Precambrian sedimentary rocks

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Burchfiel et al., DNAG

Figure 13. Regional stratigraphic correlation chart for Proterozoic sedimentary rocks in the southwestern Cordillera, illustrating the inferred correlation of quartzite sequences in this study (adapted from Link et al. 1993; additional data from Timmons et al. 2001; Cox et al. 2002; Stewart et al. 2002; Lund et al. 2003). Grinnell Mountain and Dog Wash quartzites are components of the Paleoproterozoic basement and are not representative of a regionally widespread Joshua Tree terrane. Pinto Mountain Group is correlated with Cordilleran Proterozoic succession A and is therefore similar in age or slightly younger than quartzites of the Mazatzal Group of the Tonto Basin Supergroup. Big Bear Group is pre–Stirling Quartzite in age and correlated with the early part of succession C deposited in the earliest stages of Neoproterozoic Cordilleran rifting.

Wash quartzite indicate that quartzite-bearing metasedimentary rock sequences to the west of the type section are not correlative with the Pinto Mountain Group. This observation significantly reduces the areal extent and significance of the Joshua Tree terrane of Powell (1981) but is consistent with the definition of the more diminutive Placer Mountain assemblage of Powell (1993). We conclude that the Pinto Mountain Group is an early postorogenic shallow shelf sedimentary succession deposited on west Mojave province crust, coincident with but unrelated to the rift that initiated the Cordilleran miogeocline in this region.

Structural and stratigraphic evidence suggests that the Big Bear Group is distinctly younger than the Pinto Mountain Group yet older and deposited in a different tectonic setting than the Neoproterozoic-Cambrian miogeoclinal sequence (Stirling Quartzite and higher units) that overlies it. Paleo-current data suggest that siliciclastic sediment was transported north and northeastward during Big Bear Group deposition but southwestward, off the established west-facing Cordilleran continental shelf, by upper Stirling and Wood Canyon time. Detrital zircon data indicate that the shift in palo-current directions, although not accompanied by a recognizable shift in transport distance or degree of recycling, was accompanied by a shift in the geochronologic and possibly the lithologic character of siliciclastic sediment provenance. We therefore propose that the older Big Bear Group records a different depositional setting than the Stirling and younger miogeoclinal units in this region.

Stewart et al. (2002) suggested a correlation with Cordilleran Proterozoic succession B, their Neoproterozoic Rodinian epicontinental sequence. However, if further work confirms that much of the Big Bear Group is younger than 625 Ma yet pre-Stirling in age, a correlation with the early part of succession C and a tectonic setting in the earliest stages of Cordilleran Neoproterozoic rifting seems more likely (fig. 13).

The paleocurrent and detrital zircon age data reported here can help to define the location and geologic character of the provenance of these sedimentary sequences. As discussed by Stewart et al. (2001), most age populations of detrital zircons in miogeoclinal rocks (3.4–2.3, 1.8–1.6, 1.45–1.40, and 1.2–1.0 Ga) can be matched to observed basement rocks, suggesting a western North American Belt Supergroup.
Doe et al., 2013

**Figure 1:**

A. **Epsilon Hf vs. Age (Ga) Plot**

- **DM**: Detrital Melt
- **CHUR**: Chondritic Uniform Reservoir
- **T_{DM} = 2.1 Ga**: Time of Detrital Melt

**Legend:**
- **Gawler**: Green Circles
- **Mt. Isa**: Yellow Squares
- **Defiance**: Blue Diamonds
- **Blackjack**: Light Blue Diamonds

**Age Ranges:**
- 1.60–1.54 Ga
- 1.59–1.50 Ga
- 1.54–1.48 Ga
- 1.48–1.45 Ga
- 1.45–1.40 Ga
- 1.40–1.35 Ga
- 1.35–1.30 Ga
- 1.30–1.25 Ga
- 1.25–1.20 Ga
- 1.20–1.15 Ga
- 1.15–1.10 Ga

B. **Map of Australia and Surrounding Regions**

- **NAC**: North Australian Craton
- **MI**: Mt. Isa Inlier
- **WAC**: West Australian Craton
- **SAC**: South Australian Craton
- **GC**: Gawler Craton
- **Mawson**: Mawson Province
- **E. Antarctica**: East Antarctica

**Signatures:**
- **Ca. 1.5–1.45 Ga**: Sedimentary basins
- **Ca. 1.6–1.5 Ga**: Magmatism/tectonism
- **Ca. 1.6–1.3 Ga**: Accretionary orogen
- **Ca. 1.6–1.2 Ga**: Proterozoic orogen
- **Archean-Proterozoic craton**

C. **Relative Probability Distributions**

- **Mt. Isa Province**: 1.60–1.54 Ga
- **Gawler Craton**: 1.62–1.55 Ga
- **Blackjack**: 1.60–1.48 Ga
ROSS and VILLENEUVE

Figure 20. Summary figure of basin geometry and source-area evolution for the Belt basin (during deposition of the Lower Belt and Middle Belt Carbonate). Age-density probability-distribution diagrams are shown for all relevant units examined in this study; the diagrams have common age scales, and the Archean-Proterozoic boundary (2500 Ma) and North American magmatic gap (red lines) are shown as comparative benchmarks. The general basin geometry is modified from that of Winston (1986a). The eastern source area is viewed as geomorphically subdued and contributed limited detritus to the basin. The southern source area was tectonically active and contributed material that was restricted largely to the Helena embayment, although paleocurrents may have flowed as far north as British Columbia (e.g., Aldridge Formation). The western craton dominated the provenance signature to the basin as shown by regional Nd data and facies patterns. According to Winston et al. (1999), the southern part of the Belt basin, west of the Dillon block, may have been closed. The nature of the boundary between the western craton and the Belt basin is unknown. The source area may have lain tens to hundreds of kilometers to the west. Additionally, the boundary to the basin may have been a normal fault, strike-slip fault, and/or an oblique-slip structure.

Figure 21. Speculative model for the tectonic setting of the Belt basin and western North America ca. 1450 Ma wherein western North America is a convergent margin. The geology of pre-Grenville Laurentia is taken from Figure 1 (this paper) and the lower part is a model for Cretaceous tectonics of central Iran, centered on the Caspian Sea with north towards the top of the page (from Şengör et al., 1988). In the Cretaceous example, the south Caspian Sea is a pull-apart basin developed behind a collisional belt that includes magmatic components. Analogy is drawn between the pull apart origin of the south Caspian and the Belt basin. Broadly speaking, the western craton is postulated to have been analogous to the accretionary blocks of central Iran, whereas the Laurentian craton is analogous to the Turan block. The inset to the left shows a large-scale shear couple with the Dillon Block as the extensional head of the pull-apart basin, the Laurentian craton as the passive basin margin, and the western craton as the tectonically active basin margin. The Belt basin and south Caspian Sea are plotted at approximately the same scale.
Lower Belt Detrital Zircons

These ~1.5 Ga zircons uncharacteristic of NAm, but common in Australia, Baltica (and Amazonia)
Ross and Villeneuve

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Belt basin contains extensional structures...
...maybe oblique pull-apart? Analogy to K SW Asia

Ross & Villenueve, GSA Bull 2003
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Corsetti and Hagadorn 2000) and overlying Wood Canyon Formation (Signor and Mount interval in the upper Stirling Quartzite and over- including the Neoproterozoic-Cambrian boundary units correlative with the Cordilleran miogeocline, Bear Group lies structurally above a sequence of Paleoproterozoic gneiss with angular unconfor- mity on the underlying gneiss. Both the gneiss and quartzite, or quartzite rest with angular unconfor- mity on the Paleoproterozoic basement in the San Bernardino Mountains. The nomenclature for these metased-imentary rocks evolved as workers recognized their stratigraphic and structural complexity (see review figs. 8, 10), though structural and stratigraphic nomenclature for Proterozoic sedimentary sequences in the Transverse Ranges, showing relative stratigraphic position of detrital zircon sample horizons. The Pinto Mountain Group is a siliciclastic-carbonate se-quence that rests unconformably in the Paleoproterozoic basement in the Pinto Mountains and extends southeastward along the north-central range front (Brown 1991).

Paleozoic time (Stewart 1982; Bahde et al. 1997). Stratigraphic sequence, sedimentary struc- 
rion—coupled with the lack of identified Ordovi- 
ian and Silurian rocks suggests that the San Bernardino Mountains region lay within the cra- 
licher, low quartzite-dominat ed sequences stra- 
ter character of this metasedimentary sequence—including 
graphically beneath rocks of the upper Stirling 
phyllite of the Big Bear Group originated strati- 
mites, and paleocurrent data, however, suggest that 
work on the Green Spot Formation is necessary to 
zoic in age; if so, the offset across the southern 
movement of ca. 1400–1450 Ma detrital zircons suggests that 
bars show the range of ages of basement igneous rocks; 
similar detrital zircon age distributions, defining a max-

Dog Wash 
$n=19$

Pinto Mountain Group 
$n=80(4)$
1.4 Ga plutonism really a SE US thing...
Mesoproterozoic:
Extension in Belt
Stable in Pinto Mtns
Stable + little extension in Apache Group
“Anorogenic” granites
Figure 13. Regional stratigraphic correlation chart for Proterozoic sedimentary rocks in the southwestern Cordillera, illustrating the inferred correlation of quartzite sequences in this study (adapted from Link et al. 1993; additional data from Timmons et al. 2001; Cox et al. 2002; Stewart et al. 2002; Lund et al. 2003). Grinnell Mountain and Dog Wash quartzites are components of the Paleoproterozoic basement and are not representative of a regionally widespread Joshua Tree terrane. Pinto Mountain Group is correlated with Cordilleran Proterozoic succession A and is therefore similar in age or slightly younger than quartzites of the Mazatzal Group of the Tonto Basin Supergroup. Big Bear Group is pre–Stirling Quartzite in age and correlated with the early part of succession C deposited in the earliest stages of Neoproterozoic Cordilleran rifting.

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Grand Canyon Supergroup (Chaur Group over Unkar group)
The Dox Formation is interpreted here as a fluvial-dominated distributary channel sandstone bed in intrafluvial deposits with unidirectional paleocurrent indicators dominating the base of the Dox section that records a regression from marine Shinumo marginal marine deltaic to tidal flat beds (Stevenson, 1973). Mafic intrusive rocks cross-cutting rocks of the Unkar Group are commonly associated with Cardenas magmatism. The 1600-m-thick Chuar Group unconformably overlies the Nankoweap Formation and includes two main formations, the Galeros and Kwagunt Formations. A thin (30 cm) carbonate bed and a sandstone bed, and a thin (30 cm) carbonate bed in the Comanche Point Member, a continuation of Shinumo-age seismicity, and two marker layers are described as informal members: the bottle-green member, and the fan-jointed member, and three marker layers are described as informal members: the bottle-green member, the fan-jointed member, and the lapillite member (Lucchitta and Hendricks, 1983). The lapillite member is ~90 m thick, highly interbedded with massive fluvial red-bed sandstone, and volcanic bombs (<1 m) in matrix, suggesting that basaltic volcanism was contemporaneous with red-bed deposition. The Cardenas Basalt shows interbedding of basalt with volcanic bombs (<1 m) in matrix, suggesting that intrusive and extrusive rocks were coeval and shared a common source. Intrusive rocks of the Unkar Group are similar in mineralogy and chemistry to the basalts, suggesting that intrusive and extrusive rocks were coeval and shared a common source. Intrusive rocks cross-cutting rocks of the Unkar Group are commonly associated with Cardenas magmatism.
Mild 1.2 Ga NE-trending monocline
1.1 Ga grabens
0.76 Ga extension (e.g., 700m slip on Butte Fault)
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Crystal Spring below Beck Spring
Substrate is: Crystal Spring Formation south of Goler Wash, lower Proterozoic metamorphic rocks in Goler Wash and Coyote Canyon.

Miller, GSA Bull, 1985
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Figure 16. Correlation of lower Mesoproterozoic and Neoproterozoic successions in the southwestern United States, showing three main tectono-stratigraphic packages and unconformities: (1) 1350–1250 Ma intracratonic successions; (2) 1250–1100 Ma syntectonic intracratonic deposition; (3) ca. 900 Ma unconformity bounded sedimentary rocks; and (4) ca. 800–700 Ma synrift deposits (Dehler et al., 2001). Radiometric ages are cited in the text (figure modified after Link et al., 1993).

Timmons et al., 2005
Several observations suggest that the older crust is the source of the detritus that formed the Uinta Mountain Group arkosic arenites. These conclusions are based on the following evidence:

1. The oldest detrital zircons in the Uinta Mountain Group are Paleoproterozoic, consistent with the presence of an ancient source.
2. The dominance of detrital micas of Archean age suggests a source of Archean age.
3. Step-heated grains of Mesoproterozoic age are compatible with the presence of Archean zircons in the source.
4. The cooling ages of 2.1–2.2 Ga are consistent with the Proterozoic mica ages.
5. The distribution of Hf isotopic compositions from the modern Mississippi River sands is compared to those from the Uinta Mountain Group.

In summary, the evidence supports the conclusion that the older crust is the source for the detritus that formed the Uinta Mountain Group arkosic arenites.

**Map**

- **Legend**
  - Cambrian quartzite
  - Red Pine shale
  - Mount Watson Formation
  - formation of Hades Pass
  - formation of Dead Horse Pass
  - formation of Moosehorn Lake
  - formation of Red Castle
  - Precambrian basement

- **Color Coded**
  - Meso-Neoproterozoic sedimentary rocks
  - Canadian Grenville
  - Appalachian Grenville

- **Locations**
  - UMG-1
  - UMG-2
  - UMG-3
  - UMG-4

**References**

Mueller et al., Geology 2007
with proposals by numerous workers that the Grenville-age crust of the southern Appalachian orogen, in particular, shows evidence of crustal recycling (e.g., DeWolf and Metzger, 1994; Sinha et al., 1996; Loewy et al., 2003; Tohver et al., 2004; Mueller et al., 2005).

The lack of correlation between detrital mica ages from UMG-2b and the minimal Mesoproterozoic zircon signal in UMG-2 likely reflects rapid changes in provenance during deposition of the Uinta Mountain Group, rather than varying degrees of reworking of detritus from a single source (e.g., Wallace and Critten-den, 1969). In particular, the presence of white mica in these sedimentary rocks strongly suggests that the Mesoproterozoic detritus is not multicyclic and is unlikely to have been derived from older strata (e.g., Unkar Group; Timmons et al., 2005; Fig. 1). These data are compatible with the interpretation of Condie et al. (2001), who suggested that the psammitic and pelitic components of the Uinta Mountain Group sands had significant differences in provenance based on heavy mineral assemblages.

The fact that these arenites and arkosic sands are interbedded in the Uinta Mountain Group (e.g., Sanderson, 1984; Dehler and Sprinkel, 2005) indicates that detritus from two distinct sources was alternately admitted and excluded from the basin to a significant degree and is compatible with a depositional model in which the Uinta Mountain Group was deposited in a rift basin marginal to the southern Wyoming province (e.g., Link et al., 1993). The interplay of Archean and Mesoproterozoic detritus preserved in the Uinta basin suggests that the northern (e.g., Wyoming craton) and eastern margins were topographically higher than the southern and western boundaries (Yavapai-Mazatzal terrane) throughout most, if not all, of the depositional history. Detrital zircon ages reported here and in Fanning and Dehler (2005) suggest a continuous flow of Mesoproterozoic detritus that was episodically diluted or excluded from the basin in favor of Archean detritus derived from the southern Wyoming province when the northern (and/or eastern) margin was actively eroding. Evidence for this interpretation is the similarity of the Mesoproterozoic detrital age distributions of the composite Uinta Mountain Group and Stewart et al. (2001) databases, despite the more pronounced Archean signature in the Uinta Mountain Group composite (Fig. 2). Although there are no rigorous constraints for the time at which the Grenville flood...
Maximum depositional age and provenance of the Uinta Mountain Group and Big Cottonwood Formation, northern Utah

Abundance of the colonial bacteria *Bavlinella faveolata* in both the Red Pine Shale and the upper Chuar Group suggest a pre-Sturtian age (>~726–660 Ma; Dehler et al., 2007; Hoffmann and Li, 2009; Nagy et al., 2009) (Fig. 2B).

Paleo magnetic data from the Uinta Mountain Group also suggest a mid-Neoproterozoic age (and correlation with the Chuar Group) based on comparison with the apparent polar wander path (APWP) for Laurentia (~800–740 Ma from Chuar Group data; Weil et al., 2006). The microfossil *Cerebrosphaera buickii* was recently found in the lower Chuar Group (Nagy et al., 2009). This acritarch is thought to be an index fossil for pre-glacial strata younger than ~777 Ma (Hill et al., 2000). Maximum depositional ages for the Uinta Mountain Group and the Chuar Group are 900 and 942 Ma, respectively, and come from U-Pb analysis of detrital zircons (Timmons et al., 2005; Mueller et al., 2007).

**Big Cottonwood Formation**

The Big Cottonwood Formation, exposed in the central Wasatch Range east of Salt Lake City and areas to the west (Slate Canyon, East Tintic Mountains, Stansbury Island, and Carrington Island), is a 5-km-thick succession of sandstone, orthoquartzite, and argillite with a basal conglomerate interval (Figs. 1 and 2A). This unit is positioned structurally below the thrust sheets of the Sevier orogenic belt and, although associated with thrust faults (several km of displacement), has not been significantly displaced with respect to its original location on the craton (Crittenden, 1976; Ehlers et al., 1997). Ehlers and Chan (1999) interpreted this formation to represent fluvial and marine deposition based on facies architecture and analysis, and the presence of tidal rhythmites in some intervals. The Big Cottonwood Formation is interpreted to have been deposited together with the Uinta Mountain Group to the east in a tide-dominated estuary whereby a west-flowing fluvial system was intermittently drowned by the open ocean (Ehlers et al., 1997). Paleocurrent data show three modes of flow directions (NW, SW, and SE), similar to paleoflow trends in the Uinta Mountain Group units (Table 1).

Dehler et al., GSA Bull 2010
Mountain Group, Big Cottonwood Formation, correlation. These correlations place the Uinta hypothesized age of the lower Chuar Group of geographic relationships. The maximum age of further supporting their correlation and paleo-
trital zircon age populations from the Big
Succession B of western North America. De-
refi

Paleogeography and Tectonics

DISCUSSION

were ultimately carried via marine currents dur-
less of the primary source, the 766 Ma grains
Arc in South Australia (Preiss, 2000). Regard-
jugate Rodinia rift margin, such as from the
from eastern Laurentia or the proximal con-
Considering the paucity of ~766 Ma grains in
760 Ma (Su et al., 1994). There are no known
North Carolina Blue Ridge are between 750 and
plutonic rocks of the Crossnore Complex in the
line during maximum transgression onto western Laurentia at ~766 Ma.

Also shown are the potentially coeval Shaler and related river systems in northern Lau-
nental margins (black arrows).

Dehler et al. (2008) good geology, showing transcontinental Uinta
fi

Figure 7. Paleotectonic recon-
ed from Goodge et al. (2008)

Dehler et al., GSA Bull 2010
Figure 13. Regional stratigraphic correlation chart for Proterozoic sedimentary rocks in the southwestern Cordillera, illustrating the inferred correlation of quartzite sequences in this study (adapted from Link et al. 1993; additional data from Timmons et al. 2001; Cox et al. 2002; Stewart et al. 2002; Lund et al. 2003). Grinnell Mountain and Dog Wash quartzites are components of the Paleoproterozoic basement and are not representative of a regionally widespread Joshua Tree terrane. Pinto Mountain Group is correlated with Cordilleran Proterozoic succession A and is therefore similar in age or slightly younger than quartzites of the Mazatzal Group of the Tonto Basin Supergroup. Big Bear Group is pre–Stirling Quartzite in age and correlated with the early part of succession C deposited in the earliest stages of Neoproterozoic Cordilleran rifting.

The paleocurrent and detrital zircon age data reported here can help to define the location and geologic character of the provenance of these sedimentary sequences. As discussed by Stewart et al. (2001), most age populations of detrital zircons in miogeoclinal rocks (3.4–2.3, 1.8–1.6, 1.45–1.40, and 1.2–1.0 Ga) can be matched to observed basement rocks, suggesting a western North American basement source.

Late pC Extension everywhere... no igneous activity but still connected?
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Wash quartzite indicate that quartzite-bearing metasedimentary rock sequences to the west of the type section are not correlative with the Pinto Mountain Group. This observation significantly reduces the areal extent and significance of the Joshua Tree terrane of Powell (1981) but is consistent with the definition of the more diminutive Placer Mountain assemblage of Powell (1993). We conclude that the Pinto Mountain Group is an early postorogenic shallow shelf sedimentary succession deposited on west Mojave province crust, coincident with but unrelated to the rift that initiated the Cordilleran miogeocline in this region.

Structural and stratigraphic evidence suggests that the Big Bear Group is distinctly younger than the Pinto Mountain Group yet older and deposited in a different tectonic setting than the Neoproterozoic-Cambrian miogeoclinal sequence (Stirling Quartzite and higher units) that overlies it. Paleo-current data suggest that siliciclastic sediment was transported north and northeastward during Big Bear Group deposition but southwestward, off the established west-facing Cordilleran continental shelf, by upper Stirling and Wood Canyon time. Detrital zircon data indicate that the shift in paleocurrent directions, although not accompanied by a recognizable shift in transport distance or degree of recycling, was accompanied by a shift in the geochronologic and possibly the lithologic character of siliciclastic sediment provenance. We therefore propose that the older Big Bear Group records a different depositional setting than the Stirling and younger miogeoclinal units in this region. Stewart et al. (2002) suggested a correlation with Cordilleran Proterozoic succession B, their Neoproterozoic Rodinian epicontinental sequence. However, if further work confirms that much of the Big Bear Group is younger than 625 Ma yet pre-Stirling in age, a correlation with the early part of succession C and a tectonic setting in the earliest stages of Cordilleran Neoproterozoic rifting seems more likely (fig. 13).

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The youngest concordant grain has an age of 114 ± 2 Ma, providing a maximum depositional age for the basal part of the Big Bear Group that is much younger than we infer for the Pinto Mountain Group.

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Note miogeocline peaks don’t match Big Bear Group, which shows transport from southwest...

so something was still attached to North America at this time but maybe rifting off...
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Figure 1. Regional map of the U.S. and Canadian Cordillera showing exposure belts for Neo-Proterozoic miogeoclinal rocks (Nelson, 1991; MacIntyre, 1991; Goodfellow et al., 1993). In northern Nevada, most Paleozoic miogeoclinal rocks that originated during the rifting along western North America rift-segment interpretation adds another aspect to understanding the geometry and polarity of that new data for the northern U.S. Cordilleran miogeocline as well as with younger mineral deposits along the length of the Cordilleran-wide evaluation of mineral deposit occurrence data in conjunction with those in other segments.

Paleozoic miogeoclinal rocks:
- Slope to basin
- Platform to margin
- Windermere Supergroup and correlative rocks

Neoproterozoic miogeoclinal rocks:
- Alkaline igneous rocks
- Late Neoproterozoic-Early Cambrian igneous rocks
- Late Cambrian-Early Ordovician alkaline igneous rocks
- Devonian-Mississippian igneous rocks

Rift geometry:
- Rift orientation
- Lower plate extension direction
- Upper plate extension direction

Structural features:
- Trace of arch
- Transform zone
- Transfer zone

Lund, Geosphere, 2008