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Evaluation of boundary lines in the total alkali - silica diagram for the discrimination between subalkali and alkali basalts, and a new method to distinguish transitional basalts

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ABSTRACT

Some boundary lines in the total alkali-silica diagram have been evaluated for their effectiveness to discriminate between alkali and subalkali basalts. The boundary line of Macdonald and Katsura has been found to be the most effective line for this purpose. Another equally effective boundary line, introduced in the present paper, is a line with constant suite index of 2.2 constructed in a modified Rittmann diagram. An assessment of available graphical means for distinguishing transitional basalts has revealed that none of these methods is satisfactory. A new method, based on a combination of CIPW norm, the two discriminants of the Macdonald and Katsura boundary line, the Poldervaart index, and Rittmann's suite index, has been introduced as a more reliable method to distinguish transitional from alkali and subalkali basalts.

Keywords: alkali basalt; subalkali basalt; transitional basalt; boundary lines; total alkali-silica diagram; suite index.

INTRODUCTION

Several authors introduced boundary lines in the total alkali-silica diagram to discriminate between subalkali and alkali basalts (Macdonald and Katsura, 1964; Macdonald, 1968; Kuno, 1966; 1968 and Irvine and Baragar, 1971). These boundary lines were constructed visually by these authors between the lowest populations of both types of basalts. Rickwood (1989) reviewed some of these diagrams and gave the co-ordinates of the different boundary lines. More recently, the Subcommission on the Systematics of Igneous Rocks of the International Union of Geological Sciences (referred to hereafter as "IUGS") introduced two boundary lines in the total alkali-silica diagram (IUGS, 2005). According to IUGS, basalt analyses that fall below the lower boundary line are considered subalkalic, those that fall above the upper boundary line are considered alkalic, whereas analyses falling between the two boundary lines (in the so-called "overlap" field) are probably more alkalic than subalkalic.

Few attempts have, hitherto, been made to evaluate the effectiveness of the different boundary lines to discriminate between subalkali and alkali basalts. Macdonald and Katsura (1964) pointed out that their boundary line separated between both types of basalts from Hawaii very satisfactorily. They indicated that their line reflects the trace of the critical plane of silica undersaturation in the basalt tetrahedron of Yoder and Tilley (1962). Irvine and Baragar (1971) tested the Macdonald and Katsura line using some analyses of volcanic rocks from regions other than Hawaii, and indicated that 90% of the samples were classified properly. They proposed another boundary line (slightly curved) to separate between subalkalic and alkalic rocks. The IUGS (2005) claims, on the basis of 7594 analyses of basalts, that the analyses falling below the lower boundary line in their diagram are 89% likely to be subalkalic, and those falling above the upper boundary line are 97% likely to be alkalic, whereas those falling between the two boundary lines, in the overlap field, are three times more probable to be alkalic than subalkalic.

Besides the common graphical methods mentioned above, Rittmann (1957) introduced the serial index (σ), which was later called the suite index (Rittmann, 1962), as a quantitative measure to distinguish between subalkalic and alkalic volcanic rock suites. Rittmann gave a table of σ

values to characterize each group of rocks, calculated from the weight percentages of Na_2O, K_2O and SiO_2, according to the equation:

$$\sigma=(Na_2O+K_2O)^2/(SiO_2-43) \quad (1)$$

In addition, Rittmann used a total alkali-silica diagram, with several parabola of constant σ values, to delineate the different rock suites. No attempt has, hitherto, been made to assess the effectiveness of Rittmann's method for the discrimination between alkali and subalkali basalts.

The aim of the present paper is to give a detailed evaluation of the effectiveness of the different boundary lines introduced in the total alkali-silica diagram for the discrimination between subalkali and alkali basalts, and to introduce a method for distinguishing the so-called transitional basalts.

DATA AND METHODS USED

Six thousand chemical analyses of tholeiitic and alkali basalts (as described so by the different authors) were compiled from the GeoRoc Database of the Max Planck Institute of Chemistry, Mainz (GeoRoc, 2015; http://georoc.mpch-mainz.gwdg.de/georoc/) and from the literature. The analyses were first screened to discard incomplete ones, and those that reported water content greater than 2 wt% and/or CO_2 greater than 0.5 wt%, as recommended by IUGS (2005). The remaining analyses were 5300, representing basalts from different regions and tectonic settings. The analyses were for basalts from:

(a) Ocean Island setting (Hawaiian Islands, Iceland, Galapagos Islands, Canary Islands, Mascarene Island, Ontogo Java, and Kerguelen);

(b) Convergent margin setting (Tonga Arc, Izu Bonin Arc, Scotia Arc, Honshu Arc, Andean Arc, and Central Andean Arc);

(c) Continental Flood Basalt (North Atlantic Igneous Province, Ethiopian Plateau, and Deccan Trap);

(d) Rift Volcanics (Ethiopian Rift);

(e) Intraplate Volcanics (Central Asian Fold Belt, and Arab-Nubian Shield).

The CIPW norm of the selected basalts was calculated using the SINCLAS programme (Verma et al, 2003), after adjusting the degree of iron oxidation (Fe_2O_3/FeO ratio) according to the method recently introduced by El-Hinnawi (2016). The calculated norms were then used to classify the basalts following, in general, the basalt tetrahedron of Yoder and Tilley (1962). Accordingly, the following types have been identified:

(a) Quartz tholeiites, olivine tholeiites, and picritic basalts (totaled 2300 samples). The calculated Rittmann suite index σ of these basalts was found to be less than 2.2.

(b) Alkali basalt (Ne-normative basalt, with Ne less than 5%), totaled 2150 samples. Their calculated σ values were greater than 2.2.

(c) Olivine-basalt (850 samples). These basalts were distinguished from olivine tholeiites by using the Polervaart index (Poldervaart, 1964) calculated according to:

$$P.I.= Ab-1.96\ Hyen-1.5\ Hyfs \quad (2)$$

Olivine tholiite has a P.I. less than 0, and olivine basalt has a P.I. greater than 0. The calculated σ values of these rocks varied between 1.8 and greater than 2.2. Accordingly, samples of olivine basalt that had σ values less than 2.2 were added to the subalkalic group mentioned above in (a); these were then totaled 2750. The olivine basalts that had σ values greater than 2.2 were not added to the alkalic group (b) because none of these samples was Ne-normative; these basalts were considered transitional basalts (see later).

RESULTS AND DISCUSSION

The Macdonald and Katsura boundary line (MK line)

The original Macdomald and Katsura boundary line extends between SiO_2 41.75 and 52.5 wt%, and corresponding total alkali of 1 and 5 wt% (Macdonald and Katsura, 1964, Figure 1). It is a straight line; its regression equation has been calculated as follows:

$$Alk=0.3721\ SiO_2-14.535 \quad (3)$$

This equation is slightly different from the one given by Chayes (1974), namely:

$$Alk=0.374\ SiO_2-14.6 \quad (4)$$

But the difference between both equations (3) and (4) is practically negligible.

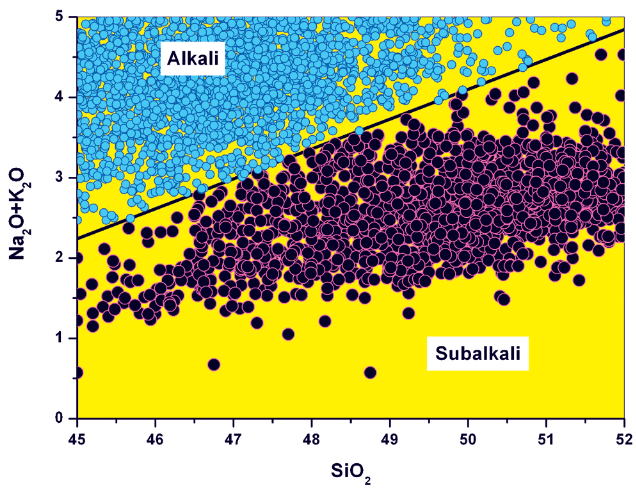


Figure 1. The total alkali - silica diagram, with the Macdonald and Katsura (1964) boundary line (solid black line). The line separates effectively between the alkali and subalkali basalt analyses.

Figure 1 shows the total alkali-silica diagram with the MK line, constructed according to equation (3), in the basalt field defined in the IUGS-TAS diagram (SiO_2 from 45 to 52 wt%, and total alkali up to 5 wt%). The figure shows that the MK line provides complete separation between the subalkali and alkali basalts.

Instead of using the graphic of Figure 1, Chayes (1974) introduced a discriminant equation for the MK line. Based on the regression equation (3), the discriminant equation can be written as follows:

$$DMK=0.372\ SiO_2-Na_2O-K_2O-14.54 \quad (5)$$

where DMK is the disriminant for the MK line. If DMK is greater than 0, the rock is subalkalic and if DMK is less than 0, it is alkalic.

As the MK line reflects the critical plane of silica undersaturation in the basalt tetrahedron of Yoder and Tilley (1962), Chayes (1974) introduced a second disciminant equation based on the normative olivine, diopside and hypersthene:

$$DC=Hy'+0.134\ Ol'-26.942 \quad (6)$$

in which Hy'=100 Hy/(Ol+Hy+Di) and Ol'=100 Ol/(Ol+Hy+Di).

If DC is greater than 0 the basalt is classified as subalkalic, and if DC is less than 0 it is classified as alkalic.

Using 627 analyses of Hawaiian basalts, Chayes found that 87% of the samples are consistently classified with the two discriminants, DMK and DC (i.e. both are positive in case of subalkalic rocks, and both are negative in case of alkalic rocks). He found in the remaining 13% of the analyses inconsistency between DMK and DC, and attributed this inconsistency to arise more from compositional peculiarities of Hawaiian lavas than from inadequacy of the DC discriminant. In the present work, the author found that there is consistency between the calculated DMK and DC discriminants in all the samples of the subalkali basalt group, and in all the samples of the alkali group (Ne-normative basalts). Inconsistency between DMK and DC was, however, encountered in olivine basalt samples. As indicated above, most of these rocks are considered transitional basalts (see later). Therefore, it seems that the 13% inconsistency found by Chayes was due to the fact that his calculations included the basalt group as a whole, without considering the different types of basalt. To reduce inconsistency, Chayes (1978) suggested the modification of both the DMK and DC discriminants. However, his modification of DMK into:

$$DMK'=0.374\ SiO_2-Na_2O-K_2O-14 \quad (7)$$

shifts the original MK line upwards, with the result that several samples of alkali basalt will fall below the modified MK line into the subalkalic field. Therefore, the present author believes that the original MK line should be left as it is, and that the modification suggested by Chaues (1978) should not be adopted.

Irvine and Baragar boundary line (IB line)

The original boundary line introduced by Irvine and Baragar (1971) extends from SiO_2 39.2 to 66.4 wt% and from corresponding total alkali 0 to 10 wt%. The line is slightly curved at SiO_2 values greater than 52 wt%, but within the field of basalt it is a straight line, with the following regression equation:

$$Alk=0.42\ SiO_2-16.19 \quad (8)$$

Figure 2 shows that the IB boundary line is effective in separating the subalkali basalt samples, but it is not so effective in separating the alkali basalt ones. About 15% of the alkali basalt samples were found, using the discriminant of the IB line formulated from equation (8), to fall below the IB boundary line in the subalkalic field.

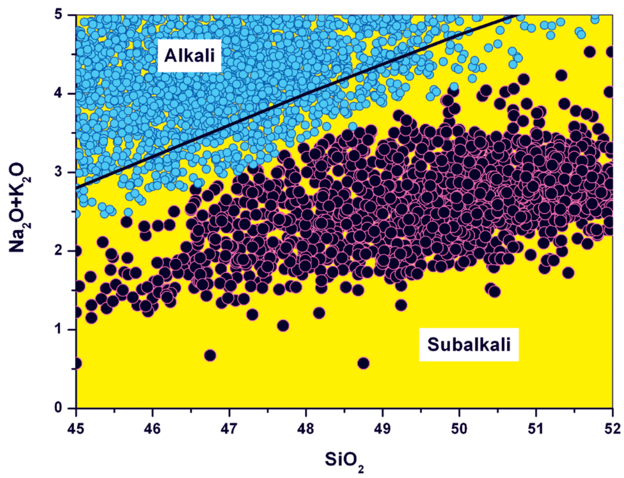


Figure 2. The total alkali - silica diagram, with the Irvine and Baragar (1971) boundary line (solid black line). The line is effective in separating the subalkali basalt analyses, but less effective in separating the alkali basalt ones.

The IUGS boundary lines

The two boundary lines introduced by IUGS (2005) are straight lines (Figure 3), with the following regression equations:

$$\text{For the lower line: } Alk=0.514\ SiO_2-21.74 \quad (9)$$

$$\text{and for the upper line: } Alk=0.933\ SiO_2-39.8 \quad (10)$$

Figure 3 shows that the lower line is slightly ineffective in separating the subalkali basalt samples. Using the discriminant of that line, about 4.5% of the samples of subalkali basalt were found to fall above the line in the overlap field. The upper boundary line is more ineffective in separating the alkali basalt samples. About 44% of the samples of alkali basalt fall below the line in the overlap field. These findings differ from those reported by IUGS (2005). In the present work, the separation of subalkali basalts by the lower boundary line is better than that given by IUGS (95.6% in the present work vs 89% in IUGS). Conversely, the separation of alkali basalts by the upper boundary line in the present work is less effective than that reported by IUGS (56% in the present work vs 97% in IUGS). It is not clear from the IUGS assessment what types of basalts were used, in particular if the alkali basalts were Ne-normative (which is the main criterion for defining alkali basalts, according to Yoder and Tilley, 1962).

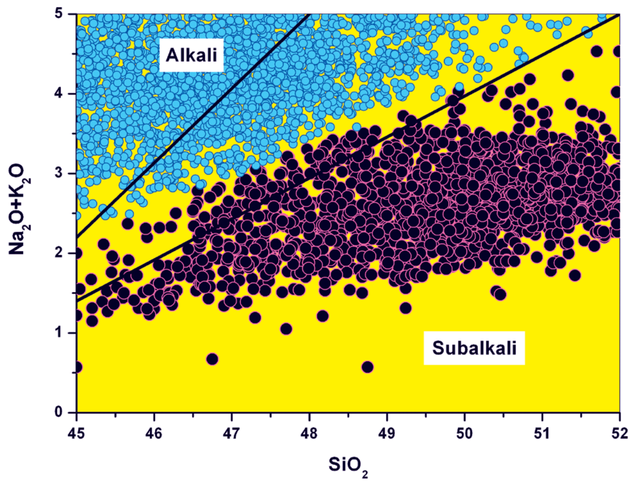


Figure 3. The total alkali - silica diagram, with the IUGS (2005) boundary lines (solid black lines). The lower line is ineffective in separating entirely the subalkali basalt analyses. The upper line is even more markedly ineffective in separating the alkali basalt analyses.

Rittmann's suite index (σ) and diagram

The original diagram of Rittmann (1957; 1962) was constructed for SiO_2 values from 35 to 80 wt% and corresponding total alkali from 0 to 14 wt%, with several parabola as boundary lines of constant suite index (σ). According to Rittmann, the boundary line between subalkalic and alkalic rocks was set at σ value of 3.3, but Yang (2007) modified this boundary line into σ value of 3.5.

Rittmann (1962) pointed out that it might be difficult to use the suite index to characterize basalts because of the narrow variation near the vertex of all parabola (SiO_2=43 wt%, Alk=0 wt%) in his diagram. Figure 4, drawn in the present work for the basalt field of TAS, shows that separation between subalkali and alkali basalts can be achieved by a boundary line of constant σ of 2.2. The present author found that the SiO_2 and total alkali values used in constructing this boundary line are nearly the same as those values that characterize the Macdonald and Katsura boundary line. Therefore, the boundary line of constant σ value of 2.2 in the modified Rittmann diagram introduced here in Figure 4 approximates also the critical plane of silica undersaturation in the basalt tetrahedron of Yoder and Tilley (1962).

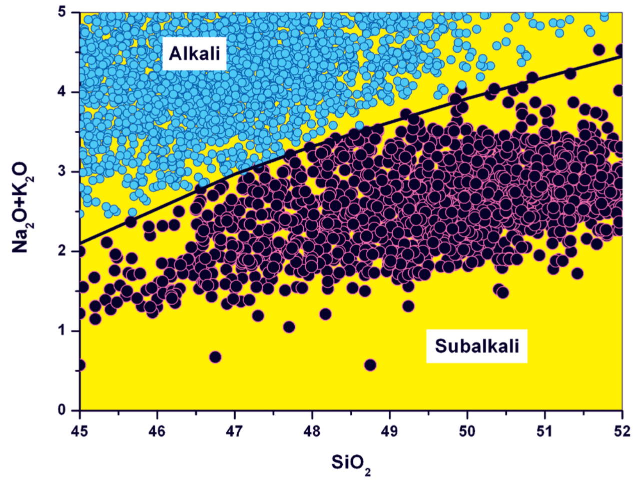


Figure 4. The total alkali - silica diagram, plotted with a boundary line of constant suite index (σ) value of 2.2 (Rittmann's parabola) that separates effectively between alkali and subalkali basalt analtses.

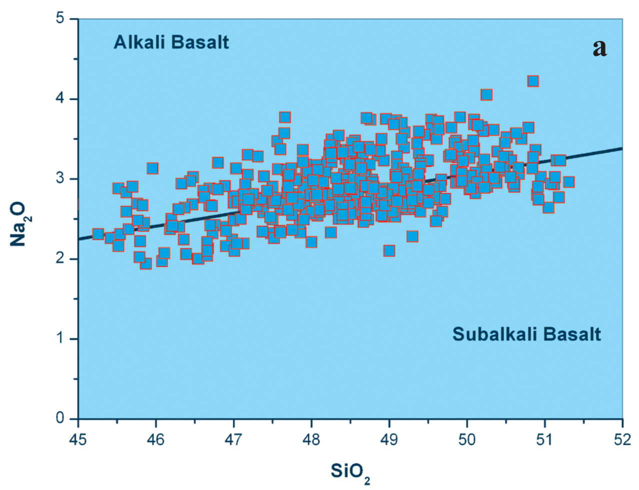
Transitional basalts

It is known that a continuum links between subalkali and alkali basalts. The term "transitional basalt" has been used to describe basalts with intermediate composition and characteristics between the typical tholeiitic and alkali basalts. However, the term has not been defined rigorously. The IUGS (2005) did not deal with the subject and contended only by a general definition in its glossary of terms, namely "a transitional basalt is a variety of basalt transitional between typical tholeiitic basalt and alkali basalt. It consists of olivine, Ca-rich augite, plagioclase and Ti-magnetite plus variable, but small amounts of alkali feldspars. Ca-poor pyroxenes are absent". Therefore, the characteristics, classification, occurrence and origin of these basalts remain a matter of debate, speculation and controversy.

Some authors (e.g., Bellieni et al., 1981) characterized transitional basalts as having moderate MgO (about 5 wt%), low K_2O (0.4 to 0.6 wt%), high TiO_2 (3 to 3.4 wt%) and moderate Al_2O_3 (about 13 wt%). However, other authors (e.g.. Brotzu et al., 1974; Pik et al., 1983; Feigenson et al., 1983; Frey et al., 2002; Naumann et al., 2002 and Kuepouo et al., 2006) have shown that the composition of transitional basalts is rather variable. The present author believes that a more appropriate chemical definition of transitional basalt would be that: "for a given SiO_2 content, the total alkali of a transitional basalt should lie between the average total alkali of subalkali basalts and that of alkali basalts".

Some attempts have been made to distinguish transitional basalts graphically. Middlemost (1975) pointed out that when transitional basalts are plotted in two diagrams: Na_2O vs SiO_2 and K_2O vs SiO_2, they fall within the alkalic field in one diagram and in the subalkalic field in the other one. In the present work, 560 chemical analyses of basalts described as transitional basalts were compiled from the literature. The analyses are for basalts from Ethiopia, Iceland, Hawaii, Galapagos Archipelago, Central Kerguelen Archipelago, Somalia Trap, Turkana (Kenya), Bana (Cameroon Line) and the North Atlantic Igneous Province. Figure 5a shows the distribution of these analyses in the Na_2O vs SiO_2 diagram. The analyses are nearly equally distributed between the alkalic and subalkalic fields. Figure 5b, which is a plot of K_2O vs SiO_2, indicates that nearly all the analyses fall in the subalkalic field. This demonstrates that the method proposed by Middlemost (1975) is rather unsatisfactory for distinguishing transitional basalts.

In the total alkali-silica diagram with the MK boundary line, some authors (e.g. Frey et al., 2002) described transitional basalts as those "straddling" the MK line. The term "straddle" is a descriptive term that has no mineralogical or chemical meaning; an analysis of a transitional basalt would fall either above or below the MK line. Piccirillo et al. (1979), in their study of Ethiopian volcanic rocks, introduced two arbitrary lines, one above and one below the MK line, at a distance of 1 wt% total alkali. They indicated that basalt analyses falling in the zone between their upper line and the MK line are transitional basalts with alkaline affinity, whereas those falling in the zone between their lower line and the MK line are transitional basalts with tholeiitic affinity. The Piccirillo et al. (1979) lines were used in some studies of Ethiopian basalts (e.g., Pik et al., 1998), and in studies of basalts from other regions (e.g., Bellieni et al., 1981; Moussa, 1997; Abou El-Maaty et al., 2011). However, when the Piccirillo et al. (1979) lines are applied to the data plotted in Figure 1, a considerable number of the



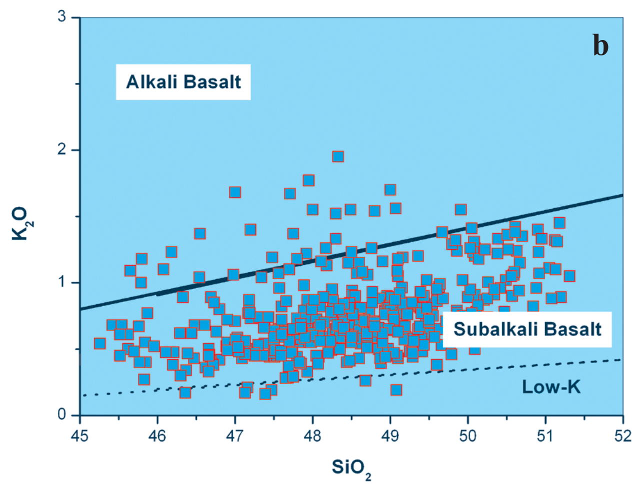


Figure 5. a) The Na_2O vs. SiO_2 diagram of Middlemost (1975) showing analyses of transitional basalts falling on both sides of the boundary line. b) The K_2O vs. SiO_2 diagram of Middlemost (1975) showing analyses of transitional basalts falling mostly under the boundary line.

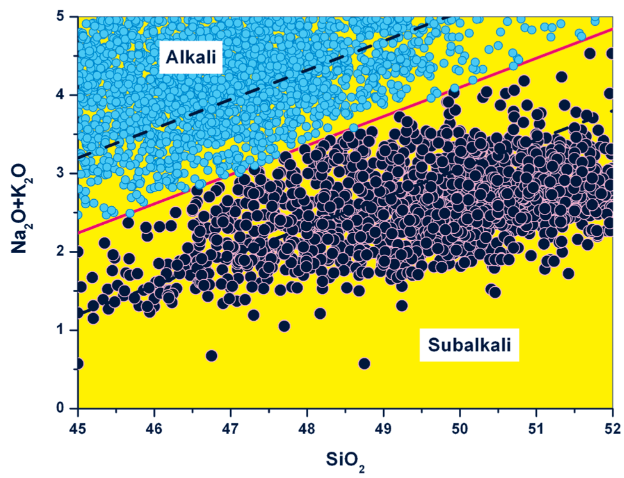


Figure 6. The total alkali-silica diagram, with the boundary line of Macdonald and Katsura (1964)- red line- and the two arbitrary boundary lines of Piccirillo et al. (1979)-dashed lines. The analyses plotted in the figure are the same as those plotted in Figure 1. This figure shows that many of the analyses appear between the two Piccirillo et al. lines, i.e. should be considered transitional basalts, which is not the case.

analyses of subalkali and alkali basalts would be classified as transitional basalts, which is not the case (Figure 6). Figure 7 shows the distribution of the 560 chemical analyses of transitional basalts referred to before. Although nearly all the analyses fall within the zone between the two arbitrary lines of Piccirillo et al. (1979), when this figure is compared with Figure 6, it is rather difficult to distinguish transitional basalts from either subalkali or alkali basalts.

A detailed examination of the calculated CIPW norms of the 560 transitional basalts, their distribution around the MK line, the calculated discriminants DMK and DC, and suite index σ, revealed the following:

1. Basalts falling above the MK line

These transitional basalts are mainly olivine basalts, with subordinate amounts of olivine tholeiite and quartz tholeiitic basalt. These basalts can be classified into:

(1.1) olivine basalts in which the discriminants DMK and DC are compatible (i.e. both are negative). These basalts are Ol-Hy normative, with Ol>Hy. The percentage of Ol in the norm is ~12% and that of Hy is ~5%.

(1.2) Olivine basalts in which the dicriminants DMK and DC are incompatible (i.e. DMK is +ve but DC is +ve). These basalts are Ol-Hy normative, with Ol<Hy. The percentage of Ol in the norm is ~6% and that of Hy is ~11%.

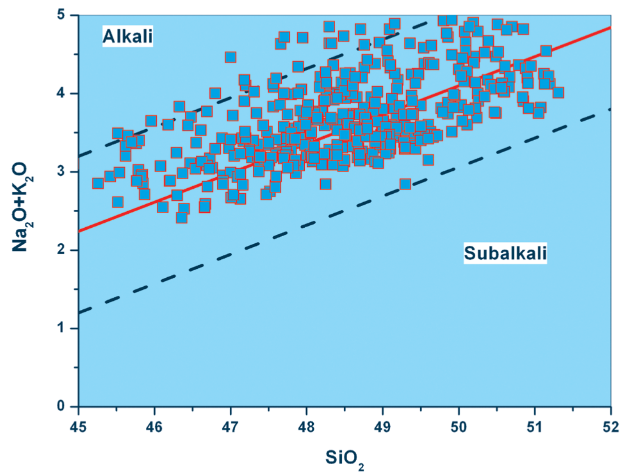


Figure 7. The total alkali- silica diagram, with the boundary lines of Macdonald and Katsura and those of Piccirillo et al., showing that transitional basalts plot mostly between the Piccirillo et al. lines, above and below the Macdonald and Katsura line. The figure demonstrates the difficulty of distinguishing these transitional basalts from alkali and subalkali basalts on the basis of this graph only.

Table 1. Key for the identification of transitional basalts*.

Rock	DMK	DC	Normative Ol,Hy			Norm. ~Q%
			Ol:Hy	~Hy%	~ Ol%	
1. Transitional basalts plotting above the MK line (DMK –ve) Rittmann Suite Index σ>2.2						
1.1 Olivine basalt	-ve	-ve	Ol>Hy	5	12	----
1.2 Olivine basalt	-ve	+ve	Ol<Hy	11	6	----
1.3 Olivine tholeiitic basalt	-ve	+ve	Ol<Hy	15	5	----
1.4 Quartz tholeiitic basalt	-v4	+ve	----	----	----	<2
2. Transitional basalts plotting below the MK line (DMK +ve) Rittmann Suite Index σ 1.8-2.2						
2.1 Olivine basalt	+ve	+ve	Ol<Hy	11	4.5	----
2.2 Olivine basalt	+ve	-ve	Ol>Hy	6	10	----
2.3 Olivine tholeiitic basalt	+ve	+ve	Ol<Hy	16	5	----
2.4 Quartz tholeiitic basalt	+ve	+ve	----	----	----	<5

Note:

* DMK : discriminant of Macdonald and Katsura boundary line, calculated from:
DMK = 0.372 SiO_2-Na_2O-K_2O-14.54
DC : discriminant of Macdonald and Katsura boundary line, calculated from:
DC = Hy’+0.134 Ol’-26.942, where Hy’=100 Hy/(Ol+Hy+Di) and Ol’=100 Ol/(Ol+Hy+Di).
Rittmann’s Suite Index (σ) calculated from: σ=$(Na_2O+K_2O)^2/(SiO_2–43)$.

(1.3) Olivine tholeiite in which DMK and DC are incompatible (DMK is +ve but DC is +ve). These tholeiites are Ol-Hy normative, with Ol<Hy. The percentage of Ol in the norm is ~5% and that of Hy is ~15%.

(1.4) Quartz tholeiitic basalt in which DMK and DC are incompatible (DMK is -ve but DC is +ve). These basalts are Hy-Q normative; the percentage of Q in the norm is generally less than 2%.

In all the above-mentioned transitional basalts, the Rittmann suite index σ is >2.2.

2. Basalts falling below the MK line

These transitional basalts consist of olivine basalt, olivine tholeiite and quartz tholeiite. They can be classified into the following:

(2.1) Olivine basalts, in which DMK and DC are compatible (both discriminants are +ve). These basalts are Ol-Hy normative, with Ol<Hy. The percentage of Ol is ~4.5% and that of Hy is ~11%.

(2.2) Olivine basalts, in which DMK and DC are incompatible (DMK is +ve but DC is -ve). These basalts are Ol-Hy normative, with Ol>Hy. The percentage of Ol in the norm is ~10% and that of Hy is ~6%.

(2.3) Olivine tholeiite, in which DMK and DC are compatible (both discriminants are +ve). These tholeiites are Ol-Hy normative, with Ol<Hy. The percentage of Ol in the norm is ~5% and that of Hy is ~16%.

(2.4) Quartz tholeiitic basalt, in which DMK and DC are compatible (both discriminants are +ve). These basalts are Hy-Q normative, with a normative Q content of <5%.

In all the above mentioned four transitional basalts, the Rittmann suite index σ is between 1.8 and 2.2.

Table 1 gives a summary of the above findings, and can serve as a key for distinguishing the different types of transitional basalts.

Examples of application of the key for distinguishing transitional basalts

Table 2 gives three examples of the application of the key given in Table 1 for distinguishing transitional basalts. The first example is a basalt from Kohala volcano, Hawaii (Feigenson et al., 1983). The calculated DMK is negative (i.e. the basalt plots above the MK line in the alkalic field). However, the basalt is not an alkali basalt since it is not Ne-normative. The calculated DC discriminant is positive, hence there is an incompatibility between DMK and DC. The calculated CIPW norm shows a Q content of 1.18% (less than 2%). Therefore, according to the Key in Table 1, the rock is a transitional Q-normative tholeiitic basalt (type 1.4), which is in accordance with the findings of Feigenson et al. (1983). The second example is a basalt from the Somali Trap Series, south-east of the Ethiopian Rift (Brotzu et al., 1974). The calculated DMK is negative (i.e. the basalt plots above the MK line). The CIPW norm of the rock indicates that it is an Ol-Hy normative basalt. The calculated DC discriminant is positive, i.e. it is incompatible with DMK. Since normative Ol is less than normative Hy, the rock is a transitional olivine basalt (type 1.2). The third example is a basalt from Cudia Bruciata, Pantelleria, Italy (White et al., 2009). The calculated DMK is negative (i.e. the rock plots above the MK line). The CIPW norm shows that the rock is an Ol-Hy normative basalt. The calculated DC discriminant

Table 2. Examples for the Application of the Key in Table 1.

	1	2	3
SiO_2	48.25	48.17	48.23
TiO_2	3.21	2.68	2.63
Al_2O_3	16.30	14.59	15.82
Fe_2O_3	----	4.64	----
FeO	11.28*	8.63	10.75*
MnO	0.16	0.22	0.16
MgO	4.59	4.72	6.23
CaO	9.51	9.29	11.33
Na_2O	3.32	3.52	3.09
K_2O	0.95	0.97	0.89
P_2O_5	0.68	0.35	0.52
CIPW Norm			
Q	1.15	----	----
Or	5.69	5.86	5.26
Ab	28.48	30.46	26.13
An	27.13	21.62	26.65
Di	13.06	18.93	21.03
Hy	10.43	8.21	2.87
Ol	----	1.99	6.29
Mt	6.26	6.87	5.53
Il	6.18	5.20	4.99
Ap	1.59	0.82	1.20
Calculated Parameters**			
DMK	-0.66	-0.80	-0.57
σ	3.17	3.37	3.04
DC	17.45	2.16	-14.63
Ol:Hy	----	Ol<Hy	Ol>Hy
Q	1.18	----	----

Note:
Tholeiitic basalt, Kohala Volcano, Hawaii (Feigenson et al., 1983)
Basalt, Somali Trap SE Ethiopian Rift (Brotzu e al., 1974)
Basalt, Cudia Bruciata, Pantelleria, Italy (White et al., 2009)
* Total Fe
** For calculated parameters see footnote to Table 1

is negative, i.e. there is compatibility between DMK and DC. Since the Ol in the norm is higher than the Hy, the rock is a transitional basalt (type 1.1).

CONCLUSIONS

The evaluation of some boundary lines in the total alkali-silica diagram for the discrimination between alkali and subalkali basalts has shown that the Macdonald and Katsura (1964) boundary line is more effective than the boundary line of Irvine and Baragar (1971) or those of IUGS (2005). Another effective boundary line, with a constant Rittmann suite index of 2.2, has been introduced in the present work in a modified Rittmann diagram constructed for the basalt field.

Graphical means, hitherto used, have been found to be rather ineffective in distinguishing transitional basalts. A new method, based on a combination of CIPW norm, the two discriminants of the Macdonald and Katsura boundary line, the Poldervaart index, and Rittmann's suite index, has been introduced in the present work to distinguish transitional basalts from alkali and subalkali basalts.

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