Clashach to Covesea, Morayshire

[NJ 162 703]–[NJ 173 706]

Introduction

The coastal exposures between the quarries of Clashach and Covesea provide an excellent section in the Hopeman Sandstone Formation. This formation is dated as latest Permian in age on the basis of its contained fossil reptile remains and footprints. The sandstones show a variety of sedimentary lamination types within large-scale dune bedding. The site is significant for the detailed evidence it affords for a variety of desert dune types, including the unusual large-scale star dune form. Cross-strata, often affected by spectacular post-depositional defor mation structures, dip generally to the west, indicating that contemporary winds blew from the east.

The sediments and palaeoenvironmental reconstruction of the Hopeman Sandstone Formation have received much attention, with descriptions by Peacock *et al.* (1968), Williams (1973), Glennie and Buller (1983), Benton and Walker (1985), Clemmensen (1987), Frostick *et al.* (1988), Andrews *et al.* (1990), McKeever (1991, 1994), and Edwards *et al.* (1993).

Description

Numerous quarries were opened along the coastal cliff section between Covesea and Clashach in the 19th century, when the buff-coloured sandstone was shipped by sea to neighbouring towns for building purposes. The quarries were all abandoned until recently; modest quarrying has been resumed at Clashach. An alternative spelling of Clashach was 'Clashack' (Judd, 1873).

The Hopeman Sandstone Formation has been described under several names: the 'Sandstones of Cummingstone' (Huxley, 1859b, 1877), the 'Cununingstone Beds' (Hickling, 1909; Watson, 1909; Watson and Hickling, 1914), the 'Reptiliferous Sandstone' (Symonds, 1860; Harkness, 1864; Judd, 1873, 1886), the 'Sandstones of Cutties Hillock and Hopeman-Cummingstone' (Weston, 1951), and the 'Sandstones of Cutties Hillock and Cum-mingstone' (Peacock *et al.,* 1968). The unit was formalized as the 'Hopeman Sandstone Formation' by Warrington *et al.* (1980), and that term has been used since.

Sedimentology

The Hopeman Sandstone Formation consists of fine- to medium-grained, well-sorted, yellowish sandstones, with well-rounded, quartz-rich grains and well-defined, often complex, cross-bedded units that dip towards the west (Figure 2.3)a. Other sedimentary structures include rippled surfaces. In places the sediments have been deformed, producing spectacular examples of contorted bedding (Peacock *et al.,* 1968; Glennie and Buller, 1983; Clemmensen, 1987; (Figure 2.3)b. The formation has been divided into two informal units by Glennie and Buller (1983): the lower unit, exposed on the foreshore, consists of large-scale cross-bedded sandstones that pass laterally into substantial areas of deformed sediments; the upper unit has large-scale cross-bedding, but lacks soft-sediment deformation.

Two main sediment types have been distinguished (Clemmensen, 1987). Type-I sediments are typically arranged in trough-cross-bedded units that range from small (less than 1 m thick) to large (between 1 and 10 m thick), and even giant scale (more than 10 m thick). The dune slip faces and the lee faces of the trough-cross-bedded units are characterized by high to medium angles of dip. The foresets commonly contain evidence of sand flows. Type-II sediments are characterized by wedge-shaped large-and giant-scale, medium-angle cross-bedding. The foresets commonly preserve wind-rippled surfaces.

Scattered throughout the sequence are thin layers of coarser-grained sediments containing clasts that include granules, small pebbles, clay curls and flakes encrusted with sand grains, and intraformational clay rip-up clasts.

The excellent exposure of the sediments, especially along the coast, has enabled detailed descriptions of the sandstone units, nine of which have been identified from Covesea westwards to Hopeman Harbour (Clemmensen, 1987; (Figure 2.4)).

Sandstone unit 1 is exposed in the sea cliffs and on the foreshore to the north and north-east of Covesea village [NJ 171 705]; it consists of two large- or giant-scale, southward-dipping sets, each with large-scale deformation structures in the upper part. At the top of the unit, large-scale, southwards-dipping, trough-cross-bedded sets and medium-scale eastwards-dipping sets occur. Sandstone unit 2, exposed to the north and north-west of Covesea village [NJ 170 705], consists of two large sets, the lower with foresets dipping steeply towards the northeast, and the upper overlying the lower at an erosion surface. The upper set contains many deformation structures, and the foresets dip steeply towards the south. These large sets are overlain by several small- and medium-scale sets that form a wedge-shaped unit that thickens towards the south-west.

Sandstone unit 3 is exposed in the cliffs to the south-west of sandstone unit 2 (Figure 2.3)a. It comprises approximately 10 m of interbedded horizontally bedded and low-angle cross-stratified sandstone with multiple angles of dip, which infills the low-lying areas between sandstone units 2 and 4.

Sandstone unit 4 consists of two giant-scale sets, with maximum thicknesses of 15 m (set 4) and 30 m (set 5). Set 4 foresets dip towards the north and north-east and the angle of dip decreases towards the north, set 5 foresets dip towards the west, and there are well-developed tangential foresets. This set is subdivided into a series of small subsets that generally dip towards the north-east, and often wedge out in either the up-dip or down-dip directions. The giant-scale sets are associated with numerous intrasets, which are typically trough-formed and wedge-shaped.

On the foreshore between the Clashach and Covesea quarries [NJ 167 705] the two giant sets, with clearly defined bounding surfaces, of sandstone unit 5 are exposed. Set 6 is characterized by foresets that dip towards the southwest and south-east, and is trough-formed. Set 7 shows a range from trough to planar bedding and foresets dip towards the SSE.

Beds of sandstone in unit 6 are best seen in Clashach Quarry [NJ 162 702] and in the nearby coastal exposures. These sediments have a complex geometry and consist of several overlapping units; they display sand-flow layers, trough cross-bedding, and low-angle stratified sand sheets with a wide range of angles and directions of dip.

Sandstone unit 7 is composed of bi-modally-dipping large- and giant-scale sets, and is associated with low-angle beds with channels, scatters of granules, and small current ripples.

Near Hopeman Harbour [NJ 145 700], sandstone unit 8 is characterized by two bi-modally-dipping, large- and giant-scale sets. Towards the east, a sequence of low-angle interdune and channel sediments occurs. To the west, the large-scale trough-cross-bedded sets of sandstone unit 9 occur; these generally have a high angle of dip towards the south-west.

Deformation structures are common throughout the Hopeman Sandstone Formation, and fre quently occur in the lower unit of Glennie and Buller (1983); they are complex and take several forms (Figure 2.3)b. In the cliffs close to the coastguard's station [NJ 176 708], the cross-bedded sandstones preserve a 10-m-high, triangular-shaped, fluid escape structure (Glennie and Buller, 1983, p. 58). Within the core of this structure, the deformed bedding is very poorly defined, although at the margins the laminae and beds are better preserved; crumpling of the beds suggests that vertical compaction of the sediments also took place. Close to Hopeman, the sandstone has been deformed into a shallow saucer shape, composed of laminated sediments cut by narrow vertical bands of structureless sediment. The laminated sediments were deposited on the upper windward face of the dunes, and appear to have collapsed into an underlying patch of quicksand. Also close to Hopeman, 3 m of deformed sandstones have been inverted over a low-angle fold plane that dips towards the north-west.

The sediments are unevenly cemented by silica and iron oxides, with smaller patches of barite and carbonates. Where carbonate cements predominate, the softer, less resistant sediment has been removed by erosion, producing hollows and cavities (Mackie, 1902a; Peacock *et al.,* 1968; Clemmensen, 1987).

Palaeontology

The Hopeman Sandstone Formation has yielded many vertebrate footprints. At Clashach Quarry a substantial slab of sandstone displays a series of large footprints arranged in a short length of trackway (Sarjeant, 1974; Benton and Walker, 1985; Benton and Spencer, 1995; Hopkins, 1999). The footprints have been assigned to four ichnospecies of *Chelichnus* (McKeever and Haubold, 1996). It is likely that the animals responsible for these tracks were dicynodont mammal-like reptiles and pareiasaurs (McKeever, 1991, 1994). A skull of *Dicynodon* (*Gordonia*) has also been reported from the working Clashach Quarry (Clark, 1999).

Interpretation

The Hopeman Sandstone Formation sediments were deposited on the southern edge of the largely offshore Moray Firth Basin (Clemmensen, 1987; Frostick *et al.,* 1988; Andrews *et al.,* 1990; Edwards *et al.,* 1993). The sandstone units exposed along the coastline between Covesea, Clashach, and Hopeman Harbour have been collectively interpreted as part of a substantial dune field. The dominant processes of sediment accumulation and deposition were aeolian, although there is evidence for periodic, minor, fluvial activity. The individual sandstone units represent localized features within the desert environment. The dominant wind direction during deposition was from the NNE, with secondary winds from the SSE, and subordinate winds from the north-west (Clemmensen, 1987). Glennie and Buller (1983) interpreted the main dune type as transverse dunes, while Clemmensen (1987) regarded them as mainly crescentic and star dunes (Figure 2.4); the latter interpretation is followed below.

Sandstone unit 1, characterized by large-scale southward dipping foresets capped with smaller-scale east and southwards dipping troughs and sets, has been interpreted as the slip-face deposits of a southwards-migrating crescentic dune, or possibly as an incipient star dune, that were eroded and overlain by sandsheet deposits. The dominant wind direction was from the north, although the dips of the foresets in the upper beds suggest alternation between southerly and north-easterly winds (Clemmensen, 1987).

Sandstone unit 2, with two sets with foresets that dip at high angles to the north-east and south, and are overlain by smaller-scale sets arranged in a wedge, is interpreted as the two faces of a NW–SE-trending arm of a star dune. This feature was eroded and replaced by sand sheets deposited under the influence of bi directional prevailing winds.

The interbedded, laminated and low-angle aeolian cross-bedded facies of sandstone unit 3 indicate interdune sedimentation. The great thickness of this unit suggests that contemporary star dunes were relatively static features of the landscape.

Sandstone unit 4, characterized by two giant-scale sets, with widely differing angles of foreset dip, formed part of a NNW–SSE-trending arm of a star dune. The intrasets formed during periods when the wind direction fluctuated between the north-east and south. This resulted in the faces of the star dune arm alternating between the lee- and stoss-side. Set 5 is interpreted as the west-facing side of the dune arm, and also preserves features consistent with deposition under fluctuating wind directions. The north-east face of the dune merges into an area dominated by relatively small barchans (Clemmensen, 1987).

The trough and planar cross-bedded sediments of sandstone unit 5 were deposited by crescent-shaped dunes, probably as part of a complex star dune migrating to the south-west. A similar mode of deposition is considered likely for the unit 6 sandstone. Here, the characteristic wide range of directions of dip is best explained in terms of a complex star dune with many crescent-shaped segments. The unit 6 star dune is a development of the feature recorded by sandstone unit 5, and it continued to migrate towards the south-west.

The bi-modally dipping large-scale sets with the associated coarse-grained material and channels of sandstone unit 7 record both aeolian and fluvial environments. The aeolian sediments were deposited on a large arm of a star dune. Nearby, interdune areas contained small channels, and the presence of small current ripples indicate that the interdune regions were periodically flooded (Clemmensen, 1987). Sandstone unit 8 represents deposition on and around the arm of a sinuous-crested star dune arm.

The overlapping large-scale trough-cross-bedded sets of unit 9 were deposited by barchan dunes that were migrating mainly towards the south-west (Clemmensen, 1987).

The soft-sediment deformation structures have been interpreted as either the result of a major phase of air escape following a dramatic transgression event (Glennie and Buller, 1983), or as liquefaction induced by heavy rainfall (Peacock, 1966; Clemmensen, 1987). The latter interpretation seems more likely, by comparisonwith soft-sediment deformation structures seen elsewhere in aeolian sequences. Frostick *et al.* (1988) suggested that the deformation happened by slumping of the sands down the flanks of large dunes following heavy rainfall. The air-escape and marine inundation idea is weakened by the fact that there is no evidence of erosion anywhere, nor are there any superincumbent marine beds.

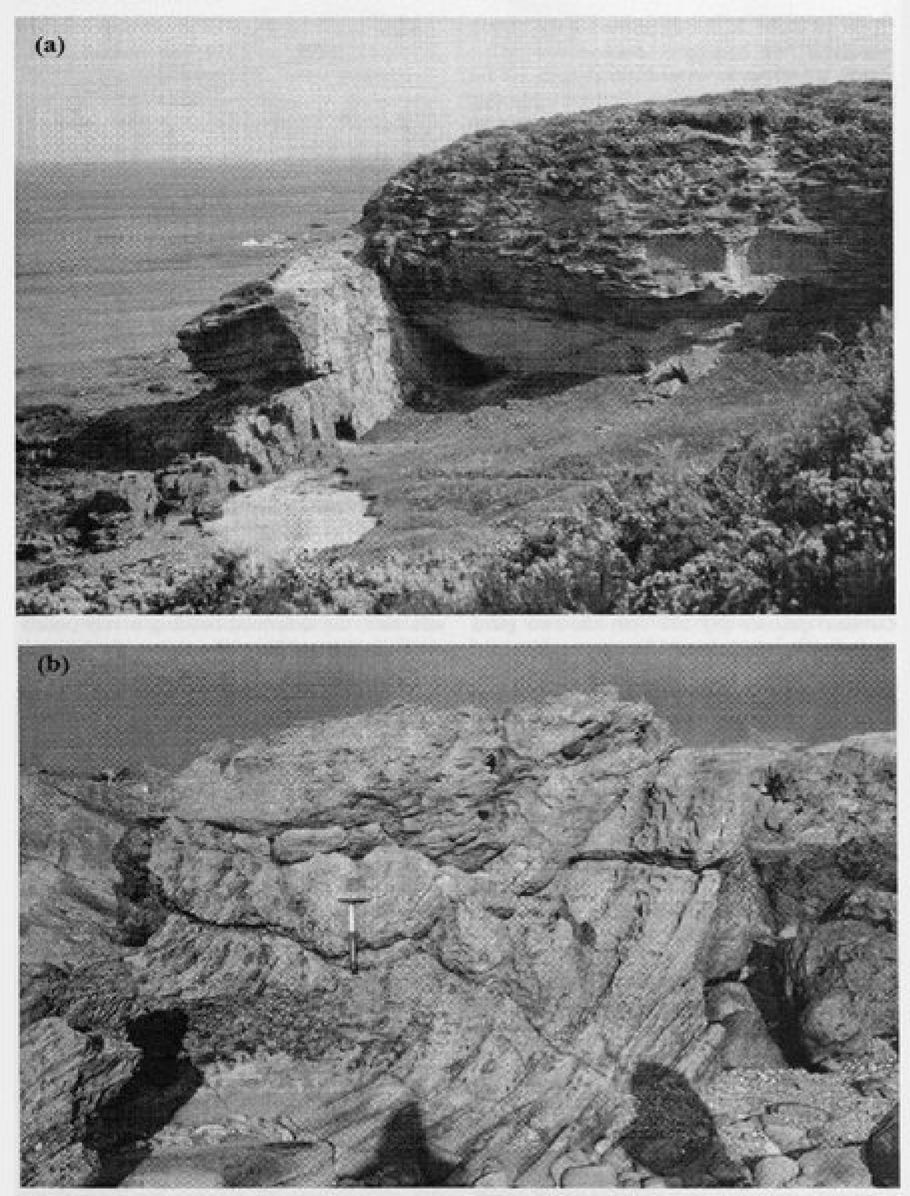
The age of the Hopeman Sandstone Formation has been the subject of much discussion (see above). The footprints, and the recent find of *Gordonia* (*Dicynodon*), from Clashach and Masonshaugh, and the reptile skeletons from probably coeval sandstones inland at Cutties Hillock, have been used to posit either a Late Permian or an Early Triassic age. The dicynodonts *Gordonia* and *Geikia* from Cutties Hillock, and the interpretation of most of the footprints as having been made by dicynodonts, is not immediately helpful since dicynodonts range from Late Permian to Late Triassic in age. However, *Gordonia* is virtually identical with *Dicynodon* from the Late Permian rocks of South Africa, and this indication of a latest Permian age is confirmed by the pareiasaur *Elginia* from Cutties Hillock; pareiasaurs are known only from latest Permian deposits.

The deformation structures might also offer evidence of age. Glennie and Buller (1983) argued that they matched those in the Weissliegend of Germany (see (Figure 1.3)) and the southern North Sea, and hence indicated a Mid Permian age. The deformation structures in both units were linked to the Zechstein transgression. However, analysis by Clemmensen (1987) indicates that there is no stratigraphical relationship between the various examples of deformation structures, and the palaeontological evidence for age takes precedence.

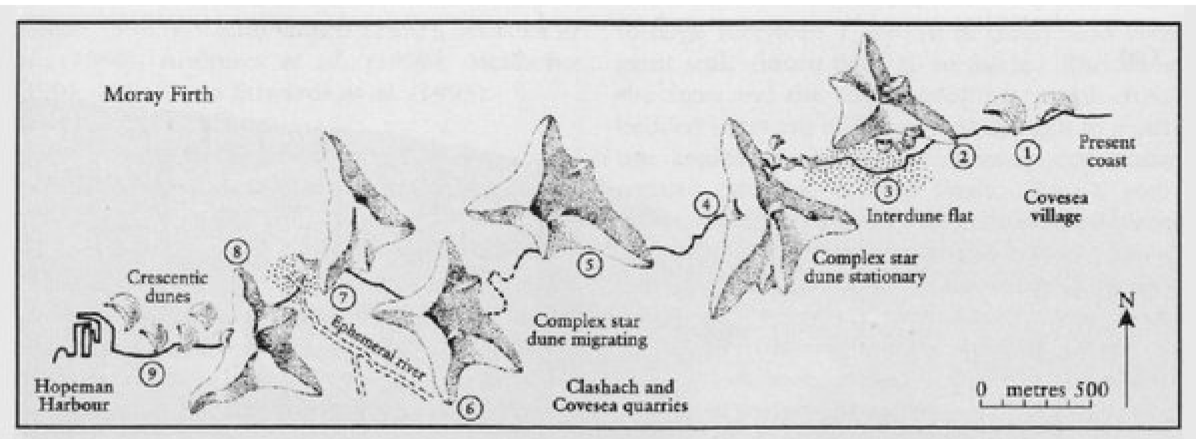
Conclusions

The Permian sediments of the Hopeman Sandstone Formation preserve rare examples of star dunes. The dominantly arenaceous sediments were deposited in a substantial dune field characterized by crescentic barchan dunes, mobile and stationary star dunes, and interdune accumulations and coarse-grained fluvial deposits. Fossil footprints, and the skull of a dicynodont, indicate that the dune field was inhabited by a fauna of reptiles.

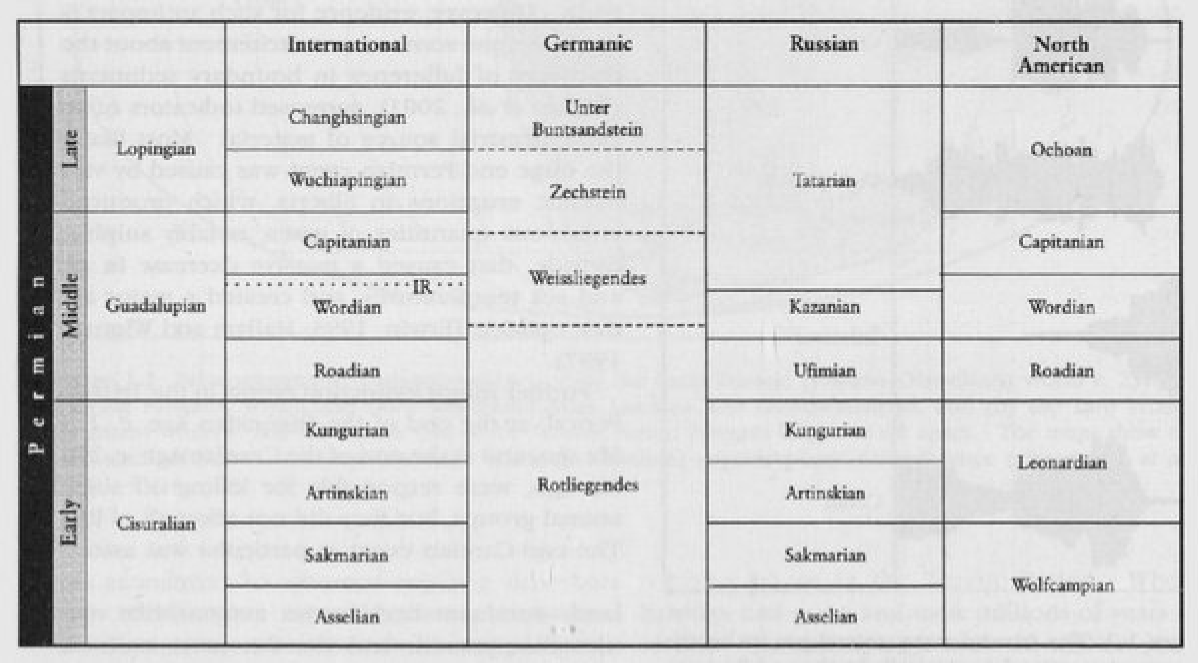
References



(Figure 2.3) The Permian Hopeman Sandstone Formation in the cliffs between Clashach and Covesea. (a) Cliff section (looking east) showing cross-bed dune sets representing a complex star dune. (b) Sand dune deposits north of Covesea Quarry, showing localized synsedimentary deformation; part of dune No. 5 on <a href="gcr24_02_04.html (Figure 2.4) (Photos: (a) C. J. MacFadyen, (b) P Turner.)</figcaption>



(Figure 2.4) Reconstruction of the large-scale star dunes shown by outcrops in the Clashach–Covesea section. Numbers (1) to (9) are the individual dunes, as referred to in the text. (After Clemmensen, 1987.)



(Figure 1.3) Permian stratigraphy, showing the international scale (Jin Yugan et al., 1997), and main equivalent divisions from successions in Germany and central Europe, Russia, and North America. The Illawarra magnetic reversal event (IR) is documented in the top Wordian Stage, and high in the Rotliegendes, so the 'Zechstein' lithostratigraphical unit falls in the Capitanian Stage or higher. (Based on Jin Yugan et al., 1997 and Wardlaw, 2000.)