Experimental constraints on the origin of potassium-rich adakites in eastern China

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Abstract Adakites are geochemically distinct volcanic and plutonic granitoid rocks found in intraoceanic island arc settings where relatively young, hot oceanic lithosphere has been subducted and melted (termed “slab melting”), and in continental arcs, such as the Andes, where melting has taken place at the base of tectonically- or magmatically-thickened lower crust (termed “lower crustal melting”). In both settings, the distinctive geochemical signature of adakitic granitoids is attributed to an origin by partial melting of a variably-hydrated metabasaltic protolith at sufficient depths for garnet to be stable within the residual crystalline assemblage (i.e., residues of garnet-amphibolite and/or eclogite). Once generated, “pristine” or “parental” adakite melts may have their composition subsequently modified by processes of assimilation (of either mantle or continental material) and crystal fractionation during transport to and emplacement in the middle-upper crust. Late Mesozoic (early-mid Cretaceous, ~160–110 Ma) adakites in eastern China are unusually rich in potassium (K₂O) and other large-ion lithophile elements (e.g., Ba, Th, U), with low Na₂O/K₂O ratios (~1.0–1.1), in contrast to sodic adakites, found in eastern China and elsewhere, which resemble experimental adakite liquids produced by dehydration melting of basalt in the garnet-amphibolite to eclogite facies, and which formed by either slab melting of oceanic crust, or by partial melting of broadly basaltic, lower crustal protoliths. Despite these compositional differences, their overall geochemical character defines the potassic granitoids of eastern China as adakites. We attribute the unique chemistry of these potassium-rich adakites to either peculiarities in the composition of their source, or to the processes, including assimilation and fractional crystallization (AFC), that subsequently modified parental adakite magmas. Although the apparent lack of proximity to a subduction zone suggests that adakites in eastern China formed by partial melting of underplated (magmatically-thickened) mafic lower crust, geodynamic scenarios involving “flat slab” subduction in eastern China during the Yanshanian period cannot be ruled out.

Key words Potassium-rich adakites, Experimental constraints, Eastern China

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Adakites as slab melts

An alternative to the slab melting model for adakite genesis was proposed by Atheron and Pelford (1993) to explain the origin of Norikura post-orogenic volcanic rocks (NPOVRs) in the Cordilleran magmatic complex in the Andes of NW Peru. As the Cordilleran magmatism occurred in a relatively small region (the Nazca Plateau) and similar volcanic rocks are known from the Andean Cordilleras, it was suggested that these rocks formed by slab melting. This model was further developed by Nakamura et al. (1994) and Nakamura and Ogasawara (1994).

The slab melting model requires that the subducting slab is partially molten, which is not always the case. In addition, the slab melting model does not explain the origin of the post-orogenic volcanic rocks in the Cordilleran magmatic complex in the Andes of NW Peru. Furthermore, the slab melting model does not explain the origin of the post-orogenic volcanic rocks in the Andean Cordilleras.

Adakites as crustal melts

Adakites are a type of volcanic rock that is typically associated with subduction zones. They are characterized by high Mg, Fe, and Ni contents, and low Nb and Ta contents. These rocks are thought to form by the melting of subducted oceanic crust, which is a process known as slab melting.

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of the Andes (Atherton and Petford, 1993; Petford and Atherton, 1996), similar to the model put forth by Smith and Leeman (1987) for the petrogenesis of Na-rich dacites at Mt. St. Helens in the Cascade Range of North America. Adakite-like rocks from South Island, New Zealand (Muir et al., 1995), the Antarctic Peninsula (Wachern et al., 1997), and the Klamath Mountains of California and Oregon (Barnes et al., 1992; 1996) were subsequently interpreted as the products of partial melting of mafic lower crust, formed in response to crustal thickening achieved through underplating of mantle-derived mafic magmas (emplaced at the base of the existing arc crust). It was argued that displacement of this over-thickened “keel” of mafic crust to depths sufficient for garnet stability led to partial melting attendant to dehydration and adakite magmatism. Recent numerical models suggest that the appropriate P-T conditions can be achieved for partial melting of underplated “mafic lower (arc) crust” to take place, generating adakite parent magmas with mixed mantle- and crustal-like geochemical and isotopic signatures (Petford and Gallagher, 2001).

Intermediate-felsic volcanic and plutonic rocks of late-Cretaceous age (160 — 110 Myr old) from eastern China possess all of the characteristic geochemical attributes of adakites, including high SiO2 and Al2O3 contents and high La/Yb and Sr/Y ratios, and strong relative depletions in the HREEs, Y, and HFSE. Yet many of the adakites in eastern China are distinctly more potassic than typical sodium-rich adakites associated with subduction, with Na2O/K2O ratios close to 1 (see Pan et al., 2001; Wang and Zhang, 2001; Wang et al., 2001; Zhang et al., 2001), and they are generally more potassic than the more typically sodic adakites from the Cascades, Antarctica, and the Andes. The “adakite-like” or “adakitic” granitoids which occur throughout eastern China have been termed continental or “C-type” adakites (Zhang et al., 2001), because they appear to lack any temporal or spatial association with subduction, and a lower crustal melting origin has been proposed, (Wang and Zhang, 2001; Pan et al., 2001; Wang et al., 2001). “C-type” adakites are contrasted with more sodic “oceanic” or “O-type” adakites (with Na2O/K2O ratios > 2.0) possessing a clear association with subduction (e.g., Xu et al., 2000; Xu et al., 2001). If the potassium-rich adakites of eastern China are also derived by partial melting of a garnet-bearing, hydrous mafic source, then their compositional differences with “O-type” adakites must be due either to differences in the source, or in the processes (e.g., assimilation and fractional crystallization; AFC) that subsequently modified the composition of “pristine” or parental adakite magmas.

Melting experiments on hydrous basalt provide a geochemical reference point from which the geochemical effects of melt-rock reaction, wall rock assimilation, and intracrustal fractionation on adakite composition can be assessed.

**Basalt compositions used in melting experiments**

A variety of both natural and synthetic starting materials have been used to study the high-pressure melting behavior of hydrous basalt (Table 1). Rapp et al. (1991) and Rapp and Watson (1995) conducted melting experiments at 0.8 — 3.2 GPa and 1000 C — 1150 C on four different natural amphibolites compositionally representative of variably altered and metamorphosed MORB. Potassium content in these starting materials ranges from < 0.1 wt% to 0.8 wt% K2O, and Al2O3 contents range from 14.2 wt% to 17.0 wt% (Table 1). Adakitic liquids were produced by dehydration melting reactions involving hydrous minerals (primarily amphibole) whose breakdown produces silica-rich liquids at relatively low- to moderate-degrees of melting. Dehydration melting experiments were also conducted by Sen and Dunn (1994) at 1.5 and 2.0 GPa, temperatures between 800 and 1150 C, using a natural high-K amphibolite basalt as starting material (Table 1), and Winther and Newton (1991) conducted melting experiments over a range of pressures (0.5 — 3.0 GPa) and temperatures (850 C — 1000 C), using two different low-K tholeites (one a natural high-Al basalt, and the other a synthetic low-Al basalt representing “average Archean tholeite”) and variable amounts of water (from < 1.0% to 15%H2O).

Despite the fact that the various starting materials used in these experimental studies possessed a broad range in K2O (0.1 — 0.8 wt%), Na2O (2.2 — 4.3 wt%), and Al2O3 (14.2 — 19.3 wt%) contents, and highly variable Na2O/K2O (3 — 28), they all produced Na-rich granitoid liquids closely comparable to natural adakite by low- to moderate-degrees of melting (~ 10 — 30% by weight), leaving generally eclogitic crystalline residues. Note however, that the Na2O/K2O ratio of average basalt from China is much lower than any of the starting materials used in the basalt melting experiments, with a K2O content (2.51 wt%) much higher than the worldwide average (1.10 wt%).

**Melting phase relations of hydrous basalt to 5 GPa**

The melting phase diagram for hydrous basalt (Fig. 1) represent a composite constructed from the results of a number of experimental studies, on both natural and synthetic starting materials and with variable amounts of water present. Several of these studies focused on sub-solidus phase relations and the stability limits of important hydrous minerals, such as amphibole, lawsonite, zoisite and clinzoisite, and phengite (Poli and Schmidt, 1995; Schmidt, 1996; Kerrick and Connolly, 2001; Lopez and Castro, 2001). The actual position of the solidus for a given bulk composition will be determined by the form and

**Review of Experimental Studies**

Whether formed by slab melting or lower crustal melt-
Granitoid melts generated by hydrous melting of basalt

Fig. 1 Composite phase diagram for basalt-H₂O, with P-T locations of melting experiments in which adakitic granitoid liquids were formed (see references in text), the water-saturated or “wet basalt” solidus and the water-absent or dehydration melting solidus, and major phase boundaries for garnet and hydrous minerals. At pressures less than 3.5 GPa, liquids formed by very low degrees of melting (<10%) near the solidus have low Na₂O/K₂O ratios (< 1.5); adakitic liquids with higher Na₂O/K₂O ratios form at higher temperatures and greater degrees of melting (10-30%). At higher pressures (> 3.5 GPa), granitoid liquids formed by low- to moderate-degrees of melting possess high SiO₂ and K₂O contents, very low Na₂O/K₂O ratios, and low Al₂O₃ contents (see Table 2).

Table 1 Major-element oxide composition of starting material in melting experiments on hydrous basalts (wt%)

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<th>5</th>
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<td>SiO₂</td>
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<td>48.30</td>
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<td>48.28</td>
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<td>TiO₂</td>
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<td>0.85</td>
<td>1.19</td>
<td>1.23</td>
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<td>10.70</td>
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<td>0.29</td>
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<tr>
<td>MgO</td>
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<td>6.07</td>
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<td>6.89</td>
<td>8.29</td>
<td>7.09</td>
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<tr>
<td>CaO</td>
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<td>9.66</td>
<td>12.60</td>
<td>10.99</td>
<td>10.50</td>
<td>10.80</td>
<td>11.33</td>
<td>8.07</td>
</tr>
<tr>
<td>Na₂O</td>
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<td>2.27</td>
<td>2.56</td>
<td>3.11</td>
<td>2.35</td>
<td>2.52</td>
<td>3.40</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.82</td>
<td>0.21</td>
<td>0.08</td>
<td>0.19</td>
<td>0.39</td>
<td>0.26</td>
<td>0.80</td>
<td>2.51</td>
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availability of water in the source; if a free hydrous fluid phase is present, then the source can be considered to be “fully hydrated”, and melting will commence at the “wet basalt” solidus. If no free fluid phase is present, all water will be bound in hydrous minerals, and melting will commence at the “fluid-absent” solidus through dehydration melting reactions involving amphibole, zoisite, and other water-bearing phases. The solidus for dehydration melting occurs at somewhat higher temperatures than the water-saturated or wet basalt solidus, with its exact location being determined by the relative degree of hydration of the source, and the proportion of hydrous phases present (Lopez and Castro, 2001; Vielzeuf and Schmidt, 2001).

Melt compositions at 1—4 GPa

Also shown in Fig. 1 are the P-T locations of experiments in which granitoid melts (that is, liquid compositions that contain more than 10% quartz in a CIPW normative calculation) were reported (Winther and Newton,
1991; Sen and Dunn. 1994: Rapp and Watson. 1995). These experiments were generally conducted under fluid-absent conditions, where melting proceeds via dehydration reactions involving hydrous phases, primarily amphibole. Because potassium and the LILEs behave generally as highly incompatible elements during partial melting, the most potassic liquids, those richest in LILEs, will form at the lowest degrees of melting, nearest the solidus, and liquids formed by progressively higher degrees of melting will be less potassic and increasingly dilute with respect to the LILEs. Partial melts formed by very-low degrees of melting (<10%), will thus be more potassic, with lower Na$_2$O/K$_2$O ratios (0.9–1.2), than their sodium-rich counterparts (Na$_2$O/K$_2$O > 1.5–2.0), formed at slightly higher temperatures and higher degrees of melting (10–30 wt%). The amount of K$_2$O in the melt at a given degree of melting also appears to increase with increasing pressure (Winther and Newton, 1991), so that 20% melting at 3.8 GPa produces a more potassic liquid than 20% melting of the same basalt at 1.8 GPa (see Table 1). The lowest degrees of melting should also produce liquids with the highest Sr/Y and La/Yb ratios.

The amphibole-out phase boundary exerts strong control over the alumina saturation index (ASI, or A/CNK = molar Al$_2$O$_3$/(CaO + Na$_2$O + K$_2$O)) of the partial melt, such that metaluminous adakitic liquids (i.e., A/CNK < 1.0–1.1) are only produced close to or beyond this boundary (Rapp, 1995). Most adakites, whether in a subduction zone or lower crustal setting, are metaluminous, and therefore they probably formed at temperatures at which residual amphibole was either a minor phase, or not present at all, and an eclogite phase assemblage (garnet and clinopyroxene) was predominant. In this regard, we note that most of the adakites from eastern China possess A/CNK ratios less than 1.1 (Zhang et al. 2001).

**Geochemical Comparisons with C-type Adakites**

Geochemical comparisons between the experimental adakitic liquids, adakites from eastern China, and adakites formed either by slab melting or lower crustal melting of subducted slabs reveal important similarities and differences, as outlined below, providing some initial constraints on the petrogenesis of the compositionally-distinctive potassic adakites.

**Major-element comparisons**

Like “pristine” adakitic liquids in the basalt melting experiments, potassic adakites are typified by high SiO$_2$ and Al$_2$O$_3$ contents, Mg$^{#}$’s less than 40–45 (where Mg$^{#}$ = 100 x molar (Mg/[Mg + Fe])), and A/CNK ratios generally < 1.0–1.1. Adakites related to slab melting often have higher Mg$^{#}$’s at lower SiO$_2$ contents, and A/CNK ratios less than 1.0, reflecting varying extents of interaction with peridotite in the overlying mantle wedge, but trace element abundance patterns remain largely unaffected (see discussion in Rapp et al., 1999, and Smithies, 2001). Clear distinctions can therefore be made between relatively “pristine” and “mantle-hybridized” adakitic magmas, and although it is premature to call potassic adakites “pristine”, it seems clear that they have experienced little interaction with a mantle component (as attested to by their low Mg$^{#}$’s and low Cr and Ni contents). As shown by Wang et al. (2001) and Zhang and Wang (2001), the primary difference, in terms of major-elements, between potassic adakite (C-type) and sodic adakite (O-type) is that the former is characterized by higher K$_2$O contents and lower Na$_2$O/K$_2$O ratios over a comparable range of SiO$_2$ contents (60–73 wt%). When plotted on a ternary feldspar (Ab-An-Or) diagram, potassic adakites fall close to or within the granodiorite and granite fields, relative to the more typically tonalitic-trondhjemitic compositions of sodic adakites, as well as most experimental adakite liquids (Rapp et al., 1991; Winther and Newton, 1991; Sen and Dunn, 1994), with the exception of those produced from very low degrees of melting (i.e., < 10 wt%).

**Trace element comparisons**

Trace-element data for experimental liquids is relatively scarce; ion microprobe data has been published for adakitic liquids produced at 1–3 GPa (analyzing several samples from Rapp and Watson, 1995), and both “pristine” and “mantle-hybridized” adakitic liquids at 3–4 GPa (Rapp et al., 1999). This data is combined with additional unpublished data (Rapp and Shimizu, in prep.) in making trace element comparisons between experimental adakitic liquids, potassic-rich adakites from China, and Na-granitoids of the Cordillera Blanca batholith (to typify adakites derived by partial melting of thickened crust). Plots of La/Yb versus Yb and Sr/Y and Y were first used by Martin (1987) and Defant and Drummond (1999) to discriminate adakites and their Archean analogues (TTG) from normal calc-alkaline andesite-dacite-rhyolite volcanics. Mantle-normalized trace element abundance patterns for liquids formed at 3–4 GPa, from melting of two different basalts, and taken to be representative of pristine adakite (unpublished data of Rapp and Shimizu), are used to make broader geochemical comparisons.

**Sr/Y versus Y and La/Yb versus Yb**

A relatively broad distribution is observed in La/Yb versus Yb (Fig. 2a) of the experimental adakites, a result of variable degrees of partial melting, at different P-T conditions, and different basaltic starting materials, but the overall fractionation of La from Yb coupled with the relative depletion in Yb is obvious. Similar to other adakites, associated with subduction, O-type adakites from Chinashow variable but somewhat less pronounced fractionation of La from Yb, with comparable depletion in Yb. In contrast, C-type adakites show more highly variable, and in some cases extreme, degrees ofREE fractionation and Yb depletion (comparable to the range seen in the experimental melts). Intermediate and felsic samples (tonalites and sodic ignimbrites) from the Cordillera Blanca are distributed over a range comparable to the experimental melts and C-type adakites.
Fig. 2  La/Yb versus Yb (a) and Sr/Y versus Y (b) for experimental melts at 1−4 GPa (samples of Rapp and Watson (1995) and Rapp et al. (1999), "normal" sodic adakites from eastern and central China (data of Li et al., 2001; Wang and Zhang, 2001; Xiaong et al., 2001; Xu et al., 2000, 2001; Zhang et al., 2001), potassic adakites from eastern China (data of Pan et al., 2001; Wang and Zhang, 2001; Wang et al., 2001; Zhang et al., 2001), and tonalites and quartz diorites, and leucogranodiorites from the Cordillera Blanca batholith (squares with cross, data of Atherton and Petford, 1993; Petford and Atherton, 1994).

Fig. 3  Trace-element abundance patterns, normalized to primitive mantle (Sun and McDonough, 1989) for experimental adakite melts of basalt #1 at 3.8 and #2 at 3.5 GPa (Rapp and Watson, 1995; Rapp et al., 1999), coexisting with rutile-bearing eclogite residues. Similar patterns are observed in adakite melts from lower pressure experiments at 1−3 GPa (data of Table 2 and unpublished data of Rapp and Shimizu). Shown for comparison are the patterns for potassium-rich adakites from eastern China (data of Wang et al., 2001; samples DBS 1019 and DBS JZ05); Pan et al., 2001; sample 2174-1); Zhang et al., 2001; sample 134a), and tonalites and quartz diorites from the Cordillera Blanca batholith, NW Peru (Petford and Atherton, 1996).
No clear distinctions are apparent between these data sets in terms of Sr/Y versus Y (Fig. 2b), with adakites from melting experiments, western China and the Peruvian Andes all showing the same general distribution trend, that of increasing fractionation of Sr from Y, coupled with decreasing Y concentrations. Based on the experimental samples, the range in the distribution of the data for the natural adakites is attributable to a combination of factors, including variable degrees of melting, at various P-T conditions, of compositionally variable yet broadly basaltic sources.

**Mantle-normalized trace element abundance patterns**

The overall distribution of trace elements during partial melting is controlled by mineral-melt partition coefficients for adakite liquids and crystalline phases present in the residue of melting (dominantly garnet, clinopyroxene, and rutile at pressures above 2 GPa). The characteristic trace element signature of adakite is distinguished by an overall enrichment in large ion lithophile elements (including Ba, Th, U, K, LREEs, Sr), and strong depletions in HFSEs (e.g., Nb, Ti) and the HREEs and Y (Defant and Drummond, 1990; Kay et al., 1993). These features are the consequence of equilibration between adakite melts and eclogite residues containing rutile, typify adakite liquids in equilibrium with eclogitic residues at 1.2–3.8 GPa, and are exemplified by the mantle-normalized trace-element abundance patterns (spidergrams) for two liquids from melting experiments at 3–4 GPa (Fig. 3). Patterns for C-type adakites from eastern China (data from Pan et al., 2001; Wang and Zhang, 2001; Wang et al., 2001) show close similarities to the experimental melts, with general enrichment in LILEs, sharply negative Nb-anomalies, strong depletions in HREEs and Y, and variable relative depletion in Ti. The Chinese adakites, however, are distinguished by LREE and LIL abundances that are as high or higher than liquids formed at 3.8 GPa from the most potassic basalt from Table 1; Ba, Th and K abundances are especially high in the Chinese samples. Potassic adakites have higher abundances of LREEs (La and Ce), MREE (Nd and Sm), Th and Ba, and lower U, when compared to tonalites and lueconotolites from the Cordillera Blanca. Similar comparisons with other Na-granitoids (i.e., adakites) interpreted as lower crustal melts reveal similar compositional contrasts with the potassic adakites.

Nevertheless, the trace-element abundance patterns in Fig. 3 do strongly suggest that all these samples are related in the sense that they originated by partial melting of hydrous, garnet-bearing metapbasalt, and the adakite geochemical signature was imparted through mineral-melt partitioning with the residual phase assemblage (garnet + clinopyroxene).

**Discussion**

Potassium-rich adakites from eastern China appear to be compositionally unique among granitoids possessing the adakite geochemical signature and interpreted as lower crustal melts. Similarities between the major- and trace-element characteristics of adakites from eastern China and experimental melts clearly indicate an origin by dehydration melting of garnet-bearing metabasalt. The metuluminous A/CNK ratios (0.0–1.1) and uniformly low MgO’s (less than 40–45) of the Chinese adakites suggest the following, respectively: (1) amphibole was absent or a minor phase in the residue of melting, and thus temperatures approached or exceeded the amphibole-out phase boundary (~1000°C at 2 GPa), and (2) the parental adakite magmas had limited interaction with mantle (peridotitic) assemblages. At pressures above 1.5–2.0 GPa, sphere and/or rutile play a crucial role in effecting the sharp negative anomalies in Nb, Ti and other HFSEs apparent in Figure 3.

Liquids produced at pressures above 4 GPa (Table 2 and Fig. 1) have very low Na2O/K2O ratios (~0.5), but their Al2O3 contents are much lower than those of the potassic adakites and implied crustal thicknesses are unrealistic (> 150 km). Potassium-rich granitoids formed at slightly lower pressure (3.5–3.8 GPa; see Table 2) correspond more closely to C-type adakites in terms of Na2O/K2O ratios and Al2O3 contents, but would still require crustal thicknesses in excess of 120 km. Very low degrees of melting at pressures of 1–3.5 GPa (40–120 km depth) can produce high-potassium liquids, but these liquids possess A/CNK ratios that are too high (<1.1–1.2) and Al2O3 concentrations that are too low to correspond to most adakites. Furthermore, such melts would also be expected to have the highest La/Yb and Sr/Y ratios, due to the partitioning effects of residual eclogitic phases, yet there is no obvious correlation between La/Yb or Sr/Y on the one hand, and Na2O/K2O ratios on the other. And adakites with low Na2O/K2O ratios occur over a range of SiO2 contents, rather than at uniformly high SiO2, which would be expected for very low-degree partial melts.

More likely, the compositional distinctiveness of potassic adakites is either attributable to a basaltic source that is unusually enriched in potassium and other LILEs, or to the effects of assimilation of intermediate lithologies in the lower-middle crust. Isotopic studies clearly indicate some level of crustal involvement in eastern China, but adakites from the Andean Austral Volcanic Zone which show isotopic evidence for significant interaction with the subarc crust (e.g., Burney and Reclus volcanoes; Killian and Stern, 1996) still have “normal”, adakitic, Na2O/K2O ratios (3–5), and significantly lower LILE abundances than the potassic adakites of eastern China.

These considerations lead us to believe that the geochemical peculiarities that distinguish potassium-rich adakites arise from some unique aspect of either their source, or the lower crustal material with which they interacted. Potassium-rich shoshonites with high LILE abundances (e.g., Ba, Th, U, LREEs) erupted in eastern China in the early Cretaceous (Wang and Zhang, 2001) attest to mantle activity and suggest a possible “enriched” source for the C-type adakites that followed upon magmatic underplating and crustal overthickening. Alternatively, assimilation of compositionally intermediate granulitic lithologies in the middle to lower crust (Taylor and
McClennen, 1995) could explain the preferential enrichment in potassium and other LILEs. In either case, C-type adakites are considered to be the products of partial melting at the base of magmatically thickened lower crust; adakite magmatism was followed by a period of crustal extension and thinning, possibly in response to the foundering of dense eclogitic residues of melting, lower crustal delamination, and inflow of hot asthenospheric mantle (Wang and Zhang, 2001).

“Flat slab subduction” models based on seismic, geochemical and geochronologic evidence have recently been proposed for the Andes in Peru and southern Ecuador (Beate et al., 2001; Gutscher et al., 1999; Gutscher et al., 2000), offering an alternative to the lower crustal melting models of Atherton and Peford (1993). In these models, adakite magmatism is the result not of partial melting in the lower crust, but a consequence of slab melting. Subduction of the thick and buoyant “lost Inca Plateau” proceeded at a shallow angle and flattened out after penetrating 300 – 400 km inboard of the trench (Beate et al., 2001), providing an alternative (melting of the flat slab) to the lower crustal melting models for adakite volcanism in northern Peru and southern Ecuador. It remains to be seen whether or not such geoynamic models are applicable to eastern China. Kimura et al. (1999) suggest that eastern Asia was being intensely deformed in the early Cretaceous as a consequence of collision between the Indochina Block and the Eurasian continent, arguing that these events controlled the evolution of subduction along the eastern continental margin. Yanshanian adakite magmatism in eastern China would then have to be understood within the context of this more complex geodynamic setting, and any petrogenetic model for potassium-rich adakites would have to account for their compositional uniqueness.

### Conclusions

Potassium-rich adakites of eastern China appear to be compositionally among adakites formed by either “slab melting” or “lower crustal melting” of broadly basaltic sources. The distinctiveness of the potassic adakites is attributable either to unique aspects of the source (alkaline basalt enriched in LILEs), or to the nature of the material with which it reacts during transport and emplacement. For most of the eastern China adakites, there is evidence for only limited mantle involvement in their petrogenesis, given their generally low Mg**'s (<45); assimilation of granulitic lithologies in the lower to middle crust could explain both the low Mg**'s and the preferential enrichment in potassium and other LILEs, while being consistent with the isotopic evidence. Clearly, additional experimental study (including melting and assimilation experiments) is needed to better constrain the petrogenesis of potassium-rich adakites, and their role in crustal growth in eastern China, but their inclusion in the adakite family of granitoids, with origins in the dehydration melting of garnet-bearing metasalt, seems appropriate.
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