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Tracing geochemical signatures in hot rocks across the Caribbean

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Abstract

Professor Trevor A. Jackson (1941–2016) was a distinguished igneous geochemist at the University of the West Indies in Jamaica for many years. This document is based on his professorial inauguration presentation from 2002. Jackson's contributions spanned the length of the Caribbean, concerning both intrusive and extrusive rocks of the Cretaceous and Cenozoic. Territories of interest, apart from Jamaica, included Belize, Carriacou, Tobago and Trinidad. His research was significant and substantial, shedding light on the geochemical evolution and tectonic settings of the Caribbean Plate.

Key words: Jamaica, Carriacou, Trinidad, Tobago, Belize, igneous geology

[Professor Trevor Anthony Jackson (1941–2016) (Fig. 1) was a leading expert on the geochemistry and environments of Caribbean igneous rocks. Recently, sorting through my papers, I uncovered the following manuscript of Trevor's professorial address from 2002. He had intended to publish the text and sent it to me for comment. I supported publication, but other projects obviously took precedence. Yet, over 20 years later, it remains a worthy communication, providing an historical perspective on Trevor Jackson's view of his own contributions. I have edited the text – lightly – for publication. I do not have access to Trevor's images used in the presentation, but have included some relevant figures, mainly geological maps. I have not added references to Trevor's papers; these can be found in the comprehensive bibliography of Donovan and James-Williamson (2017).]

1. Introduction

I presume I was destined to be a geologist, in that I was born in the oil belt of Trinidad and grew up in the oil fields, I had two distinguished geologists living on the same road as my parents' home and, when my father died shortly after I left college, I worked with geologists and petroleum engineers in the oil fields for three years. So it was no surprise when I was awarded a Texaco scholarship in 1965 to pursue a bachelors degree in geology at the University of the West Indies (UWI) in Jamaica. The intention was to return to the oil industry and become a petroleum geologist. However, during my three years at UWI I developed an interest in igneous petrology and in my final year I was encouraged by Dr John Lewis, my lecturer in igneous petrology, to apply for a UWI postgraduate scholarship. I was awarded the scholarship and was given the choice of mapping the geology of either Dominica or Carriacou for my Masters degree. I chose Carriacou, which marked the beginning of my long career in igneous petrology and geochemistry.

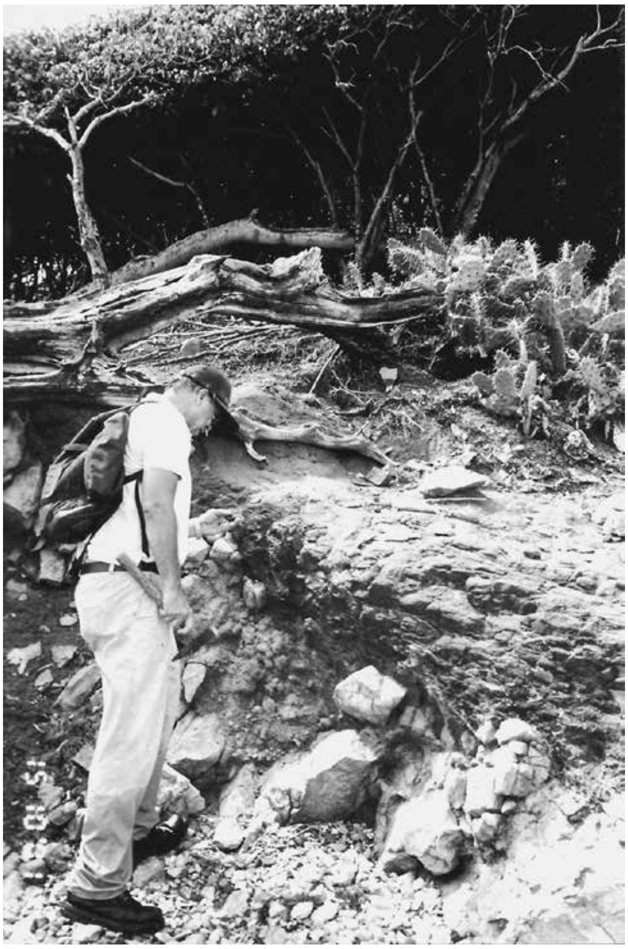

Fig. 1. Professor Trevor A. Jackson (1941–2016) in the field on the east coast of Carriacou in 2001. Image by S. K. D.

2. Carriacou

Carriacou (Fig. 2) is one of a chain of islands known as the Grenadines located between Grenada and St. Vincent in the southern part of the Lesser Antilles island arc. For my Masters thesis I mapped and analysed the volcanic rocks of Carriacou and some of the neighbouring islands of the southern Grenadines. In those days, of the late 1960s, the chemistry of rocks was determined by wet chemical techniques using an ultra violet-visible spectrophotometer. Rock powder samples were digested in acid and then a series of chemicals added to produce a colour for each element whose intensity was then measured on the spectrophotometer. The method, while useful, was restrictive in that it could only analyse elements that had concentrations of greater than 0.1 wt % in the rocks. Therefore, one could determine no more than about ten elements in igneous rocks which were referred to as the major elements.

My thesis on Carriacou confirmed that there was a higher concentration of basaltic rocks in the southern part of the Lesser Antilles island arc chain, especially south of St Lucia, than those in the northern half. The southern islands also contained some very primary basalt rocks that clearly were derived from the partial melting of the mantle.

3. Canada

On completion of my Masters, I headed off to the greener pastures of Canada. I took with me a little piece of Jamaica in the form of some volcanic rocks, namely the Newcastle and Halberstadt volcanics from the Port Royal Mountains that form a part of the early Cenozoic Wagwater Belt (Fig. 3).

A year later these rocks were to play an important role for my Ph.D. thesis, when I was employed by the University of Windsor in Ontario as a research assistant in the Department of Geology. Here, I worked with a former lecturer at UWI, Professor Terrence Smith, who had just received a sizeable grant from the NSERC (Natural Sciences and Engineering Research Council of Canada) to purchase an X-ray fluorescence (XRF) spectrometer. This instrument revolutionised the method of study of rocks because it could not only analyse the major elements, but also investigate for trace elements (<0.1 wt %). Instead of analysing for about ten elements, igneous petrologists were now in a position to determine another 15 more at such low concentrations as parts per million. A further plus was that sample preparation was much easier and did not require acid digestion, but instead the crushed powder was either fused or pelletized.

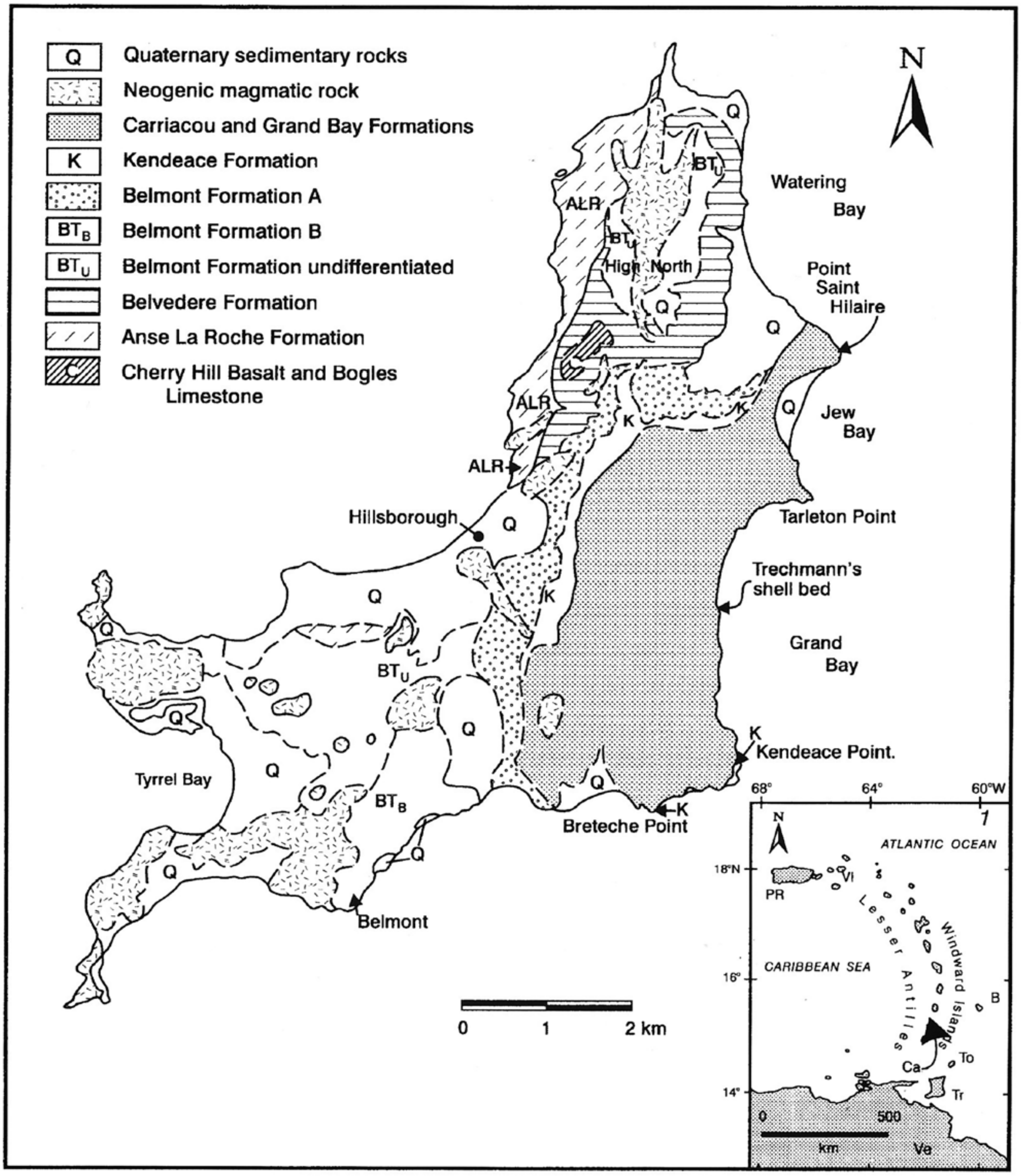

Fig. 2. Simplified geological map of Carriacou, the Grenadines (after Donovan et al., 2003, fig. 1). Inset map of Lesser Antillean region shows the position of Carriacou (arrowed). Key: B = Barbados; Ca = Carriacou; PR = Puerto Rico; To = Tobago; Tr = Trinidad; Ve = Venezuela; VI = Virgin Islands.

As soon as the machine was up-and-running, I crushed some of my Jamaican rocks and had them analysed purely to provide samples for the machine. The chemical results baffled us at first. Initially, we thought the samples to be contaminated, but, eventually, a search through the geology literature revealed that we had discovered an unusual group of rocks referred to as spilites and quartz keratophyres which had never been described from Jamaica. This marked the commencement of my Ph.D. research for which I registered at UWI because the University of Windsor offered degrees only to the Masters level.

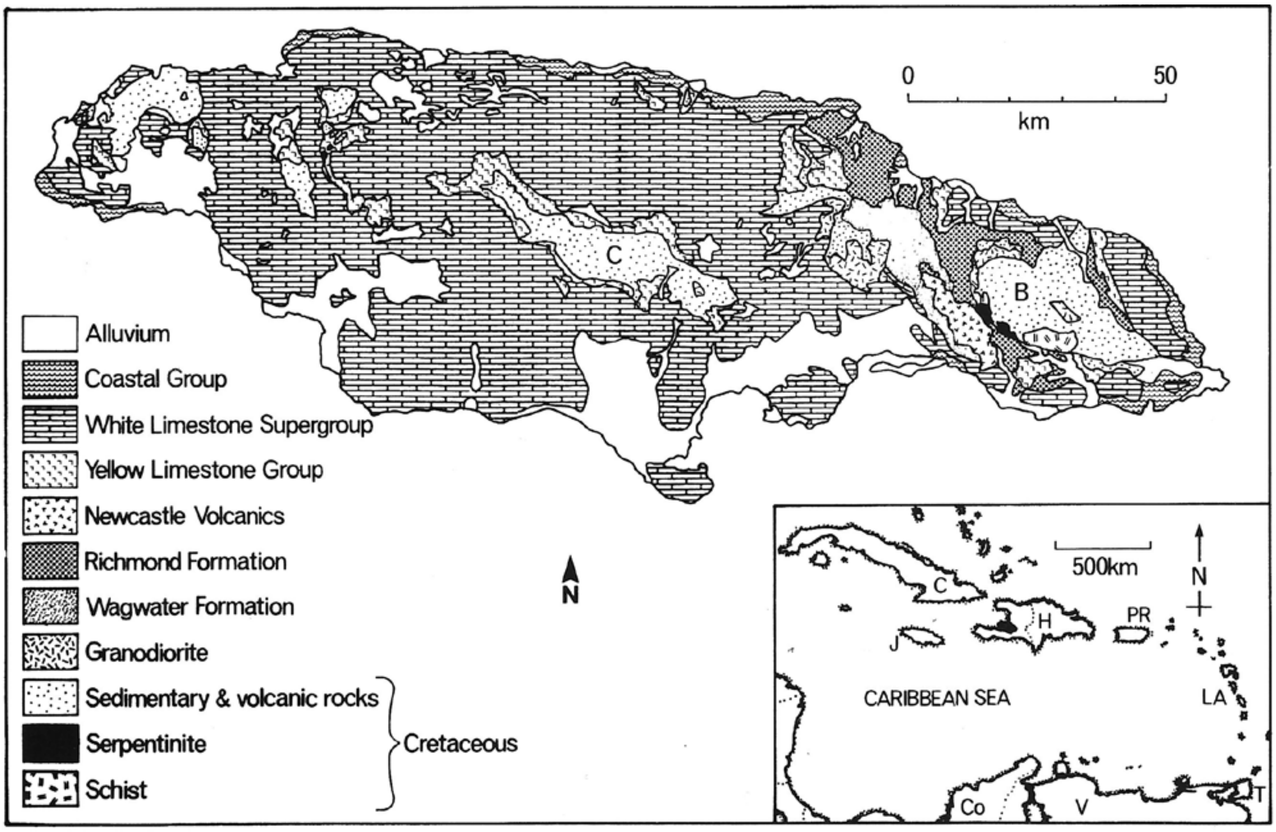

Fig. 3. Simplified geological map of Jamaica, showing the principal lithological units (after Donovan, 1993, fig. 1). Faults are omitted for clarity. Key: B = Blue Mountains Inlier; C = Central Inlier. The inset map shows Jamaica in the Caribbean: J = Jamaica; C = Cuba; H = Hispaniola; PR = Puerto Rico; LA = Lesser Antilles; T = Trinidad; V = Venezuela; Co = Colombia.

This marked my first introduction in the use of trace element chemistry in igneous rocks. At that time, in the late 1960s and early 1970s, there were many geological laboratories in North America, Europe, Asia and Australia that were using similar XRF instrumentation to analyse igneous rocks. Thus, there was a trend to place less reliance on the major elements in the classification and genesis of igneous rocks and to focus more on the trace elements, more so where the igneous rocks had undergone post-magmatic alteration.

4. Doctoral research

In my Ph.D. thesis I noted that some major and trace elements were mobile (that is, affected by post-magmatic alteration), viz. the large-ion lithophile elements (LILEs) such as K, Na, Rb, Sr and Ca, whereas there were others that were unaffected and could be described as immobile/stable viz. the high-field-strength elements (HFSEs) such as Zr, Y, Nb, Cr, Ti and Ni. The latter group was particularly important and there were several publications during the 1970s in the international journals documenting the importance of these immobile elements in discriminating between rock types and their tectono-magmatic settings. These immobile elements retained their original concentrations in the rock despite post-magmatic alteration, unlike the LILEs that were either depleted or enriched. In the Caribbean region a re-examination of the pre-Cenozoic igneous rocks was undertaken when it was realized that many of these rocks were affected by post-magmatic alteration either by hydrothermal or metamorphic processes, so that the need arose to re-analyse them for their trace-element chemistry.

My thesis provided a new interpretation for the origin of the volcanic rocks of the Wagwater Belt of Jamaica. It showed that the spilites and quartz keratophyres were originally basalts and dacites, respectively, that had been altered by metasomatism. I calculated that metasomatism took place at temperatures of below 400˚C and at very low shear stress.

Their trace element chemistry showed that the two rock types were not genetically related, in that basalts were clearly intra-plate tholeiites while the dacites were calcalkaline and formed in a volcanic arc setting at a convergent plate margin. The close temporal and spatial association of intra-plate basalts and convergent-plate dacites indicated that crustal extension and subduction were occurring simultaneously in Jamaica during the early Cenozoic. I interpreted the geologic setting in Jamaica at that time to be analogous to volcanic arc settings that currently exist in the western Pacific.

This interpretation has recently been modified. Formerly, I thought the basalts were back-arc in origin, but, with the availability of more recent trace element data in the literature, I now interpret them as rift-related. These basalts formed in association to much thicker crust than those of a back-arc. They are similar to rift-related basalts in the western USA and south-west Mexico. The occurrence of intra-plate basalts during the early Cenozoic within the Wagwater Belt provided evidence that shearing and extensional tectonics were taking place in Jamaica and which coincided with the initial opening of the Cayman Trough.

5. Jamaica

It was during the closing stages of my Ph.D., in 1974, that I returned to Jamaica where I joined the teaching staff at UWI. Once I had completed my thesis, I began research work on the geochemistry of the 'older' Cretaceous igneous rocks of Jamaica.

In 1978 I was awarded a 3-year CIDA Research Associateship to the University of Windsor where I had the opportunity to use the XRF laboratory during the summer to analyse Cretaceous rocks. This work demonstrated that Jamaica was a part of a volcanic arc that had evolved from a primitive submarine arc in the Early Cretaceous to a more mature, subaerial arc with thick crust at the end of the Mesozoic. This was confirmed from the chemistry of both the volcanic and plutonic rocks. On the latter, I worked with Mike Isaacs who had completed a Masters degree at the universities of Leeds and Oxford on the petrology of Jamaican plutonic rocks.

Of special interest among the volcanic rocks was the Cretaceous basalts/spilites, since their chemistry provided useful indicators of the magmatic evolution of Jamaica at that time. The oldest of these rocks outcrop in the Benbow Inlier and their pillowed structure indicate that they were extruded in a submarine environment at water depths of 300–400 m. Their chemistry is similar to that of PIA basalts and differs to the younger Cretaceous rocks of the Central Inlier which are predominantly calcalkaline.

While the Cretaceous basalts of the Clarendon Block are clearly volcanic-arc related, the Late Cretaceous basalts of the Blue Mountain Inlier are chemically different and display ocean floor basalt signatures. Their pillowed nature and lack of vesicles indicate that they were extruded at water depths of 4–5 km. They are characteristic of basalts that extrude on a deep ocean floor.

Similarly, the Late Cretaceous granitic plutonic rocks show genetic links to the volcanics in plotting in VAG and ORG fields, with the latter being associated with the ocean floor basalts along the southwest section of the Blue Mountain Inlier.

Once the existence of an arc was established for the Cretaceous, the debate shifted to the possible location of the plate boundary during the Late Cretaceous. Several tectonic reconstructions of the northern Caribbean arc were proposed at that time, some authors having the plate boundary to the north of Jamaica, others to the south and yet others to the east. Mike Isaacs and I attempted to resolve this problem by normalizing the VAG granitic data for the Maastrichtian-Campanian Above Rocks and northern Blue Mountain plutons. We detected a significant K (0.73–2.54 wt %) and Rb (18–57 ppm) geochemical polarity between these plutons, suggesting that the Above Rocks granites were formed over a deeper part of the subduction plate than those in the east.

The crust was also established to be much thicker in the central part than the eastern part of Jamaica, indicating that the northern Blue Mountain granites formed in crust of intermediate thickness (20–30 km) and over an intermediate subduction depth (100–200 km). The Above Rocks granites formed in thick crust (>30 km) and over a deep subduction zone (200 km).

Since there has been little tectonic rotation of Jamaica since the Cretaceous, this confirmed that the subduction zone must have been located generally to the east and not to the north nor south during the Late Cretaceous. By combining the basaltic data for the Cretaceous with that of the Cenozoic, a shift from plate margin magmatism to intra-plate magmatic activity was determined. This shift from a convergent plate to an intra-plate setting coincided with the eastward movement of the Caribbean Plate relative to the North and South American Plates at the beginning of the Cenozoic, and the creation of the northern Caribbean Plate margin.

During the 1980s another method was introduced to analyse igneous rocks, namely Neutron Activation Analysis. This technique, using a small nuclear reactor, was able to analyse several trace elements that could not be detected by XRF. Notable among the group was the rare earth elements (REEs) or Lanthanides, and other elements that were all regarded as useful and immobile, such as Ta and Hf. This meant that one could now analyse as many as 50 elements in the igneous rocks, many of which could be used in determining their genesis.

In order to use this facility, I became attached to laboratories at the University of Michigan and, later, the University of Alberta. Together with the University of Windsor, we published work on Jamaica, Tobago, Trinidad and Belize. In Jamaica, the newly determined REE chemistry confirmed the earlier theories on the crustal evolution of Jamaica during the Cretaceous and showed the basalts of the Blue Mountain Inler as N-MORB. Further, the Clarendon Block basalts display the patterns of volcanic arcs.

6. … and further afield

Over in the eastern Caribbean, in Tobago and Trinidad, I examined the metamorphosed and deformed rocks of Late Jurassic-Early Cretaceous age. These rocks were chemically analysed for the first time in the 1980s by myself and the team.

In 1982 and 1984, I supervised a group of UWI final year geology students in Tobago (Fig. 4). I noted that the Parlatuvier Formation was metavolcanic and that there had been no previous geochemical analyses of these rocks. This contrasted with the younger mid-Late Cretaceous igneous rocks which had been analysed. Because the Parlatuvier Formation had been metamorphosed and deformed, the immobile trace element chemistry again played an important role in determining the pre-metamorphic protolith. The rocks of Tobago were identified as PIA volcanics that were originally basaltic and andesitic in composition, and that represented part of young island arc terrane.

In 1986, a group of final year students were assigned to map in the Northern Range of Trinidad. In mapping the western section of the Range (Fig. 5), I identified a metavolcanic horizon within the metasedimentary Maracas Formation that had a similar grade of metamorphism as the Parlatuvier Formation of Tobago (Fig. 4). These rocks had been previously described by Cliff Potter as metatuffs, but they never had been chemically analysed. It was of interest to me, as they were of similar age to the Parlatuvier Formation, to ascertain if the Maracas Formation metatuffs were ash deposits that were genetically related.

But their geochemical signatures indicated that they were clearly different genetically to those of Tobago and showed ocean floor geochemical signatures. Instead, they had similarities to the Sans Souci volcanics (Fig. 5), a succession of Cretaceous ocean floor basalts and volcaniclastics that crop out along the north-east coast of Trinidad.

Therefore, although structurally Tobago and the Northern Range both represent allochthonous blocks, they clearly belonged to different terranes. That is, Tobago was part of an island arc terrane, whereas the Northern Range is a fragment of an ocean floor terrane.

In 1990, I became involved in a six-year research link between the University of Leicester and Camborne School of Mines that was funded by the British Council. I not only continued to conduct rock analyses using XRF spectrometry, but I analysed the chemistry of the minerals that composed these rocks using Scanning Electron Microscope and Electron Microprobe techniques that were available at both Leicester and Camborne. The mineral chemistry helped to complement the whole rock analyses. My first opportunity to utilize the facility came in 1991 when I was awarded an Association of Commonwealth Universities Carnegie Fellowship to Leicester.

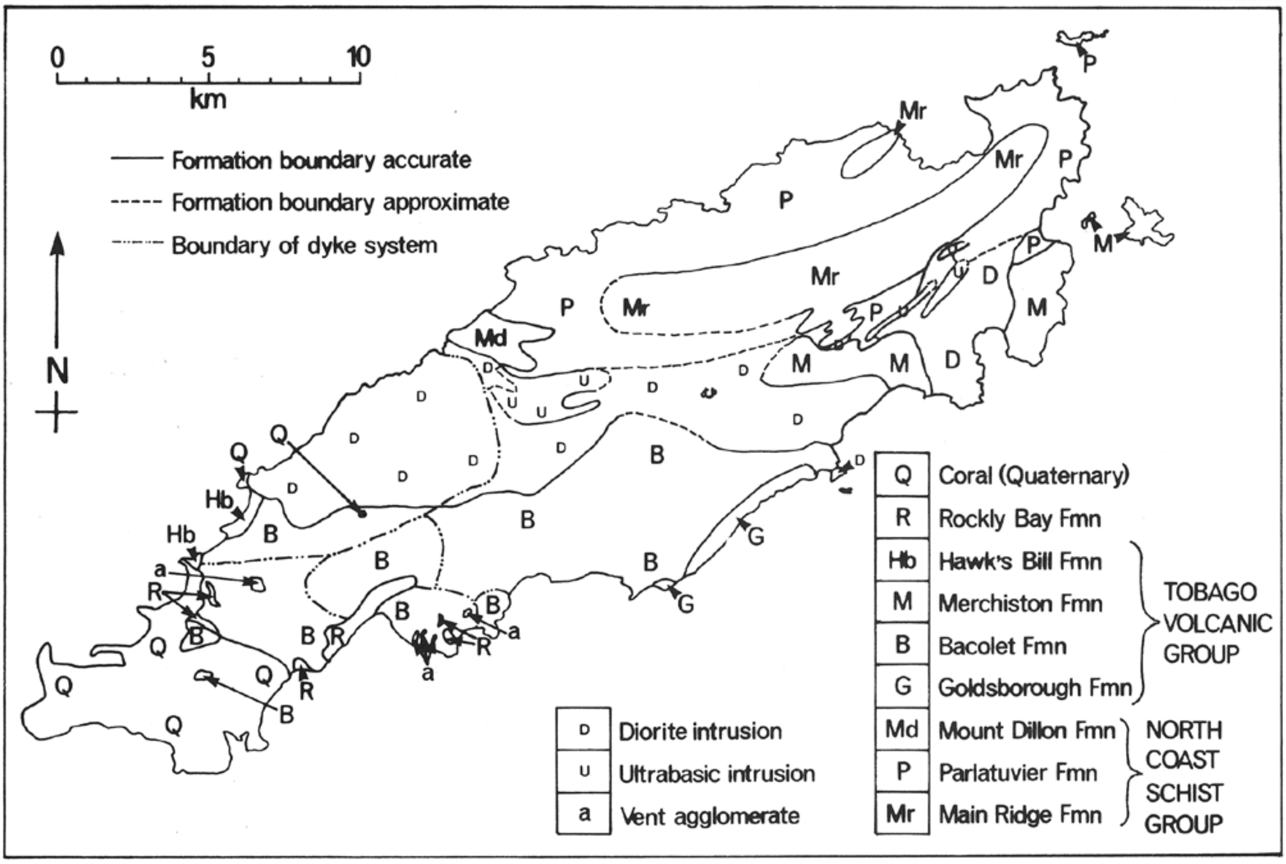

Fig. 4. Geological map of Tobago (after Jackson and Donovan, 1994, fig. 11.1).

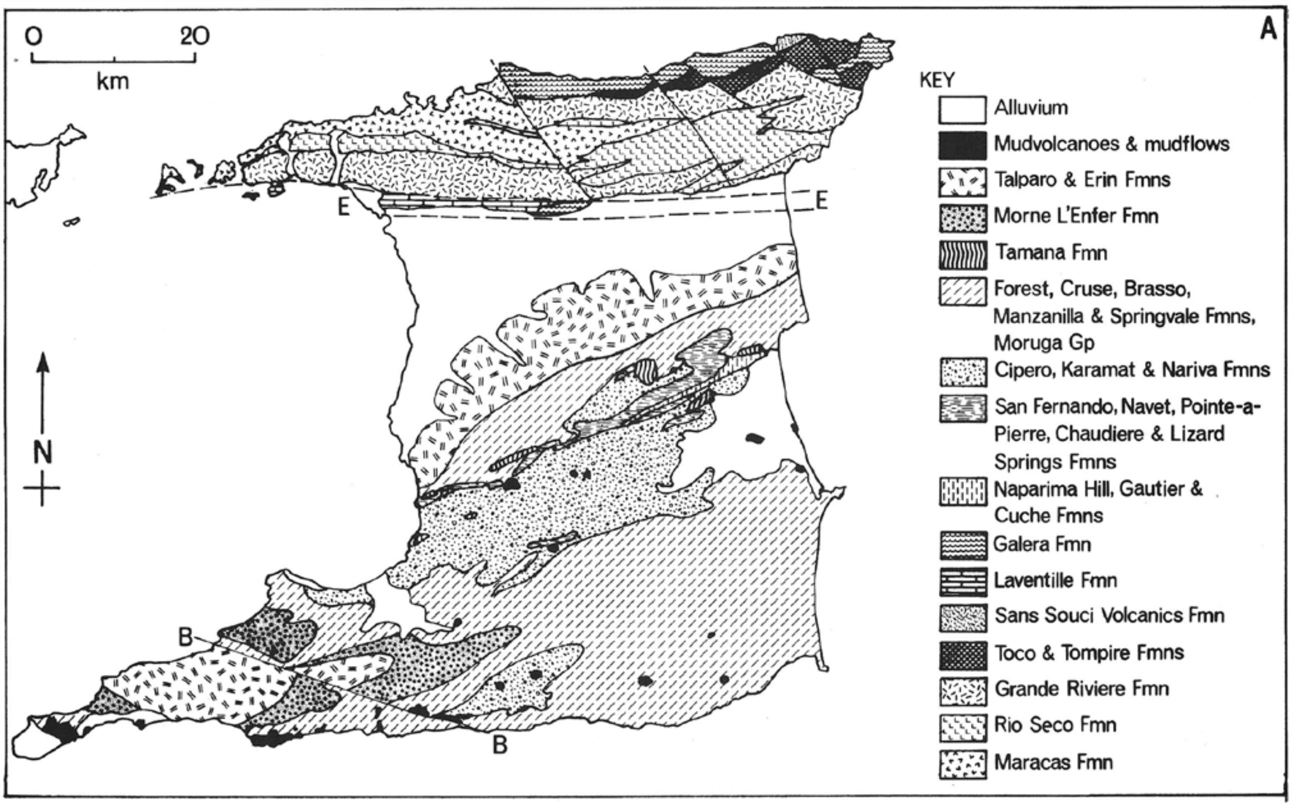

Fig. 5. Simplified geological map of Trinidad (after Donovan, 1994, fig. 12.3). Key: B-B = Los Bajos Fault; E-E = El Pilar Fault Zone.

In the same year, I had supervised a final year UWI geology student from Belize, where we undertook fieldwork at the invitation of the Belizean government. During the summer we undertook the mapping of the Mountain Pine region of the Maya Mountains in Belize. Upon completion of the mapping, I took some of the granitic samples that we had collected to Leicester. I analysed them for major and trace elements as well as probed the minerals for their chemistry. What had previously been reported as a granite pluton emplaced during a single episode turned out to be three genetically distinct suites of granites. These also showed differences in the chemistry of the biotite minerals that were common in all three suites.

The exposure to microprobe analysis led to further studies on the granites of Jamaica and an examination of the mineral chemistry of the Above Rocks pluton. The chemistry of the hornblende minerals proved useful in determining the pressure conditions under which the granitic magma formed. The Al(T) in hornblende indicated that crystallization of the amphibole took place over pressures of between 2.56 and 1.04 kbar and at estimated depths of between 9.67 and 3.93 km. The variation of Al(T) from core to rim of the magnesio-hornblende crystals showed that, as crystallization was taking place, the magma was rising to lower levels in the crust and, therefore, the magma was mobile and not stationary.

Our British Council work led us to examine the ultramafic rocks of Tobago and Jamaica. Intrusions of this composition are hosts for some of the world's largest deposits of chromium, nickel and platinum. For example, in the Caribbean, Cuba is a world producer of chromium, and both Cuba and the Dominican Republic mine nickeliferous laterites. Chromium spinel is the common Cr-bearing mineral and, although it was not present in significant economic quantities, the mineral chemistry revealed that the ultramafic rocks were formed in different magmatic settings. In Tobago, the ultramafic rocks arose from accumulation of mafic crystals in the crust, whereas those of Jamaica represented depleted mantle. Likewise, the study showed that neither nickel nor platinum were present in commercial quantities although they were present in ultramafic rocks. In Tobago, these nickel- and platinum-bearing minerals were identified for the first time.

More recently, I collaborated with John Comer of the Indiana Geological Survey in a study of the Miocene bentonites (clays) of the White Limestone Group of Jamaica. The bentonites represent altered volcanic ash that could be the source of the Jamaican bauxites. There are three theories that have been proposed for the origin of Jamaican bauxite, one of which is the volcanic ash theory hypothesised by Comer. This theory postulates that sufficient volcanic ash was 'dumped' on Jamaica during the Miocene that was later converted to bauxite.

Evidence of volcanic ash deposition around Jamaica is recorded in the deep-water limestones of Miocene age that were below sea level at the time of ash deposition, but which were subsequently uplifted. These limestones are now exposed along the north coast of Jamaica and contain numerous bands of altered ash known as bentonite. In 1971 Comer had analysed these bentonites only for their major elements and had concluded that the source was either from the Cayman Trough or Hispaniola. Since that time immobile element chemistry has been successfully used in determining the derivation of the original ash by bentonite workers such as Warren Huff, at the University of Cincinnati, and researchers at the University of Leicester to determine the original composition of altered ash/bentonites from the USA, British Isles and Greece.

The immobile chemistry of the bentonites collected from the Coral Spring quarry in the parish of Trelawny, north-central Jamaica, correlates with altered volcanic ash from drill cores in the Deep Sea Drilling Project Leg 165 that visited the Caribbean in early 1996. The source of the ash is postulated to have been erupted in Central America (not the Cayman Trough nor Hispaniola) and the bentonites show that the ash may have had compositions that ranged from basalt/andesite to dacite and rhyodacite.

The chondrite normalised REE pattern for one of the samples shows a volcanic arc-related pattern. During the Miocene, Central America was already an active volcanic arc so that it is possible that ash from these eruptions could be transported to the north-east and east in the upper atmosphere.

7. Acknowledgements

There are many igneous petrologists, like myself, who continue to examine and analyse igneous rocks in the Caribbean. We meet every three years at the Caribbean Geological Conference where we have an opportunity to present our results, and to share and exchange data and ideas. In the 1990s, we met even more regularly in working groups funded by the IGCP. The research that I have undertaken over the years at the UWI required cooperation and collaboration without which I would not have been able to analyse my rocks. I thank the many persons and organizations to whom I am indebted. S.K.D. thanks Professor D.A.T. Harper (Durham University, UK) for his supportive review.

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