# Pennyland (Thurso–Scrabster), Caithness

[ND 102 696]–[ND 115 685]

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## Introduction

The cliff and foreshore section between Thurso and Scrabster provides excellent exposures of part of the Middle Devonian Upper Caithness Flagstone Group. The lithofacies present were produced during the cyclical deepening and shallowing of a large lake occupying part of the Orcadian Basin; about 20 cycles are represented, with abrupt transitions from laminated mudstones deposited in a deep lake, to cross-bedded sandstones deposited in an ephemeral, playa-lake environment. A remarkable range of shrinkage cracks have either a subaqueous or subaerial origin, and their correct interpretation is crucial for an understanding of lake history within the Orcadian Basin. Fossil fish faunas from the laminated mudstones are of great importance and have led to the site being separately selected for the GCR for its fossil fishes (Dineley and Metcalf 1999). Of the 20 laminite horizons, 16 yield fish remains, most of them small fragments, but 7 or 8 laminites contain complete plates or complete fishes. Field guides to the site are provided by Donovan (1978), Parnell *et al.* (1990) and Trewin (1993).

The regional importance of the Pennyland (Thurso–Scrabster) site lies in the exceptionally well-preserved evidence for lacustrine depositional cydicity, allowing interpretation and characterization of an otherwise poorly exposed part of the Orcadian Basin succession. The site is also important in the broader interpretation of the tectonics, lithostratigraphy and palaeogeo-graphy of the Orcadian Basin. The conservation value and importance of the site also rests in the good quality of its fossil fish remains.

## Description

Along the south-west side of Thurso Bay, between Thurso and Scrabster, an extensive coastal section affords excellent exposure through part of the Mey Subgroup of the Upper Caithness Flagstone Group. The highest beds seen are probably transitional into the overlying John o'Groats Sandstone Group. A Givetian (Mid-Devonian) age is likely for the succession, which comprises lacustrine, fluvial and aeolian facies. Gentle, consistent northwest dips result in almost 200 m of strata being exposed along about 1.5 km of shoreline (Figure 2.45), but continuity is repeatedly disrupted by minor faulting. Exposure is in the cliffs and on a wide intertidal rock platform.

The oldest strata within the GCR site, at the eastern end of the section, are thinly bedded, laminated grey-green shales and paler, fine-grained, locally lenticular sandstones. They are affected by a range of styles of shrinkage cracks, all well exposed on bedding planes on the intertidal platform. Polygonal arrays ((Figure 2.46)a) are particularly well-developed (probably giving rise to the local name for this area — 'Samson's Footmarks') and grade into more orthogonal patterns of more widely spaced cracks ((Figure 2.46)b). Lenticular cracks tend to be smaller and to form complex, interlocking patterns (Figure 2.46)c. Rippled surfaces commonly alternate with those affected by shrinkage cracks and some of them are also cracked. The sandstone layers commonly extend downwards into the small shrinkage cracks that penetrate the underlying shale or mudstone to create the so-called 'fang structures' of Donovan (1980). Differential compaction strongly deformed many of the crack infills so that in cross-section they are bulbous or sinuous (Figure 2.47). Originally mistaken for burrow-fills (Crampton and Carruthers, 1914), their origin remains a subject of controversy (see 'Interpretation', below). More likely examples of bioturbation are very small, *Skolithos*-like, circular structures less than 1 mm across on some bedding surfaces.

Finely interlaminated organic-rich mudstone and carbonate beds, some containing scattered, disarticulated fish remains, occur sporadically within the sandstone-mudstone laminites. There are 20 such units within the Thurso–Scrabster section, 16 of which contain fish. However, most of these units are disrupted by shrinkage cracks and contain only small fish fragments, and only seven or eight thicker calcareous laminites with no cracks contain complete plates or complete fishes (Dineley, 1999a). Complete specimens of *Dipterus* are fairly common and *Millerosteus minor* is very well-preserved as disarticulated and semi-articulated plates in the lower part of the section [ND 113 688]–[ND 110 692]. Orange-or brown-weathering stromatolites also occur in the organic, fish-bearing strata, mainly as small, millimetre-scale hemispheroids (Parnell *et al.,* 1990) and as sheets (Trewin, 1993). The fish-bearing laminates occur on average at about 7 m intervals through the lower (eastern) part of the section (Parnell *et al.,* 1990). This cydicity is superimposed on a general, but irregular, trend of upward-increasing sandstone proportion. Many of the sandstone beds have soft-sediment deformation structures, with widespread convolute lamination, load-induced 'pseudonodule' layers (Figure 2.48) and sandstone dykes, which cut up to 3 m of strata. Cross-bedded sandstone bodies up to 4 in thick occur towards the top (the western end) of the section. Some have trough cross-bedding, with locally abundant rip-up mudstone lasts, suggesting a fluvial origin.

Others have low-angle cross-bedding, with lag accumulations of coarse, well-rounded quartz grains, and are probably aeolian. Small pyrite nodules are locally common in some of the more massive sandstone beds. Stratigraphically, this part of the Thurso section forms a link with the overlying John o'Groats Sandstone Group, in which high-energy, fluvial sandstones aredominant. These can be examined near the type locality of John o'Groats south of Duncansby Head ([ND 405 735]; see GCR site report, this chapter). There, trough and planar cross-bedding, low-angle planar bedding and primary current lamination are seen in broadly cyclic, upward-fining channelized units, and mudstone clasts are common in the channel bases (Trewin, 1993).

## Interpretation

The strata exposed in the coast section between Thurso and Scrabster record the interaction of lacustrine, fluvial and aeolian processes in and around an Orcadian Basin lake of fluctuating water-level. The lithofacies can be correlated with the facies associations recognized by Donovan (1980) (Figure 2.3), and record the repeated, abrupt variations in lake level from the deepest-water, fish-bearing laminites ('association A') to intermittently emergent playa-lake deposits ('association D'). The shallower lake deposits ('associations B and C') are poorly represented in the Thurso section.

The fish-bearing laminites ('association A') represent the slow accumulation from suspension of fine-grained sediment in the deeper part of a large lake over a period of hundreds, possibly thousands, of years. The sub-millimetre scale alternations of fine clastic siltstone, carbonate and organic laminae have been interpreted by Donovan (1980) as varved sediments deposited under annual, seasonal, climatic control. Trewin (1993) interpreted the clastic layers as representing input from rivers in the rainy season, the carbonate laminae as the deposits of the dry, warm summer season when the photosynthetic activity of phytoplankton was at a maximum, and the organic laminae as the product of autumnal, annual decay of the phytoplankton. Water depths may have been as great as 80 m (Hamilton and Trewin, 1988), but the presence of stromatolitic layers within the laminites necessitates shallower water in the photic zone, perhaps up to about 50 m, for at least part of the depositional cycle.

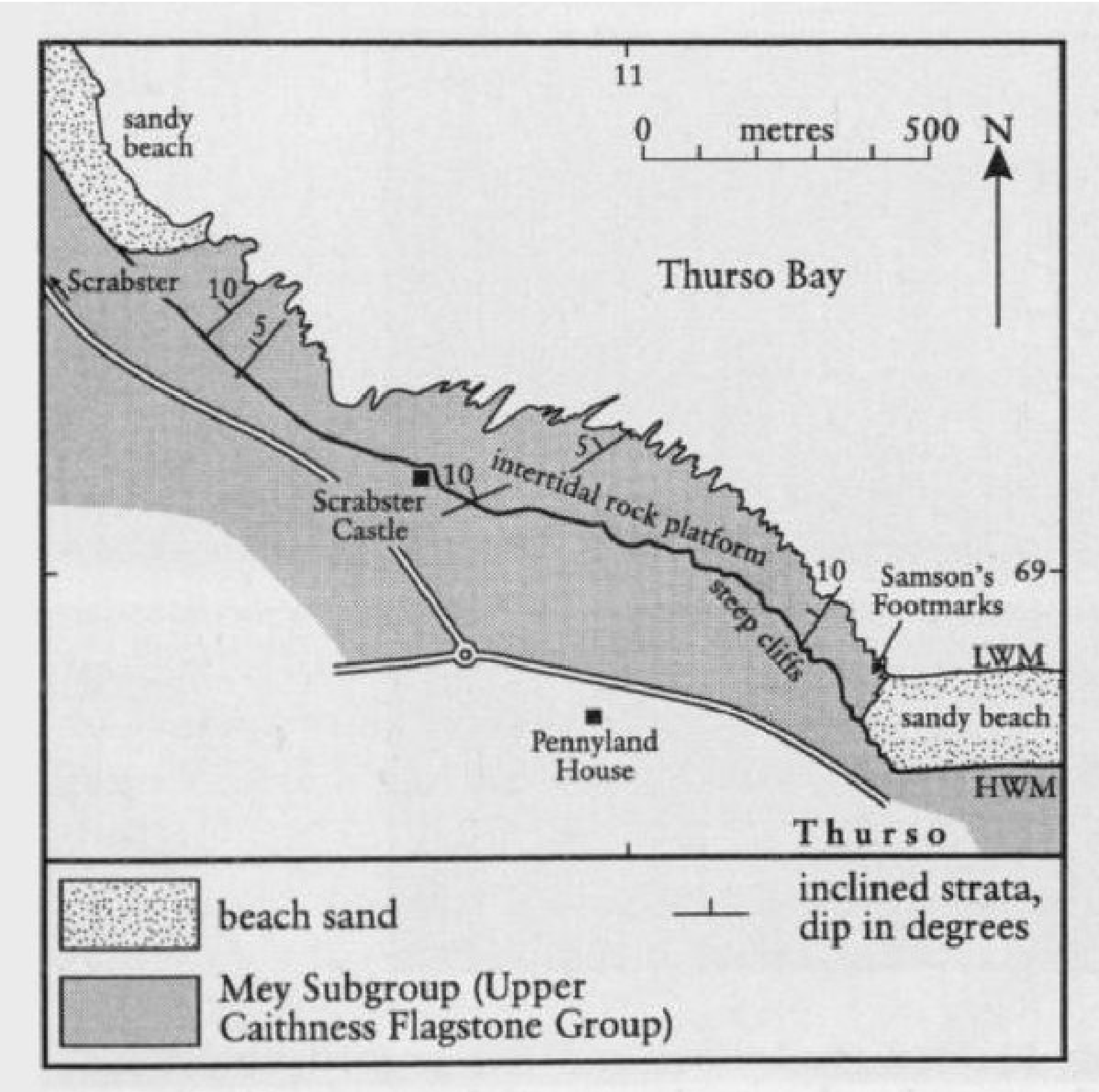
The laminites pass gradationally up through thinly interbedded fine-grained sandstones and mudstones into interbedded internally cross-laminated siltstones and sandstones. The latter lithofacies forms most of the succession between the fish-bearing laminites. It indicates a depositional environment in which the lake floor was periodically emergent and sand was transported by shallow streams and reworked by wave action (Trewin, 1993). The abundant polygonal desiccation cracks are evidence of the intermittent emergence and drying out of the lake-bed sediments, but the origin of the equally abundant, lenticular cracks has been the subject of debate. Donovan and Foster (1972), Trewin (1992) and Barclay *et al.* (1993) considered that the lenticular cracks were subaqueous in origin and developed by a synaeresis-like process perhaps linked with salinity changes in the lake. Astin and Rogers (1991, 1992, 1993) expressed a contrary view, suggesting that the formation of gypsum (and possibly halite) crystals during the drying-out of the lake (with commensurate increase in salinity) was an important precursor to the formation of the lenticular cracks. These were then initiated by the crystal pattern in a subaerial environment with the type of crack pattern developed being controlled by the extent of desiccation and the thickness of the sediment layer involved. During dry periods, wind-blown sand filled the open cracks and was deposited as thin lenses and laminae on the exposed playa-lake floor. The interpretation of Astin and Rogers requires many more and longer periods of subaerial conditions than the Donovan and Foster model.

Superimposed on the cycles of lake sedimentation is the overall upward increase in both the thickness and frequency of sandstone beds. These show a combination of sedimentary features that suggests aeolian reworking of fluvial sands into small dunes and rippled sheets. The environment was probably marginal to a receding lake, with fluvial sedimentation in broad, shallow channels and intermittent influxes of wind-blown sand. The thicker sandstones are commonly convoluted and disrupted by a combination of loading and water-escape structures.

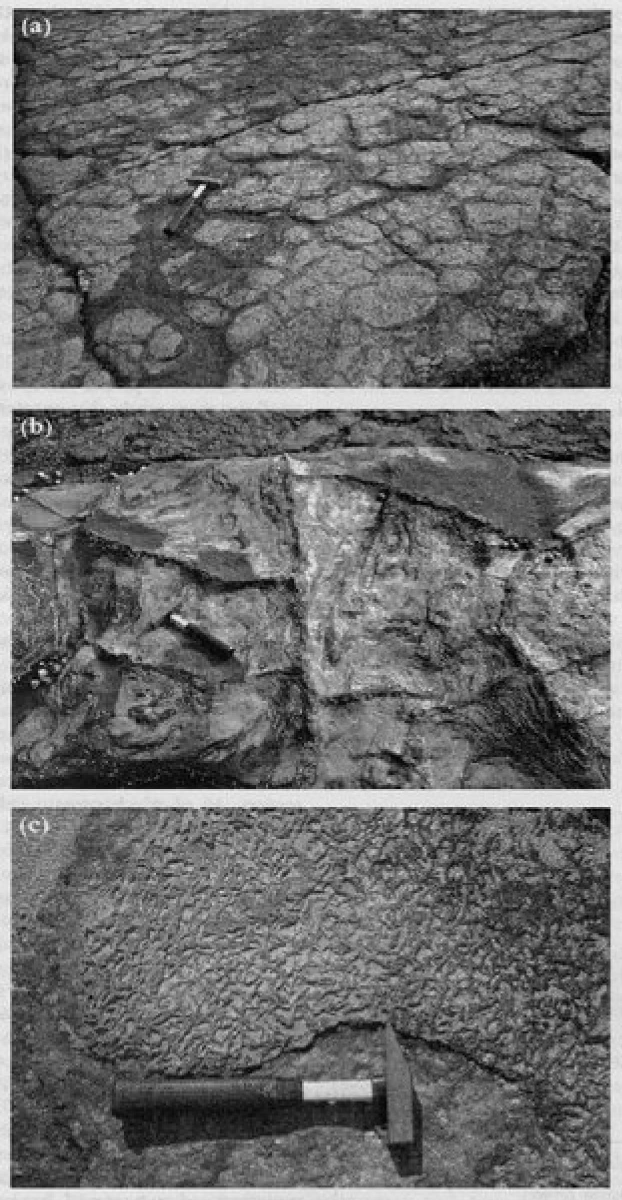
## Conclusions

The Pennyland (Thurso–Scrabster) GCR site provides an exceptionally well-exposed representative section for part of the Middle Devonian Upper Caithness Flagstone Group and its transition into the overlying John o'Groats Sandstone Group. The cyclical arrangement of the strata represents variations in the depth of the Orcadian Basin lake. The site is therefore of great importance in regional interpretation of the tectonics and palaeogeography of the Orcadian Basin. In addition, there is good preservation of a spectacular array of shrinkage cracks, the origins of which remain a matter of debate. The site is also of great importance because of its well-preserved late Givetian fossil fish fauna (Dineley, 1999a).

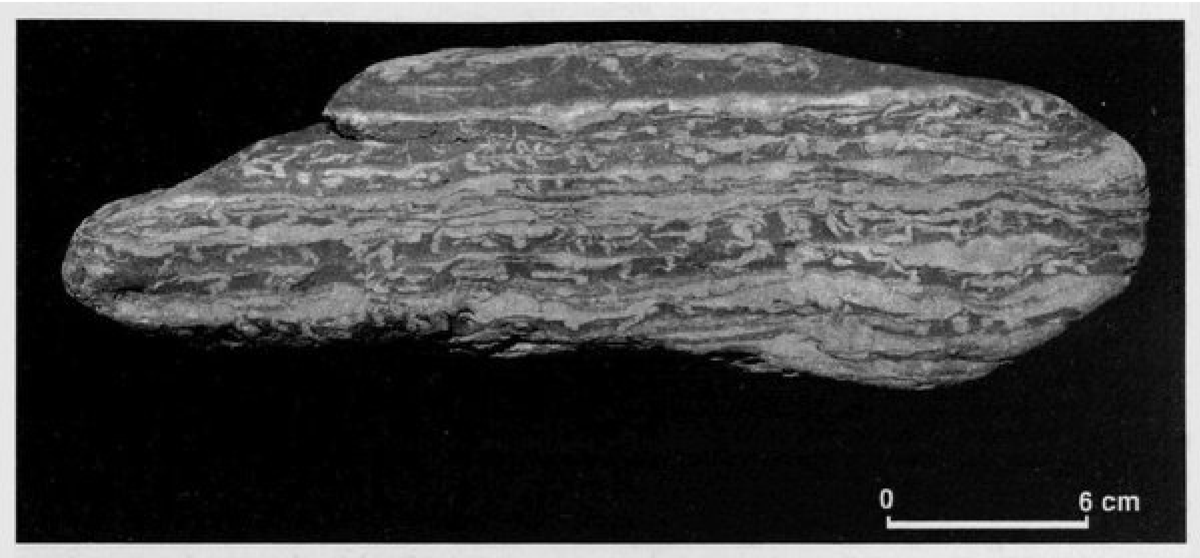
**References**



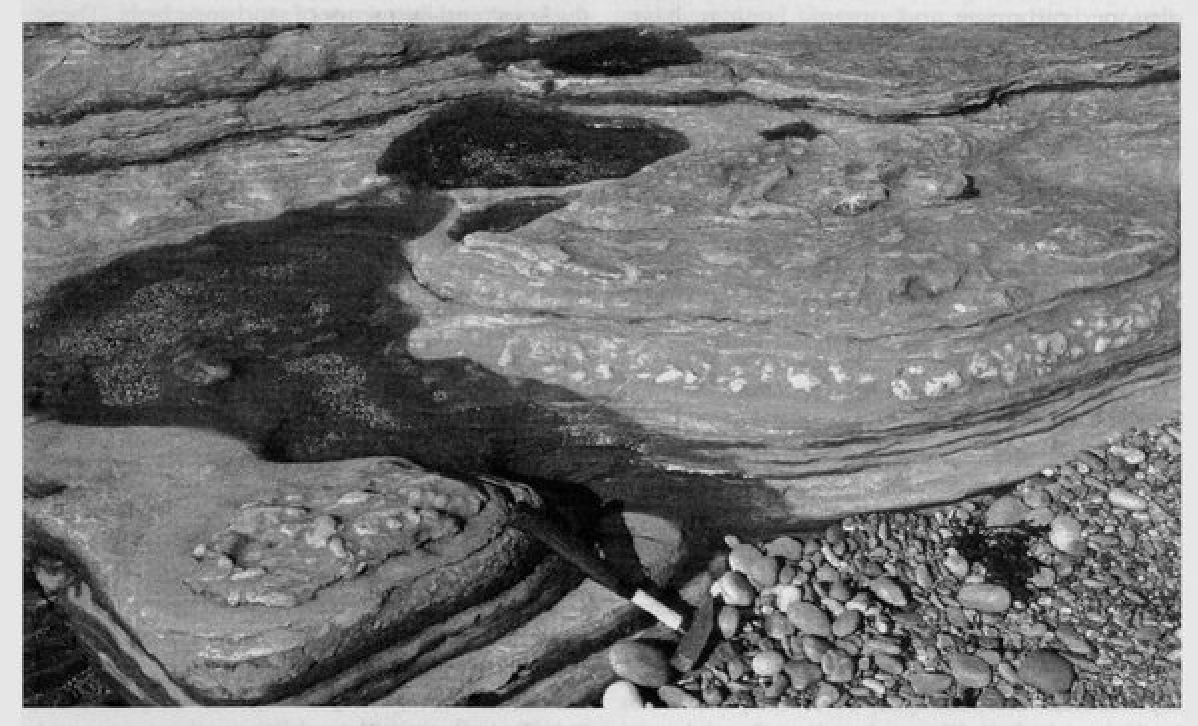

*(Figure 2.45) Locality map of Pennyland GCR site.*



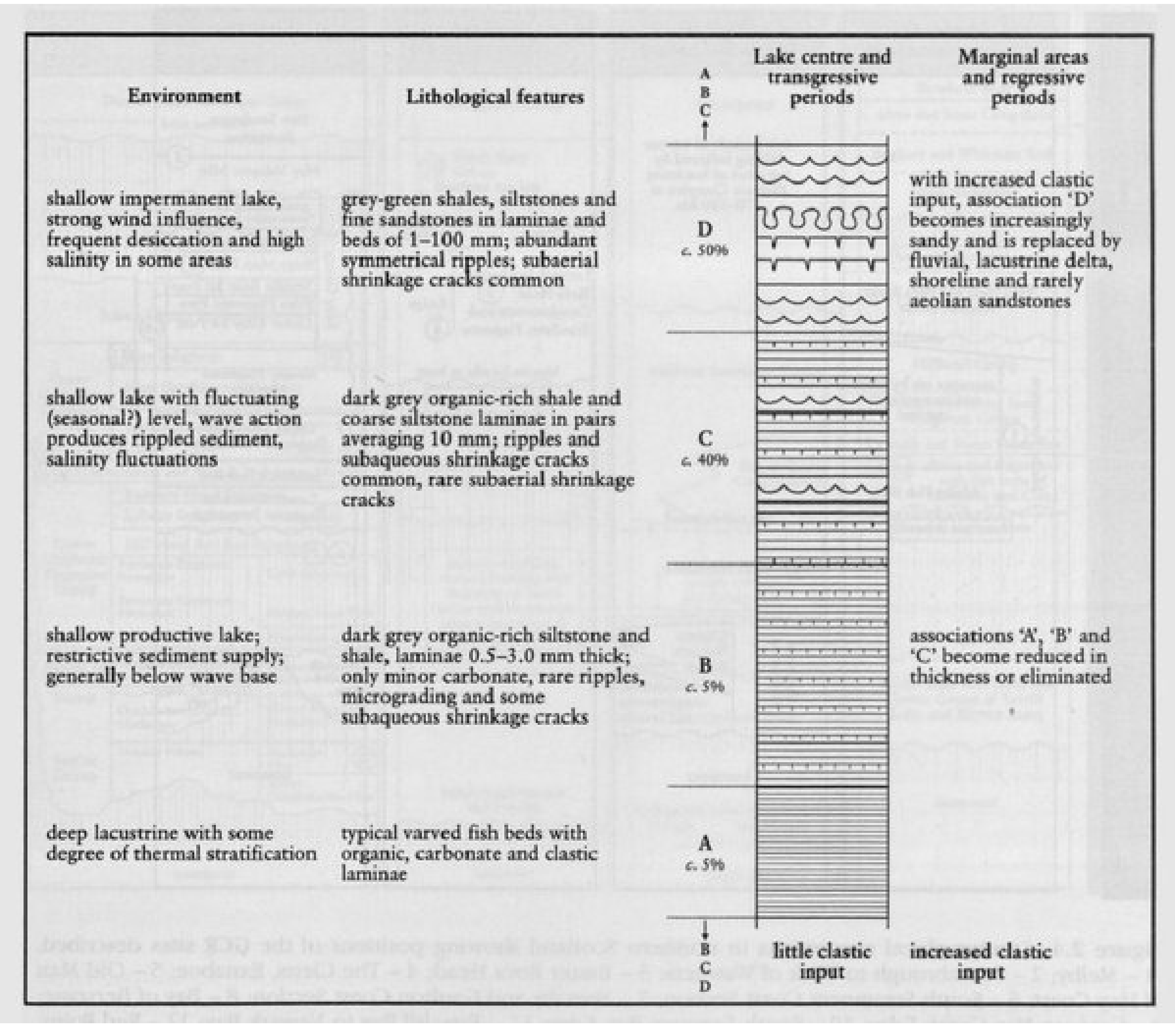

(Figure 2.46) Styles of shrinkage cracks affecting, thinly bedded mudstones and fine-grained sandstones. (a) Polygonal array of desiccation cracks; (b) more widely spaced orthogonal array of desiccation cracks; (c) lenticular shrinkage cracks forming complex interlocking pattern. (Photos: P. Stone.)




(Figure 2.47) Compressed, deformed shrinkage cracks in cross-section. (Photo: BGS No. P547102, reproduced with the permission of the Director, British Geological Survey, © NERC.)



(Figure 2.48) Load-induced 'pseudonodule' layer. (Photo: P. Stone.)




(Figure 2.3) Cyclic lacustrine facies in the Caithness Flagstone Group. After Trewin and Thirlwall (2002), from Donovan (1980).