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Carn Goedog is the likely major source of Stonehenge doleritic bluestones: evidence based on compatible element geochemistry and Principal Component Analysis

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ABSTRACT

The Stonehenge bluestones were first sourced to outcrops in the high parts of the eastern Mynydd Preseli in SW Wales by H.H. Thomas in the early 1920s. He recognised the distinctive 'spotted dolerite' from his fieldwork in that area and suggested that the tors of Carn Meini (also known as Carn Menyn) and Cerrigmarchogion were the most likely sources. In the early 1990s, in a major contribution to our understanding of the Stonehenge bluestones, the geochemistry of a set of samples from Stonehenge monoliths and debitage was determined and compared against the geochemistry of dolerites from the eastern Mynydd Preseli by a team from the Open University led by R.S. Thorpe. They argued that the majority of the Stonehenge dolerites could be sourced from outcrops in the Carn Meini-Carn Gyfrwy area, based on the concentrations of the so-called 'immobile' elements (elements which are not affected by rock alteration processes), in particular TiO_2, Y, and Zr. However, these elements are incompatible during crystallization of mineral phases in basaltic systems (that is they do not enter into the mineral phases which are crystallizing but are concentrated in the residual liquid) which severely hampers their use in discriminating between different pulses of an evolving magma (as is the case of the doleritic sills emplaced high in the crust and now exposed in the Mynydd Preseli). An alternative strategy in this study re-examines the data set of Thorpe's team but investigates the concentration of elements which are compatible in such basaltic systems (that is elements which do enter into the crystallizing mineral phases), namely MgO, Ni, Cr and Fe_2O_3. On the basis of the abundances of these elements on bivariate plots and also by using Principal Component Analysis on the dataset available and various sub-sets we identify three compositional groupings for the Stonehenge doleritic monolith and debitage samples and conclude that the majority of them (Group 1 of this paper) can be sourced to the prominent outcrop in the eastern Mynydd Preseli known as Carn Goedog. We also offer potential sources (with one exception) for those Stonehenge dolerites which appear not to relate to Carn Goedog.

1. Introduction

Stonehenge is arguably one of the most famous prehistoric monuments in the World. Located on Salisbury Plain in Wiltshire, England it is, along with other archaeological sites in the immediate vicinity (in the so-called 'Stonehenge Landscape'), a World Heritage site. Interest in Stonehenge dates back centuries, with the earliest written account being by Geoffrey of Monmouth in about 1136 AD.

The monument is renowned for the enormous size of the sarsen monoliths used in its construction which comprise the Outer Circle and Outer Horseshoe. It is generally agreed that these stones were sourced from the Marlborough Downs area, some 30 km to the north of Stonehenge (see Buckland, 1823, 1826). However, a set of smaller stones, comprising the Inner Circle, the Inner Horseshoe and the Altar Stone, are exotic to the Salisbury Plain area; these are the so-called bluestones, and have been the subject of petrographical, and subsequently geochemical, investigations since the latter part of the 19th Century. Early petrographical studies by Maskelyne (1878), Cunnington (1884), Teall (1894) and Judd (1902) recognised that the bluestones largely comprise a range of altered volcanic, intrusive and tuffaceous rocks with rarer sandstones but they could not provide a definitive source; a provenance in Ireland was proposed as early as 1833 by Conybeare, whilst Judd (1902) proposed a source in southwest England.

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However, it was the seminal paper by H.H. Thomas in 1923 that persuasively argued that the characteristic spotted dolerite component of the bluestones could be sourced to outcrops exposed towards the eastern margin of Mynydd Preseli in southwest Wales, citing the tors Carn Meini (also known as Carn Menyn) and Cerrigmarchogion as the most likely sources (Thomas, 1923, p.250). Thomas (1923) also argued that other lithologies in the bluestone assemblage, notably the rhyolites and the 'calcareous ash', could be sourced in the same locale, in particular from Carn Alw and the northern slopes of Foel Drygarn respectively. Fig. 1 shows the location of all sites in north Pembrokeshire referred to in the text, whilst Fig. 2 is an oblique aerial view of the eastern Mynydd Preseli showing the location of Carn Meini, Carn Alw, Foel Drygarn and a number of other important outcrops in order to provide some context to later discussions. In particular this panorama demonstrates the nature of the terrain in the eastern Mynydd Preseli, namely a bleak upland landscape with only scattered outcrops. This illustrates the problems associated with the identification of particular source outcrops for the Stonehenge bluestones in the field in view of the fact that it is very difficult to trace individual intrusions laterally and hence to understand which exposures are actually part of the same intrusion and which belong to a different intrusion, perhaps with differing petrography and geochemistry. Further complications arise because the area is structurally complex, with the rocks being deformed into a series of NE-SW oriented folds (British Geological Survey, 2010).

Bevins et al. (1989) provided an account of the dolerites exposed in the area between Fishguard and the eastern Mynydd Preseli, identifying them on field, petrographical and geochemical evidence as representing a suite of intrusive doleritic sills which were emplaced at a high crustal level and which are the lateral equivalents of basaltic lavas (and associated sub-volcanic doleritic sills) comprising the basic member of the Ordovician age Fishguard Volcanic Group, the major expression of which is exposed further to the west (Bevins, 1982). Bevins et al. (1989) suggested that the basaltic magmas were erupted in a submarine environment in a graben or half-graben structure centred in the Fishguard to Strumble Head area, with the magmas being channelled up the bounding faults. The Preseli district was peripheral to this graben structure and accordingly the magmas were emplaced as high-level sills in the adjacent sedimentary sequence.

The first major investigation of the geochemistry of the Stonehenge bluestone assemblage was by Thorpe et al. (1991) who compared whole rock analyses determined by WDXRF (wavelength-dispersive X-ray fluorescence spectrometry) from both monoliths and debitage at Stonehenge with whole rock analyses from Mynydd Preseli published by Bevins et al. (1989) along with previously unpublished data from one of the current authors (REB) and a number of new analyses based on samples collected by Thorpe and colleagues. Subsequently Ixer (1996, 1997) offered new insights into provenancing the doleritic bluestones by expanding on earlier preliminary examinations of samples utilising reflected light petrography and although concurring in part with the proposals presented by Thorpe et al. (1991) he offered important alternatives. Later investigations considering the geochemistry of Stonehenge and Preseli bluestones include those by Williams-Thorpe et al. (1999), Jones and Williams-Thorpe (2001), and Williams-Thorpe et al. (2004, 2006) who used both WDXRF and portable X-ray fluorescence (PXRF)

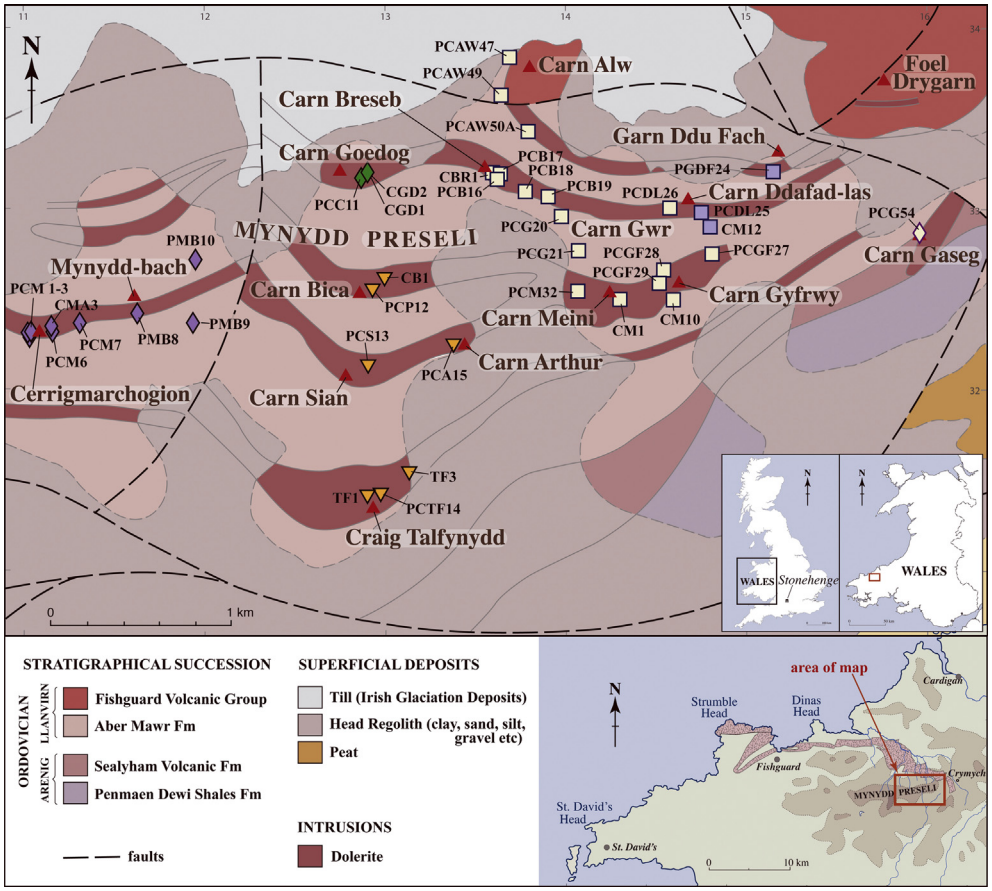

Fig. 1. Simplified geological map of the eastern Mynydd Preseli showing the locations of the main outcrops and the geographic locations of the analysed samples used in the geochemical plots in this paper. Geological detail based on British Geological Survey (2010).