Gallois, R. W. 2004. *Geoscience in south-west England*, **11**, 51-58.

THE TYPE SECTION OF THE JUNCTION OF THE OTTER SANDSTONE FORMATION AND THE MERCIA MUDSTONE GROUP (MID TRIASSIC) AT PENNINGTON POINT, SIDMOUTH

R.W. GALLOIS

Gallois, R.W. 2004. The type section of the junction of the Otter Sandstone Formation and the Mercia Mudstone Group (mid Triassic) at Pennington Point, Sidmouth. *Geoscience in south-west England*, **11**, 51-58.

An almost complete section through the Otter Sandstone Formation and the Mercia Mudstone Group is exposed in the cliffs between Budleigh Salterton and Axmouth on the south Devon coast. This is the most complete succession at this stratigraphical level in Britain and has been proposed as the type section for the formation and the group. The conformable junction of the Otter Sandstone Formation and the overlying Mercia Mudstone Group (Sidmouth Mudstone Formation) is wholly exposed in the cliffs at Pennington Point, Sidmouth over a distance of 250 m. The shingle beach that fronts this section of cliff is subject to seasonal variations in thickness of up to 5 m. The cliff and foreshore sections are continually refreshed by wave action at times of low beach level. They expose about 15 m of interbedded sandstone and mudstone, for which the new name Pennington Point Member of the Otter Sandstone Formation is proposed, overlain by the uniform mudstones of the Mercia Mudstone Group. The member marks the transition from the predominantly fluviatile environments of the Otter Sandstone Formation to the arid environments of the Mercia Mudstone Group. Concentrations of fossil material in winnowed deposits in the Pennington Point Member at Pennington Point have yielded a more diverse assemblage of vertebrate fossils than at any other Triassic locality in Devon. This includes genera previously known only from Russia and central Europe, and the type material for two new species. The section is nationally important for correlation at this stratigraphical level and internationally important for magnetostratigraphical comparison with sections in southern Europe.

92 Stoke Valley Road., Exeter EX4 5ER, U.K.
(E-mail: gallois@geologist.co.uk)

INTRODUCTION

An almost most complete succession through the Mercia Mudstone Group is exposed in the cliffs between Sidmouth and Axmouth on the east Devon coast (Gallois, 2001). The sections are the most complete at this stratigraphical level in Britain, and among the best in Europe. They form an integral part of the East Devon-Dorset Coast World Heritage Site, which exposes strata that represent an almost continuous record of 185 million years of Earth history. The completeness of the south Devon coastal sections has enabled them to be used as the U.K. standard for the magnetostratigraphy of the Triassic Period. Detailed sampling at Pennington Point has shown that a magnetic reversal within ±1 m of the junction of the Otter Sandstone Formation and the Mercia Mudstone Group can be correlated with a similar event close to the base of the Ladinian Stage in southern Europe (Hounslow and Jenkins, pers. comm., 2002).

The outcrop of the base of the Mercia Mudstone Group and its junction with the underlying Otter Sandstone Formation is repeated by faulting in the Sidmouth area (Figure 1). It is well exposed, but inaccessible, in cliffs at Ladram Bay [NGR SY 098 853] and beneath High Peak [NGR SY 104 858], and at sea level below Peak Hill [NGR SY 109 865]. At this last locality the sections are backed by high, unstable mudstone cliffs and are wholly or partially covered by debris much of the time. In recent years, the most complete accessible sections have been those at Pennington Point, where the junction is wholly exposed in the cliffs and foreshore [NGR SY 1294 8731 to 1319 8734] over a distance of 250 m of eastwards from the outfall of the River Sid. A low easterly dip carries the junction from about 15 m above Ordnance Datum at the outfall to below low-water mark (Figure 2). The underlying beds are discontinuously exposed for about 100 m north of the point in a contiguous river cliff. The beach, predominantly composed of chert and flint derived from the Cretaceous Upper Greensand and Chalk that crop out in the upper cliffs east of Pennington Point, is subject to seasonal variations in thickness of up to 5 m. It is generally replenished by eastward-moving longshore drift under the influence of easterly and south-easterly winds, and is denuded during periods of westerly and south-westerly winds. As a consequence, accelerated periods of erosion refresh the cliff and foreshore sections at times when the foreshore is swept free of shingle.

PENNINGTON POINT SECTION

The sections at and adjacent to Pennington Point were first described in detail by Irving (1888) who recorded about 15 m of sandstones in the river cliff that runs northwards from Pennington Point, overlain by interbedded sandstones and mudstones in the sea cliff that runs eastwards from the point. These latter are overlain by several hundred metres of mudstone exposed in the cliffs between Sidmouth and Branscombe. With the exception of those in the river cliff, which are now more vegetated than in Irving's day, the exposures remain complete. The river cliff exposes about 6 m of fine- to coarse-grained sandstones disconformably overlain at Pennington Point by about 15 m of interbedded fine-grained sandstones and mudstones. Eastwards from there, the highest of these sandstones is overlain with sharp lithological contrast by the sand-free mudstones of the Mercia

Mudstone Group (Sidmouth Mudstone Formation). The interbedded sandstones and mudstones are here grouped with the Otter Sandstone Formation under the proposed new name Pennington Point Member (see below).

In the coastal sections between Sidmouth and Weston Mouth [NGS SY 164 879], the Sidmouth Mudstone Formation comprises 165 m of relatively uniform red-brown mudstones and orange-brown muddy siltstones with a few prominent beds of laminated green mudstone up to 0.3 m thick. The formation has been divided into five members on the basis of variations in mudstone type, and mudstone and siltstone contents (Gallois, 2001). The oldest member, the Sid Mudstone Member, is wholly exposed in the cliffs at and immediately east of Pennington Point: for completeness, it is included in the description here.

The Otter Sandstone Formation succession at and adjacent to Pennington Point is laterally variable, but relatively uniform in total thickness. It can be summarised as follows:

Sidmouth Mudstone Formation (pars)

Sid Mudstone Member

Mudstones, red-brown and reddish orange, silty; common gypsum-rich horizons with associated green beds or concentrations of green patches; calcitised and/or dolomitised hardground surfaces and associated gypcrete nodules at two levels; base taken as a sharp lithological upward change from sandstone to mudstone …..15.0 m

Otter Sandstone Formation

Pennington Point Member

Interbedded fine-grained sandstones (referred to here as 1 to 7 in ascending order) and mudstones. The member shows relatively little lateral thickness variation, but there are marked variations in the proportions of sandstone to mudstone. All seven sandstones persist throughout the section, but some of the mudstones are locally cut out by channels at the bases of the overlying sandstones. As a result, several of the sandstone beds vary in thickness by several hundred percent within the length of the exposure (Figure 3). Most of the contacts between the beds are sharp with evidence of sedimentary breaks at each lithological boundary. The thicker sandstone beds are prominently cross-bedded and locally have channel-lag deposits up to 0.4 m-thick at their bases. These last are mostly made up of angular clasts of red mudstone and quartz granules. The tops of the sandstone beds are mostly relatively smooth, planar or curved, and are commonly capped by winnowed ripples of coarse sand with pebbles up to a few millimetres across.

The thickness variations within the section can be summarised as follows:

Sandstone 7: generally thins eastwards from 0.10 to 0.08 m; locally only 0.05 m, but present throughout the 250 m-long section: underlying mudstone 0.6 to 0.8 m thick.

Sandstone 6: thickness 0.4 to 0.6 m: underlying mudstone 0.4 to 0.6 m in thick.

Sandstone 5: thickness 1.8 to 2.2 m: underlying mudstone 2.8 to 3.0 m thick; contains a sandstone bed (0.12 to 0.24 m thick) which is cut out by the overlying sandstone in the western part of the section.

Sandstone 4: thickness 0.3 to 1.2 m: underlying mudstone 0.6 to 2.1 m thick.

Sandstone 3: thickness 2.7 to 3.9 m: underlying mudstone up to 1.5 m thick, locally cut out by channels at base of the sandstone.

Sandstone 2: thickness 1.0 to 2.7 m: underlying mudstone up to 1.0 m thick locally cut out by channels at base of the sandstone.

Sandstone 1: thickness 0.5 to 3.1 m: channels infilled with thinly interbedded fine-grained sandstone and muddy sandstone, commonly with a clast-rich basal bed, locally infill an irregular topography cut into the underlying sandstones.

Total thickness ….. 15.0 to 15.5 m

Otter Sandstone Formation undifferentiated

Sandstones, fine-grained, strikingly trough cross-bedded, infilling shallow (mostly 2m deep), broad (mostly >15 m) intersecting channels; a few small, angular clasts of red mudstone at channel bases; highest sandstone capped by an 0.6 m-thick bed of red-brown mudstone over a small (1.5 m) length of outcrop, representing a high point below the overlying erosion surface …..up to 2.8 m

Sandstones, trough cross-bedded, fine- to coarse-grained, infilling stacked and intersecting steep-sided (mostly 2 m deep and 10 m across) channels. Most channels have a coarse, basal lag deposit with common angular and rounded clasts of red mudstone up to 0.2 m across, and common calcrete clasts. Discontinuous, thin (< 0.1 m thick) lenses of red mudstone occur within and capping the channels …..3.5 m seen

LITHOSTRATIGRAPHY

Pennington Point Member

A similar channelled contact to that described above separates thick units of cross-bedded sandstone from a succession of interbedded sandstones and mudstones 3 km west of Sidmouth at Ladram Bay, and below High Peak and Peak Hill. This suggests a widespread sedimentary break at this stratigraphical level. The younger of the two sandstone units and the mudstone described above in the undifferentiated Otter Sandstone has not been recognised in the sections west of Sidmouth. This might indicate lateral variation at this stratigraphical level, or that the Pennington Point section preserves younger strata than those farther west.

Seven sandstone beds are also present within the interbedded unit in the sections west of Sidmouth, the highest being overlain with lithological contrast by the sand-free Sidmouth Mudstone (Figure 4). As at Pennington Point, the sandstone-mudstone ratios are laterally variable, but the thickness of the unit remains relatively constant at about 15 m. The interbedded sandstones and mudstones were noted by Irving (1888; 1892) and Hull (1892) as lithologically different from the underlying and overlying beds. They were referred to by Newell (in Hounslow and McIntosh, 2003) as a separate genetic unit (Unit D) within the Otter Sandstone Formation. They are grouped here with the Otter Sandstone Formation, because of their high sandstone content, under the proposed new name Pennington Point Member. The cliffs at Pennington Point and for 250 m eastwards from there [NGR SY 1294 8731 to 1319 8734] are proposed as the type section. The base of the member is exposed at the point, where it is taken immediately above the topographically irregular erosion surface described above (Figure 5). The top of the member is exposed in the cliffs 50 to 250 m east of the point. It is taken at the lithological change from sandstone to mudstone at the top of the highest of the seven sandstone beds described above (Figure 6). The full thickness of the member is also permanently exposed in sea stacks and cliffs at Ladram Bay and beneath High Peak and, sporadically, at beach level below Peak Hill.

Base of the Mercia Mudstone Group

In one of the earliest detailed descriptions of the Triassic rocks of the Devon coast, Ussher (1876) noted that at Sidmouth the “lower sandy marls” of the Upper Marls (subsequently the Keuper Marl, and now the Mercia Mudstone Group of Warrington *et al*., 1980) formed a “comfortable passage down” into the Upper Sandstones (now the Otter Sandstone Formation of Henson, 1971). At Pennington Point, Irving (1888) recorded about 15 m of “thick bedded coarse sandstones” in the river cliff overlain by “sandstone of finer texture” interbedded “in increasing importance upwards” with “brown-red marls” in the sea cliff, overlain by over 50 m of “well-bedded marl” exposed in the cliffs between there and Salcombe Mouth. He placed the junction of the Upper Sandstones and Upper Marls at a level within the interbedded sandstones and mudstones at which mudstone became the principal component.

Following a visit to the site with Hull, Irving (1892) agreed that the base of the Upper (Keuper) Marls should be revised downwards to the base of the interbedded sandstones and mudstones. The boundary was placed at a level at which Hull (1892) had recorded an 0.6 m-thick calcareous breccia which he believed marked a widespread erosion surface that could be correlated with a similar breccia at the base of the Keuper Marl in the Midlands. The exposure described by Hull (1892, fig. 1), adjacent to the Alma Footbridge, is now obscured by vegetation (Figure 3).

However, it is clear from his description that the breccia was at or close to the level of the base of the Pennington Point Member as described here. A similar channel-lag breccia is exposed at the base of the member 75 m east of the bridge at times of low beach level.

A similar transition from almost wholly arenaceous to wholly argillaceous deposits to that exposed at Pennington Point occurs throughout the subcrop of the junction of the Otter Sandstone Formation and Mercia Mudstone Group in the Wessex Basin. Geophysical logs in numerous boreholes indicate 10 to 20 m of sandstone with mudstone interbeds that have commonly been referred to as 'transition beds' (e.g. Lott *et al*., 1982, p. 341). When Warrington *et al*., (1980, p. 13) formally introduced the name Mercia Mudstone Group, they recommended that in areas where the boundary was gradational the base of the group should be taken "where mudstone and siltstone become dominant over sandstone".

When faced with the practical problem of surveying the boundary, the first geological surveyors of the Sidmouth district (Sheets 326 and 340) in 1874-75 placed the base of the Upper (Keuper) Marls at Pennington Point at a level 15 m above the beach at 73 m east of the outfall of the River Sid (Woodward and Ussher, 1911, p.14). When allowance is made for the retreat of the cliffs during the intervening 130 years, this equates with a level at or close to the top of the highest sandstone in the Pennington Point Member. A similar definition was used during the resurvey of the district in 1987-2000 (Edwards and Gallois, 2004). The Warrington *et al*. (1980) definition was not used, for two reasons. First, because of the commonly channelled nature of the deposits, the ratio of sandstone to mudstone at any particular stratigraphical level shows marked lateral variation in the coastal sections. As a result, the level at which mudstone becomes 'dominant' is both subjective and variable over short distances. Inland, where there are few exposures, such a definition is impracticable for mapping purposes. Second, the highest sandstone in the Pennington Point Member is lithologically markedly different from the Sidmouth Mudstone Formation which contains no similar sandstone. As in the coastal exposures, the inland exposures recorded during the survey show the boundary beds to comprise of interbedded sandstones and mudstones in which the highest sandstone forms an unambiguous, readily definable marker bed.

BIOSTRATIGRAPHY

The palaeontological importance of the beds adjacent to the Otter Sandstone-Mercia Mudstone boundary has long been known. Johnston-Lavis (1876) and Metcalfe (1884) described an "Ossiferous Zone" at the junction of the Upper Sandstones and Upper Marls that cropped out in the cliffs just west of High Peak and at Pennington Point. These beds yielded relatively common fragmentary vertebrate remains including bones and teeth of the amphibian *Mastodontosaurus* (formerly *Labrinthodon*) *lavisi* (Seeley), and reptile remains including rhynchosaurs. Almost all the early finds came from fallen blocks on the beach at Picket Rock Cove [NGR 1031 8574] and Pennington Point, and although Johnston-Lavis provided a graphic section (1876, fig. 1) showing the locations, there was disagreement as to the precise stratigraphical level from which the fossils were derived. This was resolved when Hull (1892) revised the base of the Upper (Keuper) Marls at Pennington Point downward to the base of the interbedded sandstones and mudstones. It enabled Irving (1892, p. 69) to conclude that all the vertebrate remains previously described from the Upper Sandstones should be regarded as Keuper: i. e. from the Pennington Point Member using the terminology proposed here. The matrix lithologies of specimens held at the Royal Albert Memorial Museum in Exeter support this conclusion. They suggest that much of Johnston-Lavis' material from west of Exeter came from channel-lag deposits in the Pennington Point Member. All the earlier specimens from Pennington Point are likely to have come from the extensive outcrop of the member because that of the underlying sandstones is confined to the river cliff and a small area at the point (Figure 2). In addition to those from the 'ossiferous zone', vertebrate fossils have been recorded from horizons throughout the Otter Sandstone Formation (see Benton, 1997; Benton and Spencer, 1994 for reviews).

The Pennington Point Member at Pennington Point has yielded a more diverse terrestrial fossil assemblage than any other Permian or Triassic locality on the Devon coast. Much of the material now housed in the Royal Albert Memorial Museum in Exeter, Bristol Museum at Bristol University and in the Cincinnati Museum Center in the USA, came from *in situ* outcrops exposed at times of low beach level. Most of the material, in the form of bones, teeth and fish scales, has come from concentrations of coarser material in the channel-lag deposits in the member. Less commonly, isolated teeth and other material is preserved in the overlying sandstones and in the winnowed deposits that cap the sandstones. The stratigraphical and palaeontological significance of this fauna has only come to be appreciated in recent years, partly because of its fragmentary nature and partly because of the impersistence of the exposures.

The following description of the Pennington Point fauna and its biostratigraphical significance has been provided by Dr P. S. Spencer. " The Pennington Point fauna includes the first occurrences in the British Triassic of two reptiles, the procolophonine procolophonid *Kapes* and the prolacestiform *Tanystropheus*, previously only known from Russia and central Europe respectively. Additionally, the type and referred specimens of two species, *Kapes bentoni* and the possible lepidosauromorph *Coartaredens isaaci* came from this site (Spencer and Storrs, 2002). The Otter Sandstone exposures at Pennington Point have produced fossils of vertebrates, invertebrates and plants. To date, the following taxa have been collected: the reptiles *Kapes bentoni* Spencer and

Storrs, *Coartaredens isaaci* Spencer and Storrs, *Rhynchosaurus spenceri* Benton, *Tanystropheus* sp. and ?*Bromsgroveia;* the amphibians *Mastodonsaurus lavisi* (Seeley) and *Eocyclotosaurus* sp.; the fishes cf. *Dipteronotus cythus* Egerton, *Gyrolepis*, *Lepisosteus* sp. and *Osteicthyes* indet.; the crustacean *Euesteria*; and the plant *Shizoneura* (horsetail).

Some elements of this fauna are of biostratigraphical importance. For example, *K. bentoni*, for which all the material collected to date in Britain came from Pennington Point, provides a correlation with the Triassic of Russia where *Kapes* occurs in the Lower Triassic Gamskaya Svita of the Komi Republic and in the Middle Triassic Donguzkaya Svita of the Orenburg region. The Benthosuchidae is also present in both the Russian and Devon assemblages, demonstrating a further palaeoecological link between the two regions. Elsewhere in Britain, *Rhynchosaurus* is known from the Helsby Sandstone Formation of Shropshire and the Bromsgrove Sandstone Formation of Warwickshire. Milner *et al*. (1990) have suggested that the fauna of the Otter Sandstone Formation is most similar to those of the Scythian-Anisian late Bundsandstein and Voltzia Sandstone formations of Germany and France. However, *Rhynchosaurus* is absent from these latter assemblages. If the correlation with the Otter Sandstone Formation is correct, it suggests that the vertebrate assemblages in each region contain a mixture of local and widespread elements."

CONCLUSIONS

In recent years the most accessible and most complete section of the junction of the Otter Sandstone Formation and Mercia Mudstone Group (Sidmouth Mudstone Formation) has been that in the cliffs at and adjacent to Pennington Point, Sidmouth. The sections there mark a relatively rapid climatic change from the predominantly fluvial environments in which the Otter Sandstone Formation was deposited to the hot desert environments of the Mercia Mudstone Group. The combined palaeontological and magnetostratigraphical data, although by no means conclusive, suggests that the Otter Sandstone Formation is of Anisian age (Benton and Spencer, 1994; Hounslow and McIntosh, 2003) and that the arid 'red-bed' part of the Mercia Mudstone Group spanned the Ladinian to Norian stages (Warrington *et al.,* 1980), a period of about 34 million years. The climatic change marked by the Pennington Point Member was, therefore, both fundamental and long lasting.

ACKNOWLEDGEMENTS

The author is greatly indebted to Patrick Spencer for his palaeontological advice and contribution, to Richard Edwards for stratigraphical advice and assistance in the field, and to an anonymous reviewer for substantial improvements to the account.

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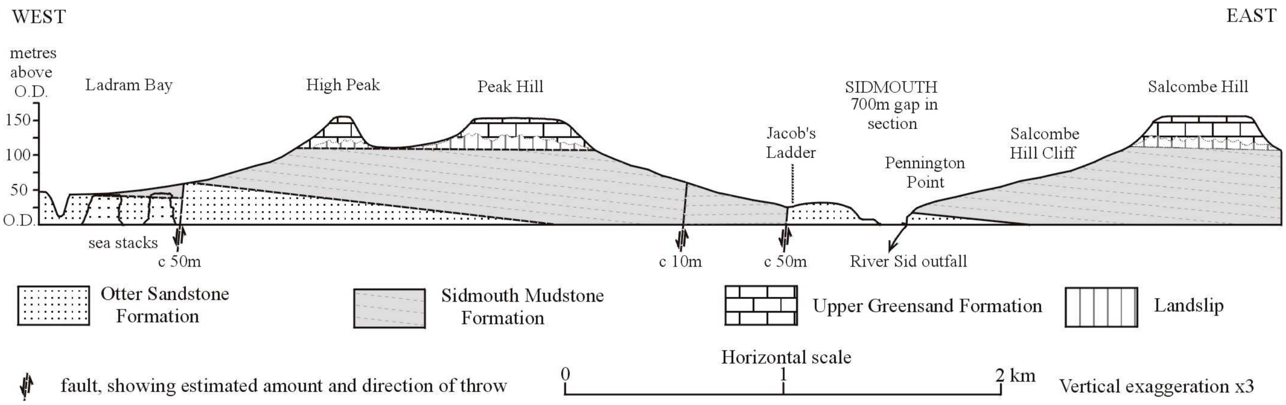

Figure 1. *Geological sketch section of the coast between Ladram Bay and Salcombe Hill, Sidmouth.*

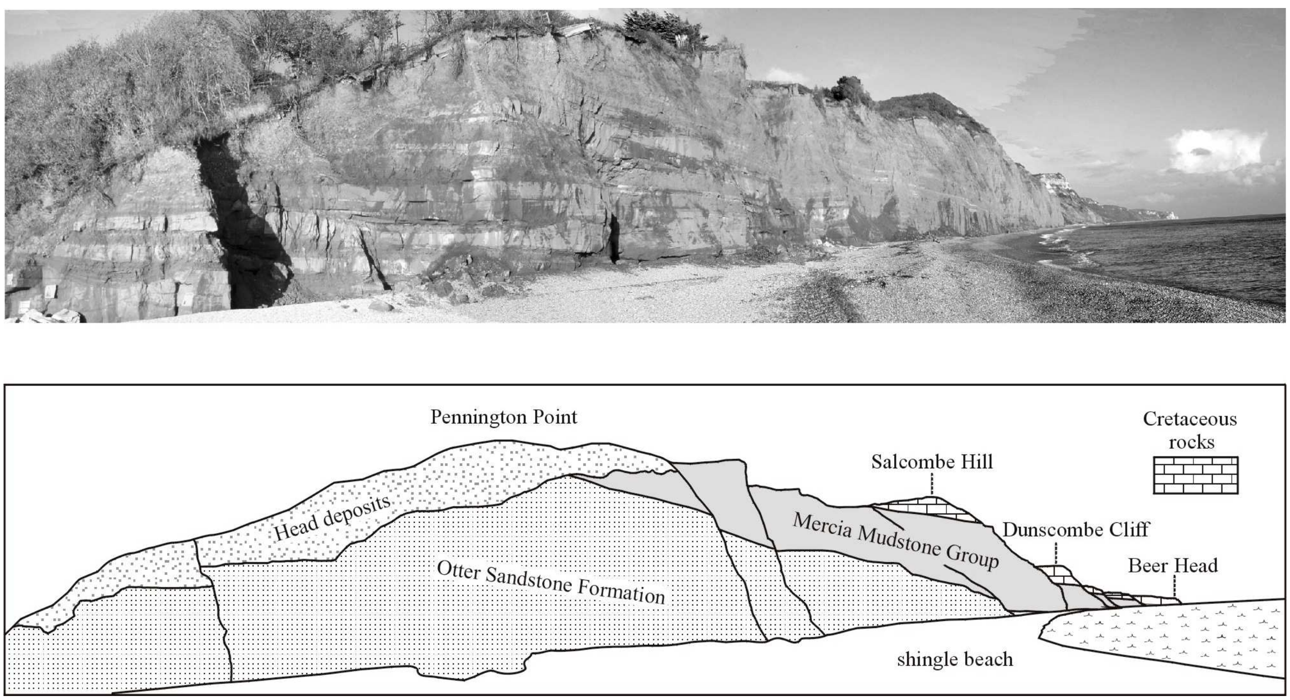

Figure 2. *The easterly dipping junction of the Otter Sandstone and Sidmouth Mudstone formations is continuously exposed over a distance of 250 m eastwards from Pennington Point. Based on photographs taken from the outfall of the River Sid.*

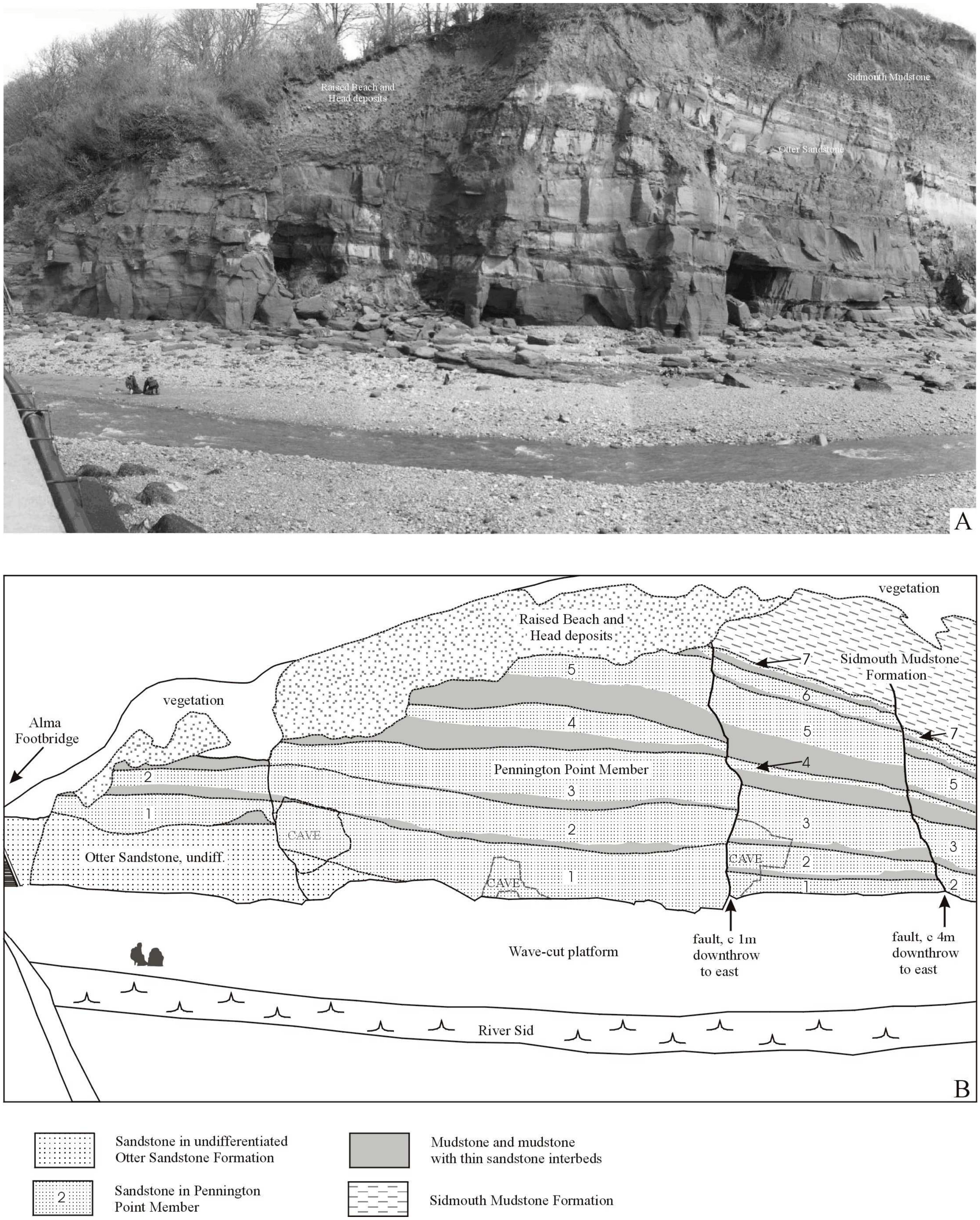

Figure 3. *(***a***) Pennington Point at a time of low beach level after a south westerly gale (January 2001).*

(b) *Sandstones 1 to 7 and interbedded mudstones in the Pennington Point Member (Otter Sandstone Formation).*

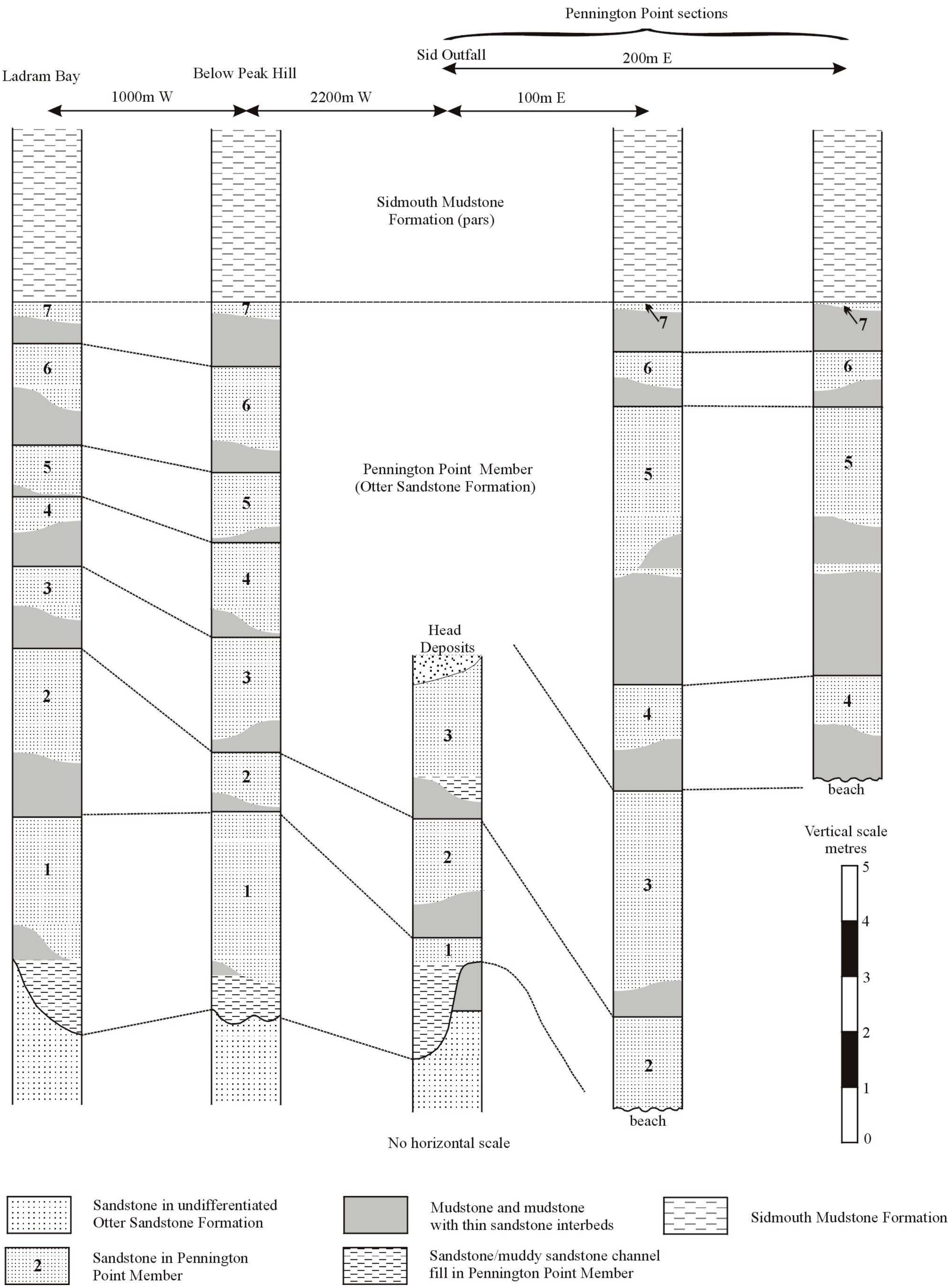

Figure 4. *Lateral variations in the Pennington Point Member between Ladram Bay and Pennington Point. Ladram Bay and Peak Hill sections inaccessible: based on photographs.*

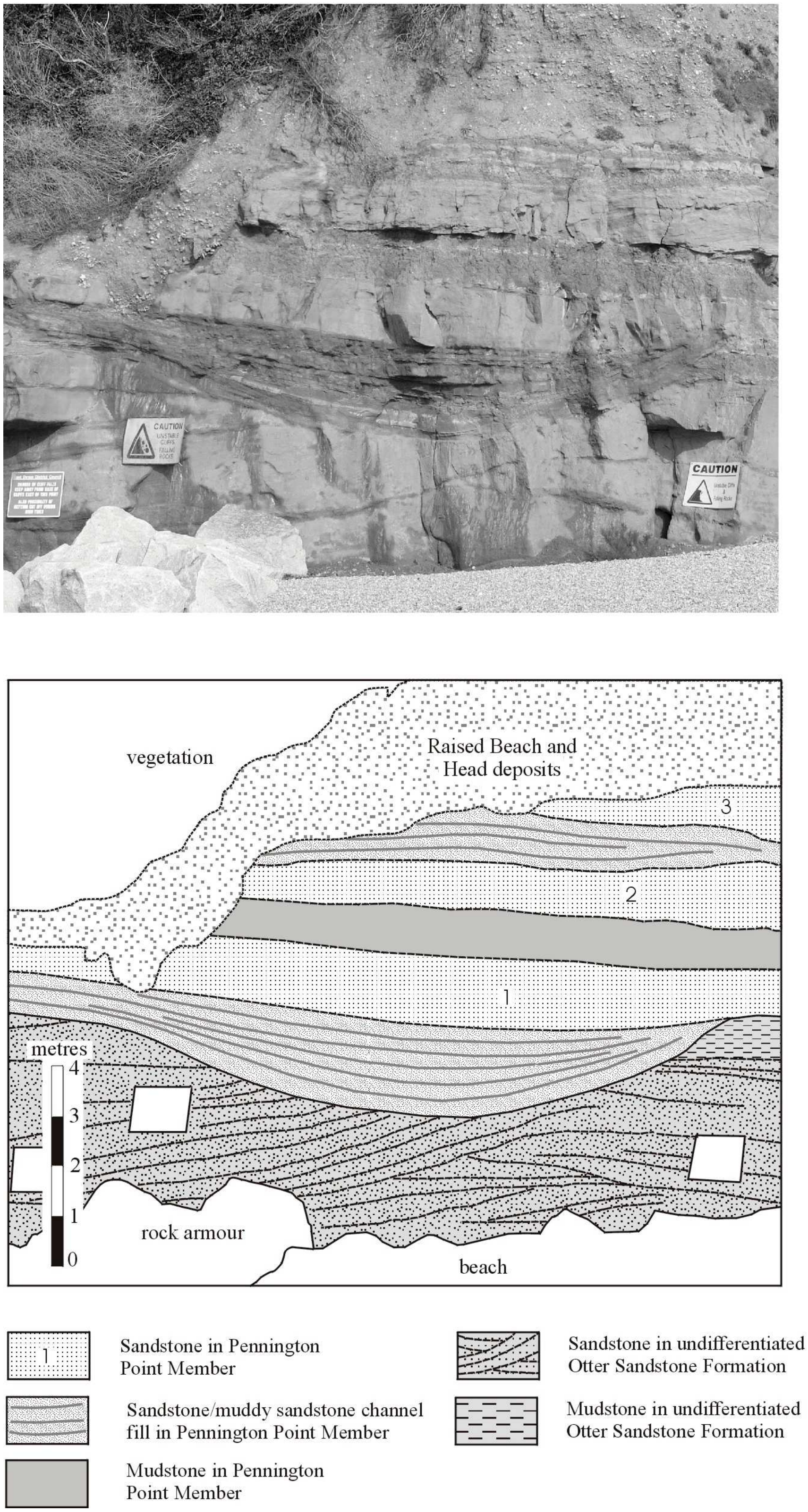

***Figure 5.** The junction of the Pennington Point Member and the underlying undifferentiated Otter Sandstone Formation at Pennington Point.*

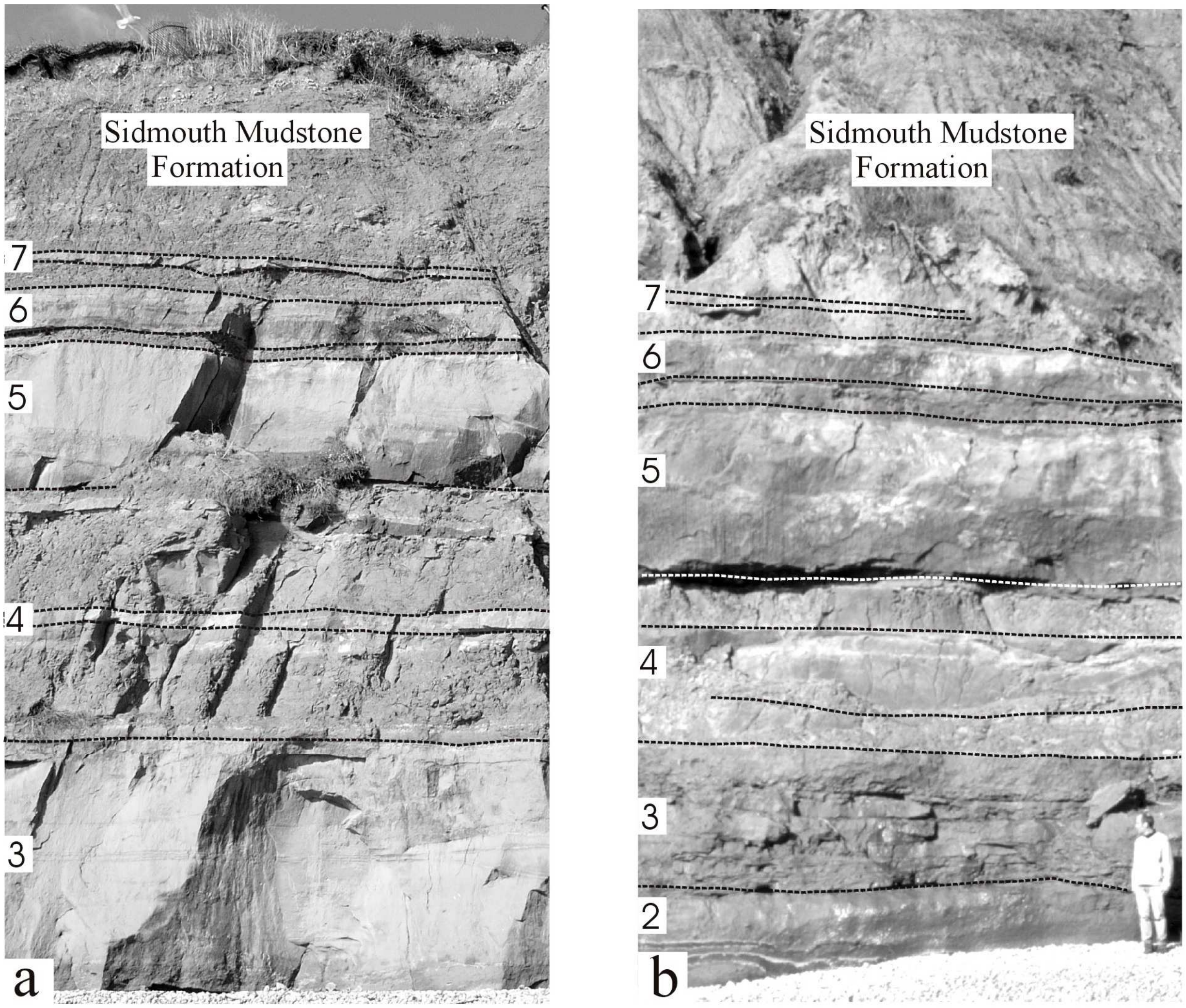

Figure 6. *The junction of the Pennington Point Member and the Sidmouth Mudstone Formation.*

(a) *150 m east of Pennington Point [NGR 1318 8736].*

(b) *Below Peak Hill [NGR 1058 8637], 2.6 km WSW of (a).*