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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

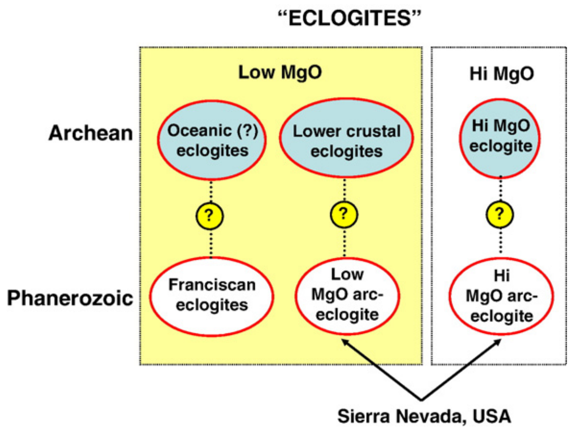

Fig. 1. Breakdown of the Archean and Phanerozoic eclogites. Archean eclogites divided into lower crustal-derived eclogites (low MgO) and mantle-derived eclogite xenoliths (high and low MgO). Phanerozoic eclogites divided into high and low MgO arc-eclogites (e.g., the Sierra Nevada) and Franciscan eclogites.

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.