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Geochemistry, Sources and Transport of the Stonehenge Bluestones

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Summary. Stonehenge on Salisbury Plain, UK, is famous for its construction from large lintelled sarsen stones, and also because it has been proposed that some of its stones—the bluestones which are foreign to the solid geology of Salisbury Plain—were brought to the site by humans from a distant source in Preseli, South Wales. The bluestones include hard dolerites (mostly 'spotted') and rhyolites, and softer structurally unsuitable sandstones and basic tuffs. Chemical analysis of eleven dolerites and four rhyolite bluestones indicated that the dolerites originated at three sources in Preseli within a small area (*ca.* 2 km^2), while the rhyolite monoliths are from four different sources including localities in northern Preseli and perhaps on the north Pembrokeshire coast, between 10 and 30 km apart. Opaque mineralogy of the dolerites supports the conclusion of a Preseli source, while modal analysis of a sandstone fragment excavated at Stonehenge shows that it is not from the Cosheston or Senni Beds of South Wales, as has been suggested. This variety of source implies selection of material from a mixed (glacial) source, not at a carefully human-chosen outcrop. Glacial erratic material from south-west Wales has been identified as far east as Cardiff, and early (Anglian) glaciation of the Bristol/Bath area is indicated by an erratic find and glacial landforms. The apparent lack of glacial erratics between Bristol and Stonehenge (except perhaps for the Boles Barrow boulder) and in rivers draining Salisbury Plain, is consistent with the irregular deposition of 'free' boulders at the edge

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*It is with very deep regret that we report the death of Dr. Richard Thorpe in August 1991.

of extensive ice sheets. Bluestone fragments on Salisbury Plain without clear archaeological context, and pieces incorporated, sometimes apparently accidentally, in monuments of Neolithic age onwards (some predating the bluestone erections at Stonehenge) may be remnants of erratics. Clearance of boulders from Salisbury Plain for agricultural purposes is clearly described by the geologist J.A. de Luc, and a boulder consistent in appearance with an erratic was found at Stonehenge in the 1920's.

It is concluded that the bluestones of Stonehenge were available locally to the builders, and were transported from south Wales not by humans, but by glacial activity of perhaps the Anglian period (*ca.* 400,000 years BP) or earlier. This conclusion has prompted re-examination of other suggestions of long-distance transport of megaliths. The sarsen stones at Stonehenge need not have been brought from 30 km to the north as has been suggested, since recent surveys show small concentrations of sarsens near Stonehenge, the remnant of boulders largely cleared during 18–19th centuries. Calculations of the manpower required to construct Stonehenge need to be re-assessed in view of the absence of long-distance stone transport. Other megaliths in Britain and in northern Europe show no evidence for stone transport of greater than *ca.* 5 km, and reveal a preference for use of erratics in some glaciated areas. In at least some cases the availability of stone has dictated the location of the monuments. It is therefore inappropriate to interpret the positions of megaliths in terms of social or economic territories without first examining the geological constraints on their siting.

1. Introduction

Stonehenge on Salisbury Plain is one of the most spectacular, and probably the most famous, of all British prehistoric monuments. It is unique partly because of its construction from huge lintelled sarsens, and also because it has been suggested that some of its stones—the 'bluestones' of the inner circle and horseshoe—were brought by humans from a distant source in south Wales, in a feat of endeavour unparalleled in British prehistory. The bluestones consist of a variety of igneous and sedimentary rock types which are foreign to the solid geology of Salisbury Plain, and their geological sources and mode of transport to Salisbury Plain—whether by humans or by natural (glacial) processes—have formed a subject of controversy for over 200 years. In 1923 H.H. Thomas suggested in a paper presented to the Society of Antiquaries that the distinctively spotted dolerite bluestones (the most common type at Stonehenge) could only originate in the Preseli Hills of south

Wales, and that these and the rhyolite bluestones were obtained from here, at and/or near the Carnmenyn outcrop, while the sandstone Altar Stone came from the Devonian Old Red Sandstone (Cosheston or Senni Beds) of south Wales. He further suggested that the stones could not have been moved to Salisbury Plain by glaciation but were transported the whole distance from south Wales by human action. This interpretation has dominated both academic and popular accounts of the Stonehenge bluestones for nearly 70 years.

The aim of our work has been to use geochemical and petrological analysis of samples of monoliths and of excavated fragments from Stonehenge to determine the location and number of sources of the bluestones. We use these data and a review of evidence for glaciation and recent boulder clearance on Salisbury Plain, to re-assess the mode of transport of bluestones to their present site.

Stonehenge and other megalithic monuments have been used to support hypotheses of social and technological organisation in British prehistory: such exercises are meaningful only if the geological constraints affecting the building and siting of such monuments are first considered.

Structural phases of Stonehenge referred to in this paper follow the outline summarised by Atkinson (1979). Dates are quoted as in data sources, following the convention of BC = calendar years; bc = uncalibrated carbon-14 years.

2. Bluestones at and around Stonehenge and elsewhere in the UK

The term "bluestone" is commonly used to refer to the non-sarsen monoliths at Stonehenge, and is also used loosely in much published literature to mean any apparently non-local stone similar to Stonehenge monoliths, found on or in the vicinity of Salisbury Plain.

The bluestone monoliths extant at Stonehenge include twenty-seven spotted dolerites (two broken in two pieces), three dolerites with no spots visible on the surface, five rhyolites (two lavas, two ignimbrites, one unknown type), five volcanic ashes or tuffs (composition unknown, possibly basic tuffs), and three micaceous sandstones (one of them the Altar Stone). All the volcanic ash and two of the sandstone monoliths are stumps no longer visible above ground. The monoliths, representing the remnants of perhaps eighty-two stones (*cf.* Atkinson 1979) are therefore of six distinct types, including hard durable rhyolite lavas and dolerites, and relatively soft, structurally poor volcanic ashes and sandstones. Burl (1987, 139–140) has summarised historical evidence which suggests that two stones each *ca.* 2 m high now in the High Street of the village of Berwick St. James 6 km south-west of Stonehenge are pieces of a monolith removed from Stonehenge during the 17th Century AD. These stones were examined by the authors in 1989 and, notwithstanding earlier reports that they are of sarsen (Engleheart 1933), they are in fact of peloidal packstone and packstone/grainstone, rare in the Lower Jurassic, and therefore perhaps from a Middle or Upper Jurassic source (R.C.L. Wilson, pers. comm.). Such rocks outcrop at many localities within southern England, and the nearest feasible source to Stonehenge is near Tisbury *ca.* 22 km to the south-west. This new evidence suggests the use of yet another type of rock for the Stonehenge monoliths.

Bluestones are found at Stonehenge in the form of fragments, including at least one weathered rounded boulder 13 × 20 cm, of sheared ignimbrite, unsuitable for working and consistent in appearance with a glacial erratic (G.A. Kellaway, pers. comm., following information from R.S. Newall). Other (non-bluestone) foreign stone fragments at Stonehenge are frequent and varied, and include limestone, schist, varied sandstones, quartzite and shale (Hawley 1922; 1925; Howard 1982; Evens *et al.* 1962; summary in Clough and Cummins 1988). Some of these could be from implements, finds of which include rhyolite (Howard 1982) and dolerite (Implement Petrology Group XVIII (Whin Sill); I.F. Smith pers. comm. 1990), and axes of greenstone (Groups I, Ia, III), tuff (Group VI) and sandstone (Clough and Cummins 1988). Bluestone was present at Stonehenge I, *ca.* 3000 BC (glauconitic sandstone found in the packing of Stone 97 (Howard 1982)) before its first use as monoliths in Stonehenge II.

Bluestone fragments are frequently reported in association with other archaeological monuments on and near Salisbury Plain (summaries in Howard 1982 and Thorpe *et al.* in press). It is noteworthy that these are recovered from a wide variety of monuments of disparate periods (round and long barrows, henge, cursus; e.g., Ashbee 1978; Cunnington 1924; J. Richards pers. comm. 1989; Stone 1948), and always from surface or fill soil (i.e., not deposited within burials as valued objects). Stray finds of rhyolite from near Avebury (find in Salisbury Museum, no. p.1.494. 5/1917–18) and spotted dolerite from Lake (Kellaway 1971) have no recorded archaeological context. A piece of rhyolite from a Neolithic pit may be dated to *ca.* 2500 BC (J. Richards pers. comm. 1989), and a 340 kg spotted dolerite boulder was incorporated in the long barrow at Heytesbury (Boles Barrow; Cunnington *op. cit.*) probably hundreds of years before the erection of Stonehenge II bluestones (the Boles Barrow boulder is compositionally identical with two of the bluestone monoliths; see source discussion below). The impression is therefore of frequent and unremarked presence of fragments and larger boulders of varied bluestones on Salisbury Plain incorporated, perhaps sometimes by accident, in monuments from the Neolithic period onwards.

This scenario is supported by the wide variety of other foreign (non-bluestone) stones found in other Wessex monuments. Amesbury Barrow 39 contained fragments of quartz diorite, hornblende diorite and granodiorite (Ashbee 1981), a combination of types found also in glacial assemblages in south Wales (*cf.* Strahan *et al.* 1914). Briggs (1976, 12) has also pointed out the similarity of foreign stone assemblages at Windmill Hill to those at Stonehenge.

Elsewhere in Britain there is no evidence that the main bluestone type used at Stonehenge—spotted dolerite—was particularly valued or preferentially used. Even within south Wales, near to the presumed Preseli source of the spotted dolerite, a survey by the authors (details in Thorpe *et al.* in press) has shown that of twenty-six megalithic monuments of Neolithic to Bronze Age date (including five stone circles, four of which may be dated to around 2000 BC, near the date of Stonehenge II), only one monument, Gorsfawr stone circle, is built of spotted dolerite similar in appearance to that at Stonehenge. In every single case, the monuments were built of stones readily available at the site of construction or within *ca.* 1 km of it, either in outcrop, or more frequently, as glacial erratic boulders; Gorsfawr for example lies in a field littered with spotted dolerite erratics.

Axes of spotted dolerite (Implement Petrology Group XIII) are a rare type (total number no more than thirty finds, Clough and Cummins 1988; Thorpe *et al.* in press), have no known factory site (*cf.* Drewett 1987), while their distribution (Clough and Cummins *op. cit.*; Thorpe *et al. op. cit.*) may be at least partially interpreted as use of glacial erratics removed from the source area and naturally dispersed eastwards (*cf.* below). It is thus necessary to invoke limited human traffic only for examples reported from north Wales and for the small number found in (presumed unglaciated) parts of eastern and south coast England (*cf.* Briggs 1989 on use of erratics for axes). Group XIII axes are not therefore evidence for direct links between Preseli and Wessex in the Late Neolithic/Early Bronze Age periods, or for knowledge of or interest in the Preseli area.

3. Sampling and description of bluestones

Fifteen bluestone monoliths at Stonehenge were sampled on the afternoon of October 15th 1987, including eleven dolerites (eight spotted, three unspotted) and all four rhyolites now above ground (Figure 1). Ten samples were removed by drilling with a 1 inch diameter diamond drill to a depth of *ca.* 5 cm and removing cores whole. Five samples were removed as chips from the surface of the stones. Samples were typically 50–100 g in weight. The Altar stone was examined macroscopically *in situ* only. Monolith samples were

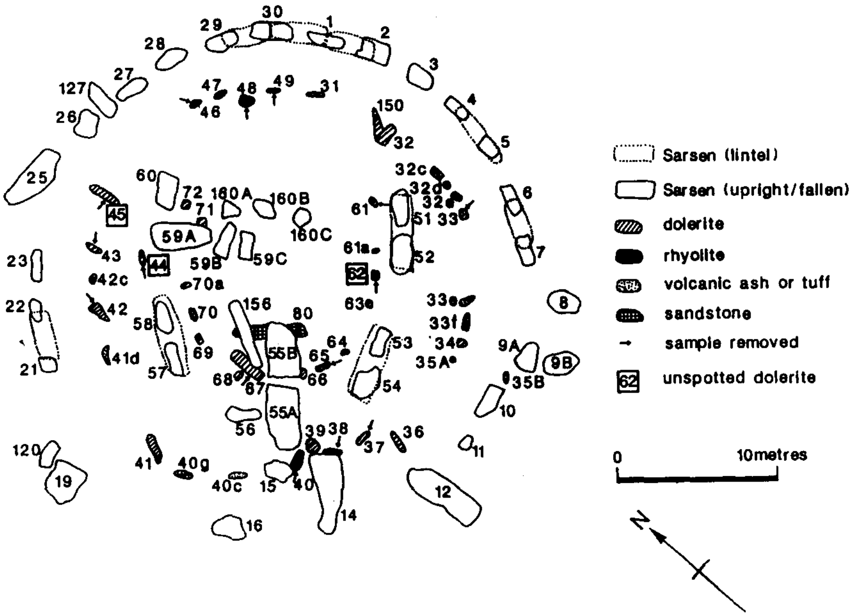

Figure 1. Plan of central stone settings at Stonehenge, after Newall (1959), Chippindale (1987), Atkinson (1979) and authors' observations, showing petrology of the stones and locations of samples removed for this work. Stone types are defined on the diagram. All dolerites are spotted except for stones 44, 45, and 62. Stone numbering is after Atkinson (1979) except for stone 61a which is our number (stump noted by Cunnington (1884), now above ground). From Thorpe *et al.* (in press).

numbered as the stones from which they were taken (numbering system after Petrie 1880 and Atkinson 1979) with the addition of prefix SH.

Excavated fragments of bluestone from Stonehenge were examined at the Salisbury and South Wiltshire Museum, Salisbury, and twenty-three (numbered OU1 to OU12, OU14 to OU24) selected for further study, including nine pieces of dolerite, thirteen of rhyolite, and one of sandstone (noted in museum record as 'Cosheston Beds?'). These include pieces found in Aubrey Holes 1, 5, 10, 11, 15, 16, 17, 21 and 22, the Heelstone ditch, Holes Y6 and Z6, and the Avenue. In addition, the Boles Barrow boulder, also housed in the Salisbury and South Wiltshire Museum, was sampled to remove 23g.

The dolerite samples are typically composed of clinopyroxene and plagioclase showing ophitic texture and variable alteration. The whitish spots, typically 2 mm—10 mm, which are the most distinctive feature of the spotted dolerites are formed by metamorphism resulting in small-scale element migration, and are not distinctive in thin section. The rhyolite samples have alkali feldspar plus or minus plagioclase in a fine grained to cryptocrystalline matrix, with *fiamme* visible in ignimbritic samples (two monoliths and two fragment samples). Full sample descriptions are given in Thorpe *et al.* in press.

4. Analytical methods

All monolith samples and fragment samples except for OU9 (sandstone) were analysed for major and twelve trace elements using X-Ray Fluorescence analysis at the Open University (following the procedure of Potts *et al.* 1984), and the Universities of Keele and Southampton. Precision at 1 sigma is typically below 1% relative for major elements and below 5% relative for many traces. Accuracy, measured by comparison of our data for international reference materials QLO-1, BE-N and BHVO-1 with recommended values (Gladney and Roelandts 1988) is comparable to precision values. Standard petrological thin sections were prepared for all samples, and modal analysis of one sample (OU9, sandstone) determined by point counting (R.G. Thomas, University of Calgary, Canada). A polished thin section of monolith sample SH61 (spotted dolerite) was prepared for examination of opaque mineralogy in reflected light (R.A. Ixer, University of Birmingham).

In addition to analysis of archaeological samples, forty new geological samples from outcrops of dolerite and rhyolite in the Preseli area and six of glacial erratics in Preseli and near Lampeter Velfrey (Figure 6) were collected and analysed as described above. Analysis of six samples of igneous erratics from near Cardiff (Pencoed, Figure 6) are given in Donnelly *et al.* (in preparation). Selected data are given in Tables 1 and 2 and full data are available in Thorpe *et al.* (in press) and from the authors on request.

5. Potential source areas of the bluestones

The distinctive spotted texture of most of the Stonehenge dolerites was noted by Thomas (1923) to occur only within the Preseli Hills of south Wales, and this remains the case today. Therefore in this paper we examine the Stonehenge samples in relation to rocks from this area. We also consider rocks of andesite, dacite and rhyolite composition in the Mendip Hills (Figure 2) since this forms a proximal occurrence of igneous rocks to Stonehenge and also lies close to the route proposed for human transport. It should be borne in mind that our study involved only fifteen monolith samples, and sourcing of these (below) to south Wales may not necessarily be the case for all other (unsampled) Stonehenge monoliths.

Igneous rocks occur in south Wales within extensive Ordovician and

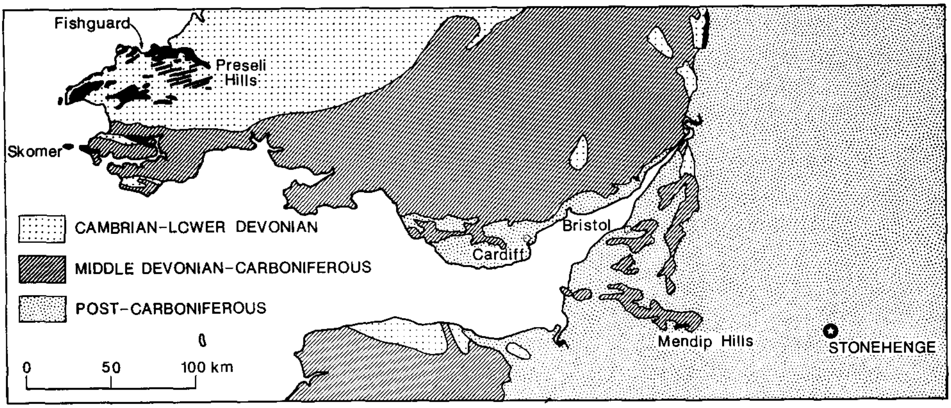

Figure 2. Geological map of south Wales and south-west central England showing the distribution of major stratigraphic units (*cf.* key) and Precambrian—Lower Palaeozoic intrusive and extrusive igneous rocks (in black). The stratigraphic units and the igneous rocks include the possible sources for Stonehenge bluestones discussed in text sections 5 and 6 (*cf.* Figures 3 and 4).

(more limited) late Precambrian outcrops, shown on Figure 2 and discussed by, particularly, Bevins *et al.* (1984), Kokelaar *et al.* (1984), Leat *et al.* (1986) and Leat and Thorpe (1986a; 1986b) and Thorpe *et al.* (1989). The Ordovician rocks comprise chemically varied basalt-andesite and bimodal basalt-subalkaline/peralkaline rhyolite provinces in which lavas have volcanic arc or transitional volcanic arc/within-plate chemical characteristics.

Intermediate to acid composition lavas and ignimbrites occur within this province in the Roch, Trefgarn and Sealyham groups (Thomas and Cox 1924; Evans 1945), Ramsey Island (Kokelaar *et al.* 1985), and within the Fishguard Volcanic Group (e.g., Bevins 1982). Dolerite intrusions are extensive on the coast near and to the north of St. Davids Head (Figures 2 and 6) and within the Fishguard Volcanic Group (Evans 1945). Spotted dolerites are restricted to outcrops within the eastern part of the Fishguard Volcanic Group in the eastern Preselis (Figure 5). The concentration of spots varies within one outcrop from less than 5% to approximately 15% of the visible surface. Samples from within these outcrops are petrographically identical to the Stonehenge spotted dolerites. The rhyolites are less distinctive and petrographic features cannot be used to suggest sources of the Stonehenge rhyolites. Chemical analyses of these volcanics are given in Bevins (1979; 1982) and Bevins *et al.* (1989), and new data from the present authors. Geochemical characteristics of the groups are summarised in the discrimination graphs below (Figures 3(a) and 4).

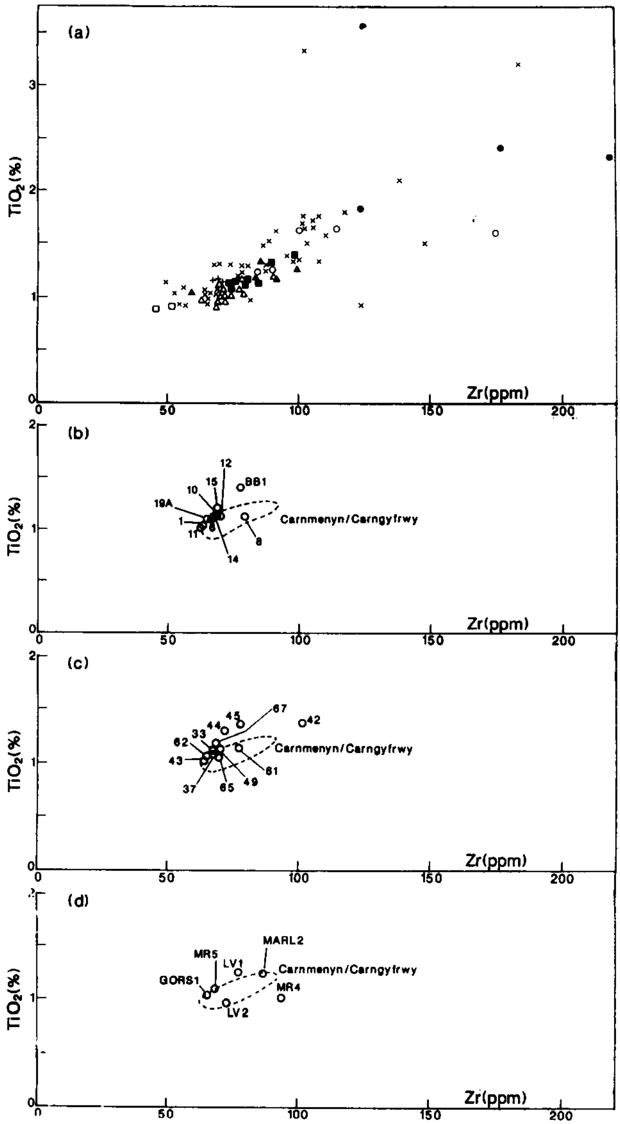

Figure 3. Graph of TiO_2 against Zr for (a) dolerites from the Preseli Hills, (b) excavated fragments from Stonehenge, (c) Stonehenge monolith samples and (d) glacial erratics. The symbols for the geological samples are as follows: open triangles = Carnmenyn/Carngwyfry; open squares = Carnbica; filled triangles = Carnbreseb; horizontal crosses = Carngeodog; filled squares = Cerrigmarchogion; open circles = Carnalw; filled circles = Foeldrygarn; oblique crosses = undifferentiated intrusions. SH and OU sample prefixes are omitted on the diagram. From Thorpe *et al.* (in press).

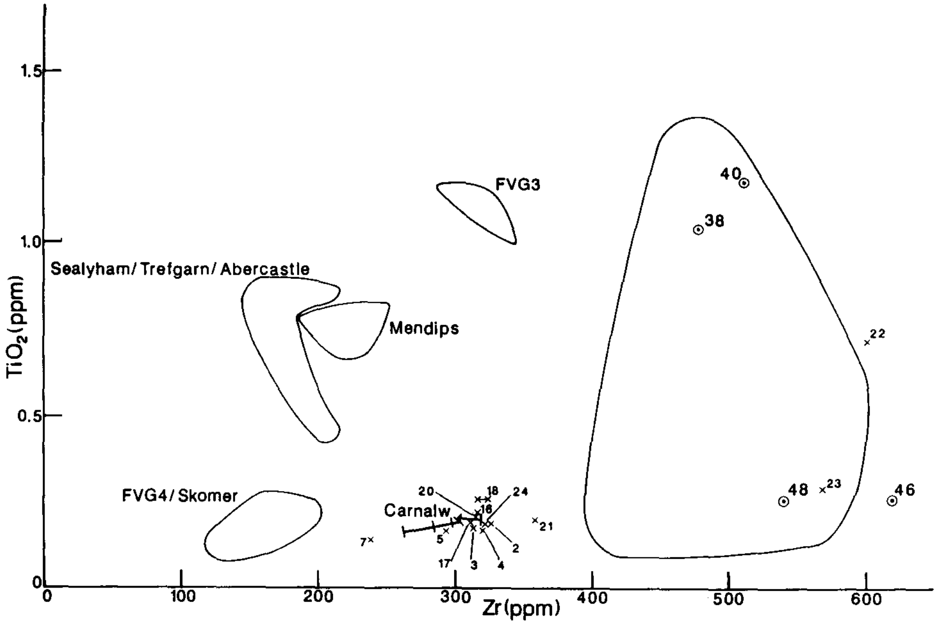

Figure 4. Graph of TiO_2 against Zr for andesite-rhyolite groups from Pembrokeshire and the Mendip Hills, showing excavated fragments from Stonehenge (crosses) and Stonehenge monolith samples (circles with dots in the middle). SH and OU prefixes are omitted on the diagram. Roch group not plotted (Y = <3 ppm, Thorpe *et al.* in press). Duplicate analyses plotted for OU18. From Thorpe *et al.* (in press).

6. Results and provenancing of samples

6.1 Chemical analysis

The Precambrian and Ordovician volcanic rocks of south Wales have undergone chemical alteration as a result of burial and regional metamorphism (Bevins and Rowbotham 1983), hydrothermal alteration, and low temperature hydration of glassy rocks. These processes have caused mobility of most major elements and several trace elements (see, for example, Macdonald *et al.* 1987) on a large (outcrop) scale, and smaller scale migration of Al_2O_3, CaO and Sr into "spots" from surrounding rock. It is therefore important to use representative samples particularly of spotted dolerites, and to use variation diagrams based on elements unaffected by such alteration, in particular the high field strength elements Ti, Zr, Nb and Y.

Homogeneity within a single sample of *ca.* 1000 cm^3 was shown to be within 10% relative and mainly within precision (Thorpe *et al.* in press). Within an outcrop of *ca.* 900 m^2 (Carngyfrwy, Figure 5), variation of 10x precision was observed for some major elements, and of 2–6x precision for

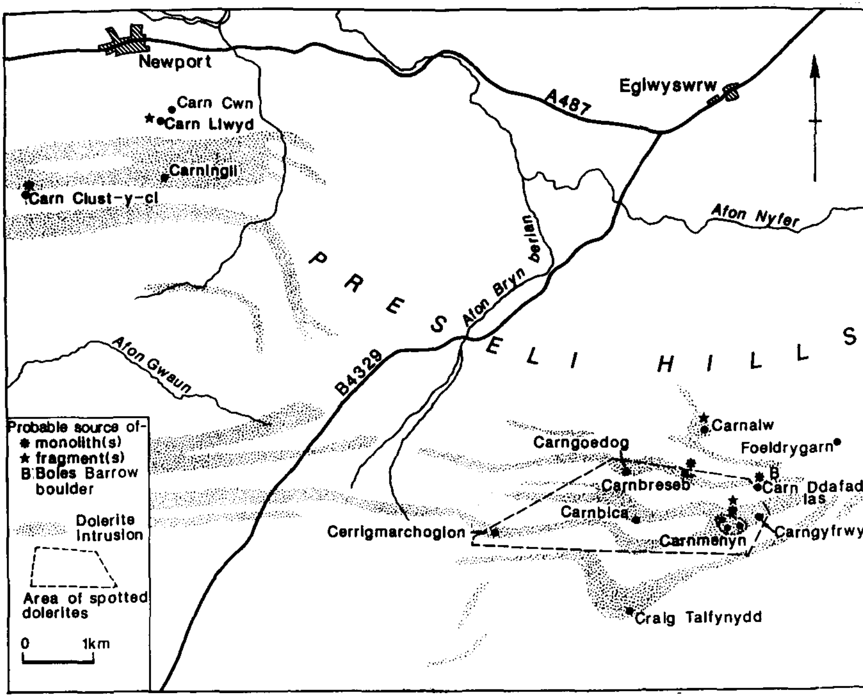

Figure 5. Sketch map of the Preseli Hills showing location of important outcrops mentioned in the text. The three outcrops surrounded by a dotted line are all part of the Carnmenyn outcrop. The dashed line shows the approximate extent of spotted dolerite, after Evans (1945). Map base is after Evans (*op. cit.*) and Bevins *et al.* (1989). Some dolerite areas contain small rhyolite occurrences, for example at Carnalw and Carningli. Probable sources of Stonehenge monolith and fragment samples, and of the Boles Barrow sample, are indicated. From Thorpe *et al.* (in press).

some traces, with Nb, Y and Zr among those elements showing least variation (Thorpe *et al.* in press, Table 7).

Figure 3(a) summarises the chemical variation of TiO_2 and Zr in Preseli dolerites (SiO_2 *ca.* 45–49%), (representative analyses in Table 1(a)). The good positive correlation between TiO_2 and Zr confirms the immobile behaviour of these elements, while greater scatter of TiO_2 at high Zr values may reflect accumulation/loss of Fe-Ti oxide. The graph also shows some regional variation within Preseli outcrops: for example, the Carnmenyn—Carngyfrwy, Carnalw and Foeldrygarn intrusions show restricted chemical ranges within the Preseli field. Excavated dolerite fragment samples are plotted on Figure 3(b) and, except for BB1 (Boles Barrow sample), show similar compositions to the Carnmenyn-Carngyfrwy field which also contains samples from Carnbreseb, Carngoedog and Cerrigmarchogion (within *ca.* 4 km of Carnmenyn) and other chemically undifferentiated dolerites studied by

Bevins *et al.* (1989). Monolith samples (Figure 3(c)) have the same restricted chemistry except for SH42, and SH44 and 45 (the last two identical to each other for unaltered elements), which may therefore come from different intrusions. Examination of all elements analysed (*cf.* Tables 1(a), 2(a) and compare Thorpe *et al.* in press Table 11) shows that most of the monolith samples and fragments have chemical characteristics consistent with an origin within the Carnmenyn-Carngyfrwy or Cerrigmarchogion and Carngoedog intrusions, while SH44, SH45 and BB1 are similar within or near precision to Carn Ddafad-las *ca.* 550 m north of Carnmenyn, and SH42 similarly matches a high Y and Zr dolerite from Carnbreseb. Figure 3(d) shows analyses of glacial erratics from the Lampeter Velfrey area and from near the Gorsfawr stone circle (*ca.* 3 km south-west of Carnmenyn), and these also derive from the same restricted area as most of the monolith and fragment samples. Thus the chemical evidence for the dolerites does not clearly distinguish between selection from *in situ* outcrop or from a glacial deposit.

Figure 4, again using TiO_2 plotted against Zr, exemplifies the variations within andesite—rhyolite sources in south Wales and Mendip (*cf.* Table 1(b)). Of the rhyolite fragments analysed, most are chemically identical (including OU3, quoted in Table 2(b)) and plot with the Carnalw source in eastern Preseli. Three fragments, nos. OU7, OU22 and OU23 are chemically different and therefore originate at different sources. The four Stonehenge monolith rhyolite samples are all different from each other (*cf.* Table 2(b)), and all lie within or near to the high-Zr field which forms part of the Fishguard Volcanic Group (chemically differentiated here into four groups: Carnalw, Fishguard Volcanic Groups (FVG) 3 and 4, and high-Zr samples; *cf.* Bevins *et al.* 1989; Thorpe *et al.* in press), which contains outcrops in eastern Preseli, north Preseli and on the north Pembrokeshire coast near Strumble Head west of Fishguard (compare Figures 2 and 6). Monolith sample SH38 is identical in chemical composition to the outcrop of Carn Clust-y-ci in northern Preseli (RGR14, Table 1(b)), and SH46 and SH48 are characterised by very high Y and Zr and may be parallelled in similarly siliceous rocks on the north Pembrokeshire coast (see, for example, SP2, Table 1(b)); however no exact source match could be found for these. No source parallel was found for SH40, and while its characteristics are generally consistent with a Pembrokeshire origin it should be noted that similar ignimbrites also occur in north Wales (*cf.* Howard 1982). Fragment 23 is identical to monolith sample SH48, while fragment 22 is chemically identical to Carn Llwyd in northern Preseli (RGR16, Table 1(b)). No source was found for fragment 7.

The rhyolite samples were also compared with glacial erratics analysed by

Table 1(a). Chemical analyses of dolerites from the Preseli Hills, south Wales

Sample	CM1	CM10	CM12	CBR1	CB1	PFT53
G.R.	SN 143325	SN 146325	SN 148329	SN 136332	SN 130326	SN 15613340
Location	Carnmenyn	Carngyfrwy	Carn Ddafas las	Carnbreseb	Carnbica	Foeldrygarn
SiO_2%	47.61	47.75	45.98	48.05	44.77	49.05
TiO_2	1.02	1.06	1.32	1.27	0.89	1.85
Al_2O_3	18.93	19.11	17.20	16.29	19.98	14.94
Fe_2O_3	8.40	8.70	10.25	10.38	9.46	0.26
FeO	–	–	–	–	–	10.24
MnO	0.15	0.14	0.17	0.17	0.14	0.21
MgO	6.49	6.59	8.85	7.34	7.28	6.76
CaO	10.29	10.87	10.03	10.92	10.50	10.04
Na_2O	2.71	3.08	2.35	2.33	2.66	1.95
K_2O	0.83	0.44	0.31	0.79	0.45	0.08
P_2O_5	0.10	0.11	0.13	0.14	0.06	0.16
H_2O^+	–	–	–	–	–	4.12
LOI	2.82	2.88	3.41	2.75	4.22	–
TOTAL	99.35	100.73	100.00	100.43	100.41	99.66
Ba ppm	326	204	306	150	167	–
Cr	213	285	195	295	320	189
Cu	60	56	49	33	63	60
Nb	3	3	4	5	3	2
Ni	29	33	118	34	120	40
Rb	19	15	9	17	12	2
Sr	276	318	276	249	303	343
Th	1	1	2	2	1	–
V	190	190	202	235	198	325
Y	20	18	20	28	16	32
Zn	68	64	79	72	68	96
Zr	68	70	73	99	45	123

Notes: LOI, Loss on ignition, included in totals; — not determined; iron as Fe_2O_3 total iron except PFT53 (FeO and Fe_2O_3); data from Thorpe *et al.* in press (PFT53 from Bevins *et al.* 1989).

Table 1(b). Chemical analyses of andesites and rhyolites from south Wales and Mendip

Sample	RGR14	SP2	CA2	RGR16	SW16	MH3
G.R.	SN 04193702	SM 88704058	SN 13903375	SN 06243805	SM 72260894	ST 666464
Location	Carn Clust-y-ci	Strumble Head	Carnalw	Carn Llwyd (Nr Carningli)	Skomer	Moons Hill
Group	High Zr	High Zr	Carnalw	High Zr	Skomer	Mendip
SiO_2%	65.63	76.90	78.70	67.28	75.74	66.82
TiO_2	1.01	0.50	0.19	0.56	0.12	0.77
Al_2O_3	13.97	12.40	10.06	13.86	12.61	14.92
Fe_2O_3	1.62	1.87	2.74	3.91	3.52	4.42
FeO	4.12	-	-	2.09	-	-
MnO	0.06	0.03	0.02	0.13	0.02	0.03
MgO	3.05	0.64	0.37	0.70	0.66	1.90
CaO	1.53	0.99	0.22	2.13	0.12	1.97
Na_2O	4.34	2.80	1.15	4.73	3.56	4.49
K_2O	2.74	2.79	6.04	2.32	3.62	3.52
P_2O_5	0.22	0.07	0.03	0.13	0.04	0.16
H_2O^+	2.39	-	-	1.61	-	Cl+S 0.02
LOI	-	0.90	0.72	-	-	-
TOTAL	100.68	98.99	100.24	99.44	100.01	99.02
Ba ppm	-	-	1004	600	-	-
Cr	3	-	14	n.d.	10	-
Cu	5	-	1	4	-	14
Nb	13	29	20	17	-	11
Ni	7	-	3	10	8	8
Rb	35	34	110	37	101	61
Sr	89	135	75	193	139	304
Th	-	-	13	6.14	-	8
V	84	-	4	15	-	-
Y	76	85	97	104	42	23
Zn	68	-	63	124	-	29
Zr	481	553	300	613	150	234

Notes: LOI, Loss on ignition, included in totals except in SP2; — not determined; iron as Fe_2O_3 total iron except RGR14 and RGR16 (FeO and Fe_2O_3); data from Thorpe *et al.* in press (MH3, CA2), Bevins *et al.* 1989 (RGR14, RGR16), Hughes 1977 (SW16), and Bevins 1979 (SP2); n.d., not detected.

Table 2(a). Chemical analyses of selected dolerite samples from Stonehenge monoliths and excavated fragments, and of the Boles Barrow boulder

Sample Location	SH33 Stone 33	SH42 Stone 42	SH44 Stone 44	SH45 Stone 45	SH61 Stone 61	OU6 Aubrey Hole 10	BB1 Boles Barrow boulder
SiO_2%	47.89	48.07	48.10	48.34	47.70	46.55	47.46
TiO_2	1.15	1.37	1.30	1.37	1.17	1.11	1.40
Al_2O_3	17.77	17.79	15.76	15.51	18.11	16.14	17.66
Fe_2O_3	9.29	9.17	11.82	10.22	9.05	9.91	10.33
MnO	0.16	0.15	0.19	0.22	0.14	0.17	0.17
MgO	6.99	5.73	8.37	8.58	6.17	9.42	6.07
CaO	11.30	11.53	9.06	9.24	11.92	10.15	11.20
Na_2O	2.85	3.31	2.17	2.91	2.69	1.97	3.33
K_2O	0.18	0.15	0.42	0.08	0.18	0.76	0.07
P_2O_5	0.11	0.22	0.12	0.10	0.11	0.11	0.13
LOI	2.80	2.87	3.30	3.62	2.90	3.21	2.65
TOTAL	100.49	100.36	100.61	100.19	100.14	99.50	100.47
Ba ppm	120	123	225	232	114	184	119
Cr	479	279	216	262	258	277	257
Cu	52	46	70	81	80	47	53
Nb	6	7	7	6	6	4	4
Ni	45	29	70	111	38	124	31
Rb	10	8	12	7	8	16	7
Sr	225	235	235	273	217	328	244
Th	2	1	n.d	n.d	n.d	1	3
V	210	213	240	237	208	209	251
Y	21	31	23	24	22	20	23
Zn	72	69	91	82	76	69	96
Zr	67	101	71	77	77	66	77

Notes: LOI, Loss on ignition, included in totals; n.d., not detected: iron is total Fe as Fe_2O_3%; number of separate analyses averaged in these figures are: majors—n = 2 for SH33, SH45, SH61, n = 3 for SH44, n = 1 for SH42, OU6, BB1; traces—n = 2 for all samples; samples SH44 and SH45 are from unspotted dolerites, remainder are spotted dolerites; data from Thorpe *et al.* in press.

Table 2(b). Chemical analyses of rhyolite samples from Stonehenge monoliths and selected excavated fragments

Sample Location	SH38 Stone 38	SH40 Stone 40	SH46 Stone 46	SH48 Stone 48	OU3 Hole Z6	OU22 Aubrey Hole 16	OU23 Aubrey Hole 11	OU7 Aubrey Hole 17
SiO_2%	66.74	67.16	74.63	75.42	77.23	68.80	74.31	83.13
TiO_2	1.04	1.09	0.26	0.26	0.18	0.72	0.29	0.14
Al_2O_3	13.36	12.78	12.16	11.48	11.11	14.32	12.05	9.13
Fe_2O_3	6.10	7.43	3.35	3.40	1.78	5.31	3.73	0.80
MnO	0.11	0.19	0.08	0.11	0.01	0.07	0.12	n.d
MgO	2.43	2.13	0.68	0.51	0.10	1.66	0.68	0.07
CaO	2.04	1.68	0.35	0.89	0.52	0.89	0.57	0.26
Na_2O	4.86	4.49	3.93	3.92	4.46	6.20	3.95	3.52
K_2O	1.36	0.83	2.77	2.94	3.13	0.06	3.06	2.69
P_2O_5	0.24	0.37	0.03	0.03	0.03	0.21	0.03	0.02
LOI	2.15	2.24	1.35	1.50	0.56	1.65	1.02	0.39
TOTAL	100.43	100.39	99.59	100.46	99.11	99.89	99.81	100.15
Ba ppm	415	837	592	544	549	69	576	572
Cr	64	1	6	8	28	n.d	12	24
Cu	8	7	1	n.d	1	3	1	n.d
Nb	15	19	31	24	15	17	25	13
Ni	12	7	8	7	3	3	3	2
Rb	24	22	46	43	67	8	45	51
Sr	236	579	158	47	52	459	48	55
Th	1	3	8	8	13	6	8	10
V	100	50	14	15	13	5	13	4
Y	75	89	155	105	84	114	116	80
Zn	71	127	135	109	24	107	88	21
Zr	478	510	621	539	312	601	566	237

Notes: LOI, Loss on ignition, included in totals; n.d., not detected; iron is total Fe as Fe_2O_3%; number of separate analyses averaged in these figures are: n = 2 for all except majors in OU3, 22, 23, 7 (n = 1). Samples SH38, SH40 and OU22 are ignimbritic, others are lavas; data from Thorpe *et al.* in press.

Donnelly *et al.* (in prep.), from Pencoed near Cardiff (Figure 6) but no chemical parallel for any was found in this assemblage.

The Stonehenge dolerites thus come from three sources chemically consistent with an origin within the Preseli Hills; the rhyolites come from a further seven sources (four for the monoliths, a further three for the fragments). These source areas are shown on Figures 5 and 6, and it is clear that the sources are both numerous and widespread, separated by distances of at least 10 km and perhaps over 30 km.

6.2 Opaque mineralogy of monolith sample SH61

One sample, from monolith SH61, was examined in polished thin section in reflected light by R.A. Ixer at the University of Birmingham, for comparison with Carnmenyn samples of dolerites. SH61 is characterised by heavily altered titanomagnetite and ilmenite, with minor amounts of altered pyrrhotite, chalcopyrite and pyrite, and trace amounts of spinel and violarite. With the single exception of violarite, these features are also encountered in Carnmenyn samples examined in the same way, and in addition the identical alteration history implied for both SH61 and for the Carnmenyn samples by the textures of the iron-titanium oxides (titanomagnetite and ilmenite) and the presence of metamorphic minerals surrounding aggregates of chalcopyrite, pyrrhotite and pyrite, suggest a common origin for all the samples. (A full list of the mineralogy of the samples is in Thorpe *et al.* in press). This supports the chemical provenancing of most of the monolith samples to the Carnmenyn—Carngyfrwy (or Carngoedog—Carrigmarchogion) area of Preseli.

6.3 Provenance evidence from sandstones at Stonehenge

Sandstone fragment OU9 excavated from Aubrey Hole 1 was examined in petrological thin section by R.G. Thomas of the University of Calgary, and modal analysis carried out by point counting, for comparison with Cosheston Group and other Lower Devonian sandstones of south Wales (Thomas 1978). Sample OU9 was found by Col. Hawley in the 1920's and its labelling as 'Cosheston Beds?' reflects an assumption of origin probably based on H.H. Thomas' provenancing of the Altar stone to the Cosheston or Senni Beds of south Wales in 1923 (*cf.* above). OU9 is characterised by pervasive pressure solution cleavage and paucity of rock fragments, features which indicate that it did not originate in either the Lower Devonian Cosheston or Senni Beds (full modal analysis in Thorpe *et al.* in press). It is more likely to be derived from a Silurian or older Lower Palaeozoic formation (*cf.* Figure 2) exposed in the Caledonian foldbelt of south-west Wales, or possibly from a Lower Devonian sandstone in westernmost Pembrokeshire, where such cleavage as is seen in OU9 has developed.

No sample was obtained from the Altar stone, and examination of this was based on macroscopic features. R.G. Thomas makes the comment that since it is more highly micaceous than OU9 it is not derived from the same unit. The Altar stone may be from the Senni Beds which form part of the Lower Devonian, approximately stratigraphically equivalent to the Cosheston Beds (Milford-Neyland-Cosheston districts) but cropping out to the east of Carmarthen Bay, from Kidwelly as far as the Abergavenny district *ca.* 90 km to the east. The evidence from the sandstones thus adds two more source areas for the Stonehenge bluestones, and shows that previous assumptions of source are unjustified in the case of OU9.

7. Review of evidence for glaciation and boulder clearance on Salisbury Plain

Controversy concerning the possible glaciation of Salisbury Plain has been a central factor in discussion concerning mechanisms of bluestone transport to Stonehenge. The main arguments against such glaciation have included the apparent lack of erratics on Salisbury Plain, and the absence of glacial material in Pleistocene river gravels draining Salisbury Plain, analysed by Green (1973). It can now be shown that neither of these arguments is as significant as previously suggested. Figure 6 illustrates the glacial movements referred to in this section.

Glaciation of south Wales including Pembrokeshire is well documented,

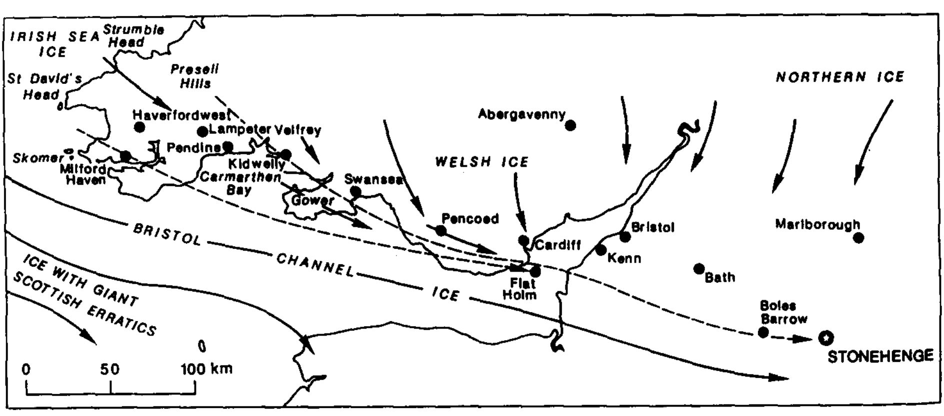

Figure 6. Map of south Wales and south-west central England showing generalised directions of ice movement (based on distribution of erratics) inferred for the Anglian glaciation (*cf.* Kellaway, 1971; Figure 2), and localities discussed in the text.

from early (Anglian or pre-Anglian; *ca.* 400 ka BP or earlier) features described by Bowen and Sykes (1988), Bowen (1982; 1989) and John (1970a; 1970b), through Wolstonian (*ca.* 150 ka BP) ice moving from the Irish Sea over Pembrokeshire into the Bristol Channel (e.g., Synge 1970; Kellaway 1971), to more recent (Devensian; *ca.* 20 ka BP) ice of more limited extent. Further east, glaciation of the Severn Estuary and the Bristol-Bath area is indicated by a relict till near Nunney (Kellaway 1971) and an erratic boulder at Kenn pier (Hawkins and Kellaway 1971), while amino acid racemisation dating of deposits at Kenn gives an age exceeding 400–600 ka (i.e., Anglian or pre-Anglian) for these features. Recent studies by Kellaway (pers. comm. and 1991) propose movement of northern ice (i.e., from Scotland and north Wales, not crossing south Wales) onto Salisbury Plain during a glaciation of *ca.* 500 ka BP (Beestonian) or earlier.

Igneous boulders were transported glacially south and eastwards from south-west Wales to the Haverfordwest area where they reach 4 m (Strahan *et al.* 1914), to *ca.* 20 km south-east of Carnmenyn (Lampeter Velfrey, Figure 6) where they reach over 2 m in size (Strahan *et al. op. cit.*; Thorpe *et al.* in press), and to near Carmarthen Bay *ca.* 2 km north of Pendine (spotted dolerite reported by Strahan *et al. op. cit.*, 218, Figure 20). Varied igneous erratics presumed to be from Scotland, Ireland and/or south-west Wales are described in Gower by George (1933) and Jenkins *et al.* (1985), and erratic boulders from Pencoed (Figure 6) near Cardiff analysed by Donnelly *et al.* (in prep.) include material from the St. Davids Head area and Skomer island (Figure 6). Igneous erratics on Flatholm island in the Severn Estuary (Figure 6) have been deduced to be from the Lake District and north and south Wales (Kellaway 1971) and erratics on the east side of the Severn estuary include a striated Carboniferous limestone boulder (*cf.* above; Hawkins and Kellaway 1971).

Between the Bristol area and Stonehenge (*ca.* 68 km) there is an apparent absence of glacial erratics. The Boles Barrow boulder (*ca.* 19 km west of Stonehenge on the proposed route of glacial movement; *cf.* Figure 6) appears unworked and is consistent with an erratic in appearance, and its likely early date of use (*cf.* above) suggests that it was obtained independently of the Stonehenge bluestones; as such the most obvious explanation for its presence is as a locally available erratic. Other fragments of bluestone on Salisbury Plain without secure archaeological context were noted above.

There is also evidence for removal of erratics from Salisbury Plain during intensification of agriculture in the 18th—19th centuries. De Luc (1811) (reported by Bartenstein and Fletcher 1987 and Thorpe *et al.* in press) made geological observations of the area between 1777 and 1809 and reported "masses of granulated quartz (sarsen? authors' comment) ...... associated with blocks of granite and of trap" (igneous rocks? authors' comment) (de

Luc 1811, 471). He commented on October 11 1809 that "as I approached *Marlborough*, I took particular notice of the state of the agriculture; and I was surprised at seeing what progress it had made since 1805, when last I had passed this way; the ground was all enclosed, and the blocks of *granulated quartz* had entirely disappeared. It will therefore be of advantage for future geologists and especially to those who may pay any attention to Stonehenge, that an account has been given of these blocks still scattered here not more than thirty years ago, and of the progress made since that time, by agriculture, which has thus occasioned their disappearance" (de Luc 1811, 501; original emphasis).

Geinitz (1886) describes similar removal of erratics in Germany, where, he says, the local inhabitants dispose of the stones partly through burial in pits; such a method of disposal may account for the rarity of sarsens in buildings on Salisbury Plain (*cf.* Atkinson 1979, 116). In the Drenthe Plateau of the Netherlands, Bakker and Groenman-van Waateringe (1988) note the difficulty in determining the original distribution of erratics "because the country was stripped of its boulders in historic times" (Bakker and Groenman-van Waateringe *op. cit.*, 146).

Deposition of boulders by an extensive ice sheet such as is proposed for Anglian glaciation of Britain is often sporadic and discontinuous, particularly at the margins of such ice sheets. Thus, for example, the distribution of Scandinavian erratics in the east of England is irregular, with concentrations at Cromer, Norwich and Cambridge (Norwich to Cambridge, *ca.* 100 km) (Phemister 1926, Figure 1; Charlesworth 1957, Figure 129), while North American ice in Dakota has left boulders so dispersed that "in some areas in the outermost, western part of the region (i.e., nearer to the limit of glaciation; authors' comment) one can travel several miles between boulders" (Flint 1955, 85). Such boulders may be deposited without accompanying fine material, (*cf.* Green 1973) as "free boulders" (Flint 1957, 129–130), either derived from nunataks or deposited from clean glacier ice (Flint 1955 in Flint 1957, 129).

In view of this evidence regarding behaviour of ice sheets in erratic dispersal, and of boulder clearance on Salisbury Plain, neither the "gap" in erratics between Bristol and Stonehenge, nor the absence of glacial material in river gravels can be used as evidence against the glaciation of Salisbury Plain.

8. Discussion of evidence for the mode of transport of the bluestones to Stonehenge

We have presented evidence above for the variety of rock types forming the

Stonehenge monoliths, originating at at least eight outcrops (including the Altar stone) dispersed over a distance of at least 10 and perhaps 30 km in south-west Wales. This does not imply selection at a carefully chosen *in situ* source but exploitation of an (already glacially) mixed deposit. The presence of monoliths of structurally poor rock types, the possibility of on site (i.e., at Stonehenge) working of bluestones (*cf.* Judd 1902), the availability of more durable rocks along the proposed human transport route from Wales to Stonehenge (e.g., Mendip, Bath) and the complete absence of evidence for valuing of bluestone in the source area of south Wales all argue against human transport. Antiquarian accounts (de Luc *op. cit.*) indicate the existence of glacial erratics on Salisbury Plain, now removed through agricultural clearance. The presence of bluestone fragments in a wide range of archaeological monuments of varied dates (incorporated casually, not as valued objects) and their finding without clear archaeological context also argue for their local availability as erratics. There is evidence of pre-Wolstonian glaciation at least as far as the Bristol-Bath area, and the present absence (or sporadic occurrence e.g., Boles Barrow) of erratics over the small (68 km) distance between Bristol and Stonehenge is consistent with the irregular dispersal of (free) boulders at the edge of an extensive ice sheet. Glacial erosion also removes preferentially hard, well-jointed rocks such as dolerite (Flint 1957), and this is also reflected in the predominance of dolerites at Stonehenge. All these arguments militate strongly in favour of glacial transport.

In contrast, the evidence in favour of human transport is limited to the account of Geoffrey of Monmouth, which Burl has suggested reflects contemporary knowledge of Irish megaliths rather than a folk memory of bluestone transport (Burl 1985a), and the proposed traffic in axes and Irish metals from or passing near the Preseli source area (*cf.* Atkinson 1979). These (tenuous) links are insufficient evidence for the unique feat of megalith transport proposed.

We conclude from our evidence therefore that the bluestones of Stonehenge were transported to Salisbury Plain by glaciation of the Anglian (*ca.* 400 ka BP) period or earlier.

9. Comment on the sources of the sarsen stones at Stonehenge

Sarsens are the silicified remnants of formerly extensive Cenozoic sedimentary cover within southern England. It has been proposed that the source of the Stonehenge sarsen monoliths lies in the Marlborough Downs some 30 km north of Stonehenge, and this proposal is still widely accepted (e.g., Atkinson 1979, 116; English Heritage Guide to Stonehenge (text by R.J.C. Atkinson)

1987), and elaborate models for the stone transport have been developed (Atkinson 1979, 116–120). Since 16th century writers propose a Marlborough source, (e.g., Lambarde 1580; *cf.* Harington, 1591; reported by Chippindale 1987, 36–37), it seems that at that period large sarsens were not common on Salisbury Plain. Aubrey (1665–1693) also proposes a Marlborough source, noting this area as "being scattered over with them (i.e., sarsens, authors' comment) ..... for about 20 miles in compass" (he does not say in which direction they are scattered). Early illustrations of Stonehenge may be unreliable as factual guides, but the 16th century illustrator 'R.F.' shows boulders around Stonehenge, as do early 19th century artists Fielding and Constable (reproduced in Chippindale 1987, Figure 22, plates VI and VII respectively).

Recent surveys of sarsens in southern England (Bowen and Smith 1977; Summerfield and Goudie 1980) show that there are examples near Stonehenge, including a concentration near Amesbury. These may not now contain stones as large as those in Stonehenge, but neither do the Marlborough deposits (*cf.* Chippindale 1987, 40). The presence at Stonehenge of one sarsen monolith clearly smaller than the others (stone 11) may imply that the builders were indeed exploiting a very limited, almost worked out, supply of large stones.

Summerfield and Goudie (*op. cit.*, 72) note that "the present distribution of sarsens reflects, to a large extent, their removal by man, and those remaining are only a vestige of the numbers in existence prior to man's arrival in Britain". This is consistent with the observations of de Luc noted above, reporting clearance of sarsen ('granulated quartz') boulders from Salisbury Plain in the late 18th and early 19th centuries. No chemical study of the Stonehenge sarsens has yet been done, but heavy mineral analysis carried out by Howard (1982, 119–123) on 5 excavated pieces of sarsen from Stonehenge showed mineralogical differences between these and two pieces from Piggledean in the Marlborough Downs. However, Howard also notes distinctions in thin section between material from two deposits in the Marlborough Downs, so that full interpretation of her data require further sampling, especially of the source material.

The evidence summarised, in particular the widespread occurrence of sarsen in southern England, and accounts of field clearance, suggests that sarsens were locally available for use in Stonehenge. While the tooling and erection of the sarsens gives Stonehenge its predominance in British prehistory, labour-intensive transport of sarsens from the Marlborough Downs was not required.

10. Implications of local availability of the bluestones and sarsens, for Stonehenge and other megalith studies

The conclusion that all the stones of Stonehenge, both bluestones and sarsens, were locally available at or close to the site of monument, necessitates a re-appraisal of estimates of the labour involved in the construction of Stonehenge II and IIIa, for which existing calculations are weighted heavily by assumptions of labour-intensive transport from remote sources (see, for example, Atkinson 1979, 121). The manpower required to build Stonehenge has also been used in the construction of monument 'hierarchies' within prehistoric Wessex (e.g., Renfrew 1983, 12; Startin and Bradley 1981: 292). Renfrew (*op. cit.*) suggests a total input of 30 million man-hours for 'Stonehenge', while Startin and Bradley propose that Stonehenge II required 360,000 man-hours, and Stonehenge IIIa, 1.75 million man-hours. Startin and Bradley (*op. cit.*) note that "we know the approximate source areas for the different stones used at Stonehenge" (*op. cit.*, 290) and this appears to imply that the factor of stone transport is incorporated in their figures. Such estimates now require revision to determine whether the construction of Stonehenge II and IIIa *without* stone transport from remote sources still requires more labour than that needed for monuments e.g., the larger henges.

Long distance transport of stones used in prehistoric megalith construction has been proposed for a number of other sites in the UK (although in no case does the distance proposed approach the 240 km suggested for the Stonehenge bluestones). For example, in the absence of geological study, human transport of *c.* 20 and 10 km has been assumed for the standing stones of Rudston and Boroughbridge (Devils' Arrows) in Humberside and North Yorkshire respectively (e.g., Burl 1979, 286; Dymond 1966). Similarly, transport over 11 km has been suggested for the stone circles of monoliths at Brogar and Stenness in Orkney (*cf.* Collins 1976). Ready acceptance of such proposals may have been influenced by the apparent existence of a parallel at Stonehenge. However, since this parallel can no longer be accepted, the present authors were prompted to re-assess evidence for transport of other megaliths such as those cited above.

This study (full details in Thorpe and Williams-Thorpe 1991) draws evidence from glaciated areas of the UK, Scandinavia, northern Germany and the Netherlands, and non-glaciated areas of France. The use of glacial boulders for megalith construction has been noted in south Wales (Thorpe *et al.* in press), in Ireland (O'Riordain 1965), in England (Thomas 1976), and in southern Scandinavia and northern Germany (Kaelas 1983; Geinitz 1886). In particular, Bakker and Groenman-van Waateringe (1988) point out the correlation between the distribution of Funnel-Necked Beaker (TRB) period megaliths (*hunebedden/hunebeds*) and the glacial boulders of the Drenthe Plateau in the Netherlands. Use of glacially transported blocks, and of locally quarried slabs, can be shown respectively for the Rudston and Boroughbridge stones (Thorpe and Williams-Thorpe 1991), and for the Stenness and Brogar megaliths (*cf.* Collins 1976, 45; Renfrew 1979, 41). Evidence presented by Burl (1985b) for Britanny (non-glaciated) shows that stones were transported no more than *ca.* 5 km, and in most cases much less. Evidence from France is extended by the comprehensive study of Mohen (1989) in which the maximum transport recorded is *ca.* 5 km.

Thorpe and Williams-Thorpe (1991) conclude therefore that European megaliths were built of readily available materials and that there is no evidence for megalith transport exceeding *ca.* 5 km, though the form of some monuments requires small scale (1–2 km) re-arrangement of stones (e.g., within the West Kennet Avenue, 2 km in length).

The distribution of megaliths in Arran and Orkney (Rousay) has been used by Renfrew to develop a hypothesis of segmentary society based on territories, each signalled by a megalithic tomb and delimited by Thiessen polygons drawn around that tomb (e.g., Renfrew 1973, 146–156; 1983). Renfrew maintains that 'the construction of these monuments represents a *serious, coherent, indeed patterned activity*' (Renfrew 1983, 9; original emphasis). However, evidence presented above suggests that the siting of megaliths is closely related to or even dictated by, the availability of stone. Bakker and Groenman-van Waateringe (1988, 155) note that for the TRB megaliths of Drenthe 'the presence of boulders dictated the place of the tombs' (*cf.* also O'Riordain 1965, 73: "The availability of suitable building material—especially a great glacial erratic to provide the capstone—without the necessity of long transport could have exercised an influence on the siting of individual tombs"). Bakker and Groenman-van Waateringe (*op. cit.*, 174) also conclude that "nothing was found to show that *hunebeds* lay in the centre of the territories of local communities (as Renfrew suggested for other megalithic landscapes)". It is therefore clear that socio-spatial analysis based on megaliths must be preceded by analysis of the geological sources of the stones and their mechanisms of transport, and consideration of the possible influence of these factors on megalith siting.

11. Conclusions

Chemical analysis of fifteen samples from bluestone monoliths at Stonehenge shows that they derive from seven different outcrops in Preseli (including Carnmenyn) and other parts of south-west Wales, up to 30 km apart. Twenty-two excavated fragments of dolerite and rhyolite from Stonehenge were also analysed, and include some which originate at a further three sources. A sandstone fragment originated not in the Senni or Cosheston Beds, but probably from a Lower Palaeozoic exposure in the Caledonian foldbelt in south-west Wales, while the Altar Stone may derive from the Senni Beds. This variety of source suggests selection from a mixed (glacial) deposit. Igneous rock erratics from south-west Wales have been identified near Cardiff, and other erratics are present in the Bristol Channel (Flatholm) and near Bristol. The apparent gap in erratic distribution between Bristol and Stonehenge is consistent with irregular dispersal of (free) boulders at the edge of ice sheets, and with intensive agricultural clearance of such boulders reported in historical times. This evidence, together with the presence at Stonehenge of structurally poor monoliths, suggests that the bluestones were glacially transported to the present site of Stonehenge, and were not transported by humans. A review of evidence for sarsen distributions and clearance in southern England suggests that these also were available locally, and did not need to be transported from the Marlborough Downs as has been proposed. The conclusion that all the Stonehenge monolith stones were available locally necessitates re-assessment of calculations of the labour required for the construction of the monument. A study of other European megaliths shows that there is no evidence for transport of any megalith stone over more than *ca.* 5 km, and the availability of stone, particularly as erratics, may influence the siting of megaliths. This means that hypotheses of social organisation based on megalith distribution are not meaningful unless the geological constraints on their siting are first considered.

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