METASOMATISM IN THE TERTIARY VOLCANICS OF THE WAGWATER BELT, JAMAICA, W.I.

T. A. JACKSON[1] & T. E. SMITH[2]

ABSTRACT

Jackson, T. A. & T. E. Smith (1978). Metasomatism in the Tertiary volcanics of the Wagwater Belt, Jamaica, W.I. *In:* H. J. Mac Gillavry & D. J. Beets (eds.): The 8th Caribbean Geological Conference (Willemstad, 1977) Geol. Mijnbouw, 57, p. 213-220.

The Wagwater Belt represents part of a former inter-arc basin in which approximately 5,000 m of Tertiary sediments and volcanics accumulated. The volcanics are made up of minor amounts of submarine mafic flows and their sedimentary derivatives, and extensive silicic flows, volcanic breccia, conglomerates and tuffs. The mafic flows have been identified as basalts and spilites, and the silicics as dacites and quartz keratophyres.

The stable-element geochemistry of the spilites is similar to that of the basalts. Ti, Zr and Y indicate that these mafic rocks were erupted in an intra-plate tectonic setting and are comparable to plateau-type tholeiitic basalts. The levels of concentration of the stable elements in the quartz keratophyres are comparable to those of the dacites. The rare-earth elements of these silicic rocks confirm that they belong to the calc-alkaline series.

Mineralogical, textural and geochemical data support the view that most of the basalts and dacites in the Wagwater Belt were metasomatized to spilites and quartz keratophyres respectively.

INTRODUCTION

The island of Jamaica has an area of approximately 11,425 square kilometers. It is situated in the northwestern part of the Caribbean, south of Cuba and west of Hispanola. The Wagwater Belt crosses the eastern third of the island (GREEN, 1972). It has an area of some 950 square kilometers and runs in a NW-SE direction from the north coast at Port Maria to the south coast at Bull Bay, and then eastwards to Holland Bay and Morant Point (ZANS ET AL., 1962).

The petrology and geochemistry of the Tertiary volcanic rocks outcropping within the Wagwater Belt is described. The various rock types are identified and their significance discussed.

[1] Department of Geology, University of the West Indies, KINGSTON 7, Jamaica.

[2] Department of Geology, University of Windsor, WINDSOR (Ontario), Canada.

GEOLOGICAL SETTING

The Wagwater Belt is a fault-bounded structural unit in which approximately 3,700 m of strongly folded and faulted (?) Paleocene to Lower Eocene sedimentary and volcanic rocks are contained. The belt is bounded on its western side by the Wagwater Fault and on its eastern side by the Yallahs-Plantain Garden Fault (Fig. 1).

HORSFIELD (1974) postulates that these faults became active since the early Tertiary. During this period downthrow on the Wagwater Fault was to the east, and on the Yallahs-Plantain Garden Fault to the west and south (HORSFIELD, op. cit. p. 10). On either side of these faults two uplifted Cretaceous blocks, represented by the Blue Mountain Massif to the east, and the Cornwall-Middlesex Block to the west, provided a sedimentary source (CAMBRAY & JUNG, 1970; ROBINSON & LEWIS, 1971).

Volcanism in the form of submarine mafic flows and subaerial felsic flows occurred within the Wagwater Belt during this period. The centres of volcanism were located in the central and northern section of the Wagwater Belt (ROOBOL, 1972). Jackson & Smith (in preparation) interpret the Wagwater Belt as an interarc basin (KARIG, 1970). The basin developed as a result of the splitting of a mature, Late Cretaceous volcanic arc into a frontal and third arc, represented by the

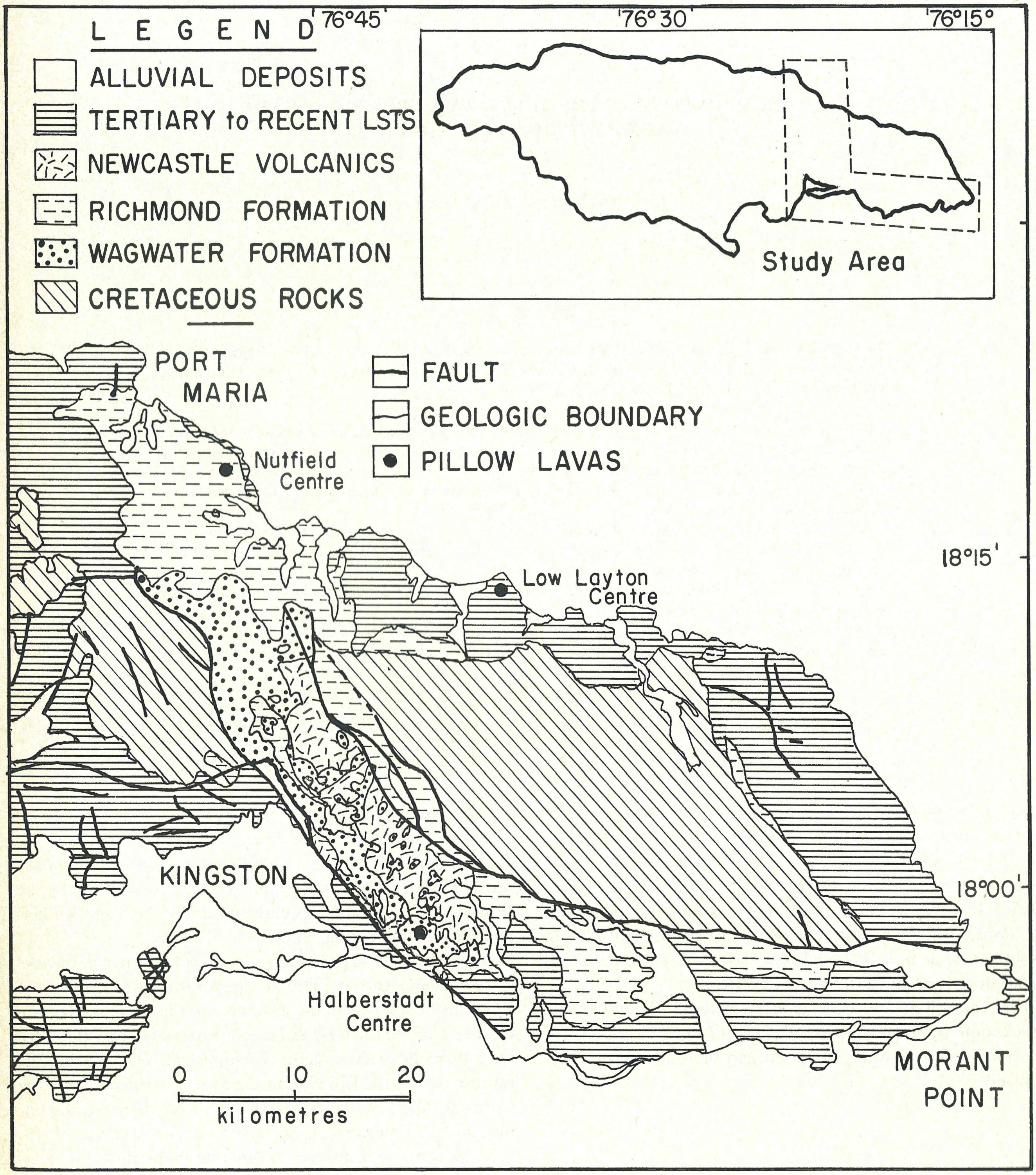

Fig. 1
Geological map of the Wagwater Belt

Blue Mountain Massif and the Cornwall-Middlesex Block respectively.

The mafic lava flows, known as the Halberstadt Volcanics (MATLEY, 1951), consist of basaltic pillow lava and their sedimentary derivatives. The textures displayed in the basaltic rocks are comparable with those seen in the spilites. However, the mineralogy of these two rocks is different; labradorite and augite are the two essential minerals in the basalt, whereas albite, chlorite and calcite are the common minerals in the spilites.

The felsic rocks, named the Newcastle Volcanics (GREEN, 1972), overlie the Halberstadt Volcanics and are composed of dacite and quartz keratophyre lava flows and volcaniclastics. Both rock types show similar volcanic textures but differ in their mineralogy. The dacites contain phenocrysts of andesine, quartz, hornblende and clinopyroxene, and the quartz keratophyres show phenocrysts of albite, quartz, chlorite and clinopyroxene.

ANALYTICAL METHODS

Major and trace element analyses were carried out using a Philips PW1410 Universal Vacuum X-ray Spectrometer. Major elements were determined using 2:1 mixture of lithium tetraborate and rock powder. Trace elements were analyzed using undiluted rock powder pellets. Mass absorption corrections were made by successive approximation with an IBM 360 computer. Total volatiles ($H_2O + CO_2$) were determined by loss on ignition, and total water by the Penfield tube method. Carbon dioxide was estimated by difference. The U.S.G.S. rock powder standards W-1, AGV-1 and GSP-1 were used for the analysis. Values obtained by FLEISCHER (1969) and FLANAGAN (1969) for major elements, and ABBEY (1973) for trace elements, were used.

Rare earth elements were analysed by neutron activation using a Herald R 61.1 nuclear reactor. Five specially selected rock samples were analyzed at the Atomic Weapons Research Establishment Laboratory in Reading, England, by Mr. J. Herrington.

GEOCHEMICAL COMPARISON OF THE BASALTS AND SPILITES

The geochemistry of the basalts that compose part of the Halberstadt Volcanics, reveals that these rocks are tholeiitic according to the volcanic-rock classification of IRVINE & BARAGAR (1971). These basalts compare best with plateau-type tholeiitic basalts and differ in their geochemistry from island arc, ocean island and abyssal tholeiites. The most distinguishing feature is the behaviour of the rare-earth elements. The chondrite normalized REE pattern for these rocks shows a strong enrichment of the light rare-earth elements (Fig. 2). This behaviour is characteristic of plateau-type basalts and differs from other tholeiites which show a depletion of light

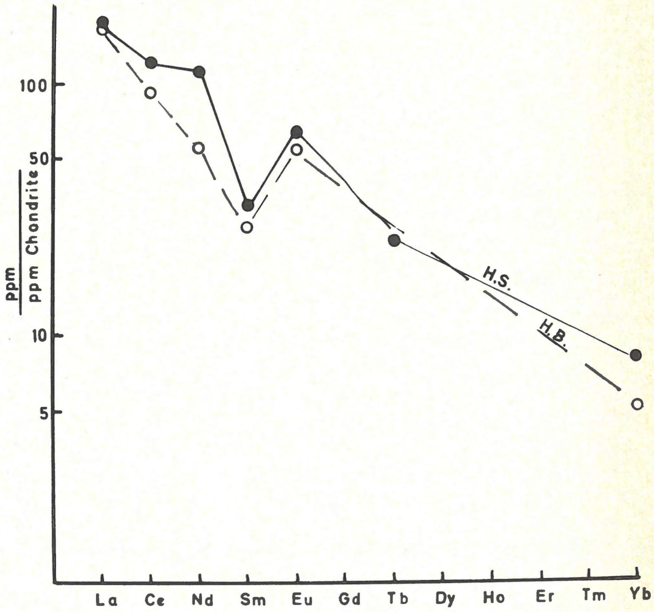

Fig. 2
Comparison of rare earth patterns in Halberstadt basalt (H.B.) and Halberstadt spilite (H.S.).

Table I
Comparison of average chemical compositions of selected elements in Jamaican Tertiary spilites and basalts with those of other tholeiitic basalts.

wt%	1	2	3	4	5	6
TiO_2	2.50	2.28	2.52	2.19	1.49	0.80
P_2O_5	0.35	0.31	0.39	0.36	0.16	0.11
ppm.						
Cr	130	163	152	118	297	50
Zr	208	125	—	175	95	70
Y	26	25	112	55	43	—

1. Halberstadt Spilite. Av. of 12 analyses.
2. Halberstadt basalt. Av. of 3 analyses.
3. Av. values for Colombia River basalt. (Waters, 1955, Table 1; Prinz, 1967, Table 4)
4. Av. values for 'normal' basalt. Deccan. (Tiwari, 1972, Table 12).
5. Abyssal tholeiite (Engel et al., 1965, Table 2).
6. Island arc tholeiite (Jakes & White, 1972).

Table II
Major and trace element composition of oceanic and continental spilites.

	1	2	3	4	5	6
SiO_2	47.43	47.58	43.58	51.75	46.85	47.96
TiO_2	1.51	1.79	0.84	1.27	1.22	2.50
Al_2O_3	16.04	14.98	10.71	16.30	14.16	14.80
FeO	9.14	12.13	12.10	7.87	13.81	9.40
CaO	8.70	5.53	4.47	7.42	5.82	6.77
MgO	8.94	9.03	16.65	6.62	7.19	6.28
Na_2O	3.28	3.47	1.70	3.95	3.08	3.08
K_2O	0.15	0.10	0.40	0.77	1.56	0.36
P_2O_5	0.12	0.14	0.37	0.28	0.38	0.35
MnO	0.17	0.19	0.14	0.15	0.24	0.10
H_2O (T)	4.71	5.08	7.18	2.58	5.29	4.89
CO_2	nil	nil	0.80	0.22	0.72	3.48
Cr	—	—	—	—	52	130
Ni	—	150	750	99	48	102
Cu	—	100	123	28	360	101
Zn	—	—	104	53	—	113
Rb	—	n.d.	13	97	35	9
Sr	—	77	194	324	335	287
Y	—	44	—	—	25	26
Zr	—	141	—	—	360	208
Ba	—	—	—	—	963	267

1. Av. Oceanic Spilite, Mid-Atlantic Ridge. (Shido et al., 1974, p. 184).
2. Av. Oceanic Spilite, Carlsberg Ridge. (Cann, 1969, p. 3-4)
3. Av. Continental Spilite, W. Germany. (Hermann et al., 1974, p. 6, 8)
4. Av. Continental Spilite, Switzerland. (Hermann et al., 1974, p. 6, 9)
5. Av. Continental Spilite, Deccan, India. (Vallance, 1974, p. 84; p. 90)
6. Av. Halberstadt Spilite, Wagwater Belt, Jamaica.

rare earths (JAKES & GILL, 1970; SCHILLING, 1971).

The concentration of P_2O_5, TiO_2, Cr, Zr and Y match best with values for either the Columbia River or Deccan tholeiitic basalts (Table I). These elements have been successfully used to discriminate between magma types (PEARCE & CANN, 1971; BLOXAM & LEWIS, 1972; WINCHESTER & FLOYD, 1976). A triangular plot of Ti against Zr and Y (Fig. 3) shows that the basalts were erupted in an intra-plate tectonic setting. Plateau-type tholeiites are shown to originate in such a tectonic setting.

The spilite geochemistry is similar to that of continental spilites but differs from that of oceanic spilites (Table II). The spilites contain relatively high levels of CO_2, a feature that is absent in oceanic spilites but prevalent in continental spilites because of the abundant carbonate minerals in these rocks (CANN, 1969). The potash and strontium values correspond to those of continental spilites. Both these elements tend to have higher concentrations in continental spilites than in oceanic spilites.

A comparison of the bulk composition of the basalt and spilite in the Halberstadt Volcanics (Table III) shows that the values for certain elements differ. Some of these differences may be accounted for by igneous petrogenesis whereas others may not, viz. Na, K, Ca, CO_2 and Sr. Soda and carbon dioxide are higher and lime, potash and strontium are lower in the spilite.

The stable-element values for the spilite are similar to those of the basalt (Table I). These elements, which are regarded as useful indicators in tracing the origin of spilites, are P_2O_5, TiO_2, Cr, Zr, Y and the rare-earth elements (PEARCE & CANN, 1971; BLOXAM & LEWIS, 1972; HERMANN ET AL., 1974; WINCHESTER & FLOYD, 1976). Figure 2 shows that the chondrite REE pattern for the spilite is identical to the pattern for the basalt, and Fig. 3 indicates that both the spilites and basalts plot in the intra-plate field.

GEOCHEMICAL COMPARISON OF THE DACITES AND QUARTZ KERATOPHYRES

The dacites which form part of the Newcastle Volcanics are calc-alkaline according to the classification of IRVINE & BARAGAR (1971). Apart from the low potash, their major-element chemistry corresponds closely to that of TAYLOR's (1969) calc-alkaline dacites and differs from JAKES & WHITE's (1972) tholeiitic dacites.

The calc-alkaline nature of these rocks is verified by the concentration of certain trace elements, especially the rare-earth elements. A chondrite normalized pattern of these elements (Fig. 4) shows that there is an enrichment of light rare-earth elements, a feature characteristic of calc-alkaline dacites (TAYLOR, 1969). The REE pattern is different for tholeiitic dacites which show a depletion of light rare earths and displays a pattern similar to abyssal tholeiites (JAKES & GILL, 1970).

The quartz keratophyres of the Wagwater Belt are comparable to quartz keratophyres elsewhere. These rocks contain high silica (>66%), the typically high soda, and the generally low potash and lime (SCHERMERHORN, 1972). The sum of $Na_2O + K_2O$ falls within the limits outlined by Schermerhorn and the mean is close to BATTEY's (1955) value of 8% for the New Zealand quartz keratophres.

As in the case of the spilites, there is a group of elements in the quartz keratophyres which is uncontrolled by igneous petrogenesis. These elements include CaO, Na_2O, K_2O, Sr, Ba and CO_2. They show a definite gain or depletion relative to the dacite (Table III). CaO, Sr and Ba are less concentrated in the quartz keratophyres than in the dacites whereas Na_2O and CO_2 are higher.

Those elements which have similar values in both the quartz keratophyres and dacites are Al_2O_3, total iron oxide, TiO_2, P_2O_5, Cr, Y, Zr and the rare-earth elements. Some of these elements have been previously established as being stable in the spilites, viz. Ti, P, Cr, Y, Zr and REE. A comparison of the

Table III
Bulk composition of basalt, spilite, dacite and quartz keratophyre in the Wagwater Belt.

	1	2	3	4
SiO_2	47.96 ± 3.64	46.20 ± 1.21	67.85 ± 3.15	68.77 ± 2.06
Al_2O_3	14.80 ± 1.08	14.88 ± 0.46	15.08 ± 0.56	14.90 ± 0.60
EFeO	9.40 ± 2.75	11.51 ± 1.85	3.00 ± 0.84	3.10 ± 0.63
MgO	6.28 ± 2.58	8.72 ± 1.27	1.27 ± 0.34	1.31 ± 0.42
CaO	6.77 ± 2.56	8.76 ± 0.24	3.81 ± 1.15	1.56 ± 0.99
Na_2O	3.08 ± 1.26	1.73 ± 0.59	4.01 ± 0.54	6.50 ± 0.86
K_2O	0.36 ± 0.41	0.48 ± 0.05	1.36 ± 0.62	0.99 ± 0.52
TiO_2	2.50 ± 0.63	2.28 ± 0.27	0.39 ± 0.10	0.36 ± 0.09
P_2O_5	0.35 ± 0.14	0.31 ± 0.10	0.17 ± 0.06	0.17 ± 0.08
MnO	0.10 ± 0.02	0.17 ± 0.01	0.09 ± 0.03	0.05 ± 0.03
H_2O(T)	4.89 ± 1.64	4.82 ± 1.26	2.17 ± 1.35	1.60 ± 0.63
CO_2	3.48 ± 1.63	0.73 ± 0.20	0.44 ± 0.63	0.57 ± 0.68
Cr	130 ± 49.76	163 ± 12.75	21 ± 2.75	21 ± 2.73
Ni	102 ± 30.92	160 ± 12.92	—	—
Cu	101 ± 63.62	64 ± 26.04	35 ± 11.05	32 ± 5.08
Zn	113 ± 66.02	175 ± 12.04	41 ± 21.00	41 ± 33.37
Rb	9 ± 6.82	7 ± 1.53	25 ± 13.05	20 ± 8.57
Sr	287 ± 215.02	505 ± 128.78	338 ± 153.00	246 ± 136.00
Y	26 ± 3.67	25 ± 1.73	12 ± 2.28	12 ± 2.92
Zr	208 ± 66.92	125 ± 17.52	164 ± 25.00	161 ± 38.00
Ba	267 ± 140.26	269 ± 57.35	690 ± 202.00	471 ± 129.00

1. Halberstadt Spilite. Av. of 12 analyses plus one standard deviation.
2. Halberstadt basalt. Av. of 3 analyses plus one standard deviation.
3. Newcastle Dacite. Av. of 14 analyses plus one standard deviation.
4. Newcastle Quartz Keratophyre. Av. of 20 analyses plus one standard deviation.

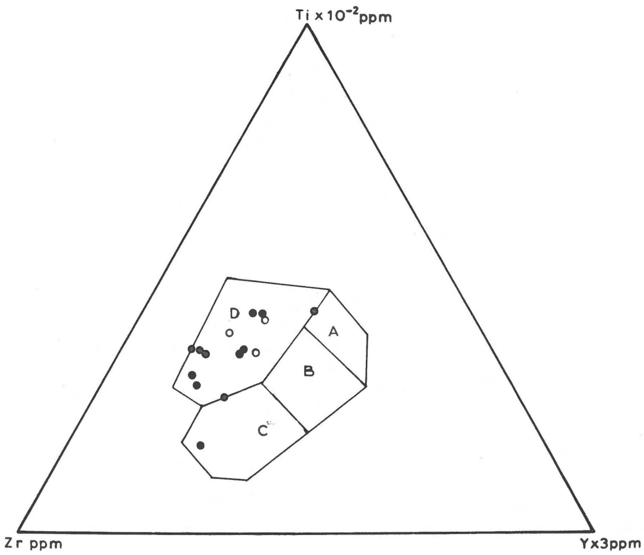

Fig. 3
Ti-Zr-Y triangular diagram of Halberstadt basalt and pilite. Open circles=basalt; closed circles=spilite.

Low potassium tholeiite=Fields A and B.
Calc-alkali basalts=Fields C and B.
Intra-plate basalts=Field D.
Ocean floor basalts=Field B.

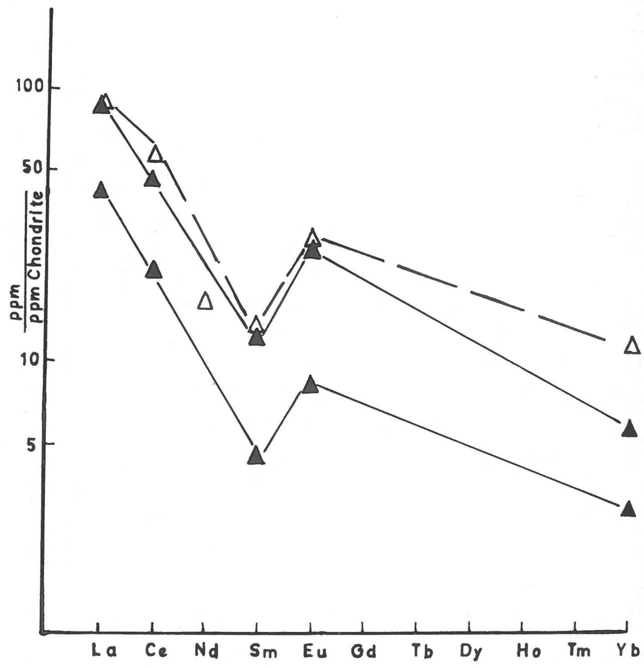

Fig. 4
Comparison of rare earth patterns in Newcastle dacite (open triangles) and Newcastle quartz keratophyres (closed triangles).

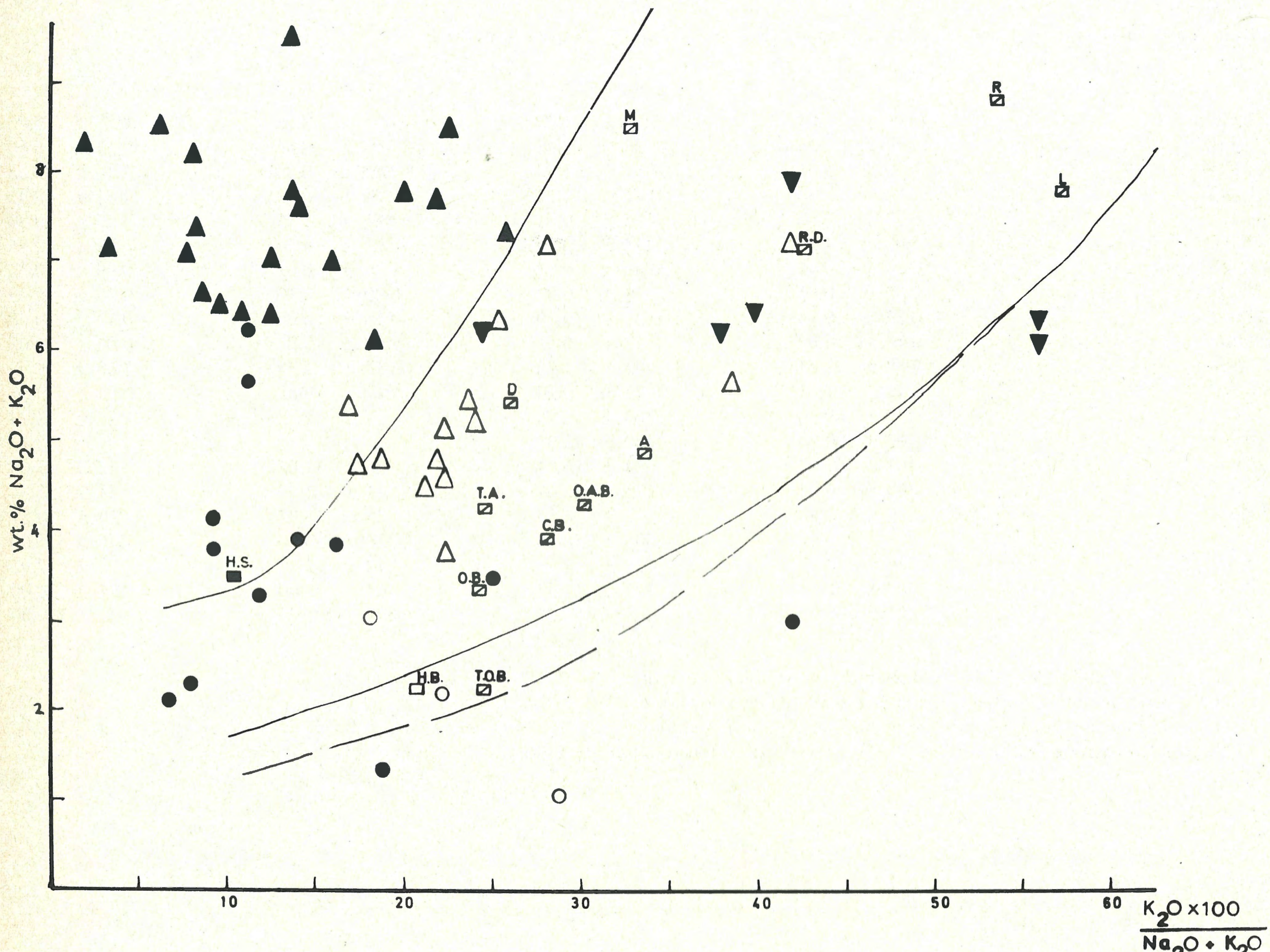

Fig. 5
Hughes diagram. Broken line indicates proposed expansion of igneous spectrum field. Open circles=Halberstadt basalts, closed circles=Halberstadt spilites, open triangles=Newcastle dacites, closed triangles=Newcastle quartz keratophyres.

TOB = Average tholeiitic olivine basalt (Nockolds, 1954).
OB = Average oceanic basalt (Manson, 1967).
CB = Average continental basalt (Manson, 1967).
OAB = Average olivine alkali basalt and dolerite (Manson, 1967).
TA = Average tholeiitic andesite (Nockolds, 1954).
A = Average circum-Pacific calc-alkali andesite (Taylor, 1969).
D = Average dacite (Nockolds, 1954).
M = Average mugearite (Nockolds, 1954).
RD = Average rhyodacite (Nockolds, 1954).
R = Average rhyolite (Nockolds, 1954).
L = Average latite (Nockolds, 1954).
H.B. = Average Halberstadt basalt.
H.S. = Average Halberstadt spilite.

REE pattern for the quartz keratophyre and the pattern for the dacite shows that these elements display similar behaviour. The REE pattern for the quartz keratophyre shows that there is an enrichment of the light rare-earth elements (Fig. 4).

ORIGIN OF THE SPILITES AND THE QUARTZ KERATOPHYRES

Although there is still some controversy surrounding the origin of spilites and quartz keratophyres (AMSTUTZ, 1974), it is our contention that these rocks are formed by a metamorphism post-dating extrusion and cooling of volcanic rock. The textures displayed by the spilites and quartz keratophyres in the Wagwater Belt are typically volcanic, but the mineralogy is comparable to the mineralogy of low grade metamorphic rocks.

The preservation of texture but change in mineralogy in these rocks was achieved under conditions of relatively low temperature and shear stress. Temperatures were probably below 400 °C so that there was insufficient energy to nucleate and grow some or all of the new mineral phases in the rock (HUGHES, 1972). Instead, a retrograde metamorphism took place in which the high-temperature primary minerals broke down into low-temperature minerals.

The lack of foliation in both the spilites and quartz keratophyres indicates that shear stress was low. Under such conditions nucleation is also inhibited and mimetic textures are favoured (CANN, 1969).

An examination of these elements which are purported to be unaffected by weathering and/or low grade metamorphism reveals that there is a genetic relationship between the spilites and basalts, and the quartz keratophyres and dacites. The matching values of the stable-elements, viz. TiO_2, P_2O_5, Cr, Zr, Y and the rare-earth elements in the basalts and spilites strongly suggest that the spilites are the metamorphozed equivalent of the basalts. Similarly the behaviour of certain elements in the dacites and quartz keratophyres, particularly the REE, indicates that these elements are stable and that the two rock types are genetically related.

The difference in the bulk composition of the basalt and the spilite, and the dacite and quartz keratophyre (Table III), particularly Na, Ca, K, Sr and CO_2, suggests that metamorphism took place in an open or allochemical system. This type of metamorphism, which is infrequently termed metasomatism or hydrothermal metamorphism, involved the introduction of Na and CO_2, and the removal of Ca, K and Sr from the system.

The behaviour of Na and K is illustrated in the Hughes diagram (Fig. 5). A plot of $Na_2O + K_2O$ versus $K_2O \times 100/Na_2O + K_2O$ shows that the majority of spilites and quartz keratophyres falls outside the igneous spectrum whereas the basalts and dacites fall within the spectrum. HUGHES (1972) regards those rocks which lie outside the spectrum as metasomatized.

This type of metamorphism often takes place in many present day geothermal fields and involves the introduction and migration of certain elements by hydrothermal fluids (MIYASHIRO, 1973). Greenschist and zeolite facies metamorphism have been reported at shallow depths in these areas. This is due to the high geothermal gradients that are encountered in these regions.

A similar situation is postulated for Jamaica during the Tertiary. Evidence of such activity is indicated by the presence of a few remaining thermal springs (HUGHES, 1973). These springs have surface temperatures that range from 35 °C to 55 °C and represent the waning stages of a formerly active geothermal region.

The Tertiary volcanic history of Jamaica suggests that the Wagwater Belt would have been the ideal area for geothermal activity. Volcanic activity commenced in the Wagwater Belt during the Paleocene or early Eocene and did not cease in Jamaica until the close of the Pliocene, as shown by the presence of the Low Layton basalt lavas (Williams, in ZANS ET AL., 1962).

The absence of zeolites from both the spilites and quartz keratophyres is attributed to the high concentration of CO_2 present in the hydrothermal fluids. Large amounts of CO_2 cause an increase of P_{CO_2} in the system and result in the precipitation of calcite in preference to Ca-bearing silicates (MIYASHIRO, 1973). This type of condition existed throughout a major portion of the Wagwater Belt during the Tertiary.

CONCLUSIONS

A geochemical study of the volcanics in the Wagwater Belt reveals that the spilites and quartz keratophyres are the metasomatized equivalents of plateau-type tholeiitic basalts and calc-alkaline dacites respectively. Alkali metasomatism post-dating volcanic activity accounted for the formation of these rocks. Hydrothermal fluids enriched in Na and CO_2 and at temperatures below 400 °C converted the high-temperature primary minerals of the basalts and dacites into the low-temperature minerals seen in the spilites and quartz keratophyres.

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