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The provenance of volcanogenic sediments in the Miocene Buff Bay Member, Buff Bay, Jamaica

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ABSTRACT. Thinly-bedded, fine-grained volcaniclasts have been identified in the marlstones of the Miocene Buff Bay Member (Layton Formation) in Jamaica. The minerals contained in the rocks indicate a silicic volcanic ash source with well preserved crystals of feldspar and quartz in a matrix of smectite, calcite and anhydrite. Sedimentation occurred in the bathyal zone, but involved a mixing of shallow- and deep-water sediments and fauna, indicative of rapid downslope transportation. The source of the volcanic ash was distal and was transported as windblown tephra from Central America to the northwest Caribbean, where it was deposited on a tectonically emerging landmass.

Keywords: Miocene, Greater Antilles, ash fall, volcaniclastic turbidites, silicic volcanism

1. INTRODUCTION

The Miocene of the Greater Antilles marks a transition from extensive marine sedimentation in the early Miocene to emergence and erosion by the late Miocene. The distribution of sedimentary rocks in the region indicates that during the early Miocene much of the Greater Antilles was below sea level and that carbonate sedimentation was prevalent. However, by the middle to late Miocene uplift had commenced, and, by the end of the Miocene a large portion of the present day Greater Antilles was above sea level forming islands and platforms of relatively low relief (Lewis and Draper, 1990).

Submarine volcanic activity accompanied uplift. This was associated with ocean floor spreading in the Cayman Trough and the generally eastward movement of the Caribbean Plate with respect to the Americas (Mann et al., 1990). Basaltic volcanism occurred both within the Cayman Trough (**Figure 1**), and along the strike-slip faults associated with the opening of the trough, as seen at Low Layton, in northeast Jamaica, and in the Jamaica Passage (Wadge, 1982).

Outside of the Greater Antillean area, subduction related volcanic arc activity occurred both to the east in the Lesser Antilles, and to the west in Central America. In northern Central America there were major siliceous ignimbritic eruptions as the Cocos Plate subducted beneath the western Caribbean Plate (Donnelly et al., 1990). Evidence of this extensive explosive volcanism in the Miocene is recorded as ash fall beds that were identified in the cores of the ODP Leg 165 oceanographic cruise (Sigurdsson et al., 1997). These authors have identified four major episodes of volcanism that impacted the Caribbean during the Cenozoic, of which the Miocene epoch represented one such episode.

Evidence of this silicic volcanism in the Miocene has been identified in the uplifted carbonate rocks of Jamaica in the form of altered volcanic ash referred to as bentonites (Comer, 1972; Comer and Jackson, 2004). Numerous bentonite beds measuring 5-15 cm thick occur within the deep water limestones of the Montpelier Formation and, according to Comer (1974) the volcanic ash source was also the source from which the bauxites of Jamaica were formed. Bentonite beds are especially prevalent along the north coast of Jamaica and within the fault controlled North Coast Belt. In addition to the White Limestone Group, beds of volcanic ash are reported from the overlying Coastal Group and, in particular within the Buff Bay Member, Layton Formation, which represents the base of the Coastal Group (**Figure 1**). In this study we examined the mineralogy and chemistry of some of these beds located within the Buff Bay Member and compared them to ash beds of similar age recovered from the ODP 165 project (Sigurdsson et al., 1997).

2. THE BUFF BAY MEMBER

The type locality of the Buff Bay Member (formerly the Buff Bay Formation) crops out along the north coast road some 3.5 km east of the village of Buff Bay. Here, a section of almost uninterrupted,

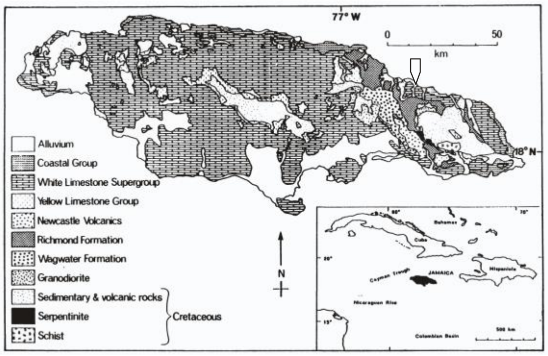

Figure 1. Geological map of Jamaica modified after Donovan (1993). Arrow points to location of Buff Bay Formation. Inset map shows the position of Jamaica in the Greater Antilles.

highly fossiliferous and well-bedded Neogene carbonate-rich rocks ranging from middle Miocene to mid-Pliocene (Berggren, 1993) are exposed along a road section of about 600 m in length on the south side of the highway. The oldest of these formations is a white, chert-poor, chalky limestone described by Robinson (1969) as the Spring Garden Member of the Montpelier Formation. This sequence grades conformably into the marlstones of the Layton Formation (James-Williamson and Mitchell, 2012) represented by the Buff Bay Member, which in turn is unconformably overlain by the Bowden Member, comprising bioclastic limestones and calcareous clays.

The total thickness of the Buff Bay Member is estimated to be about 80 m, within which there are breaks in the outcrop due to land slippage and possible minor faulting. The planktonic foraminiferal stratigraphy places the Buff Bay Member in the middle to late Miocene and within biozones N14 to N17 (Berggren, 1993) which correlate to calcareous nannofossil zones NN8 to NN10 (Aubry, 1993). Although the contact with the underlying Spring Garden Member is conformable, Jackson et al. (1998) noted that there is a change in carbonate lithology, from pure white chalky limestones of the Spring Garden Member to blue-grey marlstones representing the Buff Bay Member. Jackson et al. (1998, p. 18) further suggested that the change to a less calcareous rock corresponds to the "carbonate crash" identified in cores of ODP Leg 165. Within the Buff Bay Member there are numerous thin, silty-textured beds of reddish-brown volcanogenic clastics whose thicknesses do not exceed 3 cm and which can be easily identified by their difference in colour to the host rock (**Figure 2**). These beds are extensively weathered and often strongly bioturbated.

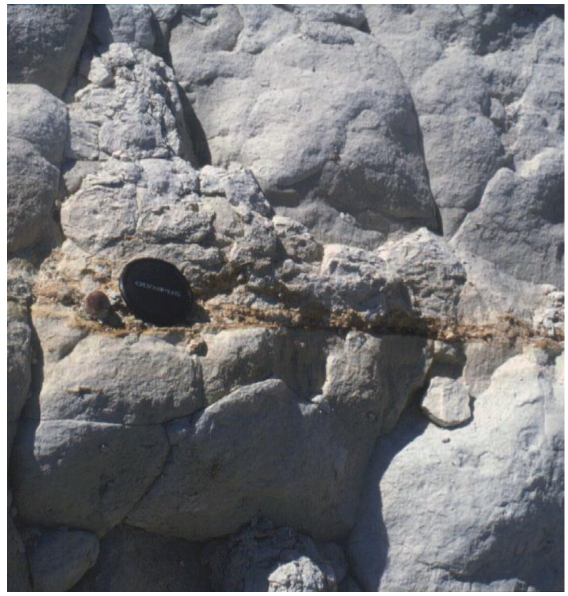

Figure 2. Outcrop showing a thinly bedded volcaniclastic horizon within thickly bedded marls of the Buff Bay Member. Lens cap measures 4.5 cm in diameter.

3. METHODOLOGY

This study is based on the results of sampling six of the volcanogenic clastic beds along the main road cutting representing the lower part of the Buff Bay section. The section that was sampled corresponds to planktonic foraminifer zones N14 and N15 of Berggren (1993). Each bed, averaging about 1 cm in thickness, was sampled and labelled JA599, 600, 601, 602, 603 and 604 beginning with the lowermost/oldest (599) and ending with the highest/youngest (604). The spacing between each bed was relatively uniform and was approximately 1 m apart, with the exception of JA604 (the uppermost) which was about 3 m above 603. Between these sample levels were other, much thinner, beds that were less than 1 cm in thickness and which were difficult to properly sample. Fossiliferous limestone clasts were also contained within the horizons, plus in the two uppermost horizons anhydrite was also identified, indicating a mixing of carbonate, sulphate and volcaniclastic sediments.

Whole rock analysis was carried out on five of these horizons using X-ray fluorescence (XRF) spectrometry. Major and minor elements were analyzed using a Philips PW 1400 spectrometer with a Rh tube. A fusion bead technique was employed for the major element determination with the exception of Na which was determined from a

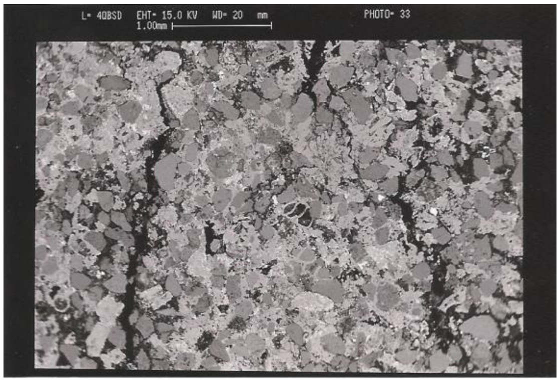

Figure 3. Scanning electron micrograph of the Buff Bay anhydrite-bearing volcaniclastic turbidite displaying subangular and subrounded quartz and feldspar grains (grey) contained in a matrix of anhydrite (white). Note the presence of microfossils (centre and lower left), which are replaced by anhydrite. Black areas represent resin.

pressed pellet. All trace elements were determined using a Sc/Mo tube and pressed pellets. Total carbon and sulphur were measured by LECO analyser and expressed as % element.

Mineral analysis was determined by whole rock X-ray diffraction (XRD) using a Cu Kα radiation source, and by electron microprobe using a JOEL-8600 superprobe with three wavelength spectrometers at 15 kV and a probe current of 3.00 x 10-8 amperes. XRD analysis was carried out on samples 600 and 601. Ground powder samples were placed in a cavity mount holder of aluminium, and scanned between a 2θ angle of 4° and 60°. Sample 603 was examined by microprobe.

4. RESULTS

4.1. Mineralogy

The X-ray diffraction data show quartz, feldspars, smectite, calcite, aragonite and anhydrite as the major minerals in the volcanogenic beds. Silt-sized, well-sorted, subangular and subrounded quartz, compositionally zoned plagioclase feldspar ranging from labradorite to albite, and sanidine, ranging in size from 50 µm to 200 µm, are preserved in each of the beds and show no sign of post depositional alteration (**Table 1**; **Figures 3-4**). Although the volcanic crystals show no sign of degradation, the associated volcanic glass has completely altered to smectite. The presence of iron oxide, accounts for the reddish brown colour that makes these beds easily distinguishable from the marlstones (**Figure 2**). The occurrence of calcite, aragonite and anhydrite are attributed to a marine source where their occurrence is primarily as a cementing agent in the rocks, but within which there are minor amounts of clasts of similar composition. Diagenetic calcite and anhydrite can be seen enclosing the feldspar and quartz crystals as well as infilling tiny pores in the altered volcanic glass (**Figure 3**). In the two uppermost beds (**Table 2**, JA603-4), the cement is dominantly anhydrite, whereas in the lower horizons calcite is dominant. In the anhydrite-bearing beds barytes, celestite, framboidal pyrite and jarosite were identified from microprobe analysis.

4.2. Geochemistry

The presence or absence of anhydrite is reflected in the geochemistry of the volcaniclastic beds in the Buff Bay Member. The anhydrite-bearing beds contain high concentrations of SO_3 whereas those that are anhydrite-poor and calcite-rich contain higher levels of CO_2 (see **Table 2**, JA600-1, JA603-4). The presence of CO_2 and SO_3 represent the admixing of calcite and anhydrite, respectively, with the volcanic ash. Apart from these major differences, there are other differences in their chemistry, noticeably the concentrations of SiO_2, Al_2O_3, $*Fe_2O_3$, CaO, Na_2O, K_2O, P_2O_5, and the trace elements Zr, Sr, Rb and Ni. When compared, the anhydrite-bearing beds are lower in SiO_2, Al_2O_3, CaO, Na_2O, K_2O, P_2O_5, Zr and Rb and higher in $*Fe_2O_3$, Sr and Ni.

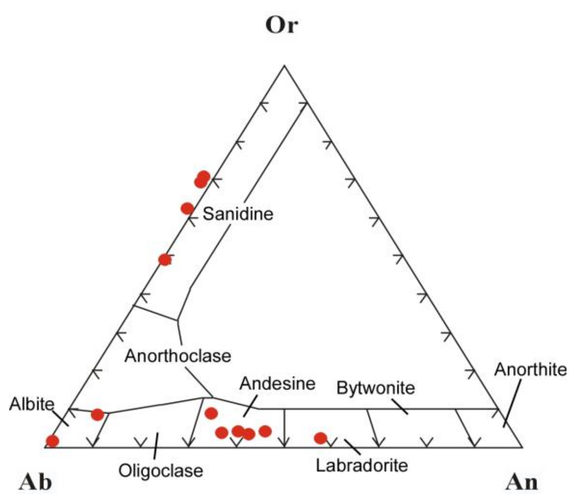

Figure 4. The composition of feldspar grains in the Buff Bay volcaniclastic rocks.

5. DISCUSSION

Similar occurrences of middle to late Miocene thinly-bedded volcaniclastic turbidites within a carbonate host have also been described in cores collected from ODP Leg 165, particularly at sites 998, 999 and 1000 where they have been mineralogically and chemically analysed

Table 1. Representative electron microprobe analyses of smectite, plagioclase feldspar, alkali feldspar, quartz and anhydrite in the Buff Bay volcaniclastics. [Chemical analyses were made using a JEOL-8600 superprobe in the wavelength dispersive mode (three spectrometers at 15 kV and a probe current of 3.00 x 10 amps). Detection limits are: SiO_2, 0.04%; TiO_2, 0.05%; Al_2O_3, 0.02%, FeO, 0.04%; MnO, 0.05%; MgO, 0.02%; CaO, 0.03%; Na_2O, 0.05%; K_2O, 0.03; BaO, 0.02%; SrO, 0.03%; SO_3, 0.05%. All Fe reported as FeO.]

Wt %	1	2	3	4	5	6
SiO_2	53.31	57.7	66.02	65.59	99.71	
TiO_2	0.24				0.06	
Al_2O_3	17.84	26.41	18.53	18.94	0.01	
FeO	4.06	0.43	0.12	0.26	0.03	0.27
MnO	0.03	0.01		0.02	0.03	0.27
MgO	4.24	0.02				
CaO	1.41	8.84	1.95	0.09	0.01	46.32
Na_2O	0.4	6.27	10.51	4.38	0.01	
K_2O	0.64	0.38	1.39	10.59	0.01	
BaO						0.01
SrO						0.17
SO_3						53.04
Total	82.17	100.06	98.52	99.87	99.87	100.08

1 Smectite 2 Andesine 3 Oligoclase 4 Sanidine
5 Quartz 6 Anhydrite

Table 2. Major, minor and trace element chemistry of Buff Bay Formation volcaniclastic beds

wt %	JA599	JA600	JA601	JA603	JA604
SiO_2	48.93	32.57	35.81	23.07	14.34
TiO_2	0.87	0.35	0.4	0.37	0.08
Al_2O_3	11.53	7.72	7.33	5.2	2.25
$^*Fe_2O_3$	18.3	10.57	10.45	22.97	24.52
MnO	0.06	0.04	0.03	0.01	0.01
MgO	2.22	1.82	1.76	0.84	0.73
CaO	14.04	44.47	40.84	20.59	32.66
Na_2O	2.72	1.53	2.07	1.04	0.72
K2O	2.01	1.37	1.59	1.1	0.67
P_2O_5	0.21	0.27	0.18	0.11	0.07
SO_3	nd	0.25	0.05	25.74	23.34
Total	100.89	100.96	100.51	101.04	99.39
LOI	11.53	27.72	25.58	7.12	11.18
CO2	6.63	22.52	21.84	1.76	9.67
ppm					
Nb	8	3	2	3	1
Zr	79	45	48	38	22
Y	10	7	7	6	3
Sr	659	1463	1521	2331	2147
Rb	40	26	29	24	20
Th	2	5	2	1	4
Ga	12	11	10	9	5
Zn	111	31	34	15	-
Ni	287	68	112	192	232

nd = below detection limit

(Sigurdsson et al., 1997). The mineralogy of the volcanic ash identified within the Buff Bay Member is similar to those described from the cores of similar age in which quartz, plagioclase feldspar and sanidine occur. Particle size for the feldspars and quartz in the ash fall layers at Buff Bay fall within the range of grain size outlined by Carey and Sigurdsson (2000) for tephra deposits contained at sites 998, 999 and 1000. Absent from the Buff Bay volcanogenic turbidites is amphibole, biotite and volcanic glass shards described by Carey and Sigurdsson (2000) from some of the cores at the ODP sites. Their lack of preservation in the Buff Bay beds may have been caused by degradation of the ash to clay as a result of post-depositional alteration.

The presence of anhydrite and carbonate clasts in the Buff Bay Member, the occurrence of bathyal and neritic fossils, and the subrounded to subangular nature of the volcanic crystals suggest some degree of reworking of sediment. The depth at which sedimentation occurred is estimated between 1,300-2,000 m based on ranges of certain benthic foramiferal taxa (Katz and Miller, 1993). Aubry (1993) estimated that deposition in the upper Spring Garden Member and the lower Buff Bay section occurred from <12. 6 Ma to >9 Ma, during which time sedimentation rates remained high, probably as a result of localized tectonic events. The prevalence of tectonic activity into the Pliocene is substantiated by key bathymetric marker species that indicated a change in paleodepths from the lower bathyal fauna of the Buff Bay Member to an upper bathyal fauna of the Pliocene Bowden Member over a period of approximately 4-5 Ma (Katz and Miller, 1993).

Of particular interest is the presence and influx of anhydrite in some of the beds. Sedimentary anhydrite has never been reported from any of the Neogene volcaniclastic turbidites collected from the ODP Leg 165 cruise, and, therefore, we regard its introduction into the Buff Bay Member as a proximal one. The source of the anhydrite can either be from hydrothermal fluids associated with the nearby Low Layton submarine volcanic activity or from the development of shallow-water, semi-enclosed basins which would have provided ideal conditions for the formation of evaporites together with carbonates on the shelf. Additional isotope analysis would be required to confirm whether the anhydrite was from a sedimentary exhalative or a marine evaporate source.

6. Conclusions

The mineralogy of the volcanic crystals of the Buff Bay Member indicates a volcanic source of silicic composition. The mineralogy is significantly different to the mineralogy of the contemporaneous basalts of the proximal Low Layton volcano where submarine lava flows intruded into rocks of the Montpelier Formation and dated at circa 9.5 ± 0.5 Ma (Wadge, 1982). Instead, the source of the silicic volcanics is regarded as distal and originated from subaerial volcanic eruptions that occurred in Central America, where crystal and vitric ash were transported eastwards in the troposphere and deposited as pyroclastic fall on the Miocene sea floor of the Caribbean (Sigurdsson et al., 1997; Carey and Sigurdsson, 2000)

The occurrence of thinly-bedded layers of fine-grained volcanic ash throughout the section represents periods in which volcanic airfall mixed with shallow water carbonates and evaporates that originated on the continental shelf. In the case of Jamaica, this distal volcanic activity was synchronous with tectonic events in the northern Caribbean that began in the middle to late Miocene and which included the uplift of Jamaica. The presence of both neritic and bathyal benthic foraminifers in the Buff Bay Member, coupled with the occurrence of coral fragments and bivalves, confirm downslope transportation and mixing of shallow-water sediment with deep-water sediment (Katz and Miller, 1993: Donovan et al., 2013). The inclusion of volcanically derived minerals and glass represented periods in which pyroclastic fall associated with Central America volcanic activity mixed with resedimented carbonate and sulphate turbidites within the bathyal zone.

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