

for the (111) plane of halite and for the (100) plane of fluorite in the cases considered so far, and it is physically unrealistic. If a crystal did fracture in such a direction there would have to be sufficient departures from a perfectly flat plane to permit local neutralization of charge. There are also mathematical difficulties involved. Thus the obvious Evjen molecule to use for the (100) plane of fluorite is a square pyramidal  $\text{Ca}(\frac{1}{2}\text{F})_4$  with its base on the (100) plane, but such a molecule would possess a dipole and a summation of potential energy terms due to an array of such molecules would not converge to the Madelung value. An attractive device to avoid the problem would seem at first sight to divide the crystal into non-polar Evjen slices which share partial ions with one another. This would be achieved by using cubic  $\text{Ca}(\frac{1}{4}\text{F})_8$  molecules to evaluate the (100) plane of fluorite but this procedure still leads to an excessively high cleavage energy for the plane of 15% of the Madelung energy of the crystal. This is because the Madelung energy of such a slice is diminished (numerically) by the repulsions between the large number of close contacts of partial anions. It was concluded that the minimum cleavage energy would be obtained if there were no sharing of partial ions between adjacent slices, but that the charge neutralization were as local as possible. For fluorite (100) this was achieved by using tetrahedral  $\text{Ca}(\frac{1}{2}\text{F})_4$  molecules corresponding to omission of alternate vertices of the  $\text{Ca}(\frac{1}{4}\text{F})_8$  cubes. In the case of halite (111) the problem proved more difficult and was only resolved by using the dimeric unit  $(\frac{1}{2}\text{Na})_4(\frac{1}{4}\text{Cl})_8$  shown in the figure. It is clear that each case must be treated on its merits.

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The results obtained are as follows, with the cleavage energies expressed (a) as percentages of the total Madelung energy of the crystal, and (b) in energy per unit area relative to that for the cleavage plane itself. In each case an indication is given of the form of the Evjen molecule that was used.

		(a) (%)	(b)
Halite	(100) square planar $\text{Na}(\frac{1}{4}\text{Cl})_4$	3.9	1
	(110) linear $\text{Na}(\frac{1}{2}\text{Cl})_2$	12	2.2
	(111) $(\frac{1}{2}\text{Na})_4(\frac{1}{4}\text{Cl})_8$ , see fig. 1	11	3.3
Fluorite	(100) tetrahedral $\text{Ca}(\frac{1}{2}\text{F})_4$	8	2.4
	(110) flat rectangular $\text{Ca}(\frac{1}{2}\text{F})_4$ parallel to (110)	8	1.7
	(210) flat rectangular $\text{Ca}(\frac{1}{2}\text{F})_4$ parallel to (110)	21	5.6
	(111) oblate trigonal antiprism $\text{Ca}(\frac{1}{3}\text{F})_6$	2.9	1

Although the perfect cleavage of fluorite on (111) is well known, it is interesting that 'an indistinct parting or cleavage' on (110) is also said to occur (Palache *et al.* 1951) and the calculated relative cleavage energy per unit area accords with this observation.

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## A Carboniferous arfvedsonite-aegirine trachyte from West Kilbride, Scotland

WEST of Glasgow in the West Kilbride-Fairlie district of Strathclyde Region the sedimentary rocks underlying the Clyde Plateau Carboniferous lavas are intruded by a number of sills of trachyte and felsite. The rocks forming these sills are highly altered, their ferro-magnesian minerals being usually completely decomposed so that their exact original nature has been unknown. Brief mention of these rocks has been made by Geikie (1903, p. 64) and

by Wilson in Richey *et al.* (1930, p. 87). Material containing some unaltered amphibole and clinopyroxene has recently been discovered and is described here. The specimens came from the now disused Biglees Quarry which is 500 m SSE of Biglees Farm and 3.5 km north of West Kilbride; the grid reference of the quarry is NS 210 516. The quarry rock is a rudely columnar trachyte containing small feldspar phenocrysts. The intrusion is a

sill of Lower Carboniferous age emplaced in sediments assigned to the Upper Old Red Sandstone. A narrow dyke of fresh olivine-tholeiite trending E.-W. cuts the quarry face. This dyke can be matched both as to type, and trend, by dykes of Tertiary age seen on the shore of the Firth of Clyde south of West Kilbride.

Thin sections show the fresher trachyte to be composed of phenocrysts of orthoclase, usually in groups with individual crystals reaching 3 mm long, in a groundmass of laths of alkali-feldspar, 0.2 to 0.5 mm long and showing a good fluidal arrangement, a soda-amphibole which occurs both interstitially to the groundmass feldspars and as ragged prisms, and aegirine, together with quartz, calcite, and irregular areas of opaque and poorly translucent matter. The quartz occurs interstitially in the groundmass, where it may be primary, and in larger areas, many of which show well-developed crystal faces and enclose isolated groundmass feldspars the orientation of which has been preserved, suggesting strongly that they have replaced feldspar. The calcite replaces feldspar, especially the phenocrysts, as well as some of the mafic minerals, and it may enclose crystals of amphibole and pyroxene. Some of the areas of opaque matter, which reach a length of 2 mm, are greenish-grey and show complicated zonation in reflected light; others resemble hematite. The poorly translucent matter is probably chloritic. The orthoclase phenocrysts are cryptoperthitic and extensively dusted with hematite and alteration products. Their refractive indices bracket 1.530;  $2V_x$  by Mallard's method is *c.* 60°, thus demonstrating an orthoclase structural state, not sanidine. A fine streaky twinning can sometimes be observed and perthitic inclusions of twinned albite occur rarely. These feldspars are probably orthoclase cryptoperthites. The groundmass feldspars are similarly altered in their cores and usually have clear margins. The amphibole has extreme absorption in the  $\alpha$  and  $\beta$  directions with anomalous absorption and interference colours with failure to extinguish especially in (010) sections. The refractive indices, as determined by immersion on a fragmented extra thin section, are:  $\alpha$  (very deep blue-green) 1.667,  $\gamma$  (greenish-grey) 1.679. Some sections exhibit shades of indigo-blue. The measurement of extinction or optic angles has not been satisfactorily achieved. The aegirine has the following optical properties;  $\alpha$ :  $z \sim 0^\circ$ ;  $\alpha$  (deep green) 1.750;  $\beta$  1.784,  $\gamma$  (pale yellow green) 1.805; optically —. A honey-yellow mineral having feeble pleochroism occurs both in parallel growth with aegirine and in separate crystals. As merging junctions can occasionally be observed it would seem to be an acmitic variety of the green pyroxene.

Microprobe analyses (Table I) of the minerals

TABLE I. Analyses of minerals from Biglees Quarry

	1	2	3	4	5	6
SiO <sub>2</sub>	52.08	50.07	50.65	0.67	30.58	32.28
Al <sub>2</sub> O <sub>3</sub>	0.00	0.40	0.36	0.24	6.26	7.47
TiO <sub>2</sub>	0.56	0.45	0.51	28.29	0.00	0.00
Fe <sub>2</sub> O <sub>3</sub>	33.76	6.23	8.62	22.82	31.67	40.14
FeO	—	29.02	26.44	41.24	—	—
MgO	0.00	0.00	0.00	0.00	3.24	4.45
CaO	0.74	0.73	0.33	0.36	0.50	0.41
Na <sub>2</sub> O	13.53	8.71	8.86	—	0.74	0.00
K <sub>2</sub> O	0.00	1.27	1.44	2.75*	1.34	1.36
MnO	0.00	1.38	1.50	2.26	0.00	0.00
	100.67	98.26	98.71	97.63	74.99	92.83
Ions per	6(O)	23(O)	23(O)	6(O)		
Si	1.99	8.00	8.00	0.04		
Al	0.00	0.07	0.07	0.01		
Ti	0.06	0.05	0.06	1.17		
Fe <sup>3</sup>	0.97	0.75	1.02	0.95		
Fe <sup>2</sup>	—	3.88	3.49	1.90		
Mg	0.00	0.00	0.00	0.00		
Ca	0.03	0.12	0.06	0.02		
Na	1.00	2.70	2.71	—		
K	0.00	0.26	0.29	0.11*		
Mn	0.00	0.18	0.20	0.11		

\* ZnO or Zn.

1. Aegirine. All Fe assumed to be Fe<sub>2</sub>O<sub>3</sub>.

2 and 3. Arfvedsonite. Calculated to 23(O) and 8.00 Si, the Fe<sub>2</sub>O<sub>3</sub> and FeO contents being adjusted to achieve 8.00 Si.

4. Opaque mineral. FeO equivalent to TiO<sub>2</sub> assumed.

5. Dark opaque mineral. Includes S 0.66. All Fe assumed to be Fe<sub>2</sub>O<sub>3</sub>.

6. Dark opaque to brown mineral. Includes ZnO 0.42, CuO 0.30. All Fe assumed to be Fe<sub>2</sub>O<sub>3</sub>.

described above reveals a remarkably Mg-poor amphibole and pyroxene with MgO being undetected which implies a content of less than 0.06%. The aegirine is close to the theoretical end-member composition of NaFe<sup>3+</sup>Si<sub>2</sub>O<sub>6</sub> while the amphibole is close to the theoretical formula for pure arfvedsonite NaNa<sub>3</sub>Fe<sub>4</sub>Fe<sup>3</sup>Si<sub>8</sub>O<sub>22</sub>(OH)<sub>2</sub> (Leake, 1978). The amphibole is slightly zoned with generally a little more Ca in the core than the rim. Two representative analyses are given in Table I but up 1.20% CaO was detected in some grains of amphibole corresponding to a maximum of 0.20 Ca in the formula unit. Traces of Zn were also present. The amphibole becomes dark brown and opaque with alteration, probably resulting in oxidation and hydration but, unlike the Ailsa Craig microgranite (Howie and Walsh, 1981), aenigmatite has not been detected, judging from the available microprobe analyses.

The feldspar phenocrysts analysed range from cores of Ab<sub>26</sub>Or<sub>74</sub>An<sub>0</sub> with 0.90% Fe<sub>2</sub>O<sub>3</sub> to rims of Ab<sub>59</sub>Or<sub>41</sub>An<sub>0</sub> with variable contents of Fe<sub>2</sub>O<sub>3</sub> (0.45 to 1.40%). The groundmass feldspar is rather variable, typically Ab<sub>10-30</sub>Or<sub>90-70</sub>An<sub>0</sub> with *c.* 0.7% Fe<sub>2</sub>O<sub>3</sub>.

A variety of opaque or semi-opaque ore minerals

are present of complex composition which might be in part altered aenigmatite, but the low Ti of the silicate grains does not support this, even accepting the loss of Na during hydration. The original composition of these grains remains unknown and analyses 5 and 6 of Table I record typical compositions.

**Conclusions.** Remarkably iron-rich amphibole and pyroxene corresponding to arfvedsonite and aegirine have been identified.

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## Babingtonite in an early Archaean metabasalt from the Pilbara Block, Western Australia

THE rare mineral babingtonite has been found in a sequence of early Archaean metavolcanics in the Kelly Greenstone Belt (Long. 119° 49' 30" E., Lat. 21° 40' 25" S.) approximately 30 km west of Nullagine in the eastern Pilbara, Western Australia. Babingtonite typically occurs in skarns, veins, and in basaltic rocks which have been altered during low-grade burial metamorphism (Burt, 1971). It has been reported from only two other locations in Australia (Gole, 1981, 1982) and has not previously been reported from metabasalts in Archaean granitoid-greenstone terrain.

The Pilbara Block is the smaller of the two Archaean crustal blocks within the Western Australian Shield. It consists of 56 000 km<sup>2</sup> of granitoid-greenstone terrain in which sequences of metamorphosed volcanics and sediments (greenstone belts) occur between large batholiths of granitoid and gneiss. The major sequence of Archaean metavolcanics in the Pilbara, the Warrawoona Group is between 3500 and 3300 Ma old (Hickman, in press). In the Kelly Greenstone Belt, Warrawoona Group volcanics have been extensively altered and largely recrystallized to prehnite-pumpellyite and

greenschist-facies mineral assemblages. However, primary volcanic structures and textures are still very well preserved.

The babingtonite occurrence is in a 30 m thick basalt flow with a mineral assemblage typical of the lower greenschist facies. The upper 15 to 20 m of the flow has a mottled appearance due to irregular yellow-green epidote-rich patches (metadomains) up to 20 cm across surrounded by grey albite-rich basalt. The lower portion of the flow is composed of grey-green relatively unaltered basalt with minor epidote-rich metadomains. Veins containing quartz-albite-chlorite-calcite and epidote-quartz, with or without calcite, occur throughout the flow. Relatively unaltered basalt consists of plates of tabular relict clinopyroxene (0.5 to 2.0 mm long) which wholly or partly enclose laths of albite dusted with fine chlorite and epidote, replacing original calcic plagioclase crystals, with interstitial devitrified basaltic glass (replaced by chlorite, epidote, and sphene) and Fe-Ti oxide. Relict clinopyroxene crystals are commonly mantled by epitaxial overgrowths of pale green fibrous actinolite. The epidote-rich metadomains consist of