The use of An and Sr data on plagioclase in a study of basic xenoliths in a gabbroic mass at Hamar, Somalia

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Summary. In this paper we give data for An and Sr in plagioclase to demonstrate the presence of numerous amphibolite xenoliths within parts of a basic igneous mass where, after initial reconnaissance mapping, none was suspected. The data also show that the concentration of Sr in plagioclase from the margin of some amphibolite xenoliths is appreciably higher than in plagioclase from either the cores of the xenoliths or the enclosing metagabbro even though the modes and An contents of the plagioclase are similar. An explanation is offered, which implies that some of the xenoliths were amphibolites rather than anhydrous equivalents prior to their enclosure in the basic magma.

THE structure and petrological environment of the Hamar mass has been described by Daniels *et al.* (1965). The intrusion occupies a roughly rounded area of about seven square miles and consists largely of olivine–gabbro and metagabbro derivatives together with some well-developed ultrabasic layers of peridotite and dunite. Olivine–gabbro predominates in the southern half of the mass whereas metagabbro occurs more especially in the north-west and east. The mass was intruded into country rocks that are now broadly divisible into acid types, including gneisses, and migmatites and quartz-free types, including amphibolites and pyroxene-hornfelses (fig. 1).

It was anticipated that An–Sr relationships in plagioclase from the Hamar basic rocks would be broadly similar to those found for plagioclase from the Dudub basic mass six miles to the north. In that mass it may be recalled that plagioclase from 12 gabbro and 17 non-marginal metagabbro specimens ranged in An composition from An_{67} to An_{56} and in Sr concentration from 1000 to 1450 ppm; and it was concluded that processes involving merely the amphibolitization of gabbro to produce metagabbro do not lead to any enrichment of Sr in the plagioclase.

Results for An and Sr in plagioclase from 32 specimens of gabbro, olivine–gabbro, hypersthene–gabbro, and olivine–hornblende–biotite–

gabbro in Hamar (table 1, upper portion, and fig. 2) confirm the narrow scatter of value to be expected for plagioclase samples from a little-differentiated igneous mass. However, values of An range from An_{62} to An_{48} and of Sr from 1450 to 1900 ppm and whenever An values for plagioclase from Hamar and Dudub are similar, Sr values are different

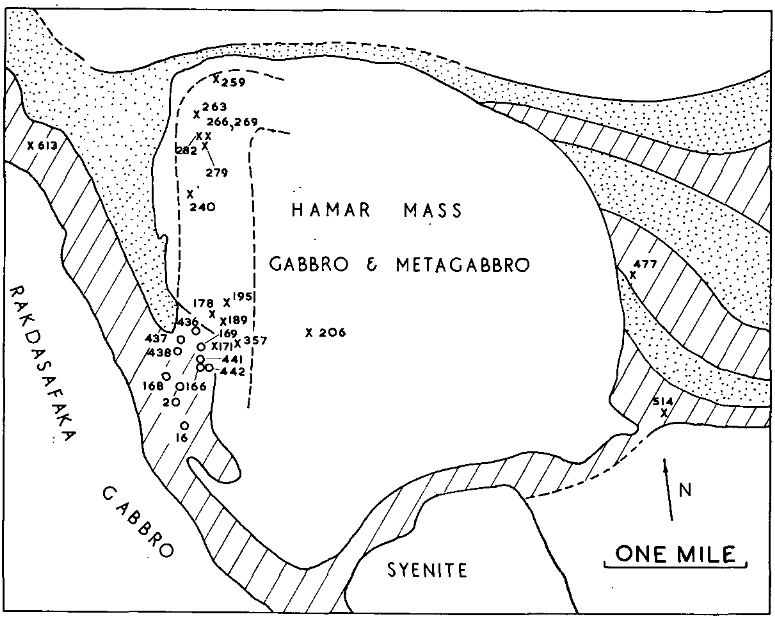

FIG. 1. Localities of amphibolites and pyroxene-bearing rocks in the amphibolite facies (pyroxene-hornfelses) occurring in the country rock and as xenoliths in the Hamar mass, Somalia. The area bounded by dotted lines in the west of the mass is particularly rich in xenoliths. Shaded areas represent amphibolites and pyroxene-hornfelses, stippled areas represent acid gneisses and migmatites.

and distinctive—the masses cannot have been derived from the same magma and undergone similar cooling histories.

On the basis of a reconnaissance survey of Hamar the occurrence of xenoliths was thought to be restricted to sporadic marbles and acidic rocks near the western margin of the intrusion. The recognition of xenoliths of such composition enclosed in gabbro or metagabbro is, of course, straightforward. It is another matter, however, to demonstrate the existence of a xenolith when the suspect xenolith is an amphibolite and the host rock is a metagabbro lacking recognizable igneous texture.

Nevertheless the establishment of a distinction between amphibolite derived from country rock and that derived from the amphibolitization of gabbro became necessary soon after the early stages of more detailed

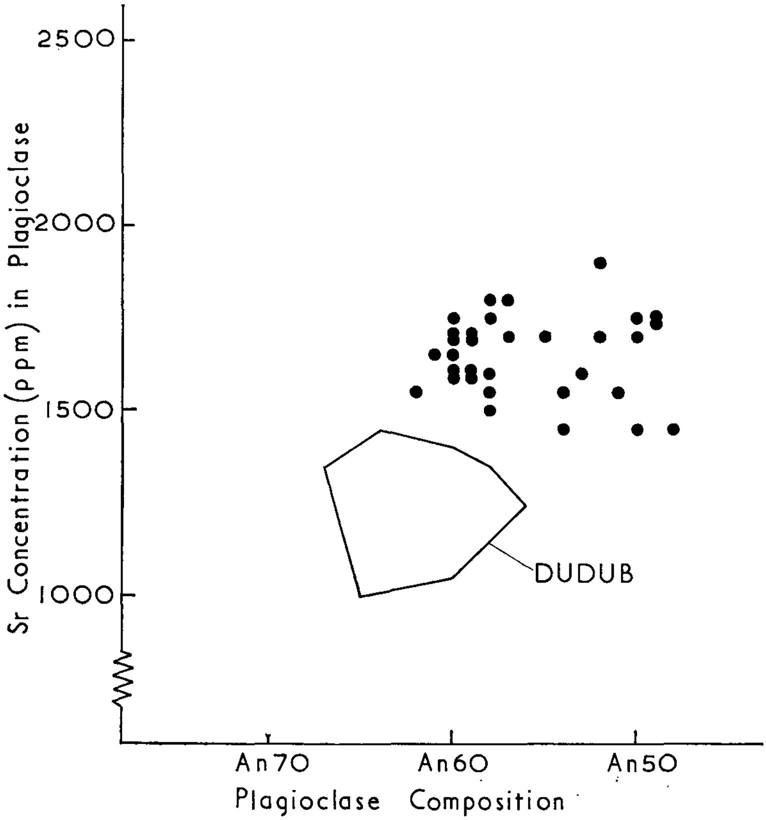

FIG. 2. An and Sr values for plagioclase from gabbro, olivine–gabbro, hypersthene–gabbro, and olivine–hornblende–biotite–gabbro specimens from Hamar, Somalia. The polygon encloses An and Sr values for plagioclase from basic, ultrabasic, and non-marginal metagabbroic rocks from the Dudub mass, Somalia (Skiba and Butler, 1963, fig. 4).

mapping. In the south-west corner of the intrusion several masses of amphibolite were seen to be discordant, with weakly developed layering, and it seemed a likely possibility that the amphibolites were xenoliths. Moreover, to the north of the south-west corner a topographical feature required an explanation. Ridges of high ground running north–

south were of massive (unlayered) amphibolite similar in appearance and texture to amphibolites forming the lower ground. The development of the ridges could be interpreted as a reflection of the primary structure of the gabbro. Alternatively the ridges could represent partially digested country rock forming a discontinuous band of

TABLE I. An and Sr values for plagioclase from basic igneous rocks and their derivatives from the Hamar intrusion, Somalia. Localities are shown in figs. 1 and 3. The basic rocks are largely olivine-gabbros but H 79 and H 121 are gabbros, H 117 and H 383 are hypersthene-gabbros, and H 21 and H 170 are olivine-hornblende-biotite-gabbros. Of the derived rocks H 36, H 207, H 268, H 531, and H 591 are metagabbros with pyroxene, and the remainder metagabbros without pyroxene.

Basic Rocks

No.	An	Sr	No.	An	Sr	No.	An	Sr
H 79	55 %	1700 ppm	H 209	54 %	1550 ppm	H 451	58 %	1600 ppm
H 121	50	1450	H 305	59	1700	H 454	57	1700
			H 310	60	1700	H 497	50	1750
H 13	61	1650	H 313	59	1600	H 541	52	1900
H 67	58	1800	H 319	59	1600	H 547	60	1650
H 76	60	1750	H 323	60	1600			
H 77	53	1600	H 359	60	1600	H 117	51	1550
H 99	62	1550	H 366	60	1700	H 383	58	1500
H 104	48	1450	H 444	57	1800			
H 105	54	1450	H 446	58	1750	H 21	58	1550
H 106	50	1700	H 447	49	1750	H 170	52	1700
H 174	59	1700	H 448	49	1750			

Derived rocks

No.	An	Sr	No.	An	Sr	No.	An	Sr
H 36	50 %	1850 ppm	H 190	54 %	1500 ppm	H 299	61 %	1600 ppm
H 207	53	1750	H 255	59	2850	H 301	60	1550
H 268	53	2100	H 258	55	2450	H 302	62	1450
H 531	59	2000	H 280	50	2200	H 342	58	1800
H 591	54	1800	H 284	55	2400	H 452	57	1800
			H 285	56	2500	H 458	59	1900
H 73	51	1900	H 286	56	2450	H 460	58	2550
H 97	49	2100	H 287	56	2350	H 538	60	1600
H 129	50	1850	H 296	61	2400	H 641	60	2700

amphibolite xenolith resting in massive and unlayered metagabbro. Any ambiguity in interpretation was removed by considering An–Sr relationships in plagioclase from the hornblende–plagioclase rocks supposedly differing in petrogenesis. The Sr concentration in plagioclase from the core of suspected amphibolite xenoliths was found to be appreciably lower than that in plagioclase from metagabbro and olivine–gabbro (irrespective of An content). The interpretation that amphibolites with plagioclase low in Sr were in fact xenoliths was confirmed by analysing for Sr in plagioclase from the country-rock amphibolites and pyroxene-hornfelses. Table II and fig. 4 give the data and it will be seen that there is a very clear-cut distinction between Sr–An values for plagioclase from the olivine–gabbro and Sr (especially) for plagioclase from the xenoliths and country rocks. The scatter of

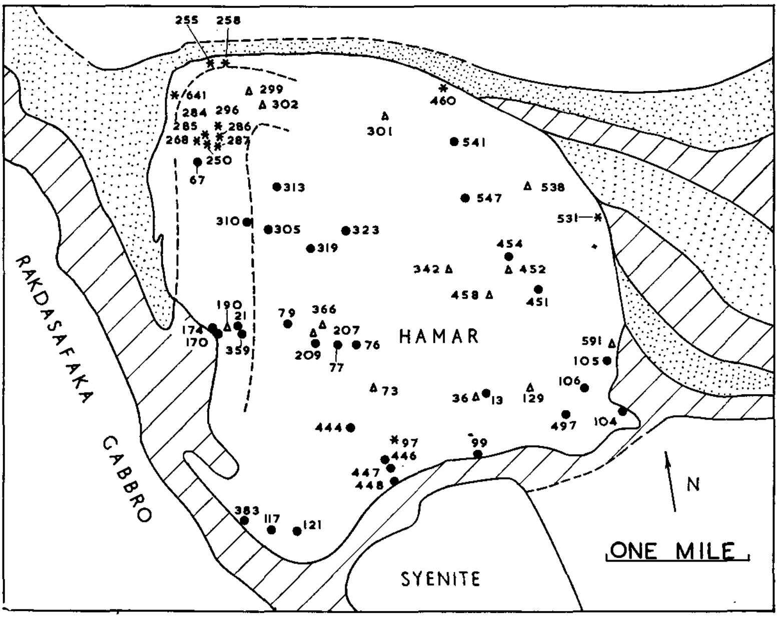

FIG. 3. Localities of gabbro, olivine–gabbro, hypersthene–gabbro, and olivine–hornblende–biotite–gabbro (solid circles) from the Hamar mass, Somalia (table I, upper portion); and localities of metagabbroic specimens (triangles) from the same mass (table I, lower portion). Asterisks represent metagabbro samples with Sr-enriched plagioclase (Sr above 1900 ppm; see text). The area bounded by broken lines in the west of the mass is rich in xenoliths of amphibolite and pyroxene-hornfels. (For 250 read 280.)

points representing Sr and An values for the latter (fig. 4) indicate, moreover, that the country rocks are largely para-amphibolites.

By a combination of analytical data and careful field mapping the existence of a wide xenolith-rich band of amphibolites near and parallel to the western margin of the intrusion has been proved. The strike of the country rock amphibolites changes considerably from about 300° to about 20° as the south-west border of the intrusion is approached; within the intrusion however, the xenolithic belt runs nearly north–

TABLE II. An and Sr values for plagioclase from country rocks and basic xenoliths sampled at their centres. Hamar area, Somalia; localities shown in fig. 1.

Country rocks

No.	Rock type	An	Sr	No.	Rock type	An	Sr
H 16	Amphibolite	68 %	500 ppm	H 477	Pyroxene-amphibolite	57 %	1150 ppm
H 20	Amphibolite	56	700	H 613	Pyroxene-amphibolite	48	990
H 166	Amphibolite	59	660	H 442	Granular pyroxene-hornfels	63	670
H 437	Banded amphibolite	59	700	H 168	Granular pyroxene-hornfels	55	740
H 441	Banded amphibolite	73	890	H 169	Granular pyroxene-hornfels	60	450
H 514	Amphibolite with granulitic texture	48	900	H 436	Granular pyroxene-hornfels	70	750
				H 438	Granular pyroxene-hornfels	71	730

Basic xenoliths

No.	Rock type	Size	An	Sr	No.	Rock type	Size	An	Sr
H 171	Amphibolite	9′ × 6′	56 %	1250 ppm	H 195	Pyroxenite band in amphibolite	300′ × 120′	70 %	820 ppm
H 178	Amphibolite	60′ × 24′	56	1700					
H 189	Amphibolite	30′ × 4′	59	980	H 263	Granular pyroxene-hornfels	10′ × 2′	57	990
H 206	Amphibolite	8′ × 3′	53	1250	H 266	Granular pyroxene-hornfels	30′ × 1½′	63	1000
H 240	Amphibolite	120′ × 12′	59	800	H 357	Granular pyroxene-hornfels	30′ × 1½′	59	1200

south, that is, in a direction roughly parallel to the strike of the country rocks near the contact.

Arising from the study and establishment of the amphibolite-xenolith–metagabbro relationship an unexpected feature of the comparative

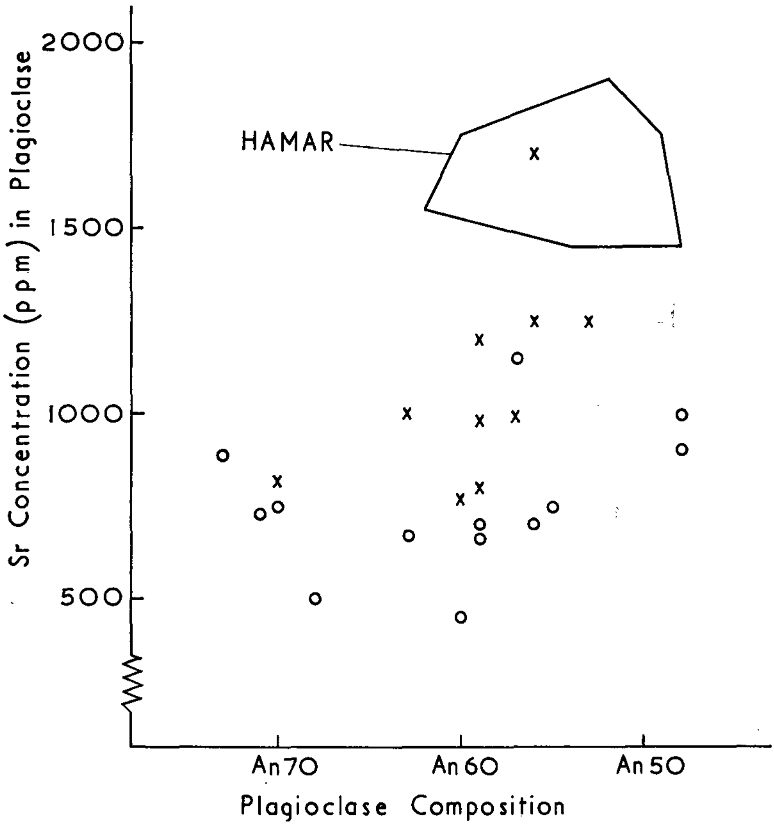

FIG. 4. An and Sr values for plagioclase from country rocks around (open circles) and from the centre of xenoliths within (crosses) the Hamar mass, Somalia. The polygon encloses the values for plagioclase from the basic rocks shown in fig. 2 (and listed in table I, upper portion).

geochemistry of Sr and Na (or Sr and Ca) has emerged. Thus it has been shown that plagioclase from the core of the amphibolite xenoliths is lower in Sr than that in plagioclase from olivine–gabbro. However, plagioclase from the margins of some xenoliths contains more Sr than that found in plagioclase from any of the olivine–gabbro specimens analysed. Data for plagioclase from a xenolith 150 ft $\times$ 17 ft sampled across its width illustrate the phenomenon (H 279, H 280, table III). The mode of plagioclase varies between 35 % and 55 % in specimens H 279/1 to H 279/10 and H 280 and the An content ranges from An 50 to An 63. Sr in plagioclase from the core of the xenolith and across most of its width is below 1000 ppm; that in plagioclase from 'amphibolite at the margin of the xenolith' (H 279/10) is 1800 ppm, and in plagioclase from 'metagabbro at the junction with H 279/10' (H 280) it is 2200 ppm. This concentration of Sr is appreciably higher than the highest concentration of 1950 ppm found in plagioclase from olivine–gabbro but An values are comparable. Data for plagioclase from the centre and periphery of two other xenoliths, H 259 and H 282, support these findings (table III). There is, of course, some difficulty in deciding how to name the specimens at the margin of or marginal to the xenolith; this is the reason for enclosing the description in inverted commas at this stage. We conclude from thin section study that H 279/10 texturally resembles H 279/1 more than metagabbro near the xenolith and therefore describe it as '. . . amphibolite . . .', and that H 280 texturally resembles nearby and other metagabbro specimens rather than amphibolite at the centre of xenoliths or in the country rock. We believe that the 'amphibolite' specimens H 279/1 to H 279/9 have remained in an essentially solid state during and since attempted digestion by the magma but that H 279/10 represents a mixed product of, locally, partially melted xenolith and gabbro magma; H 280 represents a mixed product of substantially melted xenolith with a higher proportion of gabbro magma. It may be emphasized that there is no gradual or regular build up of Sr in plagioclase from specimens across the xenolith H 279 and into the gabbro and it is therefore suggested that the source of Sr in the Sr-enriched plagioclase from H 280 is the magma itself. A number of the amphibolite xenoliths are mineralogically and chemically closely similar to the metagabbros (hence the lack of the development of reaction rims). However, although the amphibolite xenoliths and the metagabbro are closely similar to each other now, this does not necessarily imply that the xenolith and the gabbro magma were compositionally closely similar during the initial stages of digestion. A xenolith of amphibolite at the time of digestion would contrast with the magma in having a higher water content; as decomposition and dehydration of the amphibolite proceeds the magma immediately surrounding the xenolith would doubtless absorb the steam evolved and it is suggested that plagioclase crystallizing from this wet magma is

Table III. An and Sr values for plagioclase from the centre and at the periphery of amphibolite xenoliths from the Hamar intrusion, Somalia. Plagioclase modes vary from 35 % to 55 %. Localities are shown in fig. 1.

No.	Rock type and size	An	Sr
H 279/1	Amphibolite 150′×11′ sampled at its centre (H 279/1) and at 7″ to 8″ intervals progressively to its margin.	60 %	770 ppm
H 279/2		60	860
H 279/3		60	980
H 279/4		60	910
H 279/5		56	930
H 279/6		61	940
H 279/7		58	950
H 279/8		61	980
H 279/9		63	780
H 279/10		52	1800

No.	Rock type	Size	An	Sr
H 280	Metagabbro marginal to H 279/10	—	50 %	2200 ppm
H 259/1	Amphibolite sampled at its centre	6′×2′	58	1500
H 259/2	Metagabbro marginal to H 259/1	—	57	2050
H 282/1	Amphibolite sampled at its centre	3′×10″	52	1050
H 282/2	Metagabbro marginal to H 282/2	—	54	2100

able to concentrate Sr more readily than that crystallizing from the original, drier, magma. If the introduction of water from a xenolith is responsible for the production of Sr-enriched plagioclase then it follows that rocks with such feldspars are better described as metagabbros than amphibolites in the sense that the Sr-enriched plagioclase will have crystallized from a largely liquid environment.

It has already been shown that Sr concentrations in plagioclase from gabbro, olivine-gabbro, hypersthene-gabbro, and olivine-hornblende-biotite-gabbro specimens from Hamar lie in the range 1450 to 1900 ppm and it has been mentioned that this is a relative spread in concentration similar to that found for plagioclase from gabbro and metagabbro specimens from Dudub. At Dudub it was previously concluded that the change gabbro → metagabbro did not affect the Sr–An relationships in the plagioclase. Consideration may now be given to data for plagioclase from samples described as metagabbro with pyroxene (i.e. primary pyroxene) and metagabbro from Hamar given in the lower portion of table I. The An values (An_{49} and An_{62}) are comparable to those for plagioclase from the olivine-gabbro, etc. (An_{48} to An_{62}) shown in the upper portion of table I; Sr values, however, are not. Significantly all but one of the metagabbro specimens in which Sr in the plagioclase exceeds 1900 ppm are either specimens near xenoliths in the xenolithic belt (H 268, H 284, H 285, H 286, and H 296) or they are marginal to the intrusive boundary of the mass (H 255, H 258, H 460, H 531, and H 641). Localities are given in fig. 3. It is suggested that the reason for the enhanced Sr content in the plagioclase of these specimens is that they have crystallized from part of the Hamar magma that was more hydrous than elsewhere due to the uptake of water derived from the nearby xenoliths and country rock. This implies that the xenoliths were more hydrous than the magma immediately prior to the intrusion; the xenoliths would have been, for example, amphibolites rather than pyroxene-hornfelses. This is of direct relevance to the understanding of the metamorphic history of the Hamar area for it implies that some of the country-rock hornfelses were affected by amphibolitization metamorphism prior to the Hamar intrusion.

Not all metagabbro samples adjacent or near to xenoliths or the country rock margins contain Sr-enriched plagioclase; this would not be expected if the xenoliths or country rocks were relatively anhydrous at the time of the intrusion. Specimens of metagabbro in which the Sr concentration in the plagioclase is comparable to that in plagioclase from olivine-gabbro include rocks that have been amphibolitized in the solid state and after the consolidation of the Hamar mass. This may have occurred during the metamorphic period when the Dudub gabbro was partially amphibolitized to metagabbro.

The importance of water in the uptake of Sr during the crystallization of plagioclase in igneous rocks could be investigated in synthetic melt systems; but this requires apparatus we do not at present possess. It would be expected that the partition coefficient (Sr in liquid):(Sr in plagioclase) would change in favour of more Sr entering the feldspar of a particular An content as the water content increased. Thus basic feldspar, say An_{85}, crystallizing from a relatively hydrous magma containing a few hundred ppm Sr may concentrate Sr to such an extent that less basic feldspar, say An_{50}, will crystallize from a (later) liquid rather depleted in Sr; despite a favourable partition coefficient the An_{50} plagioclase may contain less Sr than the An_{85} variety. This is a possible explanation for the Sr–An relationship shown for plagioclase from rocks of the Southern Californian batholith (Sen *et al.*, 1959); as An falls from An_{93} to below An_{40}, Sr tends to fall also (in the range 1300 to below 500 ppm). The rocks—olivine-hornblende-gabbro, noritic-hornblende-gabbro, norite, biotite-norite, tonalite, etc.—all contain either primary hornblende or biotite and plagioclase has evidently crystallized from a magma more hydrous than that from which the Somalian plagioclase from Dudub, Hamar, etc. crystallized.

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References

Butler (J. R.), and Skiba (W.), 1962. Min. Mag., vol. 33, pp. 213–225.
Daniels (J. L.), Skiba (W.), and Sutton (J.), 1965. Quart. Journ. Geol. Soc., vol. 121, pp. 111–141.
Sen (N.), Nockolds (S. R.), and Allen (R.), 1959. Geochimica Acta, vol. 16, pp. 58–78.
Skiba (W.) and Butler (J. R.), 1963. Journ. Petrology, vol. 4, pp. 352–366.

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