Strontium isotope and lithophile element values from the submarine Jan Mayen province

SVEND PEDERSEN, OLE LARSEN, NIELS HALD, JOHN CAMPSIE
AND JOHN C. BAILEY

Pedersen, S., Larsen, O., Hald, N., Campsie, J. and Bailey, J. C.: Strontium isotope and lithophile element values from the submarine Jan Mayen province. *Bull. geol. Soc. Denmark,* vol. 25, pp. 15–20. Copenhagen, October, 19th, 1976. https://doi.org/10.37570/bgsd-1976-25-02

$^{87}Sr/^{86}Sr$ ratios (0.70327–0.70364) and contents of K, Rb and Sr in basaltic rocks dredged from the environs of the Western Jan Mayen Fracture Zone compare well with isotopic compositions (mean 0.70343) and elemental values of volcanic rocks from Jan Mayen Island.

S. Pedersen, O. Larsen and N. Hald, Geologisk Centralinstitut, Østervoldgade 10, 1350 Copenhagen K., Denmark. J. Campsie and J. C. Bailey, Ocean Study Group, Geologisk Centralinstitut, Østervoldgade 10, 1350 Copenhagen K., Denmark. 3rd. March, 1976.

Jan Mayen Island is located near the intersection of several tectonic lineaments in the Norwegian-Greenland Sea (Birkenmayer 1972; Johnson & Vogt 1973; Eldholm & Windisch 1974; Johnson 1974; Johnson & Campsie 1974; Talwani & Eldholm 1974; Talwani et al. 1975) (fig. 1). To the north the Mohns Ridge accretion axis (60 – 0 m.y. BP) is located midway between the continental margins of Norway and Greenland. The southern end of this spreading centre is offset by the Jan Mayen Fracture Zone (JMFZ) over 210 km to the west reappearing as the Kolbeinsey Ridge which continues southwards to Iceland. South of the eastern JMFZ the extinct Norwegian Basin spreading centre (about 60 – 30 m.y. BP) is believed to have shifted westward splitting a continental fragment (the Jan Mayen Ridge) from the Greenland block. A further westward shift about 10 m.y. BP is supposed to have initiated the still active Kolbeinsey Ridge. Three Deep Sea Drilling Project cores on the Jan Mayen Ridge revealed sediments of which the oldest – late Eocene to Oligocene – are almost completely of terrigeneous origin (Talwani et al. 1975). Jan Mayen Island thus lies near the confluence of an accretion axis, a major fracture zone and a drowned continental splinter.

The emergent portion of Jan Mayen Island is believed to be no older than 0.5 m.y., but it has been suggested that the foundation may date from Middle Tertiary (Fitch et al. 1965). Ankaramites, alkali basalts, trachyandesites and trachytes are the main rock types on the island (Fitch et al. 1965; Hawkins & Roberts 1972; Weigand 1972; Noe-Nygaard 1974). Xenocrysts and/or phenocrysts sometimes make up to 20–50 % of the basic rocks. They include chromian diopsides and Ni-rich olivines and are thought to have crystallized within the upper mantle at greater than 20 kb pressure (Hawkins & Roberts 1972).

A plume origin has been proposed for Jan Mayen Island (Weigand et al. 1972). This may be consistent with the occurrence of a zone with alkalic volcanism which appears to extend from the outer Vøring Plateau (Talwani et al. 1975) through the Jan Mayen area to the East Greenland coast and the inland nunataks (Noe-Nygaard 1974). This zone is roughly parallel to the Faeroes-Iceland-Greenland aseismic ridge. It is a major petrologic challenge to assess the role of these possible geotectonic influences on the origin of Jan Mayen volcanism. The value of isotopic studies to this assessment is obvious and has prompted this reconnaissance study.

The Iceland Plateau immediately south of the western part of JMFZ is characterized by flat-topped submarine banks. Dredge 10 recovered ankaramites, alkali basalts, trachyandesites and trachytes. Since similar materials occur on the nearby Jan Mayen Island an

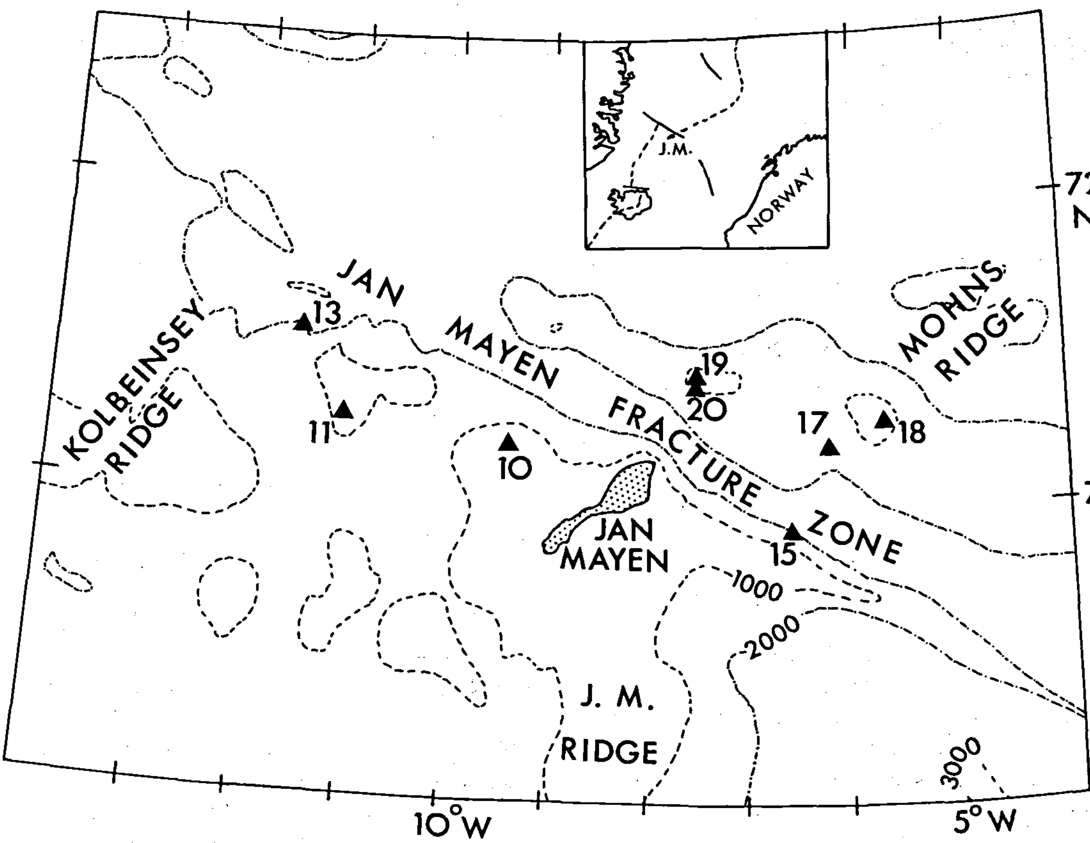

Fig. 1. Bathymetric map (depths in metres) of the Jan Mayen area showing dredge sites. The inset indicates the major fracture zones and spreading axes in this region.

ice-rafted origin for at least some of dredge 10 should not be ruled out, especially as some of the material showed signs of ice-working. Dredge 11 further to the west yielded abundant ankaramites, alkali basalts and a few trachyandesites plus crystal-lithic tuff-agglomerates. Stations 10 and 11 were both highly reflective to seismic energy suggesting a lack of or a very thin sedimentary cover. Bathymetric highs to the north of the western JMFZ, sampled by dredges 17–20, are sharper peaks, also relatively free of sediments and with a magnetic signatųre. These dredges mainly recovered alkali basalts and ankaramites. Dredge 15 from the south wall of the western JMFZ east of Jan Mayen Island contained a large amount of agglomerates plus minor quantities of ankaramites, alkali basalts and trachyandesites. Dredge 13 was taken from the rugged south wall of the western JMFZ near the axis of the Kolbeinsey Ridge. It recovered coarsely crystalline ultramafic rocks, microgabbros and microdiorites, all with evidence of low grade metamorphism.

The distinctive and narrow range of rock types found at several of these stations suggest that the recovered rocks were of local origin. Glassy margins to the dredge 18 basalts indicate subaqueous extrusion.

Analytical techniques

Strontium was extracted by the conventional procedure of dissolution in HF plus $HClO_4$ followed by ion exchange. Strontium (0.5 – 1 μg) was loaded as chloride on rhenium filaments. Isotopic ratios were measured on a Varian MAT TH 5 mass spectrometer using

Table 1. Dredge locations from the Jan Mayen volcanic province.

Dredge no.	Depth, m	Lat./Long.	Location
10	145–165	71°10.5' N 09°25.6' W	Flat-topped seamount W. of Jan Mayen
11	275–290	71°14.5' N 11°08.0' W	Flat-topped seamount W. of Jan Mayen
13	~ 2400	71°33.0' N 11°36.2' W	JMFZ, South wall
15	1100–1280	70°53.9' N 06°35.7' W	JMFZ, South wall
17	1280–1460	71°10.1' N 06°13.6' W	Bank ENE of Jan Mayen
18	~ 1000	71°16.5' N 05°44.7' W	Bank ENE of Jan Mayen
19	730	71°25.3' N 07°36.5' W	Bank NE of Jan Mayen
20	820	71°24.1' N 07°38.9' W	Bank NE of Jan Mayen

a double filament cartridge. The Faraday collector was connected to a unity-gain DC-amplifier (10^{11} Ohm feedback resistor) and subsequently transferred to digital output on punched tape for off-line processing. Each sample was measured at a current level close to 10^{-11} Amp through 40 – 50 peak switching cycles, all masses between 84 and 88 being measured during each cycle. The standard deviation (1σ) on the mean of the ratios thus obtained is less than 0.0001. Duplicates on repeated standard measurements indicate an overall precision better than 0.00018 (1σ). The isotope ratios quoted in table 2 were calculated as the weighted mean of up to 5 replicate measurements.

The measured ratios were corrected to an $^{86}Sr/^{88}Sr$ value of 0.1194 and adjusted to a value of 0.70800 for $^{87}Sr/^{86}Sr$ in the Eimer and Amend $SrCO_3$ standard. The weighted mean of 7 measurements on the Eimer and Amend standard is 0.70835 ± 4 (corrected to $^{86}Sr/^{88}Sr = 0.1194$). Similarly corrected ratio measurements on the NBS987 Sr-standard give a weighted mean of 0.71054 ± 3. Adjusted to 0.70800 for the Eimer and Amend standard an $^{87}Sr/^{86}Sr$ ratio of 0.71019 ± 3 is obtained for the NBS987 standard. This value may be compared to the $^{87}Sr/^{86}Sr$ ratio reported for the same standard at the Oxford Laboratory by Pankhurst & O'Nions (1973) which becomes 0.71024 when adjusted in the manner described above.

A reference sample OSG 68b from the Reykjanes Ridge at 58°54′ N was measured as a further intercalibration with the Oxford data. A weighted mean of 5 determinations yields an $^{87}Sr/^{86}Sr$ ratio of 0.70298 ± 5 (1σ). Two determinations on the same sample are reported by O'Nions & Pankhurst (1974): 0.70297 ± 5 (2σ) and 0.70298 ± 5 (2σ).

K, Rb and Sr were measured by x-ray fluorescence spectrometry using the techniques of Norrish & Chappell (1967) with W–1, BCR–1 and synthetic materials as standards.

Results and discussion

Table 2 presents levels of $^{87}Sr/^{86}Sr$ and K, Rb and Sr in seven basaltic and ankaramitic rocks, one microdiorite and one ultramafic sample from the dredges of the Jan Mayen area.

The seven basaltic and ankaramitic samples lie in an isotopic range from 0.70327 – 0.70364. This range covers the mean ratio of $^{87}Sr/^{86}Sr$ reported for Jan Mayen Island of 0.70343 (O'Nions & Pankhurst 1974).

Table 2. $^{87}Sr/^{86}Sr$*, K, Rb and Sr values from the Jan Mayen volcanic province.*

Dredge no.	Sample no.	Rock type	$^{87}Sr/^{86}Sr$[1]	No. of det.	K %	Rb[2] ppm	Sr[2] ppm	K/Rb	Rb/Sr[3]
10	26024	Ankaramite	0.70339± 5	5	0.78	20	300	390	0.0610
11	26031	Ankaramite	0.70327± 6	4	1.11	30	530	370	0.0531
13	26004	Microdiorite	0.70344± 5	5	1.63	45	340	360	0.116
13	26152	Pyroxenite	0.70435± 8	3	0.052	~ 1	15	~ 500	~ 0.06
15	26241	Ankaramite	0.70340± 8	3	1.26	35	430	360	0.0698
17	26023	Alkali Basalt	0.70364± 9	2	1.83	45	740	410	0.0531
18	26182	Alkali Basalt	0.70348± 6	2		30	620		0.0433
19	26259	Ankaramite	0.70348± 5	3	0.90	25	360	360	0.0646
20	26252	Ankaramite	0.70345± 6	5	1.14	25	480	460	0.0532

[1] Normalized to $^{86}Sr/^{88}Sr$ = 0.1194 and adjusted relative to 0.70800 for the E. & A. standard.
[2] Values only ±10 % because of matrix variations.
[3] Values are ±1–2 % because independent of matrix variations.

Although isotopic and large ionic radius lithophile (LIL) element ratios are similar between the ankaramitic and basaltic rocks from the sea floor and from the nearby Jan Mayen Island, absolute contents of K, Rb and Sr appear to exhibit different ranges (table 3). The differences seem to be related to the higher contents of pyroxene and olivine crystals in the dredged material. The values are clearly different from oceanic tholeiites as shown in table 3.

Dredge 11 is located about 40 km to the south of the western JMFZ. There are 12 fairly uniform ankaramitic basalts in this dredge, with contents of K, Rb and Sr lower than typical material from Jan Mayen Island (our unpublished data). The slightly lower contents of LIL elements are consistent with the fairly high content (about 25 %) of xenocrysts and phenocrysts in the rocks of dredge 11. However, the markedly lower isotopic ratio of sample 26031 (0.70327) may possibly indicate some departure from the Jan Mayen isotopic province. The extent of this province and the geochemical features of its marginal areas remain to be determined. At about 71°N on the Kolbeinsey Ridge dredged tholeiites show no similarity in LIL element contents and ratios to the Jan Mayen volcanic rocks (Dittmer et al. 1975). However, Schilling et al. (1974) have reported a normalized La/Sm ratio greater than 1.0 for a Kolbeinsey Ridge sample only 15′ of latitude south of the western JMFZ, so the Jan Mayen volcanic province possibly terminates between these two localities.

Sample 26004 from station 13 recovered from the south wall of the western JMFZ is a microdiorite (chemically a trachyandesite) carrying primary amphibole and biotite. Its LIL elemental and isotopic (0.70344) values are essentially similar to the volcanic rocks of the Jan Mayen province, although its Rb/Sr ratio is higher.

Sample 26152 – also from station 13 – is an ultramafic rock consisting of 60 % chromian diopside ($Ca_{47}Mg_{46}Fe_7$; Cr_2O_3 about 0.5 %) and 2 % olivine (Fo_{84}) set in a matrix of serpentine which probably has replaced olivine. Rocks of this composition have not yet been described from other fracture zones in the Atlantic. It is supposed that the ultramafics from dredge 13 are related to the Jan Mayen province volcanism. As mentioned earlier an olivine-clinopyroxene xenocryst assemblage is found in the Jan Mayen lavas. Ultramafic rocks of similar composition occur as nodules in the alkalic lavas of Hawaii

Table 3. $^{87}Sr/^{86}Sr$, K, Rb, Sr and element ratios in Jan Mayen ankaramites and basalts, with comparisons.

	$^{87}Sr/^{86}Sr$	K %	Rb ppm	Sr ppm	$\frac{K_2O}{K_2O + Na_2O}$	K/Rb	Rb/Sr	No. of samples	Ref.
Jan Mayen submarine	0.70327 – 0.70364	0.78– 1.83	20– 45	300– 740	0.402– 0.445	360– 460	0.043– 0.070	7	This paper
Jan Mayen Island	0.70338 – 0.70344	1.93– 2.09	57– 61	735– 800	0.425– 0.456	339– 343	0.076– 0.078	4	1
Jan Mayen Island	0.7035 0.7039	0.90– 2.60	27.5– 75.5	452– 1026	0.398– 0.476	329– 384	0.061– 0.074	7	2
Jan Mayen Island		2.11– 2.22	60	826	0.434– 0.451	394	0.073	4	3,4
Jan Mayen Island		0.91– 2.64			0.373– 0.524			12	5,6
Snaefellsnes Iceland	0.70326 – 0.70341	0.75– 1.39	10– 33	295– 560	0.219– 0.278	422– 588	0.031– 0.059	4	1
Terceira Azores	0.70349	0.82	18	550	0.235	457	0.033	1	1
Spitsbergen	0.7044 – 0.7104	0.46– 1.46	3.3– 49.7	337– 2026	0.133– 0.396	266– 1379	0.010– 0.042	6	2
Rockall	0.7065		170	40.6			4.19	1	7
NE Atlantic oceanic tholeiites	0.70290 – 0.70298	0.03– 0.07	0.52– 1.2	53– 78	0.019– 0.036	620– 740	0.009– 0.017	5	1
Oceanic tholeiites	0.70265	0.12	1.11	135		1060	0.0082	15	8

1. O'Nions & Pankhurst (1974), 2. Lussiaa.Berdou-Polve & Vidal (1973), 3. Weigand (1972), 4. Weigand et al. (1972), 5. Fitch et al (1965), 6. Hawkins & Roberts (1972), 7. Moorbath & Welke (1969), 8. Hart (1971).

(White 1966) and other oceanic islands, and in layered ultramafic complexes on the Canary Islands (Gastesi 1969). They have generally been interpreted as olivine-clinopyroxene cumulates formed from basic magmas. Investigations by Stueber & Ikramuddin (1974) have shown that olivine-clinopyroxene inclusions from Hawaii have higher isotopic ratios than their host lavas. The cognate character of nodules of this type is thus uncertain. Similarly the $^{87}Sr/^{86}Sr$ ratio of the olivine-clinopyroxenite in dredge 13 (0.70435) seems to exclude a cognate relationship between these ultramafic rocks and the associated alkaline microdiorite or the ankaramitic lavas from neighbouring dredge stations. On the other hand it is quite likely that the original isotopic ratio of the clinopyroxenite has been disturbed as a result of serpentinization possibly involving sea water. Another factor to be considered is low temperature sea water alteration which has been reported to increase the $^{87}Sr/^{86}Sr$ ratio of pillow lavas (Dasch et al. 1973; Hart et al. 1974).

The comparability between the $^{87}Sr/^{86}Sr$ ratios of the basalts and ankaramites on and around Jan Mayen Island indicates that these lavas constitute a single volcanic province. The isotopic composition of Sr in the volcanic rocks of this province compares well with isotopic ratios about 0.7034 found in the Snaefellsnes neovolcanic zone of Iceland and on Terceira (Azores) (O'Nions & Pankhurst 1974). At these localities the alkaline volcanism is also associated with major fracture zones (Sigurdsson 1970; Ward 1971; Ridley et al. 1974). However, according to the data of O'Nions & Pankhurst (1974) and Schminke (1973) these latter areas differ from Jan Mayen by the lower $K_2O/K_2O + Na_2O$ and Rb/Sr ratios of their lavas (table 3).

The isotopic ratios of the basaltic and ankaramitic rocks reported here are not suggestive of continental contamination. Acid-intermediate xenoliths, of likely crustal origin, have not been described in the Jan Mayen literature. Isotopic values as high as those in the Rockall granite: 0.7065 (Moorbath & Welke 1969) and in Quaternary Spitsbergen lavas: 0.7044–0.7104 (Lussiaa-Berdou-Polve & Vidal 1973), attributed to crustal contamination, seem to be absent in the volcanic rocks of the Jan Mayen area (table 3).

Acknowledgements. We thank the officers and crew of the USNS "Lynch" and also Prof. A. Noe-Nygaard, Dr. G. L. Johnson, F. Dittmer and M. Rasmussen for their support.

Dansk sammendrag

Sr-isotopforholdene i basalter og ankaramiter opsamlet på havbunden omkring den vestlige del af Jan Mayen frakturzonen svarer til isotopforholdene i tilsvarende bjerarter på selve Jan Mayen (omkring 0.7034). Vulkanismen på Jan Mayen og på den omkringliggende del af havbunden synes således at tilhøre en og samme provins.

Et noget lavere indhold af K, Rb og Sr i havbundsprøverne i forhold til Jan Mayen bjergarterne tilskrives, at de først nævnte gennemgående er rigere på strøkorn af olivin og clinopyroxen.

References

Birkenmajer, K. 1972: Geotectonic aspects of the Beerenberg Volcano eruption 1970, Jan Mayen island. *Acta geol. Pol.* 22, 1–15.

Dasch, E. J., Hedge, C. E. and Dymond, J. 1973: Effect of sea water interaction on strontium isotope composition of deep-sea basalts. *Earth Planet. Sci. Lett.* 19, 177–183.

Dittmer, F., Fine. S., Rasmussen, M., Bailey, J. C. and Campsie, J. 1975: Dredged basalts from the mid-oceanic ridge north of Iceland. *Nature* 254, 298–301.

Eldholm, O. and Windisch, C. C. 1974: The sediment distribution in the Norwegian-Greenland Sea. *Bull. geol. Soc. Amer.* 85, 1661–1676.

Fitch, F. J., Grasty, R. L. and Miller, J. A. 1965: Potassium-argon ages of rocks from Jan Mayen and an outline of its volcanic history. *Nature* 207, 1349–1351.

Gastesi, P. 1969: Petrology of the ultramafic and basic rocks of Bentacuria Massif, Fuertaventura Island (Canarian Archipelago). *Bull. volcan.* 33, 1008–1038.

Hart, S. R. 1971: K, Rb, Cs, Sr and Ba and Sr isotope ratios of ocean floor basalts. *Phil. Trans. roy. Soc.* A268, 573–587.

Hart, S. R., Erlank, A. J. and Kable, E. J. D. 1974: Sea floor alteration: Some chemical and Sr isotopic effects. *Contr. Mineral. Petrol.* 44, 219–230.

Hawkins, T. R. W. and Roberts, B. 1972: The petrology of the volcanic and intrusive rocks of Nord-Jan, Jan Mayen. *Norsk Polarinst. Årbok* 1970, 19–41.

Johnson, G. L. 1974: Morphology of the mid-ocean ridge between Iceland and the Arctic Basin. *In:* Kristjansson, L. (editor) *Geodynamics of Iceland and the North Atlantic Area* 49–62. Dordrecht: Reidel.

Johnson, G. L. and Campsie, J. 1974: Morphology and structure of the Western Jan Mayen Fracture Zone. *Norsk Polarinst. Årbok* 1974, 69-81.

Johnson, G. L. and Vogt, P. R. 1973: Marine geology of Atlantic Ocean north of Arctic circle. *In:* Pitcher, M. G. (editor) Arctic Geology 161–170. *Mem. Am. Assoc. Petroleum Geologists* 19.

Lussiaa-Berdou-Polve, M. and Vidal, P. 1973: Initial strontium isotopic composition of volcanic rocks from Jan Mayen and Spitsbergen. *Earth Planet. Sci. Lett.* 18, 333–338.

Moorbath, S. and Welke, H. 1969: Isotopic evidence for the continental affinity of the Rockall Bank, North Atlantic. *Earth Planet. Sci. Lett.* 5, 211–216.

Noe-Nygaard, A. 1974: Cenozoic to recent volcanism in and around the North Atlantic basin. *In:* Nairn, A. E. M. and Stehli, F. G. (editors) *The Ocean Basins and Margins* 2, 391–443. New York: Plenum.

Norrish, K. and Chappell, B. W. 1967: X-Ray Fluorescence Spectrography. *In:* Zussmann, J. (editor) *Physical Methods in Determinative Mineralogy* 161–214. London: Academic Press.

O'Nions, R. K. and Pankhurst, R. J. 1974: Petrogenetic significance of isotope and trace element variations in volcanic rocks from the Mid-Atlantic. *J. Petrol.* 15, 603–634.

Pankhurst, R. J. and O'Nions, R. K. 1973: Determination of Rb/Sr and $^{87}Sr/^{86}Sr$ ratios of some standard rocks and evaluation of X-ray fluorescence spectrometry in Rb-Sr geochemistry. *Chem. Geol.* 12, 127–136.

Ridley, W. I., Watkins, N. D. and MacFarlane, D. J. 1974: The Oceanic Islands: Azores. *In:* Nairn, A. E. M. and Stehli, F. G. (editors) *The Ocean Basins and Margins* 2, 445–483. New York: Plenum.

Schilling, J.-G., Johnson, D. G. and Johnston, T. H. 1974: Rare earth latitudinal variations along the MAR. (Abstract.) *Trans. Am. geophys. Un.* 55, 294.

Schminke, H.-U. 1973: Magmatic evolution and tectonic regime in the Canary, Madeira and Azores Island Groups. *Bull. geol. Soc. Amer.* 84, 633–648.

Sigurdsson, H. 1970: Structural origin and plate tectonics of the Snaefellsnes volcanic zone, Western Iceland. *Earth Planet. Sci. Lett.* 10, 129–135.

Stueber, A. M. and Ikramuddin, M. 1974: Rubidium, strontium, and the isotopic composition of strontium in ultramafic nodule minerals and host basalts. *Geochim. Cosmochim. Acta* 38, 207–216.

Talwani, M. et al. 1975: Leg 38. *GeoTimes* 20 (2), 24–26.

Talwani, M. and Eldholm, O. 1974: Margins of the Norwegian-Greenland Sea. *In:* Burk, C. A. and Drake, C. L. (editors) *The Geology of Continental Margins* 361–374. Berlin: Springer Verlag.

Ward, P. L. 1971: New interpretation of the geology of Iceland. *Bull. geol. Soc. Amer.* 82, 2991–3012.

Weigand, P. W. 1972: Bulk-rock and mineral chemistry of Recent Jan Mayen basalts. *Norsk Polarinst. Årbok* 1970, 42–52.

Weigand, P. W., Brunfelt, A. O., Heier, K. S., Sundvoll, B. and Steinnes, E. 1972: Geochemistry of alkali olivine basalts from an eruption on Jan Mayen. *Nature Phys. Sci.* 235, 31–33.

White, R. W. 1966: Ultramafic inclusions in basaltic rocks from Hawaii. *Contr. Mineral. Petrol.* 12, 245–314.