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On the origin of hot metasedimentary quartzites in the lower crust of continental arcs

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ABSTRACT

Volcanic arcs associated with subduction zones are thought to be the primary building blocks of continents. The composition of the magmas, particularly in continental arcs, is the product of mixing between differentiation of juvenile magmas and pre-existing crustal wallrock, the former being typically mafic and the latter more silicic. Because the upper continental crust is on average thought to be more silicic than the mafic lower crust, mixing with silicic endmembers should occur primarily in the upper crust. However, we show here that the lower crust of continental arcs contains silicic metasediments. We examine garnet-bearing, granulite-facies sedimentary quartzite xenoliths from the Sierra Nevada batholith in California, a Cretaceous continental arc. The quartzites have equigranular textures and contain quartz ($>50\%$), plagioclase ($<30\%$), garnet (10%), and small amounts ($<1\%$) of rutile, aluminosilicate, biotite, monazite, zircon, graphite and trace orthopyroxene. Cathodoluminescent images show zircons with rounded detrital cores mantled by metamorphic overgrowths. Hf isotopic model ages and U–Pb upper intercept ages, for a given zircon, are similar, but the zircon population shows variable protolith ages ranging from Proterozoic to Archean. In contrast, all zircons share similar lower intercept U–Pb ages (103 ± 10 Ma), which coincide with the peak of arc magmatism in the Sierra Nevada. The Precambrian protolith ages are similar to North American cratonal basement, and together with the abundance of quartz and detrital zircons, suggest that these quartzites represent ancient, passive margin sediments instead of juvenile active margin sediments in the oceanic trench and accretionary prism. Importantly, these quartzites record peak metamorphic temperatures and pressures of 700–800 °C using Ti-in-quartz thermometry and 0.7–1.1 GPa using garnet–aluminosilicate–plagioclase thermobarometry, indicating that these xenoliths experienced significant heating and possible partial melting in the lower crust, most likely related to arc magmatism as suggested by similarities between the lower intercept U–Pb ages and the ages of plutonism in the Sierra Nevada. Possible mechanisms by which these sediments were transported into the lower crust include continental underthrusting beneath the continental arc, underplating by buoyant slab-derived sedimentary diapirs, or viscous downflow of country rock in response to diapiric ascent of plutons. Continental underthrusting has been independently documented during the Sevier orogeny, coinciding with the peak of arc magmatism. We thus speculate that supracrustal rocks may have been underthrusted into deep crustal magmatic zones. Regardless of how these metasediments arrived in the lower crust, our observations indicate that silicic metasediments occur in the lower crust of volcanic arcs, not just in the upper crust as is commonly thought. Transport of metasediments into deep crustal magmatic zones should influence the composition of arc magmas and continental crust in general.

1. Introduction

Arc magmas formed above subduction zones are considered to be essential components in building continents. The compositional stratification of continental crust, from felsic upper crust grading into mafic lower crust, is attained through a combination of igneous differentiation and interaction of juvenile arc magmas with pre-existing wallrocks (Hildreth, 1981; Hildreth and Moorbath, 1988). Fractional crystallization of a basaltic melt results in the retention of dense, mafic cumulates in the deep lithosphere, leaving the residual felsic melts to escape to shallower crustal levels owing to their lower densities. Further refinement of magmas in the upper crust may also involve mixing with pre-existing wallrocks, which are typically felsic.

In this study, we present evidence for silicic metasedimentary rocks in the lower crust of a mature continental arc, the Sierra Nevada Batholith in California. The metasediments are nearly

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pure quartzite or metasandstone xenoliths (> 85 wt% SiO_2). They contain metamorphic garnet and last equilibrated within the granulite facies, recording temperatures in excess of 700 °C and pressures of 1 GPa. Upper intercepts of U–Pb discordia and Hf isotope systematics in detrital zircons show that the metasediments represent strata of the ancient passive margin of North America. Detrital zircon cores are rimmed by metamorphic overgrowths, which yield a common U–Pb lower intercept age coeval with the Late Cretaceous peak of arc magmatism in the Sierra Nevada.

Such quartz-rich sediments are anomalous in the mafic lower crust, suggesting that they were transported from their origin in shallow passive margin depocenters into the deep crust. We propose continental underthrusting as one mechanism, but explore other hypotheses, such as wallrock downwelling associated with plutons rising into the crust and underplating by sediment diapirs derived from the subducting slab. The Sierran lower crustal quartzites offer a unique window into the lower crust, and regardless of the mechanism of their emplacement, indicate that the lower crust may be more felsic than previously thought.

2. Geologic setting

During the Paleozoic, the western margin of North America was defined by a passive margin. In the early Mesozoic, island arcs and other exotic terranes were accreted on to this margin (Dickinson, 1981). This transition in tectonic environment was manifested as two distinct Cordilleran depositional settings: mature passive margin sediments (historically referred to as "miogeoclinal") deposited in the Paleozoic, and juvenile ("eugeoclinal") sediments associated with the Mesozoic active margin (Kistler, 1990; Moore and Foster, 1980; Stewart, 1970). The passive margin sediments formed a westward thickening wedge of siliciclastics and carbonates extending from eastern Utah to southwestern Nevada and eastern California. Its maximum estimated thickness was ∼10 km in the west (Armstrong, 1968; Stewart, 1970). Facies changes, sediment

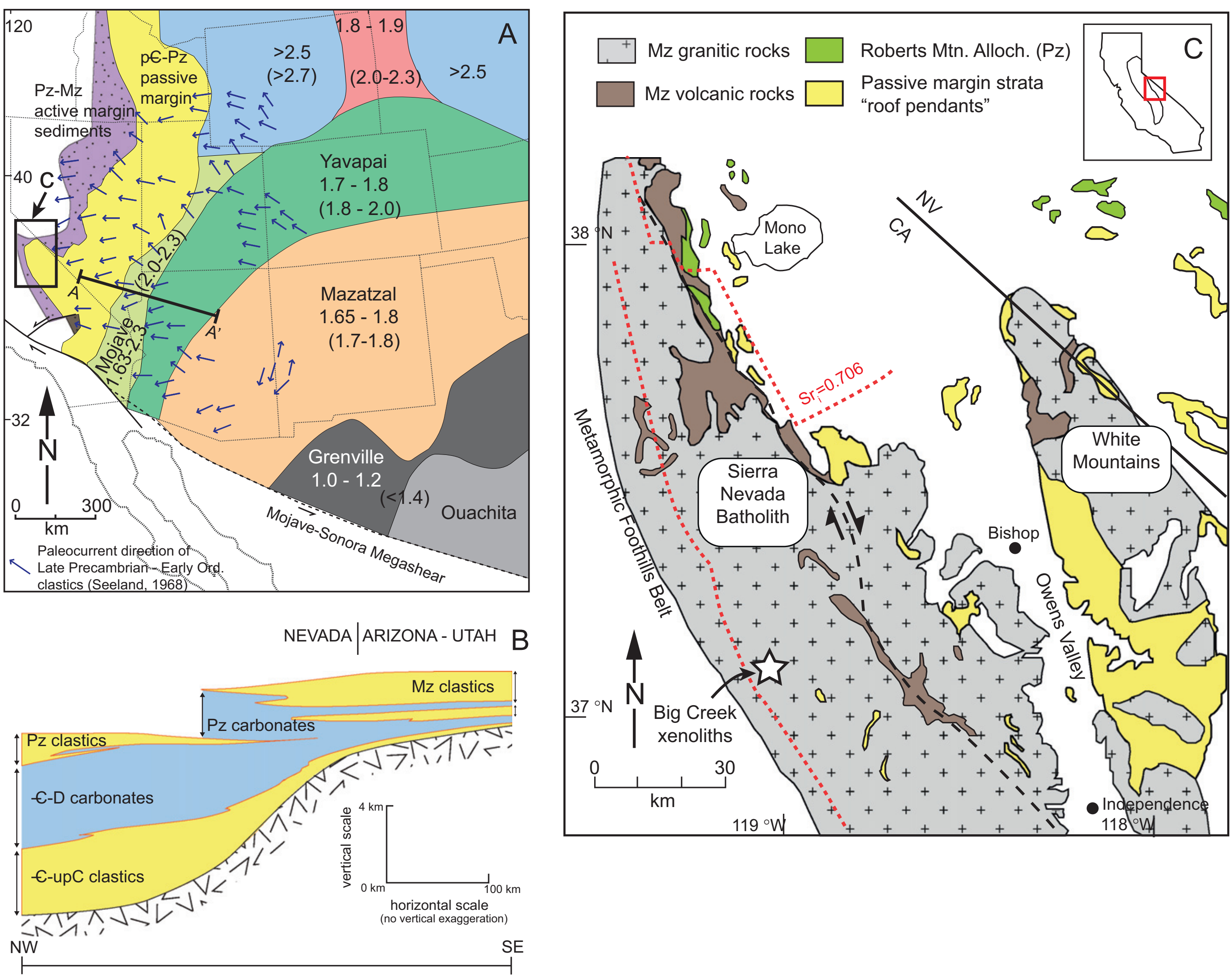

Fig. 1. (A) Map of the Western US, showing the major basement terranes. U–Pb crystallization ages and Hf model ages (parenthesized) are shown. Blue arrows denote paleocurrent directions of Late Precambrian to Early Ordovician clastic sediments and deposition onto the Cordilleran passive margin. (B) Schematic cartoon, modified after Suppe (1985) showing the westward thickening clastic wedge of the Cordilleran miogeocline (passive margin). Sedimentary thickness reached a maximum of ∼10 km at the westernmost limit in western Nevada/eastern California. (C) Simplified map of the central–northern Sierra Nevada Batholith. White star represents xenolith locality. Yellow areas represent passive margin rocks now cropping out as roof pendants. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)