Classification of granitic rocks: a march from alphabet soup to petrogenetic recipes

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One of the most fascinating aspects of the 'granite problem' is the definition of the problem itself. There has been a paradigm shift in the definition of the granite problem through time. The statement of the problem has travelled a long way from 'Neptunist versus Plutonist' in the 1760s, through 'Metasomatic versus Magmatic' in the 1960s, to 'Fractional crystallization versus anatectic direct melt' in the 1970s. At present, the problem pivots around 'sources', 'processes' and 'geodynamic setting'. As the definition of the problem has evolved through time, so has also the classification of the rocks.

Classification of the granitic rocks has remained one of the fundamental and inseparable aspects of the granitic study from the beginning. Much work and progress has been made since Read's[1] 'granites and granites' to Pitcher's[2] 'granites and yet more granites'. Over the years, there has been a proliferation of classification schemes which has resulted in chaos rather than putting things in order. About 20 different schemes have emerged during the last 30 years. None of them, however, is universally acclaimed. The reason for such large number of classification schemes is because of the problem of convergence. Many different sources and processes converge to give rise to essentially the same end-product granite mineralogy.

A critical reappraisal of the schemes proposed so far reveals that they are broadly based on three categories: (i) measurable parameters, (ii) inferred or presumed parameters and (iii) measured-to-inferred parameters. Here we give a brief account of the commonly used major classification schemes of the granitoids.

Modal mineralogy/IUGS classification

This scheme is based on measurable parameters. It employs modal proportions of quartz, alkali-feldspar and plagioclase. It is simple and truly non-genetic, but is tedious involving staining and point-counting. In addition, the scheme has the major scientific disadvantage of not taking into account the mafic minerals and other minor phases like muscovite which may have great petrogenetic implications. Because of this obvious handicap, geochemical classification schemes flourished.

Alphabet soup classification

This scheme is based on measured-to-inferred parameters. Chappell and White[3] introduced two alphabets, I and S, to denote two distinct types of granitoids. I-type granitoids are metaluminous to weakly peraluminous, relatively sodic and have a wide range of silica content. A priori knowledge of source seems to be necessary for this classification. It is inferred that I-type granitoids have formed from an igneous source. S-type granitoids are strongly peraluminous and relatively potassic with restricted but higher silica content. They are presumed to have formed from sedimentary rocks. This scheme gained instant popularity, because of its straightforward approach. Through time, more alphabets were added to the soup. The classification was expanded by adopting one more type: A-type. This was added to denote granitoids with alkaline and anhydrous characteristics[4]. There is also anorogenic tectonic connotation attached with the A-type granitoids. Two more alphabets, M-type[5] and C-type[6], soon managed to secure their position in the soup. M-type refers to those granitoids which are thought to have formed from mantle or by melting of a juvenile crustal rock in a presumably island arc setting. C-type refers to charnokitic granitoids. Castro *et al.*[7] proposed the H-type to encompass the granitoids showing hybrid characteristics of both the mantle and the crust.

The alphabet classification, particularly I–A–S has been widely applied with the pretext that such classification can help readily identify the precursor of the granitoids. One of the major problems of this classification is the oversimplified assumption that individual granitoids have single simple source and that chemical composition of the granitoids has a one-to-one relationship with the sources. However, as a matter of fact, in most of the cases, more than one source and process do participate in the origin and evolution of a granitoid pluton. Besides, granitoid magmas crystallize over a broad compositional spectrum resulting in significant overlap in the I–A–S characteristics. Such a situation has been observed, for example, Bundelkhand granitoids of the central Indian shield[8–11] (M. E. A. Mondal, unpublished).

The definition of M-type, like I–A–S, is also not without flaw. M-type granitoid has not been defined explicitly and it merges technically with the definition of the I-type. Similarly, C-type mineralogy (orthopyroxene, pigeonite or fayalite) is a function of fluid composition of the magma. Another serious drawback of the alphabet soup classification has been the connotation in which the alphabets have been used. This aspect has been compromised, and uniform connotation has not been maintained in this scheme. I-type and S-type refer to igneous and sedimentary precursor sources respectively, whereas A-type indicates anorogenic setting of emplacement, and not the precursor source. Further, I-type and S-type indicate one-stage origin of the granitoid, derived directly from the igneous or sedimentary sources, whereas M-type may be one-to-more-than-one stage origin, derived directly or indirectly from the mantle. Moreover, alphabet classification, being a genetic classification, is inferior and the interpretations are equivocal. As a result, this classification scheme is gradually losing its sheen.

Normative mineralogy classification

One simple way to substitute the rigorous point counting for modal analysis is to go for normative mineralogy, which is calculated from the major element composition of the rock. Normative mineralogy assumes paramount importance for the rocks, which are porphyritic in nature, because porphyritic texture leads to imprecise modal data during point counting. Using the CIPW normative abundance of albite, anorthite and orthoclase, O'Connor[12] and Barker[13] proposed a ternary classification scheme to classify the granitoids into tonalite, trondhjemite, granodiorite, granite and quartz monzonite.

Alumina saturation

This system uses the concept of alumina saturation. A simple parameter A/CNK, defined by molecular $Al_2O_3/(CaO + Na_2O + K_2O)$, is used to classify the rocks into metaluminous (A/CNK < 1), or peraluminous (A/CNK > 1) or peralkaline A < NK.

Magnetite-ilmenite series

Ishihara[14] observed that granitoid rocks of magmatic arcs can be conveniently divided into two groups: magnetite series and ilmenite series. Magnetite series are relatively oxidized, whereas ilmenite series are relatively reduced. It has been found that although such distinction between magnetite series and ilmenite series may be possible in arc environments, the scheme fails in other tectonic environments.

Mineralogical classification

This classification is based on mineralogy and its relationship with alumina saturation of the granitoids. Barbarin[15] identified six types of granitoids based on this criterion and then correlated them with distinct tectonic environments. The scheme appears too simplified to accommodate the large spectrum of granitoids.

Multi-cationic functions

De la Roche *et al.*[16] proposed two multi-cationic functions, $R1$ [= 4Si – 11(Na + K) – 2(Fe + Ti)] and $R2$ [= Al + 2Mg + 6Ca], which is a two-dimensional projection of the basalt tetrahedron of Yoder and Tilley[17]. The two functions are particularly suitable for the basaltic rocks, but less so for the granitic rocks as K-feldspar and plagioclase plot at the same point on this diagram. As a consequence, most granitic rocks are encompassed within a very small area on this diagram. Debon and LeFort[18] also proposed two multi-cationic parameters, A and B, defined as A = Al–(K + Na + 2Ca) and B = Fe + Mg + Ti. They have identified three major granitoid types, viz. aluminous, cafemic and alumino-cafemic.

Tectonic discriminant schemes

Many authors have attempted to establish the links between chemical composition of the granitoids and the tectonic setting of their emplacement. Batchelor and Bowden[19] proposed a tectonic discriminant scheme based on a function involving Si–Ti–Fe–Na–K against another function involving Al–Mg–Ca to demonstrate the relationship between chemical composition and tectonic environment of emplacement. A similar attempt was made by Maniar and Piccoli[20]. They classified the granitoids on the basis of major elements into seven tectonic settings, viz. island arc, continental arc, continental collision, post-orogenic, rift, continental epeirogenic uplift, and ocean ridges and islands. Based on similar premise, Rogers and Greenberg[21] discriminated the granitoids into four groups: late orogenic, post-orogenic, anorthosite–rapakivi domain, and ring complex. The tectonic classification scheme that has found wide application is the one by Pearce *et al.*[22]. The scheme, solely based on trace elements, discriminates granitoids into four major tectonic environments: volcanic arc, ocean ridge, within plate and syn-collision. Most of the tectonic discriminant diagrams, including the one proposed by Pearce *et al.*[22] have been used indiscriminately in the literature. The major drawback of the tectonic discrimininant diagrams is that the elemental composition of the granitoids is a direct manifestation of the sources and the magmatic processes, and not the tectonic environment in which they are emplaced.

Three-tier chemical scheme

Frost *et al.*[23] proposed a classification scheme based on three geochemical parameters: Fe-number, modified alkali-lime index (MALI) and alumina saturation index (ASI). Based on Fe-number (= FeO/(FeO + MgO), the granitoids have been divided into two groups: ferroan and magnesian. On the basis of MALI (= $Na_2O + K_2O$–CaO), the granitoids have been divided into four groups: calcic, calc-alkalic, alkali-calcic and alkalic. Based on ASI, (= molecular Al/(Ca – 1.67P + Na + K), granitoids have been grouped as peraluminous (ASI > 1.0), metaluminous (ASI < 1.0, but Na + K < Al) and peralkaline (ASI < 1.0, but Na + K > Al). A total of sixteen compositional groups has been proposed for the whole compositional range of the granitoids. All compositional groups are not equally represented in geological history and some are not reported at all, e.g. ferroan calcic granitoids.

Archaean granitoids

Because of greater heat production in the Archaean, the tectono-magmatic processes that operated in the Archaean time were much distinct from those that operated during the post-Archaean. This resulted in the production of voluminous granitic rocks, viz. tonalite, trondhjemite and granodiorite (TTG) in the Archaean. These granitic rocks are sodic in nature and are characterized by highly fractionated rare earth element patterns with no or minor Eu-anomaly. A specific type of granitoids, referred to as Archaean sanukitoids[24], was emplaced mainly during the Archaean–Proterozoic transition. Major and trace element characteristics of these rocks are intermediate between typical Archaean TTG and post-Archaean arc granitoids. The sanukitoids typically have high MgO, K_2O, Sr, Ba, Cr and Ni content, along with high content of light rare earth elements and large ion lithophile elements, and low content of heavy rare earth elements. They are considered to have formed from enriched mantle, the enrichment possibly taking place by subduction-slab-derived melt and/or fluids[25].

Epilogue

Classification has been one of the indispensable activities of science in the quest to comprehend the patterns of the processes of the natural systems and to understand how different members of the intra- and inter-groups compare. No classification scheme is, or can be, expected to be perfect. Nonetheless, every classification scheme is expected to be utilitarian. In the case of granite classification, many schemes are based on inferred and deductive parameters. Such schemes are subjective and genetic, and should be deemed inferior to objective and observational classification schemes. Simple criteria, leading to oversimplifying the not-so-simple systems, have caused havoc towards understanding the granite kingdom. The need of the hour is to abandon the genetic classification schemes based on presumed or inferred parameters, and to reorient the thrust towards understanding the tectono-magmatic processes involving source, processes and evolution of the granitoids. Future classification schemes should be based on observable measurable criteria (in the direction of solving) in understanding the complex petrogenesis of the granitoids.

1. Read, H. H., *Geol. Soc. Am., Mem*., 1948, **28**, 1–19.
2. Pitcher, W. S., *Geol. Rundsch*., 1987, **76**, 51–79.
3. Chappell, B. W. and White, A. J. R., *Pac. Geol.*, 1974, **8**, 73–174.
4. Loiselle, M. C. and Wones, D. R., *Geol. Soc. Am. Abstr*., 1979, **11**, 468.
5. White, A. J. R., *Geol. Soc. Am*., *Abstr*., 1979, **11**, 539.
6. Kilpatric, J. A. and Ellis, D. J., *Trans. R. Soc. Edinburgh: Earth Sci*., 1992, **83**, 155–164.
7. Castro, A., Moreno-Ventas, I. and de la Rosa, J. D., *Earth Sci. Rev*., 1991, **31**, 237–253.
8. Mondal, M. E. A., Open Workshop UNESCO-IGCP 510, Geological Survey of India, Nagpur, 2009, pp. 42–43.
9. Zainuddin, S. M., Rahman, A. and Mondal, M. E. A., In *Geology in South Asia – I, Islamabad* (eds Ahmad, R. and Sheikh, A. M.), South Asian Geological Congress, pp. 161–168.
10. Mondal, M. E. A. and Zainuddin, S. M., *Terra Nova*, 1996, **8**, 532–539.
11. Mondal, M. E. A. and Zainuddin, S. M., *Recent Res. Geol.*, 2004, **17**, 124–135.
12. O'Connor, J. T., *U. S. Geol. Surv. Prof. Paper*, 1965, 525-B, 79–84.
13. Barker, F. (ed.), In *Trondhjemites, Dacites and Related Rocks*, Elsevier, Amsterdam, 1979, pp. 1–12.
14. Ishihara, S., *Mining Geol*., 1977, **27**, 293–305.
15. Barbarin, B., *Lithos*, 1999, **46**, 605–626.
16. De la Roche, H., Leterrier, J., Grandclaude, P. and Marchal, M., *Chem. Geol*., 1980, **29**, 183–210.
17. Yoder, H. S. and Tilley, G. E., *J. Petrol*., 1962, **3**, 342–532.
18. Debon, F. and LeFort, P., *Trans. R. Soc. Edinburgh.: Earth Sci*., 1983, **73**, 135–149.
19. Batchelor, R. A. and Bowden, P., *Chem. Geol*., 1985, **48**, 43–55.
20. Maniar, P. D. and Piccoli, P. M., *Geol. Soc. Am. Bull*., 1989, **101**, 635–643.
21. Rogers, J. J. W. and Greenberg, J. K., *Geol. Soc. Am. Bull*., 1981, **92**, 57–93.
22. Pearce, J. A., Harris, N. B. W. and Tindle, A. G., *J. Petrol*., 1984, **25**, 956–983.
23. Frost, B. R., Barnes, G. C., Collins, W. J., Arculus, R. J., Ellis, D. J. and Frost, C. D., *J. Petrol*., 2001, **42**, 2033–2048.
24. Shirey, S. B. and Hanson, G. N., *Nature*, 1984, **310**, 222–224.
25. Martin, H., Moyen, J. F. and Rapp, R., *Earth Environ. Sci. Trans. R. Soc. Edinburgh*, 2010, **100**, 15–33.

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