Glen Vale, Fife

[NO 171 068]–[NO 195 072]

Potential GCR site

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Introduction

The stream sections and crag exposures in the Glen Vale area, Fife and Kinross (Figure 3.30), are recommended for the GCR for the Upper Old Red Sandstone windblown (aeolian) facies sandstones that are exposed. The importance of these sandstones, which belong to the Upper Devonian Knox Pulpit Sandstone Formation (of the Stratheden Group), lies in their aeolian origin, in contrast to the fluvial origin of most of the Upper Old Red Sandstone succession in the Midland Valley. The exposures at John Knox's Pulpit [NO 1891 0582] and Dow Craig [NO 1892 0702] (Figure 3.31) allow a three-dimensional study of many of the key sedimentological features of the formation. In the Glen Vale area, the Upper Old Red Sandstone succession comprises, in ascending order, the Burnside Sandstone, Glenvale Sandstone and Knox Pulpit Sandstone formations. The site thus allows the aeolian facies rocks to be placed in stratigraphical context, between the underlying Glenvale Sandstone Formation and the overlying lower Carboniferous Kinnesswood Formation (of the Inverclyde Group). Chisholm and Dean (1974) gave a comprehensive account of the Upper Old Red Sandstone succession in the area. Although they noted that an aeolian origin could not be discounted for the Knox Pulpit Sandstone Formation, these authors favoured a shallow marine origin. Subsequently, an aeolian origin was recognized (McAlpine, 1978; Mader and Yardley, 1985; Hall and Chisholm, 1987).

Description

The lowermost beds within the proposed site boundary belong to the Glenvale Sandstone Formation. This consists of white, yellow, brown, red and purple, fine- to coarse-grained, feldspathic sandstones. Clasts of red, green and cream-coloured mudstone up to 0.15 m are common, but siliceous pebbles are rare to absent. Fish remains include fragments, as well as complete specimens, of *Holoptychius.* Large-scale trough cross-stratification, in sets up to 1.5 m thick is the commonest sedimentary structure, but low-angle cross-bedding and planar lamination are also found. Palaeocurrent flow was towards the east. Subsidiary beds of greenish grey and red silty claystone and siltstone are also present, some forming the upper parts of upward-fining cycles. The transitional junction with the underlying Burnside Sandstone Formation is exposed in the Glen Burn [NO 170 076] north of the site boundary, west of Lappie Farm. It is placed at the point above which the siliceous pebbles that are characteristic of the Burnside Sandstone Formation are absent. The formation includes the well-known Dura Den Fish Bed, which elsewhere has yielded abundant *Bothriolepis* (including *B. hydrophila*)*, Glyptopomus* and *Holoptychius.* This fauna indicates a Famennian age (e.g. Westoll, 1977).

The Knox Pulpit Sandstone Formation consists of 130–180 m of soft, weakly cemented, white, buff and yellow, very fine- to coarse-grained, feldspathic sandstones. The transitional junction with the Glenvale Sandstone Formation is faulted and poorly exposed in Glen Burn [NO 181 063], where the lowest exposed strata include sporadic laminae of greenish grey, silty mudstone. The most characteristic feature of the formation is the marked grain-size lamination, with laminae 1 mm to 10 mm thick ('pin-stripe' lamination) of aeolian origin. Other distinctive features are the rarity of pebbles, a greenish grey, silty claystone near the base, ochreous, decomposed calcrete nodules near the top, and an absence of clastic mica flakes that are common in the other Upper Old Red Sandstone formations in the Midland Valley. Bedding forms include tabular planar cross-bedding and planar wedge-shaped cross-bedding, planar lamination and convoluted bedding. The cross-bedding sets are mainly about 1 m or less, with foresets dipping at 20° to 30°, although some sets in the lower part of the formation at Dow Craig are up to 2.5 m. The cross-bedding is predominantly directed to the west and north-west, but bi-modal, east- and west-directed palaeocurrents are also present. Herringbone pattern is seen locally, as at Dow Craig [NO 1892 0702], John Knox's Pulpit [NO 1891 0582] and Kilgour Craigs [NO 226 078]. Erosional, first-order bounding surfaces occur between some sets at Dow Craig. Convolutions affect the larger (up to 2.5 m) sets towards the

base of the formation (Chisholm and Dean, 1974). Ripple lamination is rare, except near the top. Well-rounded millet seed grains are common in the coarser laminae. Trace fossils referred to *Skolithos are* most common towards the top of the formation, where they occur in ripple-bedded sandstones as simple, vertical tubes up to 2 cm across and 7–30 cm long. Concentrations of up to 1000 per m^2 are recorded, although they are generally much sparser.

The Kinnesswood Formation is the basal formation of the Inverclyde Group, which is characterized by the presence of sandstones with pedogenic carbonate ('cornstones) and by mudstones with thin beds of dolomite and limestone ('cementstone). The base of the formation is placed at the appearance of carbonate-bearing strata. The junction with the Knox Pulpit Sandstone Formation is seen in the Glen Burn, at the lip of a small waterfall [NO 1908 0570], where there is a transition over a few metres. Miospores of Tournaisian (LN–PC biozones) age from near the base of the formation elsewhere (Smith, 1996) show that it straddles the Devonian–Carboniferous boundary, but that most of it is of early Carboniferous age. It consists predominantly of purple-red, yellow, white and grey-purple, fine- to coarse-grained sandstones that are mostly cross-bedded and arranged in upward-fining units. Fine-grained, planar bedded and poorly bedded sandstones, red mudstones and nodules and thin beds of calcrete also occur. The calcretes range from immature types, in which the host sandstones have a patchy carbonate matrix with ill-defined concretions, to mature types, in which well-defined nodules (glaebules) are elongate perpendicular to the bedding and overlain by laminar and pisolitic beds. Some of the laminar calcrete, in which the laminae are bedding-parallel, is brecciated and the carbonate is replaced by chert.

Interpretation

The Knox Pulpit Sandstone Formation was initially interpreted as marine in origin (Chisholm and Dean, 1974). However, compelling evidence for an aeolian origin was provided by Balin (1993), drawing on earlier aeolian interpretations by McAlpine (1978), Mader and Yardley (1985) and Hall and Chisholm (1987). The types of planar cross-bedding and heights of the sets are typical of modern aeolian dunes. Some are 2.5 m high in the lower part of the formation at Dow Craig (Figure 3.31). The grain-size lamination may be formed by grainfall (normal graded) and grainflow avalanche (reverse graded) deposition. Inter-set bounding surfaces, as seen for example at Dow Craig, are common in aeolian sands, with coarser sands occurring above them. They may be caused by shifts in wind direction, often accompanied by a slight increase in wind velocity, which introduces coarser sand (Balin, 1993). The planar lamination is produced by traction currents at high wind velocities.

The convoluted, soft-sediment deformation and the opposed (bi-modal) cross-bedding directions (including herringbone cross-bedding) in the sandstones suggested a tidal origin to Chisholm and Dean (1974). Balin (1993) noted that contorted bedding is present in all types of aeolian dune and suggested that the bi-modal cross-bedding was caused by alternating east- and west-directed winds, although bi-modality can also be created in self (longitudinal) dunes by unidirectional winds as a result of changes in the slip faces of their linear crests. However, Balin (1993) argued that the bounding surfaces in the Knox Pulpit Sandstone Formation are too shallow-dipping to be related to such well-developed steep crests. She further noted that modern, large star dunes form from multi-modal wind directions, but that multiple slip faces are not usually preserved in the stratigraphical record because they are best developed in the easily eroded upper part of the dune. However, they are surrounded by much smaller crescentic and reversing dunes, which form where larger crescentic and linear dunes (the precursors to the star forms) advance into areas affected by variable wind directions. On this basis, Balin concluded that the bi-modal foreset was due to deposition in reversing dunes by opposing wind directions. Adjusting the palaeocurrent data for polar rotation (about 25° anti-clockwise), Bailin (1993) found that the prevailing wind direction was to the WSW, with a secondary direction to the south-east. Neither direction is compatible with the presumed north-west trade wind direction, and Balin suggested that an exposed early Devonian volcanic terrane in the Ochil Hills exerted a topographic and orographic influence. Rapid heating of dark volcanic rocks in the daytime may have generated the main winds, with the weaker opposing winds produced by rapid air cooling over the hills at night.

Wavy lamination, small-scale convex-up lamination, climbing translatent ripple lamination (in co-sets up to 2 cm) and the *Skolithos* burrows were interpreted by Balin (1993) as features of interdune sedimentation. Thin wavy laminae are thought to have formed in wet interdune areas as a result of weak, variable wind conditions or falling water-table, leading to modification of the ripples. The convex-up laminae may be adhesion warts, formed where small mounds of sand

adhere to a damp substrate. The climbing translatent ripple forms show slight upward coarsening of grain size and lack internal foreset lamination, which are apparently only associated with a dry substrate. These suggest aeolian, rather than waterlain, deposition. *Skolithos* is generally regarded as a marine trace fossil, and its presence was used by Chisholm and Dean (1974) to argue for a tidal origin for the Knox Pulpit Sandstone Formation. Balin (1993) favoured a wet interdune habitat.

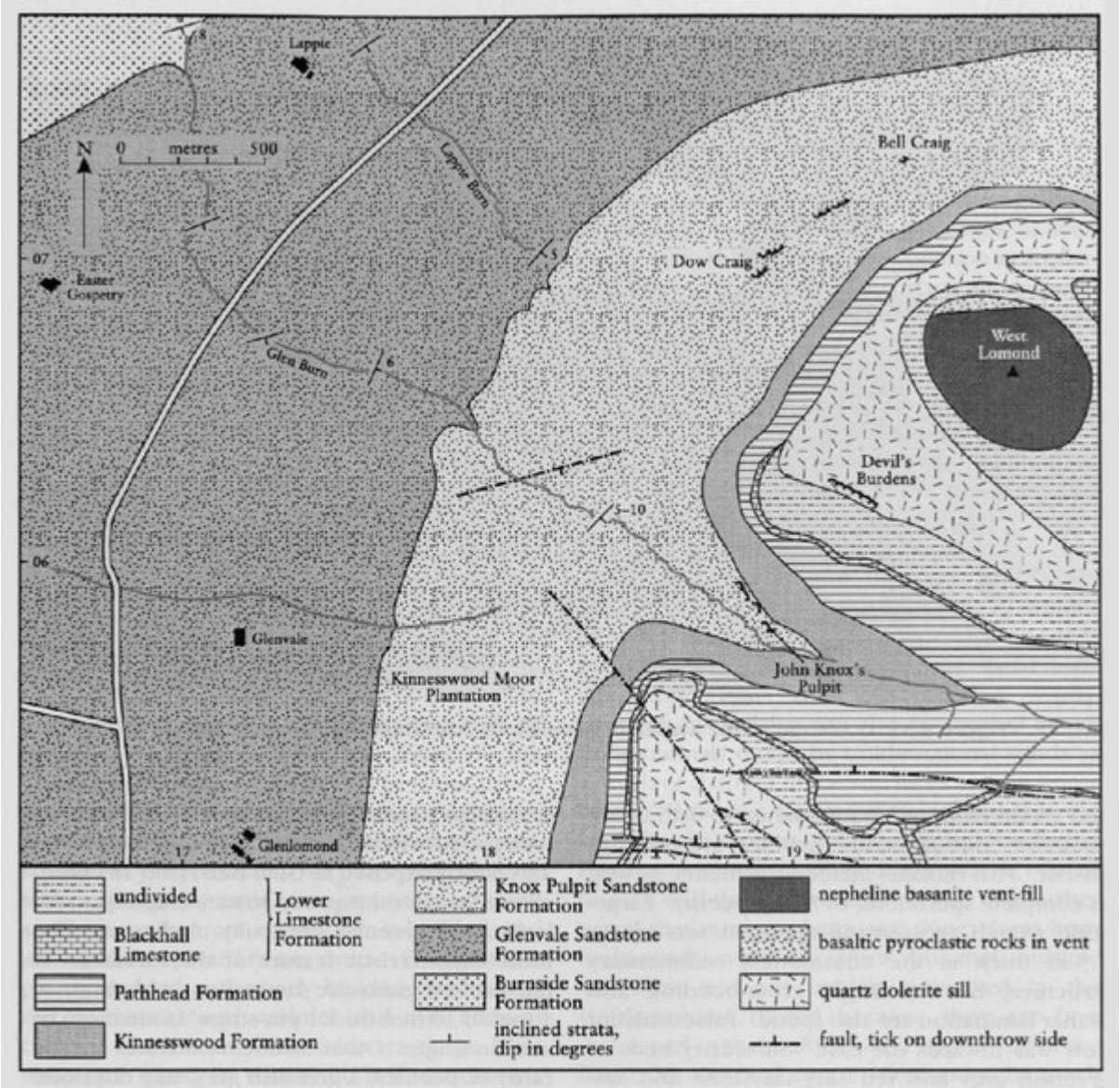
The strata below (Glenvale Sandstone Formation) and above (Kinnesswood Formation) the Knox Pulpit Sandstone Formation are of fluvial origin. The cross-bedded sandstones of the Kinnesswood Formation were deposited in river channels and the fine-grained sandstones and mudstones were formed on the adjacent flood-plains. Evidence of an arid to semi-arid palaeoclimate and inhospitable terrestrial environments indudes desiccation cracks, pedogenic carbonates, the scarcity of fauna (other than fish) and an almost total absence of micro- and macro-floral remains. It is difficult to assess the aridity of the climate, since it is unclear as to how evolved the terrestrial vegetational cover was in the Midland Valley during Late Devonian times. However, large rhizoliths in pedogenic carbonates in the Kinnesswood Formation elsewhere in the Midland Valley (Balin, 2000; see Milton Ness GCR site report, this chapter) demonstrate the presence of substantial trees in Late Devonian to Early

Carboniferous times. The Knox Pulpit Sandstone Formation shows evidence of hot desert environments, with higher water-table conditions in the interdune areas. The presence of small, ochreous carbonate nodules in the upper part of the formation may herald a less arid climate, the pedogenic carbonates in the Kinnesswood Formation showing that the climate during its deposition was semi-arid, with seasonal (?monsoonal) rainfall.

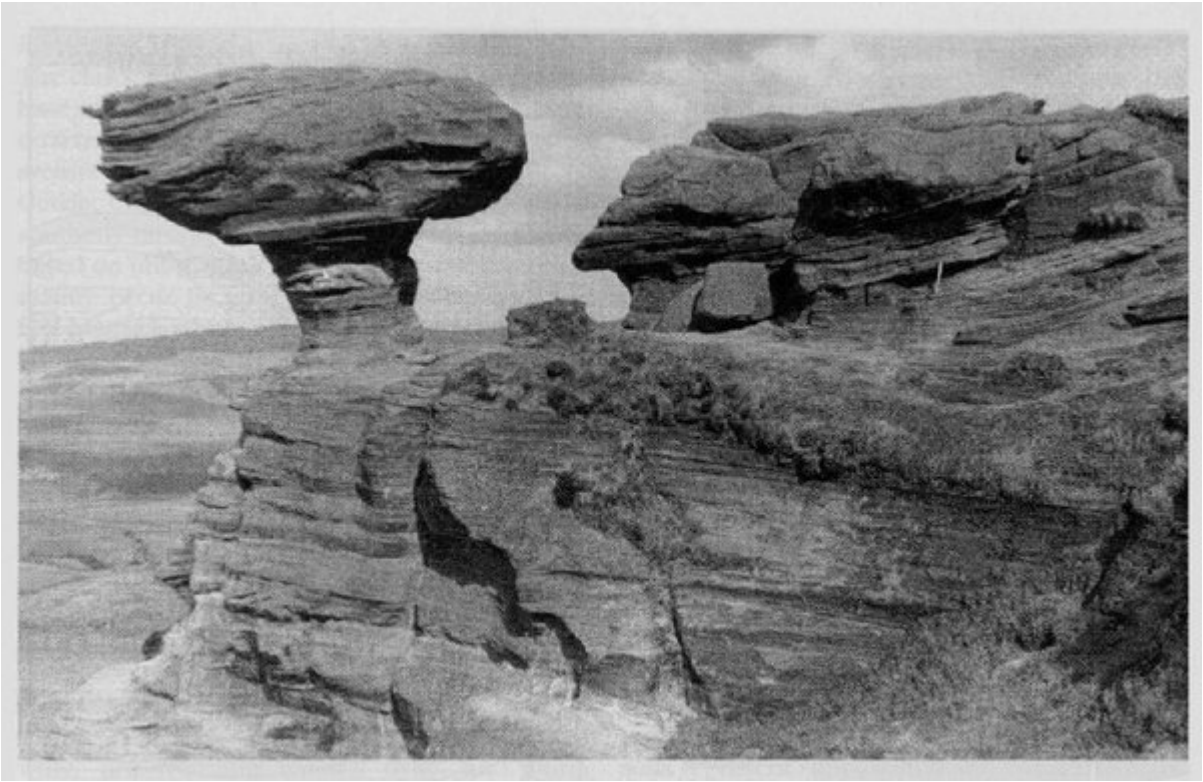
Conclusions

The natural stream sections in the Glen Burn and nearby crag exposures, including John Knox's Pulpit and Dow Craig, are proposed for GCR site status. The crags provide fine exposures of the Upper Devonian (Famennian) Knox Pulpit Sandstone Formation. This formation represents strata that were deposited by winds, in contrast to most of the Old Red Sandstone succession of the Midland Valley, which is of fluvial origin. The underlying (Glenvale Sandstone) and overlying (Kinnesswood) fluvial formations are well exposed in Glen Burn. The site is therefore important in providing evidence of the changing sedimentary environments of Late Devonian to Early Carboniferous times and in interpretation of the climate and palaeogeography at that time.

References



(Figure 3.30) Geological map of the Glen Vale area showing limits of the potential GCR site.



(Figure 3.31) Dow Craig in the Knox Pulpit Sandstone Formation. (Photo: J.I. Chisholm.)