New look at the Siberian connection: no SWEAT

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New look at the Siberian connection: No SWEAT

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ABSTRACT

The Proterozoic connection between northeastern Siberia and western Laurentia that we proposed in 1978 is strongly supported by several new lines of evidence. New age data and refined structural trends in predrift basement rocks improve the resolution of the fit between the cratons. The mouth of the large river that is inferred to have provided the point source for the lower part of the Mesoproterozoic Belt-Purcell Supergroup in western Laurentia aligns with the Mesoproterozoic Udzha trough of Siberia. The elbow bend in the Udzha trough bypasses the Archean Wyoming Province to link the Belt-Purcell basin with Paleoproterozoic regions in southwest Laurentia having appropriate Nd crustal-residence ages and zircon crystallization ages to have provided sources for much of the sediment. The Grenville and Granite-Rhyolite provinces of southwest Laurentia provide sources for detrital zircons and felsic volcanic fragments in the east-derived Mesoproterozoic Mayamkan Formation of Siberia. The ages of mafic sills in the Sette-Daban region of Siberia overlap those in southwest Laurentia. Ediacara occur in off-shelf environments on both margins. The two margins have very similar latest Neoproterozoic–earliest Cambrian rift-drift signatures, including a breakup unconformity and Tommotian shelf assemblages that record the onset of thermally driven subsidence. Two possible submarine volcanoes with archeocyathan caps may confirm the establishment of Early Cambrian seafloor spreading.

The Siberian–west Laurentian connection provides better correlations among prerift terranes than does the southwest United States–East Antarctic connection (SWEAT), and is more compatible with the overall geologic history of Laurentia and Gondwana.

Keywords: Siberia, Laurentia, Gondwana, Belt-Purcell, Rodinia, tectonics, rifting, reconstruction, paleogeography.

INTRODUCTION

The Siberian connection that we proposed in 1978 (Sears and Price, 1978) was challenged during the 1990s by a number of reconstructions of the hypothetical Precambrian supercontinent Rodinia. Following an original idea by Jefferson (1978), the southwest United States–East Antarctic (SWEAT) connection and its many variants placed the eastern margin of Australia-Antarctica against the western margin of Laurentia (Moores, 1991; Dalziel, 1991; Hoffman, 1991; Ross et al., 1992; Young, 1992; Borg and DePaolo, 1994; Li et al., 1995; Blewett et al., 1998; Karlstrom et al., 1999). Other restorations placed the Siberian craton in various orientations against the northern margin of Laurentia (Hoffman, 1991; Condie and Rosen, 1994; Frost et al., 1998; Rainbird et al., 1998). Meert (1999) concluded that existing paleomagnetic data are sufficient only to test paleogeographic relationships between two or three proposed Rodinian fragments, and only at discrete and widely separated time intervals.

Geological restoration of the western Laurentian margin is thus a critical step in resolving more difficult questions concerning the overall configuration of Rodinia. In this paper we improve the geological resolution of our original restoration with the new data from Siberia and Laurentia, and propose an Early Cambrian time of separation for the Laurentian and Siberian cratons.

PALEOPROTEROZOIC

The western margin of Laurentia, as defined by the palinspastically restored initial $^{87}Sr/^{86}Sr = 0.706$ isopleth, fits tightly against the northeast margin of the Siberian craton, as defined by the Taimyr and Verkoyansk thrust belts (Fig. 1). In this configuration, basement trends and age domains of the Siberian craton dovetail with those of western Laurentia.

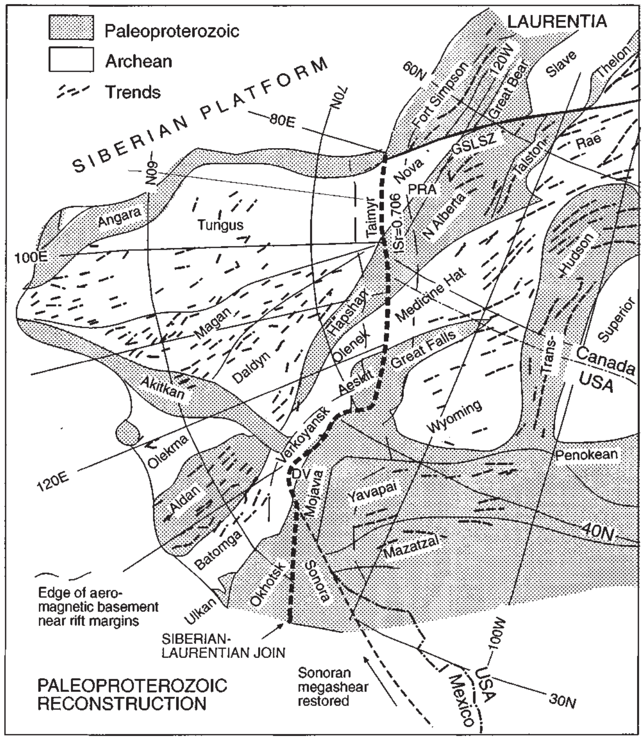

Figure 1. Paleoproterozoic reconstruction of Siberian craton and western Laurentia. Margin of Laurentia is ISr = 0.706 isopleth, in Canada as defined by Armstrong (1988), but with 450 km of right slip restored on Tintina–Northern Rocky Mountain Trench fault system, and in United States as structurally restored by Link (1993) and Price and Sears (2000). Conjugate margin of Siberian craton is Taimyr and Verkhoyansk thrust belts. Precambrian domains and trends of Laurentia compiled from Hoffman (1988), Gehrels and Ross (1998), and Van Schmus and Bickford (1993). Precambrian domains of Siberian craton are compiled from Condie and Rosen (1994) and Frost et al. (1998); structural trends are from Kosygin and Parvenof (1975) and Khain (1985). Present lines of latitude and longitude are shown for orientation. PRA—Peace River arch; GSLSZ—Great Slave Lake shear zone.

Condie and Rosen (1994, p. 168) objected to our original reconstruction (Sears and Price, 1978) because ". . . juvenile Early Proterozoic crustal belts in southwestern North America do not continue into Siberia, which is almost entirely Archean crust." However, Ramo and Calzia (1998) found Nd isotopic evidence for a substantial Archean source component in the Death Valley area of Mojavia, near the rifted Laurentian margin, and a 1740 Ma U-Pb zircon crystallization age from the Okhotsk massif in Siberia (cf. Rainbird et al., 1998) correlates with U-Pb dates from the Mojave, Yavapai, and Mazatzal provinces (Van Schmus and Bickford, 1993).

MESOPROTEROZOIC

The Mesoproterozoic Belt-Purcell basin is a focal point in the predrift restoration question because it is a large, distinctive feature that is truncated at the western margin of Laurentia (Fig. 2). Sedimentological analyses show that most of the terrigenous sediment in the Belt-Purcell Supergroup entered the basin from the southwest (Frost and Winston, 1987; Cressman, 1989). Price (1964) interpreted the voluminous fine siliciclastic sediment in the lower part of the supergroup as the load of a large river that drained a terrane of continental dimensions. Cressman (1989) suggested that the large river entered the Belt-Purcell basin at a distinct point on the southwest side (arrowhead in Fig. 2). On our restoration, that point aligns with the Mesoproterozoic Udzha trough in Siberia (Kosygin and Parfenov, 1975; Khain, 1985). Accordingly, we conclude that the Udzha trough directed a large sediment-laden river into the Belt-Purcell basin, and that this explains the rapid filling of the basin with relatively fine siliciclastic sediment. Furthermore, the elbow bend in the Udzha trough links the Belt-Purcell basin with provinces in southwest Laurentia of appropriate Nd crustal residence ages to have provided sources for the sediments, while bypassing the Archean Wyoming Province (cf. Frost and Winston, 1987).

Ross et al. (1992) and Ross and Villeneuve (1999) reported ages of 1.86–1.435 Ga for detrital zircon that entered the basin from the southwest. These broadly overlap the zircon ages of source rocks in southwest Laurentia (Van Schmus and Bickford, 1993). The 1590–1575 Ma detrital zircons are comparable with the ca. 1576 ± 13 Ma Laclede gneiss of Idaho (Doughty et al., 1998).

The Belt-Purcell basin followed a linear depression from central Montana to the rifted Laurentian margin. Isopachs in the northwest part of the basin are truncated at the Laurentian margin (Cressman, 1989). Our restoration aligns the truncated Belt-Purcell basin with the truncated Taimyr trough, a deep linear depression on the north margin of the Siberian platform that contains a thick but poorly understood Mesoproterozoic stratigraphic section (Kosygin and Parfenov, 1975; Khain, 1985).

East-derived feldspathic sandstones of the Mesoproterozoic Mayamkan Formation of Siberia contain lithic fragments of granite and felsic volcanic rock and yield detrital zircon grains ranging in age from 1.50 to 1.05 Ga (Rainbird et al., 1998). Our model places the Mayamkan region near the 1.2–1.0 Ga Grenville province, the 1.37 Ga Granite-Rhyolite province, and 1.5–1.4 Ga granite of southwest Laurentia, thereby providing proximal sources of the appropriate ages for the immature Mayamkan sandstones. Furthermore, detrital zircon grains from the Mayamkan sandstone correlate with those from Cambrian platformal-miogeoclinal rocks of southwest Laurentia (cf. Rainbird et al., 1998; Gehrels and Stewart, 1998).

Rainbird et al. (1998) reported U-Pb dates of 1005 and 974 Ma from two mafic sills in the Sette-Daban area. They noted that these dates do not correlate with the Franklin or MacKenzie mafic provinces near the northern Laurentian margin, obviating three proposed Siberian–northern Laurentian restorations (Hoffman, 1991; Condie and Rosen, 1994; Frost et al., 1998). On our reconstruction, the sills occur near the region of southwest Laurentia characterized by 1.1–1.0 Ga mafic sills, volcanic rocks, and dikes (Heaman and Grotzinger, 1992; Elston and McKee, 1982; Van Schmus and Bickford, 1993).

NEOPROTEROZOIC

The northeast margin of the Siberian craton and the western margin of Laurentia can be correlated as sides of an intracontinental rift, more than 2500 km long (Fig. 3). The Laurentian side formed the footwall (Warren, 1997). In southwest Canada, the Windermere Supergroup contains ~4 km of pebbly, immature, feldspathic grits that contain detrital zircons indicative of a provenance in uplifted basement rocks of southwest Canada (Ross and

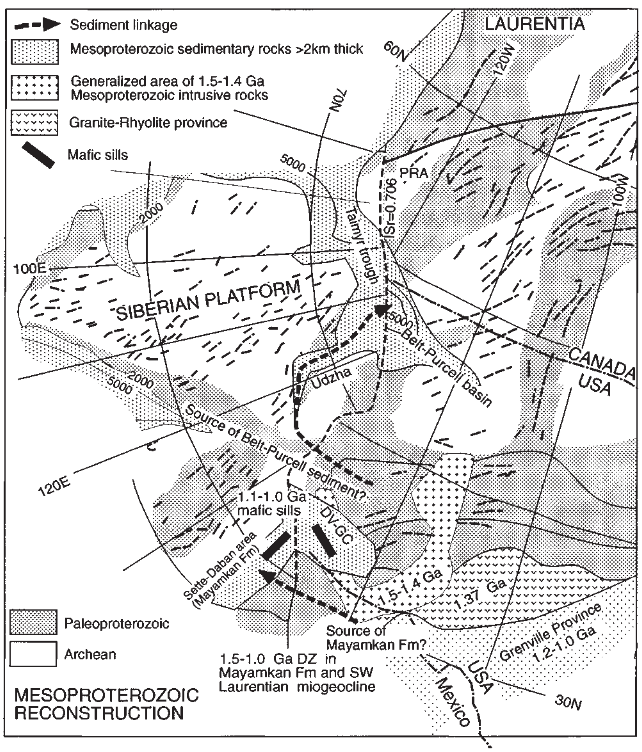

Figure 2. Mesoproterozoic reconstruction of Siberian craton and western Laurentia. Axis of palinspastically restored Belt-Purcell basin (Price and Sears, 2000) is aligned with Taimyr trough, and point of input of lower Belt-Purcell fine siliciclastic sediment (Cressman, 1989) is aligned (arrowhead) with Udzha trough. Isopachs in meters are from Kosygin and Parfenov (1975) and Cressman (1989). To explain ages of detrital zircon and mean Nd-isotopic age of Belt-Purcell Supergroup we suggest that Udzha trough funneled sediments from southwestern Laurentia to Belt-Purcell basin. Mayamkan Formation in Sette-Daban area (Rainbird et al., 1998) may have been derived from Grenville and Granite-Rhyolite provinces. DV-GC—Death Valley–Grand Canyon; PRA—Peace River arch; DZ—detrital zircon.

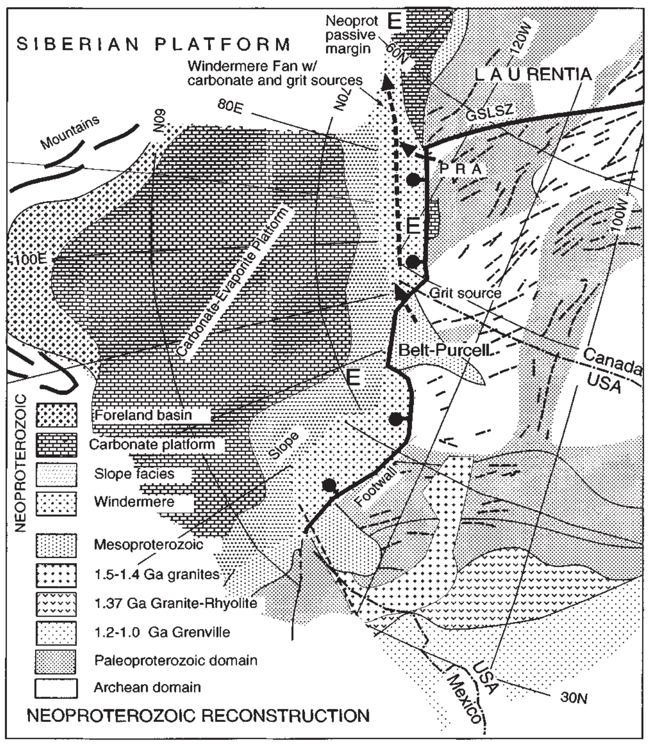

Figure 3. Neoproterozoic reconstruction of Siberian craton and western Laurentia. Siberian craton facies are after Pelachaty et al. (1996); Laurentian facies are after Ross et al. (1995), Ross (1991), and Stewart (1972). Eastern margin of Windermere basin was west-dipping detachment fault (Warren, 1997). Uplifted footwall provided coarse feldspathic clastic sediments to asymmetric rift that opened north of Great Slave Lake shear zone (GSLSZ) and Angara-belt margin of Siberia into older ocean basin with Neoproterozoic shelf-slope break (Dalrymple and Narbonne, 1996). Peace River arch (PRA) formed source area at rift corner. Neoproterozoic carbonate shelf and slope on Siberia faced uplifted rift margin on Laurentia that provided granitic basement source rocks for gritty turbidites in northwest-flowing sediment dispersal system in Windermere Supergroup of Laurentia (Ross et al., 1995). Ediacaran fauna (E) occur in off-shelf environments on both margins.

Bowring, 1990). The grits form part of an extensive, deep-water turbidite dispersal system in which flow was mainly to the northwest (Ross et al., 1995). Allodapic carbonate beds are intercalated with the turbidites at several stratigraphic levels. These were interpreted by Ross (1991) as the vestiges of a hypothetical former passive-margin carbonate shelf subsequently removed by pre-Paleozoic uplift and erosion. Other carbonate units occur in the upper part of the succession and an extensive carbonate ramp occurs along the northeast side of the Siberian craton (Pelachaty et al., 1996). Both contain Ediacaran fauna in off-shelf environments.

A late Neoproterozoic carbonate platform and related slope facies with contourites occur in northwestern Laurentia (at ~60N in Fig. 3), and imply the existence of an adjacent ocean basin (Dalrymple and Narbonne, 1996). We suggest that the Windermere intracontinental rift opened into this passive margin at the Angara belt (Siberia) and Great Slave Lake shear zone (Laurentia).

LATE NEOPROTEROZOIC–EARLIEST CAMBRIAN

The Siberian and Laurentian margins (Fig. 4) both record Early Cambrian rift-drift transitions. Conspicuous uplift and volcanism on the northeast Siberian rift shoulder, beginning possibly at 555 Ma and culminating from ca. 543 to 530 Ma, was followed by postrift thermal subsidence in the early Tommotian (Pelachaty et al., 1996). In southwest Canada, late Neoproterozoic grabens and associated mafic volcanics are overlain, above a breakup unconformity, by an extensive late Neoproterozoic–Early Cambrian quartz arenite in the upper Hamill–Gog Groups (Devlin and Bond, 1988; Lickorish and Simony, 1995; Warren, 1997). The southwestern United States has a Neoproterozoic stratigraphic record that includes two rifting events (Link, 1993; Prave, 1999), the first of which failed to open an ocean basin. Thermally induced passive-margin subsidence began after the second event, but prior to formation of archeocyathan reefs that occur along both the western margin of Laurentia and on the Siberian platform (Fritz et al., 1991; Riding and Zhuravlev, 1995).

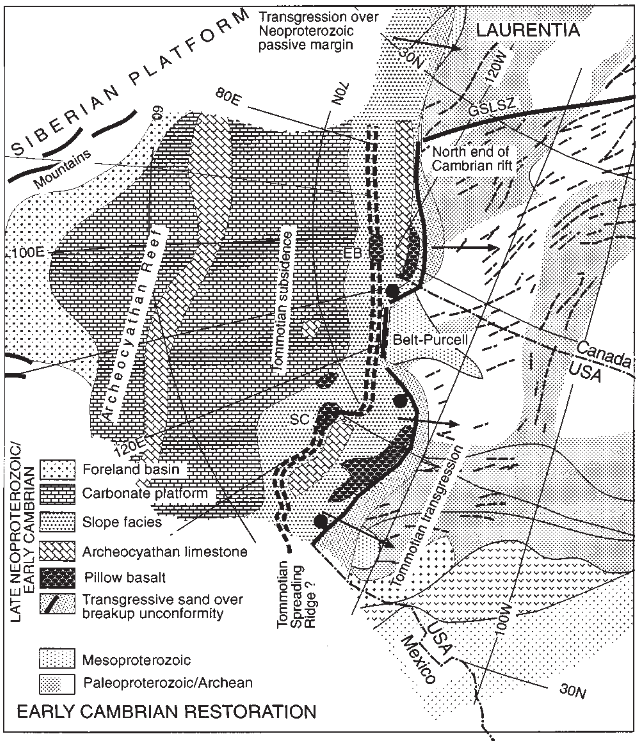

Figure 4. Early Cambrian reconstruction of Siberian craton–western Laurentia Siberian craton at onset of drift (ca. 530 Ma). Siberian facies are after Riding and Zhuravlev (1995) and Pelachaty et al. (1996); Laurentian facies are after Stewart and Suczek (1977), Fritz et al. (1991), Warren (1997), and Schiarizza (1986). Prominent uplift, extensional faulting, and related mafic volcanism occurred in latest Neoproterozoic–Early Cambrian, followed by Tommotian thermal subsidence at various localities along margin. Archeocyathan localities associated directly with pillow lavas and oceanic facies sediments in Eagle Bay Formation (EB) and Scott Canyon Formation (SC) may mark volcanic seamounts associated with Tommotian mid-ocean ridge. Cambrian rifting is limited to area south of Great Slave Lake shear zone (GSLSZ).

The Scott Canyon Formation of northwest Nevada and the Eagle Bay Formation of southeast British Columbia comprise mafic pillow lava and volcaniclastic rocks and archeocyathan limestone in associations that could represent the flanks of oceanic volcanoes (Stewart and Suczek, 1977; Schiarizza, 1986). These allochthonous assemblages restore outboard of the Isr = 0.706 isopleth. They could be vestiges of a Tommotian spreading ridge, and could provide direct evidence for onset of the seafloor spreading that separated Laurentia and the Siberian craton.

SWEAT AND NORTHERN LAURENTIA–SIBERIA RESTORATIONS

The SWEAT connection failed a key geologic test when a giant radiating dike swarm that was proposed to have been fragmented by the separation of Laurentia and Australia (Park et al., 1995) proved to be noncorrelative on the separate fragments (Wingate et al., 1998). The SWEAT hypothesis also suffers from a severe timing constraint; it requires Australia-Antarctica to have separated from Laurentia in time to have recombined with Gondwana (Hoffman, 1991). A key test that three proposed Siberian–northern Laurentian connections fail is that the widespread and distinctive 723 Ma Franklin and 1267 Ma Mackenzie mafic dike swarms do not extend into Siberia (cf. Rainbird et al., 1998). Our Siberian connection provides more proximal sources for the immature Mayamkan Formation than does the fourth northern Laurentian version (Rainbird et al., 1998).

CONCLUSIONS AND TESTS

We conclude that the Siberian and western Laurentian cratons were contiguous in Mesoproterozoic time, and that they were separated by latest Neoproterozoic–earliest Cambrian rifting and seafloor spreading.

We offer the following specific tests for our hypothesis: (1) further isotopic study of Okhotsk massif for correlation with southwest Laurentia; (2) sedimentologic analysis of Mesoproterozoic rocks of northern Siberia for correlation with Belt-Purcell Supergroup; (3) isotopic dating of mafic dikes in Olenek massif for correlation with mafic complexes in truncated Belt-Purcell basin, and search for Laclede gneiss equivalent; (4) sedimentologic analysis of Mayamkan sandstone of Siberia for correlation with Proterozoic sandstone of southwest Laurentia; (5) additional precise U-Pb dating of mafic sills and dikes in southwest Laurentia for correlation with Sette-Daban area; (6) dating of mafic rocks in Taimyr for correlation with mafic rocks in Windermere Supergroup; (7) mapping Neoproterozoic-Cambrian faunal diversity between Siberia and Laurentia; (8) sedimentologic analysis of early Paleozoic rocks of Sette-Daban for comparison with Cordilleran miogeocline; (9) U-Pb dating and isotopic fingerprinting of Eagle Bay and Scott Canyon pillow basalts to test for mid-ocean ridge or ocean island basalt signatures and comparison with Siberian basalts; and (10) refinement of Mesoproterozoic-Cambrian paleomagnetic data from the Siberia platform for comparison to Laurentia.

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