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Application of palynological data to the chronology of the Palaeogene lava fields of the British Province: implications for magmatic stratigraphy

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Abstract: New high-precision ages, determined from palynomorph assemblages within intercalated sedimentary deposits, are presented for the Palaeogene lava fields (Skye, Mull and Antrim) of the British Province. These data reveal very rapid averaged eruption rates (1 m/200 years) and the non-synchronous formation of the lava fields. Eruption of the volumetrically dominant transitional to mildly alkaline lavas of the Skye (58.25–58.0 Ma) and Mull (post 55 Ma) lava fields (the Skye Main Lava Series, and the Plateau Group of Mull, respectively) is separated by the eruption of the MORB-like Preshal More flows of olivine tholeiite found at the top of the preserved sequence on Skye and at the base of the Mull Lava Field. The Lower Formation of the Antrim Lava Field correlates with the Skye Lava Field and the Upper Formation correlates with the Preshal More flows. The new ages indicate that the eruption of the Preshal More flows was synchronous with the main ocean floor spreading event which occurred 500 km to the NW, at *c.* 55 Ma, during Chron 24r. A combined thinspot and channelized plume model may best explain the temporal and spatial distributions of the lava fields and associated subvolcanic complexes of the British Province.

Keywords: British Province, Palaeogene, lava fields, palynology, dating.

The rapid eruption of thick and laterally extensive sequences of flood lavas during continental breakup is a major and spectacular consequence of the arrival of a mantle plume at the base of a continental lithospheric plate (e.g. Duncan & Pyle 1988; Renne *et al.* 1992; Turner *et al.* 1994). Elucidation of the short time scale for these voluminous eruptions is possible by high precision $^{40}Ar–^{39}Ar$ dating procedures on both whole-rock samples and mineral separates. Eruption rates have been estimated based upon known or estimated stratigraphic thicknesses and lateral extents of these predominantly subaerial lava fields, and have yielded spectacularly high values (Renne *et al.* 1992; Turner *et al.* 1994). Based upon these data, a variety of implications have been examined, including explanations for mass faunal extinctions (Rampino & Stothers 1988) and dramatic environmental effects (Officer & Drake 1983).

In this contribution we report and discuss new high precision age dates based on palynomorphs recovered from sedimentary horizons within the main Palaeogene lava fields of the British Province (Fig. 1), preserved within the Inner Hebrides of Scotland and the Antrim area of Northern Ireland, and associated with a major rifting and ocean floor spreading episode between NW Europe and East Greenland (White & McKenzie 1989; Thompson & Gibson 1991). Currently available radiometric age dates yield errors that do not permit the relative ages of these major lava fields and certain of the subvolcanic complexes to be determined with any confidence (Mussett 1986; Mussett *et al.* 1988). In a number of instances radiometric ages conflict with observable stratigraphic and cross-cutting field relationships (Mussett *et al.* 1988).

The data we present utilize detailed palynological analysis of volcaniclastic, sedimentary and soil horizons, as follows: (i) from throughout the preserved thickness of the Skye Lava Field; (ii) from near the base of the Mull Lava Field; and, (iii) from near to the top of the Lower Formation and from the Interbasaltic Formation of the Antrim Lava Field. The correlation of these biostratigraphic markers is with the new and detailed geomagnetic polarity time scale for the Late Cretaceous and Cenozoic of Cande & Kent (1992, 1995), using the biostratigrapically-constrained magneto-stratigraphy deduced by Ali & Jolley (1996) for late Palaeocene and early Eocene strata from the Anglo–Belgium–Paris Basin. Our age data yield certain important and unexpected results: very rapid eruption rates for the lava fields, and a significant length of time between the near-coeval eruption of the Skye and Antrim lava fields and the younger Mull Lava Field. We examine the implications of these data for the formation of the extrusive and intrusive units of the British Province, together with the evolution of the associated subcontinental mantle plume (Thompson & Gibson 1991).

Stratigraphy of the British Province lava fields

The British Province comprises three main lava fields (Skye, Mull, Antrim) and a number of subvolcanic (central) complexes (including, Skye, Mull, Rum, Ardnamurchan, Arran, Mourne, Carlingford, Slieve Gullion (Fig. 1); together with a number of submerged centres, e.g. Ritchie & Hitchen 1996). The relative ages of the lava fields and the subvolcanic complexes can be deduced from intrusive relationships and the presence of material derived from rapidly unroofed subvolcanic complexes and preserved within sedimentary units interstratified within the lava fields (e.g. Williamson & Bell 1994). Table 1 is a synopsis of critical and well-constrained relative time relationships between the lava fields and the

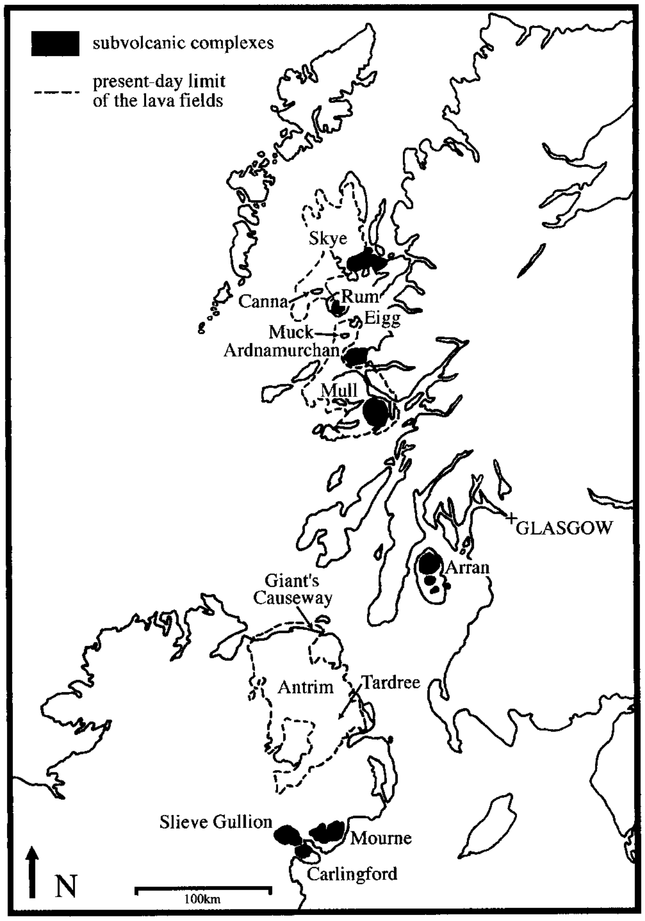

Fig. 1. Location map of the present-day limits of the lava fields and subvolcanic complexes of the British Province.

spatially-associated subvolcanic complexes of the British Province. Figure 2 is a summary of the stratigraphy of the British Province lava fields.

Locally, the Skye Lava Field can be subdivided into a number of groups on the basis of interstratified sedimentary units which developed during hiatuses in the volcanic activity (Anderson & Dunham 1966; England 1994; Williamson & Bell 1994). The base of the lava pile rests with minor disconformity upon Middle to Upper Jurassic sedimentary rocks and the volcanic activity commenced with the eruption of the Palagonite Tuff (Anderson & Dunham 1966), which comprises hydrated glassy basaltic ash and pillowed lavas formed by the effusion of magma into shallow water. Evidence of sedimentary reworking of the fine-grained ashy material is common.

The youngest recognized sedimentary unit within the Skye Lava Field is the Preshal Beg Conglomerate Formation (Williamson & Bell 1994), which is composed of a heterogeneous sequence of conglomerates, breccias, grits and tuffaceous siltstones. Between the Palagonite Tuff and the Preshal Beg Conglomerate Formation are all of the lavas of the Skye Lava Field which belong to the volumetrically dominant Skye Main Lava Series (or magma type) (Thompson 1982), and which are of transitional to mildly alkaline affinity. The only other lavas belonging to the Skye Lava Field are two thick intra-canyon flows which rest directly on top of (and therefore are younger than) the Preshal Beg Conglomerate Formation (Williamson & Bell 1994). These intra-canyon flows are of olivine tholeiite composition and are of the Preshal More magma type, akin to the MORB-type magmas being erupted on Iceland at the present day. Both flows were assigned to the Talisker Lava Group (Fig. 2) by Williamson & Bell (1994). Consequently, the Preshal Beg Conglomerate Formation is an important chronostratigraphic marker between two very contrasting magma types. Furthermore, the Preshal More magma type is responsible for the formation of many of the basic and ultrabasic units of the Skye Intrusive Complex (Bell *et al.* 1994) and its involvement in the construction of the Skye Lava Field is considered to be both very late and of minor importance in terms of the lavas still preserved (Williamson & Bell 1994).

To the south, on the islands of Rum and Canna, there is clear evidence that this extension of the Skye Lava Field post-dates the Rum Intrusive Complex; clasts of a variety of unique lithologies derived from the upper part of the Rum Intrusive Complex occur within conglomerates which are interstratified with lavas of the Canna Lava Formation at a relatively low stratigraphic level (Emeleus 1985, 1996).

The Mull Lava Field rests with minor disconformity upon Upper Cretaceous sandstones and chalks. Volcanic activity

Table 1. *Synopsis of relative ages of the lava fields and subvolcanic complexes of the British Province*

Lava field	Subvolcanic complex	Lava field older than complex?	Evidence
Skye	Skye	Yes	Intrusive contact and thermal overprint (1)
Skye	Rum	No	Clasts derived by unroofing of the Complex present within conglomerates interstratified with the lavas (2)
Mull: northern extent (Eigg Lava Formation)	Rum	Yes	Invaded by dykes of the Rum Swarm, themselves cut and thermally overprinted by the Rum Complex (3)
Mull: southern extent	Mull	Yes	Intrusive contact and thermal overprint (4)
Mull: northeastern extent	Ardnamurchan	Yes?	Ambiguous intrusive relationship (5)
Antrim	Mourne	Not known from field relationships	Rb–Sr age of *c.* 56 Ma (6)
Antrim	Slieve Gullion	Yes?	Large blocks of basalt tentatively identified as lava within volcaniclastic breccias of the Complex (7)
Antrim	Carlingford	Yes	Relicts of altered lavas preserved around margin of the Complex (8)

See main text and Mussett *et al.* (1988) for further discussion. References: (1) Harker (1904); (2) Williamson & Bell (1994); (3) Emeleus (1996); (4) Bailey *et al.* (1924); (5) Richey & Thomas (1930); (6) Gibson *et al.* (1987); (7) Richey & Thomas (1932); (8) Le Bas (1965).

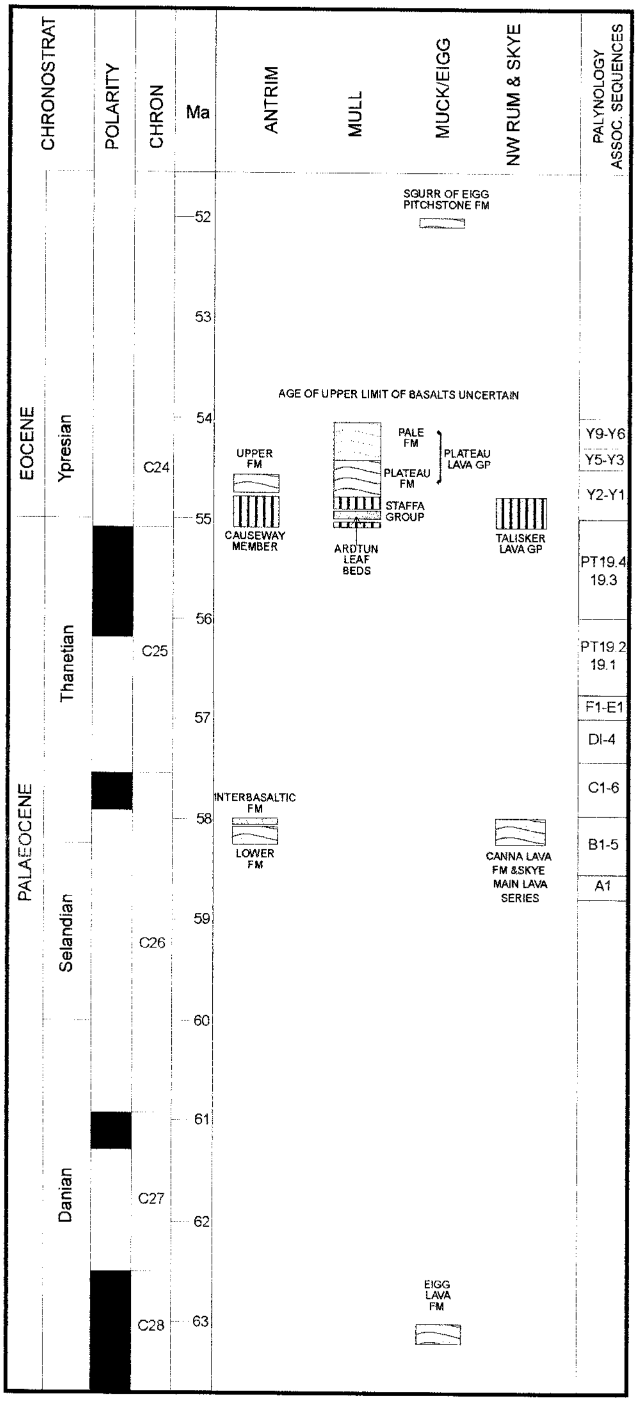

Fig. 2. Absolute ages of the lava fields of the British Province, based on palynomorph assemblages from interbedded sedimentary horizons (Jolley 1997).

commenced with the eruption of a basaltic ash, subsequently ferrallitized and now represented by a reddened claystone (the Basal Mudstone of Bailey *et al.* 1924). The first effusive units of the lava field are distinctive, columnar-jointed olivine tholeiites of the Staffa Group (of the Staffa magma type, Thompson *et al.* 1986) which tended to infill palaeo-valleys. Interstratified, but near to the top of this sequence of olivine tholeiite flows, and therefore relatively early in the stratigraphy of the lava field, are the Ardtun Leaf Beds (Gardiner 1887; Bailey *et al.* 1924), which comprise a sequence of conglomerates, grits, silty sandstones, limestones and claystones. Within the fine-grained lithologies are superbly preserved plant megafossils, mainly leaves (Bailey *et al.* 1924). At the base of this sedimentary sequence is a thin coal and a concretionary root clay, below which is an olivine tholeiite lava with pillow-like structures. Overlying the olivine tholeiite lavas and sedimentary rocks, and forming the main thickness of the Mull Lava Field (almost 1000 m thick, based upon the present-day stratigraphy), are transitional to mildly alkaline basaltic flows (and their more fractionated equivalents) of the Plateau Group (Bailey *et al.* 1924).

Further to the north, the Eigg Lava Formation is cut by numerous NW–SE-trending dykes and is considered to pre-date the Rum Intrusive Complex (Emeleus 1996) (Table 1). Flows from this formation crop out on the islands of Eigg and Muck, and on the SE part of Rum (Fig. 1), and are transitional to mildly alkaline in composition (Emeleus 1996). Overlying the Eigg Lava Formation, and separated from it by a valley-fill fluviatile conglomerate, is the Sgurr of Eigg Pitchstone Formation, which is of dacitic affinity.

The Antrim Lava Field is composed, predominantly, of flows (and less abundant ash accumulations) of olivine- and hypersthene-normative tholeiite, and can be subdivided into Lower and Upper formations. Near to the top of the Lower Formation are rare flows of icelanditic composition. A number of flows within the Upper Formation are of olivine tholeiite composition, almost identical to the Preshal More flow(s) of Skye (Lyle 1985). Between the two formations is the Interbasaltic Formation, which comprises a thick sequence of lateritic deposits (together with lignites and bauxites) which developed during a period of volcanic quiescence. Locally, quartz tholeiites (for example, at the Giant's Causeway), and rhyolites (for example, at Tardree), were erupted during the period of weathering associated wth the formation of the Interbasaltic Formation, thus producing two identifiable sedimentary members within the Interbasaltic Formation: the Port na Spaniagh Member (pre-dating the Giant's Causeway tholeiites), and the Ballylagan Member (post-dating the Giant's Causeway tholeiites, but pre-dating the Upper Formation) (Preston 1982).

The age data presented here are for the following horizons: (i) the Palagonite Tuff (defining the base of the Skye Lava Field), the Preshal Beg Conglomerate Formation (defining a horizon near to the top of the Skye Lava Field, and at the top of the volumetrically dominant Skye Main Lava Series, but below the Preshal More olivine tholeiite flows), together with all of the main intervening sedimentary horizons (Anderson & Dunham 1966; Williamson & Bell 1994); (ii) the Ardtun Leaf Beds (near to the base of the Mull Lava Field, but close to the top of the thin sequence of Staffa Group olivine tholeiite flows which occur at the base of the lava field, above which are the volumetrically dominant lavas of the Plateau Group); and, (iii) a bauxite from near to the top of the Lower Formation, and volcaniclastic siltstones and lignitic claystones overlying the lowest flow of the Giant's Causeway Member of the Interbasaltic Formation, both of the Antrim Lava Field.

Ages of the volcaniclastic, sedimentary and soil horizons

The chronology presented in this paper is based on the palynological study of interlava sedimentary deposits by Jolley (1997, see especially Fig. 3). A synopsis of these results is presented here for completeness, concentrating on the age determinations. Details of the palaeoenvironmental analysis are given in Jolley (1997).

Details of the sample sites and the palynomorph assemblages recorded are presented by Jolley (1997). In the case of the material from the Preshal Beg Conglomerate Formation and the Ardtun Leaf Beds, the finer (silt or clay) fractions were sampled. All samples were processed for palynomorphs by dissolution of the silicate phases in hydrofluoric acid, with minimal oxidation in nitric acid. Residues were collected through a 7 Mm sieve and prepared as strew mounts for examination under a phase contrast optical microscope.

The presence of palynomorphs in the interlava sedimentary rocks of Mull has previously been recorded by Simpson (1961), Srivastava (1975) and Boulter & Kvacek (1989). It has not been possible to assign an age to these palynofloras because of their terrestrial origin, which has prevented the application of widely used dinoflagellate cyst-based zonations such as that of Powell (1992). Jolley (1997) presented a regional pollen and spore spectrum for the West Shetland Basin, based on a series of well sections, utilizing core, sidewall core and ditch cutting samples. This profile (Fig. 3) has been used as a regional standard for the terrestrial palynoflora, and shows the broad differentiation of the record into palynofloral types. Similarities with the record from the North Sea and SE England allow comparison of West Shetland Basin events to chronostratigraphically dated sections (Ali & Jolley 1996).

The oldest palynofloras recorded in the British Province are from the sedimentary deposits interstratified with the lavas of Skye and NW Rum. On Skye, sedimentary deposits from the Palagonite Tuff at the base of the sequence, through the entire thickness of the lava pile up to, and including, the Preshal Beg Conglomerate Formation, show a lowland palynoflora dominated by *Inaperturopollenites hiatus* and *Momipites tenuipolus*, with common occurrences of *Sequoiapollenites polyformosus* and *Plicapollis pseudoexcelsus* in assemblages typical of the 58.0–58.25 Ma interval in the West Shetland Basin (Fig. 3). Similar, and most likely correlative, palynofloras were recovered from the interlava sedimentary deposits of the Canna Formation on Rum, confirming the link between the Rum and Skye lavas proposed by Williamson & Bell (1994). These data indicate that the entire sequence of flows which constitute the Skye Lava Field, up to the level of the Preshal Beg Conglomerate Formation, was erupted within the 58.0–58.25 Ma interval of Chron 26r (Cande & Kent 1992, 1995; see Fig. 2). Consequently, the thickness of this portion of the lava field, estimated to be *c.* 1200 m (England 1994), was erupted over *c.* 250 000 years, giving a minimum average accumulation rate of 1 m/200 years (given that no allowance has been made in this figure for the effects of subsidence; Jolley 1997).

Similar *Momipites tenuipolus*-rich palynofloras were obtained from a bauxite in the upper part of the Lower Formation, from boles in the Interbasaltic Formation, and from lignitic claystones partly overlying the lowermost flow of the Giant's Causeway Member of the Interbasaltic Formation, all of the Antrim Lava Field. These occurrences confirm the 58.0–58.25 Ma age of at least part of the Antrim Lava Field (Fig. 2), although data are lacking from the oldest and youngest parts of the lava sequence.

Whereas being closely similar in overall composition, the Antrim Lava Field palynofloras were derived from predominantly lowland forests, unlike the mixed lowland to montane forests of the Skye Lava Field. This is perhaps related to altitudinal differences between the two areas, and is reflected in the lower eruption rates which can be calculated for the Antrim Lava Field (Jolley 1997).

In contrast, the palynofloras recovered from the Ardtun Leaf Beds by Jolley (1997), and previously recorded by Simpson (1961), Srivastava (1975) and by Boulter & Kvacek (1989), are rich in assemblages of greater diversity. They are characterized by abundant *Inaperturopollenites hiatus*, with common *Momipites* and *Caryapollenites* species and common *Monocolpopollenites tranquilus*. Together with occurrences of *Aquilapollenites* species, this assemblage provides a close correlation with those seen immediately above the Faeroes lavas in the West Shetland Basin. This palynoflora is typical of a major sequence boundary present over the region and dated at 55 Ma (Figs 2 & 3), within Chron 24r (Cande & Kent 1992, 1995). This assemblage has also been recorded from the sedimentary sequence between the Lower and Middle series of the Faeroes lava pile by Lund (1988). These data constrain the transition from the basal olivine tholeiite flows of the Staffa Group to the overlying, volumetrically dominant, Plateau Group lavas on Mull. Although data are currently lacking for the base of the Mull Lava Field, palynofloras similar to those seen in the Ardtun Leaf Beds have been recorded by Simpson (1961) from the base of the lava pile on the south side of the Ardnamurchan Peninsula (Jolley 1997), indicating an approximately 4 million years cessation in volcanic activity between the termination of the Skye Main Lava Series on Skye and the eruption of the Staffa Group on Mull.

Discussion and conclusions

A rapid accumulation rate for the Skye Lava Field is evident from the bracketing ages presented above. From estimates of the rates of plant community development on fresh flows, Jolley (1997) argued that the total eruption interval may have been as short as 180 000 years. Taking as a more conservative estimate the longer period of time, and given that there were many hiatuses in the volcanic activity, as represented by lateritic tops to flows and interflow sedimentary horizons (Williamson & Bell 1994; Bell *et al.* 1996), these eruption rate data are approximately comparable, if not more extreme, to those deduced for other continental flood lava sequences such as the Deccan (Duncan & Pyle 1988) and the Parana (Renne *et al.* 1992). These age data also permit us to assemble and examine the 'magma stratigraphy' for the British Province, in terms of the volumetrically-dominant effusive material (e.g. Kerr 1995), with a chronstratigraphic precision not previously available (Mussett *et al.* 1988).

It is evident that the majority of the Skye Lava Field was erupted during the same period as the Lower Formation of the Antrim Lava Field; the transitional to mildly alkaline affinities of both sequences are comparable (Thompson *et al.* 1972, 1980; Lyle 1985; Wallace *et al.* 1994). The hiatus in volcanic activity recorded by the development of the Preshal Beg Conglomerate Formation on Skye and the Interbasaltic Formation in Antrim may well be contemporaneous, although the complex nature of the sedimentary stratigraphy of the latter suggests that more than one protracted period of weathering occurred.

The two olivine tholeiite flows of the PM type at the top of the preserved sequence on Skye (Williamson & Bell 1994), together with the Upper Formation of the Antrim Lava Field and the Staffa Group on Mull, fall within the age bracket

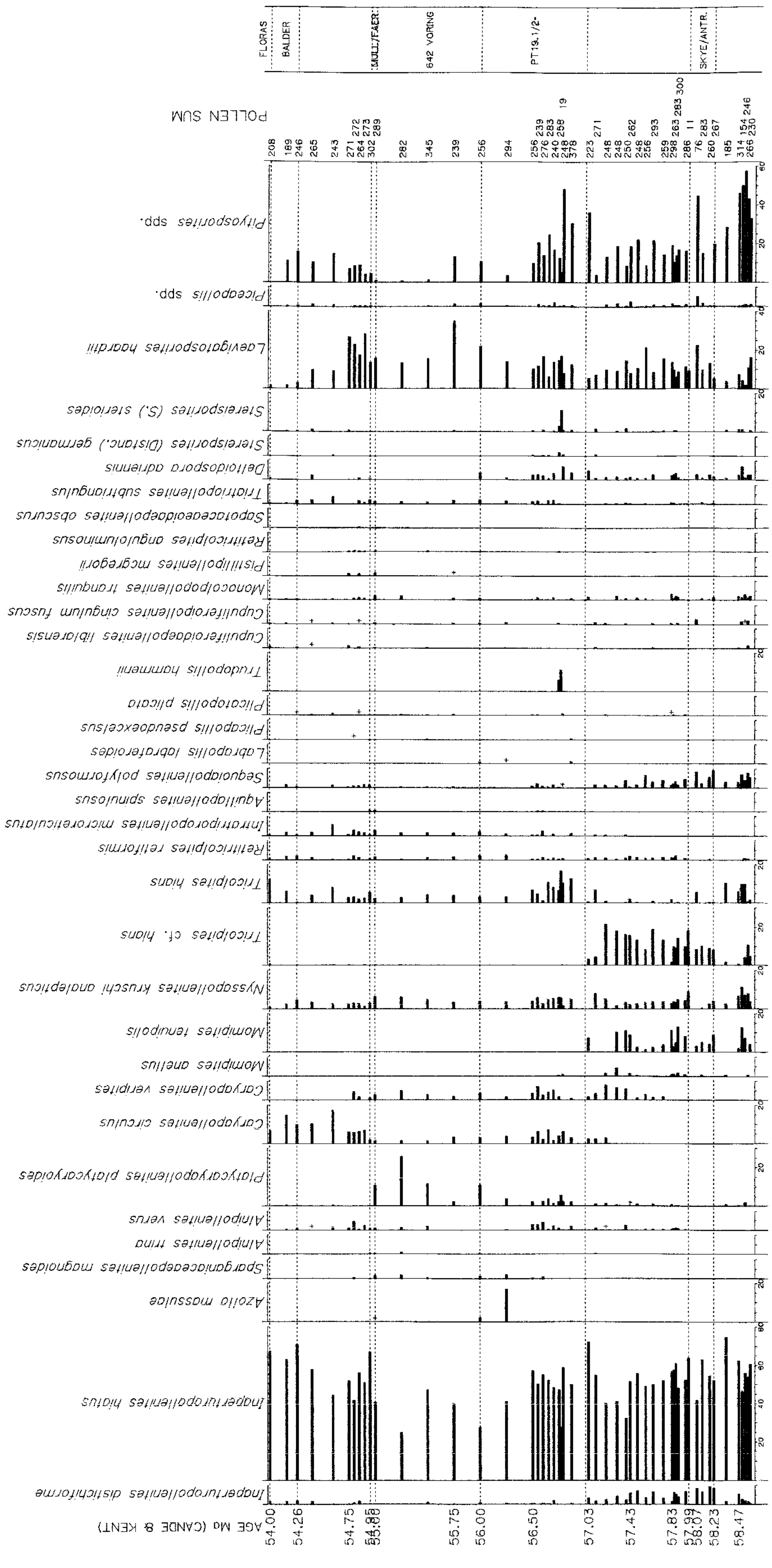

Fig. 3. Selective normalized frequency plot, composite West Shetland Basin section. The right-hand column indicates the stratigraphical relationships of the Skye, Antrim, Mull and Faeroes interlava sedimentary deposits. The age of the palynofloras in the interlava sedimentary deposits in ODP borehole 642 on the Voring Plateau and the Balder Formation are also indicated.

58–55 Ma, although the eruption period may have been considerably shorter (Jolley 1997). This time interval also covers the emplacement of the Cuillin Intrusive Complex on Skye, which is dominated by tholeiitic intrusions (e.g. Bell *et al.* 1994). Furthermore, work in progress suggests a direct link between the formation of the Cuillin Complex and the effusion of the two Preshal More flows of Skye onto a dissected lava field land surface (Walker 1993). Consequently, given that the intrusive complex developed over a relatively long time interval, then the Preshal More flows may have been erupted towards the younger end of the age bracket given above.

The lavas of the Plateau Group which overlie the Ardtun Leaf Beds on Mull, and which record a return to transitional to mildly alkaline magmas, were erupted at some time (shortly?) after 55 Ma. No upper age limit is available for this thick sequence of flows, and no sedimentary intercalations have yet been identified within it.

Volcanic activity certainly continued until *c.* 52 Ma, as deduced from the dacitic pitchstone flow of the Sgurr of Eigg Formation (52.1 ± 0.5 Ma, by Rb–Sr techniques; Dickin & Jones 1983), which was erupted onto a mature, dissected topography sculpted out of the older Eigg Lava Formation. Sedimentary intercalations within the Eigg Lava Formation have not yielded diagnostic palynomorph assemblages (Jolley 1997) and therefore the published radiometric age dates are the only reliable indication of the absolute age of the formation. Mussett *et al.* (1988) reported Ar–Ar dates for flows low down in the sequences which crop out on Eigg and Muck (63.3 ± 1.8 Ma and 63.0 ± 3.4 Ma, respectively), and which are considerably older than the flows of both the Skye and Mull lava fields. An excellent corroboration of this age is provided by Pearson *et al.* (1996), taking the form of two ages, 62.8 ± 0.6 Ma and 62.4 ± 0.6 Ma, determined for sanidines within tuffaceous deposits intercalated with flows close to the base of the lava pile on Muck (and forming part of the Eigg Lava Formation; Emeleus 1996). Consequently, the lavas of the Eigg Lava Formation appear to represent the oldest eruptive products of the British Province and developed within a relatively restricted area.

The lava fields of the British Province evolved within pre-Palaeocene basins, which controlled their distribution (White & McKenzie 1989; Thompson & Gibson 1991; England 1994). Eruption was from fissure feeders, now represented by NW–SE-trending dyke swarms. The central complexes represent sites along the fissure feeder systems where magma flux was anomalously high (Walker 1993; Bell *et al.* 1994). Based on the new age dates presented here, it is clear that there are no simple spatial–temporal–compositional relationships for the development of the main lava fields (Kerr 1995).

The magmatic activity associated with the British Province was located 700–900 km south of the contemporaneous plume head and in excess of 500 km landward of the location at which rifting finally occurred in the NE Atlantic (Kent 1995). White & McKenzie (1989) concluded that, based upon the time scales of Harland *et al.* (1982) and Berggren *et al.* (1985), the magmatism of the British Province predated the initiation of the main seafloor event by up to four million years. However, the revised time scale of Cande & Kent (1992, 1995) indicates that chrons within the critical period around Chron 24 are some two to three million years younger than previously proposed. Consequently, taking these revised dates and the new dates for the sedimentary horizons presented here, it is evident that the Preshal More type olivine tholeiite flows of the British Province lava fields, which have a MORB-type geochemical signature, were erupted at the same time as the initiation of the main seafloor spreading event further to the NW.

It is generally accepted that the transitional to mildly alkaline magmas which built the majority of the Skye Lava Field and the Plateau Group of Mull were derived by crustal contamination of melts produced by low degrees (<10%) of partial melting of a mantle spinel lherzolite which had already seen a prior depletion event (Thompson 1982). The Preshal More type lavas represent a second-stage extraction event from the same mantle, involving a greater degree of partial melting (>10%), but from a shallower depth (Kerr 1994). The new chronology established here indicates that the magmas which built these two lava fields represent more than one cycle of the melting process, implying that either the Plateau Group on Mull records a return to smaller degrees of melting of the same mantle volume, and at greater depth, or, more likely, from a 'new' volume of mantle material. However, substantial polybaric fractional crystallization (Thompson *et al.* 1980) and variable amounts of crustal assimilation/interaction (Bell *et al.* 1994) considerably mask the geochemical signatures of the original mantle-derived melts. The new age data imply that models which assumed the synchronous development of the lava fields of the British Province, for example Skye and Mull (Morrison *et al.* 1986), are not valid, although geochemically (i.e. internally) sound.

It is evident that the oldest of the subvolcanic complexes of the British Province is Rum, which was emplaced and unroofed prior to *c.* 58 Ma (Meighan *et al.* 1981; Williamson & Bell 1994). It may be of significance that a significant proportion of the magmas involved in the construction of the Rum Intrusive Complex were relatatively primitive, ranging in composition between magnesian basalt and picrite, implying anomalously high potential temperatures within the subjacent mantle (Kent 1995). Chalmers *et al.* (1995) and Kent (1995) explored various explanations for the presence of these (and other) high-temperature primitive magmas within the British Province, given the estimated location of the plume head during the Palaeogene (White & McKenzie 1989) and discussed the problems of inferring a considerably larger-diameter plume than is commonly advocated (Campbell & Griffiths 1990).

The thinspot model presented by Thompson & Gibson (1991), in which chronological and compositional complexities between the erupted magmas (lava fields) are attributed to previous heterogeneous thinning of continental lithosphere, together with the possibility of channellized lateral flow of plume magmas (Rubin & Mahoney 1993), may more accurately provide a framework to explain the complexities of the magma stratigraphy outlined above. In addition, access for the magmas to the Earth's surface via pre-existing deep structures may have played a significant role in the large gaps in time (up to 3 Ma) between eruption of the individual and non-interconnected lava fields. Such structures have been proposed as having been fundamental to the siting of the subvolcanic complexes of the Province (Richey 1937; Gass & Thorpe 1976).

Future studies, involving integrated palynological and precise $^{40}Ar–^{39}Ar$ dating procedures, should focus on the timing and duration of the tholeiitic magmatism of the Skye, Mull and Antrim lava fields. Studies comparing and contrasting the geochemistry of the transitional to mildly alkaline lavas of the Eigg Lava Formation (*c.* 62 Ma), the Skye Main Lava Series of the Skye Lava Field and the Lower Formation of the Antrim

Lava Field (*c.* 58 Ma), and the Plateau Group of the Mull Lava Field (post *c.* 55 Ma), should take into account these age differences, together with the possibility that they have been derived from different mantle materials during convection within the subjacent plume during the interval between 62 Ma and 55 Ma.

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