Faunas in a volcaniclastic debris flow from the Welsh Basin: A synthesis of palaeoecological and volcanological observations

By MARTIN G. LOCKLEY

Investigations of a diverse, Llanvirn-age faunal assemblage from peri-insular volcaniclastic sedimentary rocks in Central Wales, provide evidence of palaeocommunity mixing by submarine debris flows. The assemblage also contains rare elements, hitherto unknown in this area or at this stratigraphic horizon, which tend to blur distinctions between previously defined faunal provinces.

Together these observations suggest that insular faunas may not be as inherently diverse or endemic as previously supposed. The special sedimentological conditions associated with volcanic islands evidently play a significant role in the mixing and preserveation of faunas. Palaeontological and volcanological observations must therefore be combined in order to evaluate the factors contributing to the marginal rock and fossil accumulates of volcanic islands.

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Recent analyses of palaeocommunity and facies distributions in the Ordovician of Wales and North America (Lockley 1983, Sepkoski & Sheehan 1983) provide useful models for generalised shoreface to open shelf and ocean basin settings. However rocks of the Appalachian-Caledonide Orogen indicate the existence of volcanic islands in the Iapetus Ocean throughout the Ordovician. Such facies contain unusual faunal assemblages variously described as "curious" (Neuman 1976: 13) or "peculiar" (Horne 1976: 1, Bruton & Harper 1981a: 37, 1981b; in press). These faunas are often diverse with many new forms (Neuman 1976) and therefore are frequently regarded as endemic because they cannot be readily compared with those from standard platform successions. Since the general models of Lockley (1983) and Sepkoski & Sheehan (1983) do not embrace island settings, these unusual peri-insular faunas need to be explained in the context of the special environmental and sedimentological conditions which prevail around volcanic islands.

Investigations of a diverse, well-preserved faunal assemblage from peri-insular volcaniclastic sandstones of the Builth-Llandrindod inlier (Jones & Pugh 1949, Furnes 1978) provide evidence that submarine debris flows played a significant role in:

1) mixing and redistribution of well-documented faunas, including most elements of the *Hesperorthis* and *Dalmanella* palaeocommunity spectrum,
2) preservation of valuable "census" samples through rapid burial.

This latter phenomenon appears to have enhanced the quality of preservation. Rarer discoveries, including forms like the brachiopods *Porambonites, Parastrophinella, Mcewanella* and *Christiania* (Lockley & Williams 1981), *Kullervo, Rhynchorthis* and the trilobite *Atractopyge* (this paper) add significantly to our knowledge of faunal distributions. Moreover many of the above-listed forms, now known from the Anglo-Welsh province (*sensu* Williams 1969, 1973), have traditionally been ascribed Celto-Baltic affinities. This blurring of provincial differences by new finds suggest that current concepts of endemism may in some extent reflect an incomplete knowledge or record of the distribution of taxa. Perhaps the endemism is a little more apparent than real.

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The relationship between faunal assemblages and volcanogenic sediments in the Builth-Llandrindod area

Ordovician rocks of the Builth-Llandrindod inlier have long been the subject of attention and are generally considered to represent a classic example of a volcanic island complex (Murchison 1833, 1839; Geike 1897; Elles 1939; Jones & Pugh 1941, 1948, 1949; Hughes 1969, 1971, 1979; Williams 1969; Williams *et al.* 1972). However, recent studies (Lockley & Williams 1981, Williams *et al.* 1981, Sutheren & Furnes 1980, Furnes 1978 and pers. comm.) have shown that much is still unknown about the faunas and volcanogenic sediments in which they are entombed. Although palaeontology and volcanology are traditionally separate geological subdisciplines, integration of these areas of investigation considerably enhances our understanding of Welsh Basin palaeonenvironments (see Fig. 1 for location of sampled succession and volcanic rocks).

Faunas recovered from various stratigraphical units in the Howey Brook section (Murchison 1839, Elles 1939, Lockley & Williams 1981) include a diverse assemblage (Table 1 herein and Williams *et al.* 1981: Table 4) which Furnes (1978 and pers. comm.) interprets as occurring in a submarine debris flow deposit. According to Furnes the Howey Brook succession consists of a fining upwards sequence of massive and graded sandstones and black shales, respectively representing proximal, mid and distal fan deposits. The sandstones generally lack sedimentary structures but contain "rip up" clasts of black shale indicative of submarine erosion. Such deposits are essentially similar to those described by Carey & Sigurdsson (1980) and Sparks *et al.* (1980); see Figs 2 and 3 herein. Continued investigation of this locality and a consideration of palaeocommunity interrelationships (Lockley 1983) supports the debris flow interpretation and provides further valuable palaeontological evidence with a variety of implications.

The new evidence includes the discovery of a linguilid brachiopod and species of *Petro-*

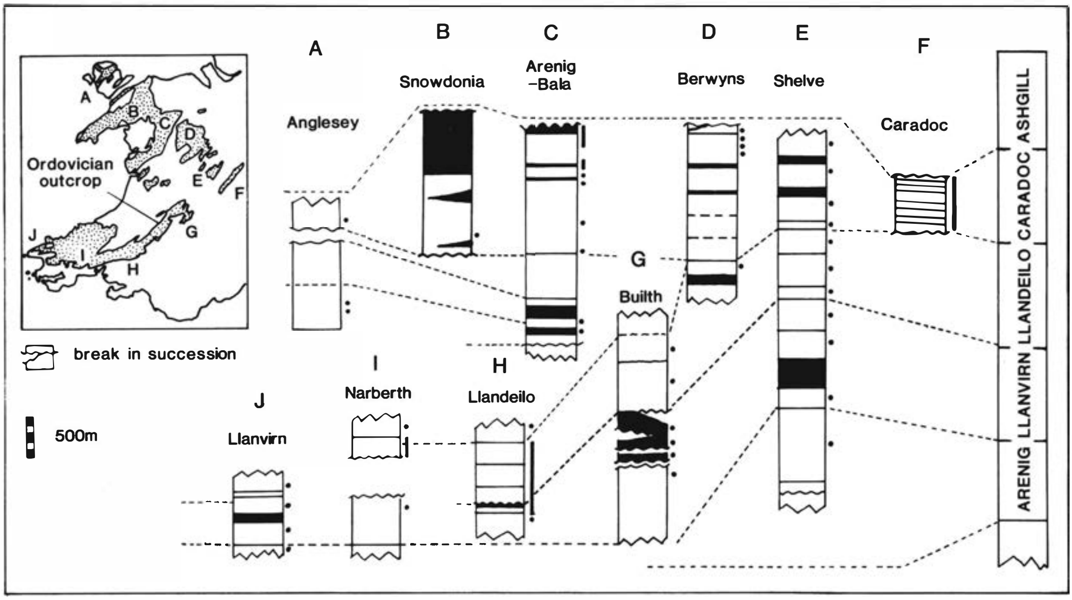

Fig. 1. Type and classic Ordovician (Arenig-Caradoc) sections in Wales and the Welsh borderland (modified after Lockley 1983, Text-Fig. 1) showing the widespread distribution of volcanic rocks and volcanogenic sediments (in black). Vertical bars indicate continuously sampled sections, dots indicate other known faunas.

crania, Rhynchorthis, Kullervo and *? Tritoechia* as well as the trilobite *Atractopyge* and some hitherto unidentified molluscan and bryozoan remains which differ from these previously listed by Williams *et al.* (1981 Table 4). The diversity of this enlarged collection (see Table 1) is now known to be at least 40 species, a value which exceeds those of all other known Welsh Basin assemblages and diverse shelf faunas of Caradoc age (Hurst 1979).

A convincing explanation of this high diversity assemblage can be derived from a knowledge of palaeocommunity and volcanogenic sediment distribution as shown in Fig. 3. Modern studies of late Quaternary volcanogenic debris flows, "the submarine counterparts ... of subaerial pyroclastic flow deposits" in the Lesser Antilles Arc (Sparks *et al.* 1980; Sigurdsson *et al.* 1980) have convincingly shown that flows will travel for "over 13 km offshore". Such movement perpendicular to shoreline (or arc axis) will cut across any shore-parallell zones thereby mixing faunas whose distribution is controlled by depth or contour-parallel facies belts.

The Howey Brook faunal assemblage contains an anomalous mixture of elements from the "shoreface" *Hesperorthis* palaeocommunity and the "open shelf" mixed *Dalmanella* palaeocommunity as well as a few nektic and planktic elements like cephalopods and graptolites (Fig. 3). The sediments themselves also contain rip-up clasts of fine grained dark mudstone similar to that in which inarticulate-dominated, offshore faunas typically occur (cf. Lockley 1983).

Constitutents of each fauna are readily identified and can be separated out (Fig. 3) to show that the assemblage represents a relatively comprehensive census of at least two palaeocommunities. *Hesperorthis* palaeocommunity constituents identified by Williams *et al.* (1981) and Lockley (1983) as Bryozoan, *Hesperorthis* and *Salopia* associations (A_{1-3} respectively of Fig.

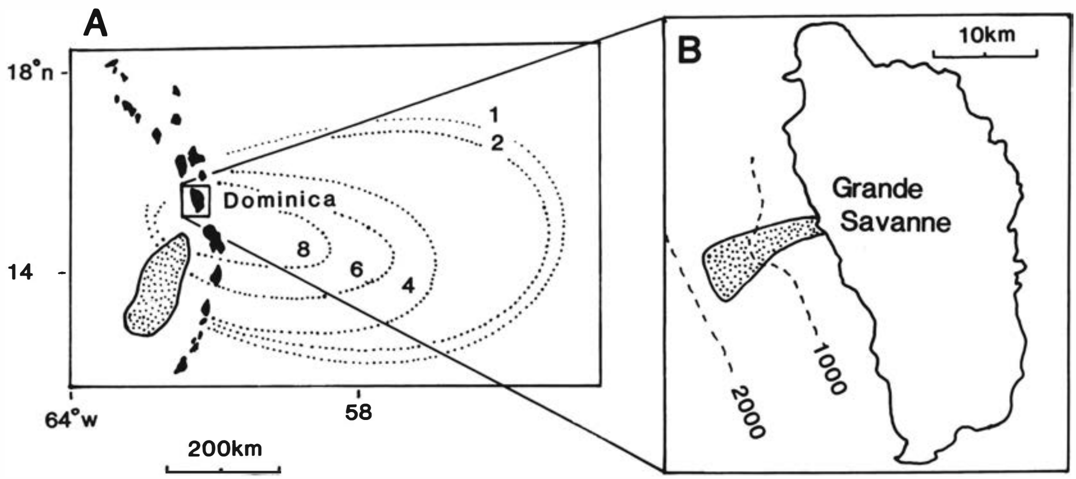

Fig. 2. Distributions of some volcanogenic sediments in the Lesser Antilles Arc lincluding. A. subaqueous pyroclastic debris flows (stippled) and an airfall tephra layer (with isopachs in cm), modified after Carey & Sigurdsson (1980, Fig. 5); B. detail of bathymetry and a submarine debris flow associated with the late Quaternary Grande Savanne pyroclastic apron on the Western flanks of Dominica, modified after Sparks et al. *(1980 Fig. 4).*

3) are all recorded in the Howey Brook assemblage and collectively comprise an estimated 43% of the fauna. The remainder of the fauna is comprised largely of elements like *Glyptorthis, Dalmanella* and *Macrocoelia* which are typical of the mixed *Dalmanella* palaeocommunity (Lockley 1983). The absence of offshore palaeocommunity elements such as *Schizocrania* may be attributed to two factors. Firstly they show relatively low abundance and diversity, and secondly they appear to be comprised largely of nektic and planktic elements (cf. Lockley & Antia 1980) which would not be severely affected by down-slope debris flow. The rarity of elements from this palaeocommunity is therefore predictable.

Although transported faunas are often regarded as inappropriate for palaeoecological analysis, it appears that the high diversity of the Howey Brook assemblage, and the excellent preservation of juveniles and delicate forms, may reflect the potential of such debris flows for preserving valuable census samples (cf. Cisne 1973). Although the higher diversity estimates obtained from such assemblages are only partly attributable to mixing, which does not necessarily explain the preservation of rare forms, unknown elsewhere, there is a close correspon-

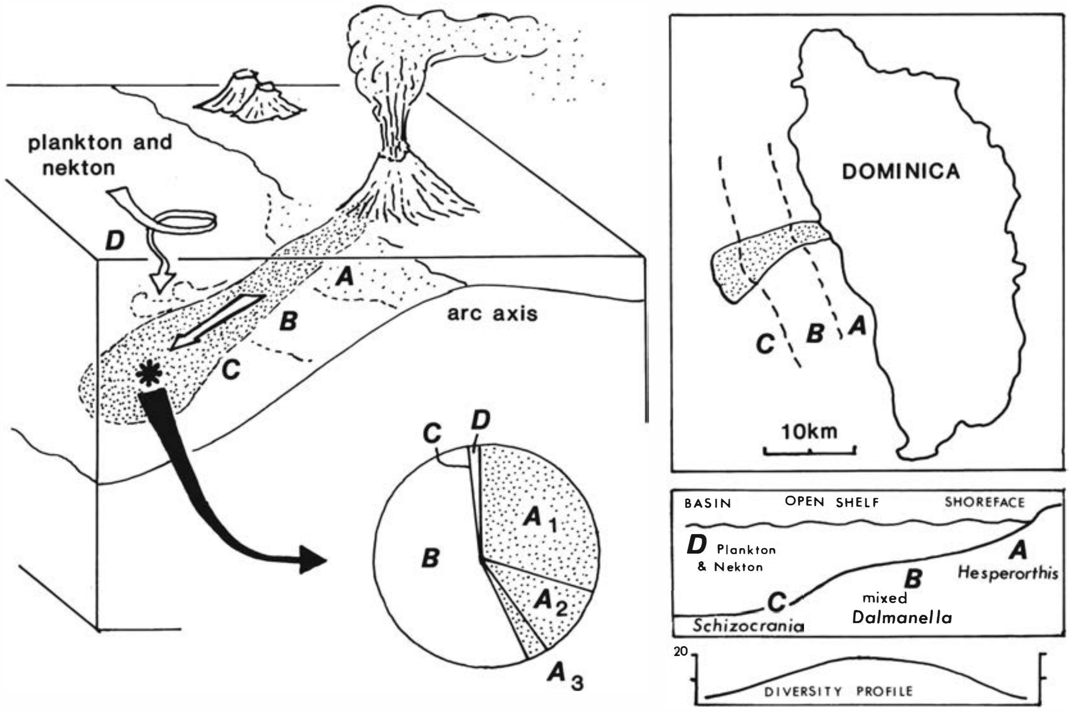

Fig. 3. Inferred discordance between distribution of debris flows (dense stipple) and facies belts controlling the distribution of palaeocommunities A–C; based on Dominica Model (Sparks et al. *1980) and type Ordovician palaeocommunity Model (Lockley 1983). Block diagram shows inferred location of mixed assemblage (⋆) in offshore location associated with dark mudstone facies (C). Pie diagram indicates proportions of shoreface fauna assignable to associations within the nearshore* Hesperorthis *palaeocommunity (A_{1-3}), the more distal mixed* Dalmanella *palaeocommunity (B) and nektonic and planktonic palaeocommunities (D); see text for details.*

dence between the total diversity of the Builth sample and the sum of diversities for component palaeocommunities.

Other interpretations

In addition to the taphonomic interpretations given above, reassessment of the Howey Brook fauna permits other conclusions pertaining to faunal province concepts. In particular it is noteworthy that the recently discovered brachiopod genera *Petrocrania, Rhynchorthis* and *? Tritoechia* all occur in Arenig rocks of Anglesey, which also apparently represent peri-insular settings (Neuman & Bates 1978). Consequently the coefficient of association (0.13) between Anglesey and Builth is significantly greater than tha 0.03 value previously estimated from available brachiopod data (Lockley 1983). *Kullervo* and *Christiania* which also occur at Builth are traditionally regarded as Baltic or Celtic province elements rather than of Anglo-Welsh affinity (Williams 1969, 1973).

It is therefore becoming apparent that faunas from volcanic island settings are not necessarily as endemic as hitherto supposed (Williams 1969, 1973; Neuman & Bates 1978). The extent to which some of the recent discoveries in Wales have tended to blur the concept of provincial boundaries can be ascertained from the following list which indicates some of the genera (with age in brackets) recently recorded from Wales, their traditional provincial affinities (Scoto-American, Celto-Baltic or Anglo-Welsh *sensu* Williams 1969, 1973) and the source of information (in brackets):

Protozyga and *Bimuria,* (Caradoc), Scoto-American, (Lockley 1980).
Mesotaphraspis, (Llanvirn), Scoto-American, (Williams *et al.* 1981, Owen & Bruton 1980).
Christiania, (Llanvirn), Baltic, (Lockley & Williams 1981).
Kullervo and Rhynchorthis, (Llanvirn), Celto-Baltic, (This paper).

There is no reason to expect all provincial boundaries to be clearly defined; thus as more data has accumulated, more examples of interprovincial exchange have been recognised. Although he defined provinces on the basis of their distinct faunal composition, Williams (1969, 1973) cited several examples of pandemic genera as well as others which could not be considered strictly endemic. Neuman (1972, 1976) and Neuman & Bates (1978) have already commented on the similarities between American and Celtic faunas, while a view from the Welsh side of the Proto-Atlantic highlights Celtic–Welsh affinities. Current investigation of Arenig rocks in Wales suggest that American-Welsh affinities may also prove to be much greater than hitherto supposed (M. G. Bassett, pers. comm.).

Conclusions

Type and classic Ordovician successions of the Welsh Basin must be viewed in the context of their probable palaeogeographic setting which is generally interpreted as a back arc basin (or marginal sea) dominated by island arc volcanism (Woods 1974, Windley 1977). In such distinctive geological settings local sedimentation patterns are strongly influenced by specific factors including volcanism itself, slope and prevailing wind. It is therefore desirable to view faunas entombed in volcaniclastic sediments from an appropriate depositional environment perspective rather than attempt to reconcile them with shoreface-open shelf models which are appropriate elsewhere (Hurst 1979, Lockley 1983). Furthermore, palaeoecological and volcanological investigateion should not necessarily be treated as mutually exclusive topics; data can be combined into a coherent model (as in Fig. 3) in order to provide a plausible explanation of coeval phenomena. When this was done for the Howey Brook fauna, hitherto unrelated volcanological and palaeoecological investigations appeared to corrobate each other, and demonstrate that peri-insular volcanic islands may have their own special faunal distribution patterns.

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Table 1. The composition of a diverse faunal assemblage from Upper Llanvirn volcaniclastic debris flow deposits exposed near Howey Brook (SO 092591), Mid Wales. Brachiopod, mollusc and trilobite diversities are estimated at 15, 10 and 5 respectively. (In other taxonomic categories, where it is hard to estimate number of individuals, figures are given in brackets, or simply as N.)

Taxon	Estimated number of individuals
BRACHIOPODA	
Lingulida indet.	1
Petrocrania sp.	1
Hesperorthis dynevorensis Williams	62
Glyptorthis cf. *viriosa* Williams	25
Mcewanella berwynensis MacGregor	9
Rhynchorthis sp.	1
Dalmanella parva Williams	95
Tissintia prototypa (Williams)	2
Salopia turgida (M'Coy)	15
? Tritoechia sp.	1
Kullervo sp.	2
Macrocoelia llandeiloensis elongata Lockley & Williams	98
Christiania elusa Lockley & Williams	25
Porambonites sp.	2
Parastrophinella parva MacGregor	1
Total Brachiopoda	340
MOLLUSCA	
Lyrodesma sp.	11
Similodonta sp.	3
Pterneid indet.	1
Modiomorphid indet.	1
Matherella acuticostata Bates	1
Helical gastropod indet.	2
Sinuites sp.	1
Ornamented bellerophontid	1
Orthoceras vagens Salter	2
Cyrtoceras macrum Blake	1
Total Mollusca	24

Taxon of individuals	Estimated numbers
TRILOBITA	
Bettonia chamberlaini (Elles)	2
Atractopyge sp.	1
Calymenid indet.	1
Odontopleurid indet.	1
Total Trilobita	7
OTHER TAXA	
Fenestrate bryozoan	(6)
Ramose bryozoan (Morphotype 1)	(157)
Ramose bryozoan (Morphotype 2)	(3)
Boring organism	(1)
? Conularida indet.	(2)
Hyalostelia fasicula (M'Coy)	(N = 1)
Crinoidea	(N = 1)
? Cystoidea	(N = 1)
Spicules (? Porifera)	(4)
Didymograptus sp.	6
Estimated total number of individuals	553
Estimated minimum diversity	40

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