# Batholithic, K-rich silicic magmatism in East-Central Asia: evidence for a mantle source for progressive regional crustal potassium enrichment

**S.M. Wickham** *Department of the Geophysical Sciences, University of Chicago, Chicago, IL 60637, USA*

**B.A. Litvinovsky** *Buryat Geological Institute, Ulan-Ude 670015, Russia.*
**A.N. Zanvilevich**
**I.N. Bindeman** *Department of the Geophysical Sciences, University of Chicago, Chicago, IL 60637, USA.*

**Granitoid magmatism in East-Central Asia** Granitoid magmatism has occurred on a vast scale in Transbaikalia, East Central Asia during the Phanerozoic. Within this huge and geologically complex region, many hundreds of individual plutons of syenite, quartz syenite, and K-rich granite have been intruded within NE–SW-oriented belts 200–400 km wide and 2000–3000 km long. These belts are superimposed upon and cut across more ancient tectonic structures (including basement blocks of different age and composition). The intrusive activity was accompanied by extrusion of the volcanic counterparts of these magmas. The composition of intrusive and extrusive magmas was absolutely independent of local country-rock composition (Leontiev *et al.*, 1981; Zanvilevich *et al.*, 1985; Litvinovsky *et al.*, 1993.)

Five main stages of intrusive activity are distinguished (see Table 1), and each suite of rocks is mineralogically very distinctive. Although not all of the suites have been directly dated, they have been given the following approximate age designations: (1) Ordovician-Silurian, (2) Devonian, (3) Early Permian 1, (4) Early Permian II, and (5) Permo-Triassic. Granites and syenites occur within each suite, but the relative proportion of syenite increases with time, as does the relatively alkalinity of each suite (strongly peralkaline syenites and granites containing alkaline amphiboles and pyroxenes only occur in the Permo-Triassic suite). Plutons of younger suites intrude into earlier plutons, but contacts are sharp and there is no evidence of major assimilation of country rock at the level of emplacement, which for almost all plutons was within a few kilometres of the surface.

TABLE 1. Age and average composition of the five main plutonic igneous suites in the lower Selenga region, Transbaikalia (after Zanvilevich *et al.*, 1985)

| Age | Rock type | Props. | Average $K_2O$ (wt%) |
|---|---|---|---|
| Ordovician-Silurian | granite | 90% | 4.3 |
| (~450 Ma) | quartz monzonite | 10% | 3.8 |
| Devonian (~380 Ma) | granite | 90% | 4.8 |
| | quartz syenite | 10% | 4.8 |
| Early Permian I | syenite | 90% | 5.2 |
| (~300 Ma) | granite | 10% | 4.8 |
| Early Permian II | syenite | 70% | 6.1 |
| (~280 Ma) | granite | 30% | 4.8 |
| Permo-Triassic | peralkaline syenite | 90% | 5.8 |
| (~240 Ma) | granite | 10% | |

The K-rich plutonic belts of Transbaikalia and adjoining areas represent one of the largest concentrations of silicic magmatism on Earth, spanning ~250 Ma in age and outcropping over more than 500,000 km$^2$. There are some similarities with the Mid- Proterozoic granite-syenite-anorthosite belt of North America in the scale and composition of the granitoids, but in Transbaikalia the rocks are much better preserved, show a systematic compositional variation with time, and lack the anorthosite component. Moreover, the plutonism was extremely intense, with large areas comprising almost exclusively plutonic igneous rocks.

Inasmuch as alkaline granitoid magmatism was developed on such a huge scale and because the mineralogy and composition of the plutons show systematic change in both time and space, this area provides an excellent opportunity to make major advances in our general understanding of intracontinental granitoid magmatism. Some outstanding questions include:

(1) What was the source rock for the magmas (especially the syenites, which appear to have been

parental to the granites) and why was it uniformly available over such a wide area?

(2) Why did the magmas become more K-rich with time?

(3) Why were no other granitoid magma compositions (e.g., calc-alkaline, per-aluminous) formed?

(4) What was the heat source for magma formation, and the regional tectonic setting?

**Oxygen isotope constraints** Systematic variation of $\delta^{18}O/^{16}O$ in magmas provides important evidence regarding the identity of source materials and the nature of mixing processes. However, in plutonic igneous rocks (especially those dominated by feldspar), reconstruction of magmatic $\delta^{18}O$ values can sometimes be obscured by subsolidus isotope exchange processes, or by uncertainty as to whether bulk rock compositions represent magmas or cumulates. Both factors are problematic in the case of the K-rich granites and syenites of Transbaikalia, because some plutons have experienced meteoric- hydrothermal alteration, and because syenites can be almost monomineralic K-feldspar rocks. Analysis of refractory accessory phases such as zircon or sphene that are resistant to subsolidus alteration and formed early in the crystallization history, is a promising way to circumvent these problems, and may also be used to identify unmelted residual source material (restite) and thereby constrain segregation processes.

We have used a laser fluorination technique to analyze 0.5 to 3.0 mg-sized samples of sphene (including single grains) in the Transbaikalia granitoids. Our results indicate a highly systematic decrease in the $\delta^{18}O$ values of these magmas with time. In particular: (1) Sphene $\delta^{18}O/\delta^{16}O$ is quite homogeneous within most plutons, regardless of whether or not quartz-feldspar systematics have been disturbed by hydrothermal alteration. This indicates that sphene may be used to reconstruct mag- matic $\delta^{18}O$ values, even in hydrothermally altered plutonic rocks. (2) Within and among plutons of a given suite, sphene $\delta^{18}O/\delta^{16}O$ is fairly constant. This indicates that these magmas contain little if any restite, were little affected by high-level assimilation processes, and probably formed in an almost fully liquid state with a high degree of isotopic (and chemical) homogeneity. (3) There is a systematic, progressive decrease in $\delta^{18}O$ of sphene with time from $+6$ to $+7$ in the earliest suite to $+1$ to $+2$ in the youngest suite (corresponding to a decrease in magmatic $\delta^{18}O$ from $\sim +11$ to $\sim +6$). The source regions of these relatively silicic magmas were therefore progressively $^{18}O$-depleted and homogenized on a regional scale, during each successive melting event.

**Coupled variations in the composition of mafic and silicic magmas** Although plutonic mafic rocks are relatively rare within the Transbaikalia plutonic belts, small quantities of gabbroic rocks are found associated with plutons of all age suites. Often, these occurrences preserve spectacular mafic-felsic magma mixing textures indicating that mafic magmas coexisted with granitoids of each suite during emplacement. An investigation was made of parallel geochemical variations in the two magma types.

The original mafic magma composition was reconstructed using a variety of approaches including (1) microprobe analysis of trace elements in relict basaltic minerals (e.g. An-rich plagioclase) and recalculation of liquid compositions using available $K_D$ values; (2) bulk rock analysis of the least hybridized mafic rocks and consideration of the least mobile elements; (3) direct determination of magma composition by microprobe analysis of heated and homogenized melt micro inclusions in relict minerals. We found that just as there is a progressive increase in alkalinity (especially $K_2O$) in the silicic rocks, there is also a parallel increase in the alkalinity of the reconstructed, primary mafic magmas, accompanied by a regular enrichment in Ti, P, $Fe_{tot}$ and high field-strength elements. However, this covariation is lacking in other elements such as Sr or Ba. The consistent temporal trends of the more mobile elements in these coexisting magmas suggests that the mafic magmas were a source of both heat and some chemical components during the generation of the silicic magmas.

**Petrogenesis** The geochemical and isotopic data allow us to develop a model for the evolution of anorogenic magmatism in East Asia. In particular, we have to explain the progressive increase in alkalinity (especially $K_2O$) and decrease in $\delta^{18}O$ over 250 Ma of plutonism. These constraints may be satisfied by progressive hybridisation of K-rich (alkali) basalt magmas with crustally-derived silicic melts, accompanied by fractional crystallization of K-poor phases such as plagioclase and pyroxene. Such a mechanism could form large volumes of syenitic residual liquids, having the appropriate isotopic composition. Younger suites were derived through hybridization of material formed during earlier magmatic episodes, leading to a progressive increase in overall alkalinity and decrease in $\delta^{18}O$. In order to generate the specific compositional range of each suite, large-scale mixing and homogenization occurred during each melting episode. This model will be further tested using other isotopic and chemical data from this region, as these become available.