly the volcanic rocks. A U-Pb age of 1393 ± 22 Ma on a plagiogranite dike indicates the magmatic age of the complex (Oliver et al, 1998). Johnson and Oliver (2000) report that geochemically the rocks resemble a modern back-arc or juvenile marginal basin environment, although they also imply that a considerable width of ocean originally existed between the cratons prior to their convergence and collision.

Lurio Belt (LB).

The Lurio Belt is part of a 3000 km long orogen extending from Mozambique to the Zambezi belt in southern Africa (Sacchi, et al, 1998; Pinna et al, 1993). Rocks within this belt include metamorphosed mafic-ultramafic intrusive rocks, described as garnet pyroxenite, serpentinite, amphibolite, gabbronorite, and anorthositic gabbro. Metamorphosism attains granulite facies, and the rocks are multiply deformed. Pinna et al (1993) report chemical data suggesting tholeiitic (possibly MORB?) and calc-alkaline trends. Pinna et al (1993) and Sacchi et al (1984) suggest that the rocks represent a deformed and metamorphosed ophiolite sequence. Sacchi et al (1998) suggest that they are part of a approximately 1000 Ma orogen that subsequently was involved in Pan-African events. If so, the "pre-orogenic" ophiolitic rocks would be pre-1000 Ma.

Mayombe (MA)

The Mayombe complex is located along the Congo river along the western margin of the Congo Craton. Vellutini et al (1983) reported strongly tectonized gabbro, dolerite, and associated schistose amphibolite with an estimated thickness of about 5 km. No chemical data are available for these rocks. Their age is estimated to be about 1000 Ma.

Kubongo (KU)

In the West African Craton within the Nangodi greenstone belt of NE Ghana, the Kubongo ophiolite forms the upper allochthon of a major decollement structure (Carlson, 1993). Carlson reported a 1.5 km thick sequence, from bottom to top, of massive isotropic pyroxene gabbros (together with float of layered gabbros with magmatic foliation); locally preserved sheeted dikes or sills, pillowed and massive mafic to ultramafic (komatiitic) lavas, and laminated manganese-rich cherts. Although not dated, these rocks are part of the widespread Birrimian greenstones of the West Africa craton. Granites intruding the greenstone have yielded an age of approximately 2.1 Ga by Sm-Nd and Pb-U methods (Abouchami et al, 1990). The lavas exhibit an ε_{Nd} = +1.2 to +4.3; they isotopically do not fit well with any modern lava types (Abouchami et al, 1990).

They may represent mostly a mix of MORB, and intraplate (oceanic plateau) types (Carlson, 1993; Abouchami et al, 1990);

KALAHARI CRATON

Pietersburg complex (PI)

The Pietersburg complex is located within the Archean Kalahari Craton in NE South Africa. It includes the Jamestone "ophiolite", consisting of and at least 5-10 km thick sequence of metaperidotites, gabbros (massive and layered), pillowed-massive metatholeiites that exhibit amphibole spinifex textures, with intercalated banded iron formation, overlain unconformably by a one km. thick sedimentary sequence of banded iron formation, conglomerate, sandstone, shales. Much thrusting, folding, and structural repetition has complicated the geologic picture (deWit et al, 1992). The magmatic age is possibly 3.4 Ga, major thrusting took place about 2.7-2.9 Ga, although the actual emplacement of the possibly ophiolitic rocks may be earlier. deWit et al (1992) attempt to relate this Archean greenstone belt to oceanic crust. Most of sequence is probably metamorphosed lavas; intrusive rocks apparently lacking. The first metamorphism is thought to be seafloor metamorphism.

Jamestown ophiolite (JA).

A sequence of mafic and ultramafic rocks within the approximately 3.5 Ga Barberton greenstown belt of the Kalahari craton has been interpreted as an ophiolite by de Wit et al (1987). Rocks include possibly tectonite peridotites (Sylvester, et al, 1997, p. 81), gabbro, and spinifex textured komatiites that may represent dikes or flows. The latter are in turn overlain by a chert-shale sequence. According to de Wit's (1987) the "tectonite peridotites", are serpentinized "dunites" with a moderate preferred orientation and relict small grains. He based his interpretation on the u-shaped nature of the rare earth element pattern, a supposed characteristic of mantle tectonites. The rocks are multiply folded with the surrounding rocks, however, and it is not clear from the descriptions whether the observed textures are original mantle textures, deformation of cumulate rocks at an original spreading center by a “hot fault”, similar to ones observed, for example in the Vourinos complex, Greece (Harkins et al., 1980), or subsequently developed during subsequent deformation.

INDIA

Phulad ophiolite (PH)

This body crops within the middle Proterozoic Delhi Supergroup in Rajasthan, India, part of the Aravalli orogenic belt (Volpe and MacDougall, 1990). It consists of dismembered, regionally metamorphosed mafic intrusive and extrusive rocks, mafic and ultramafic amphibolites, and associated serpentinites. Two basalt types are present--one with MORB affinities, and the other resembling low-K island arc basalts. Volpe and MacDougall (op.cit.) report an Sm-Nd whole rock isochron corresponding to an age of 1012 ± 78 Ma on a diorite chemically similar to the basalt.

SOUTH AMERICA

Pie de Palo (PP)

This complex consists of a series of highly sheared and dismembered ultramafic and mafic rocks exposed for approximately 30 km along the western margin of the Sierra de Pie de Palo, Pampean Ranges, west-central Argentina (Vujovich and Kay, 1998). The rocks include serpentinized ultramafic-mafic cumulates, dikes, and extrusives. Possible sheeted dikes were observed on a field excursion in 1994. Metamorphism ranges from greenschist to amphibolite facies. Available ages include a 1118 Ma $^{207}Pb/^{206}Pb$ age on a zircon from a metagreywacke intercalated with amphibolite, an approximately 1050 Ma Ar/Ar age on hornblende from mafic rocks with a U/Pb upper intercept of 1102 ± 6 Ma on a mafic schist. Thus an approximately 1.1 Ga magmatic age can be inferred for these rocks. Geochemically, the several compositional types have been interpreted as "back-arc", some "arc cumulates", some "ridge or arc/backarc lavas (including shoshonites"). The rocks may have formed offshore Laurentia and subsequently incorporated into the Grenville-age orogen now represented by the Llano uplift of south-central Laurentia and the eastern margin of the Precordillera microcontinent of west-central Argentina.

Niquelandia/Barro Alto/Cana Brava (NI)

This complex, 350 km long, lies in central Brazil along the boundary between the São Francisco and Amazon cratons. The complex comprises three separate bodies, from southwest to northeast, the Barro Alto, Niquelandia, and Cana Brava. It represents a thick sequence of mafic-ultramafic cumulates overlain by basaltic volcanic rocks (see figure 4E). Detailed work in the Niquelandia complex indicates the presence of a sequence of five fault-bounded units, from bottom to top: a basal fine-grained mafic unit of "primitive, less differentiated" rocks, an ultramafic unit of dunite, harzburgite, websterite, and bronzitite with subordinate lherzolite, plagioclase lherzolite and norite, two central mafic unit of gabbronorites with subordinate norite and ultramafic rocks, and an upper anorthositic gabbro with subordinate silicic and gabbroic rocks. The entire intrusive complex is overlain by an extensive sequence of volcanic rocks, the Indianapolis volcanics, considered to be ocean floor basalts (Danni et al, 1982; Danni and Kuijmjian, 1984, Araujo and Nilson, 1984, in Ferreira Filho et al, 1992). The grade of metamorphism increases from west to east (downsection) from amphibolite to granulite. Upper intercept Pb-U ages from zircons from a meta-anorthosite and a quartz diorite are 1583 ± 25 Ma and 1565 ± 22, respectively (Ferreira Filho et al, 1994).

Interpretations of this complex as an ophiolite (e.g., Girardi et al , 1986) conflict with those arguing that it represents a deformed, metamorphosed stratiform complex (Ferreira Filho et al, 1992) that underwent subsequent deformation during the Neoproterozoic (777-794 lower intercept ages).. All authors, however, acknowledge that the complexes are fault-bounded. This fact and the ubiquitous presence of volcanic rocks thought to be oceanic imply that they represent a structurally complex, thick oceanic crustal unit. Thus the complex is tentatively included in this list of possible ophiolite complexes. The complex may contain a juxtaposition of rocks originally separated by considerable distance. The basal mafic unit, thought to be a chilled margin could be parautchonous whereas upper parts of the complex could be far-traveled oceanic crustal slices, as seen in numerous Phanerozoic ophiolite complexes (e.g. Moores, 1982).

NORTH CHINA BLOCK

Dongwanzi ophiolite (DO):

Kusky et al. (2001) report on the approximately 14 km thick ophiolite extending for approximately 50 km along strike, consisting from bottom to top of serpentinized harzburgite tectonite (maximum thickness 70 m), approximately 4 km of ultramafic cumulate rocks, 3-5 km of layered to isotropic gabbro, 2 km of sheeted dikes, and a mixed pillow lava-dike complex, overlain by chert and banded iron formation. Pb-U zircon ages from the gabbro yielded a magmatic age of 2505 ± 2.2 Ma. The main serpentinized harzburgite unit forms a lens approximately 0.2 km wide and 2.5 km long within ultramafic cumulate rocks. Mafic and ultramafic dikes transect the tectonite and cumulate rocks. The Dongwanzi ophiolite represents the first full ophiolitic sequence yet described from the Archean. But having said that, the nature of the tectonite-cumulate interlayering, the dikes cutting the tectonites are more reminiscent of some fracture-zone ophiolites, such as the Jarbo Gap ophiolite, NW Sierra Nevada, than a true spreading center complex. No geochemical data are as yet reported for this ophiolite.

SOUTH CHINA BLOCK

Anjui-Jiangxi complexes (AJ).

Two zones of ophiolitic rocks are present along the Yangtze-Cathaysia suture boundary in south China, possibly (Li et al, 1997) to be separated by an island arc complex. In southern Anhui province, several bodies along Xiuning-Xixian fault zone consist of more or less intact sequences of metamorphic harzburgite, cumulate gabbro, spilite and keratophyre. They are thrust over older granite. In NE Jiangxi blocks of serpentinized peridotite, cumulate gabbro, dolerite, diorite, anorthosite, plagiogranite, spilite, keratophyre, basalt, and andesite are present enclosed in foliated flysch (melange).

Blueschist sporadically crops out. Sm/Nd ages average 972 Ma and 970 for the Anhui and Jianxi complexes, respectively. (Li et al, 1997). The rocks are intruded by 950-900 Ma post-collision granites (Li et al, 1995). Geochemically, the rocks show major and trace element concentrations reminiscent of modern island arcs (Chen et al, 1991, Li et al, 1997, p. 141).

Sibao ophiolite (SM).

Along the NW margin of the South China block, ophiolitic rocks in the Sibao melange are approximately 1.0-1.1 Ga, unconformably overlain by Neoproterozoic deposits. (Li et al, 1995, Li 1993).

AUSTRALIA

Giles Complex (*GI*)

This complex is located in central Australia in the Arunta orogen, one of a broad series of orogenic belts that lie between the older South Australia and North Australia cratons. The complex consists of four sheet-like mafic intrusions, generally elongate EW. The largest bodies are the Jameson Range gabbro--5500 m of gabbro, lherzolite, troctolite, and anorthosite; the Blackstone Range gabbro--3350 m of troctolite, norite, and gabbro; the Michael Hills gabbro--6400 m of gabbro, anorthosite, and pyroxenite. (Myers, 1990a, p. 284-285). Some authors (e.g. Daniels, 1967, Horwitz and Daniels, 1967) considered that the intrusive rocks are gradational into volcanics. High Al and Cr in pyroxenes in ultramafic rocks suggest 10-12 km (1.0-1.2 GPa) crystallization pressures (Goode & Moore, 1975). Similar pressures are also present in acknowledged ophiolites, e.g. the Yakuno ophiolite, Japan (Ishiwatari, 1985). The complex is isoclinally folded, refolded into upright WNW-trending folds (Myers, 1990a). Age determinations from the complex include a Rb-Sr age of 1060 ± 140 (in Myers, 1990a) and an zircon Pb-U intrusive age of 1078 ±3 Ma on gabbro (Glikson, et al., 1996). Glikson et al (1996) interpreted the geochemical data to indicate an origin by multiple intrusion of primitive to evolved magmas. The complex is thought to be a N-topping refolded isoclinal fold (Myers, 1990 fig. 3-69). facies. Metamorphism may decrease from E to W and and preserved thickness of the original thrust slice may thicken to the E, implying westward thrusting.. If so, the original thrusting may have been to the west. The complex is reminiscent of the island arc/ophiolitic rocks of lower-mid Paleozoic age of the Precordillera belt of central Argentina (Davis et al, 2000, deBari, 1994). For this reason, it is retained in the "possible" category of ophiolitic complexes.

Fraser complex (*FR*)

This complex is located in the Mesoproterozoic Albany-Fraser belt of SE Western Australia, which represents the collisional orogen between the Western Australia Craton and the South Australian-East Australian (Mawson Craton. (Myers, 1985, 1990b; Condie and Myers, 1999). It most recently has been described as a series of fault-bounded blocks (e.g. Condie and Myers, 1999). The complex crops out discontinuously (Myers, 1995 a, b) in a NE-trending belt, 200 km long and 30 km wide, of pyroxene granulite, and it can be extended another 250 km using gravity and magnetic data. Rocks include gabbro, anorthosite, leucogabbro, melanogabbro, and subordinate ultramafic rocks. Quartzose metasedimentary rocks lie along the northwestern side of the complex. Although most rocks are recrystallized at granulite facies, there is local preservation of igneous textures. The multiply folded rocks may represent a series of five or so NW vergent thrust sheets. Sm-Nd and Pb-Pb ages are approximately 1300 Ma (Condie and Myers, 1999). Multiple folding, the pronounced metamorphism, and poor exposure make it impossible to restore the original sequence or shape (Condie and Myers, 1999). The original thickness is also unknown, although the present cross-sectional thickness is approximately 30 km. The whole-rock geochemistry suggests iron enrichment towards the northwest, with the Mg number ranging from 70 to 30 (Myers, 1985, figure 3). Condie and Myers (1999) report that a strongly negative Ta and Nb anomaly suggests compositions similar to those in modern subduction zones, there is no evidence of crustal contamination, and Sr and Nd isotopic data suggest derivation from primitive mantle. Condie and Myers (1999) suggest that the Fraser complex might represent an amalgamation of a series of island arc complexes.

Narracoota-Trillbar complex (NA)

This complex is located in the southern margin of the Capricorn Orogen (2.0-1.6 Ga) between Yilgarn and Pilbara cratons of Western Australia (Myers, 1989, 1990c; Hynes & Gee, 1986, Occhipinti and Myers, 1999, Occhipinti et al, 1998, Pirajno and Occhipinti, 1998). The complex comprises a complexly folded mafic-ultramafic sequence. Rock types include mafic-ultramafic schists, dunite, pyroxenite, rhythmically layered gabbro, sheeted dikes, and pillow lava (Pirajno et al, 1998; Pirajno and Occhipinti, 2000), and possibly ultramafic extrusive rocks with associated turbidites, chert, and minor carbonate. (Hynes and Gee, 1986). A maximum thickness of four to six km has been reported (Pirajno and Occhipinti, 2000), but the thicknesses are certainly affected by the structural complexity. The complex comprises at least in part a series of at least three thrust sheets, forming a refolded isoclinal, south directed, recumbent antiform (Myers, 1989, fig. 3, p. 129). The magmatic age of the rocks is approximately 2000 Ma, based upon a U-Pb age of 2014 ± 22 on detrital zircon in the overlying sediments, and a Pb-Pb age of 1929± 35 on syngenetic pyrite; metamorphism and deformation may be about 2000 Ma as well (Occhipinti and Myers, 1999). Geochemically the rocks are characterized by low Ti, variable silicon, the ultramafic rocks exhibit a Mg number of 78, but is lower in mafic intrusive and volcanic rocks (Pirajno and Occhipinti, 2000). The rocks are thought to resemble MORB and boninite compositions (Hynes and Gee, 1986, Pirajno and Occhipinti, 2000). Pirajno and Occhipinti (2000) suggested that the complex may have formed in a back-arc basin above a south-dipping subduction zone (present coordinates) beneath the Yilgarn block, but the island arc has not been identified.

Tickalara complex (*TI*)

This complex is located in the Halls Creek Orogen along the SE margin of the Kimberly block, norwestern Australia. It consists of a series of mafic and ultramafic layered intrusions as much as one km thick (Sheppard et al, 1998) and associated mafic intrusive and extrusive rocks and associated metasedimentary rocks, including chert, banded iron formation, turbidites and calcareous sediments. Rocks are metamorphosed from greenschist to granulite facies. Individual "intrusions" are as much as 300-1000 m thick (Sheppard et al, 1999; Hamlyn, 1980); the metamorphic complex extends for approximately 30 km. Ultramafic rocks include harzburgite, dunite, with minor chromitite. Mafic intrusive rocks include gabbro, anorthosite, dolerite and minor granite. Magmatic ages include Rb/Sr ages of 1764-1900 Ma (Griffin, 1990), and 1863 and 1856 Ma U-Pb on the granitic and ultramafic rocks, respectively (Page and Hancock, 1988, Page et al, 1995, in Sheppard et al., 1999). Geochemical data on the metamorphic rocks suggest the existence of two chemical groups, one similar to E-MORBs, and the other have depleted compositions similar to modern island arc/back arc basin (Sheppard et al., 1999).

In the slightly older Biscay formation Sheppard et al, (1999) reported basalts similar in composition to modern enriched mid-ocean ridge basalts (E-MORBs) and continental flood basalts (. These authors suggest an island arc/back arc basin and rifted continental margin setting, respectively for the two basalt units, with juxtaposition during the Halls Creek orogeny by *ca* 1820 Ma.

Kalgoorlie (*KA*) and Norseman (*NO*) complexes

These complexes are present in the Kalgoorlie terrane of the Yilgarn block, SW Australia (Fripp and Jones, 1997). Near Kalgoorlie, exposures along the shores of Kanowna Lake (a usually dry lake about 20 km NE of the town of Kalgoorlie) display sheet-like units of serpentinized dunite, dolerite, high-Mg mafic rock, and associated pillow lavas, volcanic breccia, and interlayered sediment. Paleo-horizontal inferences from the sediments suggest that the original angle of intrusion of the sheet-like intrusions was 35° to 80° (ibid, p. 427). The Norseman rocks crop out along the edges of the usually-dry Lake Cowan and along the margins of islands within the lake. There a assemblage exists from ultramafic intrusive rocks through massive and layered gabbro to sheet-like intrusive complexes. Both the Kanowna Lake and Lake Cowan localities display multiply chilled margins reminiscent of Phanerozoic sheeted dikes. Fripp and Jones (1997) argued for a spreading origin for these rocks, similar to Phanerozoic ophiolites. The ages of these rocks are 2.6-3.4 Ga as evidenced from Pb/U dates from xenocrystic or magmatic zircons within volcanic rocks and overlying sediments. Fripp and Jones (1997) presented no geochemical data to indicate the composition of the source of the mafic rocks. The ultramafic intrusive and extrusive rocks may be related to each other. Based on a brief wet personal visit in April, 2000, with Fripp and Jones, the evidence seems convincing for multiple chilled margins in a dike complex, as they describe. Together these sites suggest spreading involving komatiitic and mafic lavas during Archean time in the Kalgoorlie terrane, and they are reminiscent of other Archean ophiolitic rocks described above (see also Sylvester, et al., 1997). The nature of the ultramafic rocks is uncertain. Some textures suggest recrystallization reminiscent of mantle tectonites, but others suggest that they represent slightly deformed ortho- and adcumulate peridotites and dunites.

ANTARCTICA

Krylen Intrusions (***KR***)

These bodies, located in the Jekelsen Nunataks, Dronning Maud Land, Antarctica, consist of a series of mafic and silicic intrusions (Bredell, 1982). One intrusion comprises a 300 m. thick "sill" of granodiorite/monzodiorite and quartz diorite overlain by andesite. The mafic intrusions are thought to be younger than 1700 Ma. The nature of the basal contact is unknown.