Dunnottar Coast Section, Aberdeenshire

[NO 883 853]–[NO 882 839]

Potential GCR site

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Introduction

The dramatic cliffs and foreshore of the coastline extending southwards from Downie Point, south of Stonehaven Harbour to Dunnottar Castle and beyond for 1 km to Tremuda Bay (Figure 3.11) expose a Lower Old Red Sandstone succession dominated by conglomerates. This potential GCR site includes the topmost beds of the Carron Sandstone Formation (of the middle Silurian Stonehaven Group) and the type section of the Dunnottar Castle Conglomerate Formation (of the upper Silurian to lower Devonian Dunnottar–Crawton Group) ((Figure 3.5), Section 6). The northern limit of the outcrop of the Tremuda Bay Volcanic Formation marks the southern limit of the potential site. The strata lie on the steeply dipping to overturned north-west limb of the asymmetric, NE-trending Strathmore Syncline.

Description

Descriptions of the site were given by Gillen and Trewin (1987), Carroll (1995a,b) and MacGregor (1996a). Haughton and Bluck (1988) carried out a detailed analysis of the conglomerates in the section. Trewin and Thirlwall (2002) provided a summary of the succession and its depositional environments. The Stonehaven Group crops out northwards from Downie Point ((Figure 3.11); see The Toutties GCR site report, this chapter) and comprises at least 1800 m (Carroll, 1995a) of cross-bedded and horizontally laminated, quartzo-feldspathic sandstones. The lower part of the group (the Cowie Sandstone Formation) has numerous mudstone/siltstone interbeds. The upper part (the Carron Sandstone Formation) is rich in volcanic detritus, has predominantly NW-directed palaeocurrents and contains detrital garnets indicating a metamorphic source to the south-east (Robinson *et al.,* 1998).

In this area, the sandstones of the Carron Sandstone Formation range from fine-grained to pebbly, gritty and lithic. They are predominantly red to purple, with some pink, orange and yellow beds. Both tabular and trough cross-bedded sets (over 1 m thick) and planar laminated units occur, the former with convolute de-watering structures locally. Some of the sandstones are micaceous, others are tuffaceous, the latter being associated with conglomerates dominated by acid volcanic clasts. There are a few beds of red sandy mudstone up to 0.3 m thick, but little evidence of upward-fining cycles, with argillceous overbank rocks being a minor component and largely confined to pale lilac rip-up mudstone clasts in some of the sandstones. The rare conglomeratic beds and the pebbly sandstones contain clasts of chert, jasper, schistose grit, quartzite, vein quartz and rhyolite.

The Carron Sandstone Formation is overlain unconformably by thick, clast-supported conglomerates (the Downie Point Conglomerate Member), which form the basal part of the Dunnottar Castle Conglomerate Formation (of the Dunnottar–Crawton Group; Browne *et al.,* 2002) at Downie Point. The Downie Point Conglomerate Member comprises 180–225 m of strongly jointed, bimodally sorted, clast-supported cobble to boulder (generally less than 0.6 m) conglomerate with a matrix of coarse-grained sandstone (Carroll, 1995a). Massive, thickly bedded and cross-bedded units occur. The largest, well-rounded boulders are up to 1 m and mainly of resistant 'Highland' quartzites and psammites. They account for 30–60% of the coarse fraction, the remainder being largely of igneous lithologies (mostly andesitic lava, with rare granite and feldspar-phyric microgranite). A few pebbles of Highland Border Complex rocks (metabasalt, serpentinite and red chert) are also present. Beds of sandstone less than 1 m thick occur locally. The basal unconformity is seen particularly well in the quarry north-west of Downie Point (Gillen and Trewin, 1987; MacGregor, 1996a), where there appears to be about 2 m of relief on the erosion surface.

The Strathlethan Sandstone Member overlies the Downie Point Conglomerate Member, its base resting on an irregular surface that is markedly oblique to bedding, cutting down into the Downie Point Conglomerate Member from west to east. The member crops out in Strathlethan Bay and consists mainly of grey and grey-green, medium-grained, cross-bedded, locally pebbly, lithic sandstones. A thin basal bed of red, massive, medium- to coarse-grained volcaniclastic sandstone contains angular clasts of felsite and andesitic lava with rarer, rounded clasts of quartzite. Thin planar beds with normal grading are present locally, but sedimentary structures are destroyed towards the north-east of the exposures by a 1 cm-spaced parting sub-parallel to the bedding. The top of the bed is transitional with the overlying green, locally pebbly, lithic sandstone in places, but in others there is a sharp, highly convolute junction. Foreshore exposures at the north end of Strathlethan Bay show spectacular disruption in a 100 m-thick zone. Disruption is most intense at the base of the Strathlethan Sandstone Member, with rotated and partly rounded blocks of grey-green sandstone in a volcaniclastic sandstone matrix with a streaky, foliated fabric (Gillen and Trewin, 1987; Robertson, 1987). The zone apparently thickens from west to east and some of the rotated sandstone blocks are up to 30 m long. At the top of the zone, 'flames' of massive sandstone extend up into the overlying undisturbed beds.

Trough cross-bedding in sets of 1–2 m are typical of the undisturbed upper beds and in coherent blocks within the disturbed zone. Lenses of last-supported pebble conglomerate and very poorly sorted volcaniclastic sandstone and thin beds of mudstone with desiccation cracks are interbedded with the lithic sandstones in the topmost 20–30 m near the sea stack of Carlin Craig [NO 880 847] at the southern end of Strathlethan Bay, in a rapidly upward-coarsening transition into the Castle Haven Conglomerate Member.

The Castle Haven Conglomerate Member (Browne *et al.,* 2002) consists of massive and weakly bedded, clast-supported conglomerate with lenses of horizontally laminated, medium-grained sandstone. This member forms most of the Dunnottar Castle Conglomerate Formation and is almost continuously exposed in the cliffs and foreshore from Dunnicaer [NO 8825 8473] to Tremuda Bay [NO 880 830] 1 km south of Dunnottar Castle. The conglomerate is of essentially 'Highland' type, its pebble suite dominated by andesitic lavas, quartzite and psammite. There are more clasts of 'granite' and porphyritic microgranite than in the underlying conglomerates, as well as a diverse suite of lithologies including vein quartz, chert, metabasalt, gabbro, migmatitic 'gneiss' and flow-banded rhyolite (Haughton 1989). Gillen and Trewin (1987) noted a quartzite-dominated last assemblage with jasper and jasper-rich grit pebbles typical of the Highland Border Complex from the base of the member near the southern end of Strathlethan Bay.

At the north end [NO 880 842] of its type locality of Castle Haven, exposures of the Castle Haven Conglomerate Member on the wave-cut platform show well-sorted conglomerates with current imbrication of the pebbles and thin sandstone interbeds, cross-bedding in the sandstones indicating mainly SSW flow (Gillen and Trewin, 1987).

A conglomerate at the south end of Castle Haven [NO 880 840] marks the first appearance of clasts typical of the Dalradian Southern Highland Group (Gillen and Trewin, 1987). They are less well-rounded and of cleaved, low-grade metamorphic rocks. An unusual displacive sparry calcite carbonate cement may be of pedogenic origin. Sparse cross-bedding data indicate ESE flow. The succeeding conglomerate [NO 8800 8404] is also distinctive in consisting mainly of matrix-supported red, weathered andesitic lava boulders and pebbles in a matrix of argillaceous siltstone/very fine-grained sandstone with convolute laminations. The conglomerates between this unit and Dunnottar Castle (Figure 3.12) contain clasts of apparent Dalradian lithologies.

Red, coarse-grained, medium-bedded, volcani-clastic sandstone up to 30 m thick in the upper part of the member are composed largely of coarse-grained, angular clasts of fine-grained 'felsitic' material. These are present around Old Hall Bay [NO 8799 8370] just south of Dunnottar Castle, where the dip of the strata decreases from 70° to 40° to the south-east.

The overlying Tremuda Bay Volcanic Formation crops out in the cliffs southwards from Maiden Kaim [NO 882 834] to Tremuda Bay. It is 170 m thick (Carroll, 1995a) and consists of a number of lava flows of microporphyritic, olivine-bearing hawaiite (Thirlwall, 1979; Le Maitre, 1989). The basal bed of the formation is a thin, fine-grained, sandstone-to-mudstone, fining-upward unit.

Interpretation

The cliff sections between Downie Point and Tremuda Bay expose superb examples of conglomerates of Old Red Sandstone lithofacies that are interpreted as the deposits of a large braided stream system and alluvial fans ((Figure 3.13); Haughton and Bluck, 1988). The scale of the river systems that deposited the detritus can be appreciated; both large braid bars of high-stage coarse gravels and low-stage and bar-tail cross-stratified sands occur.

At the north end of the section, exposures at Downie Point show the unconformable relationship between the sediments laid down during mid- to late Silurian times in the Stonehaven Basin (the Carron Sandstone Formation) and those in the later Crawton Basin (the Dunnottar Castle Conglomerate Formation). However, the time represented by the unconformity at Downie Point, and whether the Carron Sandstone Formation has more in common with the Dunnottar–Crawton Group than with the Cowie Sandstone Formation in the Stonehaven Group, remain matters of debate (Gillen and Trewin, 1987; Carroll, 1995a; Trewin and Thirlwall, 2002). The sources of some of the detritus are also unclear.

The Carron Sandstone Formation has been interpreted as the deposits of bedload-dominated, braided streams. Phillips and Carroll (1995) interpreted reversals of palaeoflow direction within the Stonehaven Group as a whole as reflecting the interaction of transverse and longitudinal drainage systems within a fault-controlled basin. Contemporaneous tectonic activity may also have changed the local palaeoslope. Convolute bedding structures also point to rapid deposition, liquefaction and de-watering in a tectonically active basin (Trewin and Thirlwall, 2002). The topmost beds of the formation were probably braidplain deposits laid down by moderate- to high-energy streams flowing to the south-west.

The Downie Point Conglomerate Member represents a sudden influx of coarse detritus and uplift, probably to the north-east, as palaeocurrents in a large braided river system are directed to the south-west (Gillen and Trewin, 1987; Haughton and Bluck, 1988; Trewin and Thirlwall, 2002). Robinson *et al.* (1998) report northward transport based on imbrication fabrics in the basal part of the Castle Haven Conglomerate Member and the Downie Point Conglomerate Member. There is no change in clast types in the higher conglomerates, in which imbrication indicates a southerly transport direction. Haughton and Bluck (1988) recognized six types of alluvial sequence (A-F) in the Strathmore Basin on the basis of structural, textural and compositional criteria and palaeocurrent directions. The Downie Point Conglomerate Member is interpreted as polycyclic alluvium generated by large braided rivers (Type A). Haughton (1989) considered the Downie Point Conglomerate Member to have been deposited by large, SW-flowing, multi-channelled, braided streams developed on 'wet' alluvial-fans (Phillips and Carroll, 1995). The drainage system that deposited this conglomerate and the higher Castle Haven Conglomerate Member was dearly much larger than those of the Stonehaven Group, as indicated by the channel sizes (Haughton, 1989) and maximum size of the clasts. Phillips and Carroll (1995) noted that the contact between the Stonehaven and Dunnottar–Crawton groups at Downie Point represents a rapid change in these factors, but assumed a period of continuous deposition, with only minor erosion preceding deposition of the Downie Point Conglomerate Member. These authors interpreted the coarse conglomerates as the deposits of a large drainage system antecedent to the Stonehaven Basin, captured by headward erosion of consequent drainage or by tectonic adjustments. This interpretation is in contrast to a more recent one by Bluck (2000, 2001), in which the Stonehaven Group is envisaged as the fill of an older, pull-apart basin separate from that in which the Dunnottar–Crawton Group was deposited. The presence of volcaniclastic sandstones in the upper part of the Castle Haven Conglomerate Member was interpreted by Phillips and Carroll (1995) to be due to the introduction of large volumes of volcanic detritus during periods when the more general coarse gravel deposition was overwhelmed. Although largely of braided stream origin, high-concentration flood deposits and debris flows are also present. Haughton and Bluck (1988) envisaged deposition of the conglomerates mainly as gravel braid bars that were continuously accreted on one bank as the channel migrated. The laterally extensive sheet geometry and limited number of thick cross-bedded bodies suggest that the channels were shallow and wide and that flow was unconfined periodically. The upward-coarsening units represent downstream migration of coarse bar-head deposits over the finer bar-tail ones.

Like the Carron Sandstone Formation, the Strathlethan Sandstone Member has been interpreted as the deposits of sandy bedload-dominated, braided streams, on the basis of the typical trough cross-bedding. The presence of mudstone with desiccation cracks and sandy mudstone rip-up clasts suggests distal, alluvial-fan, flood deposition or a decrease in stream discharges in a more proximal setting. Haughton and Bluck (1988) described part of the Strathlethan Sandstone Member as a sequence of rapidly aggrading, first-cycle alluvium (Type C), relating the diversity of the volcanic clasts to deposition of volcanic detritus in alluvial fans and aprons (Figure 3.13). The source volcanoes may have been of high relief, independent of tectonic processes that controlled the dispersal of non-volcanic sediment.

The zone of deformed sedimentary rocks at the base of the Strathlethan Sandstone Member was interpreted by Gillen and Trewin (1987), Carroll (1995a) and Trewin and Thirlwall (2002) as a major slide of partly lithified sands triggered by an earthquake of tectonic or volcanic origin. Robertson (1987) suggested sinistral, strike-parallel shear in weakly lithified sediments, rotated to the vertical by early tectonic movements. The restriction of the deformation to Strathlethan Bay favours a slide origin (Carroll, 1995a).

The rocks of the Castle Haven Conglomerate Member were interpreted by Haughton (1989) as the deposits of large braided streams flowing south or south-west on extensive alluvial-fans. Phillips and Carroll (1995) recognized debris flow and hyperconcentrated flood deposits in the volcaniclastic sandstones, introduced when large volumes of volcanic detritus, possibly of local origin, flooded the basin. One matter of debate concerns the change in clast composition recognized by Gillen and Trewin (1987), from conglomerates sourced from the Highland Border Complex at the base of the Castle Haven Conglomerate Member at the south end of Castle Haven to Dalradian-sourced conglomerates (not recognized by Bluck, 1984) to the south. This implies that the Grampian Highland Terrane was more-or-less in its current position at the time of deposition of the Castle Haven Conglomerate Member. However, the relative paucity of Dalradian clasts and the predominance of quartzite suggests that there was a thick cover of quartzite pebble conglomerate over the Grampian Highland Terrane, with little Dalradian outcrop available for erosion at any time during deposition of the Lower Old Red Sandstone (Gillen and Trewin, 1987; Trewin and Thirlwall, 2002).

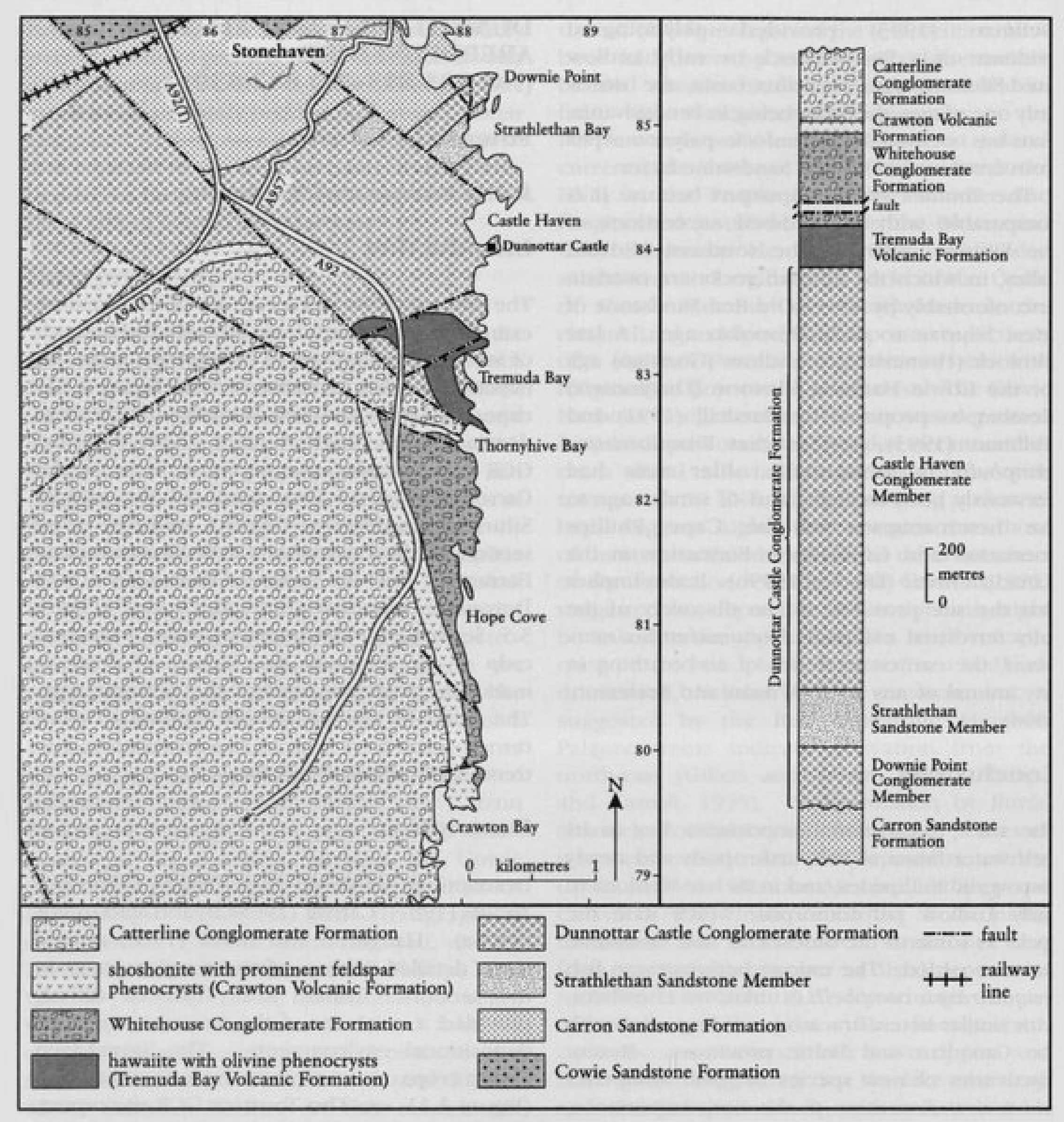
There is a strong contrast in grain size between the sandstone-dominated Stonehaven Group and the conglomerate-rich Dunnottar–Crawton Group. Both groups are thought to have been deposited in two small, separate pull-apart basins – the Stonehaven and Crawton basins. Bluck (2000, 2001) related their opening and closure to transtension and transpression respectively, along the Highland Boundary Fault Zone. The closure of basins resulted in the recycling of their sediments, with volcanic activity a natural adjunct to the rifting of the weak crust of the Midland Valley. The major depositional cycles fine upwards and become more mature petrographically upwards, indicating that initial rifting was followed by decreasing tectonic influence and a reduction in the relief of the source area.

Bluck (2000) commented on the enigmatic sources of the sediments in the Midland Valley Terrane, with both the Grampian Highland and Southern Uplands terranes extensively eroded before latest Silurian times. The Midland Valley of Scotland was therefore not a post-orogenic molasse basin, with mountainous areas to the north and south. These areas were not undergoing sufficient uplift to provide the huge volume of sediment preserved in the Lower Old Red Sandstone succession, nor were there slopes of sufficient gradient to supply much of the coarse gravels. The thick coarse conglomerates, such as those at Dunnottar, may therefore have been the product of recycling of sediment from a locally inverted, pop-up basin, or from older sedimentary cover in the area of the Highlands to the north. A now-hidden flysch below the centre of the Midland Valley to the south may also have contributed to the fill of the Dunnottar–Crawton Basin (Haughton, 1988). However, whereas local drainage may have accounted for the coarse gravels, it could not have supplied the huge volume of sands deposited. Bluck (2000) suggested a source in the Greenland–Baltica collision zone to the north-east of Scotland where major Silurian to Carboniferous (Scandian) uplift took place. Major river systems draining these mountains would have been able to enter the Crawton and Strathmore basins when relief was lowered sufficiently to allow them access. Large river bars in the Scone Sandstone Formation (Arbuthnott–Garvock Group) west of Perth provide evidence to support Bluck's (2000) model of a distant source of these major distributaries.

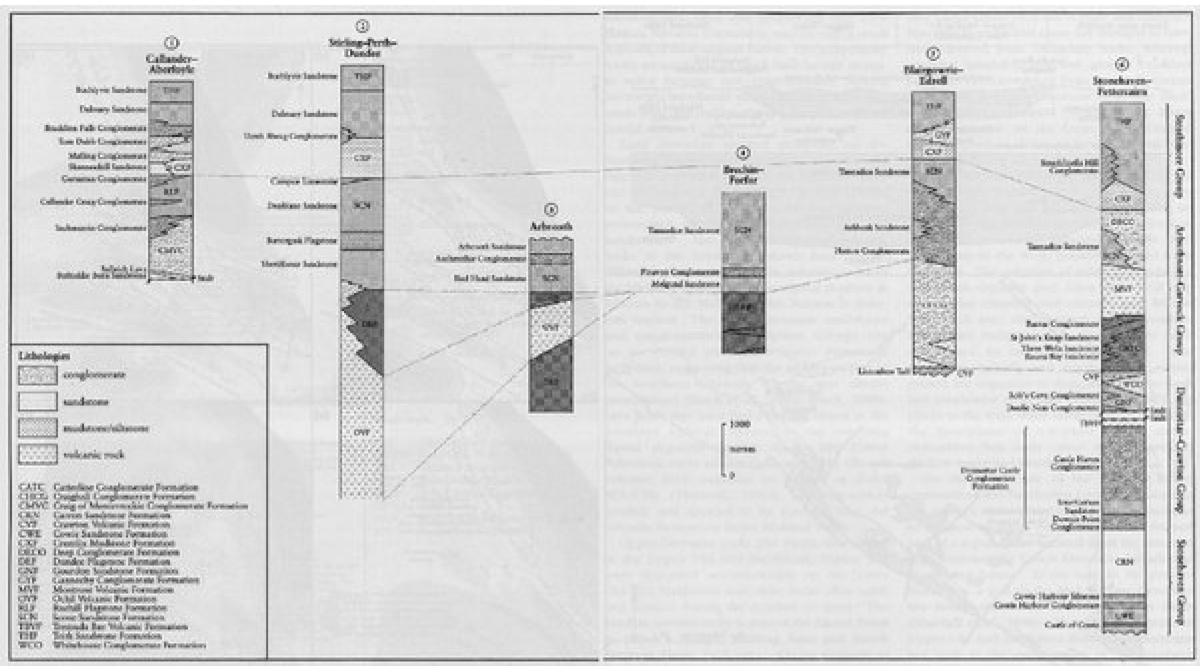
Conclusions

The sea cliffs and foreshore from Downie Point south to Dunnottar Castle and Tremuda Bay expose a magnificent section of Lower Old Red Sandstone conglomerates and sandstones. The importance of the section lies in the evidence it provides towards an understanding of the development of the earliest Old Red Sandstone basins in the Midland Valley, including the sources of the coarse gravels and sands that filled them. However, the sources remain enigmatic and interpretations are a matter of debate, and there is scope for further sedimentological and petrographical study.

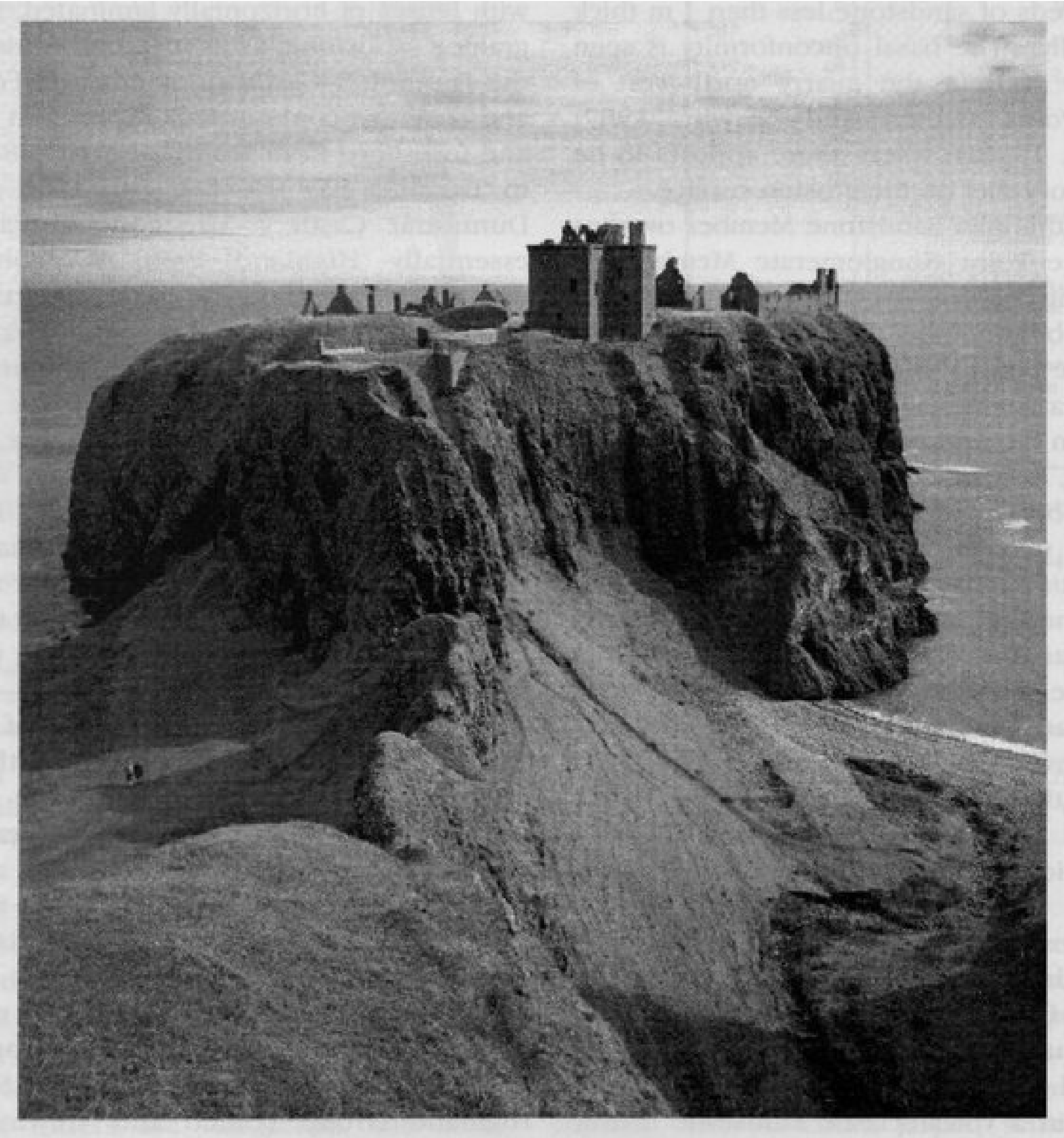
References



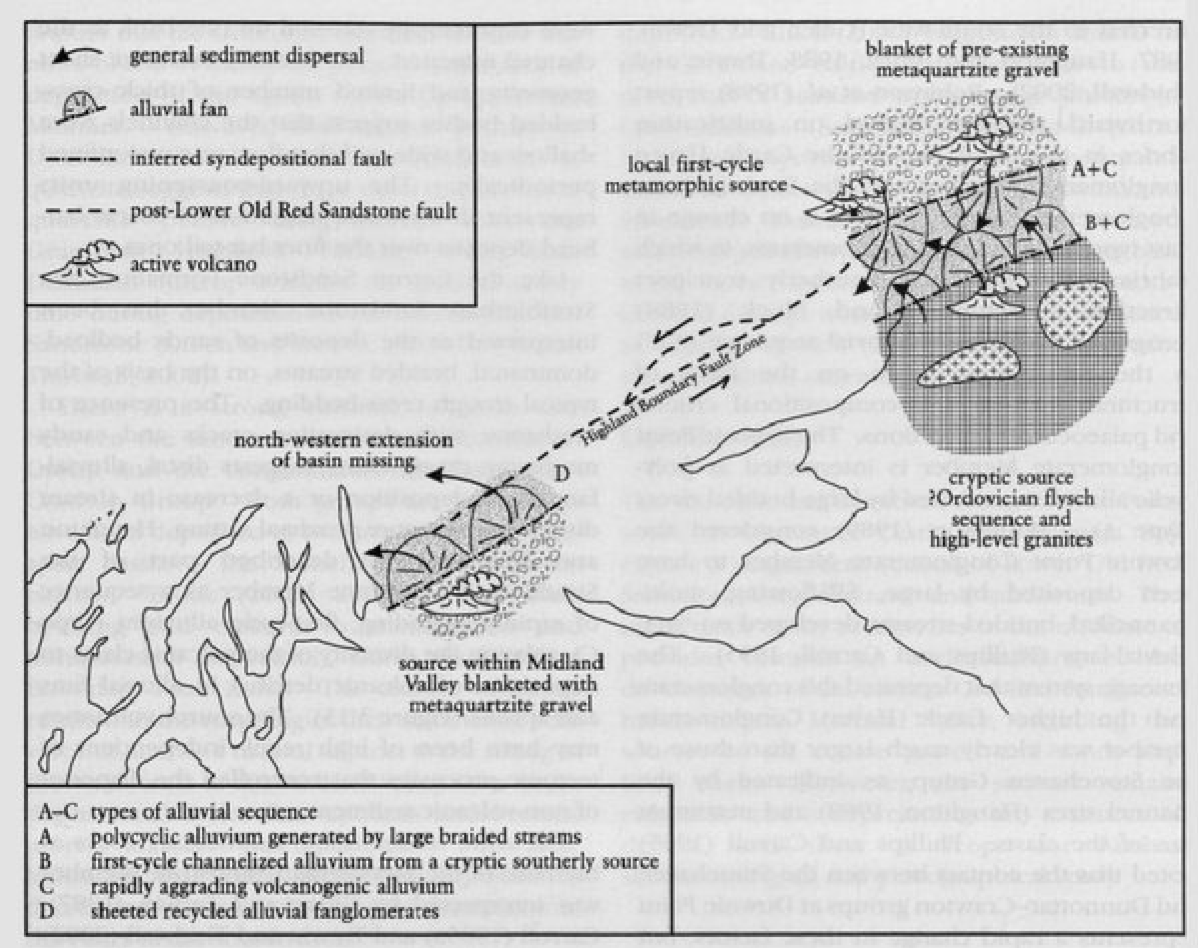
(Figure 3.11) Geological map of the area of the Dunnottar Coast Section, from Downie Point to Crawton Bay, with generalized vertical section of the strata. After British Geological Survey 1:50 000 Sheet 67 (Scotland), Stonehaven (1999).



(Figure 3.5) Sections of the Late Silurian–Early Devonian rocks in the northern Midland Valley. After Browne et al. (2002).



(Figure 3.12) Sub-vertical conglomerates of the Castle Haven Conglomerate Member of the Dunnottar Castle Conglomerate Formation at Dunnottar Castle [NO 882 839]. (Photo: BGS No. D5187, reproduced with the permission of the Director, British Geological Survey, © NERC.)



(Figure 3.13) Model for Lower Old Red Sandstone sedimentation in the northern Midland Valley. After Houghton and Bluck (1988).