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A-type granites and related rocks: Evolution of a concept, problems and prospects

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Abstract

Although A-type granites have long been recognized as a distinct group of granites, the term A-type was coined first less than thirty years ago. A-type suites occur in geodynamic contexts ranging from within-plate settings to plate boundaries, locations and times of emplacement are not random. Rare in the lower crust, as some charnockite suites, they are fairly common at shallower depths, especially at the subvolcanic level where they form ring complexes rooting caldera volcanoes. Characteristic features include hypersolvus to transsolvus to subsolvus alkali feldspar textures, iron-rich mafic mineralogy, bulk-rock compositions yielding ferroan, alkali-calcic to alkaline affinities, high LILE+HFSE abundances, and pronounced anomalies due to high degrees of mineral fractionation. Isotopic features evidence sources containing a large mantle input. Experimental data show that A-type magmas contain dissolved OH–F-bearing fluids, crystallised under reduced and oxidized conditions, and yield high-temperature liquidus, favouring early crystallisation of anhydrous iron minerals, such as fayalite. Though many petrogenetic models imply solely crustal derivation, no convincing A-type liquids were produced experimentally from crustal materials, nor have any leucosomes of A-type composition been detected within migmatitic terranes. As it occurs in association with mafic igneous rocks in continents as well as on the ocean floor, A-type granite is likely to come from mantle-derived transitional to alkaline mafic to intermediate magmas. Rare felsic materials found in the meteoritic and lunar record yield dominantly A-type features. Contrary to the more common types of granite, A-type granite is, therefore, not typical of Earth and was produced in planetary environments differing from those prevailing on Earth.

Keywords: A-type granite; Alkaline; Anorogenic; Mantle; Crust; Ring complex; Batholith; Lopolith; Terrestrial planets

1. Introduction

Granitoids are extensively studied for the following reasons: (i) they are the most abundant rocks in the Earth's upper continental crust, (ii) like other igneous rocks, they represent probes into the deep planetary interiors, and (iii) they are closely connected with tectonics and geodynamics. Even now, the proportion of granitoids and associated volcanic rocks present on Earth is low, about 0.001 of the bulk Earth (Clarke, 1996). Such a small proportion corresponds nevertheless to a total mass of at least 10^{22} kg and a volume of about $3.74 * 10^9$ km^3 (Bonin et al., 2002). Roughly 86 vol.% of the upper continental crust is granitic in composition (Wedepohl, 1991). Granite occurs also,

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albeit in smaller amounts, within lower continental crust, oceanic crust, upper mantle and meteorites (Bonin et al., 2002; Bonin and Bébien, 2005, and references therein). Overviews of the conflicting ideas on the origin of granite and their evolution in time can be found in Raguin (1946), Gilluly (1948), Roubault and Sadran (1955), Read (1957), Clarke (1992), Pitcher (1993), Bonin et al. (1997) and Young (2003).

The conventional wisdom states that granite and Earth's continental crust are tightly connected, as illustrated by White (1979) who quoted: "The chemical composition of granites precludes the possibility of direct mantle derivation. This is consistent with granite distribution. Granites are rocks of the continental crust and margins". The fact that granites do occur in oceanic areas has largely been overlooked. For example, Leake starts a discussion on the origin of granite magmas by stating: "I find it difficult why granitic bodies appear to be totally absent from the oceanic crust if granitic magma is commonly derived from the mantle. Not only are oceanic granites unknown, but geophysical evidence does not support the existence of buried batholiths in the oceanic crust" (Leake et al., 1980, page 93). That statement is not true, as A-type granites have long been recognized in continental and oceanic igneous suites.

Crisp (1984) evaluated a current rate of intra-continental output of volcanic magma at 0.03–0.10 km^3 yr^{-1} and of plutonic magma at 0.1–1.5 km^3 yr^{-1}, corresponding to 1.0–2.5% of the 26–34 km^3 yr^{-1} global rate of magma emplacement. Oceanic island output is higher and amounts to 0.3–0.4 km^3 yr^{-1} of volcanic magma and 1.5–2.0 km^3 yr^{-1} of plutonic magma. Pearce (1987) developed an Expert System for Characterization Of Rock Types (ESCORT), in which the *a priori* evidence was calculated by estimating the volume of lavas erupted in each environment since the Paleozoic (the Precambrian evidence is not considered), multiplying each value by the probability of a lava from that environment being preserved in the geologic record. Pearce recognized that these values are clearly only approximations. Intra-continental igneous formations, emplaced in post-collision and within-plate settings, amount to 52% of the total volume of the continental crust, magmatic arc formations to 41%, oceanic crust preserved as ophiolite massifs to 5%, and oceanic island formations to 2%. A-type igneous suites would constitute a major component of the continental crust, with roughly 30% basic rocks, 18% intermediate rocks and 6% granites and syenites. In Precambrian continental terranes, most A-type igneous rocks, referred to as anorogenic or cratonic (Lameyre et al., 1974), were preserved from erosion and tectonic destruction, implying that Pearce estimates are probably underestimated.

The definitions proposed so far to the term A-type and its history will be discussed. Problems concerning sources, evolutionary trends, and various modes of emplacement will be reviewed and provisional answers will be suggested. It will be emphasized that some of the scarce granitic samples recovered so far from the other terrestrial planets yield affinities with Earth's A-type granitoids. The possibility that A-type granites, though less frequent on Earth than the other types of granitoids, could be more abundant than expected within the Inner Solar System, will be explored.

2. The A-type concept

During the 70s, Chappell and White (1974, 1992) developed an internally consistent scheme, in which all granites are issued from the partial melting of crustal formations. The 'genetic alphabet soup', referred to as S-I-A-M (e.g., Clarke, 1992, pages 13 and 215), or S-I-M-A (e.g., Sial et al., 1987, page 20), was in vogue during the last decades of the 20th century. At the GSA Annual Meeting held at San Diego in November 1979, White offered a summary of the genetic alphabet scheme, with four types differing by their compositions and source rocks (Table 1). In addition to the S- and I-types already defined (Chappell and White, 1974), he introduced the M-type, inferred to be formed

Table 1
The alphabetical classification of granite types, according to White (1979)

Granite type	Chemical features	Specific minerals	Source rocks
S (1)	Peraluminous ASI ≥ 1.1	Peraluminous mafic minerals (cordierite, garnet, etc.)	Meta-sedimentary sequences
I (1)	Metaluminous ASI < 1.1	No peraluminous mafic minerals occurrence of hornblende	Igneous materials from deep crustal levels
M (2)	Volcanic arc signature		Subducted oceanic crust
No letter attributed (3)	Alkaline affinities and anorogenic	Fe-rich mafic silicates	Granulitic residue from a previous melting event

Notes:
1. S- and I-types are the oldest defined granite types (Chappell and White, 1974).
2. M-type is akin to Archean TTGs and modern adakites (for an overview, see Martin et al., 2005).
3. The type with no letter attributed corresponds to A-type.