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A PRELIMINARY VOLCANOLOGICAL AND PETROCHEMICAL SURVEY OF THE LATE PRECAMBRIAN CALC-ALKALINE VOLCANIC SUCCESSION OF EASTERN JERSEY, CHANNEL ISLANDS

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The Jersey Volcanic Group comprises one of the few examples of a calc-alkaline volcanic centre within the Cadomian orogenic belt of the Armorican Massif. The Jersey volcanics are a succession of mainly intermediate to acidic rocks, over 2,200 m thick, formed of lava flows, pyroclastic ash-flow deposits, shallow intrusive domes, and volcaniclastic deposits largely of mass flow derivation. Much of the sequence appears to have accumulated in a subaqueous environment. The volcanics overlie Upper Brioverian metasediments (the Jersey Shale Formation) without a major temporal break apparent. The volcanic succession and underlying sediments show the effects of Cadomian deformation and low grade metamorphism; they are unconformably overlain by the Rozel Conglomerate Formation, a late to post-orogenic `molasse' deposit of probable CambroOrdovician age. The three main units of the volcanic pile - the St. Saviours Andesite Formation (oldest), the St. Johns Rhyolite Formation and the Bouley Rhyolite Formation (youngest) have been sampled and reveal a sequence ranging from basalt and basaltic andesite to andesite, dacite, rhyodacite, and high-silica rhyolite. Their overall character is that of a high-K calc-alkaline (shoshonitic) suite with marked enrichment in alkalies and incompatible elements in the upper part of the succession.

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INTRODUCTION

One of the distinctive features of the igneous geology of the Cadomian orogenic belt of north-western France and the adjacent Channel Islands is the abundance of calc-alkaline plutonic rocks and the rarity of their volcanic counterparts. Only three principal occurrences of Cadomian calc-alkaline volcanic sequences are known : the Jersey Volcanic Group - by far the best exposed (Bishop and Bisson, 1984); the Tufs de Tréguier and Ignimbrites des Lézardrieux flanking the southern margin of the North Trégor batholith (Auvray, 1979) (B in the inset map in Figure 1) and the Serie volcano-sedimentaire et complexe ignimbritique de St Germain-le-Gaillard in Normandy (Graindor, 1957; Graindor *et al.,* 1976) (A in the inset map in Figure 1).

The Jersey Volcanic Group crops out in east Jersey (Figure 1) and overlies typical Brioverian siliciclastic flysch deposits of the Jersey Shale Formation (Squire, 1974; Helm and Pickering, 1985). It is intruded by the late Cadomian post-tectonic calc-alkaline plutonic complexes of north-west and south-east Jersey (Bishop and Bisson, 1984) and is overlain with marked unconformity by the post-Cadomian molasse deposit of the Rozel Conglomerate Formation (Went and Andrews, 1990). The volcanic sequence, estimated to be over 2,200 m thick (Thomas, 1977), appears to succeed the Brioverian sediments with little or no discordance and with some evidence for interdigitation at the base, implying a close temporal link between the two.

The presence of volcanic rocks in Jersey was first noted in the late 1870s. The most important studies are those of Mourant (1933) and Thomas (1977), the latter as part of the British Geological Survey Channel Islands Mapping contract at Queen Mary College, University of London. Both authors recognized the dominantly intermediate to acidic nature of the volcanic succession which they divided into three parts. Thomas (1977) gave the whole succession a Group status and the three subdivisions Formation status as follows:-

(1) St Saviour's Andesite Formation - the oldest (Andesite of Mourant),

(2) St John's Rhyolite Formation (Porphyritic Rhyolite of Mourant)

(3) Bouley Bay Rhyolite Formation* (Non-porphyritic Rhyolite of Mourant).

The St. Saviour's Andesite Formation, though poorly exposed, is composed mainly of lava flows, with subordinate lapilli tuffs, volcaniclastic deposits (including debris flow units), and acidic flows or intrusive sheets. Many of the lavas are markedly porphyritic with swallow-tailed plagioclase laths often showing marked flow alignment.

The volcanics of the St. John's and Bouley Rhyolite Formations are better exposed on the narrow coastal platforms in the north and east of the island, where they occur mainly as acidic lava flows or extrusive/intrusive domes' and pyroclastic ash flows deposits, with minor pyroclastic bedded deposits and volcaniclastic debris flows. The rocks are not exclusively acidic, however, for units of an intermediate composition occur sporadically within these two formations.

There is a marked difference in the interpretation of the nature of these later units by Mourant (1933) and Thomas (1977). Mourant considered large parts of the sequence to be composed of lava flows, whereas Thomas interpreted the sequence as being largely dominated by pyroclastic ash flow (ignimbrite) units. In view of this radical difference, a reexamination has been made of the volcanic sequence, with a view to making volcanological comparisons with more recent volcanic sequences. Remapping of certain critical sections was necessary to achieve this objective.

LITHOLOGIES OF THE JERSEY VOLCANIC GROUP

On the north coast of Jersey between Bonne-Nuit Bay and Giffard Bay an excellent section (Figure 2) provides evidence for the environment of eruption of the lithologies low in the succession, while the northerly-dipping section between Anne Port and Archirondel Tower in St. Catherines Bay on the east coast, provides evidence for the nature of the upper part of the succession.

*Thomas, (1977) used the term Bouley Bay Rhyolite Formation, but Bishop and Bisson (1984) and the BGS 1:25000 geological map use the term Bouley Rhyolite Formation.

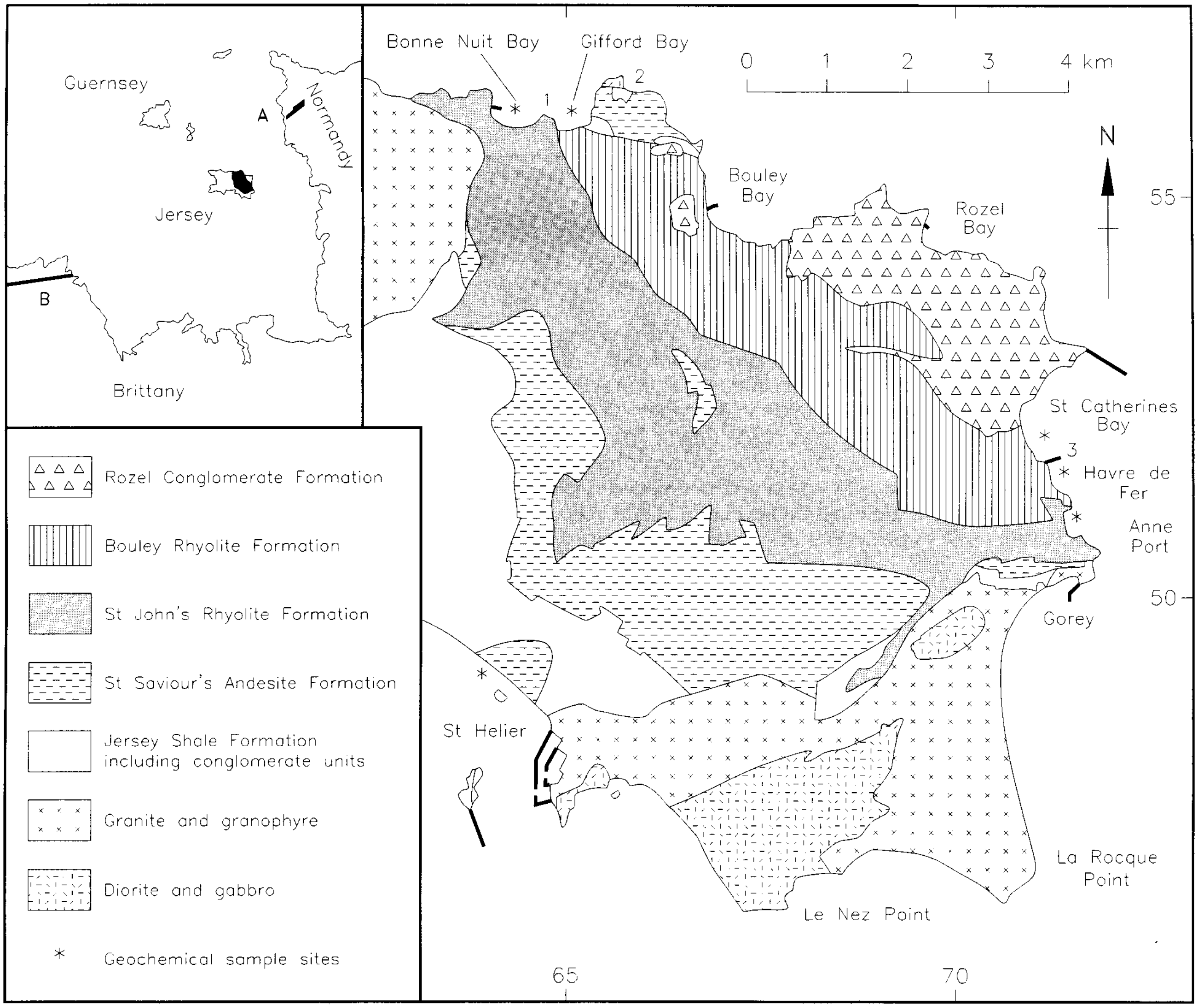

Figure 1: Simplified geological map of eastern Jersey showing the major formations of the Jersey Volcanic Group. The inset map indicates the location of other late Cadomian calc-alkaline volcanic rock outcrops in the northern Armorican Massif (refer to text).

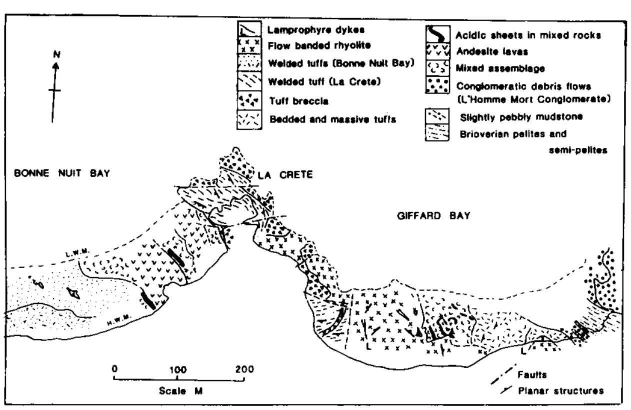

Figure 2: Geological map of eastern Bonne Nuit Bay and Giffard Bay on the north coast of Jersey showing the main volcanic units.

In both sections there are essentially six main components:

Ash Flow Tuffs (ignimbrites);

Obsidian Lava Flows;

Andesite and Basaltic-Andesite Lava Flows;

Debris Flows (forming the mixed assemblage); Intrusive Acid Sheets, Plugs and Domes.

Ash Flow Tuffs (Ignimbrites)

Both welded and non-welded pyroclastic ash flow tuffs are present. Highly welded ash flow tuff units occur in the middle of Bonne Nuit Bay and at La Crête Point (Figure 2), exceeding 100 m in thickness in places, and to the north of Anne Port on the east coast, some 50 m thick at least. They show a variety of constituent clasts : flattened tubular pumice; angular rhyolite lava; fine-grained sedimentary rocks; porphyritic andesite; fiamme of poorly-vesiculated acid volcanic glass; abundant quartz and feldspar crystals. These clasts are set in a highly welded parataxitic fabric (Figure 3a). Although now devitrified to a quartz + feldspar + sericite mosaic the outlines of flattened shards may be seen. The original parataxitic fabric is now often accentuated by concentrations of finely disseminated iron ore, and by thin, impersistent ribs of coarser recrystallized quartz.

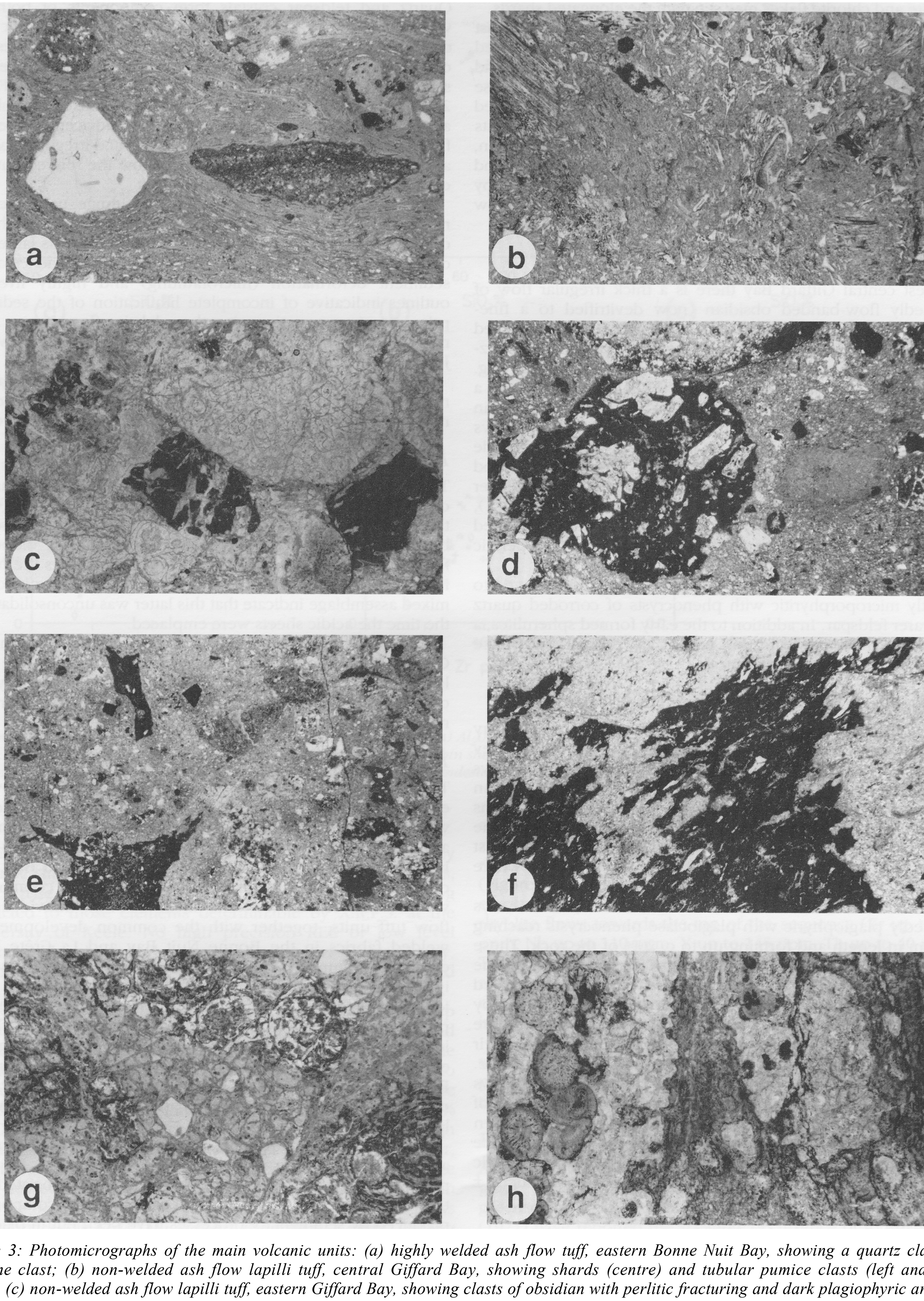

Figure 3: Photomicrographs of the main volcanic units: (a) highly welded ash flow tuff, eastern Bonne Nuit Bay, showing a quartz class and siltstone clast; (b) non-welded ash flow lapilli tuff, central Giffard Bay, showing shards (centre) and tubular pumice clasts (left and lower right); (c) non-welded ash flow lapilli tuff, eastern Giffard Bay, showing clasts of obsidian with perlitic fracturing and dark plagiophyric andesite; (d) debris flow, eastern Bonne Nuit Bay, showing a large porphyritic andesite clast (centre), a porphyritic rhyolite clast (upper centre) and a mudstone clast (right centre) in sand to silt size grade matrix; (e) peperite with fragments of andesite in a volcaniclastic debris flow, centre of Bonne Nuit Bay; (f) peperite showing filigree appearance of andesite clast in volcaniclastic debris flow, eastern Bonne Nuit Bay; (g) perlitic fracturing and quartz phenocrysts in a thin devitrified obsidian sheet, eastern Bonne Nuit Bay; (h) rhyolitic hyaloclastite with elongated fragments of spherulitic devitrified obsidian, separated by a matrix, now represented by a finer microcrystalline aggregates of quartz, feldspar and white mica, north of Havre de Fer.

Sericite and chlorite flakes may separate the elongated shards.

Non-welded ash flow lapilli tuff units are found in east Giffard Bay (Figure 2). They have a matrix of well preserved devitrified glass shards showing the classic tricuspate form and often with very delicate appendages. Set in this matrix are sparse crystals of quartz and feldspar, and also fragments of devitrified tubular pumice (Figure 3b). Internal divisions between flow units are indicated by rubbly bases with a heterogenous composition, comprising andesite and obsidian, with some mudstone and siltstone clasts. The obsidian clasts have the characteristic wispy appearance of spalled fragments, which in thin section show intensive development of perlitic cracking.

Obsidian Lava Flows

In west central Giffard Bay there is a thick irregular flow of markedly flow-banded obsidian (now devitrified to a fine-grained aphyric rhyolite). The flow-banding is commonly picked out by a millimetre-scale development of spherulitic quartz-feldspar intergrowths, which elsewhere in the island (e.g. Bouley Bay) are much coarser. Flow folding is also seen on a microscopic to mesoscopic (outcrop) scale, as for example in the rhyolites of central Giffard Bay. The acidic lava flows exhibit auto-brecciation which, in places (e.g. on the north side of Anne Port, east coast), affects the whole flow. Good columnar jointing may be developed in some of the thicker flows. Some flows, for example those at Havre de Fer (Figure 1), have the appearance of hyaloclastitites, with the fragmented obsidian clasts being characterized by a well-preserved perlitic texture and the development of spherulites (Figure 3h)

In thin section the lava flows are seen to vary from aphyric to slightly microporphyritic with phenocrysts of corroded quartz and rarer feldspar. In addition to the early formed spherulites, a variety of other devitrification fabrics are present, snowflake texture being particularly noticeable.

Andesite and Basaltic Andesite Lava Flows

Andesite and basaltic-andesite lava flows up to 70 m thick may be found in the eastern part of Bonne Nuit Bay, where they show evidence of having been emplaced into the debris flows of the mixed assemblage when the latter were in an unconsolidated state, and to have developed peperitic margins (see below). They may also be found extensively on the headland to the east of Giffard Bay. In Anne Port on the east coast, a thin andesite flow occurs high in the sequence where the volcanism is predominantly rhyolitic in nature.

These intermediate to basic rocks are almost always markedly plagiophyric with plagioclase phenocrysts reaching 10 mm in length and forming up to c. 20% of the rock. These phenocrysts occur in a groundmass characterized by the abundance of feldspar microlites often defining a marked fluxion fabric. Mafic phenocrysts, now pseudomorphed by chlorite + Fe ore ± epidote, are often rimmed with Fe-ore (magnetite or haematite) and, where recognisable by their form, were originally olivine, pyroxene and amphibole. Pyroxene-andesites are by far the most abundant. The flows are sparsely vesicular - the vesicles now infilled by a variety of secondary minerals. Alteration of the andesites has been extensive. The plagioclase phenocrysts are now albitic and the groundmass has been patchily recrystallized to a felsitic mixture of secondary chlorite + Fe-ore + sericite ± Fe calcite ± dolomite ± epidote.

Debris Flows

Debris flows show spectacular development in both the Bonne-Nuit Bay-Giffard Bay section (Figure 2) and on the north side of Anne Port, east coast. These flows usually comprise a variable content of heterolithic matrix-supported clasts. Internally the flows are either massive, or show vague, irregular and discontinuous bedding. The variety of clasts encountered include: sediment (sandstone, siltstone, and mudstone); andesitic lava (often markedly porphyritic); acid volcanic material (devitrified obsidian, microporphyritic rhyolite, and pumice). Quartz and feldspar crystals form components of both the volcaniclastic matrix and the larger clasts. The andesitic lava clasts sometimes have very irregular, even wispy, outlines and can be highly vesicular (Figures 3c and d). This may best be seen in the small bay immediately west of La Crête Point (Figure 2) where an andesite flow forming part of the mixed assemblage abuts a debris flow. Here, the debris flow adjacent to the lava flow is composed largely of highly angular and irregular clasts of andesitic lava, which in thin section show the filigree outlines characteristic of peperites (Figure 3f).

Clast sizes in the debris flows can range up to several metres (usually rhyolite blocks), e.g. in those on the north side of Anne Port, east coast. Within the debris flow units large rafts of laminated mudstone/siltstone occur, showing evidence of soft sediment deformation (microfaulting) and highly irregular outlines indicative of incomplete lithification of the sediment prior to incorporation in the debris flow units. The mudstone/siltstone clasts are typical of the Upper Brioverian Jersey Shale Formation lithologies.

The intimate association of heterolithic debris flows, rafts of metasediment, and fragmented andesitic lavas produces a mappable unit referred to as the mixed assemblage (Figure 2).

Intrusive Acid Sheets

The mixed assemblage in east-central Bonne Nuit Bay and in central Giffard Bay (Figure 2), has been intruded by thin (< 2 m thick), highly irregular sheets of acidic magma, now represented by devitrified obsidian with intense development of perlitic fracturing (Figure 3g). The margins of these sheets are highly irregular; the crenulate contacts with the adjacent units of the mixed assemblage indicate that this latter was unconsolidated at the time the acidic sheets were emplaced.

In addition to these thin intrusive sheets, there are in west Giffard Bay and on the east coast section north of Anne Port, larger intrusions of variably flow-banded devitrified rhyolitic obsidian over 100 m across. These are thought to represent near-surface domes and plugs.

Environment of Eruption

The occurrence of peperitic margins to the andesite flows in eastern Bonne Nuit Bay indicates eruption into unconsolidated water-saturated volcaniclastic sediment of the mixed assemblage. The highly irregular and intermittent acid sheets intruding the mixed assemblage in central Giffard Bay, with contact phenomena reminiscent of liquid/liquid co-mingling would reinforce this view. The thickness of the individual ash-flow tuff units, together with the common development of welded fabrics in the Bonne Nuit Bay and La Crête Point examples (Figure 2) is reminiscent of those Upper Ordovician ignimbrites in North Wales some of which have been identified as of subaqueous origin (Howells *et al*., 1991). The presence of fragmented and altered obsidian flows, interpreted as hyaloclastites, is another feature in keeping with eruptions taking place in a subaqueous environment. Fragments of hyaloclastites are also observed, together with mudstone and siltstone fragments, in the non-welded ash flow lapilli tuffs.

There is strong evidence from the nature of the mixed assemblage for extreme instability in the area of eruption, presumably due, at least in part, to earth tremors associated with the rise of magmatic material. Nearly all the components produced by sedimentary processes have been put in place by mass flow mechanisms. The components of these units are heterolithic, poorly sorted, and can contain clasts which are up to 10 m across. These can include rafts of pre-existing sedimentary and volcaniclastic material.

The coeval availability of both intermediate-basic andesitic magma and acidic rhyolitic magma is also evident. Although the products of acid magmatism dominate the upper part of the Jersey Volcanic Group, andesitic lavas were erupted sporadically until very late, as shown by the thin andesite flow towards the top of the section north of Anne Port on the east coast.

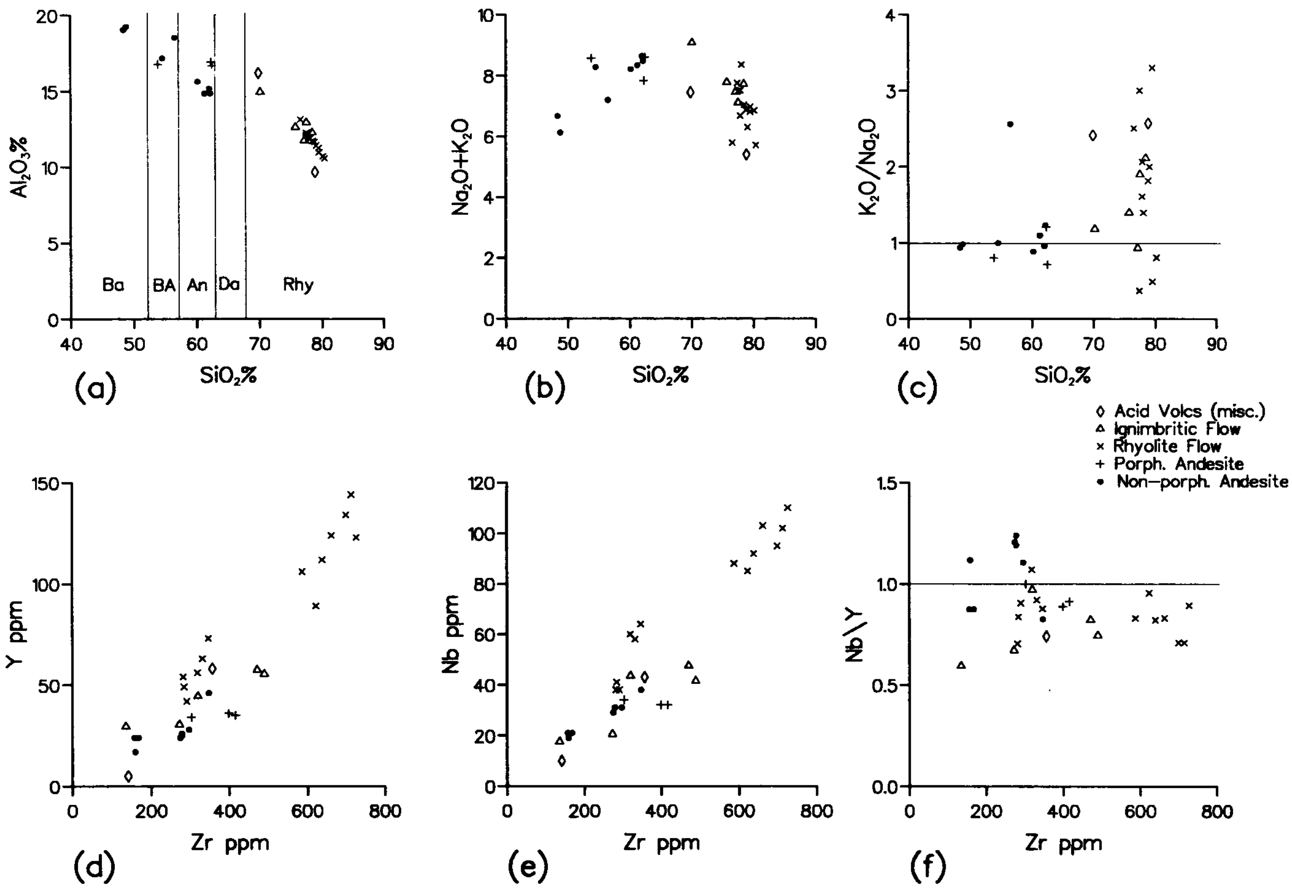

Figure 4: Chemical variation diagrams of the Jersey Volcanic Group (a) Al_2O_3 vs SiO_2; (b) Na_2O+K_2O vs SiO_2; (c) K_2O/Na_2O vs SiO_2; (d) Y vs Zr; (e) Nb vs Zr; (J) Nb/Y vs Zr. The Acid Volcanics (misc.) category refers to the thin sheets intruding the mixed assemblage (see text). The rock-type divisions in (a) are after Ewart (1979) : Ba - basalt; B-A - basaltic andesite; An - andesite; Da - dacite; Rhy - rhyolite.

Petrochemistry

Previous work on the petrochemical nature of the Jersey volcanic suite has been restricted to major elements (Thomas, 1977). The present work is at a preliminary stage, being restricted to those elements determinable by X.R.F.S. at the University of Keele. No high precision REE or low level incompatible element data are yet available. Consequently, petrochemical description and discussion will be restricted essentially to characterisation of the magma type involved.

Compositionally the rocks of the Jersey Volcanic Group range from basalt, through basaltic andesite, andesite and perhaps dacite, to high-silica rhyolites (Figure 4). The alkali-lime index (Peacock, 1931) indicates the suite to be alkalic, close to the alkalic-calcic and alkalic boundary. AP_2O_3 content (Figure 4a) shows the basic members to be high-Al basalts (c.18% AP_2O_3). The total alkali content of the whole suite is high (Figure 4b), the basaltic members having values of 6% and over, so indicating calc-alkaline to alkaline affinities. The sequence has, however, undergone low-grade regional metamorphism with the possible consequent alkali element mobility. The rocks are all markedly K-rich (Figure 4c), the $K_2O:Na_2O$ ratio varying between 0.72 and 2.56 for the basic or intermediate members, with a mean of 1.12. There is some scatter due to alkali mobility, but the preponderance of ratio values in the vicinity of 1.00 for the whole suite indicate it to have high-K calc-alkaline or even shoshonitic affinity, using the scheme of Ewart (1979), (in the absence of any evidence for large scale potash metasomatism - see discussion).

The incompatible minor elements TiO_2 and P_2O_5 show a good positive correlation. The incompatible trace elements (e.g. Zr, Y, Nb, Th) show wide ranges in concentration and reasonably good mutual correlations. However, it might be argued from the bivariate scatter plots that the andesites and the rhyolites fall on two separate trend lines - see Y-Zr, Nb-Zr (Figures 4d and e). Concentrations of these incompatible trace elements may reach quite high values in the devitrified obsidian rhyolite flows towards the top of the sequence (Zr up to 725 ppm, Nb up to 110 ppm, Y up to 145 ppm, Th up to 40 ppm). The ratios Zr/Y and especially Nb/Y (Figure 40 show restricted ranges (i.e. between 7 and 9 for andesites and 5 and 6 for rhyolites, c.0.8 for all rock types for Nb/Y) through the suite, indicating differentiation under low pressure conditions.

The LREE (La, Ce, Nd) may also reach high values in the volcanic suite, e.g. La to 95 ppm, Ce to 230 ppm, Nd to 100 ppm. However, correlation between LREE concentration and those of the incompatible elements is extremely poor.

DISCUSSION

All members of the Jersey Volcanic Group have undergone low grade metamorphism under prehnite-pumpellyite to lower greenschist facies conditions. Mourant (1933) and Thomas (1977) have reported the sporadic occurrence of tourmaline in the andesites, suggesting possible pneumatolysis of the volcanic carapace by the late granites. This raises the possibility of widespread metasomatism of the volcanics by the granites, perhaps with the introduction of significant amounts of K_2O, since the Jersey granites are the most K_2O-rich of those in the north of the Armorican Massif. Such a mechanism can be excluded on the following criteria:-

(a) the Jersey Volcanic Group, the late Cadomian plutons of Jersey (Brown *et al.*, 1990), and the Jersey Main Dyke Swarm which postdates them (Lees, 1990), all show high K_2O contents and high K/Na ratios.

(b) Overt K_2O metasomatism is usually confined to narrow zones surrounding veins and plutons, not wholesale regional enrichment such as envisaged by the French transformist school (cf. Read, 1957).

(c) There is no overt evidence for post-eruptive K fluids affecting the devitrified obsidian flows.

At present it appears that the K-rich nature of the volcanics is a primary feature of the magma, perhaps related to the regional geochemical character of late Cadomian magmatism.

CONCLUSIONS

Preliminary studies on the volcanology and petrochemistry of the late Precambrian Jersey Volcanic Group indicate a magmatic suite of coeval magmas of basic-intermediate and acidic composition, erupted in a subaqueous environment under conditions of great local instability. The volcanic components are largely lava flows and pyroclastic ash flow tuffs, commonly highly welded. Instability is reflected in the development throughout the volcanic pile of debris flows, with variable admixtures of basic to acidic lava clasts, pyroclastic ejectamenta, and epiclastic material (mainly Jersey Shale Formations clasts).

The volcanism is of calc-alkaline type, with a high K_2O signature, which is probably a primary feature of the suite. This shoshonitic character is in accord with the potassic-rich nature of other late Cadomian magmatic episodes on Jersey, as evinced by the younger granitoid plutonic complexes and the later extensional bimodal magmatism of the main dyke swarm of Jersey.

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