10 Nagy, B. *Carbonaceous Meteorites* (Elsevier, Amsterdam, 1975).
11 Woeller, F. & Ponnamperuma, C. *Icarus* **10**, 386 (1969).
12 Khare B. N. & Sagan C. *Icarus* **20**, 311 (1973).
13 Scattergood, T., Lesser, P. & Owen, T. *Icarus* **24**, 465 (1975).
14 Herbig, G. H. *Mem. Soc. Roy. Sci. Liège* Ser. 5, **19**, 13 (1970).
15 Knacke, R. F. *Nature* **217**, 44 (1968).
16 Zaikowski, A. & Knacke, R. F. *Astrophys. & Space Sci.* **37**, 3 (1975).
17 Gillett, F. C., Kleinmann, D. E., Wright, E. L. & Capps, R. W. *Astrophys. J. Lett.* **198**, L65 (1975).
18 Meinschein, W. G., Nagy, B. & Henessy, D. J. *Ann. N.Y. Acad. Sci.* **108**, 553 (1963).

Lateral variation of phenocryst assemblages in volcanic rocks of the Japanese islands

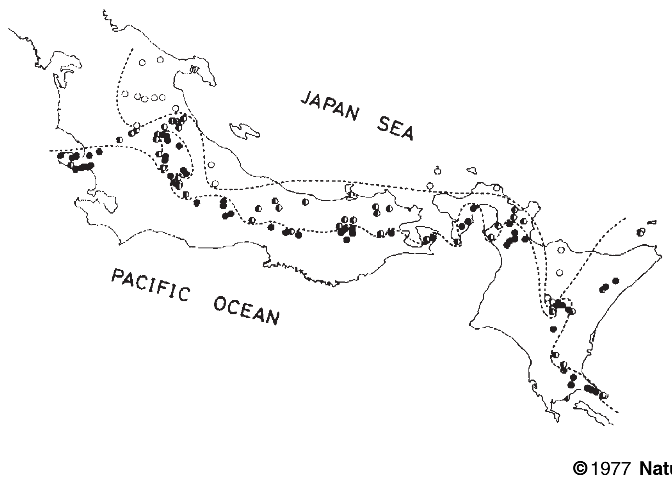
To understand the origin of calc-alkaline rocks and island arc volcanism, knowledge of the lateral variation of the petrological characters of volcanic rocks is essential. The lateral variation of chemical compositions of volcanic rocks has been investigated by several authors[1–4] and correlated to the depth of the Benioff zone. The east volcanic zone of Japanese Islands, which contains about 140 discrete Quaternary volcanoes, is the most extensively studied volcanic zone in the world. I have examined the petrological data of these volcanoes, particularly with respect to the phenocryst assemblages in volcanic rocks and their changes during the history of respective volcanoes. The references have been mostly taken from 200 papers compiled by Isshiki *et al.*[5].

The volcanoes are classified into three groups on the basis of the presence or absence of hornblende and biotite phenocrysts in essential materials: (1) those without biotite and hornblende phenocrysts in any of the lavas or pyroclastics; 2) those with hornblende phenocrysts but without biotite phenocryst at least in one lava flow or pyroclastic rock; and (3) those with biotite phenocrysts at least in one lava or pyroclastic rock. The distribution of the volcanoes of these three groups is shown in Fig. 1.

Volcanic rocks containing biotite phenocrysts were erupted only in the western part of the volcanic zone, whereas those which do not contain any hydrous mineral phenocrysts were erupted in the eastern part of the volcanic zone. Volcanoes in a belt situated between the above two belts erupted rocks containing only hornblende as hydrous mineral phenocryst.

Phenocrysts such as pyroxene, hornblende, and biotite are considered to be precipitated in a magma reservoir or during the ascent of magma. The lateral variation outlined above may be due to the lateral change in physicochemical conditions of magma reservoirs across the volcanic zone. It may also be due to a lateral variation in the chemical composition of the original magmas, for example, their alkali contents—especially the K_2O contents[3] and possibly to the variation of H_2O contents in the original magma which may increase westwards across the volcanic zone.

Fig. 1 Distribution of Quaternary volcanoes in Hokkaido and northern Honshu. ●, Volcanoes without biotite and hornblende phenocrysts in any of the lavas or pyroclastics; ◐ those with hornblende phenocrysts but without biotite phenocryst at least in one lava flow or pyroclastics; open circles represent those with biotite phenocrysts at least in one lava or pyroclastics.



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1 Kuno, H. *Bull. Volcanol.* **29**, 195 (1966).
2 Kuno, H. *Bull. Volcanol.* **32**, 141 (1968).
3 Hatherton, T. & Dickinson, W. R. *J. geophys. Res.* **74**, 5301 (1969).
4 Sugimura, A. *Bull. Volcanol. Soc. Jap. 2nd Ser.* **4**, 77 (1959).
5 Isshiki, N., Matsui, K. & Ono, K. *Geol. Surv. Jap.* (1968).

Rare earth element mobility and geochemical characterisation of spilitic rocks

HELLMAN & Henderson[1] have demonstrated the enrichment of the rare earth elements (REE) in the lower spilitic portion of the Bhoiwada lave profile relative to the fresh tholeiitic flow top. The remarkable feature of the REE distribution in the spilites was the absolute enrichment of all the elements and not only the light REE, as occasionally seen in oceanic basalts due to submarine weathering[2]. Thus the enhanced spilite REE destribution resembles either alkali basalt or tholeiitic differentiation products rather than tholeiitic basalt. As stated[1], the high degree of REE mobility suggests that these elements must be used with caution in determining the initial magma type or volcanic environment of ancient spilitic rocks.

At face value the REE distribution in the spilites is very similar to that exhibited by the more alkaline units of the Deccan basalts[3,4]. This feature suggests the possibility that the Bhoiwada profile may not be a single flow unit at all and the fresh tholeiitic 'top' may be a different unit to the more 'alkaline' spilite base. Although the section is described as gradational[5,6], there are primary textural differences (pillowed/massive; ophitic nature; vesicularity and so on) between tholeiite and spilite, and the contact seems sharp (see photomicrographs and photograph in refs 5 and 6). If the subaqueous (flow 'base') sub-aerial (flow 'top') origin postulated for the flow[5] is correct, then it lacks some of the features described for such lava flows[7,8] and does not adequately explain why spilitisation should have stopped abrupted at the water–air interface. Also the considerable REE distribution gap (Fig. 2*a* of ref. 1) between tholeiite and spilite might lend support to the differences in the two zones, especially as there is no apparent gradational increase in normalised REE patterns with progressive spilitisation. This is particularly noticeable in the sudden jump of the La/Yb ratio[1] from tholeiite to spilite and also the chemical similarity between the spilite and the (separate) basal pillow lava unit.

Irrespective of whether the profile represents a single unit or not, however, independent criteria are required to characterise the spilite and compare it with the fresh tholeiite. A variety of geochemical (and mineralogical) parameters, which will give the same characterisation, are necessary to determine the nature of ancient altered volcanics. Vallance[6,9] has advocated the use of relict pyroxenes to determine the magma type of spilitic rocks. In the case considered here, the pyroxenes in both tholeiite and spilite are low-Ca augites of tholeiitic character and are similar in composition[6]. Apart from the REE, other relatively 'immobile elements', such as Ti, P, Zr, Y and Nb, have been used to determine magma type[10,11] and again demonstrates the tholeiitic nature of