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Similarities between Archean high MgO eclogites and Phanerozoic arc-eclogite cumulates and the role of arcs in Archean continent formation

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Abstract

Some insights into the origin of cratonic mantle can be gained from "eclogite" (loosely defined here as an assemblage containing garnet and any pyroxene) xenoliths hosted in kimberlites erupted through Archean (~2.5−3.5 Gy) cratons. One subset of Archean eclogite xenoliths, the low MgO Archean xenoliths, is presently believed to represent metamorphosed fragments of ancient altered oceanic crust, leading to the suggestion that Archean cratons were built, at least in part, by the accretion of oceanic lithospheric segments. However, another Archean subset, the high MgO Archean eclogite xenoliths, have major and compatible trace-element (Ni and Cr) systematics similar to high MgO arc-eclogite xenoliths originating from the lithospheric root underlying the Sierra Nevada batholith in California, an example of a Phanerozoic arc. The Sierran high MgO arc-eclogites represent cumulates from hydrous basaltic magmas beneath a thick continental arc. The compositional similarities between the Archean and Sierran high MgO eclogites suggest that not only might the Archean high MgO eclogites have a cumulate origin, as has previously been suggested, but they may be arc-related. If so, Archean high MgO eclogites provide evidence from within the mantle roots of cratons that some form of arc magmatism contributed to the formation and evolution of Archean continents.

Keywords: craton; eclogite; xenolith; Archean; Sierra Nevada; garnet pyroxenite

1. Introduction

While a number of lines of evidence have been used to argue that oceanic lithosphere accretion and plume generation were involved in the formation of Archean lithosphere [1–13], an outstanding question is whether Phanerozoic-like processes, such as arc formation and arc accretion (and by inference subduction), may have also operated in the Archean. One way to address this question involves examining Archean rocks for an "arc" trace-element signature. Some investigators [14–16] have highlighted similarities between the trace-element signatures of Archean komatiites and basalts with modern-day arc boninites, leading to the controversial suggestion that such lavas formed in subduction zone environments, contrary to the prevailing notion that komatiites are formed by hot plume melting [17].

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Here, we are also interested in testing for "arc signatures." However, instead of looking at crustal lithologies, we focus on lithologies found in the lithospheric mantle as represented by mantle xenoliths sampled by kimberlites in Archean cratons. A logical approach would be to examine the trace-element signature of cratonic mantle peridotites. However, the trace elements most diagnostic of arcs (incompatible trace elements) are also the ones most easily disturbed or overprinted by cryptic metasomatic processes (where the term "cryptic" is used to imply that the dominant mineralogy and major element chemistry is not modified but the trace-element signatures are [18]). Cryptic metasomatism seems to pervade cratonic xenoliths, making it difficult to decipher their original signatures. We thus compare and contrast the major and compatible trace-element systematics in garnet pyroxenite lithologies found within cratonic xenolith suites with garnet pyroxenite lithologies formed within Phanerozoic continental arcs. The major element systematics of garnet pyroxenites vary more with petrogenetic and tectonic origin than the major elements in peridotites [19–27]. In addition, major element systematics are (by definition) robust to cryptic metasomatism. Similarly, compatible trace elements, such as Ni and Cr, are unlikely to be affected by cryptic metasomatism because most metasomatic agents, while enriched in incompatible trace elements, are depleted in the compatible elements.

2. Archean and Phanerozoic "eclogites"

Although strictly speaking, an "eclogite" is defined as a bimineralic assemblage of garnet and omphacitic (Na-rich) clinopyroxene [20], we use this term loosely to describe any garnet pyroxenite assemblage, thus including garnet orthopyroxenites, garnet websterites (orthopyroxene+clinopyroxene+garnet), garnet clinopyroxenites (garnet+clinopyroxene) and so-called true eclogites (garnet+omphacitic clinopyroxene). Below, we classify Archean and Phanerozoic eclogites in detail; a graphical illustration of our classification scheme is shown in Fig. 1.

2.1. Archean "eclogites" (~3.5−2.5 Gy)

Archean eclogites (from <3.5 Gy terranes) can be subdivided into low (MgO<15 wt.%) and high MgO (MgO>15 wt.%) groups (Figs. 1 and 2). The Archean *high MgO eclogites* are found as occasional xenoliths in kimberlitic host lavas and are represented by garnet websterites (garnet+clinopyroxene+orthopyroxene) and garnet clinopyroxenites (non-omphacitic clinopyroxene). The *low MgO group*, many of which are bimineralic and contain omphacite, is represented by two groups: low MgO eclogite xenoliths found along with high MgO eclogites in kimberlites and exhumed lower crustal eclogites, such as the ones shown in Figs. 2 and 3 from China [28]. The high MgO eclogites have distinctly higher Mg#s (molar Mg/(Mg+Fe)) and generally higher Cr and Ni contents compared to their low MgO xenolithic counterparts (Figs. 2–4). The SiO_2 contents of the two groups overlap, but the high MgO group has a narrower range in SiO_2, falling between the high and low extremes of the low MgO group. The high MgO eclogite xenoliths would generally fall into the group A eclogite classification of Coleman based on mineral chemistries while the low MgO mantle-derived eclogites and low MgO lower crustal eclogites would broadly fall into the Groups B and C classifications [19].

The salient distinguishing features of the two low MgO eclogite groups are as follows. Within the low MgO group, the lower crustal eclogites, as represented by the Chinese exhumed sections [28], are characterized by the lowest MgO and Mg#. The lower crustal eclogites also have systematically lower Ni and Cr contents compared to the low MgO eclogite xenoliths and the high MgO groups. The low MgO eclogite xenoliths have Mg#s and other major element systematics broadly similar to modern day mid-ocean ridge basalts (MORBs). Because the low MgO eclogite xenoliths contain non mantle-like oxygen isotopic signatures [24,25], the most popular hypothesis for the origin of the low MgO eclogite xenoliths is that they represent underthrusted fragments of altered subducted oceanic crust, some of which may have been subsequently melted during subduction [23,25]. Barth et al.

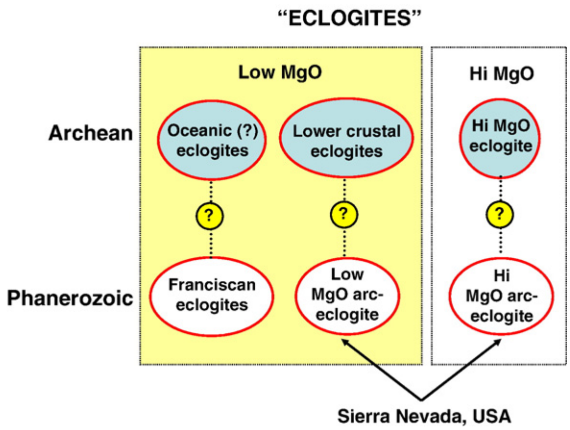

Fig. 1. Breakdown of the Archean and Phanerozoic eclogites. Archean eclogites divided into lower crustal-derived eclogites (low MgO) and mantle-derived eclogite xenoliths (high and low MgO). Phanerozoic eclogites divided into high and low MgO arc-eclogites (e.g., the Sierra Nevada) and Franciscan eclogites.

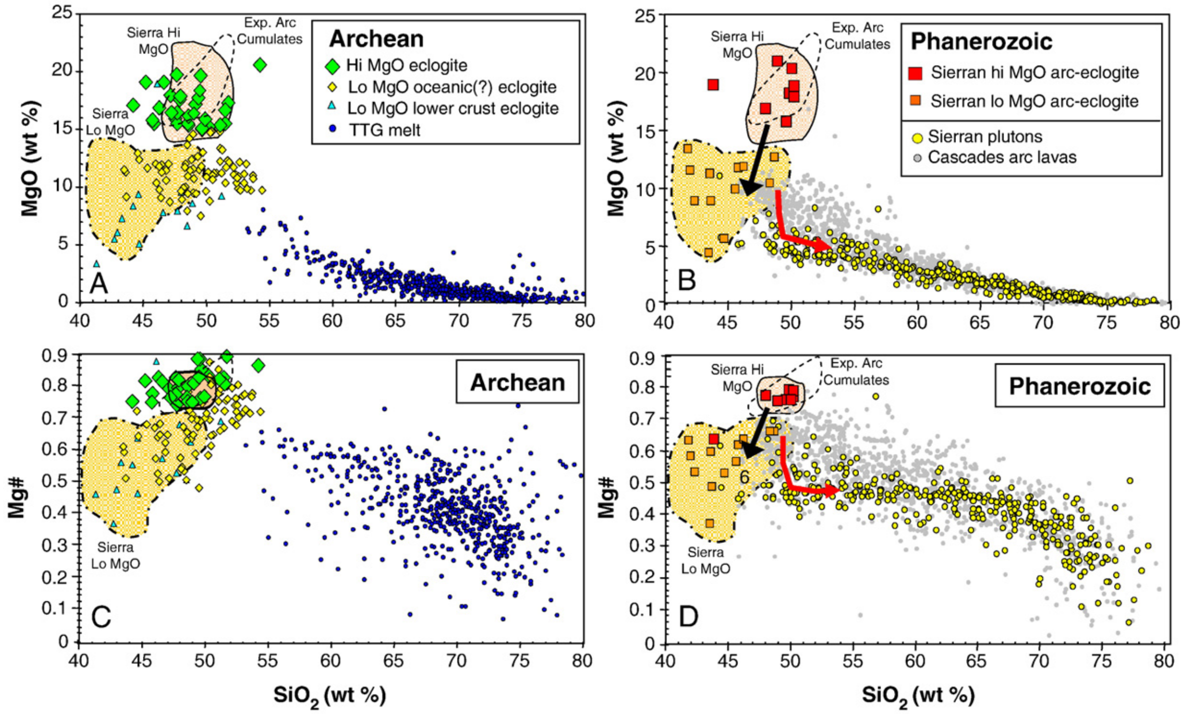

Fig. 2. Whole-rock MgO contents of Archean eclogites (A) and Phanerozoic arc-eclogites (B) versus whole-rock SiO_2. Archean (C) and Phanerozoic (D) Mg# (molar Mg/(Mg+Fe)) versus SiO_2. Phanerozoic arc-eclogite xenoliths are from the root of the Mesozoic Sierran Nevadan batholith in California [43]. Archean eclogites are from kimberlite-borne mantle xenoliths from the west African, Siberian and South African cratons. Lower crustal Archean eclogites (low MgO) are from exhumed lower crustal terranes in China. Compiled data sources referenced in the text. Red-shaded regions in each panel correspond to the field of Sierran high MgO arc-eclogites (dark red squares) (B,D), excluding one outlier. Orange-shaded regions bounded by dash–dots in each panel correspond to the field of Sierran low MgO arc-eclogites. Dashed open region represent experimental pyroxenite cumulates from hydrous arc basalt at 1.2 GPa [51]. Dark solid circles in (A) and (C) represent Archean tonalites–trondjhemites–granodiorites (TTGs) compiled from the GEOROC database. Small gray circles in (B) and (D) represent lava compositions from the active Cascades volcanic arc in the Pacific Northwest of the United States (GEOROC). Small yellow circles with black borders represent magma compositions of Sierran plutons (see [43] for compilation sources). The thin red curves with an arrow in (B) and (D) were drawn to roughly correspond to the initial magmatic differentiation trend of Sierran plutons. Sierran mafic magmas first decrease in MgO at a constant SiO_2 and then increase in SiO_2 with only slight decrease in MgO. The bold black arrow represents the cumulate or restite line of descent corresponding to the Sierran arc-eclogites and believed to be complementary to the initial magmatic differentiation trend seen in the Sierran plutons (red arrow). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

[25] noted that the reconstructed trace-element abundance patterns of low MgO eclogite xenoliths may be complementary to the trace-element patterns of Archean TTG suites. For these reasons, we refer to the low MgO eclogite xenoliths as altered oceanic(?) eclogites. As for the lower crustal eclogites, their lower Mg#s and MgO, Ni and Cr contents indicate a protolith that is much more evolved than typical basaltic magmas. Thus, one possibility is that the lower crustal eclogites represent restites of re-melting basaltic crust or cumulates from a slightly evolved basaltic magma.

The distinctive signatures of the Archean high MgO eclogites have been previously noted in the literature using xenoliths from kimberlites pipes from the ~3.0 Gy Siberian (Udachnaya and Mir), ~2.7−3.0 Gy West African (Koidu), and ~2.7−3.5 Gy South African (Jagersfontein) cratons [21,24,25,29–35]. Their high Mg#s (Fig. 2C) and high Ni and Cr contents (Fig. 4) indicate more primitive protoliths, precluding MORB-like protoliths. The Mg#s (0.75–0.90) are also too high to represent typical mantle melts unless they have komatiite-type protoliths. However, a komatiite protolith would be characterized by lower SiO_2 (40–45 wt.%) contents than the 45–52 wt.% range seen in the high MgO eclogite xenoliths (Figs. 2 and 3). Archean high MgO eclogite xenoliths have instead been suggested to represent high-pressure mantle cumulates or oceanic gabbroic cumulates, which have since been eclogitized by an increase in pressure [24]. Alternatively, it has also been suggested that Archean high MgO eclogite xenoliths are the reaction products between felsic melts and the peridotitic mantle, the former possibly

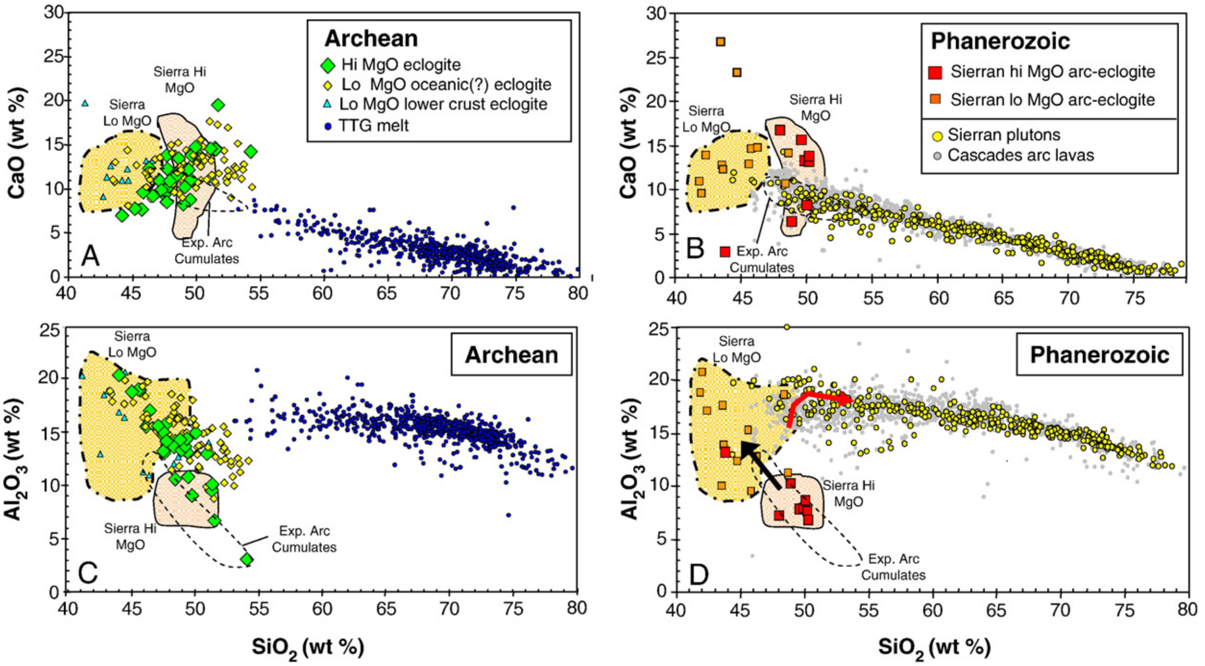

Fig. 3. Similar plot to Fig. 2. Whole-rock CaO contents of Archean eclogites and Phanerozoic (Sierran) arc-eclogites plotted against SiO_2 are shown in (A) and (B). Al_2O_3 contents of Archean eclogites and Phanerozoic arc-eclogites plotted against SiO_2 are shown in (C) and (D). All other symbols are identical to those used in Fig. 2.

deriving from slab melting itself [36,37]. In Section 3, however, we show that Archean high MgO eclogite xenoliths have very similar major and trace-element compositions to high MgO eclogite cumulates found in Phanerozoic continental arcs.

2.2. Phanerozoic eclogites

Phanerozoic eclogites can also be categorized into three groups (Fig. 1). One group (not shown in the figures), is composed of true eclogites found as exhumed blocks in accretionary prisms associated with subduction. These are the *Franciscan eclogites* which are characterized by low MgO contents and Mg#s. They are compositionally similar to modern MORB; their protoliths are most likely altered oceanic crust and hence may be roughly analogous to the Archean low MgO eclogite xenoliths, which may also have an oceanic crust origin. The other two groups of Phanerozoic eclogites are from the lower crust or lithospheric mantle beneath arcs (eclogites also occur as lenses in obducted massifs). There are very few examples of such lithologies because xenolith-bearing lavas are rare in arc environments (arc-eclogites may also not persist for very long due to their high densities, which render them unstable and prone to foundering). However, one place where Phanerozoic eclogites associated with continental arcs can be sampled is in the Sierra Nevada (in California), the eroded remnants of a Mesozoic arc batholith composed of tonalite, granite, and granodiorite [38]. The Sierran eclogites (garnet pyroxenites) are sampled as xenoliths in late Miocene alkali basalts [39], which erupted while a thick garnet pyroxenite root existed beneath the Sierra Nevada [40–43]. The lack of eclogite xenoliths in younger volcanics, the lack of a seismically defined crustal root beneath the highest elevations, and the presence of shallow hot asthenosphere indicate that since the late Miocene, the eclogitic root may have been removed (delaminated) from the mafic lower crust [40,44–50]. Thus, the late Miocene volcanics and the xenoliths that they host provide a rare snapshot of the eclogitic arc root before it foundered and was replaced by asthenospheric mantle.

The Sierran arc-eclogites can be split further into *high* and *low MgO arc-eclogites* (Fig. 2B). The low MgO group has low SiO_2 and MgO contents and low Mg#s (Fig. 2B, D) overlapping with the Archean lower crustal eclogites from China. Given that the low MgO Sierran arc-eclogites are compositionally similar to gabbroic cumulates in the Sierras, they have been interpreted to be lower crustal cumulates [43]. In contrast, the high MgO Sierran arc-eclogites have high

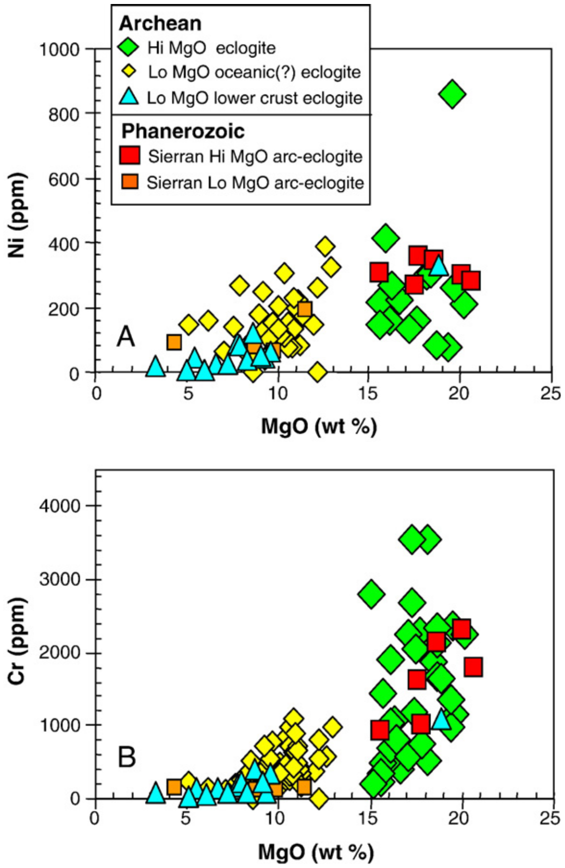

Fig. 4. Whole-rock Ni (A) and Cr (B) versus whole-rock MgO for Phanerozoic (Sierran) high and low MgO arc-eclogites [43], Archean lower crustal eclogites from China [28], and Archean high and low MgO eclogites from Sierran Leone in west Africa [24,25,31,52].

Mg#s, some exceeding 0.80, which prevents them from being frozen melts [43]. They may instead be high-pressure cumulates from a basaltic arc magma as their major element compositions are very similar to the pyroxenite cumulates of Müntener et al. [51], which were experimentally crystallized from hydrous (3–5 wt.% H_2O) arc basalts at upper mantle pressures (1.2 GPa) (see [43] for discussion). The higher pressures and the presence of water may have helped to increase the stability field of pyroxene and to eliminate that of olivine, possibly explaining the pyroxene-rich nature of the Sierran high MgO arc-eclogites.

3. Comparisons between Archean and Phanerozoic high MgO eclogites

We now compare Archean high MgO eclogites (data compiled from [21,24,25,29–35]) to the Sierran high MgO arc-eclogites [43] through major element and compatible trace-element variation diagrams. To facilitate discussion, we also plot Archean tonalite–trondhjemite–granodiorite (TTG) suites (from the GEOROC database), Sierran batholithic rocks (references in [43]), and magmas from the Cascades volcanic arc (from the GEOROC database).

Shown in Fig. 2 are MgO (A, B) and Mg# (C, D) plotted versus SiO_2 content. The shaded regions in Fig. 2B and D correspond to the field of Sierran high MgO arc-eclogites while the dash–dotted regions correspond to the Sierran low MgO arc-eclogites. Sierran high MgO arc-eclogites plot between 15–22 wt.% MgO and 45–52 wt.% SiO_2. The Sierran low MgO arc-eclogites not only have lower MgO contents (4–14 wt.%) but also lower SiO_2 contents (40–45 wt.%) compared to the Sierran high MgO eclogites (Fig. 2B). When compared to Archean eclogites (Fig. 2), we find that Sierran low MgO eclogites are most similar to Archean lower crustal eclogites rather than the Archean low MgO xenolithic eclogites having oceanic protoliths. As for the high MgO eclogites, we find that many Archean high MgO arc-eclogite xenoliths have MgO and SiO_2 systematics overlapping that of the Sierran high MgO eclogites. There is also considerable overlap between the two high MgO groups in terms of Mg#–SiO_2 systematics. CaO and Al_2O_3, however, show less overlap between the Archean and Phanerozoic high MgO suites. In particular, most Archean high MgO eclogites have slightly higher Al_2O_3 contents compared to the Sierran high MgO eclogites. This is because of the slightly higher abundance of garnet in the Archean high MgO eclogites. A higher garnet mode could be due to higher pressures of origin, allowing for greater amounts of garnet on the liquidus. Some of the garnet in the Sierran high MgO arc-eclogites could have a subsolidus exsolution origin from high temperature orthopyroxenes having high Al contents.

The Archean and Sierran high MgO groups are also similar in Ni and Cr, both compatible trace elements. Ni and Cr data from the Sierran garnet pyroxenites were compared with measured and/or reconstructed Ni and Cr data for Archean eclogite xenoliths from west Africa (Sierra Leone) [24,25,31,52]. Archean high MgO eclogites have Ni and Cr contents ranging from 50–450 ppm and 200–3700 ppm, respectively. Sierran high MgO arc-eclogites plot between 250 and 400 ppm for Ni and between 1000 and 2500 ppm for Cr (Fig. 4), overlapping the Archean high MgO fields. In contrast, Sierran low MgO arc-eclogites have very low Ni and Cr, similar to the Archean lower crustal eclogites from China. Interestingly, Archean low MgO oceanic eclogites have intermediate Ni and Cr and do not have an analog in the Sierran arc-eclogites (Fig. 4). High Ni and Cr contents necessarily imply more primitive origins, while low values hint at a more evolved protolith. Thus, as also suggested by the major element systematics, the high Ni and Cr contents of the Archean high MgO eclogites and the Sierran high MgO arc-eclogites suggest that both suites have relatively primitive protoliths. If the Sierran high MgO arc-eclogites are high-pressure arc-cumulates, it may be worth entertaining the idea that the Archean high MgO eclogites have a similar origin in terms of tectonic environment. The Archean lower crustal eclogites from China [28] may be analogous to the Sierran low MgO arc-eclogite xenoliths, which derive from shallower depths than the Sierran high MgO arc-eclogites [40,43].

4. Discussion

4.1. Speculations on the petrogenetic links between high MgO eclogite xenoliths and magmas

We showed above that Archean low MgO lower crustal eclogites and Archean high MgO eclogite xenoliths are compositionally similar to the low MgO and high MgO Sierran arc-eclogites, respectively. To the best of our knowledge, this comparison to Phanerozoic arc-eclogites has not yet been shown. We thus speculate on the implications of these similarities.

The Sierran arc-eclogites have been interpreted to be cumulates from a hydrous arc basalt [43] within a mature continental arc setting, that is, an arc built upon the margin of thick pre-existing continental lithosphere. The petrogenetic relationship of the Sierran eclogites to their plutonic complements in the crust are shown in Figs. 2 and 3. Sierran plutons have lower MgO for a given SiO_2 content when compared to basalts from the active Cascades volcanic arc in Oregon and Washington, which represents an incipient arc emplaced through thin and relatively young lithosphere. The low MgO of Sierran plutons compared to the Cascades volcanics at a given SiO_2 content is an indication of a longer differentiation history imposed by the thick lithosphere through which Sierran magmas passed (Figs 2B,D and 3B,D). If the primitive plutonic endmembers of Sierran plutons originate from a mantle-derived magma, such as a basalt, the removal of a component with high MgO but similar SiO_2 as the magma is required to decrease the MgO contents at relatively constant SiO_2. Subsequent crystallization of a low MgO eclogite with low SiO_2 would then drive the magma eventually to higher SiO_2 contents, resulting in more evolved compositions. These predicted fractionating components are matched by the Sierran high and low MgO arc-eclogite xenoliths, respectively. Lee et al. [43] suggested that the more primitive Sierran plutons are thus the magmatic complements to both types of Sierran arc-eclogites. As magmas generated in the hydrated mantle wedge above a subducting slab ascended through thick pre-existing continental lithosphere, they initially crystallized high-pressure lithologies yielding the pyroxene-rich, and hence, SiO_2-rich (compared to olivine-bearing cumulates) Sierran high MgO eclogites [51]. This initial decrease in MgO at constant SiO_2 contrasts with the early differentiation trend seen in incipient arcs built on thin lithosphere, such as the Cascades. The thinner lithosphere, through which arc magmas pass in such arcs, results in more olivine control during differentiation. This imparts an increase in SiO_2 and a decrease in MgO in the magmas during initial differentiation. The increase in SiO_2 in the Sierran plutons only occurs after the more evolved low MgO Sierran arc-eclogites begin to crystallize at shallower pressures (lower crustal depths).

Can a similar relationship be observed between Archean eclogites and TTG suites? One view is that Archean TTGs are complementary to Archean low MgO oceanic eclogites via partial melting of subducted oceanic crust [23,25]. However, in Fig. 2, there is some hint of Archean TTGs trending towards low MgO contents for a given SiO_2. The low MgO contents of the TTGs may be indicative of partial re-melting of basaltic crust. Indeed, such compositions have been reproduced experimentally in melting experiments of anhydrous and hydrous basalts [26,27,37,53]. Another way of generating low MgO contents in basaltic magmas at relatively constant SiO_2 is to remove high MgO eclogitic lithologies in the form of cumulates or restites from a hydrous basaltic magma at upper mantle pressures, such as what might have occurred during the formation of the Phanerozoic Sierran continental arc batholith. While we cannot show unequivocally that the Archean high MgO eclogite xenoliths are petrogenetically linked to Archean TTGs, it can be seen from the major element variation diagrams that a link between Archean high MgO eclogites and some TTGs is plausible [24]. In this regard, it is interesting to recall that Archean lower crustal eclogites, such as the ones from China described above, may be analogous to the Sierran low MgO eclogites, which crystallized after the Sierran high MgO eclogites had formed.

Like Barth et al. [24], we conclude that the Archean high MgO eclogite xenoliths are cumulates. However, we go further to suggest that such eclogites may have originally formed as cumulates from a hydrous basaltic magma analogous to the Phanerozoic Sierran arc-eclogites. Thus, the implication is that Archean high MgO eclogites formed in an ancient arc environment (although the nature of Archean arcs was not necessarily identical to modern arcs). Our conclusions complement suggestions that some Archean basalts and komatiites have arc-like trace-element signatures [14–16] and that some sulfides in diamond inclusions have subduction-related Osmium isotopic signatures [54].

4.2. Speculations on craton assembly

Our conclusions indicate that some fraction of Archean continental crust may have formed by primitive mantle-derived melts generated in an arc setting. Given the many other mechanisms proposed for forming Archean continental crust, such as melting of subducting oceanic crust, melting of over-thickened oceanic crust, and plume-head melting [1–13,36,55–59], Archean continent formation could have been very complicated. One conceptual model for Archean continent formation that accounts for this potential complexity is as follows. Basaltic island arcs, including the underlying arc mantle lithosphere and wedge, accrete to continental nuclei or proto-continents, such as oceanic plateaus, which may have been plume-derived (Fig. 5). During accretion, some fragments of downgoing oceanic lithosphere may also be captured within the accreted lithosphere (this is dynamically difficult, but not impossible [60]). This conceptual model predicts that 1) the pressures at which many cratonic peridotite xenoliths melted should be fairly low (e.g., mantle wedge pressures or oceanic lithospheric mantle pressures; 1–3 GPa) unlike the higher pressures implied by hot plume melting (3–7 GPa), and 2) the lithospheric mantle beneath cratons should be composed of “slivers” of oceanic crust and arc cumulates set within an overall peridotitic matrix.

Despite the abundance of garnet-bearing lithologies, the cratonic peridotites may have originally melted at pressures lower than the garnet stability field. Several studies have now shown that the Ca, Al, Yb, V, and Sc (all compatible or moderately incompatible in garnet) concentrations of cratonic peridotites are lower than that expected if garnet was to be involved during the partial melting process responsible for generating depleted cratonic peridotites [12,61,62]. If correct, this would imply that the garnets presently found in cratonic peridotites were largely formed by subsolidus exsolution from high temperature pyroxenes (which have high Al contents) after they cooled. A subsolidus origin of garnet has indeed been suggested by a few studies [63,64]. Collectively, these observations indicate that, on average, cratonic peridotites underwent partial melting at lower pressures (less than ~3–5 GPa) than their current depths of origin (up to 7 GPa; [65]). This conclusion is inconsistent with the melting pressures inferred from the very low FeO contents of some cratonic peridotite xenoliths [10]. However, the very low FeO contents have been shown to be a by-product of excess orthopyroxene [66], possibly due to melt–rock reaction with a silicic fluid/melt [3,4,67,68]. Thus, differentiation processes responsible for generating many cratonic mantle peridotites occurred at shallow pressures, and only after underthrusting of oceanic lithospheres or thickening of arc lithospheres

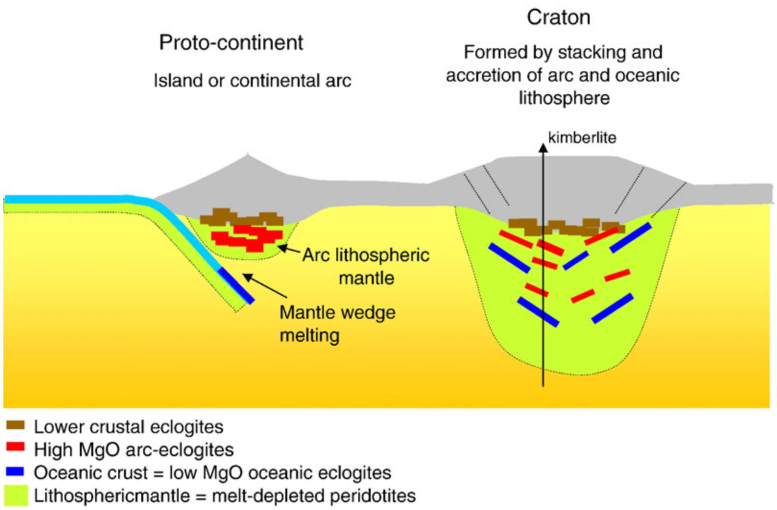

Fig. 5. Cartoon illustrating a hybrid origin for continent formation in the Archean. Archean continents formed by the amalgamation of island arcs and underthrusting of oceanic lithosphere.

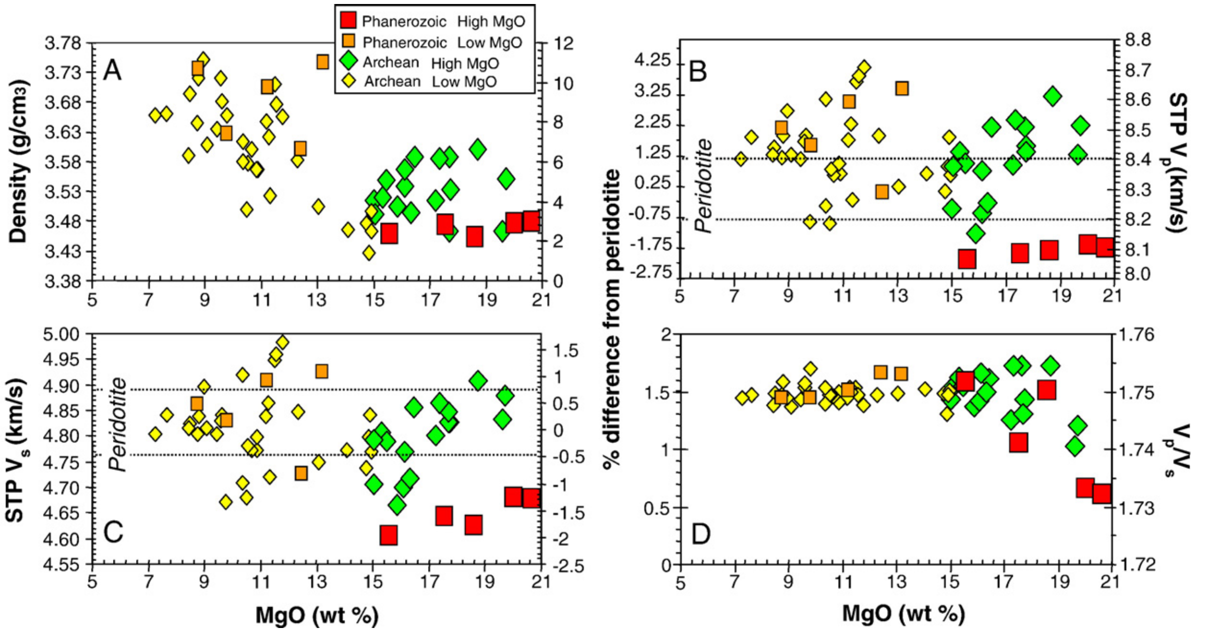

Fig. 6. Standard temperature and pressure densities (A), compressional or p-wave velocities V_P (B), shear or s-wave velocities V_S (C), and V_P/V_S ratios (D) of various eclogite xenoliths. Dashed regions in (B) and (C) correspond to the fields covered by mantle peridotites [70].

were the protoliths emplaced to the greater pressures from which they presently reside in the cratons (3–7 GPa).

Finally, the presence of eclogite xenoliths in kimberlite pipes is clearly consistent with the predictions of our conceptual model. However, the extent of these eclogite heterogeneities is not known. Thus, the question remains as to whether any eclogite heterogeneities could be seen seismically. To shed light on this question, we calculated standard temperature and pressure densities and p (V_P) and s (V_S) wave velocities [69,70] for some of the Archean [35] and Sierran eclogite xenoliths [43] (Fig. 6). While many eclogite xenoliths have significantly higher p-wave velocities than peridotite [70], some have velocities overlapping or even slightly lower than peridotite velocities. The lower velocities correspond to those samples with lower garnet contents. Although many of the samples have higher p-wave velocities than peridotite, the very high velocities reported by [71] are not reached, but this is because the representative eclogite composition they assumed had clinopyroxenes with unusually high jadeite component, thus yielding very high velocities. In contrast to p-wave velocities, most of the eclogites have s-wave velocities overlapping or falling slightly lower than peridotite (Fig. 6). Our calculations imply that eclogite layers or lenses in the lithospheric mantle should give distinct p-wave reflections in active seismic surveys, such as seen in recent seismic studies in the Canadian shield [72]. These calculations also suggest that layers of eclogite should give rise to subtle P–S conversions in receiver function studies [73]. However, one might expect both positive and negative conversions depending on the type of eclogite layer that is present [73]. Thus, receiver function studies hold some promise in testing our conceptual model, provided eclogite lithologies are concentrated in layers.

5. Conclusions

In light of the geochemical similarities between Phanerozoic arc-eclogites and mid- to late Archean high MgO eclogite xenoliths, we speculate that the origin of Archean high MgO eclogite xenoliths may have been similar to the Sierran high MgO arc-eclogites. The latter are believed to have formed as high-pressure cumulates from a hydrous arc basalt. If the Archean and Phanerozoic high MgO eclogites investigated here indeed have similar origins, then the Archean high MgO eclogite xenoliths represent evidence from the mantle roots of cratons that arc magmatism was involved in the formation of Archean continents. While the detailed nature of Archean geodynamics certainly differed from the Phanerozoic, it seems likely that the Earth was characterized by a mobile surface in which subduction zones and arc magmatism existed in the Archean.

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