The Fe_2O_3/FeO ratio of basalt analyses: an appeal for a standardized procedure

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Due to the importance of the oxidation state in the classification of basaltic rocks many procedures have been adopted for the adjustment of this parameter to minimize the effects of secondary oxidation. An appeal is made here to standardize this procedure and a case is made for the adoption of a value for the Fe_2O_3/FeO ratio of 0.15. It is probable that this is close to the original value in nature, at least for tholeiites.

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It is now almost universally recognized that nearly all basaltic rocks have suffered significant late-stage and secondary alteration and that this has a critical effect on the calculated amounts of normative constituents, which form the basis of the classification of such rocks (Yoder & Tilley 1962). Thus, as the Fe_2O_3/FeO ratio rises, more *magnetite* will be formed and increasing amounts of SiO_2 will become available for converting *nepheline* to *albite, olivine* to *hypersthene* and eventually forming free *quartz*. As it is clearly of importance to know as closely as possible the original normative composition on the rock, it is with problems of classification that post-extrusion oxidation becomes most critical.

Most workers are aware of these problems, but, unfortunately, many different methods of correcting for this oxidation have appeared in the literature. Thus, Coombs (1963) and Kay et al. (1970) proposed reducing the Fe_2O_3 in all analyses to a maximum of 1.5 %. However, this may not be reasonable in cases where the basalts are high in total FeO or TiO_2. Irvine & Baragar (1971) therefore tried to improve this by making Fe_2O_3 equal to 1.5 % + wt % TiO_2. Similarly, Thompson et al. (1972) took into account the total alkali content in addition to allow for the effect of differentiation. On the other hand, Bass (1972) adopted a value for Fe^{3+}/Fe^{2+} (atomic) of 0.1, Pyke et al. (1973) used a value of $Fe^{3+}/Fe^{3+}+Fe^{2+}$ of 0.1, O'Hara (1973) a value of 0.2 and Baker

et al. (1974) a value of 0.25. Still others have corrected the Fe_2O_3/FeO ratio to various values: 0.15 (Green et al. 1974), 0.123 (Frey et al. 1974), 0.25 (Stice, 1968) and 0.44 (Best & Brimhall 1974). In addition, norms have sometimes also been calculated with all iron as FeO, thus achieving the maximum degree of undersaturation. While the results of these various procedures are often not greatly at variance, discrepancies do arise, the situation is confusing and comparisons between the results of various workers are greatly hampered. The purpose of this note is firstly to urge that a standard data reduction method be adopted and secondly to argue for a specific value, which is probably close to the real one prior to oxidation, in the hope that this will increase the attraction of this value and lead to its widespread acceptance.

In recent years a number of analyses of low-K_2O tholeiitic glasses from the deep ocean floor have become available in the literature. Such glass is widely believed to represent highly chilled igneous material which preserves rather closely its pristine characteristics. Thus, Moore (1970) has shown that it retains unchanged its original magmatic water content and Dymond (1970) has shown that the same is true for the rare gases. It is therefore likely that the original oxidation state has been little changed. Miyashiro et al. (1969) noted that most analyses of fresh basalts from the ocean floor have Fe_2O_3/FeO ratios within a very

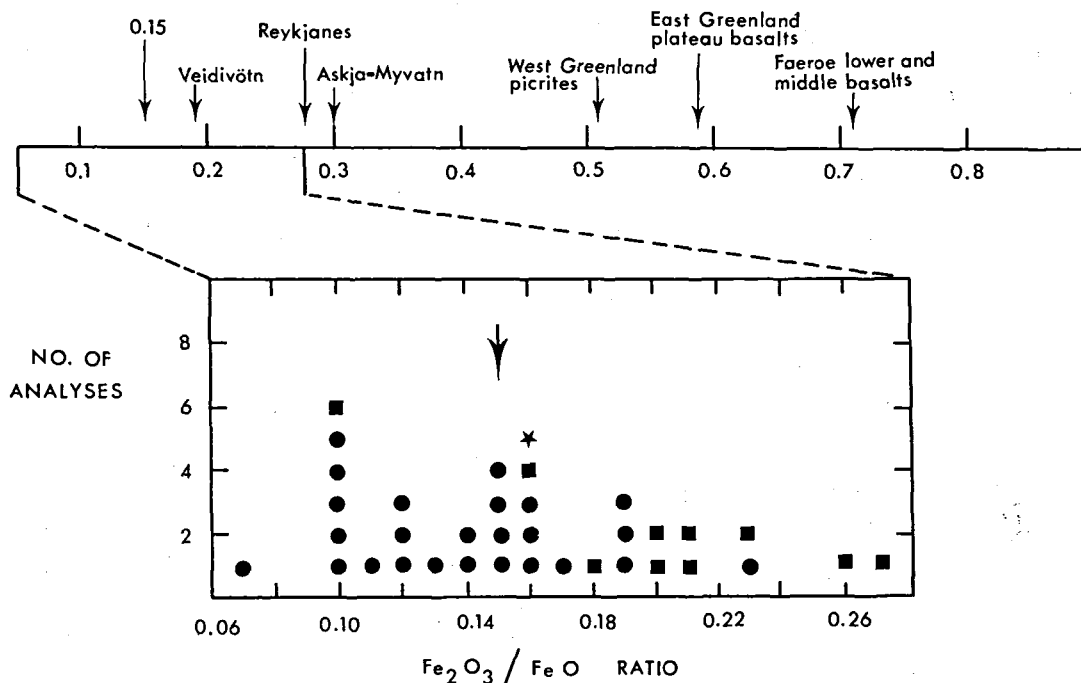Fig. 1. The distribution of Fe₂O₃/FeO ratios in fresh basaltic glasses from the deep oceans with average values from different areas of the North Atlantic· province for comparison. Circles indicate glasses analysed for both Fe₂O₃ and FeO. Data is from Campsie et al. (1973), Hekinian (1971), Melson (1969), Miyashiro et al. (1969), Moore (1965), Muffler et al. (1965), Nicholls (1965) and Thompson (1973). Values calculated from total FeO on the basis of the experimentally determined olivine-glass equilibrium are shown as squares (Melson & Thompson 1973; Fawcett et al. 1973). Comparative data for subaerial basalts from the North Atlantic province are taken from Bollingberg et al. (1975), Clarke (1970) and Brooks et al. (in press). For Postglacial Icelandic basalts from the tholeiitic rift-zone at Reykjanes, Veidivötn and Askja-Myvatn, the data are from the compilation of Jakobsson (1972). The star indicates the value for the preferred sample of the Skaergaard chilled margin (Wager & Brown 1968) and the arrow shows the suggested standard value of 0.15.

narrow interval of 0.1–0.3, which appears to confirm this assumption. I have examined all analyses of such fresh glass from the literature which report the determination of both Fe₂O₃ and FeO and have plotted the Fe₂O₃/FeO ratios in fig. 1. There are 25 points in all, more than 90 % of·which lie in the interval 0.10–0.19, an extremely small range compared to subaerial basalts, of which some values from the North Atlantic are shown in the upper part of fig. 1. Similar values may be obtained by calculation using the olivine-liquid partitioning relationship for Fe²⁺ and Mg established by Roeder & Emslie (1970). Five values obtained this way by Melson & Thompson (1973) are also shown in fig. 1, along with a single value of 0.17 derived from the data for a hyaloclastite from East Green-

land published by Fawcett et al. (1973). These clearly fall very close to the directly measured values although there is a slight tendancy for them to be higher.

In the light of this compilation, I propose that an approximate median value for the data in fig. 1 be adopted as a standard value in recalculation procedures. This value of 0.15 must lie very close to the true value, not only of the ocean-ridge tholeiites, but probably also for the majority of tholeiitic rocks. Thus many analyses of fresh subaerial basalts can be found around this level. For example, samples from the prehistoric Makaopuhi lava lake in Hawaii have Fe₂O₃/FeO down to 0.13 (Moore & Evans 1967).

Carmichael et al. (1974: 282–285) have discussed the dependance of the Fe₂O₃/FeO

ratio in silicate melts on various factors. They show that it is dependent, among other things, on the alkali content of the melt, suggesting that in alkali basalts the suggested standard value of 0.15 may be too low. However, this effect is very small, and even in widely varying compositions there is not likely to be any great departure from this value.

The actual value chosen is of less importance than that a unique procedure be adopted by all. It seems that a value which is well-founded in reality has a better chance of receiving this universal adoption than one which is completely arbitrary. I believe that the value $Fe_2O_3/FeO = 0.15$ has the former characteristic. As it is common practice in petrochemical calculations to express relationships in percentage terms, I note that $Fe_2O_3/FeO = 0.15$ is equivalent to $Fe_2O_3/(Fe_2O_3 + FeO) = 13\%$.

The star in fig. 1 represents the Fe_2O_3/FeO ratio of the preferred sample of the Skaergaard intrusion chilled margin. Skaergaard is often regarded as an unusually reduced magma and the differentiation trend ascribed to this character. However, according to the data discussed here, its oxidation state appears to be quite normal for such tholeiitic magmas and it may be that other magmas have become oxidized during their passage through the crust and follow different differentiation trends as discussed by Osborn (1957).

Dansk sammendrag

Petrokemiske parametre, beregnet udfra kemiske analyser af basalter, som normalt er sekundært oxiderede, afviger fra dem, det primære ikke oxiderede materiale ville have givet. I litteraturen gives mange metoder til korrektion af oxidationsforholdene i basaltiske bjergarter. Her argumenteres for en alment gældende standard værdi Fe_2O_3/FeO på 0.15. Denne er baseret på konstaterede værdier i friske basaltiske glasser, hovedsagelig lav-K_2O tholeiiter fra oceanbundene men også andre basaltiske typer. Tilsvarende værdier er opnået ved beregninger baseret på Fe^{2+}/MgO-fordelingen mellem olivin strøkorn og glasagtige grundmasse, kun analyseret for total jern.

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Scanning electron microscopy of some recent and fossil nodosariid foraminifera

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23 recent and fossil species representing 15 genera within the Nodosariacea have been studied with respect to lamellarity. All forms were found to be monolamellar. However, four different categories of the monolamellar construction pattern were found. Of these the ortho-monolamellar type has a one-layered chamber with an enveloping secondary lamella covering the earlier exposed shell. If the secondary lamella covers only part of the earlier exposed shell it is termed plesio-monolamellar while a lack of secondary lamination is called atelo-monolamellar. Multiple lamination in the septa covering also the earlier exposed shell parts is called poly-monolamellar. The microgranular layer in Jurassic forms is of diagenetic origin.

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The superfamily Nodosariacea *sensu* Loeblich & Tappan (1964) is an important stratigraphical foraminiferal group particularly in the Mesozoic Era and has accordingly attracted the interest of stratigraphers. The wall structure of this group has mainly been studied in specimens from older geological horizons, while the recent representatives have received considerably less attention.

The obvious disadvantage in studying geologically older tests relates to the fact that diagenetic processes play a varying rôle veiling the primary structures. Earlier works (Gerke 1957; Sellier de Civrieux & Dessauvagie 1965; Norling 1968; Reiss 1963) all used light microscopy in their studies. The present work utilizes the higher spatial resolution power of the scanning electron microscope, and the main emphasis has been placed on the study of recent representatives in order to avoid the inherent diagenetic problems of fossil specimens.

A part of the present work constitutes a partial fulfilment of the requirements for the cand. scient. degree of the senior author.

Methods and materials

Specimens to be sectioned were embedded in Lakeside 70 cement on glass slides and oriented by aid of a heated needle. In some cases not all chambers were filled in after the initial embedding. Such specimens were ground to a level where the chambers in question were opened. The cement was reheated and the shell turned over so that the sectioned plane was brought in contact with the surface of the glass slide. After this procedure the test was sectioned to the desired level on wet grinding paper no. 600.

Subsequently the section was polished on a velvet rotating disc using 1 μm Al_2O_3 paste as polishing medium.

After this treatment the section was rinsed thoroughly by washing with grease-free sulfonated soap followed by etching in an aqueous unbuffered saturated solution of EDTA for varying periods of time. The etching process was made in gradual steps interrupted by inspection of the dried section under the binocular microscope. The etching was considered sufficient when, under the light microscope in reflected light, the relief at boundaries between lamellae was seen.

The glass slides were fractured by a diamond pencil and a vice, and the sections were