BALMERINO TO WORMIT

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OS Grid Reference: NO356248

Introduction

The coastal cliff sections and foreshore beside the Firth of Tay between Balmerino and Wormit provide the most complete section through the Lower Old Red Sandstone, Ochil Volcanic Formation in Fife (Figure 9.25). The GCR site illustrates the nature and environment of this volcanic activity and complements that of the Sheriffmuir Road to Menstrie Burn GCR site at the SW end of the Ochil Volcanic Formation outcrop. The eastern half of this section is described in a field guide by MacGregor (1996). A 350 m-thick sequence of basaltic to andesitic lavas and volcaniclastic sedimentary rocks is intercalated with sandstones and minor claystones of the Dundee Formation. Rocks from the section have provided radiometric ages and micro- and macro-palaeontological evidence, both indicating an Early Devonian (Lochkovian) age.

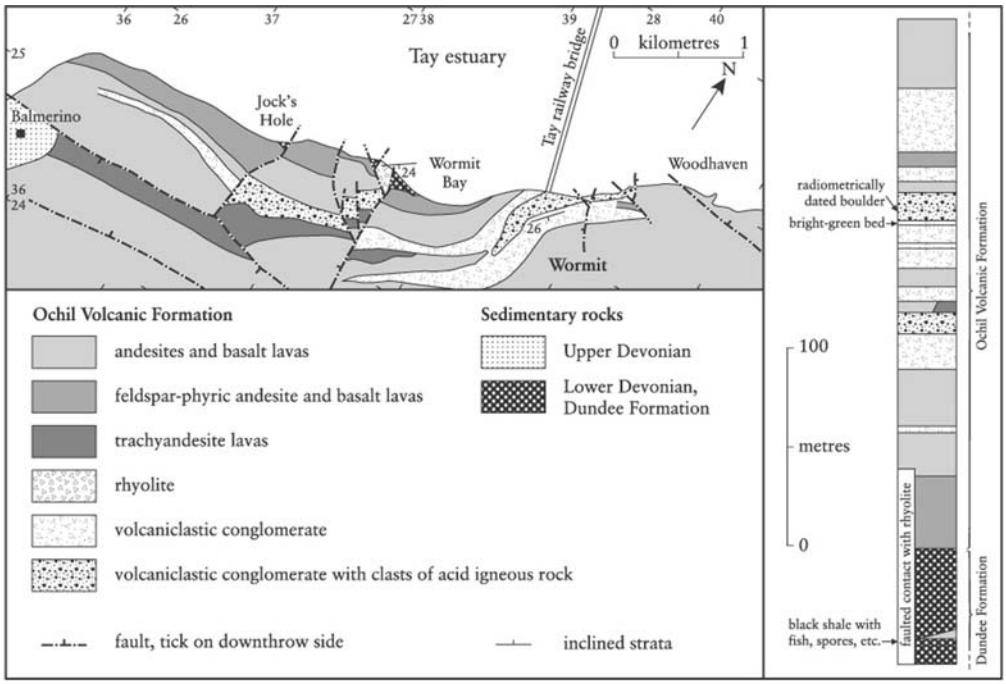

Figure 9.25: Map and generalized vertical section of the Balmerino to Wormit GCR site.

Description

The stratigraphy of the area has been described by Geikie (1902) and Armstrong *et al.* (1985). The lavas, usually less than 7–9 m thick, consist mostly of basalts and basaltic andesites, which are usually distinguishable only by geochemical analysis (Thirlwall, 1979). They vary from coarsely to finely feldspar-phyric and from fine- to medium-grained aphyric. The feldspar is labradorite–andesine and usually co-exists with small altered phenocrysts of one or more of forsteritic olivine, bronzitic orthopyroxene, titanomagnetite and diopsidic augite. Hornblende has not been reported and phenocryst biotite is restricted to the acid igneous rocks (Thirlwall, 1979). The lavas are commonly heavily altered and weather to a brown, greenish-grey (chloritic), or purplish and reddish-grey mottled appearance. When fresh they are grey or less commonly brown. They show features such as autobrecciation, amygdales and infiltrated sediment in fissures and between blocks. Possible pillow lavas have been identified. Individual flow bases are not always easy to recognize in the absence of lateritic alteration. However, because the lava flows are interbedded with both volcaniclastic and non-volcaniclastic sedimentary rocks of the Dundee Formation (Arbuthnott Group), the section displays load-cast

relationships between flow bases and underlying shales. Uneven, possibly eroded flow tops are infilled by sandstone in places, but elsewhere peperites formed by the interaction of hot magma and wet sediment are clearly seen (MacGregor, 1996) (Figure 9.26).

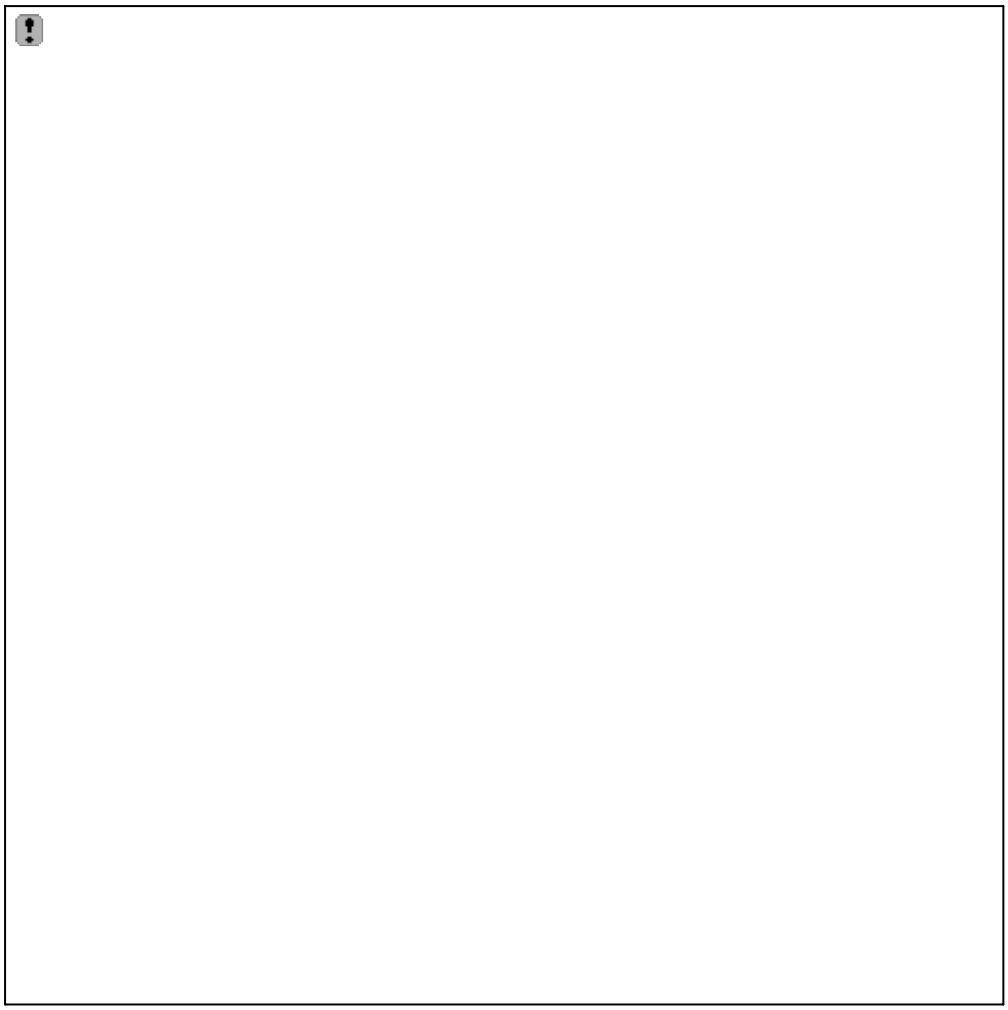

Figure 9.26: Lens of well-laminated sandstone between igneous sheets on the foreshore west of the Tay Bridge at Wormit. The lower sheet has a sharp but irregular, apparently intrusive, contact with the sandstone; the upper sheet shows evidence of magma–wet sediment interaction, with fragments of igneous material separated by irregular veins of pale sandstone and peperitic texture well seen on the right. (Photo: M.A.E. Browne.)

At Peasehill Point (3832 2580) highly altered and weathered andesite flows are faulted against a pale-grey, fawn and salmon-pink colour-banded rhyolite. On the western edge of the rhyolite outcrop, this thin flow-banding is near-parallel to the adjacent fault plane, but away from this contact it is highly irregular. The eastern contact of the rhyolite is with a rhyolitic breccia, which includes blocks of sandstone and shale. In places the rhyolite appears to intrude the breccia, which itself intrudes the sandstone country rock. Two possible origins have been suggested for the rhyolite. Harry (1956) suggested that it is a vent intrusion with the breccia pre-dating the rhyolite, whereas Geikie (1902) followed by Armstrong *et al*. (1985) suggested that it is a lava within a vent that has been faulted down into its present position.

Probably all the volcaniclastic rocks are sedimentary rather than pyroclastic. They consist predominantly of massive, thickly bedded, poorly sorted conglomerates and breccias in beds up to 9 m thick. The clasts in the conglomerates consist of basalt, basaltic andesite and rhyolitic lavas. The rhyolite clasts are probably not of local derivation and conglomerate units have been distinguished by their absence or presence and relative abundance. The clasts can be subangular to rounded and are usually less than 30 cm, but over 2 m across locally. The matrix is composed of grains of similar materials and quartz. Greenish-grey, cross-bedded, volcaniclastic sandstones are also present as impersistent lenses and beds.

The interbeddded Dundee Formation strata consist of cross-bedded, sometimes graded sandstones and finer-grained beds of siltstone and shale. The colours of these sedimentary rocks range from grey to green to red and also yellow. They are fluvial and lacustro-deltaic in origin and form part of the infill of the Strathmore Basin, which extends south-westward from Stonehaven across the whole of the Midland Valley of Scotland.Marshall *et al*. (1994) have described the vitrinite reflectivity of the carbonaceous shales at Wormit as a small part of a study of the Strathmore region. They concluded that maximum burial of 3–5 km, and therefore thermal maturity occurred during the late Carboniferous. This has major consequences for understanding the nature, depth and number of late Silurian to Early Devonian sedimentary basins in the eastern Midland Valley.

Interpretation

Thirlwall (1983b) analysed trace elements, including rare earths, and Sr, Nd and Pb isotopes of lavas within and around this site. He found all the samples from the site to be primitive basalts and andesites (high Mg, Ni and Cr) in contrast to samples farther south, which are more typical of modern calc-alkaline suites with less than 30 ppm Ni and Cr. He reported Rb-Sr age determinations on biotite and plagioclase separations from a rhyolite boulder in what he described as the lowest conglomerate in the local succession. The age was reported as 406.5 ± 5.6 Ma, later adjusted to 410.6 ± 5.6 Ma (Thirlwall, 1988).

The dark-grey, carbonaceous shales near Peasehill Point have yielded a fish fauna, including *Brachyacanthus, Ischnacanthus* and *Mesacanthus* (Westoll, 1951). The arthropods *Kampecaris* and *Pterygotus* and the plant *Parka decipiens* have also been found. Richardson *et al*. (1984) re-assessed the age of some Arbuthnott Group sedimentary rocks from the Strathmore region on the basis of a re-investigation of spore assemblages. At Wormit, samples associated with, but stratigraphically beneath the rocks dated by Thirlwall (1983b, 1988) as 410.6 Ma, yielded assemblages of Early (but not earliest) Devonian age belonging to the *micrornatus–newportensis* Zone (lower and middle subzones) of the Lochkovian Stage. The Wormit GCR site is possibly the only Lower Old Red Sandstone site where radiometric and biostratigraphical dating methods are so closely related. The radiometric dates are very close to the Silurian–Devonian boundary on most recently published time-scales and until recently may have been regarded as late Silurian. However, the palaeontological data indicate early Lochkovian (Gedinnian) and this is now accepted. Therefore this site not only provides a stratigraphical and radiometric date for the late Caledonian volcanicity in this part of the Midland Valley, but potentially it has even greater implications internationally for the dating of the Silurian–Devonian boundary.

Conclusions

The Balmerino to Wormit GCR site is a particularly important site both nationally and internationally. The former, because it represents a key 350 m-thick succession of the Ochil Volcanic Formation in the eastern Midland Valley, and the latter because of the intimate relationship it shows between the volcanic rocks and the interbedded fossiliferous claystones within the Dundee Formation (Arbuthnott Group). Studies of organic matter in the carbonaceous shales provide estimates of depth of burial and degree of maturity, which have contributed to the understanding of the development of the late Silurian to Early Devonian sedimentary basins in the eastern Midland Valley.

Geochemical studies have characterized the basalts and andesites as primitive calc-alkaline types related to subduction during the final closure of the Iapetus Ocean, and have contributed to more detailed suggestions regarding the magma source. Radiometric investigations on this site and elsewhere in the Midland Valley estimate the age of the late Caledonian magmatism as 415–410 Ma. This has been substantiated by spores which, together with the macrofauna, including fossil fish, show the succession to be early Lochkovian (Early Devonian). Hence there are possible international implications for the age of the Silurian–Devonian boundary.

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