The Paleogene Volcanic Rocks of Cuba and Jamaica: Similarities and Differences

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\textbf{ABSTRACT.}\ Paleogene volcanic lava flows and associated pyroclastic rocks are exposed in eastern Cuba in the Sierra Maestra mountain range, and in eastern Jamaica in the Wagwater Belt of the Port Royal mountain range. In Cuba, the volcanic rocks are contained within the El Cobre Group and comprise basalts, basaltic andesites, andesites and dacites, some of which have been hydrothermally altered. In Jamaica, the volcanic rocks are contained in the Wagwater Group; they are distinctly bimodal in composition, with basalts and dacites being the dominant rock types. Metasomatism is also evident in these rocks, which have been altered to spilites and quartz keratophyres. The volcanic rocks of El Cobre show tholeiitic and calcalkaline characteristics that are typical of an island-arc assemblage. In the Wagwater Group only the dacites are arc-related, whereas the basalts are intra-plate. The presence of intra-plate basalts in the Paleogene island arc of Jamaica, and their absence in Cuba, implies that the evolution of the arc-back arc system in Cuba was different to that of Jamaica, and is a reflection of the tectonic conditions that existed as the Caribbean Plate migrated ENE.

\textbf{INTRODUCTION}

Paleogene volcanic rocks of the Greater Antilles have been recognized in the islands of Jamaica, Cuba, Hispaniola, Puerto Rico and the Virgin Islands. They represent the waning stages of volcanic arc activity in the Greater Antilles region. A paleogeographic reconstruction of the Caribbean in the Early Tertiary by Pindell (1994) shows that Cuba, Hispaniola, Puerto Rico and the Virgin Islands formed a separate Greater Antilles arc from Jamaica, which was a part of the Central America Chortis–Nicaraguan Rise arc (Fig. 9.1). This chapter compares the petrology of these two Paleogene arcs using Cuba and Jamaica as examples.

\textbf{GEOLOGY AND PETROLOGY}

In this study the rock analyses from Cuba were from samples collected during the IGCP 364 field excursion to Santiago de Cuba in November 1996. Although few in number, the analyses are representative of the suite of volcanic rocks that occurs in the Sierra Maestra (see Table 9.1). The rock analyses from the Wagwater Belt were published in Jackson (1977).

\textbf{CUBA}

The Paleogene volcanic rocks crop out in eastern Cuba along the southern part of the Oriente Block,
where they unconformably overlie arc-related rocks of Cretaceous age (Iturralde-Vinent 1994). They are contained within the El Cobre Group, where they occur in the form of lava flows, pillow lavas and related volcaniclastics; together with the interbedded sedimentary rocks, they attain a maximum thickness of 6000 m. They make up a major part of the Sierra Maestra mountain range that trends E-W for some 250 km.

Throughout the area there is evidence that the El Cobre volcanics have been subjected to hydrothermal alteration, with serpentine, chlorite and sericite being the most common alteration minerals present in the rocks. In the least altered rocks, plagioclase is the dominant phenocryst phase, and is associated with minor amounts of clinopyroxene in the basalts, basaltic andesites and andesites, and with quartz in the dacites.

The altered nature of the volcanic rocks is reflected in their chemistry, particularly among the more mobile elements such as Na₂O, K₂O and Rb, and the high LOI values (Table 9.1). Hence the rocks are classified using SiO₂ versus Zr/TiO₂ (Fig. 9.2) rather than SiO₂ against Na₂O+K₂O, known as the TAS classification of LeMaitre (1989). The data show a wide range of SiO₂ chemistry, and that there are basalts (45–52% SiO₂), basaltic andesites (52–57% SiO₂), andesites (57–63% SiO₂), and dacites and rhyodacites (>63% SiO₂) present in the El Cobre Group.

Associated with the volcanics are several small coeval plutons that intrude much of the lower and
Major- and trace-element analyses of volcanic rocks from the El Cobre Group, Sierra Maestra, Cuba.

Major- and trace-elements were analysed using a Philips PW1400 XRF spectrometer. Major-elements were analysed using a Rh tube and trace-elements analysed using a Sc/Mo tube. A fusion bead technique with the sample, a La2O3 heavy absorber and a eutectic lithium tetraborate/lithium carbonate flux was used for major- and minor-elements. Na and the trace-elements were determined on pressed powder pellets.

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Fe2O3 is total iron oxide.
Figure 9.2 $\text{SiO}_2$ vs $\text{Zr/TiO}_2 \times 0.0001$ classification of the volcanic and the altered volcanic rocks (after Winchester and Floyd 1977) from El Cobre, Cuba; and Wagwater, Jamaica. Closed squares = El Cobre; open squares = Wagwater.

Figure 9.3 FMA diagram (after Irvine and Barager 1971) of volcanic and altered volcanic rocks from El Cobre and Wagwater. Closed squares = El Cobre; open squares = Wagwater.
middle sections of the El Cobre Group. These plutons do not display as much alteration as the surrounding volcanics, and radiometric K/Ar dates give an early to middle Eocene age for them (Draper and Barros 1994). These plutons range in composition from granitoid to dioritoid, and from our study show calcalkaline and tholeiitic properties.

JAMAICA

In Jamaica, Paleogene volcanic rocks occur in the Wagwater Belt, although the upper part of the Summerfield Formation in central Jamaica may be Paleocene (Ahmad et al. 1988). The Wagwater Belt is a fault-bounded structural unit that trends NW-SE and within which approximately 7000 m of Paleogene volcanic and sedimentary rocks are contained, referred to as the Wagwater Group (Green 1977).

The volcanic rocks of the Wagwater Group show similar field characteristics to the volcanics of El Cobre, in that they occur as lava flows, pillow lavas, dikes and volcaniclastic rocks. However, unlike the El Cobre suite, where there is a unimodal distribution of rock type in which the majority of rocks are basaltic andesite in composition (Kysar et al. 1998), the volcanic rocks of the Wagwater Group are distinctly bimodal in composition, with basalt and dacite being the dominant rock types (Jackson and Smith 1979). Volcanic rocks of basaltic andesite and andesite composition are rare. The chemistry of the volcanic rocks indicates that the basalts are tholeiitic and that the dacites are calcalkaline (Fig. 9.3).

The two essential minerals in the basalts are clinopyroxene and plagioclase, with a minor amount of olivine, whereas the dacites are dominated by plagioclase phenocrysts with lesser amounts of quartz and hornblende. As at El Cobre, hydrothermal alteration has affected the original mineralogy and converted them to spilites and quartz keratophyres (Jackson and Smith 1978).

Only one small plutonic stock has been reported in the Wagwater Belt. Isaacs and Jackson (1987) described a small microgranodiorite body that intrudes the silicic volcanics in the central part of the Wagwater Belt. The granodiorite is hydrothermally altered and is associated with porphyry copper deposits.

COMPARISON

Paleogene volcanic rocks of the El Cobre Group and the Wagwater Group unconformably overlie Upper Cretaceous rocks. The Cretaceous geology of the islands indicates that both were once part of an evolving volcanic arc in which Primative Island Arc (PIA) volcanism in the Early Cretaceous gave way to calcalkaline volcanism in the Late Cretaceous, with Cuba also containing Late Cretaceous shoshonites (Donnelly et al. 1990). On both islands there is a very noticeable change from a Cretaceous high-K volcanic arc suite to a Paleogene low- to medium-K volcanic arc suite (Fig. 9.5). In Cuba, high-K calcalkaline and shoshonitic volcanics have been identified in the Late Cretaceous rocks of Camaguey (Diaz de Villavilla et al. 1998), while in
Jamaica high-K andesites occur in the Summerfield Formation in central Jamaica (Roobol 1976).

A noticeable difference in the Early Tertiary volcanic activity of the two islands is that the Wagwater Belt does not contain any volcanic-arc basalts that match those of Cuba. This difference is detected in the major- and trace-element chemistry, where there are significant differences in TiO₂, Al₂O₃, P₂O₅, Y, Zr, Ni and Cr (Table 9.2). The mafic volcanics in the Wagwater Group are higher in TiO₂, P₂O₅, Y, Zr, Ni and Cr, and lower in Al₂O₃ than those of El Cobre (Table 9.2), reflecting a different tectonomagmatic setting (Fig 9.4). This is also highlighted in the MORB-normalized spidergram where the El Cobre mafic volcanics display a typical arc basalt pattern, and differ from the Wagwater volcanics by having lower concentrations of HFSE (Fig. 9.6).

There is also a rarity of volcanic rocks of intermediate composition in Jamaica. The rocks in Jamaica are distinctly bimodal in composition, containing tholeiitic intra-plate basalts, and calcalkaline low- and medium-K dacites (Figs. 9.3, 9.4 and 9.5). This close temporal and spatial association of intra-plate basalts and convergent-plate dacites led Jackson and Smith (1979) to conclude that crustal extension accompanied subduction during the Early Tertiary in Jamaica, in which the Wagwater Belt was a back-arc basin. The absence of intra-plate volcanism in eastern Cuba at that time, and the occurrence of only convergent plate volcanics ranging from basalt to dacite, signifies that the evolution of the arc-back arc system in Cuba was different to that of Jamaica.

**TECTONOMAGMATIC HISTORY**

We believe that the shift in K on both islands, from Late Cretaceous high-K volcanic rocks to Paleogene
low- and medium-K volcanic rocks, is a result of changes in plate motion that were taking place as the Caribbean Plate migrated E and NE. According to Gill (1981), significant shifts in K in arc volcanics generally signify a change in the melting behaviour of the mantle in the mantle wedge, brought about by possible changes in the movement of the subducting plate. In the case of Cuba there is evidence of a temporary break in subduction at the end of the Campanian, attributed to the collision of a mature Cuban arc with the Bahama Platform. Subduction was not renewed until the Paleocene, but with arc volcanism being confined only to the Oriente Block. The direction of subduction during the Cretaceous remains unresolved (Draper and Barros 1994), but the arc axis appears to have changed from a NW–SE trend in the Cretaceous to an E–W trend in the Paleogene (Rosencrantz 1994), suggesting that there
may have been a jumping or flipping of subduction between the Cretaceous and the Early Tertiary periods. It is the repositioning of the subducting plate and its motion that could account for the change in K.

In Jamaica, there is no evidence to suggest a cessation of subduction in the Maastrichtian, and neither is there any indication of a significant shift in arc axis, nor a major departure in the direction of subduction, which seems to have remained SW to W (Robinson 1994). Instead, there is evidence that crustal extension accompanied subduction at the end of the Cretaceous. This is based on the occurrence of lamprophyre dikes in the Cretaceous-Paleocene Above Rocks pluton which predate the volcanics of the Wagwater Group (Jackson et al. 1998). The spatial and temporal relationship of intra-plate lamprophyres and basalts, and convergent plate calcalkaline plutonic and volcanic rocks, indicates that syn-subduction rifting occurred in the Early Tertiary, a feature not seen in the Oriente Block in Cuba. Therefore the change in magma composition to a more bimodal suite in the Early Tertiary volcanic rocks of Jamaica may be related to the crustal extension that accompanied subduction.

The extensional magmatism represented by the intra-plate basalts in the Wagwater Belt is not reported in Cuba, where the basalts show a geochemistry that is typical of arc-volcanic rocks (Figs. 9.3, 9.4 and 9.6). The Paleoene basalts of Jamaica are somewhat unusual, in that their chemistry has similarities to both rift-related basalts (Gibson et al. 1992) and to enriched back-arc basalts (Stern et al. 1990). The structural history of the Wagwater Belt, coupled with the composition and geographic location of the volcanic centres (Roobol 1972), prompted Jackson and Smith (1979) to conclude that the Wagwater Belt was a back-arc basin which had resulted from the splitting of a mature Cretaceous arc. The negative Nb anomaly seen in the spidergrams would tend to support a back-arc basin basalt, which often shows a subduction signature during the early opening stages of the basin (Stern et al. 1990). However, a compari-

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**Figure 9.7** MORB-normalized spidergrams for basalts from Wagwater, Rio Grande and Bransfield. Data for Rio Grande from Gibson et al. (1992) and for Bransfield from Lawver et al. (1995). MORB values from Sun and McDonough (1989).
son of MORB- and chondrite-normalized spider-grams for back-arc basalts and rift-related basalts shows that the Jamaica basalts compare more favourably with those of rift-related basalts (Figs 9.7 and 9.8). The patterns compare well with those for the Rio Grande rift area, showing similar levels of Light Rare Earth Elements (LREE) and Large Ion Lithophile Elements (LILE); they are unlike the enriched back-arc basalts of Bransfield, where the values are generally lower.

**CONCLUSIONS**

The petrology of the Paleogene volcanic rocks of Cuba and Jamaica indicates that both islands were experiencing subduction in the Early Tertiary, producing low- and medium-K volcanics of a tholeiitic and calcalkaline nature. Cuba comprised a suite of convergent plate basalts, basaltic andesites, andesites and dacites, whereas Jamaica contained convergent plate dacites together with intra-plate basalts. These intra-plate basalts are the product of crustal thinning and rifting that took place over a subduction zone in which lavas of dacitic composition were being extruded. In contrast, Cuba appears to have undergone crustal thickening and subduction. The mean Zr/Y value (Pearce 1983) for the Cuban basalts is 5.6, with ratios ranging from 5.1 to 6.2, suggesting that Cuba was more likely a continental island arc rather than an oceanic island arc.

In Jamaica, the crustal thickness at the end of the Cretaceous is estimated to be greater than 30 km (Jackson et al. 1989), using the Rb-Sr thickness grid of Condie (1973). This would indicate that the crust underlying Jamaica was more continental than oceanic in nature, which could account for some of the continental basalt chemical signatures seen in the Paleogene basalts that make them comparable with those of the Rio Grande rift. The negative Nb anomaly in the MORB-normalized spidergram indicates that a subduction component contributed to the composition of the intra-plate basaltic magma. We believe that the Paleocene–early Eocene rifting and
submarine rift-related basalt volcanism that occurred in Jamaica signalled the break-up of Jamaica from Central America. This rifting may have been a precursor to the initial opening of the Cayman Trough, as a paleogeographic reconstruction of Jamaica in relation to the Cayman Trough in the Eocene places Jamaica next to the mid-Cayman spreading centre (Rosencrantz and Sclater 1986).

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