Excursion 9 **BALMAHA**

B.J.Bluck

Themes: The principal reasons for visiting the Balmaha area are:

1. To examine the evidence for the presence of a terrane boundary within this general area.
2. To examine the evidence for the types of movements which have occurred along the Highland Boundary Fault and associated fractures, bearing in mind that movements along terrane boundaries are complex and diverse.

   There need not be a single phase of movement but a sequence of separate movements each of which may be different in nature and sense.
3. To examine the Highland Border Complex which here has great diversity in lithologies.
4. To examine both the Lower and Upper Old Red Sandstone rocks with a view to determining the nature of their accumulation and their provenance.

Features: Conglomerates, alluvial fans, cross-stratification, unconformity, overlap, inverted cross-strata, cherts, serpentinite conglomerate, faults.

Maps:

O.S	1: 50 000	Sheet 56	Loch Lomond & Inveraray.
O.S.	1: 25 000	Sheet NS 49/59	Buchlyvie & Balmaha.
B.G.S.	1: 63 360	Sheet 38	Loch Lomond.
B.G.S.	1: 50 000	Sheet 38W	Ben Lomond.

Terrain: Lochside with muddy paths for first part of excursion; hillside for the later part.

Distance and Time; 4 km: walking time 5 hours.

Access: A809 to Drymen and the B837 from Drymen to Balmaha, On the A809 at Queen's View (NS 511 807) there is a splendid panoramic view of the Balmaha region in the context of the Highland Boundary Fault and the Old Red Sandstone of the Strathmore syncline.

The low, fertile ground in the immediate foreground belongs to the Old Red Sandstone; the high ground in the distance is mainly the metamorphic basement of the Dalradian block. The northern limb of the Strathmore

Syncline forms the rugged ground, with prominent ridges, between these two regions; and between this limb of the syncline and the Dalradian block lies the Highland Boundary Fault. At Balmaha it is possible to see a section through the north limb of the Strathmore Syncline to the Dalradian rocks. At the time of writing there is a service bus from Glasgow to Balmaha: further particulars should be sought from the Bus Station, Buchanan Street. The Island of Inchcailloch is well worth a visit for its geological and other natural history features. It is an SSSI (no permission needed at time of writing - except for parties), and a booklet is available from the Nature Conservancy Council for Scotland, Balloch Castle Country Park: transportation can be arranged through MacFarlane, The Boat Yard, Balmaha (Tel Balmaha (036087) 214).

Introduction

The Balmaha area has long been of considerable interest as being one of the most accessible places for viewing the Highland Boundary Fault - a fracture which has commanded a great deal of attention over the years. But over the past decade this fracture and its associated rocks have received renewed geological attention with the discovery that large-scale movements associated with terrane boundaries were to be found in the Caledonides (see Terrane Accretion in Western Scotland), and that they may be concentrated partly on the Highland Boundary Fault.

In this region it is possible to demonstrate the ways in which terrane boundaries may be analysed and the ways in which we are able to recognise terranes as being far travelled blocks, each of which has a history distinguishable from those now lying adjacent to it. Before discussing the localities to be visited at Balmaha, an introduction to the general problems of terrane analysis as demonstrated by these outcrops is now undertaken.

Terranes often travel such great distances that it is not possible to indentify the rocks on one side of a fault and look for their displaced equivalents on the other: i.e. the distances travelled by terranes often exceed the lateral extent of rock units. The other problem is that terranes often move along the strike of the beds, so that correlation across the faults is often not possible.

The problem posed in terrane identification at Balmaha is one of recognising differences in geological history between a basement and a sedimentary basin: the basement is the Dalradian and the sedimentary basin is the Highland Border Complex.

The Dalradian block comprises a thick sequence of sandstones,

Fig. 9.1

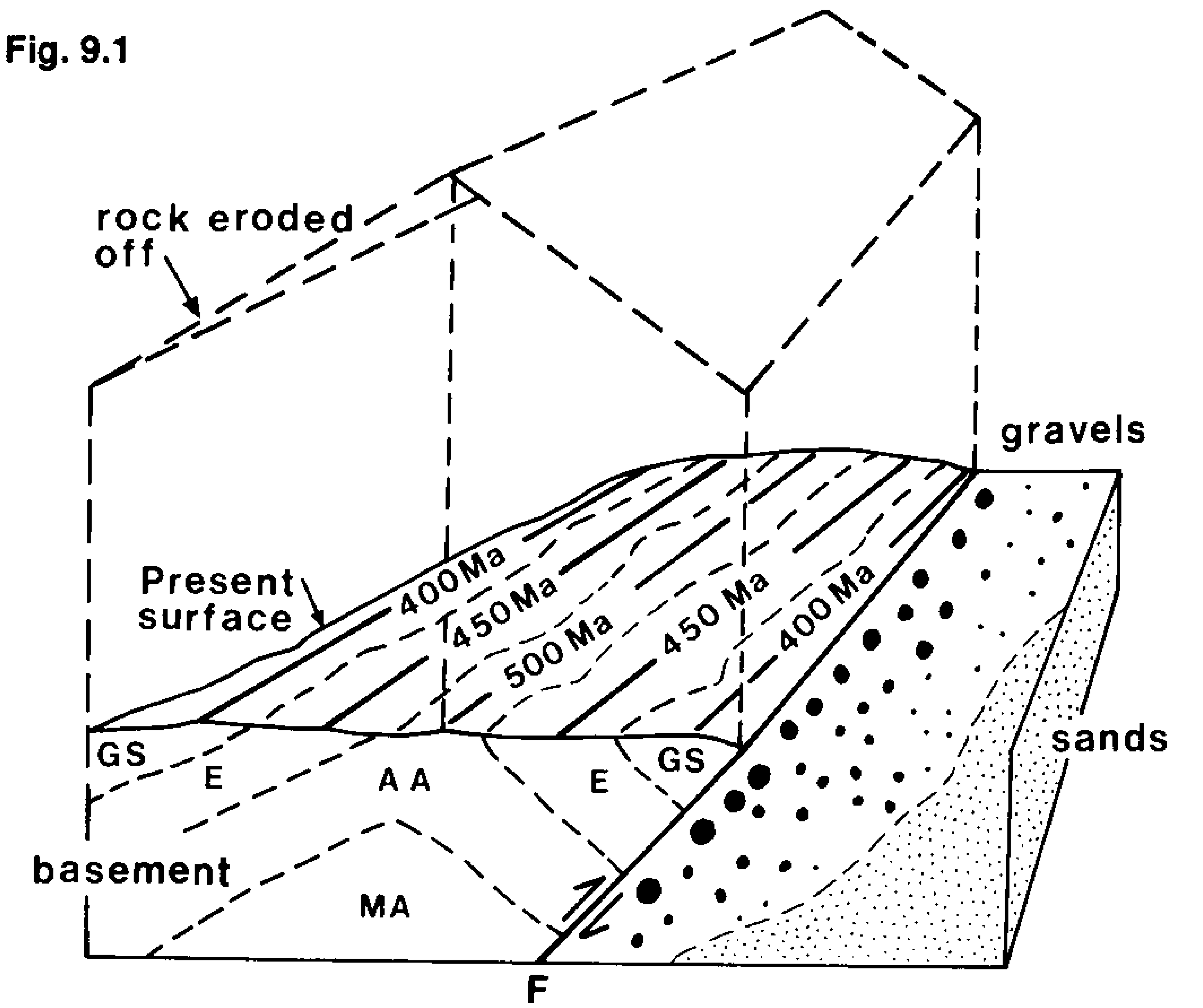

Figure 9.1 Showing the relationship between the uplift of a basement and the accumulation of the sediments, sand and gravels, which have been eroded off it. The basement in this example has been thrust over the sediment pile which has accumulated in a basin which is to the right in the diagram. Gravels accumulate near to the source and sands further away. The volume of material removed from the basement is represented by the envelope in dotted lines; the present land surface exposes the metamorphic zones, with the lowest (GS=green-schist) going via E=epidote-amphibolite facies; AA=lower amphibolite facies, to MA=middle amphibolite facies (the highest). The times at which the rocks cooled are given in Ma= millions of years, and the thick lines join all points which cooled at the age given. In the example illustrated the centre of the basement pile was uplifted first (it has the oldest ages of 500Ma) and from this region there was the greatest removal of overlying rock.

limestones, lavas and shales laid down in the Late Proterozoic. After a period of folding which occurred before 590 Ma there followed a prolonged interval when the sequence was thickened and became hot and suffered fairly intensive metamorphism. At the present erosion level there is a changing mineralogy of these Dalradian metamorphic rocks as they are traced through the Highlands: generally low metamorphic grades occur in the south; and higher grades to the north. These changing grades are a response to the changing heat and pressure which occurred during their burial, so that in a very general way the rocks in the north were more deeply buried than those to the south. In the same general sense these metamorphic grades or zones lie roughly parallel with the Highland Boundary Fault. Superimposed on this general trend, there are some anomalies, the largest of which is that the rocks in the SW of the Dalradian belt underwent a cooler but higher pressure type metamorphism than the rocks to the NE.

After burial and metamorphism the whole sequence was subject to considerable uplift. Estimates of the burial-depths of rocks now at the surface range from 15 km in the south, along the Highland Boundary Fault to > 30 km in the central regions, so that these thicknesses of rock had to be removed to expose those rocks we can at present study at the surface.

When were these overlying rocks removed? A clue to this comes from the radiometric dating of some of the metamorphic minerals. As the rocks are uplifted they cool, and certain of the minerals they contain record in their isotopic systems the time of cooling. By taking sections through the Dalradian basement one is then able to 'map-out' the cooling behaviour of the surface i.e. which metamorphic zone cooled first, second etc.

In the fictitious example given in Figure 9.1 there is a section through a metamorphic belt showing the grades ranging from low (GS, green-schist) to high (MA, middle amphibolite). The solid lines are the contours for the uplift; i.e all the rocks which fall on these lines were uplifted through the same temperature at that specified time (e.g, uplifted through 500 C at 400 Ma, 500 Ma etc). On the diagram the highest grade rocks with the greatest thickness of rock overlying them were uplifted first at 500 Ma; and the lowest grade much later, at 400 Ma. The envelope above that surface represents the relative amount of rock which has to be removed. And, if at the same time we take account of the fact that the high grade rocks were uplifted first, then the surface, in a very general way, approximates to the attitude of the land surface during uplift.

When basement blocks rise in this manner, they often yield a great deal of sedimentary detritus. The whole rock volume illustrated in the envelope in Figure 9.1 is removed in this way or, in some cases by tectonic sliding i.e. detachments which resemble huge lithospheric landslides. The detritus yielded by erosion normally accumulates around the flanks of the mountain chain as piles of coarse alluvium, which gets finer-grained away from the source as illustrated in Figure 9.1. This situation characterizes many of the great mountain chains we now see such as the Himalayas, the Andes and the Alps.

If we find a sequence of rock which formed at the same time as an adjacent basement was known to have been rising and yielding sediment we would expect the sedimentary sequence to be dominated by coarse clastic debris. We know therefore that a paradox exists when this relationship fails (Fig. 9.2) and deep-water shales with volcanic rocks typical of extensional tectonics lie next to the basement.

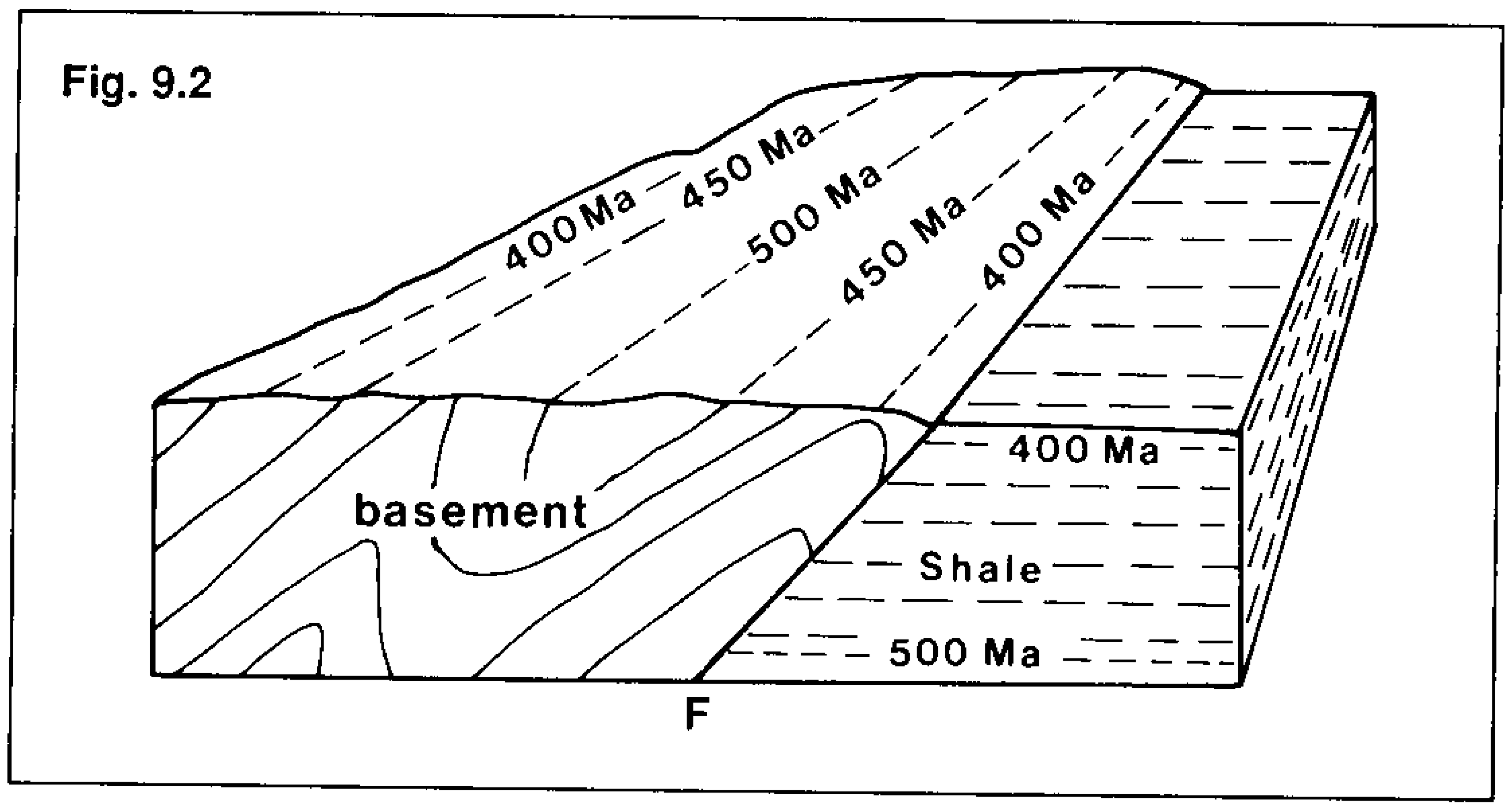

Figure. 9.2. Illustrates a similar structural situation in which the basement (as in Fig. 9.1) was uplifted at the same time as sediments were accumulating in a basin which is now juxtaposed against it. The sediment in the basin is shale which is not the sediment expected from the erosion of an adjacent mountain (compare Fig. 9.1). This situation implies that these two blocks (shale basin and basement) had a history which is not compatible with their having been formed adjacent to each other.

In this situation we would suspect that the basement and basin did not lie adjacent to each other during the periods of their individual activity, but that both or one of them to be a terrane which has moved into its present position from some distance.

The Dalradian block was uplifted in Ordovician times from 515Ma-430Ma and a huge volume of sediment was lost from it. Rocks of the Highland Border Complex, which were laid down at roughly this time, comprise fine grained sediments such as cherts and shales which accumulated in deep waters at some distance from a land source; sediments found in positions of stability and low rates of sedimentation, such as limestones and quartz-arenites, and volcanic rocks which typify regions of extension. These rock types are all totally unlike those accumulating in front of a rising mountainous source block such as the Dalradian would have been in Ordovician times. They are presently juxtaposed at Balmaha and leave us with two problems: firstly, we have to dispose of the sediment pile which the Dalradian uplift created, and secondly, we have to put in its place a basin with a totally different history. The Highland Border Complex is clearly a terrane with respect to the Dalradian block.

Once a terrane boundary has been established one must then attempt to recognise the history of terrane assembling, i.e how and when did the blocks we now see lying adjacent to each other get into that position. There is good reason to believe that a substantial portion of the assembly record was poorly recorded, has been lost or is covered over by rocks emplaced by younger events. However there is also good reason to suspect that part of the later history of amalgamation is recorded in the sediments of the Old Red Sandstone and it is to these rocks we now turn to pick up the rest of the story.

The Lower Old Red Sandstone rocks comprise a steeply dipping assemblage of conglomerates and sandstones which rest unconformably on the Highland Border Complex. The unconformity can best be seen on the Island of Inchcailloch, but can also be seen on the mainland. The Highland Border rocks beneath the unconformity have yielded very few clasts to the overlying Old Red Sandstone, so it is fairly clear that the Highland Border Complex formed the floor to the basin rather than its source.

When the whole Lower Old Red Sandstone assemblage is traced out laterally from near Aberfoyle in the NE to Inchmurrin in Loch Lomond in the SW it is seen as a sequence of overlapping lenses of

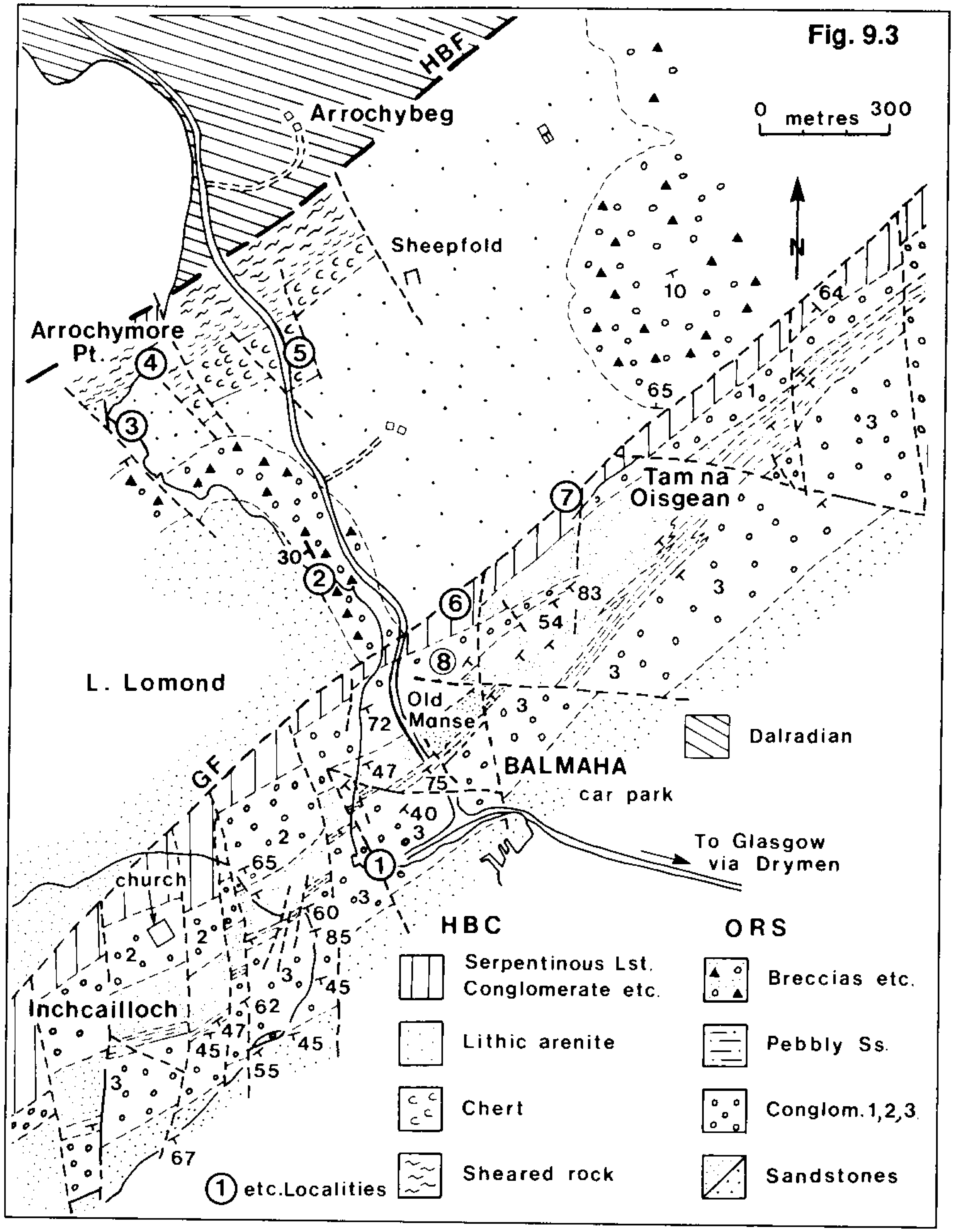

Figure. 9.3. Geological map of part of the Balmaha region with Localities. HBC = Highland Border Complex; ORS = Old Red Sandstone; GF = Gualann Fault; HBF = Highland Boundary Fault. Serpentinous Lst, Conglomerate etc. refers to rocks which include detrital as well as tectonic fragments of serpentinite. The conglomerates are marked 1,2,3 in the local order; they bear no relationship to the regional order.

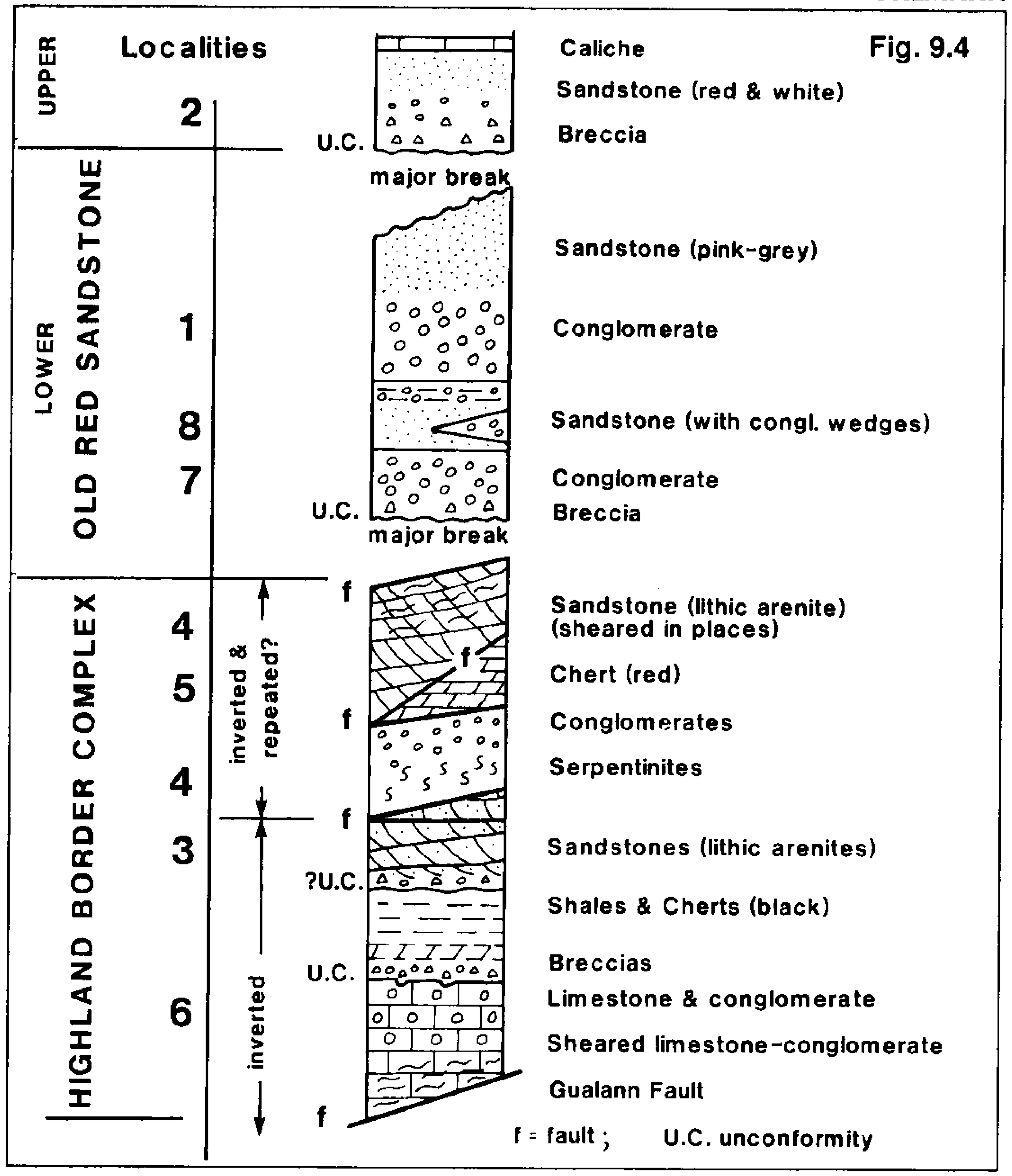

Figure. 9.4. A compound section of the post Dalradian rocks at Balmaha, together with the localities where they are to be seen. In this section the Highland Border Complex is seen to be repeated: there is a southern sequence (mainly overlain by Upper Old Red Sandstone) and a northern sequence which is seen at Arrochymore Point.

conglomerate with interspersed sandstone (Fig.9.3). The conglomerates overlap each other in a southwesterly direction, so that it appears that we are dealing with a basin which is progressively being filled in that same direction (Fig.9.6). One explanation for this, bearing in mind also the coarseness of these deposits, is that they accreted in an extensional basin generated within a strike-slip fault belt.

There are three distinctive stratigraphical units exposed south of the Dalradian block at Balmaha: The Highland Border Complex; the Lower Old Red Sandstone and the Upper Old Red Sandstone (Fig. 9.4). Each records a distinctive phase in the history of terrane accretion.

Locality 1. Balmaha Pier (NS 4155 9008) (Fig.9.3) **: Lower Old Red Sandstone.** Lower Old Red Sandstone conglomerates occur in the low ground to the immediate south of the pier and in the cliffs to the NW. The bay at Balmaha probably lies at the junction between the coarse conglomerates and the finer sandstones and siltstones which form most of the low ground around the southern end of Loch Lomond. The conglomerates contain fairly large clasts (up to 400 mm) mainly of quartzite, volcanic rocks mostly of intermediate type, together with a few orthoclase and biotite bearing granites. This conglomerate, no.3 in the local sequence (Fig.9.3), forms the uppermost conglomerate at Balmaha. It outcrops on the Island of Inchcailloch to the SW, and is responsible for the prominent hills, including Conic Hill, to the NE. When traced across the loch, it is seen to rest finally on the Highland Border Complex, thus overlapping about 200m of section. The significance of this relationship will be discussed later at Locality 7.

The conglomerates have a dispersal from the SE and NE, and taken as a whole, contain very well rounded clasts of tough quartzite and sometimes slightly less well rounded softer volcanic rocks. Some of the quartzite clasts have been broken and then re-rounded, indicating a provenance in a pre-existing, compositionally mature conglomerate comprising metamorphic clasts. The volcanic clasts may be first cycle. On the basis of the palaeocurrents in the conglomerates, this source block is thought to have existed within the Midland Valley and probably in the region which is now the Dalradian of the Southern Highlands.

At this stage it is not at all clear whether the Dalradian block along with the Highland Border Complex provided the floor to this Old Red Sandstone basin, or whether the entire Old Red Sandstone basin has been floored by the Highland Border Complex and the Dalradian block has been subsequently emplaced. From evidence in Western Ireland (Bluck and Leake 1986) it is clear that in a general sense the

Dalradian and Highland Border Complex lay near to each other by Silurian times.

The conglomerates are thought to have been deposited in bars built by braided streams. Generally speaking the thickness of the bar structures in these conglomerates increases with coarser grain size. From the study of the conglomerate **lithosome** shape and the distribution of clast sizes within it, it is concluded that these conglomerates formed in alluvial fans.

Follow the path north along the shore of the loch, passing a thick sandstone unit which underlies the conglomerate at the Pier, and head for the northern margin of the sandy bay.

Locality 2. Upper Old Red Sandstone. The conglomerates and breccias exposed beneath these low-lying cliffs are assigned to the Upper Old Red Sandstone, partly on the basis of their upward transition into quartz-arenites and caliches, which normally characterize the top of the Upper Old Red Sandstone where it grades into known Carboniferous. The Upper Old Red Sandstone rocks are also typically a brighter red colour than the Lower, and in this region rest unconformably on the Highland Boundary Rocks (as can be seen south of Locality 3, Fig.9.3) and possibly on the Dalradian.

Clasts of 'grits', slates and other rocks of greenschist metamorphic facies and vein quartz comprise most of the rock-types in these breccias. This clast assemblage strongly resembles rocks now seen in the local Dalradian block to the immediate north and serve to remind us of the appearance of a typical conglomerate of Dalradian **provenance**. They are in sharp contrast to the conglomerates of the Lower Old Red Sandstone to the south. Sedimentary structures abound in these conglomerates, and fine examples of sand-shadows behind proud clasts, imbrication and cross stratification in various scales are found. All these features indicate dispersal from the north, NW and NE, the direction in which the Dalradian is now seen to lie; the deposition was probably by braided streams.

From this outcrop it is clear that wherever the Dalradian block was with respect to the basin in which the Lower Old Red Sandstone accumulated, it was certainly close to the Highland Border Complex and the Midland Valley at the time these sediments were laid down. It therefore seems probable that the Highland Border Complex, the Midland Valley and the Dalradian had docked (united) by this time.

Follow the path (West Highland Way) northwards to Arrochymore

Point.

Locality 3. Highland Border Sandstones are exposed near the tip of Arrochymore Point (Fig.9.5), and are well exposed in a low, vegetation-covered cliff section on the right of the path as it turns to the NE. These beds have been referred to as the Loch Lomond Clastics (Henderson and Robertson 1982), and are probably equivalent to the Aberfoyle Arenites of Bluck *et al.* (1984). They are red-pink sandstones with many lithic fragments of **ophiolitic,** acidic volcanic rocks and detrital mica. The coarser members of this division contain rhyolitic clasts which are quite angular and are probably first cycle. The sequence shows abundant cross-stratification, which in the vicinity of this Point are all inverted but it has yet to be demonstrated whether this is a regional or local inversion associated with isoclinal folding.

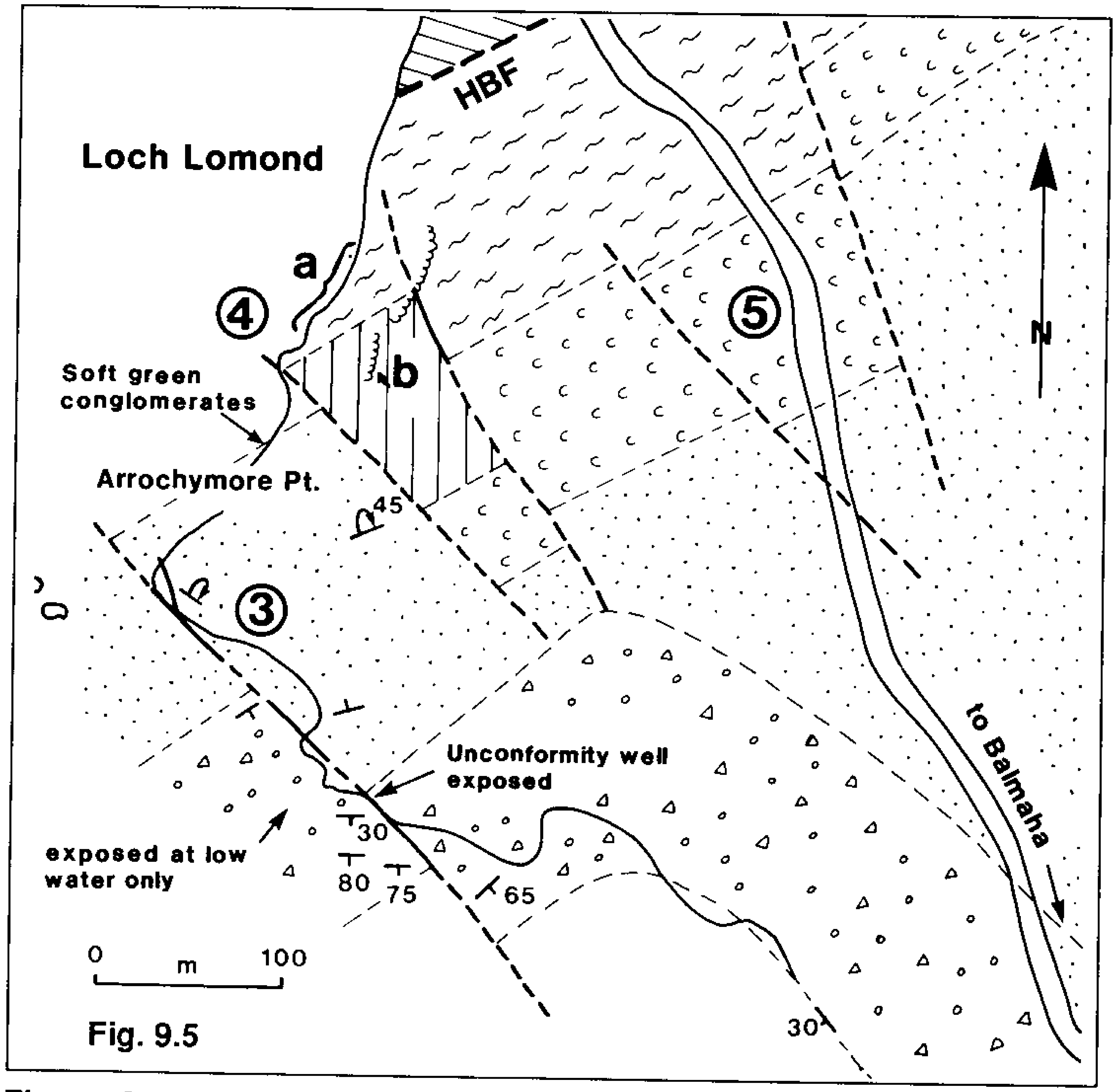

Figure. 9.5. Detail of the geology of Arrochymore Point, with localities.

These sandstones are probably of Caradocian age, for although no faunas have been obtained here, **chitinozoa** from what are probably equivalent rocks near Aberfoyle are of that age.

Locality 4 Serpentinite and sheared rock. There are two main exposures to visit here (Fig.9.5): the highly sheared rocks at the lochside (**4a**) and the serpentinite, which is comparatively unaltered, (**4b**). The sandstones of Locality 3, when traced NE along the shore, show a surprising degree of contortion, and are in places almost broken down to mylonites (**a** on Fig.9.5). Within these sheared rocks are pods of relatively undeformed red breccias of uncertain age, and in places just below the beach-gravels of the loch are soft green conglomerates with abundant ophiolitic clasts (see Fig.9.5). The outcrops have abundant shears which have a range of dips, striking in a NE-SW direction, parallel with the Highland Boundary Fault. Rocks of this type are in contact with the Dalradian farther to the NE, but along the shore the nearest exposures of Dalradian are north of the bay.

The small outcrop of serpentinite 4b (Fig.9.5) forms part of a somewhat larger mass which is terminated on either side by faults. Neither its age nor its associations are known but it differs from the southern serpentinite in being unaltered. The soft green conglomerate exposed on the lochside may be the equivalent of the southern serpentinite which, as discussed at Locality 6, is mainly or even totally a conglomerate with serpentinite and other clasts.

Follow the path NE for *c.* 200 m along the lochside to a car park, and then head south along the road (B837) back towards Balmaha. Locality 5 is an overgrown road cut on the western side of this road.

Locality 5. Red cherts belonging to the Highland Border Complex are exposed on the roadside and in the wooded area to the NE. Although quite massive here, elsewhere the cherts are interstratified with red shales. They have not yielded any fossils to date, and differ from other cherts in the Highland Border Complex which are grey-black, well stratified and associated with black shales. The age of these red cherts is unknown, but from evidence elsewhere in the Complex cherts are widespread during the Llanvirn and early Caradoc.

Walk along the road towards Balmaha, and in a shallow valley where the stream crosses the road (there is a field used as a car park here), a stile on the north side of the stream and opposite the car park allows access to a muddy footpath which winds through the trees and up the hill. The first ridge (i.e. furthest north) is distinctive because of its brown coloured soil.

Locality 6. Serpentinite conglomerate and breccias of the southern 'serpentinite'. The rocks comprising this hill are mainly breccia, conglomerate and a sheared mixture of carbonate and serpentinous rock which may be a sheared conglomerate with serpentinite pebbles in a carbonate matrix. In places the breccias and conglomerates are very distinctive and are formed of very well rounded clasts of serpentinite, basic rocks and sometimes sub-rounded quartz grains almost all of which are monocrystalline. On the continuation of this ridge to the shore at the lochside, distinctive marbles and conglomerates, normally underwater, have yielded a range of lithologies including dolerite, gabbro, spilite and well rounded clasts of quartz-arenite, and metaquartzite. Some of these metaquartzite clasts are > 300 mm in length and have ages of 1863Ma, which dates the uplift in the metamorphic block from which they were derived. This metamorphic block is substantially older than the Dalradian block, so the clasts were derived from a metamorphic terrane of unknown affinities and of uncertain location (Dempster and Bluck 1989).

These rocks on the shore have also yielded chitinozoa which suggest an Arenig age, and it is from rocks with this type of lithology that Curry *et al.* (1982) and Ingham *et al.* (1985) recovered a definite Lower Arenig fauna at Aberfoyle. It is almost certain therefore that these rocks are Arenig in age. Because they contain ophiolitic debris, there must have been in this region an ophiolite which is older than the limestone. From data elsewhere (Dempster and Bluck 1991) this ophiolite may be *c*.540Ma or older.

Along the south-eastern face of this exposure are very small outcrops of red sandstone which map out into the overlying Old Red Sandstone (see Fig. 9.3). At a few places on the hillside these sandstones are seen to rest unconformably on the Arenig rocks of the Highland Border Complex. This contact was formerly thought to be a fault and with the Old Red Sandstone conglomerates faulted against the Highland Border Complex its base was not seen, so the total thickness of conglomerate was unknown. However since the contact is now seen as an unconformity, the complete thickness of Old Red Sandstone is exposed - and that thickness is far less than previously supposed.

The serpentinite ridge is terminated along its northern margin by a fault which drops the Upper Old Red Sandstone down to the north. This fault is not the Highland Boundary Fault, as had previously been supposed: it is the Gualann Fault, named after a prominent hill on the NE termination of the conglomerate ridge. The Upper Old Red Sandstone steeply dips at the contact with this fault, as can be seen at the base of the ridge (see Fig.9.3)

Locality 7. Basal conglomerates and the overlapping fans. A line of old quarries, parallel with the ridge, exposes the conglomerates of the Lower Old Red Sandstone and rocks of the Ordovician Highland Border Complex. Conglomerates of the Lower Old Red Sandstone lie unconformably on the Highland Border Complex in most places but in others, as here, there is a small fault at the contact. The ORS conglomerates comprise well rounded or very well rounded quartzite clasts together with some volcanic clasts and very few clasts from the Highland Border Complex. In composition they closely resemble the conglomerate at the pier (Locality 1; conglomerate 3 in Fig.9.3) and probably share the same source, which lay in an approximately northeasterly direction.

The conglomerate exposed in these quarries is the oldest Lower Old Red Sandstone conglomerate in this area; it is overlain by the sandstones of Locality 6, which in turn are overlain by a conglomerate (2 of Fig.9.3) exposed on the shore and seen to rest on the Highland Border Complex on the island of Inchcailloch. The third conglomerate which forms the impressive ridge to the SE (3 of Fig.9.3), rests on sandstones in the valley: both sandstone and conglomerate have a source from the NE, east and SE. The third conglomerate is seen to rest on the Highland Border Complex on the island of Creinch further to the SW across the loch, so that they all overlap each other in that direction.

To the NW lies the low ground of the Highland Border Complex and the Upper Old Red Sandstone and a little beyond that the higher, rougher ground of the Dalradian, outcrops of which are seen on the low hills to the NNE. Between these outcrops and the lower ground of the Highland Border Complex lies the Highland Boundary Fault. The distant high peak to the east of the loch is Ben Lomond.

From this vantage point the following features can best be appreciated:

1. The low ground immediately below the ridge comprises black shales and cherts which at low water in the loch are seen to overlie the Arenig rocks which make up the ridge upon which you are standing. These rocks are replaced to the NW in the sequence by the sandstones seen at Locality 9.3 near Arrochymore Point. In a general sense this sequence of Highland Border rocks is steeply dipping and youngs towards the NW. The Old Red Sandstone rocks are also steeply dipping, but to the SE, so that at the time of the deposition of the Old Red Sandstone the Highland Border Complex was inverted (Figs. 9.5B; 9.7B).

2. As the Ordovician rocks of the Highland Border Complex were being deposited, the Highlands to the north were being uplifted. Profiles across the Dalradian metamorphic belt show that they were being uplifted from *c*.515Ma- 440Ma (Dempster 1985), and this is roughly the time span of deposition of the Highland Border Complex. Calculations suggest that well over 20 km of rock was removed from parts of the Dalradian highlands at this time, so rivers emerging from these early Dalradian mountains would be the principal agent dispersing this sediment. If the Highland Border Complex had formed where we now find it, right next to the Dalradian Block, then the basin in which rocks of the Complex accumulated would have been dominated by this sediment. Recent mountain chains and the basins which occur in front of them comprise mainly coarse detritus—gravels and sands, which are in direct contrast to the mudstones, shales and cherts of much of the Highland Border Complex.

It is therefore clear that the Dalradian block was nowhere near the Highland Border Complex in Ordovician times (Bluck 1985), and from the discussion at Locality 1, they were probably not in their present juxtaposition even in Lower Old Red Sandstone times.

3. The Upper Old Red Sandstone rocks form a thin cover over the Highland Border Complex in the immediate low ground and are disposed in a series of folds with axes running NW. The outcrops are terminated against the ridge of Arenig rocks by the Gualann Fault (Figs 9.3, 9.7). This Upper Old Red Sandstone sequence, in comparison with the Upper Old Red Sandstone to the south, is almost complete in the sense that it begins with a conglomerate (Locality 2) and is terminated by caliche beds which occur almost always just beneath the Carboniferous.

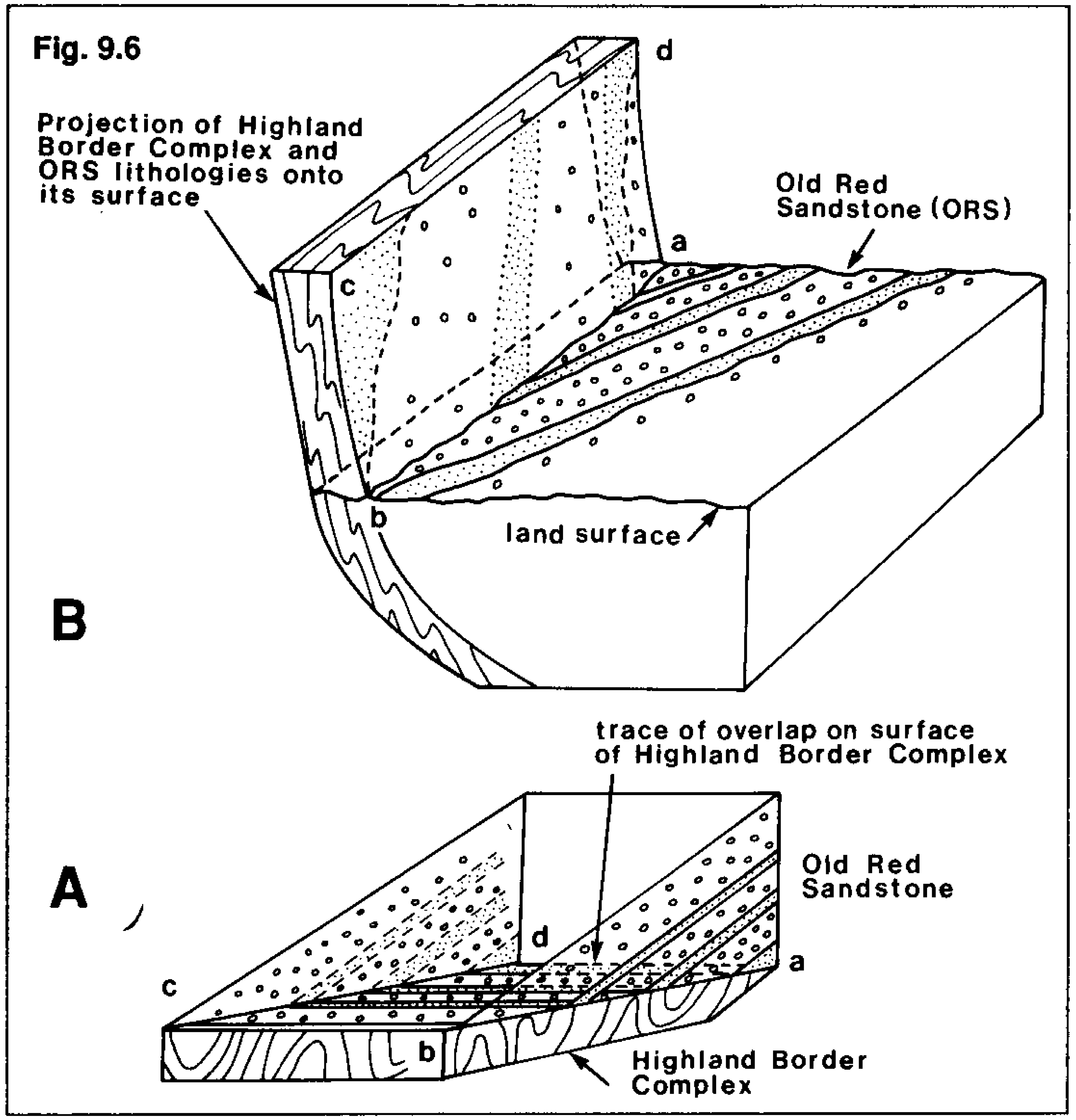

Figure. 9.6. A showing the simple overlap of sediment towards the SW as mapped out in Figure 9.3, but with the beds brought back to horizontal as at the time of deposition. The sediments rest on an eroded surface of Highland Border Complex, a,b,c,d. **B,** showing the overlap of the beds now rotated as seen in the map (Fig. 9.3) where they outcrop on the land surface. The basement to the basin and the basin itself is projected vertically and along the plane of unconformity. The present map is then seen to be a section through a basin which extends upward and downward.

The disposition of the Upper Old Red Sandstone implies that the Upper Old Red Sandstone sequence thins from >1 km where it is exposed on the south limb of the Strathmore syncline to <100m as one goes to the NW, and it thins against the Dalradian Block, which was therefore in place at this time. Moreover, if the base of the Upper Old

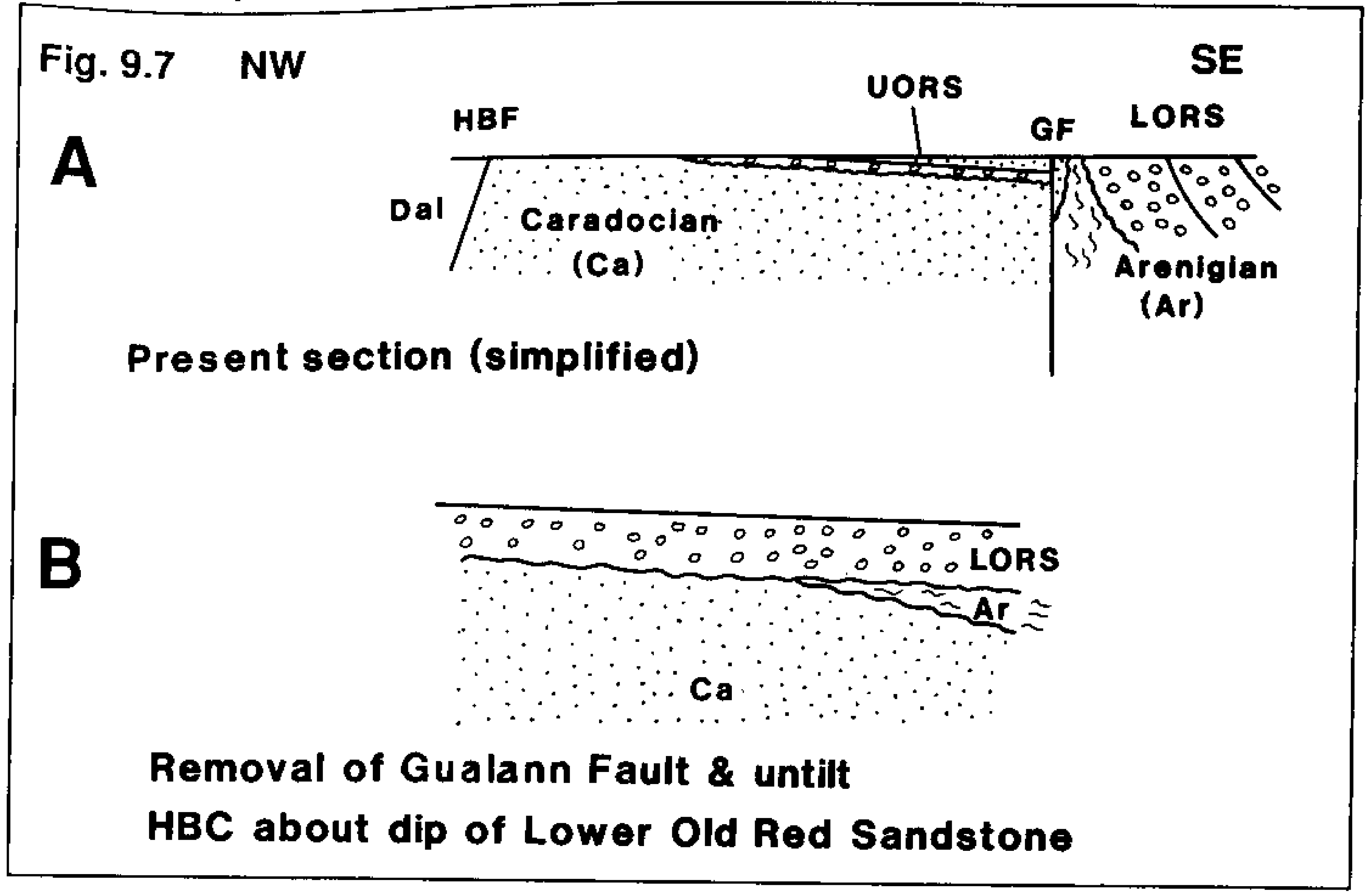

Figure. 9.7. Simplified sections through the rocks at Balmaha, **A** shows the present configuration of the rocks, **B**, the configuration at the time of deposition of the Lower Old Red Sandstone.

Red Sandstone is projected to the NW, then in order to be in this position the Gualann Fault would need to have a vertical throw of at least 500 m. It also follows that the Strathmore syncline formed before the deposition of the Upper Old Red Sandstone since these rocks are clearly not part of that structure.

Locality 8. Edge of second conglomerate NE of Old Manse which at this point is surrounded by sandstone (Fig.9.3). This conglomerate, which makes up a distinctive small conical hill has the same composition and textures as the lowest seen at Locality 7. From this point, looking over The Old Manse it is possible to see the Island of Inchcailloch, and to the SE, the valleys cut into the faulted conglomerates. From SW to NE lies the ridge of conglomerate 3 which reaches its thickest development at Conic Hill to the NE.

From this position, from the examination of Figure 9.3 and from the evidence further mapping along the outcrop a number of points emerge about the disposition of these conglomerate beds and their significance:

1. The conglomerate bodies are lensoid and this can be partly seen on Figure 9.3, SE of Locality 6. It is also clear that conglomerate 3 thins towards the SW, and (not seen of Figure 9.3) it also thins to the NE.
2. There is evidently a sequence of conglomerate bodies which overlap each other to the SW (Fig.9.6); they all had a roughly similar source in the NE, east and SE, and they form an impressive sequence which can be traced for at least 3 km to the NE.
3. There is no evidence for a local Dalradian provenance. The source area included first cycle volcanic and plutonic rock and polycyclic quartzite; it did not include a metamorphic basement. The source extended from the SE to the NE and probably lay across the region now occupied by the Highland Boundary Fault.
4. **Fanglomerate** stacks of this kind can be modelled as forming in a basin, the SE, NW and NE margins of which were bounded by faults. One has to imagine the basin as a vertical extension of the present outcrop, so that its NW margin may have been 1 or 2 km in the vertical sense (Fig.9.6). This basin was probably formed in response to a sinistral strike slip movement.
5. The sedimentation of these rocks is effectively controlled by faults other than the Highland Boundary Fault—a considerable departure from former views (including my own !!). The basin margin of the ORS sediments was probably a fault and that fault would have been in a position some distance to the north of the present Highland Boundary Fault, and therefore positioned beneath the Dalradian block. Clasts at the top of the sequence are more angular than those at the base. This suggests that the source has been firstly stripped of its overlying conglomerates and that the feeder streams began eroding the original basement which, in this instance, comprised metaquartzite.

Conclusions

The principal conclusions to be drawn from this excursion are as follows:

The Dalradian and Highland Border blocks were not juxtaposed during the Ordovician; the Midland Valley, Lower Old Red Sandstone basin received sediment which was **not** derived from the local Dalradian; by Upper Old Red Sandstone times the two blocks (Midland Valley and Highland Border Complex) were joined and therefore the Highland Boundary Fault is not the terrane boundary. It is a comparatively young fault which brought terranes together probably by thrusting during the Middle Devonian (at which time the Strathmore basin formed). The terrane boundary was probably hidden by this thrust and it now lies beneath the Dalradian block.

On a fine day it is well worth going up to the summit of Conic Hill; there is a splendid view in all directions and it is an ideal place (in good weather) to sit and muse on a majestic terrane boundary. To the SW, across Loch Lomond on a fine day it is possible to see the the tall chimney stack of Inverkip power station, beyond which lies the northern peaks of Arran. To the SE it is possible to see through the gap of the Blane Valley, Tinto Hill (the Late Silurian felsite) and the highest point in the Midland Valley. Tinto lies just north of the Southern Upland Fault, so from this point the whole width of the Midland Valley is seen. The low ground running parallel with the strike of the conglomerates, and occupied partly by the southern end of Loch Lomond is made up of sandstones and siltstones which occur in the axis of the Strathmore syncline. The impressive line of hills immediately beyond the low ground of the Strathmore syncline comprise Upper Old Red Sandstone in the foothills and Carboniferous basalts in the higher ground. The distinctive conical hills are almost all Carboniferous volcanic plugs.

References

BLUCK, B.J. 1985. The Scottish paratectonic Caledonides. *Scott. J. Geol.* **21,** 437-464.

————. and LEAKE, B.E. 1986. Late Ordovician to Early Silurian amalgamation of the Dalradian and adjacent Ordovician rocks in the British Isles. *Geology* **14,** 917-919.

————., INGHAM, J.K. CURRY, G.B. and WILLIAMS, A., 1984. Stratigraphy and tectonic setting of the Highland Border Complex. *Trans. R. Soc. Edinb. Earth Sci.* **75,** 125-133.

CURRY, G.B., INGHAM, J.K., BLUCK, B.J. and WILLIAMS, A. 1982. The significance of a reliable Ordovician age for some Highland Border rocks in Central Scotland. *J.Geol.Soc.* **139,** 451-4.

DEMPSTER, T.J. 1985, Uplift patterns and orogenic evolution in the Scottish Dalradian. *J. Geol. Soc.* **142,** 111-128.

————. and BLUCK, B.J. 1989. The age and origin of boulders in the Highland Border Complex: constraints on terrane movements. *J.Geol. Soc.* **146,** 377-380.

————————, 1991. The age and tectonic significance of the Bute

amphibolite, Highland Border Complex, Scotland. *Geol. Mag.* **128,** 77-80.

HENDERSON, W.G. and ROBERTSON, A.H.F. 1982, The Highland Border rocks and their relation to marginal basin development in the Scottish Caledonides. J. *Geol. Soc.* **139,** 433-450.

INGHAM, J.K. CURRY, G.B. and WILLIAMS, A. 1985. Early Ordovician Dounans Limestone fauna, Highland Border Complex, Scotland. *Trans. R. Soc. Edinb. Earth Sci.* **76,** 481-513.