

IUGS Task Group on Igneous Rocks

TGIR

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Rationale

The IUGS Subcommittee on the Systematics of Igneous Rocks began its work in 1970 and reached its first conclusions almost two decades later, with the publication of the book edited by Roger Le Maitre in 1989. This volume soon became the reference standard for all geoscientists concerned with magmatic rocks and in particular those working in the field of igneous petrology. The interest in the correct classification of igneous rocks is beyond just the relatively restricted group of igneous petrologists, because mapping geologists, structural geologists and geodynamicists all use such nomenclature when they encounter and describe magmatic rocks. The second edition of the IUGS classification scheme, published in 2002, helped to resolve in part some outstanding issues, particularly relating to the classification of pyroclastic rocks, carbonatites, kalsilite-bearing lithologies, lamproites and high-MgO volcanic rocks. Since its publication, the second edition has been quoted in scientific articles 6,500 times, i.e. roughly one citation each single day in the last 18 years. This emphasizes the extreme importance of this book for the scientific community. The preface of the 2002 edition makes the following statement: *"The work of the Subcommittee continues, not only to resolve these problematic areas but also to tackle new issues as they arise"*.

After almost twenty years, there has been little substantive work to address these problems and, as will be detailed below, a further revision of the IUGS classification of igneous rocks is urgently required. The goal of the proposed IUGS Task Group will be the publication of the next updated and improved edition that will help geoscientists to clarify basic aspects of the classification and nomenclature of igneous rocks. This revision will integrate new field evidence as well as the results of improved analytical techniques and experimental petrology to infer genetic links between different rock types and rock groups. Through the years IUGS has played a fundamental role in clarifying essential topics related to igneous rock classification and it is anticipated that this role will continue during future revisions.

The proposal considers relatively minor but necessary revisions, leaving unchanged the overall structure of the original nomenclature and classification. Most of the work of the Task Group can be undertaken virtually, using video conferencing, thus saving money and time for the researchers involved in this activity. If possible, the project would benefit from a short meeting in Rome, possibly accompanied by fieldwork on specific volcanic districts where the lithologies that are the object of the revision crop out.

Some key issues to be addressed in the revised IUGS classification scheme

Bearing in mind the fundamental role played by IUGS in clarifying essential topics related to igneous rock classification, the most important points that require at least some modification (e.g., modal vs mineralogical vs whole-rock chemical vs genetic classification) are listed below:

- 1) **Plutonic rock classification.** Glazner *et al.* (2019) have raised serious issues relating to the classification of phaneritic rocks as proposed by the IUGS. According to these authors, the IUGS approach is too complex, and is based on arbitrary choices and is only qualitative. The authors propose a revised approach, which eliminates ~90% of the existing igneous rock names. Frost *et al.* (2019) and Hogan (2019) have however raised significant objections of these criticisms. This example makes clear that the IUGS needs to facilitate such debate but retain oversight of the procedure for the nomenclature and systematics of igneous rocks with the goal to improve, but not to remove, classic approaches.
- 2) **Ultramafic rocks.** The modal classification of ultramafic rocks using the olivine-clinopyroxene-orthopyroxene diagram was proposed by the IUGS. The proposal for the revision does not require any change in this diagram, but clarification is needed to indicate that mantle rocks (e.g., lherzolites, dunites, harzburgites, wehrlites, websterites and pyroxenites) very often (with the exclusion of cumulitic rocks) should be more properly considered as metamorphic rocks rather than igneous rocks. Indeed, the textures shown by these rocks are compatible with sub-solidus modification, typical of metamorphic reactions.
- 3) **“Metamorphic rocks”.** The IUGS classification and nomenclature of metamorphic rocks (Fettes and Desmons, 2007) correctly describe the characteristics of eclogite as a metamorphic rock essentially composed of omphacite-rich clinopyroxene and Mg-Al-rich garnet. A basalt (by definition a rock with modal plagioclase or with a CIPW plagioclase-normative composition coupled with SiO₂ between 45 and 52 wt% and Na₂O+K₂O <5 wt%) that is subjected to pressures greater than 1 GPa is transformed to eclogite, as plagioclase is unstable at high pressures. A basaltic melt that crystallizes directly at pressures higher than 1GPa will not lead to the formation of a plagioclase-bearing igneous rock, but directly to an eclogitic assemblage. This implies that it is possible to produce a metamorphic rock (i.e., eclogite) through a classical igneous process (i.e., solidification of a magma). At least some comments on this process should be added.
- 4) **TAS (1).** The most commonly used classification diagram for volcanic rocks is the Total Alkali vs. Silica (TAS) scheme. The mildly alkaline rocks (trachybasalts, basaltic trachyandesites and trachyandesites) are sub-divided into sodic and potassic variants based on the value of the ratio $(Na_2O - 2)/K_2O$. If this ratio is <1 the rock is considered potassic, while if this ratio is >1 the rocks are considered sodic. The problem with this approach is that mildly alkaline basic magmas (e.g., trachybasalts) have a relatively low Na₂O content, and so the IUGS scheme often leads to the classification of a sodic rock as a potassic variant (potassic trachybasalt instead of hawaiite). A solution to this problem would be to vary the figure to subtract to the amount of soda in correlation with SiO₂ content, i.e., increasing the figure from ~1 to ~3 (instead of the fixed “2”) with SiO₂ increasing from 45 to 71 wt%.
- 5) **TAS (2).** The field of trachyte is divided into a proper trachyte if $q < 10$ [with $q = 100 * qz / (qz + or + ab + an)$ as CIPW normative minerals] and trachydacite if $q > 10$. From a modal classification point of view, trachyte is an alkali feldspar-rich rock [with $100 * plagioclase / (alkali\ feldspar + plagioclase)$ ratio <35], while dacite is a plagioclase-rich rock (with $100 * plagioclase / (alkali\ feldspar + plagioclase)$ ratio >65). The term *trachydacite* would imply an intermediate composition between trachyte and dacite. The problem is that, according to the IUGS classification, the distinction between *trachyte* and *trachydacite* is based on CIPW normative minerals (see the above “q” parameter), unrelated to the modal mineralogy. According to IUGS, a trachydacite is a trachyte richer in quartz, which is not completely correct.
- 6) **TAS (3).** The definition of trachyandesite in the TAS diagram is somewhat related to the previous point. According to IUGS, a potassic trachyandesite is called latite. However, the IUGS classification also defines a latite using modal mineralogy as a volcanic rock with less than 20% modal quartz and with a $100 * plagioclase / (alkali\ feldspar + plagioclase)$ ratio ranging from 35 to 65. In other words, the

classification scheme currently in use proposes two different definitions for the term *latite*: a) the potassic variant of trachyandesite using the TAS diagram, and b) a quartz-bearing volcanic rock with similar amounts of plagioclase and alkali feldspar. Furthermore, the term *trachydacite* discussed in point 5), being intermediate between trachyte and dacite, should correspond to the term *latite*, but this is not correct.

- 7) **TAS (4).** The distinction between alkali basalts and tholeiitic basalts is based on work from almost 40 years ago (Bellieni *et al.*, 1983). Based on the much larger database available now and with improved analytical methods, a review and likely revision of this distinction is clearly warranted.
- 8) **TAS (5).** Although the TAS diagram is mostly conventionally used to classify “normal” volcanic rocks, it has also been used for plutonic rocks. Although the IUGS volume suggests that in the case of phaneritic rocks a modal approach is preferred to chemical classification, many geoscientists working with plutonic rocks use the TAS diagram for coarse-grained rocks as well. This issue needs to be addressed since many authors use the 40-year-old discrimination fields proposed by Cox *et al.* (1979) that were developed from an early version of the TAS diagram.
- 9) **Silica saturation.** The concept of silica saturation of igneous rocks is of essential importance. If modal analyses are difficult to obtain, and it is not possible to identify quartz or any foid, the common approach is to use the CIPW normative classification. According to this classical scheme (Cross *et al.*, 1902), silica oversaturated rocks are quartz-normative, undersaturated rocks are quartz- and orthopyroxene-free foid normative, and critically saturated rocks are neither quartz- or foid-normative, but have olivine- and orthopyroxene-normative compositions. Not all igneous petrology researchers accept this simple definition. For example, upper mantle olivine- and orthopyroxene-bearing rocks (peridotites) are considered silica undersaturated, despite the absence of foids. IUGS should provide a forum to reach international consensus and develop a definitive scheme concerning this matter.
- 10) **Sodic vs potassic and ultrapotassic compositions.** In relation to the definition of the term *potassic*, the existing IUGS classification scheme proposes: $(\text{Na}_2\text{O}-2)/\text{K}_2\text{O} < 1$ for basic to acid compositions (see point 3) or $\text{K}_2\text{O}/\text{Na}_2\text{O} > 1$ for foiditic compositions. No reference is made to intermediate compositions. With respect to ultrapotassic rocks, the IUGS scheme indicates molar $\text{K}_2\text{O}/\text{Na}_2\text{O} > 3$ as a discriminant, but without any additional comment. Nothing is presented to explain the definition of ultrasodic compositions. Moreover, the effect of analcimization (i.e., the transformation of original K-rich leucite-bearing lithologies into Na-rich analcime-rich, leucite-poor/free lithologies) needs to be addressed. A clear standardisation of these terms, very commonly used in igneous petrology research, is required. At present, considerable confusion surrounds how to define an igneous rock as ultrapotassic-intermediate-sodic-ultrasodic.
- 11) **Tholeiitic vs calc-alkaline.** The existing IUGS classification does not provide a rigorous definition of these terms. A clear, unambiguous means of distinguishing tholeiitic from calc-alkaline melts is required, that should be independent of the geotectonic significance given to such compositions. The classification proposed by Arculus (2003) could be used as a starting point for this revision, and might involve proposing to limit the use of tholeiite and calc-alkaline to be replaced with “Low-Fe” and “High-Fe” compositions.
- 12) **Use of the term mafic.** According to the IUGS classification scheme the adjective *mafic* discriminates Q-A-P-F minerals (quartz-alkali feldspar-plagioclase-foids) from the rest of the minerals (e.g., mica, amphibole, pyroxene, olivine etc.). However, igneous petrologists routinely use the same term to characterize also primitive mantle melts that are not modified by fractional crystallization or crustal contamination processes. In much current research, the term *mafic* is used for rocks rich in MgO and FeO_{tot} , but without quantifying anything. *Mafic rocks* are commonly considered to be igneous rocks with MgO greater than 4 wt.%. It is clear that IUGS needs to provide some guidance on this issue, clearly stating that the widely used adjective *ultramafic* has a completely different meaning [i.e., rocks with $100 * \text{M}/(\text{QAPF}) > 90$].

- 13) **Kimberlites.** An important outcome of the IUGS Sub-Commission (Woolley *et al.* 1996) was to separate kimberlites (including so-called Group 1 and Group 2 after Smith *et al.*, 1985), lamproites and lamprophyres previously amalgamated under the umbrella-term lamprophyric rocks. The very brief definition of le Maitre (2002) is of limited practical value and requires updating, to include a wealth of petrographic, mineral chemical and geochemical data now available (e.g., Roeder and Schulze, 2008; Kjarsgaard *et al.*, 2009; Scott Smith *et al.*, 2018). In light of such extensive new datasets, the original kimberlite classification should be re-visited, given its interest not only to academics but also to industry. Clear-cut distinctions between kimberlites and ultramafic lamprophyre varieties need to be further developed, such as the presence or absence of melilite (Tappe *et al.*, 2005).
- 14) **Lamprophyres.** Lamprophyre is a collective term for a distinctive group of porphyritic igneous rocks displaying broadly similar petrographic characteristics. The previous IUGS Subcommission (Woolley *et al.* 1996) did not endorse the term lamprophyric clan. It is now suggested that lamprophyres do not have a common petrogenesis but are differentiates of diverse parental magma systems, or different petrological clans, reflected in a wide variety of mineral assemblages. As summarised by Scott Smith *et al.* (2018), the term lamprophyric-facies is a useful concept and term to indicate a magmatic emplacement-“facies” of variety of parental magmas created by a particular set of conditions, generally late-stage, volatile-rich (H₂O and CO₂), which are different to the main magmas. It would be valuable to update the IUGS classification accordingly.
- 15) **Lamproites vs. lamprophyres.** A clear and practical distinction between lamproites and lamprophyres is not yet available. Lamproite classification is based on the scheme of Mitchell and Bergmann (1991) that involves both mineralogical and geochemical criteria. The problem is that rocks classified as lamproites may match only one of the two IUGS criteria. Recent research (Lustrino *et al.*, 2016) indicates that more than 70-80% of the Mediterranean lamproites do not match the official IUGS definition. There is considerable overlap between lamproitic and lamprophyric rocks (e.g., the limited amount of feldspar, the often low to absent plagioclase contents, the alkali-rich and, in particular K₂O-rich whole rock compositions, Ti-rich clinopyroxene, absence of quartz or orthopyroxene, abundant presence of amphibole and mica).
- 16) **Metaluminous vs. peraluminous melts.** The molar alkali + lime content compared to alumina is used to define a non-peralkaline rock as metaluminous or peraluminous. The IUGS classification defines a rock peraluminous if $Al/(Ca+Na+K) > 1$ and metaluminous if < 1 . However, several other methods are used in the scientific literature, some of which consider 1.1 instead of 1 as the threshold, others removing a given amount of calcium combined with phosphorous to form apatite. IUGS needs to propose a definitive position on this classification.
- 17) **Carbonatites (I).** The IUGS classification defines carbonatites as rocks containing more than 50% modal carbonate. IUGS should consider adding a comment on the fact that the carbonate has to be primary in origin. This might appear obvious, but there are several cases reported in the literature according to which only the amount of carbonate is taken into consideration, without distinguishing primary from secondary carbonates (e.g., Lustrino *et al.*, 2020; Toscani *et al.*, 2020). It is also true that the carbonate can be, at the same time, primary and secondary. Indeed, there are several studies that have explained the presence of modal carbonate as the effect of limestone digestion into a silicate basic-ultrabasic magma, followed by breakdown into CaO (\pm MgO and FeO) + CO₂. If CO₂ does not escape, it can be combined with dissolved CaO to crystallize new “primary” calcite. What is the ultimate origin of such a calcite? It should be considered as a primary phase, because it is crystallized from a melt, but, at the same time, it has a secondary origin, being related to a previous digestion of sedimentary carbonates.
- 18) **Carbonatites (II).** The present IUGS classification of carbonatites occupies only about half a page. Considering the petrological and economic importance of these melts, a better explanation of the various types is clearly required. A new carbonatite classification should consider the scheme proposed by Mitchell (2005). The IUGS classification implies that carbonatites are composed of magmatic carbonate minerals, but rocks formed under hydrothermal conditions or with development of

metasomatic processes are not classified as carbonatites, despite being characterized by minerals typically also formed in magmatic processes. Carbonatites are usually polygenetic in formation, with early-stage magmatic carbonatites, late-stage volatile-rich fluid (carbothermal) carbonatites, and a final hydrothermal stage.

- 19) **Kalsilite-bearing vs. kamafugitic rocks.** The second edition of the IUGS book on the classification of igneous rocks resulted in significant modification concerning the kamafugitic rocks. In that edition, ugandite was not considered a real kamafugite because of the absence of kalsilite. The following year, an article reported the presence of kalsilite also in the type locality of ugandites (Tappe *et al.*, 2003), later confirmed by other studies. This means ugandites need to be moved from the *olivine leucitite variant* to the *kamafugite rock group*. Another problem relates to the connection of kamafugites with ultrapotassic rocks, because kalsilite has been found also in relatively sodium-rich ultrabasic rocks from Nyiragongo (Democratic Republic of Congo). It is worth noting that kalsilite can be produced as subsolidus reaction from potassic nepheline, thus contradicting the simple presence of kalsilite as the most “distinctive and important” parameter to classify a rock as a kamafugite.
- 20) **MgO-rich alkali-poor volcanic rocks.** The second edition of the IUGS classification scheme accepted the proposal of Le Bas (2000) to re-classify MgO-rich alkali-poor volcanic rocks exclusively on the basis of chemical constraints. Such rocks were subdivided into picrobasalts (SiO_2 41-45 wt%; $\text{Na}_2\text{O}+\text{K}_2\text{O} < 3$ wt%; $\text{MgO} < 12$ wt%), picrites (SiO_2 30-52 wt%; $\text{Na}_2\text{O}+\text{K}_2\text{O} < 3$ wt%; $\text{MgO} > 12$ wt%), komatiites (SiO_2 30-52 wt%; $\text{Na}_2\text{O}+\text{K}_2\text{O} < 2$ wt%; $\text{MgO} > 18$ wt%; $\text{TiO}_2 < 1$ wt%), meimechites (SiO_2 30-52 wt%; $\text{Na}_2\text{O}+\text{K}_2\text{O} < 2$ wt%; $\text{MgO} > 18$ wt%; $\text{TiO}_2 > 1$ wt%) and boninites (SiO_2 52 wt%; $\text{MgO} > 8$ wt%; $\text{TiO}_2 < 0.5$ wt%). This subdivision was immediately criticized by Kerr and Arnd (2001) because it did not take into account any petrographic information. In particular, the peculiar spinifex olivine characteristic of the komatiite type-locality (Barberton greenstone belt, South Africa), has been considered, preferring a chemically-based approach only. Following the present IUGS rules, several spinifex-olivine textured komatiites are thus improperly classified as picrites, and many euhedral olivine textured picrites (some of which are related to obvious cumulus processes) are classified as komatiites. Similarly, Ivanov *et al.* (2018) have shown that the meimechites from the type locality (Maimecha-Kotuy area in northern Siberian Craton) have less than 18 wt% MgO, and the high MgO content is related to the abundance of cumulus olivine. The classification scheme of these rocks is clearly in need of revision to iron-out these inconsistencies. Further, a new classification has been recently proposed for boninites and boninitic group rocks (Pearce and Reagan, 2019), indicating that updated guidelines for the classification and nomenclature of such rocks is overdue.
- 21) **Picrobasalts.** The IUGS classification considers a picrobasalt a volcanic rock with $\text{SiO}_2 = 41-45$ wt%, $\text{Na}_2\text{O}+\text{K}_2\text{O} < 3$ wt% and < 12 wt% MgO. By definition (Le Maitre, 2002), the term *basalt* defines a plagioclase-bearing volcanic rock (if not entirely glassy). The term *picrobasalt* would imply the presence of plagioclase as well, but the current IUGS scheme does not make any comment on the relationship between picrobasalt and basalt.
- 22) **Meteorites.** In the first two versions of the IUGS book, no mention was made of extra-terrestrial rocks. This is a significant omission, considering that several “exotic” names proposed for stony meteorites refer to parageneses similar to those observed in terrestrial plutonic and magmatic rocks (as well as metamorphic and sedimentary variants). A new section dealing with the main mineralogical and petrographic characteristics of stony meteorites is proposed to address this issue.
- 23) **Iconographic section.** The actual version of the IUGS book on the systematic of igneous rocks is free of any iconographic section reporting the most important characteristics of volcanic and plutonic rock variants. We are planning to add an electronic appendix to the book, hosted by the IUGS website, where it would be possible to download the most important petrographic characteristics of the various igneous rocks described and discussed in the book. Both macroscopic and thin sections microphotographs (at plane polarized and crossed polars) would be included (and periodically updated) in this website, with much help for future geoscientists.

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