Feature

Deep secrets of a sun and surf resort in the Atlantic

The majority of igneous rocks can be classified into either the basalt–gabbro group, or the rhyolite–granite group. However, there also exist a wide range of rocks whose composition lies outside these broad groupings, some of which are compositionally extreme and contain many rare minerals, sometimes as essential components. Petrologists have always interested themselves in these unusual rock types, just as collectors always value rare items over the commonplace. Many of these unusual rock types have been given weird and wonderful names, driving non-petrologists to distraction, although a more scientific system of nomenclature has yet to receive general acclaim. The giving of a plethora of names to igneous rocks was largely a phenomenon of the early years of petrology in the late nineteenth and early twentieth century and many will be surprised to learn that new names are still being coined as with the, as yet unauthorized, bermudite, not surprisingly, called after the island of Bermuda.

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Bermuda is an isolated island in the Atlantic (Fig. 1), exclusively composed of coral limestones—it is a coral atoll, the only example in the Atlantic. A British Overseas Territory, Britain's oldest overseas possession, it lies about 1030 kilometres east-south-east of Cape Hatteras, North Carolina and is noted today as a financial hub and tourist destination, possessing abundant golf courses and favoured by rich retirees. Snorkeling in warm coral seas, equestrian pursuits and fine restaurants and hotels are additional attractions. Bermuda has a tropical climate and perhaps the world's largest per capita GNP. It is very low lying coral limestone and geologically, apart from an extensive network of caves, is featureless.

What possibly could attract a geologist here?

Bermuda is a sea-mount and, like many other sea-mounts, occurs far from plate boundaries. The origin of such major edifices standing on the sea-floor is questionable.

Rising over 8000 feet above the surrounding ocean floor (shown on the inset in Fig. 2), the vast bulk of the island is made up of igneous rocks, as are most oceanic islands. However, the only rock at the surface is a capping of coral limestone draping a caldera rim and containing cave systems, which make an exciting tourist target. Seismic investigations show that the limestone is very thin: only about 76 metres thick. Over the course of time a number of holes have been drilled through the coral (Fig. 2): three in a search for potable water, one in connection with the building of the airport and the third and subsequent for research purposes, the only ones which were cored.

The earliest drilling was in 1912 and was done with a churn drill, which produced small chips identified by Louis Pirsson (of CIPW norm fame) as mafic basalt. The second hole, sited near the airport, used percussion drilling and likewise only produced chips. In 1972 Dalhousie University (of Halifax, Nova Scotia, Canada) drilled an 800 m hole which yielded almost continuous core. In 1973, a fourth hole was drilled, using rotary drilling, close to Hamilton, again in search of water and again only yielding chips. Two further holes were drilled by Dalhousie in 1980 and cores were recovered.

The Dalhousie drill holes penetrated 94 metres of limestone, 3 metres of red-beds representing a fossil soil and 16.4 metres of recrystallized carbonate, thought to represent a Pleistocene glacial event.

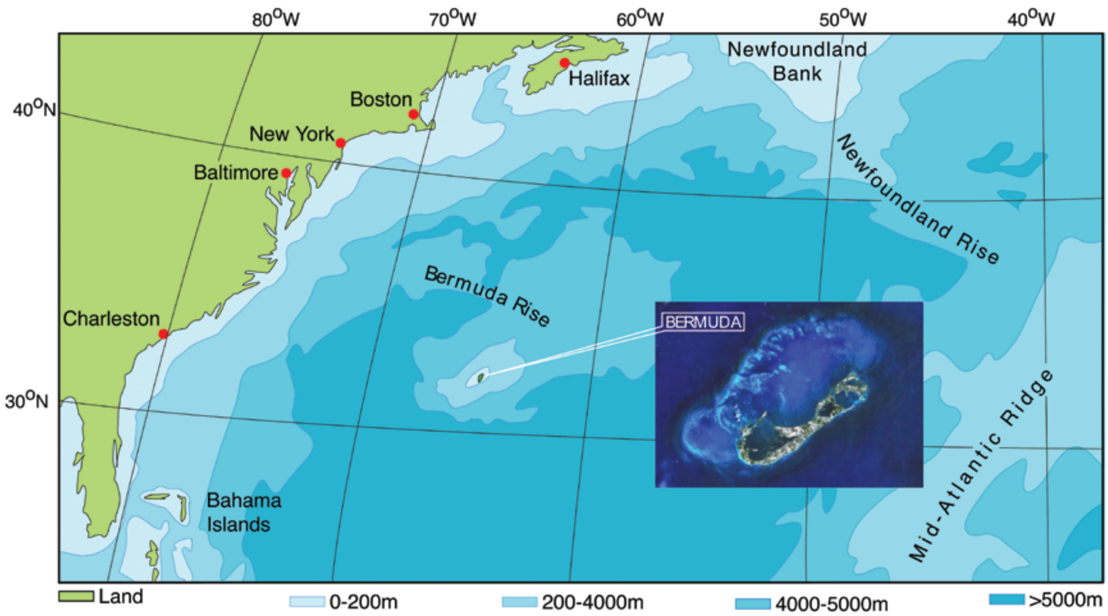
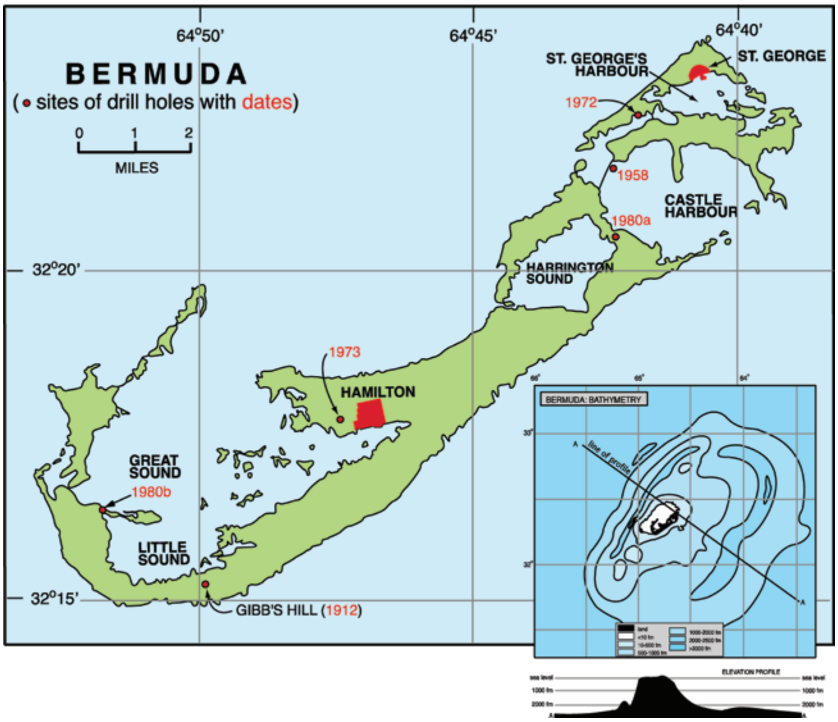


Fig. 1. Bermuda rises from a 4–5 km abyssal plain about a third of the distance between the US east coast and the Mid-Atlantic Ridge. Inset: satellite view showing extent of the atoll.

Beneath this was a weathered horizon with basalt boulders—a soil. Below this were the igneous rocks that make up the bulk of the sea-mount.

Back at Dalhousie, the cores were studied by Fabrizio Aumento (known as 'Fab') and Bernard Gunn. They found a bimodal suite of rocks and over 1000 igneous units were distinguished. The seamount itself was built of basaltic lava flows, pillow basalts (Fig. 3) and breccias. They were heavily altered by sea-water interaction, a process known as spilitization. Their original composition was deduced to be similar to that of ocean-island basalts worldwide, known as 'E-MORB' (that is, Enriched Mid-Ocean Ridge Basalt). Such basalts owe their name to the fact that they are enriched in elements with large ionic radii, or high valencies, such as alkali metals or uranium and thorium, relative to other ocean-floor basalts. Most of the sea floors are made of N-MORB (or Normal Mid-Ocean Ridge Basalt), which is not so enriched. N-MORB is the rock formed at mid-ocean ridges and makes up the major part of the upper ocean crust, which covers over two-thirds of our planet's surface and is without doubt the commonest rock of the Earth's crust. N-MORB was recovered by deep-ocean drilling close to, but outside the halo of Bermuda's influence by Ocean Drilling Program Legs 417 and 418a.

Fig. 2. Map of Bermuda with the drill-sites. Inset: bathymetric map and profile of the Bermuda sea-mount.



Cone sheets

Cutting the insular basalts were a large number of thin, inclined sheets, thought to be cone sheets. These were much fresher and often strikingly porphyritic with large pyroxene crystals. These clearly represent a later intrusive phase. The relative proportion of the two rock-types in the drill core was 63 percent altered lavas and 36 percent intrusive sheets. Lava flows have an average thickness of 0.9 m (ranging up to 4 m) and the sheets have an average thickness of less than 1 m, but range up to 7 m. Using the K-Ar method of radiometric dating, Reynolds and Aumento determined a minimum age of 91 Ma for the lavas and for the sheets an age of 34 Ma. It thus appears that the sea-mount began its career at, or close to, the Mid-Atlantic Ridge, which magnetic patterns show to have an age of 100 to 110 Ma at this latitude. It was much later reactivated by igneous activity of a quite different character, for reasons unknown. This is a rather common situation on oceanic islands: Hawai'i,

Fig. 3. A drill core from the igneous basement of Bermuda showing basaltic pillow lavas with carbonate matrix and veining: typical of submarine lavas.

for instance, also shows a hiatus in activity after the bulk of the island's construction with a later veneer of alkaline lavas. However, no convincing explanation has yet emerged as to why or how Bermuda formed at this location, or why the activity was bimodal in time and composition.

Quite how different are these sheets from the lavas was demonstrated by their chemistry, which is extreme. On standard naming systems they are melilite mela-nephelinites: extremely underaturated (low silica), high alkali rocks, similar to the rocks I described from the Gardiner intrusion in Greenland in *Geology Today* (2012, v.28, n.1). Such rocks are rare on a global basis, but on referring these analyses to extensive databases of igneous rock compositions, they were found to be unique. Not only were they very low in silica and aluminium, their contents of titanium were unprecedentedly high. Whereas E-MORB typically has TiO_2 around 2.5% and N-MORB would be expected to have around 1.5 percent, alkaline rocks are substantially higher, but none had the values extending to over 6 percent seen in the Bermuda sheets.

In 1975, Fabrizio Aumento and Bernard Gunn recognized the unique high-titanium nature of these rocks and promptly wrote a paper announcing their discovery, calling them 'bermudites', thereby honouring a long standing tradition of calling new rocks after the type locality. However, Aumento and Gunn's conviction that this was a new rock type was not shared by the editor of the journal to which they submitted their paper, and it was rejected, never to see the light of day. I can remember Gunn presenting these results at an international conference in the early 1970s, and the name 'bermudite' stuck with me. This whole saga can be read on Bernie Gunn's web site: www.geokem.com/OIB-volcanic-atlantic.html, as can the subsequent developments.

Bermudites resurface again

In the 1990s, Tony Higgins and Graham Leslie of the Geological Survey of Denmark and Greenland (GEUS) returned with rocks from the remote nunatak region of northern Greenland. These had been studied earlier, but were now subjected to detailed investigation by Stefan Bernstein, Rikke Harlou (student) and myself. When the results were published, Bernie Gunn stumbled across them and recognized them as more 'bermudites' with under 35 percent SiO_2, up to 8.5 percent TiO_2, in some cases with TiO_2 exceeding Al_2O_3. All-in-all, very unusual compositions.

After contact between Bernie Gunn and Stefan Bernstein, I set out with Símun Dalsenni Olsen, a Faroese student at the University of Copenhagen, to brave snowstorms in the depths of the Nova Scotia winter of 2003 in order to extract material from the Bermuda cores still housed in Dalhousie University (Fig. 5), with a view to generating more modern data for comparison.

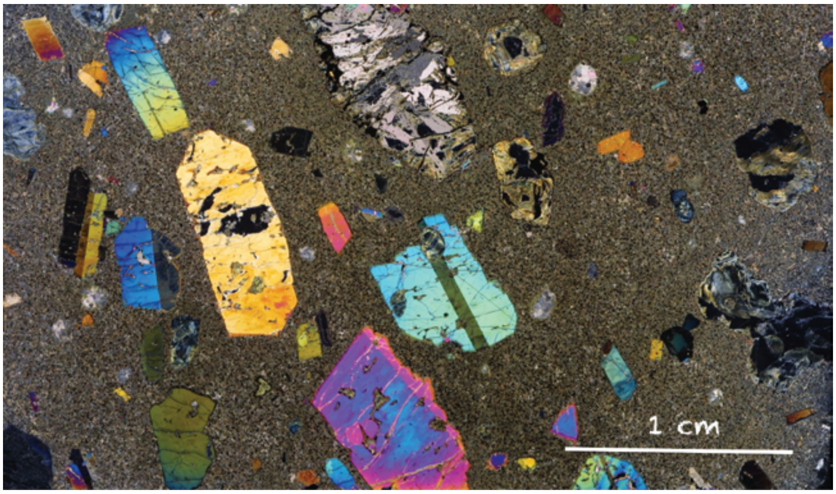
Fig. 4. Core from one of the sheets, showing numerous clinopyropxene phenocrysts (black angular grains).

Fig. 5. Cloë Younger (Dalhousie University technical staff) and Símun working on the Bermuda cores at Dalhousie University.

Símun's master's thesis demonstrated clearly using modern, high precision analytical methods both the earlier found features and the similarity to the Greenland rocks. Similar rocks were also found in the Prinsen af Wales Bjerge to the south of the nunatak zone in Greenland by David Peate and others in 2003. Even more extreme, but belonging to the same group of rocks are a suite from Bushmanland and Namaqualand, quoted by Bernie Gunn in his www.geokem.com website. A new paper is reportedly now being produced and time will show if the name 'bermudite' is accepted as a rock name or is again cast into limbo.

Over the course of time many igneous rock names have been coined, to the extent where confusion was serious. An attempt to sort this out was made by the IUGS (International Union of Geological Sciences) in 1991 and subsequent amendments. Systematic procedures were recommended and many superfluous names were discredited. Today, the golden age of igneous naming has been brought to an end and it is seldom that a new name deriving from the type locality is accepted. Time will show if 'bermudite' becomes one of these rarities.

Fig. 6. Thin section in cross-polarized light of a sample from 97.7 m in the 1972 core. Traditionally a melilite nephelinite, it contains phenocrysts of clinopyroxenne and olivine (now altered).



Suggestions for further reading

Aumento, F. & Gunn, B.M. Geology of the Bermuda Seamount. Paper submitted to *Journal of Petrology* in 1975 and rejected (see above). Manuscript on Bernard Gunn's website, Geochemistry of Igneous Rocks. www.geokem.com.html: www.geokem.com/OIB-volcanic-atlantic.html (although figures are missing).

Bernstein, S., Leslie, A.G., Higgins, A.K. & Brooks, C.K. 2000: Tertiary alkaline volcanics of the Nunatak Region, North-East Greenland: new observations and comparison with Siberian maymechites. *Lithos*, v.53, pp.1–20.

Harlou, R. 2001: *Petrology and geochemistry of the tertiary alkaline ultrabasic lavas from the Nunatak region, north east Greenland.* Unpublished Masters Thesis, University of Copenhagen.

Le Bas, M.J. & Streckeisen A.L. 1991. The IUGS systematics of igneous rocks. *Journal of the Geological Society, London*, v.148, pp.825–833.

Olsen, S.D. 2005. *Petrogenesis of Bermuda's igneous basement: petrology and geochemistry of the 1972 and 1980 recovered dyke rocks.* Unpublished Masters Thesis, University of Copenhagen.

Peate, D.W., Baker, J.A., Blichert-Toft, J., Hilton, D.R., Storey, M., Kent, A.J.R., Brooks, C.K., Hansen, H., Pedersen, A.K. & Duncan, R.A. 2003. The Prinsen af Wales Bjerge Formation lavas, East Greenland: the transition from tholeiitic to alkalic magmatism during Palaeogene continental break-up. *Journal of Petrology*, v.44, pp.279–304.

Vogt, P.R. & Jung, W.-Y. 2007. www.mantleplumes.org/bermuda.

