

Aenigmatite, Pantelleria, Coddia Mida
Italy

SiO ₂	42.08
TiO ₂	7.59
Al ₂ O ₃	0.42
FeO	40.96
MnO	1.26
MgO	0.40
CaO	0.41
BaO	0.0
Na ₂ O	7.14
K ₂ O	0.02
F	0.0
Cl	0.0

#85126.
Harvard Mineral. Museum

sum.	100.26
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number of cations on the basis of 20 oxygens.

Si	6.029
Al	0.071
Ti	0.818
Fe	4.908
Mg	0.085
Mn	0.150
	<hr/>
	6.033

Na	1.983
Ca	0.063
K	0.004
	<hr/>
	2.050

SUPER RECAL

	1
SI02	41.70
TI02	8.18
A203	0.19
FE0	40.33
MNO	1.09
MGO	0.34
CA0	0.26
BA0	0.0
NA20	7.60
K20	0.03
F	0.04
CL	0.0
SUM	99.72
-O= F+CL	0.0
SUM	99.72

AENIGMATITE ANALYSES

	2	3	4
	42.44	42.08	40.87
	7.17	7.59	8.12
	0.14	0.42	0.31
	41.52	40.96	41.39
	1.33	1.24	1.10
	0.33	0.40	0.34
	0.23	0.41	0.34
	0.0	0.0	0.0
	7.32	7.14	7.77
	0.02	0.02	0.03
	0.0	0.0	0.0
	0.0	0.0	0.0
	100.50	100.26	100.27
	0.0	0.0	0.0
	100.50	100.26	100.27

SI	6.003	*	6.080	*	6.029	*	5.903	*
AL	0.0	6.003	0.0	6.080	0.0	6.029	0.0	5.903
AL	0.032	*	0.024	*	0.071	*	0.053	*
TI	0.886	0.918	0.772	0.796	0.818	0.889	0.882	0.935
FE	4.856	*	4.974	*	4.908	*	5.000	*
MG	0.073	*	0.070	*	0.085	*	0.073	*
MN	0.133	5.061	0.161	5.206	0.150	5.144	0.135	5.207
NA	2.121	*	2.033	*	1.983	*	2.176	*
CA	0.040	*	0.035	*	0.063	*	0.053	*
K	0.006	*	0.004	*	0.004	*	0.006	*
BA	0.0	2.167	0.0	2.072	0.0	2.050	0.0	2.234
O	20.000	*	20.000	*	20.000	*	20.000	*
F/M	68.375		72.884		59.216		70.141	
F/FM	0.986		0.986		0.983		0.986	

1 PANTELLERA AENIGMATITE
 2 PANTELLERA AENIGMATITE
 3 PANTELLERA AENIGMATITE
 4 PANTELLERA AENIGMATITE

DAUGHTERY DOME: A CLOSER LOOK AT A CLASSIC FIELD EXERCISE

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Daughterly dome and related structures in south-central Oklahoma have been mapped by several institutions and thousands of geology students, and more than one interpretation has been published. No one is more vulnerable to embarrassment than an experienced instructor armed with published maps of a classic field exercise and years of proof of the solution from previous students. Under these circumstances it is difficult to accept contrary solutions even in the face of logical evidence. How can a bunch of rookies fail to understand such a beautiful area?

Two major faults have been omitted or mistakenly mapped in this region. A low-angle thrust along the southwestern nose of the dome and a high-angle reverse fault on the north-eastern flank demonstrate the direction of primary compressional stress. Assuming the accuracy of this interpretation, other structural features of the dome, which have been interpreted in various ways, can be reoriented to represent conjugate shear and the areal view demonstrates a natural view of a nearly perfect strain ellipse.

The rookies, far from destroying a beautiful area, have helped make a classic problem an even better training exercise. Any instructor using the area however, should be careful. Students not familiar with or unduly conscious of the way things are supposed to be, often discover evidence which can embarrass the over-confident field instructor.

INTEGRATED KARST MAPPING FOR ENVIRONMENTAL CONTROL ACTIVITIES, PALEOZOIC CARBONATE TERRANE, MISSOURI, U.S.A.

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Integrated karst mapping in the Paleozoic (Cambrian, Ordovician, and Mississippian) carbonate terrane of the Ozark Plateau of southern Missouri provides a basis for environmental control activities related primarily to groundwater quality. Current-cycle karst features mapped as sinkhole-drained areas, caves, and springs are superimposed on paleokarst mapped as filled sinks, clay pits, and pyrite deposits to formulate concepts of groundwater performance. Karst mapping is supplemented with water tracing, seepage runs, cave mapping, and scuba-diving mapping of springs to aid in developing strategies for environmental protection of the groundwater resource.

Speleological investigations including underwater mapping of large spring systems demonstrates active solution under phreatic conditions as deep as 100 meters, for distances as great as 50 kilometers, and travel rates of more than 2.5 kilometers per day. Such conditions make extensive knowledge of karst essential to environmental control decision-making.

USE OF THE BIOSIS DATABASE TO RETRIEVE GEOLOGY-RELATED INFORMATION

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The BIOSIS database, a major worldwide life science information service, is a rich source of information to geologists. The file, dating back to 1926, today contains over 4 1/2 million citations. Geologists can turn to BIOSIS for information on a large variety of subjects relevant to paleontology, ecology, energy, health, pollution, and soil science. These areas will be discussed in detail. The discussion will also point out any access points BIOSIS offers to the geologist, for example, specific codes to identify geologic time periods. In conclusion, examples of search questions and results will be presented.

MELTING RELATIONS OF AENIGMATITE

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Aenigmatite (= cossyrite) is a common phase in peralkaline lavas and intrusives, and is also found in some late-stage basaltic pegmatoids. Because it melts over a narrow temperature range, its presence can provide upper temperature limits for the magmas precipitating it. Melting relations were determined for two synthetic aenigmatites: ideal $\text{Na}_2\text{Fe}_2\text{Ti}_2\text{Si}_2\text{O}_{20}$, and "dirty" aenigmatite containing (in wt.%) MnO (1.15), CaO (0.55), MgO (0.49) and Al_2O_3 (0.24), corresponding to a natural sample from Pantelleria (Zies, 1966, Am. Min. 51, 200). Reversed melting experiments were performed in vacuo and at $\text{P}_{\text{H}_2\text{O}} = 0.5, 1$ and 2 kb (FMQ buffer). The melting temperatures ($^{\circ}\text{C}$) for ideal and "dirty" synthetic aenigmatite are listed below:

	$\text{P}_{\text{H}_2\text{O}}$ (kb)	0	0.5	1	2
Ideal		880-900*	810-825*	780-825*	760-780*
"Dirty"	First Liq.	<855*	800-807*	775-790*	730-755*
	Last Aen.	902-910*	<847*	825-840*	810-845*

Ideal aenigmatite melts incongruently to the assemblage $\text{Usp}_{\text{SS}} + \text{Ilm}_{\text{SS}} + \text{liquid} + \text{fayalite}$ (1 amphibole in hydrothermal runs; believed to be quench material). As would be expected, melting occurs at lower temperatures as $\text{P}_{\text{H}_2\text{O}}$ increases. "Dirty" aenigmatite begins melting at lower temperatures than ideal aenigmatite but coexists with its melt products over a temperature range of $\sim 50^{\circ}\text{C}$. The melting reaction is

similar, with fayalite formed at 0 kb, but not at 1 and 2 kb. These results indicate that crystallization temperatures of aenigmatite in peralkaline extrusives are $<902-910^{\circ}\text{C}$. Maximum temperatures for hypabyssal rocks containing aenigmatite could be as low as $\sim 800^{\circ}\text{C}$, depending on $\text{P}_{\text{H}_2\text{O}}$.

CATASTROPHIC ROCKSLIDE-AVALANCHE OF MAY 18, 1980, MOUNT ST. HELENS VOLCANO, WASHINGTON

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Following a 2-month period of outward movement of the north flank and a progressive loss of cohesion associated with magmatic injection and numerous transient fluid-pressure and seismic pulses, a rockslide-avalanche of about 2 km^3 was released as part of the 08:32 May 18 eruption of Mount St. Helens. The mass detached from a zone 3 km long by 1.3-2.4 km wide, which extended from the 2940-m summit down the north flank to an elevation of about 1500 m; the coup de grace apparently involved elevated fluid pressures and a magnitude-5 earthquake. Within minutes the avalanche surmounted a 300-m ridge, indicating a peak velocity in excess of 50 m/s (friction coefficient 0.16). Part of the avalanche displaced Spirit Lake, but the main lobe descended the north fork of the Toutle River valley on a 3 percent slope for about 22 km to an elevation of 370 m, depositing as much as 100 m of angular heterolithic breccia with a granular, low-cohesion gravel-sand lithic matrix (SG 1.6-1.8). Morphological features include levees, transverse waves, subsidence depressions, and horst-like hummocks that have local relief of as much as 50 m. The moving avalanche was overrun by a volcanogenic "blast" that stripped organic cover and deposited lapilli and ash on ground over which the avalanche soon passed. Thin blast deposits (SG 1.6-1.8) also veneer parts of the avalanche surface, as do younger, locally thick pumice flows (SG 1.3). Subsequent to emplacement, a sequence of thin mudflows (SG 1.7-1.9) moved across much of the avalanche surface and contributed to massive downvalley sedimentation along the Toutle and Cowlitz Rivers.

METAMORPHISM OF SCANDINAVIAN CALEDONIAN STRATABOUND SULPHIDE DEPOSITS

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Recent work on the stratabound polymetallic pyritic sulphide ores of the Scandinavian Caledonides has begun to define their paleo-geographic and paleotectonic environments of deposition more exactly. In Norway especially, evidence has been accumulating to define two main types of environments: 1) Constructive plate margin or spreading ridge where the host lithologies are ocean floor tholeiitic basalts, often associated with other units of ophiolitic nature. 2) Consuming plate (destructive) margin with host lithologies of island arc tholeiites, mixed with greater or lesser proportions of volcanoclastic and other sediments.

Both the original nature of the sulphide deposition and the effects on them of later metamorphism and tectonism seem to be dependent on their original depositional environment. The ophiolite-hosted deposits are most often of a proximal character, show non-stratiform morphologies and, along with their now obducted host lithologies, have been preserved in a relatively low metamorphic state, though they are often deformed by folding.

The island arc type deposits show both proximal and distal characters, plate-like to stratiform original morphologies, and strong metamorphic and deformational effects. They are typically thoroughly recrystallized and show the effects of through-going plastic deformation. Morphologically the deformation has often resulted in greatly elongated forms, which are oriented parallel to the general lineation direction in the host rocks.

PROGRESSIVE DEFORMATION, FOLD ROTATION AND MELANGE FORMATION IN MIDDLE ORDOVICIAN FLYSCH NEAR ALBANY, NEW YORK

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Accretionary processes in trenches have only been observed indirectly. An analogous environment existed when flysch deposits were deformed in front of the advancing Taconic allochthon. Austin Glen greywackes and shales show an eastward increase in deformation intensity leading to melange formation adjacent to the Taconic front. Twelve to fifteen km west of the allochthonous rocks bedded flysch is virtually undeformed. Eastward are east-dipping zones of thrusting and kink or asymmetric folding including one narrow zone of dismembered arenite in a phacoidally cleaved shale; interpreted as a zone of high shear strain. Nearer the Taconic front large, moderately to steeply plunging and steeply SE inclined folds are common. Hinges are often sheared and some folds are downwards facing. Large areas consist of disrupted greywacke beds, including fold hinges, in a phacoidally cleaved shale. Fold hinge lines become more easterly trending toward the Taconic front, particularly in the phacoidally cleaved shales where shear strains may have been higher. Horizontal hinge lines have probably been rotated towards "transport direction" in zones of high shear strain. Nearest the Taconic front exotic blocks

Pantellerite liquids and their phenocrysts.

By I. S. E. CAMERON, M.A.

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[Read 2 November 1961.]

Summary: The phenocrysts of four porphyritic obsidians from Pantelleria have been analysed chemically, together with the residual glasses (liquids). Three new analyses of anorthoclase (one partial analysis), two of sodic ferrotrochilite, one of fayalitic olivine, and two of coesynite are presented together with their optical properties, and the relationship of these phenocrysts to their liquids is considered.

The experimental studies in the system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - SiO_2 - H_2O show that for synthetic liquids of similar composition to the normative salt constituents of the pantellerite liquids, a potassic alkali feldspar crystallizes, whereas in the pantellerite liquids phenocrysts of anorthoclase (Ab_{97} - Ab_{10}) occur. It is suggested that sodium metasilicate, which appears in the norms of all the pantellerite liquids, may be responsible for the divergence in trend between the synthetic feldspar-liquid tie-lines and the pantellerite feldspar-liquid tie-lines.

THE Mediterranean volcanic island of Pantelleria has long been famous for its unusual peralkaline rhyolites and obsidians, which were first described and named pantellerite by Förstner (1881, 1884), the island becoming in consequence the type locality. Washington (1913) visited the island and he has also given an account of its geology, together with many chemical analyses and detailed petrographic descriptions illustrating the pantellerites, which are associated with the closely related comendites (a silica-rich iron-poor pantellerite (Lacroix, 1930)), with trachytes, and with later alkali olivine-basalts that may contain normative nepheline (Washington, 1914). Similar associations are found, for example, in Kenya, where pantellerites, comendites, and trachytes occur with nepheline-bearing basalts, mugearites, phonolites, and kenytes (Campbell Smith, 1931).

Comendites and pantellerites, however, are of widespread distribution, being found in the deep oceanic areas (Broch, 1946; Tilly, 1950), in Sardinia (Johnsen, 1912), in the old French territories of West Africa and Equatorial Africa (Lacroix, 1934; Koch, 1955), in Nigeria (Jacobsen *et al.*, 1958), in Abyssinia (Lacroix, 1930), in Madagascar (Lacroix, 1923), and in Australia (Jensen, 1906) and New Zealand (Marshall, 1936). The Venozio alkaline province that surrounds the sea of Japan also includes comenditic and pantelleritic representatives (Aoki, 1959; Lacroix, 1927;

Nemoto, 1934; Tomita, 1935), and the psammite rhyolites of Texas (Frost, 1964) show close affinity to many comendites.

A typical pantellerite is porphyritic with phenocrysts of anorthoclase and sometimes quartz, together with coesynite (believed to be synonymous with aenigmatite), a sodic pyroxene, and occasional olivine. The groundmass may be glassy (microfitic) or a finely crystalline intergrowth of feldspar and a silica mineral, together with needles of arginine and coesynite.

However, it is the chemical composition of pantellerites that has attracted the attention of petrologists since Washington published his analyses, for so great is the molecular excess of soda over alumina (which is characteristically low) that the CIPW norm requires the rare mineral molecule sodium metasilicate (*ms*) to be formed, the occurrence of which has been discussed by Hayes (1960) and Tuttle (1960). Since the re-analysis of two of Washington's specimens by Zies (1960) there can now be no doubt of the existence of this unusual normative molecule.

It is the purpose of this paper to present the results of a study of four porphyritic pantellerites from Pantelleria, their phenocrysts, and their residual glasses, and an attempt is made to compare the unusual chemical composition of the pantellerites with the relevant synthetic silicate systems in order to understand better these rather unusual and enigmatic natural liquids.

Petrography.

Washington (1913) has already published a detailed petrographic account of the pantellerite obsidians (hytopantellerites) and this is amplified here for the analysed specimens. The specimens available for examination (see key to tables, p. 90) were obtained from the collections of the Imperial College of Science, and were apparently purchased many years ago. In hand specimen the black obsidians are vesicular, brightly lustrous, and apparently completely fresh.

One obsidian (1B) contains abundant phenocrysts of anorthoclase (1F) together with a sodic pyroxene (1) and a fayalitic olivine (1B), the last two tending to form clusters together with ilmenite. The pyroxene, which is distinctly pleochroic from bright emerald green to brown tinged with green, may be euhedral and is rarely trimmed. Zoning is not detectable, and the pyroxene tends to enclose or be surrounded by crystals of ilmenite, which are invariably smaller than the silicate phenocrysts. Olivine, which is also a common phenocryst, may enclose or be surrounded by crystals of ilmenite. Coesynite has not been found in thin

sections of this specimen, but is sparsely present in the heavy mineral concentrates. Anorthoclase is the commonest phenocryst mineral in all the obsidians, and may be of very variable size. The large subhedral phenocrysts may show patchy extinction, and are commonly twinned on the $\{111\}$ or $\{110\}$ planes. Small fragments of feldspar of all sizes suggest by their shape that they have formed by the mechanical breakdown of the larger phenocrysts, probably as a result of flow of the viscous obsidian.

The glass (4G) that encloses these phenocrysts contains microclites of feldspar ($Ab_{65}Or_{35}$)¹ that are larger and more abundant than in any of the other glasses. Microclites of aegirine are sparsely scattered throughout the pale-brown glass together with a few small stumpy crystals of coesynite and minute crystals of zircon.

Several of the obsidians likewise contain numerous feldspar microclites in the glass, together with needles of aegirine, and in 2R the glass (2G) encloses large phenocrysts of coesynite (2A), which show intense absorption from deep red-brown to black. Olivine and ilmenite phenocrysts are rare, and the glass also contains infrequent coarse patches of quartz and feldspar in granophyric intergrowth (Lacroix, 1930, p. 93), together with independent poorly shaped phenocrysts of quartz. The larger phenocrysts of anorthoclase (2F) often form clusters and also show considerable variation in size. The phenocrysts of pyroxene (2) may similarly form clusters with fayalite, ilmenite, and anorthoclase.

Quartz and coesynite (3A) are common phenocrysts in 3R and are enclosed together with anorthoclase (3F) in a glassy groundmass (3G) almost free of feldspar microclites. Olivine and ilmenite are absent in the heavy mineral concentrates, and pyroxene seems unusually scarce. Phenocrysts of all minerals are rare in 4R, feldspar (4F) being the most abundant, and fayalite, pyroxene, ilmenite, and rarer coesynite are enclosed in a glass (4G) that has rare feldspar microclites but common birefringent spicules.

In 5R the glassy groundmass of the obsidians is replaced by a very fine-grained crystalline intergrowth of feldspar ($Ab_{53}Or_{47}$) and a silica mineral, the groundmass also containing small needles of aegirine and small equant crystals of deep red coesynite. The groundmass encloses phenocrysts of anorthoclase ($Ab_{62}Or_{38}$)¹ quartz, acicular pyroxene with a deep green outer zone, and coesynite, the deep red core of which is enclosed by a deeper, almost black, outer zone of coesynite. Near the

¹ The compositions of these feldspars were determined by the β 01 method (Bowen and Tuttle, 1950).

phenocrysts the groundmass tends to be coarser and more completely crystalline, and may grade into less well-crystallized areas with little aegirine or coesynite, but with abundant birefringent patches of pale yellow partially devitrified glass. In parts of the rock, the pale yellow colour of the less well-crystallized areas of the groundmass may grade to a reddish colour, which is presumably due to the oxidation of iron contained in these partially devitrified patches.

The trachyte obsidian from Pitcairn Island (6R) contains rare phenocrysts of alkali feldspar, rare ferroaugite and iron-rich olivine, together with micro-phenocrysts of magnetite. The dark-brown glass, which contains a few scattered feldspar microclites, may also enclose xenoliths of olivine basalt, mugearite, or trachyte.

The modal analyses of the analysed specimens are given in table I, and although five or six thin sections of each specimen were counted, the ferromagnesian minerals are so unevenly distributed throughout the obsidians that the determined ferromagnesian modal content is perhaps best considered as an order of magnitude.

The ferromagnesian phenocrysts of these pantelleritic obsidians have many features in common. The olivine is usually the largest of the ferromagnesian phenocrysts, although it may show considerable variation in size; it is feebly idiomorphic and completely fresh with no visible alteration in the fracture cracks or the frequently well-developed cleavage. Microphenocrysts of ilmenite may be enclosed by the olivine phenocrysts or be associated with them in clusters with pyroxene. Microscopically the grains of olivine are coloured pale amber and show a pale yellow colour in thin section, with feeble but distinct pleochroism.

The pyroxenes, which are completely fresh, are a deep greenish-black under the binocular microscope, and unless the grains are small are easily mistaken for coesynite. The distinctive pleochroism noted above is common to all the pyroxenes examined, and varies little, if at all, in intensity except in 5R. Simple twinning is not common, and there is no microscopic evidence of exsolution. The pyroxenes may be idiomorphic, but are commonly ill shaped, show a wide variation in size, and in those from the obsidians zoning cannot be detected.

The coesynite phenocrysts are very distinctive with their intense absorption (deep red-brown to black) and moderately high birefringence. One well-developed cleavage is seen, and rare sections show a poorly defined second cleavage. Coesynite usually forms large phenocrysts, which may be subidiomorphic with a shape (eight-sided polygon) not unlike a pyroxene, and it always appears completely fresh.

Magnetite as microphenocrysts is almost completely absent from all the panteleferites examined, but may occur as minute grains in the glasses. A small fraction was obtained by hand magnet from two samples, and the weight of sample so obtained indicates a magnetite concentration of 20 to 50 p.p.m.

TABLE I. Modal analyses (volume per cent.).

Glass.	For the key to these analyses, see below.				From		
	Feldspar.	Quartz.	Pyroxene.	Olivine.		Cassidite.	oxides.
1R (5748)	88.2	10.7	—	0.5	0.4	trace	0.2
2R (3112)	80.6	18.0	0.1	0.3	trace	0.9	trace
3R (5749)	87.6	9.4	2.0	—	—	0.9	—
4R (3114)	98.7	1.2	—	—	—	—	—
5R (5750)	85.0*	10.4	3.6	—	—	0.8	—
6R (12005)	99.3	0.6	—	0.1	—	—	trace

* Microcrystalline groundmass.

KEY TO TABLES I-VIII.

1	Sodic ferrohedenbergite from obsidian, Panteleferia, 5748.	4F	Anorthoclase from obsidian, Panteleferia, 3114.
1B	Fayalite from 5748.	4G	Residual glass from 3114.
1F	Anorthoclase from 5748.	4R	Porphyritic obsidian 3114.
1G	Residual glass from 5748.	5R	Porphyritic microcrystalline panteleferite, Panteleferia, 5730.
1R	Porphyritic obsidian 5748.	6R	Trachyte obsidian, Pitcairn Island, 12095.
2	Sodic ferrohedenbergite from obsidian, Panteleferia, 3112.	C	Aegirine-hedenbergite from Skye alkali granite (Tilley, 1949).
2A	(Cossyrite from 3112.	D	Ferroaugite from quartz-syenite (coexisting with olivine) (Hess, 1949, p. 654; Buddington, 1939, p. 120).
2F	Anorthoclase from 3112 (Car-michael, 1960b, table III).	E	Hyalopanteleferite (P.R.C. 2000; Zies, 1960, p. 307).
2G	Residual glass from 3112 (Car-michael, 1960b, table V).	F	Hyalopanteleferite (P.R.C. 2007; Zies, 1960, p. 307).
2R	Porphyritic obsidian 3112.		
3A	Cossyrite from obsidian, Panteleferia, 5749.		
3F	Anorthoclase from 5749.		
3G	Residual glass from 5749.		
3R	Porphyritic obsidian 5749.		

Analyses 1 to 6R by I. S. E. Carmichael.

Mineral analyses.

The ferromagnesian phenocrysts were separated on the Prantz isodynamic separator followed by repeated centrifuging in Clerici solution, and if necessary were then hand-picked under a binocular microscope. The elimination of cossyrite impurity from pyroxene was troublesome, as was the separation of fayalite from ilmenite, and effective separation on the small quantities of concentrates obtained could only be made by

hand-picking. The feldspars and residual glasses were initially separated on the Prantz separator followed by centrifuging in methylene iodide.

Whereas several grams of feldspar were separated and used for gravimetric analysis, only small quantities of the pyroxenes and olivine were obtained, and their chemical analyses were made on a semi-micro scale on a total sample of 100 mg or less. Ilmenite and magnetite are rare

TABLE II. Analyses and optical properties of the sodic ferrohedenbergite and fayalite phenocrysts.

	For the key to these analyses, see p. 90.				
	1.	2.	C.	D.	I.B.
SiO ₂	48.38	48.69	49.69	48.28	30.56
TiO ₂	0.71	0.86	0.43	0.28	0.72
Al ₂ O ₃	2.06	2.04	0.48	1.45	0.09
Fe ₂ O ₃	5.69	5.60	8.79	3.96	0.10
FeO	20.15	21.96	18.23	27.02	60.81
MnO	1.31	1.25	0.25	0.76	3.43
MgO	2.67	0.89	1.98	0.32	3.47
CaO	16.93	16.36	16.87	16.18	1.13
Na ₂ O	2.31	2.86	3.79	1.51	—
K ₂ O	0.09	0.09	ml	0.14	—
Total	100.30	100.60	100.53	100.20*	100.31

* Includes H₂O-0.15%, H₂O-0.15%.

and only 20 to 30 mg of magnetite was obtained from approximately 1 kg of rock, and no attempt was made to analyse these iron-titanium oxides.

Pyroxene and olivine phenocrysts. Only two pyroxenes and one olivine were successfully separated in sufficient quantity for analysis, and the results are set down in table II (nos. 1, 2, and 1B). The two pyroxenes are sodic ferrohedenbergites and their analyses have been recalculated into the standard formula (Fe^xY^z)Z₂O₆ (table III) by the method described by Hess (1949, p. 625). Thus instead of making Z = 2 by adding arbitrary amounts of Al, and where necessary Ti, to Si, the cations are allotted to groups in accordance with the balance of charge on a cation for cation basis.

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The pyroxene formulae (table III, nos. 1 and 2) show that the incorporation of Na into the pyroxene structure is almost matched by the incorporation of an equivalent amount of Fe^{2+} . There is, however, a small deficiency of Fe^{2+} in relation to Na + K, which is compensated for by Al to balance the structure. A small amount of Ti is found in tetrahedral coordination in the most iron-rich pyroxene (table III, no. 2) and also in a sodic ferrohedenbergite from the alkalic facies of a Tertiary Skye granite (Tilley, 1949) (table III, no. C). As Brown (1957,

TABLE III. Structural formulae of analysed pyroxenes and olivine. (Pyroxenes on the basis of 6 oxygens, fayalite on the basis of 4 oxygens.)

	For the key to these analyses, see p. 90.					
	<i>T</i>	<i>2</i>	<i>C</i>	<i>D</i>	<i>IB</i>	
Si	1.934	1.950	1.973	1.976	0.996	—
Al	0.064	0.038	—	0.040	0.004	—
Ti	—	0.007	0.014	—	—	—
Tl	0.021	0.019	—	0.008	0.018	—
Al	0.032	0.058	0.026	0.029	—	—
Fe^{2+}	0.172	0.168	0.252	0.123	0.004	—
Fe^{3+}	0.679	0.737	0.696	0.924	1.659	—
Mn	0.043	0.043	0.010	0.026	0.094	—
Mg	0.158	0.117	0.117	0.020	0.169	—
Ca	0.723	0.703	0.718	0.708	0.039	—
Na	0.221	0.177	0.291	0.120	—	—
K	0.005	0.005	—	0.007	—	—
Z	1.968	1.965	1.987	2.016	1.000	—
RY ¹	2.001	2.007	2.030	1.965	1.983	—
Percent Al in Z	3.2	1.9	—	2.0	—	—
Percent Ti in Z	—	0.3	0.7	—	—	—

p. 518) has pointed out, the inclusion of Ti in the Z group is not necessarily due to a high content of Ti, but rather to low Al and possibly a high content of Na + K. The concentration of Ti in these panteleitic sodic ferrohedenbergites is higher than the average (0.56%) found in a series of pitchstone ferroaugite phenocrysts (Carmichael, 1966a, table II), and Al is similarly higher than the ferroaugite average (1.4%) although tetrahedrally coordinated Al in both groups is similar.

The variation of (Ca, Mg, and Fe in these pyroxenes is shown in fig. 1. The variation of (Ca, Mg, and Fe in these pyroxenes is shown in fig. 1 together with the composition (as Mg:(Fe+Mn)) of the associated fayalitic olivine. The panteleitic pyroxenes and the Skye sodic ferrohedenbergite have similar (Ca:(Mg+Fe)) ratios to the ferroaugites and ferrohedenbergites of the Skaergaard intrusion (Muir, 1951; Brown, 1960) and to the ferroaugite phenocrysts of some North Atlantic Tertiary pitchstones (Carmichael, 1960a, fig. 1). If, as Muir (1951) suggests, pyroxenes on crossing the limit of the two-pyroxene field crystallize of

a liquidus minimum, then this minimum would seem to have a similar position with respect to Ca:(Mg+Fe) for pyroxenes crystallizing with notable amounts of Na (fig. 1, nos. 1, 2, and C) as for the tholeiitic pyroxenes that contain only negligible amounts of alkalis.

The increase of Na that may occur with the progressive iron-enrichment

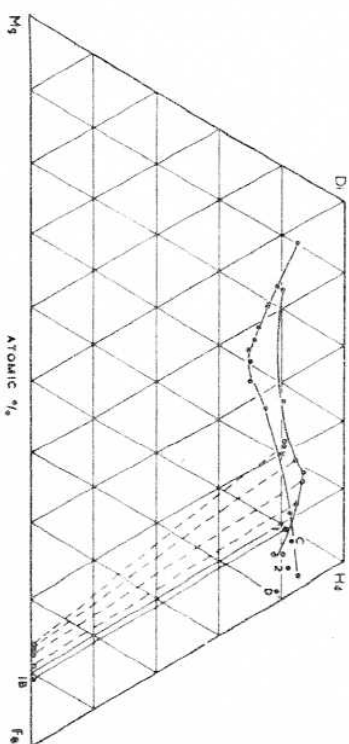


FIG. 1. The composition of sodic ferrohedenbergites plotted with respect to variation in Ca, Mg, and Fe. Solid circles Nos. 1 and 2 (table II) are panteleitic phenocrysts, and C and D are alkali-granite and quartz-syenite pyroxenes respectively (table II). The co-existing panteleitic pyroxene and olivine (plotted as Mg:(Fe+Mn)) are joined by a solid line (Nos. 1 and 2, table II). ●—●—● Skaergaard calcium-rich pyroxene trend (Brown, 1957, 1960); ○—○—○ pitchstone calcium-rich pyroxene trend, with the relevant pyroxene-olivine pairs joined by dashed tie-lines (Carmichael, 1966a, fig. 1).

of the calcium-rich pyroxenes cannot be seen in the conventional Ca, Mg, and Fe pyroxene diagram. Accordingly, in fig. 2 the alkali content of various series of calcium-rich pyroxenes has been plotted in order to illustrate such an increase of Na with progressive iron-enrichment. The formulae of the pyroxenes have been recalculated in terms of (Na+K), Mg, and (Fe²⁺+Mn+(Fe³⁺)), the last term (Fe³⁺) being the excess, if any, of trivalent iron over Na+K. This procedure is more simple than that described by Yagi (1953), which necessitates the arbitrary formation of standard pyroxene molecules.

The tholeiitic trend represented by the calcium-rich pyroxenes of the Skaergaard intrusion (Brown, 1957, 1960) (fig. 2) shows a small decrease in Na as the early magnesian augites become progressively impoverished in Ca, and only in the latest stages of iron-enrichment does Na show a small increase. The ferroaugite phenocrysts of a series of pitchstones (Carmichael, 1960a) also show an increase in soda with progressive

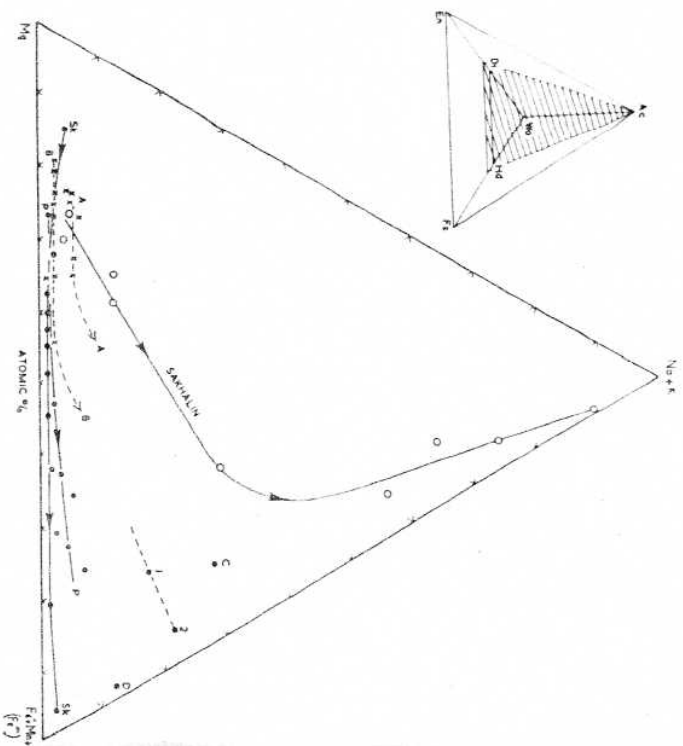


Fig. 2. The crystallization trends of various calcium-rich pyroxene series. *Sk* (crosses) represents the Skaergaard trend (Brown, 1957, 1960); *P* (circles) is the pitchstone pyroxene phenocryst trend (Carmichael, 1969a); *A* and *B* (dots) are the pyroxene trends of a differentiated teschenite sill (Wilkinson, 1957) and the Garbh Eilean sill, Shant Isles (Murray, 1954) respectively; the Sakhalin trend represents the pyroxenes from a differentiated dolerite-monzonite-syenite series (Yagi, 1953). Solid circles are sodic ferrohedenbergites (Nos. 1 and 2, pantellerite phenocrysts); *C* and *D*, alkali-granite and quartz-syenite pyroxenes, (table II). (Fe^{ex}) is the excess of Fe^{2+} over that required to combine with $Na+K$ in the calcium-rich pyroxene formulae. The inset figure shows the generalized relationship of the plane $Mg, Na+K$, and $Fe+Mn+(Fe^{ex})$ for the calcium-rich pyroxenes to the pyroxene tetrahedron enstatite (*En*), ferrosilite (*Fs*), wollastonite (*Wo*), and aegirite (*Ae*).

iron-enrichment, and are typically richer in soda than the Skaergaard ferrogaites. The two pantelleritic sodic ferrohedenbergites (nos. 1 and 2) are considerably enriched in Na compared to the tholeiitic pyroxenes, and their trend, which shows concomitant enrichment in Na, Fe^{2+} , and Fe^{ex} , cannot be considered to be a continuation of the pitchstone ferroaugite trend (cf. fig. 1), which, however, may continue to a pyroxene similar to

D (table II, figs. 1 and 2), a mildly-alkaline sodic ferrohedenbergite occurring with a fayalitic olivine in an Adirondack quartz-syenite (Hess, 1949, no. 19) (Buddington, 1939, p. 120). It is possible that the outermost zones of aegirine and aegirine-augite noted by Wilkinson (1957) in a series of Ti-rich sabbites (fig. 2) from a differentiated teschenite sill may generally correspond in composition to these pantelleritic sodic ferrohedenbergites. In a similar way, the green outer zones of the pyroxenes in the peritic pegmatites of the Shant Isles (Murray, 1954) may also show a trend in this direction (fig. 2).

The series of Ti-rich augites, sodion augites, aegirine-augites, and aegirines described and analysed by Yagi (1953) from a genetic series of dolerites, monzonites, and syenites illustrates a more extreme type of alkali enrichment (fig. 2). In a detailed discussion of the solid-solution relationships in pyroxenes, Yagi (op. cit., p. 798) suggests that aegirite and diopside may form a complete solid-solution series with $NaFe^{ex}$ replacing $CaMg$ in the pyroxene structure, and he later (Yagi, 1958) provides data on the synthesis of such pyroxenes. So far as is known to the writer, there is no experimental data on the existence of a solid-solution series between aegirite and hedenbergite, but the calcium-rich pyroxene analyses plotted in fig. 2 suggest that this solid-solution series does exist and is more common in natural pyroxenes than that between diopside and aegirite. Perhaps it may be taken that this solid-solution series does occur in natural calcium-rich pyroxenes, and in consequence it may be expected that pyroxene phenocrysts in equilibrium with acid or saline liquids will tend to be enriched in $CaFe^{ex}$ in relation to the pyroxene components ($NaFe^{ex}$) in the liquid. A similar conclusion was reached by Hyrönen (1959, pp. 85-88) with regard to aegirine-augite occurring both as phenocrysts and in the groundmass of a natrolite tinguaite. It therefore seems unlikely that crystals of pure aegirite will occur as phenocrysts in quickly cooled saline liquids, unless they are products of the synthetic reaction relationship of hematite (magnetite in nature) to liquid (Bowen *et al.*, 1930).

The analysis of the fayalitic olivine is given in table II (no. 1B) and its formula in table III (no. 1B). The olivine contains an unusually high content of Mn and Ca compared to the pitchstone ferrohedenbergite phenocrysts (Carmichael, 1969a, table 4), and although the content of Mn may be related to the high content of Mn in the liquids (table VI,

1. J. Nolan (personal communication) has found that a reaction relationship exists between magnetite and liquid to give aegirite in hydrothermal experiments in the system $NaAlSi_3O_8-NaFeSi_3O_6$.

nos. 16-4(3), there seems to be no good reason for the high n_c and the writer cannot at the moment provide a solution. In relation to the coexisting pyroxene (table II, no. 1), the olivine is enriched in Mn and Fe, and the tie-line between the two (fig. 1) is parallel to those found for coexisting pigeonite-ferropigeonite-ferrohornblende phenocryst pairs (fig. 1).

Cossyrite phenocrysts. Phenocrysts of cossyrite occur in all the analysed rocks from Pantelleria, but in rather variable amounts (table I). It is

TABLE IV. Analyses and optical properties of the cossyrite phenocrysts. Refractive indices ± 0.0005 .

	For the key to these analyses, see p. 90.			
	24.	34.	a.	b.
SiO ₂ ...	41.02	40.97	41.54	30.82
TiO ₂ ...	8.92	8.83	10.04	8.82
Al ₂ O ₃ ...	0.94	0.89	—	—
Fe ₂ O ₃ ...	1.31	1.19	—	8.82
FeO ...	38.84	38.86	40.63	35.70
MnO ...	1.16	1.08	—	—
MgO ...	0.07	0.54	—	—
CaO ...	0.45	0.55	—	—
Na ₂ O ...	7.36	6.93	7.79	6.84
K ₂ O ...	0.06	0.08	—	—
H ₂ O ⁺ ...	—	ml	—	—
H ₂ O ⁻ ...	—	0.07	—	—
Total ...	100.13	99.99	100.00	100.00
α ...	1.795	1.793	—	—
β ...	1.805	1.804	—	—
γ ...	1.87	1.87	—	—

^a Calc. for $2\text{Na}_2\text{O} \cdot 9\text{FeO} \cdot 2\text{TiO}_2 \cdot 11\text{SiO}_2$.

^b Calc. for $2\text{Na}_2\text{O} \cdot 9\text{FeO} \cdot 2\text{TiO}_2 \cdot 12\text{SiO}_2$ (Fleischer 1936).

commonly the most abundant ferromagnesian silicate, and as it is comparatively easy to separate it is not surprising that this occurrence of the mineral has long claimed the attention of mineralogists. Cossyrite is a mineral of intense absorption (deep red-brown to black), rather high birefringence (Bowen, 1937), and high refractive index (table IV).

Fleischer (1936) has collected the chemical and X-ray data of cossyrite (= aenigmatite) and has suggested a formula for this triclinic mineral. It is not, as was believed, related to the amphiboles, and does not contain essential water (table IV) although it is possible that small amounts of F or Cl may exist in the structure, as these two elements were not sought in the analyses. Fleischer's generalized formula is $X_4Y_{13}(\text{Si}_2\text{O}_7)_6$, which as a special case might become $\text{Na}_4\text{Fe}^{\text{Fe}}_9\text{Fe}^{\text{Ti}}_2\text{Si}_{12}\text{O}_{42}$, to which many of his analyses made a close approach. The two new analyses presented in table IV are very similar to one another, and not unlike many of the

analyses compiled by Fleischer (1936, table I). However, the two new analyses contain much less Fe_2O_3 than many others, and would seem to approach more closely the formula $\text{Na}_4\text{Fe}^{\text{Fe}}_9\text{Ti}_2\text{Si}_{11}\text{O}_{42}$ than Fleischer's formula (table IV).

The paragenesis of cossyrite in these obsidians may give an indication of its thermal stability. As a result of comparing the heavy mineral concentrates obtained from these obsidians the author believes that the assemblage fayalite plus ilmenite is generally antipathetic to the existence of cossyrite. Certainly the amounts of fayalite and ilmenite are drastically reduced when cossyrite is in relative abundance, and this antipathetic relationship could suggest that cossyrite may form by the reaction of fayalite ($2\text{FeO} \cdot \text{SiO}_2$) and ilmenite ($\text{FeO} \cdot \text{TiO}_2$) (or possibly ulvöspinel, $2\text{FeO} \cdot \text{TiO}_2$) with a sodium-rich liquid to give cossyrite. No petrographic evidence, however, has yet been found to suggest this reaction relationship, which, if it exists, may only be found in liquids having the unusual molecular excess of soda over ferric iron and alumina. Mere antipathy of the assemblages noted above does not necessarily imply a reaction relationship, and experimental investigation is clearly required.

Fleischer (1936) suggests that the mineral rhönite forms a solid solution series of the plagioclase type with cossyrite, (CaAl replacing the NaSi of cossyrite. If this is so then the analyses presented in table IV show a close approach to the cossyrite end-member.

Iron-titanium oxides. Ilmenite is the more frequent representative of the iron-titanium oxides in the pantelleritic obsidians (especially 1R), although its concentration would seem to fall with an increase in that of cossyrite. Magnetite is extremely rare and only 25 mg or so were obtained from each of two specimens indicating that its concentration is of the order of 20 to 50 p.p.m. Under the microscope the magnetite is quite homogeneous, with no exsolution of ilmenite or ulvöspinel, and the ilmenite is similarly undistinctive optically. The magnetites are generally extremely fine-grained, and would seem to represent a quench product of the silicate liquid, whereas ilmenite may form much larger microphenocrysts, with a distinctive hexagonal or elongate habit easily seen under the petrographic microscope. Through the kindness of Dr. R. J. Davis, the lattice dimensions of two magnetites and an ilmenite have been determined, and the results are set down below.

Ilmenite from 1R (5748) a 5.091 \pm 0.001, c 14.083 \pm 0.003 Å, c/a 2.766 \pm 0.001

Magnetite from 2R (3112) a 8.503 \pm 0.001 Å

Magnetite from 4R (3114) a 8.479 \pm 0.001 Å

Vincent *et al.* (1957, fig. 6), using Basta's data, show the continuous decrease in the cell-dimensions of ilmenite with increasing solid solution of α -Fe₂O₃. They also record the cell-dimensions of ilmenite lamellae intergrown with magnetite (Skærvaard) before and after heating *in vacuo*, and show that the lattice parameters of the ilmenite decrease in response to the increasing entry of α -Fe₂O₃; the cell-dimensions of this ilmenite before heating are larger than those given by Basta (in Vincent *et al.*) for pure ilmenite without α -Fe₂O₃, and the similarity of the cell-dimensions of the pantelleritic ilmenite to the unheated (i.e. no α -Fe₂O₃) Skærvaard ilmenite lamellae (*a* 5.088, *c* 14.082 Å, *c/a* = 2.770) indicates that the underlying cause may be common to both. Vincent *et al.* (1957, p. 641) suggest that appreciable Mn in solid solution in the ilmenite (as MnTiO₃) will tend to increase the cell-dimensions as may MgTiO₃, but the paucity of Mg in the liquid compared to Mn (table VI, no. 1B) suggests that MnTiO₃ may be responsible for the larger cell-dimensions of the pantelleritic ilmenite (coexisting fayalite (1B) contains 3.43% MnO), which like the Skærvaard ilmenite is unlikely to contain very much α -Fe₂O₃ in solid solution.

The cell-sizes of both the magnetites are unusually large and in view of the complexities of possible substitutions in the magnetite structure, and without a chemical analysis, it is only possible to speculate on the possible causes. Basta (1957) has determined the cell edge of pure magnetite as 8.396 Å and he also tabulates the cell-dimensions of the various spinels formed by elements that may enter the crystal structure of magnetite (op. cit., table III). Only Mn has a larger ionic radius than Fe²⁺, thus causing a marked increase in the cell-dimensions, and Basta reports a cell edge of 8.51 Å for MnFe₂O₄.

Ti-viospinel, Fe₂TiO₄, similarly has a larger unit cell than pure magnetite, the value for synthetic material being 8.495 Å, a value closely approached by the more complex natural ti-viospines (Vincent *et al.*, 1957). As these two combinations (MnFe₂O₄ and Fe₂TiO₄) seem to be the only ones capable of increasing the cell-size of magnetite, it can only be concluded that the pantelleritic magnetites contain considerable Mn or Ti or both.

The feldspar phenocrysts and the system KAlSi₃O₈-NaAlSi₃O₈-SiO₂-H₂O.

Only one feldspar, an anorthoclase, is found as phenocrysts in these pantellerites, and all the analysed specimens (table V) have generally similar optical properties. The anorthoclase phenocrysts of the analysed obsidians show only a small variation in composition, and are unusually

low in iron; iron, which is relatively high for sodium-rich feldspars, is taken to substitute for Al, and leads to a satisfactory formula balance (table V).

Before considering the pantelleritic feldspar-liquid relationships it is necessary to review the courses of equilibrium crystallization in the

TABLE V. Analyses, optical properties, and formulae (on the basis of 32 oxygens) of the feldspar phenocrysts. Refractive indices ± 0.002 , 21 $\pm 2^\circ$.

	For the key to these analyses, see p. 90.						Formulae	
	1F.	2F.	3F.	4F.	1F.	2F.		3F.
SiO ₂	66.71	66.75	67.18	—	Si	11.936	11.924	11.977
Al ₂ O ₃	18.86	18.84	18.54	—	Al	3.979	3.972	3.900
Fe ₂ O ₃	0.74	0.88	0.90	0.78	Fe ²⁺	0.107	0.129	0.128
CaO	0.03	0.06	0.04	—	Ca	0.005	0.011	0.007
BaO	—	0.08	—	—	Ba	—	0.004	—
Na ₂ O	7.64	7.41	7.27	7.91	Na	2.645	2.575	2.507
K ₂ O	5.92	6.12	6.46	5.59	K	1.355	1.395	1.478
H ₂ O ⁺	0.15	0.18	0.15	—				
H ₂ O ⁻	nil	0.09	nil	—				
Total	100.05	100.41	100.54	—	Σ	16.02	16.02	16.00

Composition (recalculated to 100 wt. per cent.)

Or	35.2	36.3	38.4	32.8
Ab	64.7	63.2	61.4	67.2
An	0.1	0.3	0.2	—
Ch	—	0.2	—	—
α	1.525	1.525	1.526	1.524
β	1.529	1.529	1.530	1.528
γ	1.530	1.530	1.532	1.529
$2\gamma'$	43°	45°	43°	41°

Composition by X-ray, 301 method

	Or ₉₆	Or ₈₇	Or _{77.5}	Or _{61.5}
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system NaAlSi₃O₈-KAlSi₃O₈-SiO₂-H₂O, which have been discussed in detail by Tuttle and Bowen (1958). Equilibrium crystallization of a liquid whose composition is represented by X (fig. 3) will begin with the precipitation of a feldspar slightly more sodic than Y, and with continued crystallization (cooling) the liquid will move on a curved course to Y', at which point the feldspar crystals will have the composition Y. As quartz (or a silica mineral) will start to crystallize when the liquid has reached the quartz-feldspar boundary curve at Y', the join Y'Y' is both a tie-line and a three-phase boundary. With further cooling, the liquid will move along the boundary curve towards the ternary minimum M, while the crystals of feldspar continuously react with the liquid and become more potassic than Y.

TABLE VI. Analyses of pantellerites and residual glasses. For the key to these analyses, see p. 90.

	1R.	1G.	2R.	2G.	3R.	3G.	4R.	4G.	5R.	E.	F.	6R.
SiO ₂	67.5	69.9	68.6	70.1	69.7	70.5	69.2	69.8	69.3	69.81	69.56	63.0
TiO ₂	0.49	0.54	0.46	0.41	0.38	0.35	0.52	0.52	0.39	0.45	0.47	0.60
ZrO ₂ *	0.22	0.20	0.24	0.28	0.30	0.27	0.21	0.20	0.28	0.25	0.12	0.11
Al ₂ O ₃	12.0	8.8	9.2	7.6	9.1	7.6	10.9	10.7	9.0	8.59	11.27	15.8
Fe ₂ O ₃	1.8	2.1	2.7	2.9	2.2	2.0	2.0	2.0	5.1	2.28	1.87	2.6
FeO	4.0	5.9	5.3	5.6	4.9	6.3	4.0	4.0	2.3	5.76	4.18	3.3
MnO	0.21	0.30	0.31	0.34	0.26	0.32	0.29	0.30	0.28	0.28	0.28	0.18
MgO	0.13	0.13	0.11	0.04	0.07	0.03	0.24	0.23	0.49	0.10	0.23	0.42
CaO	0.50	0.52	0.54	0.53	0.39	0.39	0.44	0.43	0.78	0.42	0.44	1.9
Na ₂ O	6.9	6.5	6.8	7.1	6.9	7.0	6.5	6.5	4.8	6.46	6.28	6.4
K ₂ O	5.2	4.7	4.6	4.6	4.8	4.6	4.9	4.8	4.6	4.49	4.60	5.1
P ₂ O ₅	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.05	0.03	0.13	0.10	0.12
H ₂ O ⁺	0.38	0.04	0.32	0.23	0.33	0.05	0.22	0.17	1.0	0.14	0.13	0.24
H ₂ O ⁻	0.02	nil	0.03	0.04	0.01	nil	0.02	0.01	1.2	0.05	0.02	0.03
Cl	(0.62)†	0.70	(0.56)	0.69	(0.72)	0.82	(0.30)	0.31	0.04	0.76	0.37	—
Loss O - Cl	100.0	100.4	99.8	100.5	100.1	100.3	99.8	100.0	99.6	100.06	99.99	—
Total	99.9	100.2	99.7	100.4	99.9	100.1	99.7	100.0	99.6†	99.88‡	99.90§	99.8

* Zr determined by X-ray fluorescence in 1R, 2R, 3R, 4R, 5R, and 6R; Zr(Hf)O₂ determined gravimetrically in 1G, 2G, 3G, and 4G.

† Cl content (in brackets) in the obsidian analyses is computed from the modal amount of glass (table I) assuming that none of the phenocryst minerals contain Cl.

‡ CO₂ present, not determined.

§ Includes SO₂ 0.06 and Cl (H₂O sol.) 0.03.

¶ Includes SO₂ 0.06 and Cl (H₂O sol.) 0.01.

TABLE VII. Norms of pantellerites and residual glasses, and refractive indices of the glasses.

	1R.	1G.	2R.	3G.	3R.	3G.	4R.	4G.	5R.	6R.
qtz	16.6	27.5	24.2	20.6	20.7	30.8	21.4	22.6	26.0	2.6
or	30.6	27.8	27.2	27.2	28.4	27.2	28.9	28.4	27.2	30.0
ab	33.0	18.9	21.5	13.6	19.0	13.6	28.8	28.3	20.4	32.9
ac	5.1	6.0	7.8	8.3	6.5	6.0	6.0	6.0	14.8	0.9
wo	1.0	1.0	1.2	1.2	0.8	0.8	0.9	0.9	1.6	3.6
en	0.3	0.3	0.3	0.1	0.2	0.1	0.6	0.6	1.2	1.0
fs	7.0	10.4	9.5	10.3	8.8	11.5	7.1	7.1	4.1	3.6
ds	3.5	5.6	5.4	7.4	6.0	7.7	4.0	4.2	0.7	1.2
hl	0.9	1.1	0.9	0.8	0.8	0.8	0.9	0.9	0.8	1.2
hl	0.9	1.2	0.9	1.2	1.2	1.3	0.5	0.5	0.5	0.3
z	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2
Resl	0.4	0.1	0.4	0.3	0.1	0.1	0.3	0.2	2.3	0.3
Total	99.7	100.3	99.7	100.4	100.1	100.3	99.8	100.1	99.5	99.8
± silice minerals	80.2	74.2	72.9	70.4	75.0	71.6	79.1	79.3	73.6	83.3
n	1.516	1.516	1.523	1.523	1.517	1.512	1.512	1.512	1.531	1.531

For the key to these analyses see p. 90.

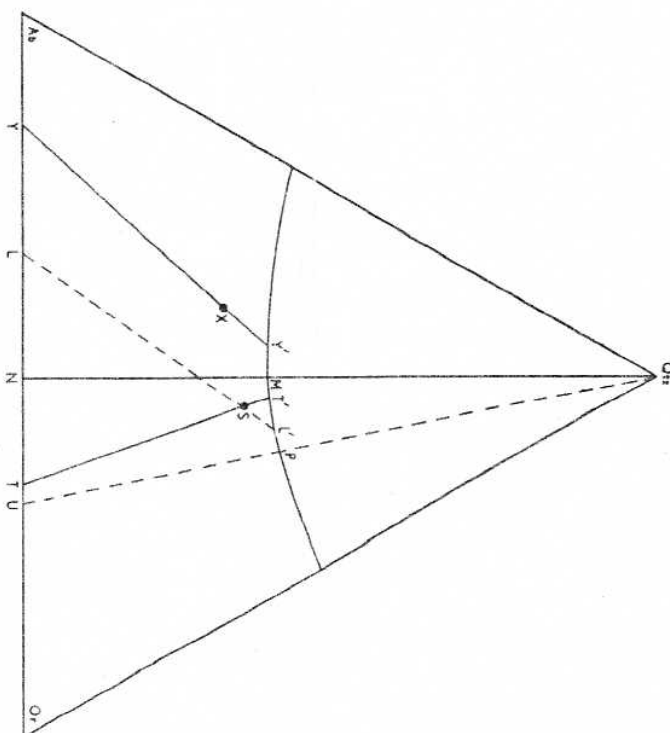


FIG. 3. Diagram showing the effect on the feldspar-liquid three-phase boundaries of a shift in the minimum in the system NaAlSi₃O₈-KAlSi₃O₈-SiO₂-H₂O, due to the addition of other components. M is the experimentally determined minimum (Tuttle and Bowen, 1958) and P is a hypothetical minimum temperature produced by the addition of sodium silicate to the system.

In a similar way, a liquid having a composition represented by the point *S* will, on cooling, crystallize a feldspar slightly more potassium than *T*, and the liquid will move on a curved course to *T'*, at which point the feldspar crystals will have a composition represented by *Z*. At the point *T'*, quartz will start to crystallize, and the liquid will move along the boundary curve towards the ternary minimum *M*. *TT'*'s, like *YY'*', both a tie-line and a three-phase boundary.

The 'thermal valley' (fig. 6) that extends from the alkali-feldspar minimum to the quartz-feldspar boundary curve (Tuttle and Bowen, 1958, fig. 30) may only rarely intersect this boundary curve at the ternary minimum, and in general the intersection is slightly displaced from the minimum. Consider now that the position of the minimum is moved to some position *P* by the addition of another component, so the composition of the feldspar at this minimum is represented by *L*. At the same time the position of the 'thermal valley' is also changed and may be considered to be near *LL'*.

The course of crystallization of a liquid having the composition *S* (fig. 3) now becomes quite different. On cooling, crystals of feldspar slightly more sodic than *L* will precipitate, and the liquid will move on a curved course to *L'*, the feldspar crystals continuously reacting with the liquid so that they have the composition *L* when the liquid reaches *L*. At *L'*, quartz (or a silica mineral) will also crystallize and the liquid will move along the boundary curve towards *P*. By analogy with *YY'*' and *TT'*, *LL'* may also be a tie-line and a three-phase boundary. A change in the composition of the minimum therefore causes a considerable change in the course of crystallization of a liquid such as *S*, and the trend of the tie-lines and the three-phase boundaries for liquids whose compositions lie close to the boundary curve in the area *MMPT* (fig. 3) will also change markedly in response to a change in the position of the minimum and the position of the 'thermal valley'.

Natural feldspar-phenocryst-liquid (glass) assemblages have been plotted in fig. 4, and it may be seen that the Icelandic feldspar-liquid tie-lines have the same general trend as the experimental tie-lines represented by *YY'*' in fig. 3. As quartz is not found as a phenocryst in the Icelandic pitchstones, the Icelandic tie-lines are not three-phase boundaries; the liquids having not yet reached the quartz-feldspar boundary curve.

The tie-line between the feldspar phenocrysts and the liquid of the Edgø subacid pitchstone (fig. 4) is also similar in trend to that found experimentally for liquids of similar composition. The feldspar-liquid

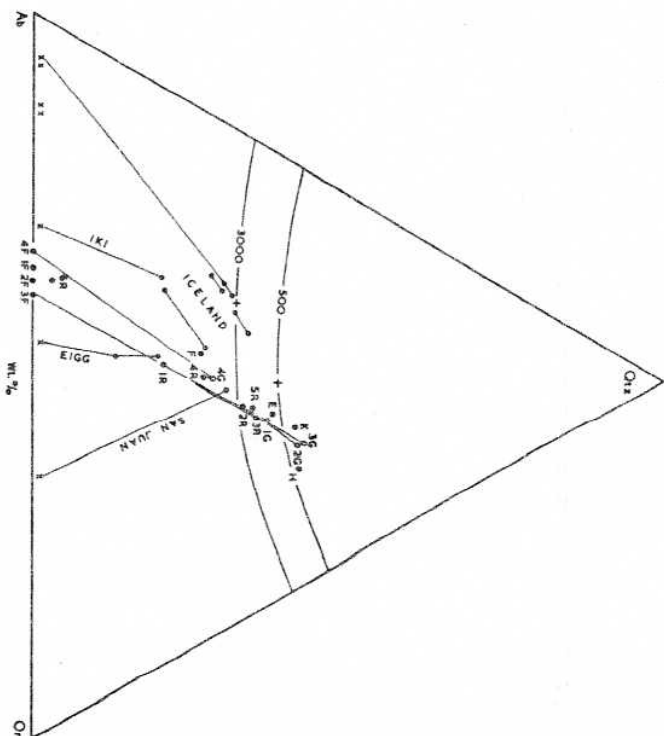


Fig. 4. Normative albite, orthoclase, and quartz of the enumerated analysed pan-tellerites (solid circles) (table VII) and their residual glasses (open circles) (table VIII) are plotted in the system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - SiO_2 . The analysed pan-telleritic feldspar phenocrysts (solid circles) (table V) are plotted on the alkali feldspar join. Only two complete pan-telleritic feldspar-residual-glass tie-lines are drawn for the sake of clarity. Analysed Icelandic pitchstones (solid circles) and residual glasses (open circles) and their analysed feldspar phenocrysts (crosses) are also plotted (Carmichael, 1960b), with only one complete feldspar-liquid tie-line shown. The Edgø (Scotland) subacid liquid is joined to its analysed feldspar phenocrysts (cross) (Carmichael, 1960b); the analysed anorthoclase phenocrysts are joined to the Iki (Japan) alkaline rhyolite (Aoki, 1959); and a San Juan, Colorado, residual glass is joined to its analysed sanidine phenocrysts (Larsen *et al.*, 1938; Larsen and Cross, 1956). *H* and *K* represent the aegirine granites of Rockall (Sabine, 1960). The boundary curves at 300 kg/cm² and 3000 kg/cm² water-vapour pressure are plotted. — indicates the position of the minimum on the boundary curves (Tuttle and Bowen, 1958).

tie-line of the San Juan rhyolite (Larsen *et al.*, 1938, p. 418, table 10, no. S'xx; Larsen and Cross, 1956, table 21, no. S'xx) is also closely parallel to that obtained experimentally (*TT'*, fig. 3); although phenocrysts of another feldspar (Larsen *et al.*, 1938, p. 235, table 5, no. 7), a strongly zoned plagioclase (Larsen and Cross, 1956, table 21, no. S'xx), are also

found, these may not be in equilibrium with the liquid (Larsen *et al.*, 1938, p. 256).

The normative salic constituents of the pantellerites and their residual glasses (liquids) have also been plotted in fig. 4: the trend of the pantelleritic feldspar-liquid tie-lines is in direct contrast to the synthetic tie-lines obtained for liquids of similar salic composition (cf. *TT*, fig. 3). This then is the problem of the pantelleritic liquids, namely the presence of phenocrysts of a relatively sodic feldspar ($Ab_{61}-Ab_{67}$; table V) in contrast to the relatively potassic feldspar that first crystallizes from synthetic melts of similar salic composition.

It is considered that if the composition of the minimum *M* (fig. 3) is changed for the pantelleritic liquids to a composition similar to *P* (fig. 3) and the 'thermal valley' is moved so as to more or less coincide with *LL*, then the presence of relatively sodic feldspar phenocrysts is readily understood. For the pantelleritic liquids, the tie-lines 2R-2F-2G and 3R-3F-3G are natural three-phase boundaries as quartz is present as phenocrysts in both these specimens (table I), and the composition of the minimum at *P* (fig. 3) may possibly be represented by the normative salic constituents of the liquids 2G and 3G (fig. 4, table VII). The cause of the change in the composition of the ternary minimum is not at the moment known, but it is suggested that Na_2SiO_3 (*ns*)¹ which is found in the norms of all these pantellerites (table VII), may be responsible.

If this hypothesis is correct, then analyses of comendites and pantellerites should show a progressive shift towards the Or-Qtz sideline with increase in the molecular excess of soda over alumina. All available analyses of these two rock types have been plotted in fig. 5 and show general conformity with the minimum in the system $NaAlSi_3O_8-KAlSi_3O_8-SiO_2-H_2O$ at low water-vapour pressure, and the average composition of pantellerites and comendites is given in table VIII. It is of interest that the analyses of Pantellerian rocks, which are unusually high in normative sodium metasilicate (*ns*), tend to be displaced towards the Or corner with respect to similar rocks from other localities. All the analyses plotted in fig. 5 were contoured with respect to the molecular ratio (Na_2O+K_2O) Al_2O_3 and the results (fig. 6) indicate that there is a progressive and regular increase of the ratio towards the Or-Qtz sideline. This would seem to indicate that the addition of Na_2SiO_3 to the system $NaAlSi_3O_8-KAlSi_3O_8-SiO_2-H_2O$ will progressively change the

¹ The formation of normative acmite requires the presence of *ns*, and a molecular excess of soda over alumina is taken, in the sequel, to indicate the existence of *ns*.

position of the minimum towards the Or-Qtz sideline when projected down into the base Ab-Or-Qtz.

If the analyses of the Pantellerian rocks (fig. 5) may be taken to indicate the position of the 'thermal valley' extending from the alkali-

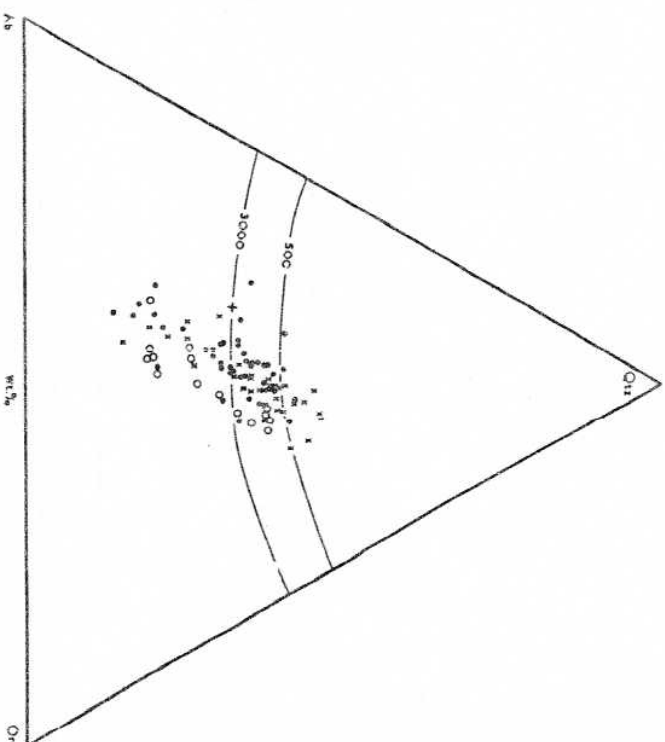


FIG. 5. Analyses of pantellerites and pantelleritic trachytes (crosses) and of comendites and comenditic trachytes (solid circles) taken from the literature are plotted in the system $NaAlSi_3O_8-KAlSi_3O_8-SiO_2$. The analyses of comendites and pantellerites from Pantelleria are represented by large open circles. The boundary curves at 500 and 3000 kg/cm² water-vapour pressure are plotted, and the minimum on the latter boundary curve is represented by + (Tuttle and Bowen, 1958).

feldspar minimum to the quartz-feldspar boundary curve, then this valley has quite a different position from that found in the system $NaAlSi_3O_8-KAlSi_3O_8-SiO_2-H_2O$.

The system $FeO-Fe_2O_3-SiO_2-Na_2SiO_3$.

It is now proposed to examine the ferromagnesian role of *ns* in silicate liquids, but it should be remembered, as Chayes (1960) has indicated,

TABLE VIII. Average analyses.

	A.	B.	F.	H.
SiO ₂ ...	74.66	71.92	47.2	30.7
TiO ₂ ...	0.28	0.48	0.7	27.8
Al ₂ O ₃	14.29	9.62	0.7	25.6
Fe ₂ O ₃	2.35	3.81	0.7	25.2
FeO	1.63	3.35	0.7	11.1
MnO	0.07	0.23	0.7	1.8
MgO	0.15	0.20	0.7	1.3
CaO	0.45	0.63	0.7	0.5
Na ₂ O	4.42	5.38	1.8	5.8
K ₂ O	4.67	4.34	1.2	—
P ₂ O ₅	0.03	0.04	0.6	0.9
Total	100.00	100.00	78.6	78.6

A. Average of 35 comendites, pinites, and peralkaline granophyres.

B. Average of 40 pantellerites.

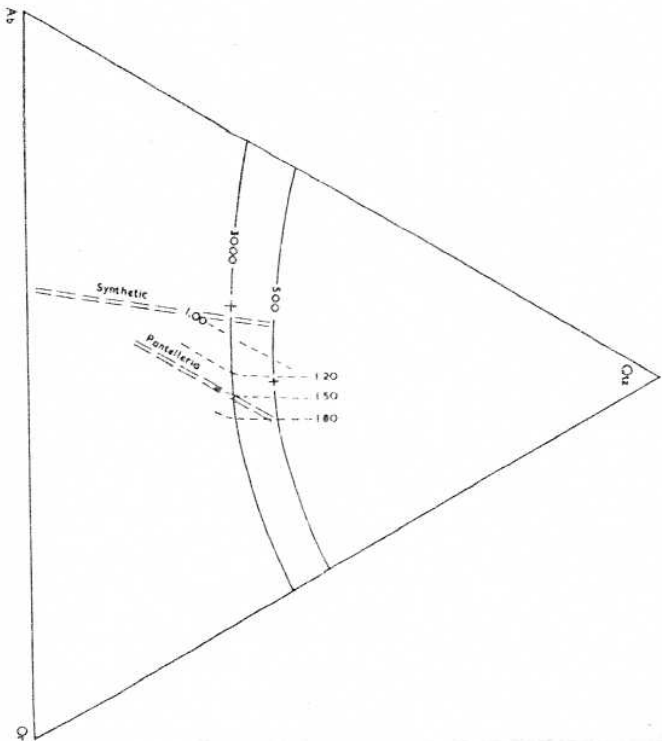


FIG. 6. The analyses of comendites and pantellerites plotted in fig. 5 are contoured (dashed line) with respect to their molecular ratios of $(\text{Na}_2\text{O} + \text{K}_2\text{O})/\text{Al}_2\text{O}_3$. Also shown is the experimental 'thermal valley' extending from the alkali feldspar minimum to the quartz-feldspar boundary curve, and the trend of the Pantellerite analyses (fig. 5) is also represented by a double dashed line.

that normative *ns* is not confined to acid liquids, but may occur in undersaturated rocks, and the ferromagnesian assemblages noted above as characteristic of acid rocks may be found in trachytes and phonolites (Campbell Smith, 1931), with which pantellerites and comendites are frequently closely associated.

Of the experimental silicate systems which involve *ns* as a component, the most important for our purpose are $\text{Na}_2\text{O} \cdot \text{SiO}_2 - \text{Fe}_2\text{O}_3 - \text{SiO}_2$ (Bowen *et al.*, 1930), $\text{Na}_2\text{O} \cdot \text{SiO}_2 - \text{FeO} - \text{SiO}_2$ (Carter and Ibrahim, 1952; Scharrer *et al.*, 1953), which together with the system $\text{FeO} - \text{Fe}_2\text{O}_3 - \text{SiO}_2$ (Muan, 1955) may be used to construct a four-component system $\text{FeO} - \text{Fe}_2\text{O}_3 - \text{SiO}_2 - \text{Na}_2\text{O} \cdot \text{SiO}_2$.

This four-component system contains many of the ferromagnesian minerals found in pantellerites and their congeners, namely fayalite ($2\text{FeO} \cdot \text{SiO}_2$), magnetite ($\text{FeO} \cdot \text{Fe}_2\text{O}_3$), and acmite ($\text{Na}_2\text{O} \cdot \text{Fe}_2\text{O}_3 \cdot 4\text{SiO}_2$), together with quartz or a silica mineral. With the inclusion of TiO_2 as a fifth component, the ferromagnesian assemblages of these pantellerites are completely defined, with ilmenite ($\text{FeO} \cdot \text{TiO}_2$) and coesynite ($2\text{Na}_2\text{O} \cdot 9\text{FeO} \cdot 2\text{TiO}_2 \cdot 11\text{SiO}_2$).

Before considering the relevance of this system to the pantellerite liquids, the presence of SiO_2 in this system, and hence of quartz, requires amplification. It has been stated above that ferromagnesian assemblages similar to those found in the pantellerites may be found in trachytes and phonolites, so that the phase volume of SiO_2 in the four-component system would suggest that these assemblages could only be obtained in liquids containing uncombined silica. However, the system $\text{FeO} - \text{SiO}_2 - \text{NaAlSi}_3\text{O}_8$ (Bowen and Scharrer, 1938) indicates that nepheline occupies an equivalent position to the silica minerals, and the two ternary eutectics found in this system consist of albite+quartz-fayalite and nepheline+albite-fayalite. It does not seem unlikely then that in the system $\text{FeO} - \text{Fe}_2\text{O}_3 - \text{SiO}_2 - \text{Na}_2\text{O} \cdot \text{SiO}_2$, the phase volume of the silica minerals will, in the undersaturated rocks, be represented by nepheline.

As the four-component system $\text{FeO} - \text{Fe}_2\text{O}_3 - \text{SiO}_2 - \text{Na}_2\text{O} \cdot \text{SiO}_2$ contains two oxidation states of iron, it is to be expected that the partial pressure of oxygen prevailing at the time of crystallization and congelation of these pantellerite liquids will influence the assemblage of the ferromagnesian minerals that precipitate. It is only possible, however, to indicate in a general way the ferromagnesian assemblages that may develop under varying partial pressures of oxygen.

Magnetite is virtually absent in the pantellerite, and it is considered that the partial pressure of oxygen was unusually low, as no mineral

containing essential ferric iron precipitated. Under more oxidizing conditions than those found in the pantellerites, fayalite may no longer be a potentially stable phase, its components forming magnetite and silica, and possibly coesynrite. However, as coesynrite may accept up to 10% ferric iron in its structure (Fleischer, 1936), it is possible that it may be a stable phase over a relatively wide range of oxygen pressures, and it is assumed here that it is stable to higher partial pressures of oxygen than fayalite in liquids of pantelleritic composition. If, then, the conditions of oxidation are such that coesynrite is no longer a stable phase, its components may form magnetite and ilmenite, and its soda will be incorporated together with ferric iron to give a pyroxene composition nearer to the acmite end-member than the sodic ferrohedenbergite actually found with coesynrite.

So far as is known to the writer (cf. Lacroix, 1927, 1930), only pyroxenes similar in composition to sodic ferrohedenbergites are found to coexist with fayalite in pantellerites, and a pyroxene near the acmite end-member is never found with an iron-rich olivine. This indicates that the oxidation conditions necessary to form a highly sodic pyroxene are incompatible with the formation of an iron-rich olivine, and it further suggests that the green outermost zones of the titanium-rich schists that coexist with iron-rich olivine in the Shant Isles granulites (Murray, 1954) are unlikely to approach acmite in composition, but rather a sodic ferrohedenbergite (fig. 2).

It is suggested, then, that an increase of the partial pressure of oxygen in the pantelleritic liquids may increase the amount of the precipitating pyroxene and also its content of soda, and it may also increase the amount of magnetite and possibly ilmenite at the expense of fayalite and coesynrite. In a hydrous environment the alkali amphiboles riebeckite and arfvedsonite may be present in the ferromagnesian assemblages, but they have been neglected from consideration here as the presence of water inevitably makes the relationships more complex. Amphiboles are, however, frequently found in pantellerites (Jensen, 1906; Koch, 1955; Lacroix, 1923, 1927, 1930), but they have not been found in the specimens described here.

The chemistry of the pantellerites.

No detailed discussion will be presented here as a further geochemical study is being undertaken, the results of which will be presented elsewhere. There are, however, several unusual features of the chemical composition of the pantellerites that have not so far been mentioned,

which perhaps the most unusual is the increase in iron (and manganese) in the residual glasses (liquids) compared to the rocks (obsidians) (table VI). As iron is predominantly in the reduced state, the concentration of iron in the liquid is possibly due to low partial pressures of oxygen preventing the precipitation of magnetite, the iron consequently being concentrated in the liquid in order to combine principally with *ns* to form coesynrite and a sodic pyroxene (groundmass of 5R).

The pantellerites are also unusually rich in Cl which is apparently expelled together with soda during crystallization of the liquid (table VI, no. 5R). Zies (1960) has already shown that Cl is unlikely to be a superficial contaminant, and it must be regarded as an original constituent of the liquid.

As Cl is very much more abundant than H_2O in the analyses of the residual glasses (IG-4t; table VI), it is possible that it may have some effect on the composition of the minimum in the system $NaAlSi_3O_8-KAlSi_3O_8-SiO_2-H_2O$, and may modify or amplify the effect of Na_2SiO_3 suggested above. It would be interesting to know whether or not Cl is always present in pantelleritic liquids; Lacroix (1934) found notable quantities in the Thibest pantellerites so that it may perhaps be regarded as a characteristic element. Zr is also unusually abundant in these obsidians, and must be concentrated in the liquid (table VI). In view of the very infrequent zircon found in the glasses, the solubility of Zr must greatly increase in acid liquids with increase in soda, as the North Atlantic Tertiary pitchstones, which contain very much less soda, indicate a solubility of Zr of only about 300 p.p.m. (Carmichael and McDonald, 1961).

The Aegirite series.

The term aegirite, which was originally used by Using (1912) to describe a series of peralkaline nepheline-syenites, has been reviewed in detail by Sorenson (1960), who concluded that aegirite rocks may best be defined as follows: 1, they are peralkaline nepheline syenites; 2, they contain aegirine, soda-amphibole and/or aegirine instead of biotite, diopside, pyroxene and hornblende, that is they are low in Ca and Mg; 3, they contain complex Zr- and Ti-silicates instead of zircon and sphene; and 4, they are rich in F, Cl and H_2O which are present in complex silicates such as euhlyte and tinkohite.

These aegirite ferromagnesian assemblages characterize the pantellerites, and to deny their inclusion under the term aegirite is to negate the close chemical and mineralogical affinities of the pantellerites to the

agapite nepheline-syenites. The underlying cause of these soda ferromagnesian assemblages is the presence of *ns*, and the author would like to widen the usage of the term agapite to include all saline rocks that develop these sodic ferromagnesian assemblages, and which may also concomitantly develop unusually high concentrations of Al , F , and Zr . There is then a proposed agapite series, namely nepheline-syenites and phonolites, syenites and trachytes, and peralkaline granites, comendites, and pantellerites all of which are characterized by a molecular excess of soda over alumina. Representatives of this series are found in Pantelleria (Washington, 1914), Kenya (Campbell Smith, 1931), and the Ihmannsaq batholith, SW, Greenland (U'ssing, 1912), where, apart from Pantelleria, a complete range of oversaturated to undersaturated saline rocks, all of agapite type, may be seen.

Tilley (1958) has discussed the generic problems of these complexes with reference to the thermal barrier that exists in the experimental system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-SiO}_2$ between the granite and the foyaitic sinks. Perhaps the influence of *ns* in changing the composition of a felsic melt precipitating from oversaturated liquids discussed above will also obtain in undersaturated saline liquids and may also in some way minimize the thermal barrier in the system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-SiO}_2$ and so allow a natural liquid to progress from an undersaturated to an oversaturated condition. This suggestion is similar chemically to that proposed by Tilley (1958, p. 332) who sought in the incongruent melting of aegirite a possible mechanism for traversing the experimental thermal saddle in the system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-SiO}_2$.

Any explanation of the generation of *ns* in natural liquids must be applicable both to the oversaturated and undersaturated saline liquids and the formation of a molecular excess of soda over alumina and ferric iron provides one of petrogeny's greatest problems. No solution is offered here, and the author appreciates that until the conditions that govern the generation of *ns* are known and understood any account of the pantellerites must be incomplete.

Acknowledgements. The author has benefited greatly from the many discussions he has had with numerous people concerning the pantellerites and their related problems; he would particularly like to record his debt to Prof. C. E. Tilley and to Dr. W. S. MacKenzie for their help and rigorous criticism, and also to Dr. R. J. Davis of the British Museum (Natural History) who kindly determined the cell dimensions of the iron-titanium oxides.

References

- AWKI (K.), 1930. Petrology of alkali rocks of the Iki Islands and Higashi-matsura district, Japan. *Sci. Rept. Tohoku Univ.*, ser. 3 (Min., Petr., Geol.), vol. 6, p. 291 [M.A. 14-361].
- BASTA (E. Z.), 1957. Accurate determination of the cell dimensions of magnetite. *Min. Mag.*, vol. 31, p. 431.
- BOWEN (N. L.), 1957. A note on aegimatte. *Amer. Min.*, vol. 22, p. 139 [M.A. 7-28].
- and SCHAEFER (J. F.), 1935. The system MgO-FeO-SiO_2 . *Amer. Journ. Sci.*, ser. 5, vol. 29, p. 151 [M.A. 6-352].
- and WILKINS (H. W. V.), 1930. The ternary system $\text{Na}_2\text{SiO}_3\text{-Fe}_2\text{O}_3\text{-SiO}_2$. *Ibid.*, vol. 29, p. 405 [M.A. 4-385].
- and TRITTE (O. F.), 1950. The system $\text{NaAlSi}_3\text{O}_8\text{-KAlSi}_3\text{O}_8\text{-H}_2\text{O}$. *Journ. Geol.*, Chicago, vol. 58, p. 489 [M.A. 11-225].
- BROCH (O. A.), 1946. Two contributions to Antarctic petrography. Scientific results of the Norwegian Antarctic expeditions 1927-1928; No. 25. Norske Vidensk. Akad., Oslo.
- BROOY (G. M.), 1957. Pyroxenes from the early and middle stages of fractionation of the Skarvgaard intrusion, East Greenland. *Min. Mag.*, vol. 31, p. 511.
- 1960. The effects of ion substitution on the unit cell dimensions of the common clinopyroxenes. *Amer. Min.*, vol. 45, p. 15 [M.A. 15-143].
- BRUNSVIGER (A. F.), 1939. Adirondack igneous rocks and their metamorphism. *Mem. Geol. Soc. Amer.*, no. 7.
- CAMPBELL SMITH (W. C.), 1931. A classification of some rhyolites, trachytes, and phonolites from part of Kenya Colony, with a note on some associated basaltic rocks. *Quart. Journ. Geol. Soc.*, vol. 87, p. 212 [M.A. 4-510].
- CARMICHAEL (L. S. E.), 1960a. The pyroxenes and olivines from some Tertiary acid glasses. *Journ. Petrology*, vol. 1, p. 309.
- 1960b. The felsic paragneisses of some Tertiary acid glasses. *Min. Mag.*, vol. 32, p. 587.
- and McDONALD (A. J.), 1961. The geochemistry of some natural acid glasses from the North Atlantic Tertiary volcanic province. *Geochimica Acta*, vol. 25, p. 189.
- CARTER (P. T.) and LIRKIN (M.), 1952. The ternary system $\text{Na}_2\text{O-FeO-SiO}_2$. *Journ. Soc. Glass Techn.*, vol. 36, p. 142.
- CHAYES (F. J.), 1960. Occurrence of normative sodium metasulfate in Washington's Tables. *Bull. Geol. Soc. Amer.*, vol. 71, p. 503 [M.A. 15-52].
- CROSS (W.), 1904. U.S. Geol. Surv. Bull. No. 228.
- FLEISCHER (M.), 1936. The formula of aegimatte. *Amer. Journ. Sci.*, ser. 5, vol. 32, p. 345 [M.A. 6-534].
- [FOENSTERER (E.)] FOENSTERER (H.), 1881. Note preliminare sulla geologia dell'Isola di Pantelleria secondo gli studi fatti negli anni 1874 e 1881. *Boll. R. Com. Geol. Italia*, vol. 12, p. 523.
- 1884. Ueber die Feldspathe von Pantelleria. *Zeits. Kryst. Min.*, vol. 8, p. 125.
- Hess (H. H.), 1949. Chemical composition and optical properties of common clinopyroxenes, part I. *Amer. Min.*, vol. 34, p. 621 [M.A. 11-15].
- HYROXER (K.), 1959. On the petrology and mineralogy of some alkaline volcanic rocks of Torso hills, Mt. Moroto, and Morungga in Karamoja, northeastern Uganda. *Bull. Comm. Geol. Finlande*, vol. 31, p. 75 [M.A. 14-421].
- JACONSON (R. R. E.), MACTERON (W. N.), and BLACK (R.), 1958. Ring complexes in the younger granite province of northern Nigeria. *Mem. Geol. Soc. London*, No. 1.

- JENSEN (H. J.), 1906. Geology of the volcanic area of the East Moreton and Wide Bay districts (Queensland). Proc. Linn. Soc. New South Wales, vol. 31, p. 72.
- JOHNSON (A.), 1912. Die Gesteine der Inseln S. Pietro und S. Antiocho (Sardinien). Abh. Preuss. Akad. Wiss., Phys.-math. Kl., Abh. 2.
- KOCH (P.), 1955. Les Panthelites du Mont Mba Nschie (Cameroun). Compt. Rend. Acad. Sci. Paris, vol. 241, p. 803 [M.A. 14-68].
- LACROIX (A.), 1923. Minéralogie de Madagascar, vol. 3.
- 1927. Les Rhyolites et les trachytes hyperalcalins quartzifères, à propos de ceux de la Corée. Compt. Rend. Acad. Sci. Paris, vol. 185, p. 1410.
- 1930. Les Roches hyperalcalines du massif du Fanfale et du col de Balla (Abyssinie). Mem. Geol. Soc. France, vol. 6, p. 89.
- 1934. Volcanisme et lithologie. Mission au Tibet (1930-1931) dirigée par M. Dalloni. Mem. Acad. Sci. Paris, vol. 61, p. 169 [M.A. 6-123].
- LARSEN (E. S.), IRYING (J.), GONNER (F. A.), and LARSEN (E. S. 3rd), 1938. Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colorado. Amer. Min., vol. 23, pp. 227 and 417 [M.A. 7-173], and Cross (W.), 1956. Geology and petrology of the San Juan region, South-western Colorado, U.S. Geol. Surv., Prof. Paper 258.
- MARSHALL (P.), 1936. Geology of Mayor Island. Trans. Roy. Soc. New Zealand, vol. 66, p. 337 [M.A. 6-123].
- MAY (A.), 1955. Phase equilibria in the system $\text{FeO}-\text{Fe}_2\text{O}_3-\text{SiO}_2$. Trans. Amer. Inst. Mining Metal. Eng., vol. 203, p. 965.
- MUR (I. D.), 1951. The clinopyroxenes of the Skærgaard intrusion, eastern Greenland. Min. Mag., vol. 29, p. 690.
- 1954. Crystallisation of pyroxenes in an iron-rich diabase from Minnesota. *Ibid.*, vol. 30, p. 376.
- MURRAY (R. J.), 1954. The clinopyroxenes of the Garbh Eilean sill, Shiant Isles. Geol. Mag., vol. 91, p. 17 [M.A. 12-418].
- NEUMOTO (T.), 1934. Preliminary note on alkaline rhyolites from Tokati, Hokkaido. Journ. Fac. Sci. Hokkaido Univ., ser. 4, vol. 2, p. 300 [M.A. 6-130].
- SARISE (P. A.), 1960. The geology of Rockall, North Atlantic. Bull. Geol. Surv. Gt. Brit., No. 16, p. 156 [M.A. 14-507].
- SCHAMER (J. F.), YODER (H. S.), and KREX (A. G.), 1954. Ann. Rept. Geophysical Lab., Yearbook No. 53, p. 126.
- SOESENS (H.), 1960. On the agpaitic rocks. Rept. 21st Internat. Geol. Congr., part 13, p. 319 [M.A. 15-52].
- TILLEY (C. E.), 1949. An alkali facies of granite at granite-dolomite contacts in Skye. Geol. Mag., vol. 86, p. 81 [M.A. 11-395].
- 1950. Some aspects of magmatic evolution. Quart. Journ. Geol. Soc., vol. 106, p. 37 [M.A. 11-394].
- 1958. Problems of alkali rock genesis. *Ibid.*, vol. 113, p. 323 [M.A. 14-219].
- TOMITA (T.), 1935. On the chemical compositions of the Cenozoic alkaline suite of the circum-Japan Sea region. Journ. Shanghai Sci. Inst., Sect. 2, vol. 1, p. 227 [M.A. 6-299].
- TUTTLE (O. F.), 1960. Occurrence of normative sodium metasilicate in Washington's talces: A reply. Bull. Geol. Soc. Amer., vol. 71, p. 505 [M.A. 15-52].
- and BOWEN (N. L.), 1958. Origin of granite in the light of experimental studies. Mem. Geol. Soc. Amer. no. 74 [M.A. 15-62].
- USSING (N. V.), 1912. Geology of the country around Julianehaab, Greenland. Medd. Grønland, vol. 38, p. 1.
- WRIGHT (E. A.), WRIGHT (J. B.), CHEVALLIER (R.), and MARTNER (S.), 1957. Heating experiments on some natural titaniferous magnetites. Min. Mag., vol. 31, p. 624.

- WASHINGTON (H. S.), 1913, 1914. The volcanoes and rocks of Panthelena. Journ. Geol. Chicago, vol. 21, pp. 653 and 683 and vol. 22, p. 1.
- WIKSTRÖM (J. F. G.), 1957. The clinopyroxenes of a differentiated tephemite sill near Gunnedsh, New South Wales. Geol. Mag., vol. 94, p. 123 [M.A. 14-390].
- YAOI (K.), 1951. Petrochemical studies on the alkalic rocks of the Moroto district, Sakhalin. Bull. Geol. Soc. Amer., vol. 64, p. 769 [M.A. 12-268].
- 1958. Synthetic pyroxenes of the acmite-diopside system. Journ. Min. Soc. Japan, vol. 3, p. 763 [M.A. 14-351].
- ZIES (E. G.), 1960. Chemical analyses of two panthelites. Journ. Petrology, vol. 1, p. 304.