

## Reconsideration of 'soda-minettes'

SHARON W. BACHINSKI\*

Department of Geology, University of New Brunswick, Fredericton, New Brunswick, E3B 5A3, Canada

**ABSTRACT.** It is shown here that dyke rocks of type localities for 'soda-minettes' are not minettes (= lamprophyres dominated by phlogopite and K-rich feldspar). It has long been suggested that 'soda-minette' also be applied to otherwise normal minettes from elsewhere that carry modally variable amounts of groundmass aegirine and/or, more commonly, arfvedsonitic to riebeckitic amphibole. Despite the presence of sodic pyriboles, these rocks are poorer in  $\text{Na}_2\text{O}$  than minettes lacking these phases. 'Soda-minette' is thus misleading and self-contradictory to the many petrologists to whom 'soda-' legitimately connotes that the rock in question either has  $\text{K}/\text{Na} < 1$  and/or is rich in albitic feldspar. To eliminate this ambiguity it is recommended, with the approval of twenty-six other petrologists, that 'soda-minette' no longer be used as a rock name. As minettes with Na-pyribole(s) are markedly K-rich and most are both ultrapotassic and peralkaline, independent of the modal abundance of the Na-pyribole, it is suggested that one of these three chemical characteristics be utilized adjectivally in naming these minettes.

**KEYWORDS:** minette, soda-minette, lamprophyre.

*Discreditation of samples from type localities.* Since the latter half of the 19th century the prefix 'soda-' attached to the name of an igneous rock has had at least three different meanings, one chemical and two mineralogical or petrographic: that the rock (1) is richer in soda ( $\text{Na}_2\text{O}$ ) than 'normal' and usually has soda in excess of potash ( $\text{K}_2\text{O}$ ), or (2) is rich in albitic feldspar such that the rock carries this as the dominant or the sole feldspar, or (3) contains a sodic pyroxene and/or a sodic amphibole (see, e.g. Holmes, 1920, p. 212; Tomkeieff, 1983, pp. 531-2).

'Soda-minette' (= natron minette) was first employed as a rock name by Brögger in 1898 for certain dark-coloured dyke rocks of southern Norway that are associated with nepheline syenites with rhombic sodic feldspar. The dykes apparently lacked phenocrysts and were said to be composed largely of Na-rich alkali feldspar (anorthoclase; ~ 50 vol. %), biotitic mica (~ 25-35%), and aegirine-augite (~ 10-20%). Selected chemical characteristics of these dykes from two of the type localities in the Lågendalen (= Lougental) area

are presented in Table I (nos. 1 and 2) where they can be compared with Rock's (1984) average minette (no. 25). Depending on whether one accepts as a sodic pyroxene an aegirine-augite that contains only about 20% of the acmite 'molecule' (Hasan, 1969), Brögger's rocks warrant the prefix 'soda-' in the first two and possibly all three of the above senses. But they are not minettes and may not even be lamprophyres.

Re-examination of the dykes in one of Brögger's 'soda-minette' localities (Håöya) led Hasan (1969) to the recognition and detailed description of sporadically distributed, rhomb-shaped, twinned, normally to patchily zoned plagioclase ( $\text{An}_{17-30}$ ) phenocrysts with poikilitic inclusions. Biotite is more abundant than pyroxene, but neither phase occurs as phenocrysts. The dominant groundmass feldspar is not the alkali feldspar required by the definition of minette (e.g. Delesse, 1856; Streckeisen, 1979) but normally zoned plagioclase ( $\text{An}_{15-26}$ ). Hasan therefore errs in saying (p. 159) that the rocks are lamprophyres of minette type. His analysis of one of these dykes (no. 3 of Table I) is similar to Brögger's (no. 2). Brögger's and Hasan's dykes may well be, as Hasan has suggested indirectly, variants of the rhomb-porphyrries so common in the Oslo graben. If, however, these dyke rocks are to be considered lamprophyres despite the presence of a phenocrystic (xenocrystic? porphyroblastic?) felsic phase and the absence of ferromagnesian phenocrysts, both of which violate many workers' definition of lamprophyre (see discussions of lamprophyre terminology in Johannsen, 1935; Joplin, 1966; Velde, 1971; Wimmenauer, 1973; Streckeisen, 1979; and Rock, 1984), then the dominance of biotite and plagioclase justifies calling them 'kersantites'. Prof. Danielle Velde has kindly investigated a fragment of 'natron minette' from another of the type localities of southern Norway (Gjonelien, Lågendalen); she concludes (pers. comm., 1985) that '... it is indeed a lamprophyre, contains no alkaline phases [i.e. alkali amphibole or aegirine] whatsoever ... [and is] probably an altered kersantite rather than a minette' on the basis of its albitized groundmass plagioclase.

\* The editors regret to report the death of Sharon Bachinski on 14 March 1986.

Table I. Critical whole-rock characteristics of Brögger's "soda-minettes" and other selected minettes

No.	Locality	modal sodic pyribole*	wt.% Na <sub>2</sub> O	wt.% K <sub>2</sub> O	atomic K/Na	atomic K+Na / Al	atomic Mg / Mg+Fe <sup>2+</sup>
1.	Bratthagen, Lågendalen, Norway	aeg-aug.	5.72	4.37	0.50	0.81	0.43
2.	Håcya, Lågendalen, Norway	aeg-aug	5.43	4.45	0.54	0.92	0.40
3.	Håcya, Lågendalen, Norway	aeg-aug	6.66	3.15	0.31	0.92	0.40
4.	The Karakorum, Pakistan	amph(+aeg?)	1.08	9.31	5.66	1.08	0.59
5.	The Karakorum, Pakistan	amph(+aeg?)	1.10	8.01	4.78	1.05	0.72
6.	Štřechovice, Czechoslovakia	amph	1.01	8.22	5.35	0.98	0.74
7.	Hartkov, Czechoslovakia	aeg+amph	1.02	7.10	4.57	0.95	0.74
8.	Velká Zdobnice, Czechoslovakia	amph	1.36	8.64	4.17	1.04	0.76
9.	Kunwald, Czechoslovakia	amph	1.13	8.38	4.87	1.00	0.73
10.	Bělá, Czechoslovakia	amph	1.17	8.63	4.84	1.09	0.73
11.	Kožichovice, Czechoslovakia	amph	1.30	8.01	4.04	1.01	0.71
12.	Sisco, Corsica, France	amph	1.03	10.00	6.37	1.04	0.73
13.	Sesia-Lanzo complex, Italy	amph	0.67	8.41	8.25	1.03	0.76
14.	Plan d'Albard, Italy	amph	1.44	9.03	4.18	1.14	0.78
15.	Saint Hélier, Jersey, U.K.	aeg+amph	2.10	7.70	2.41	1.09	0.71
16.	Trou du Diable, Jersey, U.K.	—	1.86	7.61	2.68	1.04	0.70
17.	Ronez, Jersey, U.K.	aeg	1.28	7.42	3.81	(—)**	0.64
18.	Pendennis, England, U.K.	amph	0.47	9.22	12.86	1.11	0.64
19.	Squaw Creek, S.D., U.S.A.	aeg	2.17	7.95	2.40	1.16	0.63
20.	Ship Rock, N.M., U.S.A.	aeg	2.42	5.27	1.43	0.96	0.71
21.	Washington Pass, N.M., U.S.A.	aeg+amph	2.55	5.65	2.02	0.88	0.71
22.	Walsenburg, Co., U.S.A.	aeg	3.03	4.58	0.99	0.85	0.60
23.	(average of #4-22)	(yes)	1.48	7.85	4.51	1.03	0.70
24.	(average of #4-19)	(yes)	1.26	8.35	5.08	1.05	0.71
25.	(average of 140 minettes)	(~no)	1.91	6.08	2.09	0.77	0.65

\*Subordinate to phlogopitic mica; aeg-aug=aegirine-augite, aeg=aegirine, amph=Na-rich amphibole.

\*\*As the wt.% Al<sub>2</sub>O<sub>3</sub> is exceptionally high and therefore of suspect accuracy, the peralkalinity index has not been calculated.

1 & 2: Brögger (1898). 3: Hasan (1969); analysis excludes the plagioclase phenocrysts. 4 & 5: Comucci (1937) and Viterbo and Zanettin (1959). 6: Němec (1973, 1974); central Bohemia. 7-10: Němec (1975a,b); eastern Sudeten. 11: Němec (1978); western Moravia. 12: Velde (1967); some workers (e.g., Rock, 1984, Bergman, 1985, perhaps Mitchell, 1985) consider this rock to be a lamproite as it contains priderite [Velde, 1968] and the alkali amphibole is relatively rich in potassium [0.88 K and 1.34 Na atoms per 24 O]; Velde (1971) and Wagner and Velde (1985) nonetheless call it a minette. 13: De Marco (1958). 14: average of two analyses from Venturelli et al. (1984, rock 247) and Wagner and Velde (1985). 15: Wagner and Velde (1985). 16: Velde (1970). 17: Velde (1971). 18: Hall (1982). 19: Kirchner (1979). 20: Nicholls (1969); Navajo area. 21: Williams (1936); Navajo area; petrographic and chemical data similar to that of Ehrenberg (1978). 22: Jahn et al. (1979) and Bachinski (unpubl. data); chemical data similar to that of Johnson (1964, 1968). 25: Rock (1984); worldwide average of minettes irrespective of type; only 10% of the analyses have normative ac.

*Minettes with Na-pyriboles.* As far as can be ascertained, no one has used 'soda-minette' as mineralogically defined by Brögger to name any lamprophyres other than those of southern Norway, though the term's definition in Tomkeiff's recent dictionary (1983, p. 532; see also p. 368) follows that of Brögger. Hasan (1969, p. 159) comments that 'the prefix "soda" . . . seems appropriate because of the exceptionally high soda content of the rock' and thus uses the prefix in the first of the above-mentioned senses. Johnson (1964, 1968) idiosyncratically attached 'soda-minette' to

feebly sodic (K/Na = 0.78-1.01) mica lamprophyres in Colorado in which plagioclase (An<sub>35</sub>) predominates over alkali feldspar and for which, therefore, the name 'kersantite' would have been more appropriate. With these exceptions, prefix of 'minette' by 'soda-' has exclusively been intended to connote the third meaning, viz. that the groundmass of the rock in question carries sodic pyroxene and/or sodic amphibole (e.g. Tyrrell, 1926, p. 122; Barth, 1952, p. 66; Williams et al., 1954, pp. 87-8) that is/are none the less usually greatly subordinate to the trioctahedral mica ± diopside

clinopyroxene (usually in two generations) as well as the alkali feldspar (groundmass only, generally  $\geq \text{Or}_{50}$ ) necessary for appropriate usage of the term 'minette'. This is the sense in which 'soda-minette' was recently re-introduced into lamprophyre nomenclature by Rock (1984, p. 196)\* after the IUGS Subcommission had published its nomenclatural recommendations (Streckeisen, 1979) with no mention of 'soda-minette'.

Reports of otherwise normal minettes that bear aegirine (= acmite) and/or, more commonly, arfvedsonitic to riebeckitic amphiboles (rarely richterite) in variable amounts as groundmass phases include, among others, those of Weed and Pirsson (1895); Smith (1933, 1936a, b); Johannsen (1935); Williams (1936); Comucci (1937); De Marco (1958); Viterbo and Zanettin (1959); Velde (1967, 1970, 1971); Nicholls (1969); Renouf and Bishop (1971); Némec (1973, 1974, 1975a, b, 1978); Kirchner (1979); Hall (1982); Rock (1984); Venturelli *et al.* (1984); Schulze *et al.* (1985); Wagner and Velde (1985). For chemical analyses of the aegirines, see Nicholls, 1969, Wagner and Velde, 1985; for the amphiboles, see Velde, 1967, 1971, Hall, 1982, Wagner and Velde, 1985). Although only a few of these works (Viterbo and Zanettin, 1959; Kirchner, 1979; Rock, 1984; Schulze *et al.*, 1985) explicitly use the term 'soda-minette', the rocks described by all the above authors legitimately qualify as such by Rock's definition. Pertinent chemical parameters of nineteen thus defined 'soda-minettes'† from Asia, Europe, and the USA are presented as analyses 4–22 of Table I; the arithmetic mean values for the nineteen are given as analysis 23. Note that most of the minettes of this group have atomic  $\text{Mg}/(\text{Mg} + \text{Fe}_2^+)$  ratios appropriate for undifferentiated mantle-derived magmas (as do many of the minettes that lack a sodic feric phase), so they are unlikely to be highly evolved alkali-rich differentiates of magmas corresponding to minettes without Na-pyribole. Analyses 4–23 should be compared with no. 25, Rock's (1984) mean of 140 petrographically and chemically screened minettes from a great range of localities. Given that it is logical to expect the chemistry of a rock to reflect its mineralogy, it is illuminating that, despite their bearing sodic amphibole and/or sodic pyroxene,

these 'soda-minettes' in fact contain on average *less*  $\text{Na}_2\text{O}$  and more  $\text{K}_2\text{O}$  than other minettes! The chemical nature of these rocks is disconcertingly contradicted by the prefixed name that they warrant solely on the basis of the presence of a petrographically minor phase. Viterbo and Zanettin (1959), while recognizing that rigorously speaking their samples should be called 'soda-minettes', explicitly eschewed the use of the term because it would hinder the recognition of the markedly potassic chemical character of their rocks (see nos. 4 and 5 of Table I).

As an instructive analogy, consider lamproites (= 'ultrapotassic lavas' of some workers) such as those of the Leucite Hills, USA, southeast Spain, and Western Australia. Lamproites usually contain an alkali amphibole (richterite, rarely arfvedsonite) for which atomic Na exceeds K and, very rarely, acmitic pyroxene (e.g. Mitchell, 1985). These rocks are among the most potassic of basic igneous rocks as defined by whole-rock atomic K/Na (or molecular  $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ); this ratio ranges up to 45 (see, e.g. Jaques *et al.*, 1984; Bergman, 1985), although it averages 6.5 and can be lower than 1.5. No one has proposed—and surely no one would propose, except in jest—labelling as 'soda-lamproites' such potassic to ultrapotassic rocks, which are dominated by K-rich minerals, merely because their groundmass includes a sodic amphibole. Minettes with groundmass sodic amphibole likewise are potassic to ultrapotassic basic rocks (see Table I) composed almost entirely of K-rich phases. If 'soda-lamproite' be unacceptable, then 'soda-minette' should be equally so; both terms are chemically oxymoronic.

For most igneous rocks, modal sodic amphibole and/or aegirine signals the presence of acmite in the rock's CIPW norm, both of these occurrences being manifestations of the rock's peralkalinity (as defined by Shand, 1927, and widely understood to mean that atomic  $(\text{K} + \text{Na})/\text{Al}$  or molecular  $(\text{K}_2\text{O} + \text{Na}_2\text{O})/\text{Al}_2\text{O}_3$  exceeds unity). For minettes, however, this relationship between modal mineralogy and chemical/normative character does not always hold true. Table I lists several minettes for which the bulk-rock peralkalinity index is  $\leq 1.00$  but which none the less bear Na-pyribole in amounts ranging from the trace (e.g. in thin sections of nos. 20, 21, and 22 that I have examined) to the significant (e.g. in no. 6, subequal to the phlogopite; Némec, 1973) but variable (e.g. in no. 7 Némec, 1975a, reports 9.2 vol. % alkali amphibole whereas Schulze *et al.*, 1985, report 3% alkali amphibole plus aegirine). As has been pointed out by Velde (1971, pp. 222–3), the presence of these minerals as *groundmass* phases in minettes expresses the peralkaline nature of their *residual* liquids,

\* Rock (pers. comm., 1985) confirms that Table 1 on p. 193 of his 1984 review is unintentionally erroneous: the Na-pyribole of his soda-minettes is not the modally dominant ferromagnesian mineral, it is subordinate to phlogopite/biotite.

† One of these (no. 17 of Table I) does not appear to contain a sodic phase but is none the less included here because it has 1.84 wt. % normative acmite (Velde, 1971) and closely resembles the other minettes of this set in other ways. See the following further discussion.

independent of the bulk-rocks' degree of alumina saturation. Clearly liquids that are metaluminous or subaluminous can differentiate toward and occasionally surpass the peralkaline threshold. If one compares the chemical composition of ground-mass glasses, late leucocratic segregation veins, mesostases, and other such representatives of residual liquids to that of their host minettes, it is seen that the atomic  $(K + Na)/Al$  ratios (peralkalinity indices) of the residua are higher than the equivalent ratios for the bulk-rocks host to the residua (Bachinski, unpubl. data). Analogous increases in peralkalinity indices are evident from comparison of bulk-rock to residual glass/liquid values of pantellerites (e.g. see data in Carmichael, 1962) and some lamproites and camptonites/monchiquites (Bachinski, unpubl. data).

*Suggestions for a revised terminology.* It is recommended that 'soda-minette' no longer be used as a rock name (see the following section for the names of other petrologists who support this recommendation). What might be regarded as the historical precedence for this term is overshadowed by its general ambiguity and, to the minds of many workers, self-contradiction. If this recommendation be accepted, however, one is still faced with the problem of what to call such rocks as nos. 4–22 of Table I and, indeed, whether the same name should be applied to all.

They could, of course, simply be called 'minettes', with no adjectival or prefixal adornment. More useful because more precisely descriptive would be such terms as 'arfvedsonite-bearing minette', 'sodic-amphibole-bearing minette', and 'aegirine-bearing minette' when the Na-pyribole is present in greater than trace amounts. It is to be emphasized, however, that even an abundance of Na-pyribole seems to have little reflection in bulk-rock chemistry, which must be considered when attempting to divide the minette-chemistry continuum in a manner that might be petrogenetically meaningful. For example, the Plan d'Albard and the Pendennis minettes differ greatly in their content of sodic amphibole (28.7 vs. 1 vol. % respectively), yet they have nearly identical and strikingly high  $K_2O$  contents (~ 9 wt. %) and peralkalinity indices (~ 1.1). On the other hand, the Washington Pass and Pendennis minettes both carry minimal sodic pyribole (~ ≤ 1 vol. %) but have grossly different  $K_2O$  contents (5.65 vs. 9.22 wt. %) and peralkalinity indices (0.88 vs. 1.11). The Trou du Diable minette apparently has no Na-pyribole at all but is chemically much like the Saint Hélier minette that has 9.2 vol. % arfvedsonite + aegirine. Particular attention must therefore be paid to the chemical parameters that differentiate minettes from each other.

Minettes nos. 20, 21, and 22 are relatively poor in  $K_2O$  and rich in  $Na_2O$  in comparison not only to the other Na-pyribole-bearing minettes but also to minettes that lack such a phase (see nos. 16 and 25). If these three be removed from consideration, the remaining sixteen form a distinctive group whose mean chemical parameters are given as no. 24 in Table I. These minettes, which are chemically transitional to lamproites, are either peralkaline or nearly so ( $[(K + Na)/Al] \geq 0.95$ ,  $\bar{x} = 1.05$ ) and have exceptionally high  $K_2O$  ( $\geq 7.10$ ,  $\bar{x} = 8.35$  wt. %) and low  $Na_2O$  ( $\leq 2.17$ ,  $\bar{x} = 1.26$  wt. %), the latter two features combining to give the rocks a predominantly ultrapotassic character ( $K/Na \geq 2.40$ ,  $\bar{x} = 5.08$ ). It is therefore suggested that in addition to any petrographic modifier (e.g. 'arfvedsonite-bearing') that may be deemed appropriate, the whole-rock K-enrichment or, where applicable, peralkalinity be mentioned in naming such minettes. (If no chemical analysis of the rock is available, only a petrographic modifier should be used). The former could be expressed either by 'K-rich' or, if atomic  $K/Na$  or molecular  $K_2O/Na_2O$  exceeds 3, by 'ultrapotassic'. Thus the Plan d'Albard minette, for example, would be either a 'peralkaline arfvedsonite-bearing minette' (as it has been called by Wagner and Velde, 1985) or an 'ultrapotassic arfvedsonite-bearing minette' (cf. Venturelli *et al.*, 1984); the petrographic modifier could be dropped if brevity or euphony is important. For the sake of clarity I would suggest (as have many of my correspondents) that such adjectives as 'alkali', 'alkalic', 'alkaline', and 'alkali-rich' be avoided when dealing with minettes, partly because of the inevitable confusion with 'alkaline lamprophyres' (a class of lamprophyres that does not include minettes), partly because of the ambiguity resulting from the conflicting connotations of these terms in different writers' and readers' minds (see, e.g. discussion of Sørensen, 1974, pp. 3–7), and partly because the high total-alkalis values of these rocks are due almost solely to the elevated  $K_2O$ .

*Support for the recommendation and acknowledgements.* In early 1985 a rough draft of this manuscript was set by me to a small sample of igneous petrologists in Europe, North America, and Australia who have worked with minettes, other lamprophyres, lamproites, and related rocks, with the request that each person indicate willingness of lack thereof to have his/her name published as being either in favour of or against the recommendation that 'soda-minette' cease to be used as a rock name. The results of this poll were startling. Of the twenty-seven people who responded, one person chose not to get involved with nomenclature at this time, but the remaining twenty-six

unanimously support the recommendation. I thank all the respondents and especially the many who volunteered constructive suggestions for changes or additions that have largely been incorporated into this final version. The names of twenty-four of the twenty-six respondents follow in alphabetical order (two have asked to be anonymous), but let it be noted that the appearance of a name as being in support of the discontinuance of the use of 'soda-minette' does not necessarily imply agreement with any of the other opinions and suggestions expressed in this article: J. F. Allan (USA), S. C. Bergman (USA), A. Cundari (Australia), J. B. Dawson (UK), A. D. Edgar (Canada), S. N. Ehrenberg (USA), A. Hall (UK), A. L. Jaques (Australia), A. P. Jones (UK), J. G. McHone (USA), H. O. A. Meyer (USA), R. H. Mitchell (Canada), D. Němec (Czechoslovakia), J. W. Nicholls (Canada), N. M. S. Rock (UK), M. F. Roden (USA), D. J. Schulze (Canada), B. H. Scott Smith (Canada), J. W. Sheraton (Australia), E. L. Simpson (Canada), R. N. Thompson (UK), D. Velde (France), G. Venturelli (Italy), W. Wimmenauer (West Germany).

This work has been supported by grants from the Natural Science and Engineering Research Council of Canada.

## REFERENCES

- Barth, T. F. W. (1952) *Theoretical Petrology*. Wiley, New York.
- Bergman, S. C. (1985) Lamproites and other potassium-rich igneous rocks: a review of their occurrence, mineralogy and geochemistry. *Proc. Conf. Alkaline Igneous Rocks, Edinburgh*. Geol. Soc. London (in press).
- Brögger, W. C. (1898) Die Eruptivgesteine des Kristianagebietes III. Das Gangfolge des Laurdalits. *Videnskabselsk. Skr., I. Mat.-Natur. Kl.* 1897, no. 6.
- Carmichael, I. S. E. (1962) Pantelleritic liquids and their phenocrysts. *Mineral. Mag.* **33**, 86–113.
- Comucci, P. (1937). Di una singolare del ghiacciaio Baltoro (Karakorum). *Rend. R. Acc. Lincei*, **25** (6th series), 648–734.
- Delesse, M. (1856) Mémoire sur les roches des Vosges. Minette. *Ann des Mines*, **10** (5th series, Mémoires), 517–78.
- De Marco, L. (1958) Su alcuni filoni lamprofirici radioattivi del complesso Sesia-Lanzo. *Comit. Naz. Ric. Nucl., Std. Ric. Div. Geomineral., Italia*, **1**, 3–30.
- Ehrenberg, S. N. (1978) *Petrology of Potassic Volcanic Rocks and Ultramafic Xenoliths from the Navajo Volcanic Field, New Mexico and Arizona*. Ph.D. thesis, Univ. of California at Los Angeles.
- Hall, A. (1982) The Pendennis peralkaline minette. *Mineral. Mag.* **45**, 257–66.
- Hasan, Z.-U. (1969) Petrology of the soda-minette dikes from Håøya, Langesundsfjord, S. Norway. *Norsk Geol. Tidsskr.* **49**, 159–70.
- Holmes, A. (1920) *The Nomenclature of Petrology*. Allen & Unwin, London.
- Jahn, B., Sun, S. S., and Nesbitt, R. W. (1979) REE distribution and petrogenesis of the Spanish Peaks igneous complex, Colorado. *Contrib. Mineral. Petrol.* **70**, 281–98.
- Jaques, A. L., Lewis, J. D., Smith, C. B., Gregory, G. P., Ferguson, J., Chappell, B. W., and McCulloch, M. T. (1984) The diamond-bearing ultrapotassic (lamproitic) rocks of the West Kimberley region, Western Australia. In *Kimberlites. I: Kimberlites and Related Rocks* (J. Kornprobst, ed.), pp. 225–54. Elsevier, Amsterdam.
- Johannsen, A. (1935) *A Descriptive Petrography of Igneous Rocks*, Vol. III. Univ. of Chicago Press, Chicago.
- Johnson, R. B. (1964) Walsen composite dike near Walsenberg, Colorado. *U.S. Geol. Surv. Prof. Paper*, **501-B**, B69–B73.
- (1968) Geology of the igneous rocks of the Spanish Peaks region, Colorado. *U.S. Geol. Surv. Prof. Paper* **594-G**, 1–47.
- Joplin, G. A. (1966) On lamprophyres. *J. Proc., R. Soc. New South Wales*, **99**, 37–44.
- Kirchner, J. G. (1979) Petrographic significance of a carbonate-rich lamprophyre from Squaw Creek, northern Black Hills, South Dakota. *Am. Mineral.* **64**, 986–92.
- Mitchell, R. H. (1985) A review of the mineralogy of lamproites. *Trans. Geol. Soc. S. Africa, Spec. Vol. 'Alkaline and Alkaline-Ultrabasic Rocks and their Xenoliths'* (in press).
- Němec, D. (1973) Differentiation series of minettes in the Central Bohemian Pluton. *J. Geol.* **81**, 632–42.
- (1974) Petrochemistry of the dykes rocks of the Central Bohemian Pluton. *Neues Jahrb. Mineral. Mh.* 193–209.
- (1975a) Petrographie der lamprophyrischen und lamproiden Ganggesteine im Nordostteil der Böhmisches Masse (ČSSR). *Z. geol. Wiss. Berlin*, **3**, 23–36.
- (1975b) Petrochemie und Genese der lamprophyrischen und lamproiden Ganggesteine im Nordostteil der Böhmisches Masse (ČSSR). *Z. geol. Wiss. Berlin*, **3**, 37–52.
- (1978) Ganggesteine auf der Störung von Třebíč (als Beispiel einer an eine Tiefenstörung gebundenen Gangschar). *Z. geol. Wiss. Berlin*, **6**, 1211–17.
- Nicholls, J. W. (1969) *Studies of the Volcanic Petrology of the Navajo-Hopi Area, Arizona*. Ph.D. thesis, Univ. of California at Berkeley.
- Renouf, J. T., and Bishop, A. C. (1971) The geology of the Fort Regent road tunnel. *Bull. Soc. Jersiaise*, **20**, 275–83.
- Rock, N. M. S. (1984) Nature and origin of calc-alkaline lamprophyres: minettes, vogesites, kersantites and spessartites. *Trans. R. Soc. Edinburgh*, **74**, 193–227.
- Schulze, D. J., Smith, J. V., and Němec, D. (1985) Mica chemistry of lamprophyres from the Bohemian Massif, Czechoslovakia. *Neues Jahrb. Mineral. Abh.* (in press).
- Shand, S. J. (1927) *Eruptive Rocks*. Thomas Murby, London.
- Smith, H. G. (1933) Some lamprophyres of the Channel Islands. *Proc. Geol. Assoc. London*, **44**, 121–30.
- (1936a) New lamprophyres and monchiquites from Jersey. *Q.J. Geol. Soc. London*, **92**, 365–81.
- (1936b) The South Hill lamprophyre, Jersey. *Geol. Mag.* **73**, 87–91.

- Sørensen, H. (ed.) (1974) *The Alkaline Rocks*. Wiley, New York.
- Streckeisen, A. (1979) Classification and nomenclature of volcanic rocks, lamprophyres, carbonatites, and melilitic rocks: Recommendations and suggestions of the IUGS Subcommittee on the Systematics of Igneous Rocks. *Geology*, **7**, 331-5.
- Tomkeieff, S. I. (1983) *Dictionary of Petrology*. Wiley, New York.
- Tyrrill, G. W. (1926) *The Principles of Petrology*. Methuen, London.
- Velde, D. (1967) Sur un lamprophyre hyperalcalin potassique: la minette de Sisco (île de Corse). *Bull. Soc. franç. Minéral. Cristallogr.* **90**, 214-23.
- (1968) A new occurrence of priderite. *Mineral. Mag.* **36**, 867-70.
- (1970) Remarques sur la nomenclature des minettes. *C.R. Sommaires Soc. géol. France*, **6**, 222-3.
- (1971) Les lamprophyres à feldspath alcalin et biotite: minettes et roches voisines. *Contrib. Mineral. Petrol.* **30**, 216-39.
- Venturelli, G., Thorpe, R. S., Dal Piaz, G. V., Del Moro, A., and Potts, P. J. (1984) Petrogenesis of calc-alkaline, shoshonitic and associated ultrapotassic Oligocene volcanic rocks from the Northwestern Alps, Italy. *Ibid.* **86**, 209-20.
- Viterbo, C., and Zanettin, B. (1959) I filoni lamprofirici dell'Alto Baltoro (Karakorum). Caratteri chimico-petrografici. *Mem. Acad. Patavina SS.LL.AA.: Cl. Sci. Mat. Nat.* **71**, 3-39.
- Wagner, C., and Velde, D. (1985) Mineralogy of two peralkaline, arfvedsonite-bearing minettes. A new occurrence of Zn-rich chromite. *Bull. Minéral.* **108**, 173-87.
- Weed, W. H., and Pirsson, L. V. (1895) On the igneous rocks of the Sweet Grass Hills, Montana. *Am. J. Sci.* **50** (3rd series), 309-13.
- Williams, H. (1936) Pliocene volcanoes of the Navajo-Hopi country. *Bull. Geol. Soc. Am.* **47**, 111-72.
- Turner, F. J., and Gilbert, C. M. (1954) *Petrography*. W. H. Freeman, San Francisco.
- Wimmenauer, W. (1973) Lamprophyre, Semilamprophyre und anchibasaltische Ganggesteine. *Fortschr. Mineral.* **51**, 3-67.

[Manuscript received 22 July 1985;  
revised 12 September 1985]