A chemical approximation to the modal QAPF and normative Q' (F')-ANOR classification of the igneous rocks based on their SiO_2-CaO-K_2O content

Una aproximación química a la clasificación modal QAPF y normativa Q' (F')-ANOR de las rocas ígneas, basada en su contenido en SiO_2, CaO y K_2O

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ABSTRACT

Magmas can form plutonic or volcanic rocks of the same chemical composition. The modal composition of the plutonic rocks can be quantified but in the case of volcanic rocks this is not always possible, because of its aphanitic texture and presence of glass. These characteristics prevent a mineralogical classification in equivalent diagrams for both types of rocks. To resolve this problem, the IUGS recommends the use of chemical TAS diagram in cases where obtaining the modal composition is not possible, in an attempt to adjust its nomenclature to that represented in the QAPF modal diagram. A best approximation is obtained with the normative diagram Q'(F')-ANOR in which the anorthite and the orthoclase are used as a discriminating factor. In this work, the chemical SiO_2-100·CaO/(CaO+K_2O) diagram is presented, which largely reproduces the aforementioned normative classification but in a simplified form since it uses only three discriminating chemical components (SiO_2, CaO and K_2O).

The delimitation and nomenclature of the fields has been undertaken empirically using as an example the normative diagram and plotting the analyses of typical igneous rocks. The approximate limit of silica saturation has been drawn as a straight line joining the feldspathic compositions, between orthoclase and anorthite

Key-words: *classification of igneous rocks, SiO_2-100·CaO/(CaO+K_2O) diagram, QAPF diagram, Q'(F')-ANOR diagram, igneous petrology.*

RESUMEN

Los magmas pueden dar origen a rocas plutónicas o volcánicas de la misma composición química. La composición modal de las rocas plutónicas puede ser cuantificada pero en el caso de las rocas volcánicas no suele ser posible por su textura afanítica y presencia de vidrio. Estas características impiden una clasificación mineralógica en diagramas equivalentes para ambos tipos de rocas. La IUGS recomienda el uso del diagrama químico TAS en los casos en que la obtención de la composición modal no sea posible, tratando de ajustar su nomenclatura a la del diagrama modal QAPF. Una mejor aproximación se consigue con el diagrama normativo Q'(F')-ANOR en el que se usa la relación anortita-ortosa como factor discriminante. En este trabajo se presenta el diagrama químico SiO_2-100·CaO/(CaO+K_2O) que reproduce en gran parte la clasificación normativa citada pero de forma simplificada, utilizando solamente tres componentes químicos discriminantes (SiO_2, CaO y K_2O).

La delimitación y nomenclatura de los campos se ha realizado de forma empírica tomando como ejemplo el diagrama normativo y la representación de análisis de rocas ígneas características. El límite de saturación en sílice aproximado se ha dibujado como una recta que une las composiciones feldespáticas, comprendidas entre la ortosa y la anortita.

Palabras clave: *Clasificación de rocas ígneas, Diagrama SiO_2-100·CaO/(CaO+K_2O), Diagrama modal QAPF, Diagrama normativo Q'(F')-ANOR, petrología ígnea.*

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Introduction

Since igneous rocks are constituted by mineral matter, their study and classification have been based on the precise determination of the minerals and their textural relationships. However, a large number of rocks, especially volcanic and hypabyssal, are largely made up of glass. This characteristic prevents the quantification of the minerals to determine the exact composition of the rock through the usual microscopic study.

In order to unify criteria in the classification and nomenclature of igneous rocks, an international commission (IUGS Subcommission on the Systematics of Igneous Rocks) was created and began its work in 1970 (Le Maitre *et al.* 2002). As regards plutonic rocks it was agreed that they should be named and classified according to their modal mineral content that could be represented in the double QAPF triangle.

In the case of volcanic rocks, the first problem was to decide whether their classification should be based on mineralogy or chemistry given the difficulty, or even the impossibility, of obtaining a representative modal composition. It was also considered complex to obtain a calculated mineral composition that reproduced a realistic composition of the rocks. Finally, a consensus was reached on the basis of two principles: a) if modal compositions can be obtained, volcanic rocks should be classified and named according to their position in the QAPF diagram; b) if modal analyses are not available, chemical parameters that give a result comparable to the mineralogical QAPF classification should be used. After considering several chemical diagrams, it was decided to use the TAS (alkalis-silica) diagram of Le Maitre (1984), slightly modified by Le Bas *et al.,* (1986). However, this diagram does not strictly comply with the second principle agreed by the commission itself since neither the fields obtained nor the nomenclature are consistent with those of the QAPF classification. Thus, terms such as basaltic andesite, trachydacite, tephriphonolite, picrobasalt, etc. do not have an equivalent nomenclature in the modal QAPF diagram. For these reasons, volcanic rocks (classified in the TAS) cannot be translated to a simulated QAPF classification and compared with the plutonic rocks of equivalent composition. In addition, to correctly naming the rocks in certain fields, it is necessary to obtain the CIPW normative composition (Le Maitre *et al.* 2002). By contrast, the normative Q'(F')-ANOR diagram of Streckeisen and Le Maitre (1979) (Q'=quartz/quartz+feldspars, F'=feldspathoids/feldspathoids+feldspars) constitutes a very remarkable approximation to the QAPF modal classification, both in the choice of discrimination parameters and in terminological equivalence. Its conceptual scheme is almost identical, given a) the incompatibility of quartz and feldspathoids, and b) the relative proportion between alkali feldspar (in this case normative orthoclase) and plagioclase (represented by the anorthite). Apart from the ultramafic rocks (as in the case of QAPF) and foiditic rocks, the aforementioned authors consider that the diagram is applicable to most igneous rocks. This diagram also shows a high discrimination capacity of some of the most important igneous series, as it has been clearly stated by Whalen and Frost (2013).

Object

Based on the normative classification diagram Q'(F')-ANOR of Streckeisen and Le Maitre (1979) and on its terminological equivalence with the QAPF modal diagram (Le Maitre *et al.* 2002), a diagram of major elements that serves to obtain an approximation to the QAPF nomenclature of common igneous rocks is proposed. The underlying idea is to take directly the discriminating major elements used in the normative diagram Q'(F')-ANOR and analogous parameters to obtain an empirical compositional equivalence, maintaining, as far as possible, the original modal nomenclature. The major components used are SiO_2, CaO and K_2O. Unlike the TAS diagram, which uses SiO_2, Na_2O and K_2O, this diagram takes into account the calcium that is part of all the plagioclase in the modal QAPF diagram and avoids sodium, which is part of both plagioclase and alkali feldspar.

Methodology

In order to establish the classification fields of the igneous rocks (non-ultramafic) simulating the normative diagram Q'(F')-ANOR, a new diagram was constructed in which the silica is placed on the ordinate axis and the proportion $100 \cdot CaO/(CaO+K_2O)$ on the abscissa axis. The silica content is taken directly from the analytical result and distributes the rocks in acid, intermediate, basic and ultrabasic (Le Maitre *et al.* 2002). The percentage ratio between the CaO and the K_2O of the abscissas establishes an approximation of the proportion between the anorthite and the sum of normative orthoclase and anorthite. The agreement is not identical since in the norm, the calcium of the anorthite is distinguished from that which is part of the mafic minerals, which it is not possible in the proposed diagram. However, one advantage of the diagram is that it can classify the rocks with only three oxides of the major elements whereas the normative diagram needs all of them. The classification fields and the nomenclature adopted are those proposed in the QAPF diagrams for plutonic and volcanic rocks according to Le Maitre *et al.* (2002).

The oblique line that joins the points $x = 0$, $y = 64.8$ and $x = 100$, $y = 44.4$ represents the different mixing proportions between the orthoclase and the anorthite. These correspond to hololeucocratic feldspathic rocks that indicate a line of separation between supersaturated and subsaturated rocks in silica. Since they are whole rock compositions, the mafic minerals are included with the result that the saturation line on silica is approximate. All the granitoids and rocks with quartz are above this line, whereas the rocks with feldspathoids and olivine are located below it.

The delimitation of the lines of the fields was carried out empirically using a limited number of analyses of characteristic rocks taken from the bibliography.

The provenance of the samples used is as follows: a) Cox *et al.* (1979, pp. 402-406), some characteristic plutonic and volcanic rocks; b) Carmichael *et al.* (1974, p. 499), East African alkaline rock series; c) Wager and Brown (1967), plutonic tholeiitic intrusion from Skaergaard, East Greenland; d) Enrique (1990), Ferrés and Enrique (1996), hercynian batholith from Catalan Coastal Ranges, NE Iberian Peninsula; e) Ferré and Leake (2001), plutonic Mg-K series from Corsica; f) Carmichael *et al.* (1974, p. 405), alkaline volcanics from Tenerife, Canary Islands; g) Carmichael *et al.* (1974, p. 414), Hawaiian lavas; h) Carmichael *et al.* (1974, p. 400), Galapagos tholeiitic lavas; i) Enrique and Toribio (2009), alkaline lavas from Olot, NE Iberian Peninsula.

The SiO_2-100·CaO/(CaO+K_2O) diagram

As a result of the study of the graphic representation of the samples mentioned above, a series of compositional fields were established in the SiO_2-$100 \cdot CaO/(CaO+K_2O)$ diagram that largely reproduce the modal classification of the double triangular QAPF diagram of Le Maitre *et al.* (2002). The representation in rectangular form of the same fields using normative minerals (Streckeisen and Le Maitre, 1979) is the one that has been used as a model in the construction of the proposed diagram. In figure 1, the nomenclature of the plutonic and volcanic rocks of the normative diagram of Streckeisen and Le Maitre (1979) was reproduced with small modifications to adjust it to the QAPF of Le Maitre *et al.* (2002). Figure 2 shows the nomenclature proposed in the SiO_2-$100 \cdot CaO/(CaO+K_2O)$ diagram for both plutonic and volcanic rocks. In contrast to the diagram in figure 1, some differences, which consist mainly of the vertical compression of the subsaturated fields in silica, may be observed.

The straight lines that define the classification fields of the diagram can be divided into "subhorizontal" lines that discriminate between rocks of different degree of saturation in silica, and in "subvertical" lines that discriminate the relationship between orthoclase and anorthite, depending on the degree of subsaturation.

The coordinates of the pairs of points that define the straight lines, for the diagram of the plutonic rocks, are the following: a) "Subhorizontal" lines (A, B, C, D, E), arranged from top to bottom: A1 (20, 80), A2 (100, 64.3), B1 (0, 74.9), B2 (100,

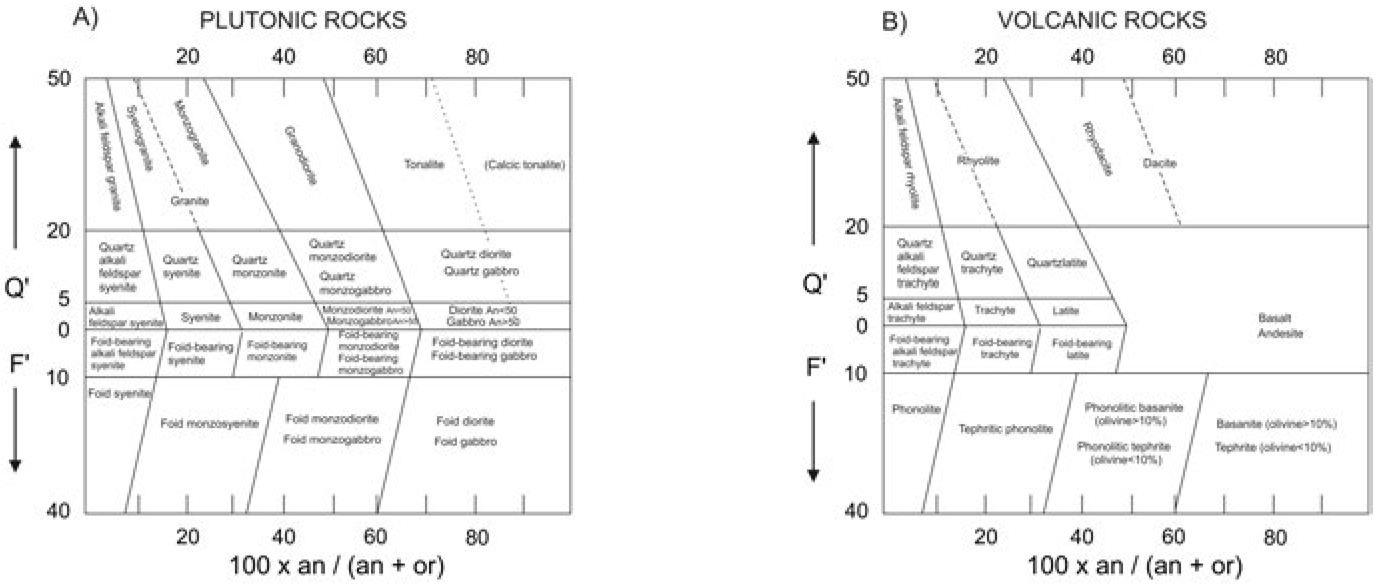

Fig. 1.- Diagram Q'(F')-ANOR (Streckeisen and Le Maitre, 1979) showing the normative fields which correspond approximately to those of the modal QAPF diagram (Le Maitre *et al.*, 2002). Nomenclature for plutonic (A) and volcanic (B) rocks.

Fig. 1.- Diagrama Q'(F')-ANOR (Streckeisen y Le Maitre, 1979) con los campos composicionales normativos aproximadamente equivalentes a los modales del diagrama QAPF (Le Maitre et al.*, 2002) Nomenclatura de las rocas plutónicas (A) y volcánicas (B).*

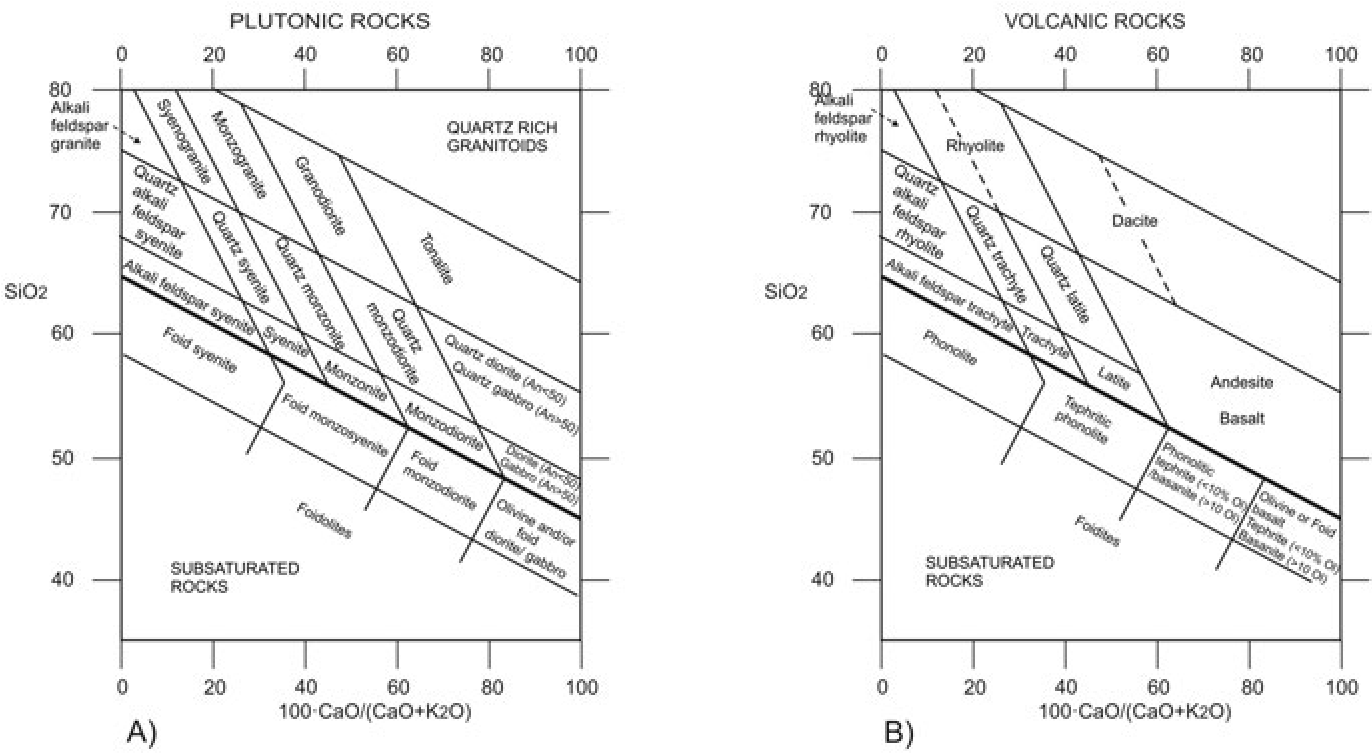

Fig. 2.- SiO_2-CaO/(CaO+K_2O) diagram proposed in this study. A and B) The fields and nomenclature of the most common plutonic and volcanic rocks coincide approximately with the QAPF modal diagrams (Le Maitre *et al.*, 2002) and the normative Q'(F')-ANOR (Streckeisen and Le Maitre, 1979). However, some differences may be observed. Olivine rocks, for example, plot below the compositional tie-line or-an. Thus, olivine basalt overlaps the basanite/tephrite field.

Fig. 2.- El diagrama SiO_2-CaO/(CaO+K_2O) propuesto en este estudio. A y B) Los campos y nomenclatura de las rocas plutónicas y volcánicas más comunes coinciden aproximadamente con el diagrama modal QAPF (Le Maitre et al.*, 2002) y el normativo Q'(F')-ANOR (Streckeisen y Le Maitre, 1979). Sin embargo pueden apreciarse algunas diferencias. Las rocas olivínicas, por ejemplo, se sitúan por debajo de la línea composicional or-an. Por esa razón se produce un solapamiento de los basaltos olivínicos con las basanitas y tefritas.*

55.3), C1 (0, 67.8), C2 (100, 48.2), D1 (0, 64.8), D2 (100, 44.4), E1 (0, 58.5), E2 (100, 38.4); b) "Sub-vertical" lines (F, G, H, I, J, K): F1 (3.4, 80), F2 (35.8, 56.1), G1 (35.8, 56.1), G2 (27.2, 50.1), H1 (12.1, 80), H2 (45.8, 55.3), I1 (26.8, 78.7), I2 (62.5, 52.2), J1 (62.5, 52.2), J2 (53.4, 45.5), K1 (47.3, 74.6), K2 (83.1, 47.9), L1 (83.0, 47.9), L2 (74.3, 41.4). The coordinates for the diagram of volcanic rocks are identical, except in two lines that become the following: C1 (0, 67.8), C2 (56.7, 56.1) and K1 (47.3, 74.6), K2 (62.3, 64.6).

Discussion and conclusions

The SiO_2-100·CaO/(CaO+K_2O) diagram enables us to classify the most common igneous rocks, both plutonic and volcanic, with reasonable precision. The nomenclature largely corresponds to the modal terminology proposed by the IUGS (Le Maitre *et al.*, 2002) and with the normative Q'(F')-ANOR of Streckeisen and Le Maitre (1979). Because this is a chemical diagram of major elements, it does not present the limitations in the percentage mineralogical determination that hinders or prevents the modal classification of volcanic rocks and many hypabyssal rocks. For this reason, igneous rocks with the same chemical composition can be represented in the same diagram, regardless of their texture and their consolidation conditions.

The use of SiO_2 in the ordinates and the ratio between CaO and K_2O in the abscissa, simulates more precisely the modal QAPF diagram than the TAS diagram proposed to equate the volcanic rocks with the plutonic modal compositions. Another important quality is the simplicity of its use since it only requires making a sum and a division of the concentrations of CaO and K_2O obtained directly from the whole rock analyses. An advantage with respect to the normative classification is that the three components used are independent of each other, whereas in the norm they are not, given that all the major elements are needed to calculate the normative minerals. This characteristic enables us to classify unaltered igneous rocks with the QAPF modal nomenclature with only the analyses (of sufficient quality) of Si, Ca and K. One disadvantage is that there is a decrease in the surface of the subsaturated fields, rich in foids, as well as a partial overlap of slightly subsaturated terms, which makes their precise classification difficult. Another drawback with respect to the normative diagram Q'(F')-ANOR of Streckeisen and Le Maitre (1979) is its inability to distinguish the subsaturated compositions with foids from the subsaturates only with olivine since nepheline appears in the norm when the critical plane of subsaturation in silica is crossed (Yoder and Tilley, 1962).

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