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Petrogenetic and tectonic interpretation of strongly peraluminous granitic rocks and their significance in the Archean rock record

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ABSTRACT

Strongly peraluminous granitic rocks (SPG), defined by an aluminum saturation index ≥1.1, become abundant in the rock record in the Neoarchean. This study identifies three different varieties of Neoarchean SPG in the Archean Wyoming Province, U.S.A. These include calcic SPG, represented by the Webb Canyon Gneiss and Bitch Creek Gneiss of the Teton Range; calc-alkaline to alkali-calcic suites composed entirely of SPG, including the Rocky Ridge garnet granite gneiss of the northern Laramie Mountains and the Bear Mountain granite in the Black Hills; and calc-alkaline to alkali-calcic suites that include both weakly and strongly peraluminous granitic rocks, such as the Mount Owen batholith, Wyoming batholith, and Bears Ears granite. Although the petrogenesis of all the SPG suites involves partial melting of crustal sources, the composition of those sources, the melting conditions, and the tectonic settings vary. The calcic suites originate by dehydration melting or water excess melting of hornblende-plagioclase rocks at relatively high temperature. The suites composed entirely of SPG formed by partial melting of metasedimentary rocks by reactions involving muscovite at lower temperatures. Suites with both weakly and strongly peraluminous granite may form by partial melting of metasedimentary rocks by reactions involving biotite or by assimilation of aluminous melts of felsic crust by differentiated calc-alkaline magma. Most of the Wyoming SPG appear to have formed in collisional orogens, but SPG of the Wyoming batholith and Bears Ears granite are associated with continental arc magmatism. The appearance of SPG in the Neoarchean rock record marks the time when subduction enabled the formation of strong, thick, increasingly felsic continental crust, which in turn allowed the development of a mature, clastic sedimentary cover. Lateral movement of crustal blocks led to collisional orogeny, SPG magma genesis, and the formation of the first supercontinents.

Keywords: Strongly peraluminous granite, crustal evolution, Neoarchean, petrogenesis

INTRODUCTION

Peraluminous rocks contain more Al than can be accommodated in feldspars alone (Shand 1947). Shand defined the aluminum saturation index (ASI) as the molecular ratio Al₂O₃/(CaO + Na₂O + K₂O). ASI will be 1.0 for any combination of plagioclase and alkali feldspars because alkali feldspars have 1 mol of Al and 1 mol of Na and/or K and anorthite has 2 mol of Al for 1 mol of Ca. The calculation of ASI commonly includes a correction for the presence of calcium in apatite, assuming all phosphorus in the rock is in apatite. The expression for ASI, including this correction¹, is

\[
ASI = \frac{\text{wt\% Al}_2\text{O}_3/101.94}{\left(\text{wt\% CaO}/56.08 - 3.33 \times \text{wt\% P}_2\text{O}_5/141.95 + \text{wt\% Na}_2\text{O}/61.982 + \text{wt\% K}_2\text{O}/94.2\right)}
\]

where the denominators are molecular weights of the respective oxides.

The aluminum saturation index differentiates peraluminous rocks, with ASI > 1.0, from metaluminous rocks, with ASI < 1.0. Peraluminous rocks may be further subdivided into weakly peraluminous (1 < ASI < 1.1) and strongly peraluminous varieties (ASI ≥ 1.1) (Bucholz and Spencer 2019; Sylvester 1998).

Because peraluminous rocks have more molecular Al₂O₃ than can be accommodated in feldspars alone, one or more other aluminous phases must be present. For weakly peraluminous rocks, this phase may be aluminous biotite, but for strongly peraluminous rocks the phases can include muscovite, cordierite, garnet, tourmaline, topaz, spinel, corundum, or an Al₂SiO₅ polymorph. The aluminous phases may be of magmatic origin or may be entrained peritectic, restitic, or inherited crystals.

Strongly peraluminous granitic rocks (SPG) are commonly interpreted to derive from sedimentary sources (Chappell and White 2001). Fine-grained clastic sedimentary rocks are aluminous as a result of removal of elements including Na and Ca during weathering and the formation of clays. Metamorphism and partial melting of such aluminous sources produce granite with peraluminous compositions (Nabelek 2020). Strongly peraluminous granitic rocks formed by partial melting of metasedimentary rocks are potential monitors of source rock composition and temperature of partial melting (Bucholz and Spencer 2019; Sylvester 1998). However, to identify the source characteristics of strongly peraluminous granitic rocks, it is also necessary to take into account the specific melting reactions involved and the effect of subsequent magmatic processes, including flow segregation,