Excursion guide 13: The Permo-Triassic sandstones of Morayshire, Scotland

S. OGILVIE, K. GLENNIE &
C. HOPKINS

The Permo-Triassic sandstones of Morayshire, NE Scotland, are host to an impressive coastal display of sedimentary structures, trace fossils and fault rocks (Fig. 1). The late Permian Hopeman Sandstone is exposed for nearly 10 km as a narrow coastal strip between Covesea [NJ199709] and Cummingstown [NJ132639], where it comes into contact with the overlying Triassic Burghead Beds along the Lossiemouth Fault. The sandstone has a maximum proven thickness of 60 m (BGS borehole data, Clarkly Hill). Other occurrences of the Triassic in the area are found at Findrassie, Spynie and on Lossiemouth shore. The 'Stotfield Cherty Rock' is a laterally extensive fossil soil horizon (calcrete with secondary silica) that forms a good seismic reflector throughout the Inner Moray Firth Basin, where it caps the Upper Triassic Lossiemouth Sandstone. It is not only a valuable marker horizon within the basin but also an indicator of structural quiescence and a semi-arid climate.

The Hopeman Sandstone lies unconformably on Devonian sediments, a relationship observable with the stratigraphically equivalent Cutties Hillock Sandstone in quarries at Quarry Wood, west of Elgin (Fig. 1). The 'New Red Sandstone' succession for onshore Inner Moray Firth is illustrated in Fig. 2.

Fig. 2. Stratigraphy of the 'New Red Sandstone' in the Elgin District.

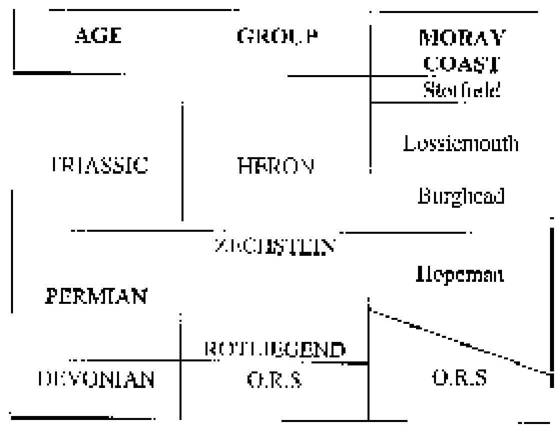

Fig. 1. Location map.

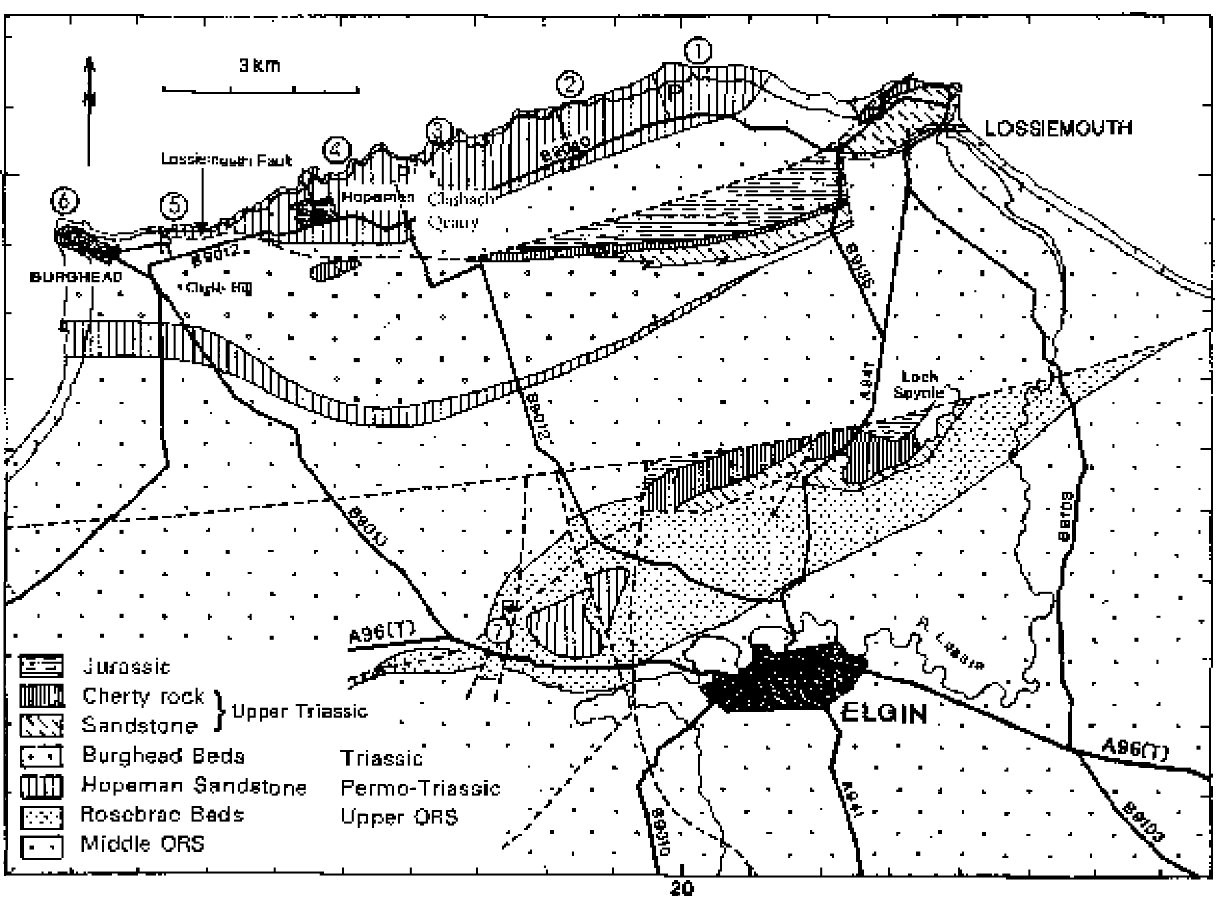

Fig. 3. South-dipping dune sand passes up abruptly into two pods of highly deformed sand separated by sandstone that has been homogenized.

The recommended map for this excursion is OS 1 : 25 000 Pathfinder 146 (Elgin). To reach the eastern extremities of outcropping Hopeman Sandstone from Aberdeen or from Inverness, take the A96 into Elgin, then the A941 towards Lossiemouth, forking left on the B9135, which will take you onto the B9040. This road parallels the coastal outcrop and tracks to each locality head northwards towards the coast. Note that the majority of localities are tidally influenced and it is advisable to check tide times before carrying out fieldwork.

Locality 1: Deformation structures at Covesea [NJ 199 709]

Continue on the B9040 past the caravan park and take the rough track to the right, which goes to the hamlet of Covesea. Park on the grass to the right of the road before reaching the cottages. Follow the path down to the right until you come to the Hopeman Sandstone outcrop, which is flanked to the east by a sandy beach. Here, a headland with extremely planar south-dipping dune foresets shows an abrupt upwards transition into highly deformed sandstone (Fig. 3). The large-scale planar dune bedding, coupled with laminated, well-sorted and rounded sand grains, is indicative of an aeolian environment of deposition – here, perhaps, as transverse dunes. The deformation features are likely to be air-escape structures formed during fluvial flooding of unconsolidated dune sands, possibly about the time the Zechstein Sea transgressed the Central North Sea Basin. The lack of deformation features on the cliffs landward from this outcrop and at the western end of this small headland, where reptile footprints are exposed on a south-facing slope, emphasizes the very localized areas where deformation was possible. Note the wave-cut, cliff-girt, probably early Holocene, embayment to the south, now above sea level.

Fig. 4. Large-scale deformation structures on the cliffs below Covesea Coastguard Tower.

Locality 2: Fluid-escape deformation structures below and just west of Covesea coastguard tower [NJ 182 707]

Continue along the B9040 and take the first turning on the right into a small parking area before the gate, flanked by a belt of trees to its west. Walk up the track (for about 360 m) leading to the coast, and at the coastguard station bear right down to the coast about 45 m along this path. Hanging in a narrow cleft in the cliff is a vertical ladder (with nylon rope) leading almost to the foot of the cliff. Negotiate large boulders at the foot and onto the wave-cut foreshore to the west. Beware of slippery, seaweed-covered sandstone outcrop and boulders. Traverse around headland, or go through high ceiling-cave, to the bay beyond. This represents the most accessible route to the bay but is certainly not for the faint hearted nor for large groups!

In the cliff at the far end of the small bay is a most impressive deformation structure, which rises vertically from homogenous sand at sea level (behind the camera in Fig. 4) to the cliff-top some 20 m higher. Undoubtedly, this is the tallest individual deformation structure in the Hopeman Sandstone! Deformation is less intense to the east and dies out rapidly to the west. There is a high degree of verticality about this structure, which is thought to have resulted from the escape of air through rain-dampened dune sand. The air was trapped within pores in the dune's core and compressed by the fluvial flood water outside, coupled with the penetrating effects of capillarity. Concertina folding of its west flank implies collapse following initial uplift, presumably as the air escaped. Some boulders on the foreshore exhibit brittle fracture of presumed moist sand.

(a)

(b)

Fig. 5. (a) Reptile footprints preserved in Hopeman Sandstone from Clashach Quarry; (b) trackways, one with sinuous tail drag.

Digitigrade: walking in such a way that only the toes touch the ground.

Locality 3: Fossil footprints and aeolian sedimentary structures at Clashach Quarry [NJ 163 702]

Further along the main road towards Hopeman, at the junction with the B9012 Elgin–Hopeman road, turn right up to the small parking area at the northern end. Do not block entry or exit of quarry trucks through the gate. Approximately five minutes walk eastwards towards Clashach Quarry is a display of reptile footprints. This was physically arranged by the quarry workers and Carol Hopkins, but the interpretation site as a whole was a joint venture between the quarrymen (Moray Stone Cutters), Carol, the National Museum of Scotland and Scottish Natural Heritage.

These trace fossils are believed to have been formed by several mammal-like reptile genera, possibly dicynodonts, and the discovery of the mould of a dicynodon skull at the adjacent quarry in 1997 confirms their presence at this locality. The trackways in the display, and over 300 others, are from recent excavations at the quarry, but similar footprints have been found throughout the Hopeman Sandstone. The footprints are preserved on bedding planes, possibly dune foresets, usually as digitigrade or foreshortened prints (Fig. 5a). A digitigrade stance had not yet evolved at the end of the Permian and the foreshortened prints are probably undertracks where only the deeper toe impressions are evident. The footprints range in size from 5 mm to 240 mm wide with clear differences in gait and morphology and over 140 of the trackways have associated tail drags (Fig. 5b). The quality of preservation of many of the prints indicates that the substrate was damp when the tracks were made, and trackways recorded in situ before extraction indicate that the reptiles were heading north, perhaps in search of water in a semi-arid river- and lake-floored predecessor in the centre of the modern Moray Firth Basin. The dicynodon skull and other trackways are on display in Elgin Museum.

The quarry itself may not be visited without prior permission of the quarry manager. The quarried sandstone is very hard and durable by virtue of abundant silica cementation and has recently been used in major building contracts (e.g. the Museum of Scotland in Edinburgh). On the seaward side of the quarry, a steep path leads past a soot-grimed cave to an old quarry face, which displays large-scale dune bedding and spectacular truncation surfaces (Fig. 6). Before taking this path, ensure that red flags denoting imminent blasting in the quarry are not displayed.

Locality 4: Sedimentary and diagenetic structures east of Hopeman village [NJ 145 699]

At Hopeman harbour, turn right along a rough coastal road and park in the second car park opposite the middle of a row of beach huts. Pass between the huts to the beach, where south-dipping Hopeman dune sand is host to star-like growths of barite (barium sulphate), which give the sandstones a nodular appearance. This results from the more rapid differential weathering of the softer sandstone. These cements are a common feature of the sandstone at many localities and have a spatial distribution related to fracture systems, suggesting that the barite was introduced into the sandstone via fractures (Fig. 7).

Fig. 6. Large-scale dune bedding and truncation surfaces at Clashach Quarry.

At the far end of the beach, a wave-cut platform shows evidence of local homogenization of the bedding and of limited deformation. At its eastern extremity, a raised sequence of gently dipping sandstone is cut by vertical deformation. A fold axis on the eastern side of the outcrop indicates that the top 4 m of the sandstone was inverted while still a soft sand. Such a structure could form only if the sand had sufficient capillary strength (provided, as in sand castles, by damp sands whose pores were still filled with air) to prevent collapse. Sand uplifted by air escaping from the site of the adjacent geo is interpreted to have slid (shear plane) down the windward slope of the dune towards the present sea (Fig. 8a). It was formed by a post-sedimentary, not tectonic, process. Figure 8(b) is a conceptual sketch of how the dune sand possibly became overturned. Air escape along the small geo (1), south of the axis of overturning, caused uplift of adjacent damp bedding on the northern (windward) flank of the dune. Being unstable, the uplifted bedding then rolled back and slid down to the north along a shear plane, perhaps helped by local subsidence as sand at (2) was extruded from below. The hollow surface of dune sand south of the geo may also have been caused by air- and water-assisted extrusion of sand.

Fig. 7. The distribution of barite cements in relation to fracture systems. Do not be confused by the limpet shells!

Continue eastwards past many deformation structures until you reach interbedded to overlying, thinly bedded, low-angle N-dipping sandstones of shallow-water origin. These represent mostly post-deformational flash-floods in a desert environment marginal to the Grampian Highlands and contain thin beds of granules (Fig. 9) and some rippled and streaming surfaces. Other structures indicative of a wet environment beneath the granule layers include sandstone dykes, which intrude subvertical dune bedding (Fig. 10), and shallow-water oscillation ripples (Fig. 11). To the right of the pencil scale in Fig. 11 there are reptile footprints embedded in the ripples, indicating that the reptiles entered into bodies of shallow water in search of food. This photograph was taken in 1995, since when one of the footprints has been stolen and the National Museum

(a)

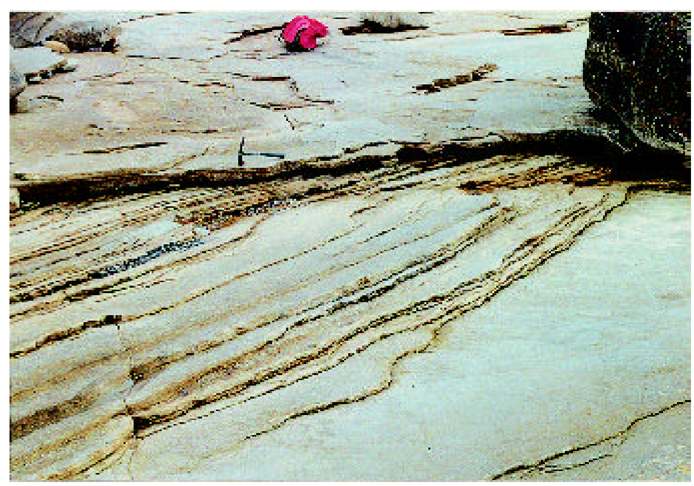

Fig. 9. (above) Shallow-water sandstones containing a bed of granular sandstone of probable fluvial origin just above the level of Fig. 10. Behind the big boulder, large ripples and streaming lineations suggest the effect of the northward flow of shallow water down a gentle slope.

(b)

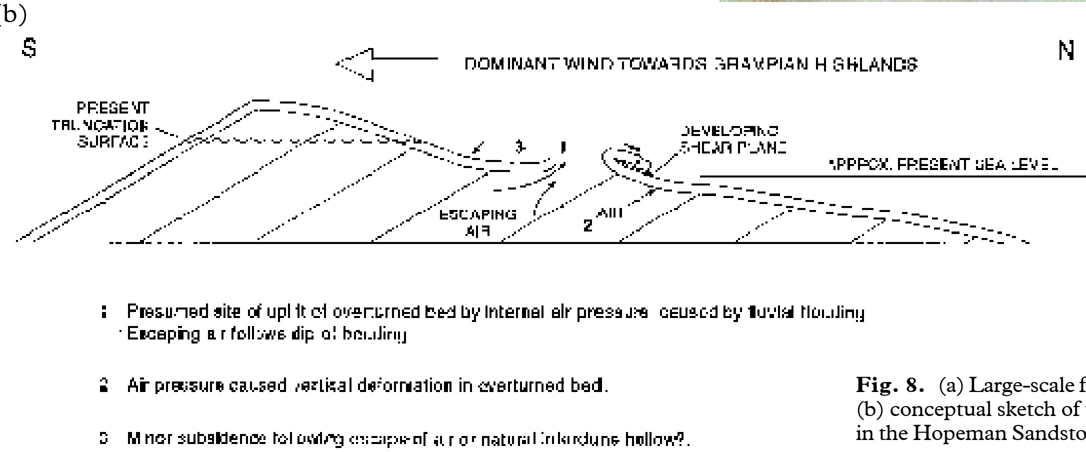

Fig. 8. (a) Large-scale folding in Hopeman Sandstone; (b) conceptual sketch of the origin of overturned bedding in the Hopeman Sandstone.

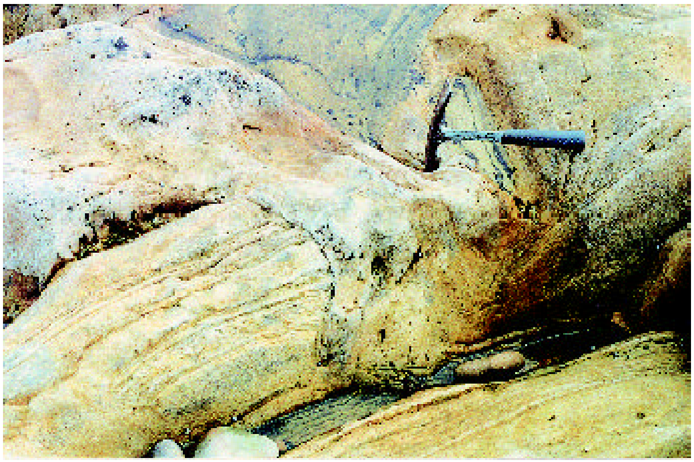

Fig. 10. (left) Sandstone dyke in the Hopeman Sandstone.

Fig. 11. (right) Shallow-water oscillation ripples and reptile footprints in the Hopeman Sandstone beyond Fig. 9.

of Scotland removed most of the remaining rippled surface for safekeeping.

Location 5: Fault compartmentalization on a wave-cut platform [NJ 126 691]

West of Cummingstown, take a right turn at the Red Craig hotel onto the backroad to Burghead. Park in the grassy area adjacent to a field on the outskirts of Burghead [NJ 123 690] and take the coastal path to Masonhaugh Quarry [NJ 126 691]. The pebbly bay to the north of the disused quarry is characterized by an extensive wave-cut platform transected by E–W-trending ridges. This is where the faulted contact between the Hopeman (Permian) and Burghead (Triassic) sandstones assumes a splaying geometry. These normal fault systems contain mm-thick microfaults, which form compound zones, accommodating metre-scale displacement (Fig. 12a). However, there are abrupt transitions into regions of relatively undeformed sandstone containing solitary microfaults, which accommodate mm-scale displacement (Fig. 12b). These structures have dramatic reductions in porosity and permeability relative to the host sandstone and hence would present baffles to the flow of hydrocarbons in analogous subsurface reservoirs. This has impact at the production stage of an oilfield but on a geological timescale such structures may be effective barriers to migrating hydrocarbons. The latter is probable as they have significantly higher values of capillarity than the host sandstones. It is therefore important to avoid such structures not only in hydrocarbon exploration but also in the development of water aquifers.

Fluorite (calcium fluoride) cements are patchily distributed throughout the wave-cut platform and like barite they have been introduced through the fractures (Fig. 13). These have the effect of further degrading the quality of the sandstone as a potential reservoir rock. They are, however, local in distribution, having been introduced through portions of the fracture zone, which have experienced dilation.

(a)

(b)

Fig. 12. (a) Compound zone of microfaults in the Hopeman Sandstone, having a well-defined slip-surface throwing to the north; (b) plan-view of (a), showing a sharp transition into a zone of abundant microfaults from a region of relatively undeformed sandstone.

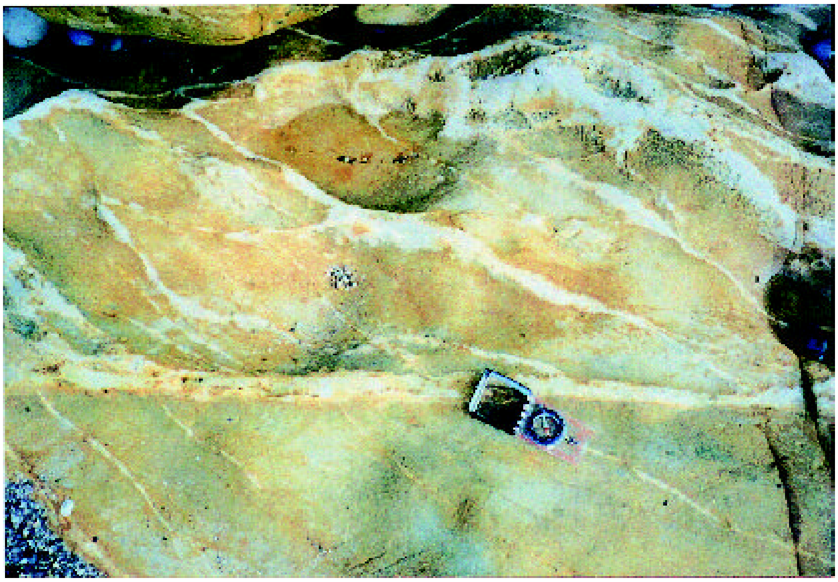

Fig. 13. Fluorite cements in Hopeman Sandstone in relation to fractures.

Location 6: Fluvial sandstones at Burghead harbour [NJ 108 692]

Follow the road into Burghead to the car park at the very end of the village. From here, go down the steps on the harbour wall to a classic section of the Burghead Beds (Fig. 14). The cliff contains yellow–brown sandstones, with pebbly bands and rare silty layers together with common calcite cements. The small-scale trough bedding is a further indication of fluvial origin. Foresetting of the sands and imbrication of the pebbles indicate fluvial transport apparently parallel to the coast, possibly controlled by local faulting. There is a channel at the top of the section, with cross-bedding to the north-east. It is likely that these sediments were transported by ephemeral streams from the south-west, and piled up against the southern unfaulted margin of a structure analogous to more recent half-graben examples.

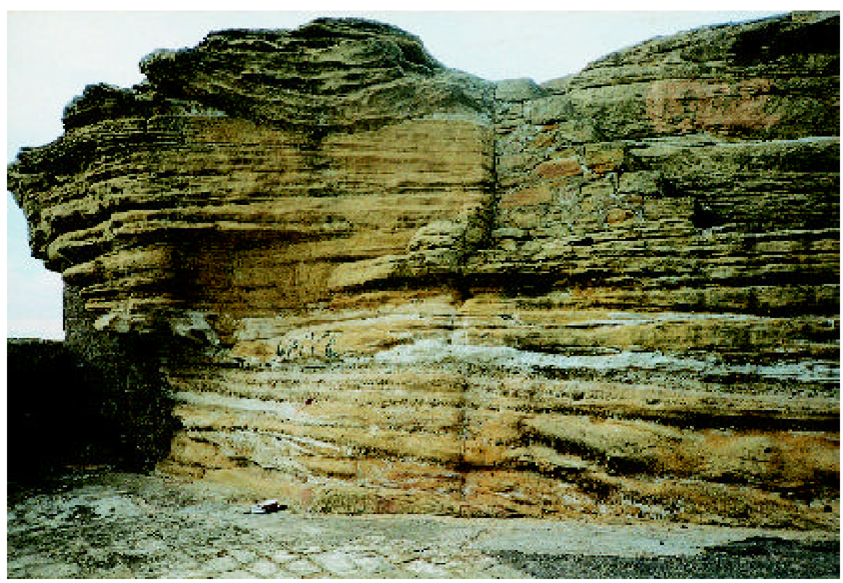

Fig. 14. Triassic fluvial sandstones at Burghead harbour.

Location 7: Triassic sandstones at Quarry Wood [NJ 174 633]

From Burghead, take the B9013 and join the A96 to Elgin. About 1 km along this road at a cross roads, turn left in the direction of Spynie Church. Park at the forestry track entrance, about 50 m along this road and walk northwards into Quarry Wood. Here the Cuttie's Hillock Sandstone (Permo-Triassic) rests unconformably upon the 'Old Red Sandstone' (Devonian). There has been some debate about the time-equivalence of the Cuttie's Hillock and Hopeman Sandstones, but both are generally considered to be of Upper Permian age.

There are two quarries at the end of the track, one of Devonian sediments and the more overgrown of the two is host to the Cuttie's Hillock Sandstone. The sandstone contains large-scale (aeolian) cross-bedding and dreikanter pebbles with rounded edges suggesting that they were exposed to the wind before being reworked by water. The quarry is one of the sites of the famous Elgin reptiles, *Elginia*, *Gordonia* and *Geikia*, discovered in 1893 and now housed in Elgin Museum.

Suggestions for further reading

Clark, N.D.L. 1999. The Elgin Marvel, *OUGS Journal*, v.20, pp.16–18.

Edwards, H.E., Becker, A.D. & Howell, J.A. 1993. Compartmentalization of an aeolian sandstone by structural heterogeneities: Permo-Triassic Hopeman Sandstone, Moray Firth, Scotland. From North, C.P. & Prosser, D.J. (eds) 1993, *Characterisation of Fluvial and Aeolian Reservoirs*, Geological Society Special Publication No. 73, pp.339–365.

Frostick, L., Reid, I., Jarvis, J. & Eardley, H. 1988. Triassic Sediments of the Inner Moray Firth, Scotland: early rift deposits, *Journal of the Geological Society, London*, v.145, pp.235–248.

Glennie, K.W. & Buller, A.T. 1983. The Permian Weissliegend of NW Europe: The partial deformation of Aeolian dune sands caused by the Zechstein transgression, *Sedimentary Geology*, v.35, pp.43–81.

Hopkins, C. 1999. New finds in the Hopeman Sandstone, *OUGS Journal*, v.20, pp.10–15.

Peacock, J.D., Berridge, N.G., Harris, A.L. & May, F. 1968. *The Geology of the Elgin District*. Memoir of the Geological Survey of Scotland, HMSO, Edinburgh. 165pp.

S. Ogilvie, K. Glennie and C. Hopkins are at the Department of Geology and Petroleum Geology, University of Aberdeen.

Literary geology: 'The importance of the North Pennines and its lead-mining industry in the poetry of W. H. Auden has yet to be properly acknowledged by Auden scholars. There are numerous works by Auden with a North Pennine setting: the poems, "The North", "Allendale", "Lead's the Thing", "The Pumping Engine, Cashwell", etc, and the plays *Paid on Both Sides* and *The Dog Beneath the Skin*; the epiphany, in which Auden became conscious of himself as an artist, occurred in 1922 at Rookhope in Weardale, when he dropped stones down a flooded mineshaft. The scene is recorded in "New Year Letter"… In the same poem, Auden wrote about "the limestone moors" and the "lead-smelting mill", and how his younger self "from the relics of old mines/Derives his algebraic signs".' – J.C., *TLS,* 28 May 1999.