Fig. 3. Schematic diagram showing the relationship between measured $^{207}/^{206}$ age and actual crystallization age for a hypothetical zircon grain that is discordant due to either Pb loss or inheritance of older radiogenic components. This example is 14 percent discordant, as measured along the $^{207}/^{206}$ line. All grains for which ages are interpreted in this study are less than 17 percent discordant, and the average discordance for these grains is 1.8 percent.
Crystalization ages
Sm stays in mantle, so crust poor in 147 Sm, so production of 143 Nd lower in crust than mantle (note that ENd is time-dependent).
Simple diagram showing how ENd would still follow same path if reworked by igneous processes within the lithosphere.
whole-rock Pb isotopes to map crustal boundaries. They divided the region into the Mojave and Arizona provinces, which broadly agree with the provinces defined by Bennett and DePaolo (1987). Wooden and DeWitt (1991) also delineated a 75-km-wide boundary zone within which Pb isotope ratios show mixing relationships between the two provinces (shaded blue area in Fig. 2; Mojave and Arizona provinces are west and east of the transition zone, respectively). Their Arizona province is equivalent to the Yavapai province of other studies (e.g., Hoffman 1988; Karlstrom and Bowring 1988, 1993; Karlstrom and Humphreys 1998; Whitmeyer and Karlstrom 2007; Duebendorfer 2015). In this article, we use the term "Arizona province" when referring to the province defined by Nd and Pb isotopes and the term "Yavapai province" when referring to the tectonic evolution of Paleoproterozoic crustal blocks. Several studies (Duebendorfer et al. 2006; Duebendorfer 2015) have proposed that this transition zone represents the rifted leading edge of the Mojave block, developed in response to slab rollback in a subduction zone farther west, prior to the accretion of the Yavapai arc.

On the basis of regional variations in isotopic and geochronologic data, the following tectonic provinces have been proposed for the western United States (Fig. 3): (1) the Archean Wyoming craton, which has protoliths and deformation ages between 3500 and 2500 Ma; (2) the Mojave province, which consists of pre-1800 Ma crustal material; (3) the Yavapai province, a 1760–1720 Ma juvenile arc terrane; and (4) the Mazatzal province, formed by 1700–1650 Ma supracrustal rocks on unknown basement (Fig. 3; Hoffman 1988; Karlstrom and Bowring 1988, 1993; Karlstrom and Humphreys 1998; Whitmeyer and Karlstrom 2007). Bennett and DePaolo (1987) assigned a TDM of 2300–2000 Ma to the Mojave province (their province 1) and 1800 Ma or younger to the Yavapai province (their province 3).

These terranes, known as the Transcontinental Proterozoic provinces, were amalgamated during the Proterozoic, between 1800 and 1600 Ma, through a process that involved accreting arcs to the stable Archean craton.

Dots here are “anorogenic” granites, 1.31–1.41 in gray, 1.41–1.49 in black. Note the numbering of provinces (1 is Mojavia as defined earlier, 2 is Yavapai, 3 is Mazatzal.
Bennett and DePaolo, 1987

"Mojavia"

TDM 2.0-2.3 Ga
U-Pb ages ~1.7 Ga

Note region 1 to north has been discredited as having the same characteristics as Mojavia (Nelson et al., Geosphere, 2011) and they suggest edge of Archean is actually near Idaho line and difference between regions 1 and 2 is amount of sediment shed onto paleoproterozoic.
“Mojavia”

$T_{DM} \ 2.0-2.3 \text{ Ga}$

U-Pb ages $\sim 1.7 \text{ Ga}$

Note range of plutonic ages (Starred) reported from Mojave
Garnet gneisses of New York Mtns.
Crusts 1 and 2 are juvenile at T1 and T2. Crust 3 is assumed mix of 1 & 2 at time T2. TSED for next plot. TDM (model ages for crust 3) meaningless. 3a and 3b are for different initial Sm/Nd ratios. When these all back project together you get the time of creation (though can be from mixing).
Approach proposed to separate mixing from juvenile crust. In this plot, juvenile crust on line 2, reworked old crust on 1, mix in between. Line 3 would be a uniform mix that then evolves so at Tsed you get a tilted line for sediments.
**INTRODUCTION**

Nd isotopic compositions of cratonic rocks analyzed in this study. Data on 36 samples from Archean Wyoming craton (Bennett and DePaolo, 1987; Koesterer et al., 1987; Wooden and Mueller, 1988; Geist et al., 1989; Frost, 1993) and best-
vue 1–2.0 Ga. Condie (1992) suggested that Wooden and Miller (1990) assessed the Mojave Desert region (e.g., DeWitt et al., 1984; Jennings (1973), Streitz and Stinson (1974), and Bortugno and Spittler (1986).

The southern Death Valley region hosts a complex lithologic assemblage ranging from anhydrous for plotting. Figure 3. A: Nd isotopic compositions of cratonic rocks analyzed in this study. Data on 36 samples from Archean Wyoming craton (Bennett and DePaolo, 1987; Koesterer et al., 1987; Wooden and Mueller, 1988; Geist et al., 1989; Frost, 1993) and best-fit lines of data on the three crustal Nd provinces of southwestern United States (see Bennett and DePaolo, 1987; Farmer and Ball, 1997) are shown for reference [1 is Mojavia]. B: εNd (at 1.7 Ga) vs. A/CNK diagram; A/CNK is molecular Al₂O₃/(CaO + Na₂O + K₂O) (data in Table A; see footnote 1). These Mojavia rocks extend the range of "Province 1" (Mojavia) to TDM of 2.6 Ga and the range of εNd indicates a non-uniform source (i.e., this was no juvenile 2.3 Ga crust).
the plutons prior to zircon crystallization. Paragneisses from the Ivanpah Mountains (IM in Fig. 2) have detrital zircon age populations of 2150–1800 Ma and metamorphic zircon ages of 1760–1670 Ma (Strickland et al. 2013), consistent with this inferred history.

Group 2 granites from Gold Butte record a younger episode of plutonism at ∼1370 Ma. Gold Butte Figure 5. Plot of 147Sm/144Nd versus 142Nd showing data from this and other studies. Colors show province affinity: red symbols represent the Wyoming province (data from Frost 1993), yellow symbols represent the Mojave province, blue symbols represent the transition area proposed in this study that is north of the Mojave, and green symbols represent province 3 of Bennett and DePaolo (1987; shown in Fig. 1 and equivalent to the Arizona province of Wooden and DeWitt 1991). The circled green triangle represents the anomalous sample from the Dead Mountains, California. The half-green/half-blue triangle represents the sample from Bagdad, Arizona (Bennett and DePaolo samples 10 and 23, respectively, in table S1). The provinces more or less follow trends that correspond to their respective model ages (illustrated as model isoage lines that radiate from modern depleted mantle). The black square corresponds to modern depleted mantle (142Nd p 10 and 147Sm/144Nd p 0.2137; White 2014). Model isoage lines are calculated using 6.54×10^2 as the decay constant for 147Sm (Lugmair and Marti 1978).

Note this is modern eNd. Blue is proposed intermediate terrain. 

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Two intriguing new insights emerge from our data. First, the geometry of the boundary lines defined by Nd and Pb isotopes resembles that of the $^{87}$Sr/$^{86}$Sr isopleth (red line in Fig. 2), which is considered the edge of Proterozoic North American continental lithosphere (Kistler and Peterman 1973). The Pb and Nd boundaries that we propose here are located to the east of this feature. The configuration of the Pb boundary is simpler than that of the Nd boundaries. The present locations of these isotopically defined features were affected by regional crustal shortening and extension during the Mesozoic and Cenozoic, respectively. Deformation would have been distributed in a nonuniform manner, thus altering the spatial relationship between these lines. However, the difference in complexity between the Pb and Nd lines prior to the deformation would be preserved. Moreover, the observation that Pb isotopes for some samples indicate province 1 (Mojave) affinity whereas Nd isotopes indicate province 3 (Arizona) affinity suggests that the extent of mixing in the Pb and Nd systems may have varied geographically. Examples of this are Gold Butte, which has $\Delta$Jerome $7.35-8.24$ but $T_{DM}$ $1750$ Ma and initial $\delta$Nd $20.5$ to $21$, and the Bennett and DePaolo (1987) samples from Bagdad, Arizona (samples 20 and 23 in table S1). These samples lie within the Pb boundary zone of Wooden and DeWitt (1991) in an area with $\Delta$Jerome between 4 and 8. One of the samples, however, has Nd isotopic characteristics that places it in province 3 (Arizona; $T_{DM}$ $1750$ Ma and initial $\delta$Nd $4.02$), and a second sample has a $T_{DM}$ that corresponds to province 2.

The Gneiss Canyon and Crystal shear zones (GCSZ and CSZ in Fig. 3), both exposed in the Grand Canyon, have been interpreted as the Mojave-Yavapai crustal boundary in western Arizona (Wooden and DeWitt 1991; Karlstrom and Humphreys 1998; Holland et al. 2015). However, despite excellent exposure and subvertical orientation in the canyon itself, the northern boundary of Mojavia is a subduction zone. $\Delta$Jerome, which is expressed as 100 times the difference between the measured $^{207}$Pb/$^{204}$Pb and a modeled $^{207}$Pb/$^{204}$Pb value that is calculated on the basis of the measured value of $^{206}$Pb/$^{204}$Pb and the 1700 Ma isochron that passes through the Pb isotopic values of galenas from a mine in Jerome, Arizona.
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Finland (Anderson 1983), is a special variant of A-type granite, with large, zoned feldspar phenocrysts. Rapaiki granites are argued by some to have been produced by partial melting of the crust in the vicinity of mantle melts and by others to have been derived exclusively from previously depleted crustal sources (Creaser et al. 1991). In North America, a belt of granites, considered to be A-type, extends for 3,500 km from Labrador to southern California (Anderson 1983; Anderson and Bender 1989) and has long been thought to represent the stabilization of the North American continent at 1450–1400 Ma (Silver 1978; Anderson 1983).

Recent studies have redefined the timing of orogenic and basin-forming events recorded by Proterozoic rocks of the southwestern United States (e.g., Jessup et al. 2006; Jones et al. 2010, 2011; Doe et al. 2012; Daniel et al. 2013), highlighting a more complex tectonic evolution than the first-order scheme reviewed above, especially during the anorogenic period of plutonism. The more recent studies suggest an interval of clastic deposition at ∼1450 Ma, coeval with or closely followed by a span of metamorphism and ductile deformation and consistent with the existence of a long-lived active accretionary margin (Jessup et al. 2006; Jones et al. 2010).

Figure 3. Map showing the location and ages of the various tectonic belts amalgamated during the Paleoproterozoic in the southwestern United States. Lines with teeth are sutures with teeth on the upper plate. Gray lines are from Karlstrom and Humphreys (1998). The bold black line represents the new northern boundary of the Mojave microplate proposed in this study. This boundary does not correspond to any particular structure in the field, and the teeth on the line suggest the direction of subduction based on the location of the arc. Black dots represent sample locations used in Farmer and DePaolo (1984; table S1). The dashed line represents the outline of the Colorado Plateau. Shaded gray areas are outcrops of Proterozoic rocks. Outcrops in central Nevada and Utah are primarily Neoproterozoic sedimentary rocks. Figure is modified from Karlstrom and Humphreys (1998), Condie (1992), and Holland et al. (2015).
These authors think this looks a lot like NAM zircon populations, so propose that this is island arc system near NAM, but note that others argue for AUS for stuff to east.
These authors think this looks a lot like NAM zircon populations, so propose that this is island arc system near NAM, but note that others argue for AUS for stuff to east.
Vishnu Schist seems to have seds from pC crust with major additions c. 1.8, 2.5, 3.2 Ga. The range at the left edge looks a lot like what is seen in Mojavia, suggesting to these authors that Vishnu sourced to the (modern) west from Mojavia and something more ancient. This leads us to..what was there?
Vishnu basin suggest that this older crust may have been part of the Mawson continent. Early arc plutons are isotopically evolved due to recycling of Vishnu basin sediments and/or older crust (Fig. 13). As slab rollback continues to extend the back-arc, plutonic rocks become progressively more isotopically juvenile through space and time (Fig. 9).

Juvenile arc plutons are typified by 1.74–1.71 Ga granodiorite plutons that intrude the Vishnu Schist in the Grand Canyon (Holland et al., 2015). This trend towards more juvenile melts is evident in all 1.79–1.73 Ga Mojave province plutons (Fig. 8), and is mimicked in detrital zircon from Death Valley metasedimentary rocks, and the Vishnu Schist (Fig. 13). Back-arc extension reached its maximum by ∼1.75 Ga, and closure began by 1.74 Ga as evident in the development of the shallow S_1 fabric attributed to west-vergent thrusting in the Cerbat Mountains (Duebendorfer et al., 2001), and continued development of S_1 until as late as 1.71 Ga in the Grand Wash Cliffs (Albin and Karlstrom, 1991) and the Grand Canyon (Ilg et al., 1996). Syn-to-post-tectonic granites are as in Model 1. When considered with the isotopic trends observed throughout the Mojave province, this late stage plutonism may be analogous to the third phase of an orogenic cycle that resembles the tripartite association of S-type, I-type, and A-type granites described in the Tasmanide orogenic system (Collins and Richards, 2008; Kemp et al., 2009).

6. Conclusions

U-Pb and Lu-Hf geochronologic analysis of zircon from Paleoproterozoic metasedimentary and plutonic rocks across the Mojave crustal province provide insights into lithospheric growth in southwestern Laurentia. We propose the existence of a regionally extensive sedimentary basin composed dominantly of turbidites and other immature clastic sedimentary rocks, which we name the Vishnu basin. The Vishnu basin received isotopically evolved detritus from a 2.0–1.8 Ga arc (Elves Chasm pluton) to Mojave. Model 1 portrays terrane accretion of a juvenile 1.84 arc (Elves Chasm pluton) to Mojave ∼1.8 Ga followed by accretion of the juvenile Yavapai province ∼1.75–1.70 Ga. Model 2 portrays a single subduction system that evolves through slab roll back, back arc extension, and instigation of the Yavapai orogeny by arrival of an oceanic plateau into the subduction system. Diamonds represent data from this study and Holland et al. (2015), circles are data from Wooden et al. (2012).
SWEAT = SW US + East Antarctica
Numbers are Nd model ages. Australia-WUS. more detailed map includes Grenville, so c. 1100 Ma
“AUSWUS”

Numbers are Nd model ages. Australia–WUS. More detailed map includes Grenville, so c. 1100 Ma.
Various Australian positions…

Numbers are Nd model ages. Australia–WUS
J.W. Sears

a Proterozoic multipolar to a Phanerozoic dipolar geometry for the surface magnetic field. Bono et al. (2019) concluded that the field generated a strong dipolar dynamo upon nucleation of the inner core after the field nearly collapsed from an ultraweak condition in late Ediacaran time. Meert et al. (2016) concluded that a strong GAD-dominated magnetic field generated an Ediacaran magnetosphere that shielded Earth from ultraviolet-B (UV-B) radiation, preparing the way for the Cambrian metazoan explosion.

Here, I offer a new perspective on the possible nature of the Proterozoic dynamo by mapping site-mean paleomagnetic data onto a robust, geology-based, Siberia-Laurentia Proterozoic continental restoration model. Rather than assuming, a priori, a GAD dynamo to construct the ancient continent from its pieces, I suggest that the geologically precise reconstruction may, instead, constrain the Proterozoic magnetic field. If geologically correct, the reconstruction provides a continental-scale field test for the surface geometry of the dynamo from ca. 1700 Ma, when the continent would have been assembled, to the Ediacaran and early Paleozoic, when it would have broken apart.

The site-mean paleomagnetic data from Siberia and Laurentia plotted on the Siberia-Laurentia reconstruction of Figure 1 imply that the Proterozoic magnetic field may have been multipolar, dominated by quadrupolar geometry. Although the variability in the spherical harmonic description of a magnetic field could create a specific surface field geometry that could correspond to any chosen tectonic reconstruction, the general correspondence of the quadrupole geometry to the site-mean Proterozoic field data for the Siberia-Laurentia connection of Figure 1 may imply its dominance over higher-order terms.

GEOLOGY-BASED SIBERIA-LAURENTIA CONNECTION

Sears and Price (1978, 2003) presented a model that connected the northern and eastern rifted margins of the Siberian craton to the southwestern rifted margins of Laurentia in a tight, spoon-in-spoon geographic fit along the 3000 km length of a zigzag conjugate rift (Fig. 1). The fit seamlessly joins more than a dozen crisscrossing Proterozoic to Cambrian geologic trends.

Sears still likes this in 2022 but has to invoke a quadrupole field to get around paleomag…
Fig. 10. Summary of core and overgrowth U-Pb-Hf isotopic systematics compared to U-Pb-Hf data from detrital zircons. Colored diamonds represent the arithmetic mean \(^{176}\text{Hf}/^{177}\text{Hf}\) values from the main magmatic populations of zircon in plutonic rocks. Inherited zircon cores and xenocrysts are shown as colored circles, color coded to match the diamonds. Gray diamonds are U-Pb-Hf isotopic data from > 90% concordant detrital zircons analyzed in this study. A summary of all > 90% concordant ages from inherited cores or xenocrysts is shown as a PDD in red, and compared to the PDD of detrital zircon from Vishnu basin metasedimentary rocks, shown in gray. Bulk-rock Nd-isotope data from Ramo and Calzia (1998), projected onto Hf-isotope space based on the linear relationship defined by Vervoort et al. (2011) are shown as colored squares. The bulk-rock Nd-isotope data are more isotopically evolved than the average zircon Hf-isotope data from all Mojave province plutons. Gray arrows schematically show the depleted mantle contributions evident from the average change in \(^{176}\text{Hf}/^{177}\text{Hf}\) values through time (Fig. 8). Thus, mixing of depleted mantle melts and partial melts of Vishnu basin metasedimentary rocks is a possible explanation for the evolved isotopic signature of the oldest Mojave province plutons. Black diamonds are Mojave province plutons without inherited zircon components (note change in scale to better show the increase in plutonic \(^{176}\text{Hf}/^{177}\text{Hf}\) values through time. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 11. Possible plate reconstruction of Australia, Antarctica (Mawson), and Laurentia in Nuna from 1.8 to 1.6 Ga. Australian cratons are shown as depicted in Betts et al., 2016. BO=Barramundi Orogen, MP=Mojave province, NC=Nimrod Complex, NAC=North Australian Craton, SR=Shackleton Range, SvC=Slave Craton, SC=Superior Craton, TA=Terre Adélie Craton, WO=Wopmay Orogen, WC=Wyoming Craton.

Their caption: Fig. 11. Possible plate reconstruction of Australia, Antarctica (Mawson), and Laurentia in Nuna from 1.8 to 1.6 Ga. Australian cratons are shown as depicted in Betts et al., 2016. BO=Barramundi Orogen, MP=Mojave province, NC=Nimrod Complex, NAC=North Australian Craton, SR=Shackleton Range, SvC=Slave Craton, SC=Superior Craton, TA=Terre Adélie Craton, WO=Wopmay Orogen, WC=Wyoming Craton.