Fuller's earth (bentonite) in the Lower Cretaceous (Upper Aptian) of Shanklin (Isle of Wight, southern England)

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RUFFELL, A. H., HESSELBO, S. P., WACH, G. D., SIMPSON, M. I. & WRAY, D. S. 2002. Fuller's earth (bentonite) in the Lower Cretaceous (Upper Aptian) of Shanklin (Isle of Wight, southern England). *Proceedings of the Geologists' Association*, **113**, 281–290. A <35 cm fuller's earth (bentonite) bed is recorded from the Upper Aptian (Lower Cretaceous) Ferruginous Sands Formation (Lower Greensand Group), southwest of Shanklin, Isle of Wight. The stratigraphic location and sedimentological context of the bed are described: the host succession is cyclical, containing evidence of non-deposition, faunal colonization and current reworking of sediments. Mineralogical and petrographic analyses demonstrate the dominance of smectite (Ca-montmorillonite) and the presence of feldspar shards in the fuller's earth bed. Geochemical data indicate a close similarity to the fuller's earth beds formerly exposed at Redhill (Surrey), for which an intra-plate, trachytic volcanic source is suggested. The sedimentological, stratigraphic and volcanic implications of the discovery are discussed.

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1. INTRODUCTION

Fuller's earths (bentonites) of volcanic origin are well known in the Upper Aptian (Lower Cretaceous) sediments of the Weald Basin and its contiguous outcrops in Buckinghamshire, Oxfordshire and Berkshire. This paper extends the known distribution of these volcanogenic deposits southward to the Channel Basin, by describing for the first time a unique bed of fuller's earth recently rediscovered in the Ferruginous Sands Formation (Lower Greensand Group) near Shanklin (Isle of Wight). The aims of this work are to place in context, describe and analyse the stratigraphy, sedimentology and geochemistry of this bed which was previously known but never before documented. The Aptian stage is often suggested to be a time in Earth history when widespread (global) volcanicity, reflecting an increase in sea-floor spreading, caused the increased atmospheric CO_2 and thus global warming (Weissert, 1989). Although the evidence for volcanicity is indeed global in nature (Larson, 1991), the widespread ash-falls (bentonites or fuller's earths) of southern England (Goldring, 1999), the Southern North Sea (Lott *et al.*, 1985) and Germany (Zimmerle, 1979) have rarely been cited in direct support. Fuller's earth is a sedimentary clay (most usually a bentonite or volcanic ash fall, all or some of which may be reworked by contemporaneous currents: Goldring, 1999) whose mineralogy is dominated by any form of the clay mineral group smectite (Moorlock & Highley, 1991). The essential property of fuller's earth is the ability of the contained clay minerals to adsorb molecules (such as water or oil) into their lattice, hence the origin of the name and the process of 'fulling' wool, which is the removal of lanolin. Many different mixtures of clay minerals occur in mudstones, some of which have similar properties to fuller's earth and thus the term has not always been used accurately. The Aptian fuller's earths of southern England are dominated by the clay mineral Ca–montmorillonite, a member of the smectite group.

2. REGIONAL BACKGROUND

Research into the Aptian fuller's earths of southern England began with regional accounts of the Lower Greensand geology (Fitton, 1847; Dines & Edmunds, 1933; Casey, 1961). It was not until the work of Hallam & Sellwood (1968) and Jeans *et al.* (1977) that the volcanic origin of the fuller's earth beds of Surrey was highlighted: the presence of glass shards, apatite and zircons, together with an absence of fossils being the most supportive evidence. The fuller's earth beds of the Lower Greensand have great economic (Moorlock & Highley, 1991), sedimentological (Goldring, 1996, 1999), volcanogenic (Jeans *et al.*, 1977; 1982) and correlative (Ruffell, 1998) value.

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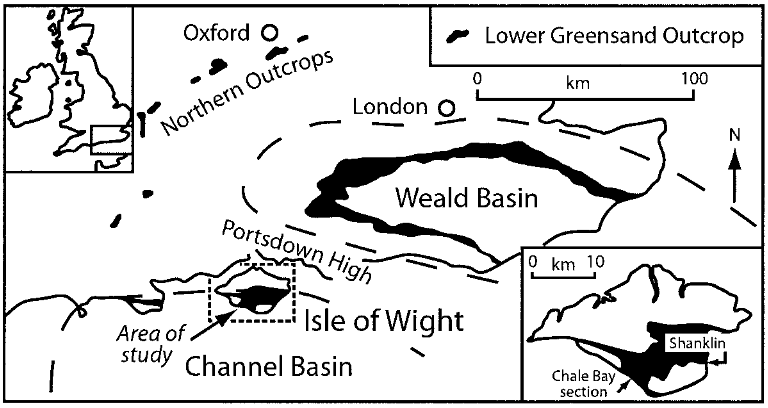

Fig. 1. Location of the study area with regard to the British Isles (inset, upper left), the Mesozoic basins and Lower Greensand Group outcrops of southern England, and the Isle of Wight (inset, lower right).

Lower Greensand Group sediments are widespread in southern England (Fig. 1). The glauconitic, calcareous, argillaceous, fossiliferous and predominantly marine sediments that make up the group (Casey, 1961) were deposited during the Aptian transgression (Casey, 1961; Gröcke *et al.*, 1999). This transgression affected both the Channel and Weald basins (Fig. 1): the Lower Greensand Group sediments of the two basins are broadly similar in facies and can be correlated through lithostratigraphy and biostratigraphy (especially using ammonites: see Casey (1961)). Significant lateral facies changes occur within the Lower Greensand Group from the Weald to Channel basins: in Kent and West Sussex, parts of the group are notably calcareous (the Hythe Formation), whilst in the Isle of Wight, the Upper Aptian fuller's earth beds known from Surrey, Kent and the northern outcrops (predominantly the eastern end of those shown on Fig. 1) were considered by Casey (1961) and Ruffell (1998) as absent.

The absence of fuller's earth beds in the Isle of Wight successions requires explanation and causes a problem in correlation because no stratigraphic break is evident from bio- or lithostratigraphy (Casey, 1961). Although no explicit statement is made in Moorlock & Highley (1991), Ruffell (1998) or Goldring (1999), it is implicit from these works that sedimentological conditions during the Upper Aptian of the Isle of Wight part of the Channel Basin were interpreted as not being conducive to the deposition or preservation of ash falls. This supposition continued in Ruffell & Wach's (1998) work on the succession. They supposed that the cyclic arrangement of hiatuses in the succession (marked by fossiliferous, pebbly, carbonate-cemented beds they termed 'firmgrounds') reflected periods of high-energy sediment bypass and non-deposition, thus explaining the absence of fuller's earth seams. Prior to the above works however, A. Hallam (pers. comm., 1989) persuaded a PhD student at Oxford (E. Dike, studying under H. Reading in the late 1960 s) to search for fuller's earth seams. Indeed, in one sedimentological log in his thesis, Dike (1972) shows a lenticular bed of fuller's earth in the Lower Greensand (Ferruginous Sands, 'Group' XIII of Fitton (1847), Shanklin), with a maximum thickness of 6 inches (or 15 cm) but with no comment in the text. This is the exact geographical and stratigraphic location of the present description, showing that Dike found the bed but did not pursue the question of its significance any further.

3. LOCAL STRATIGRAPHY

The geology of the Isle of Wight is known from a number of key works, most notably Fitton (1847), Osborne White (1921) and Casey (1961). These works are all summarized in Insole *et al.*'s (1998) field guide. Lower Greensand sequences are known primarily from the type succession, exposed in Chale Bay (Fig. 1). However, Osborne White (1921), Middlemiss (1962), Dike (1972), Ruffell (1989), Wach (1991), Insole *et al.* (1998) and Ruffell & Wach (1998) give specific details of the succession exposed southwest of Shanklin (Fig. 1). None of these authors except Dike (1972) observed the fuller's earth. The Lower Greensand Group exposed southwest of Shanklin comprises the uppermost members (*sensu* Ruffell & Wach, 1998) of the Ferruginous Sands Formation and the lower members of the Sandrock Formation (Fig. 2). The lowest recognizable bed exposed in the succession is the pebble bed (exposed in Shanklin Chine [SZ 585 811]) which marks the base of Fitton's (1847) 'Sands of Walpen Undercliff: Group (sic) XIII'. This member was re-named 'Member XIII Walpen' by Ruffell & Wach (1998): Casey *et al.* (1998) suggested that the names stay as similar to their original usage as possible but did not give any recommendations for this member specifically, their account covering only the Lower and lower Upper Aptian. This pebble bed also marks the base of the *nutfieldiensis* zone of Casey (1961) and

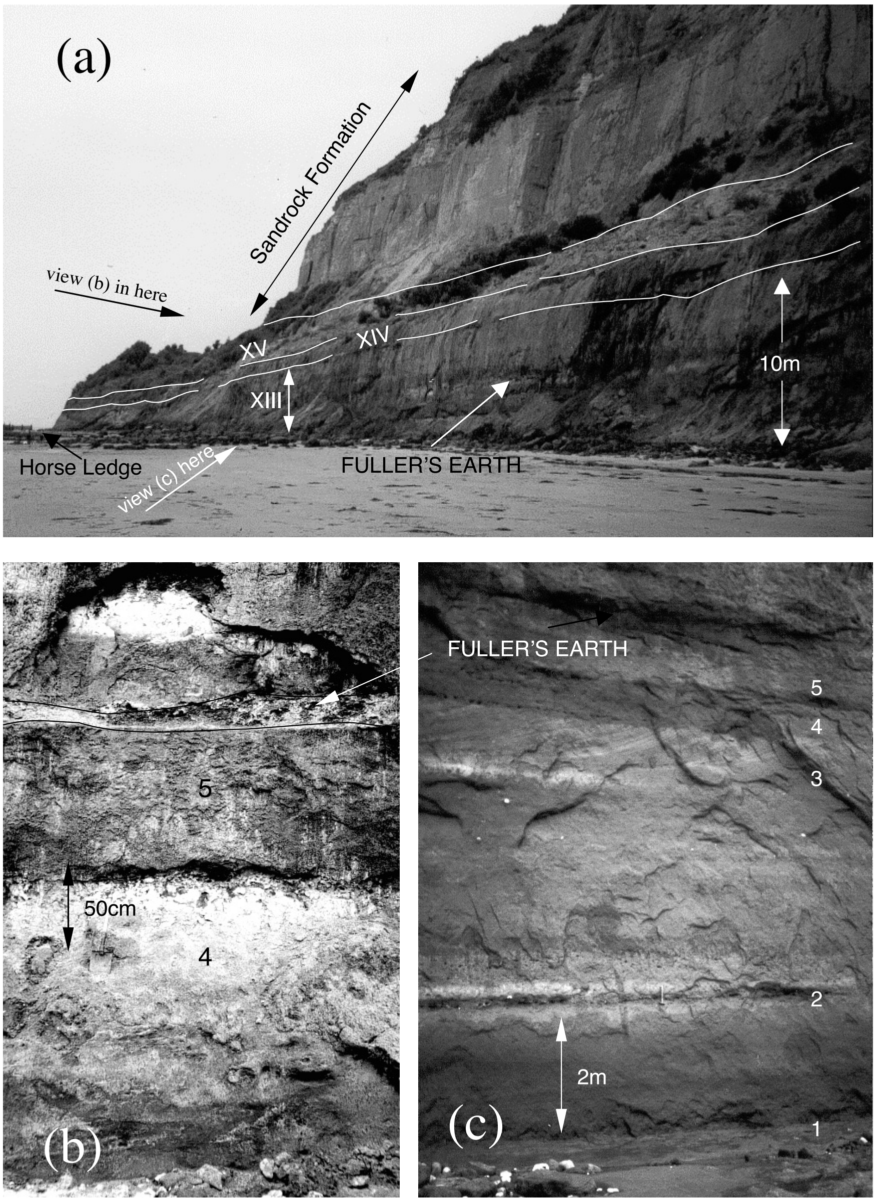

Fig. 2. Annotated field photographs of the study location at Shanklin. (**a**) View of Knock Cliff (Shanklin), taken in September 2001 at low tide from GR 586 605 looking to the southwest. The Urchin Bed occurs on the top of Horse Ledge; XIII, XIV and XV are informal members of the Ferruginous Sands and Sandrock formations (after Ruffell & Wach, 1998). The May 2001 cliff-fall, covering the high-tide portion of Horse Ledge, can be seen to the left of 'view (c) here'. (**b**) Detail of the fuller's earth bed exposed in September 2001 at GR 586 800. The undulating nature of the base of the sandstone overlying the fuller's earth is apparent. (**c**).View of the low cliff above Horse Ledge, taken in 1989 at the position of the cliff-fall in (a). White specks are fossil oysters (*Aetostreon*), note the cross-stratified bed below the fuller's earth (4). Numbers refer to beds shown in Figure 3.

subzone of Ruffell & Owen (1995). Some 3.5 m above the pebble bed, exposed on the foreshore south of Shanklin [SZ 585 804] are the glauconitic, cross-stratified and bioturbated sands described by Middlemiss (1962). Five metres above the pebble bed is the prominent cemented sandstone bed known as Horse Ledge on Ordnance Survey maps [SZ 588 803] and as the Urchin Bed in Casey (1961). The origin of this bed is discussed in Ruffell & Wach (1998). The sedimentology and palaeontology of the Ferruginous Sands Formation above the Urchin Bed are only briefly covered in Fitton (1847), Casey (1961) and

Ruffell & Wach (1998): it is in these beds that the fuller's earth occurs.

4. OUTCROP DESCRIPTION

The 10.5 m of argillaceous greensand above the topmost surface of Horse Ledge (Fig. 2) comprises three to four alternating fossiliferous and cross-stratified beds typical of the firmground cycles described by Ruffell & Wach (1998). Horse Ledge forms the erosion-resistant platform visible at the base of the cliff on Figure 2a. Above Horse Ledge there occurs a 20 m high, near-vertical cliff with a prominent 20 cm-tall cleft or erosional scarp some 10.5 m above Horse Ledge itself (Figs 2a,b,c): this is the horizon of the fuller's earth. Above the fuller's earth there occurs another 4 m of Member XIII with Member XIV (Ferruginous Bands of Blackgang Chine of Fitton, 1847) forming the top 6 m of this first low cliff. The 'Yellow Ledge' of most Ordnance Survey maps [SZ 588 798] is formed by the hardened beds of Member XIV Blackgang Chine. Member XV (considered to be the basal member of the Sandrock Formation by Dike (1972) and Ruffell & Wach (1998)) forms the vegetated bedding-parallel back-step of the cliff (Fig. 2a), the main upper part of the cliff being formed by the lowest sandstone member of the Sandrock Formation (Fig. 2).

It was while collecting fossil wood specimens (cf. Gröcke *et al.*, 1999) and logging in the units at Shanklin in 1996 that Dike's (1972) fuller's earth bed was rediscovered by SPH and AHR. At outcrop the bed is lenticular, being 35 cm thick at SZ 586 800 (mid-way between Horse Ledge and Yellow Ledge) yet absent 300 m to the north or south. From excavation of the cliff face it appears that thickness variations are due mainly to the irregular base of the sandstone bed above. This is seen clearly in Figure 2b where the base of the fuller's earth is horizontal and sharp whereas the top is more irregular. The bed is obvious in the cliffs as a line of red-stained seepages: on examination the bed itself has a cracked appearance in dry weather. Unfortunately, the bed is too badly cracked and iron-stained at outcrop to apply any of Goldring's (1996, 1999) analogue descriptions of bentonites from Berkshire. Removal of the reddened and cracked weathered surface reveals a bright blue, blocky pure mudstone with pervasive reddened cracks. On chewing, very few sand particles can be detected. Similar clays can be found below the fuller's earth horizon, most notably in Bed 2, 8 m below the fuller's earth (and correspondingly 2.5 m above Horse Ledge: the horizon with the hammer on Fig. 2c). None are as pure as the main bed, nor are such clay-rich beds common above the fuller's earth. Clay-rich beds with lithological and mineralogical similarities to fuller's earths have also been observed by the authors from the Lower Greensand some 70 m below the described horizon. Member VII, Whale Chine (exposed in the cliffs of Chale Bay) and its supposed correlative (Ruffell & Batten, 1994: exposed at Compton Bay in the west of the Isle of Wight) both possess the clay-rich, cracked appearance and smectite-rich properties of fuller's earths. However, neither are blue, blocky pure clays like the described bed.

A sedimentary log of the succession shows the position of the fuller's earth (bentonite) bed (Fig. 3). This log also provides evidence of variable sea-floor conditions prior to the proposed ash fall. Episodes of faunal colonization are evidenced by abundant *in situ* fossils. These include brachiopods, oysters and bryozoa. Such fossiliferous layers are commonly associated with cemented beds of 20–50 cm thickness, the most obvious being the Urchin Bed (equivalent to the top of Horse Ledge). Faunal colonization of the sediment is also apparent in many of the beds that display trace fossils, some of which are almost completely bioturbated. These fossiliferous beds alternate with 40 cm to 1 m-thick beds of cross-stratified sandstone. Cross-strata dip to the south and southeast.

5. LABORATORY DESCRIPTION

Upon drying, the mudstone has a cracked appearance and is blocky with wisps of brown mudstone. Thin sections prove impossible to make as the chips of mud disintegrate in water and paraffin: tenacious use of resin may prove successful in future attempts. X-ray diffraction (XRD) analysis of the whole powdered rock was made using a Siemens AS2000 diffractometer deploying Cu–*a* radiation. Following diffraction analysis of the air-dried powder, the sample was saturated with ethylene glycol. This glycolation causes any smectite crystals to expand, shifting the XRD peak of smectite. The results were analysed by comparison to Brindley & Brown (1980) and the data converted using dedicated XRD software (Diffract-at^{TM} and SIROQUANT^{TM}) and showed the presence of calcium montmorillonite (a member of the smectite group of clay minerals) (*c.* 80%), kaolinite (*c.* 10%) and quartz (*c.* 5%). Biotite and feldspar were detected in low, unquantified amounts. This confirms the bed as a fuller's earth. The samples were further dried in a 90°C oven for 12 hours and placed in distilled water for disaggregation. Examination under a binocular microscope of the sieved residues reveals 0.2 mm-long, arcuate pink-coloured shards of feldspar (Fig. 4). Other grains include rounded quartz (probably detrital contaminants), angular biotite, hornblende and epidote. These constituents make this bed mineralogically similar to the penecontemporaneous fuller's earths of the Weald Basin. A fundamental difference is the presence of feldspar shards. These have not been recorded from the Aptian fuller's earths before and discussions with volcanologists and experts on tephra have failed to provide other analogues. The coarsest sieved residue was embedded in resin on a microscope thin-section slide. The surface was polished and

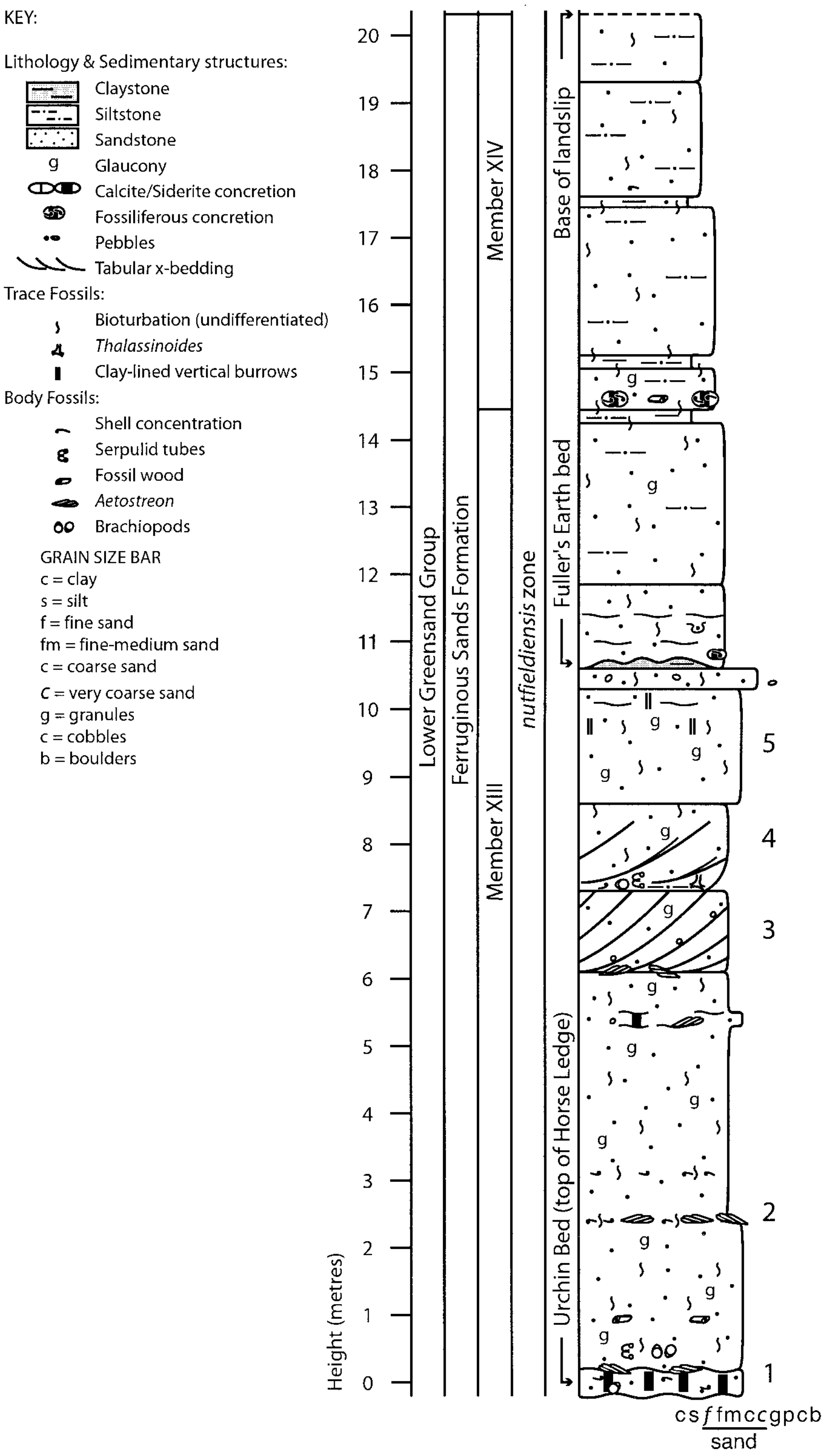

Fig. 3. Sedimentary log of the succession studied. The fuller's earth, cross-stratified sandstone beds and informal bed numbers provide comparison to Figure 2.

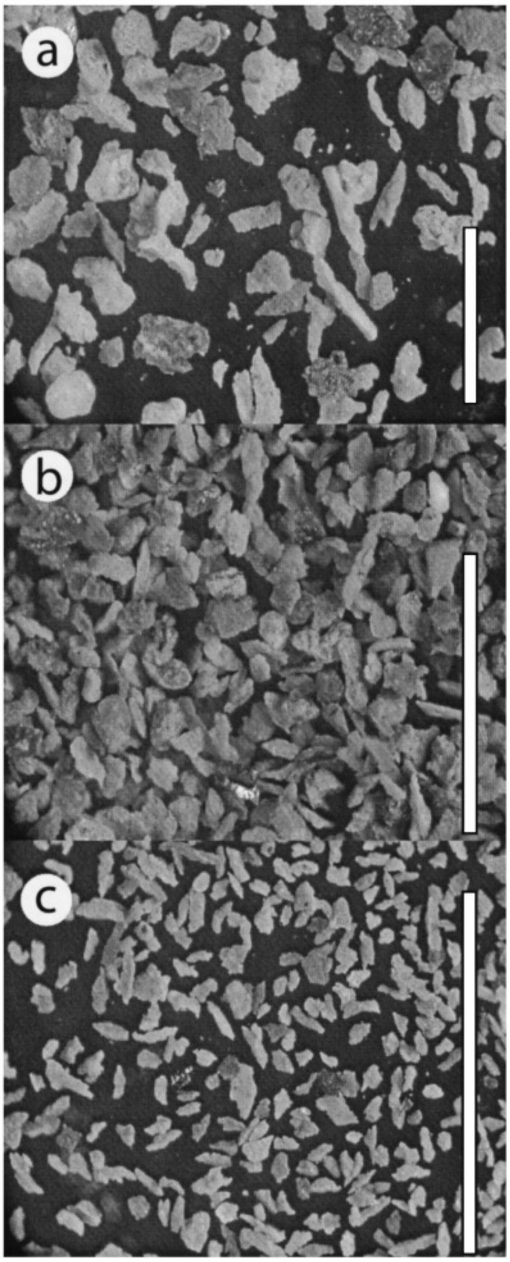

Fig. 4. Microscope (Nikon A-200 Binocular) views of the sieved residues from the Shanklin fuller's earth. The residues from all three sieve meshes (**a**, **b**, **c**) are dominated by feldspar shards. Angular biotite, hornblende, apatite fragments and rounded quartz grains also occur. Scale bars=1 mm.

examined under a petrological microscope. The small size (0.5 mm) of the shards and the problems of distinguishing orthoclase from microcline suggest that we attempt no further identification than K-feldspar.

Table 1. Geochemical data from the Shanklin bentonite.

		Standard deviation
Oxide (%)		
SiO_2	53.59	0.32
TiO_2	0.842	0.017
Al_2O_3	20.05	0.42
Fe_2O_3t	10.64	1.30
MnO	0.017	0.001
MgO	2.47	0.16
CaO	1.21	0.28
Na_2O	0.28	0.02
K_2O	0.80	0.03
P_2O_5	0.12	0.01
Element (ppm)		
Sc	5.6	0.6
Ni	187	31
Rb	15.0	1.7
Sr	81.6	8.7
Y	97	21
Zr	1036	98
Nb	258	8
Ba	41.8	24.3
Hf	34.4	1.5
Ta	17.5	0.3
Th	35.0	0.8
U	8.8	1.9
La	185	9
Ce	447	27
Pr	42.3	3.0
Nd	149	12
Sm	28.1	3.6
Eu	4.29	0.67
Gd	24.8	3.3
Tb	3.66	0.60
Dy	19.8	3.2
Ho	4.12	0.83
Er	10.4	2.01
Yb	7.52	1.18
Lu	0.99	0.22

Data presented are the mean of three samples collected on two separate occasions.

6. GEOCHEMISTRY

Three samples of the Shanklin bentonite (collected on two separate occasions) have been investigated. Samples were analysed by ICP-OES and ICP-MS after grinding in an agate ball mill and dissolution using a $LiBO_2$ fusion (see Wray & Wood, 1998 for further details). Results are presented in Table 1. Rare-earth element (REE) data are presented graphically after normalizing to shale using data derived from USGS CRM SCo-1 (Cody Shale) that was analysed at the same time as the samples (see Jarvis & Jarvis, 1985 for discussion), and chondrite using values obtained from Nakamura (1974) and Haskin *et al.* (1968). These results are shown in Figure 5.

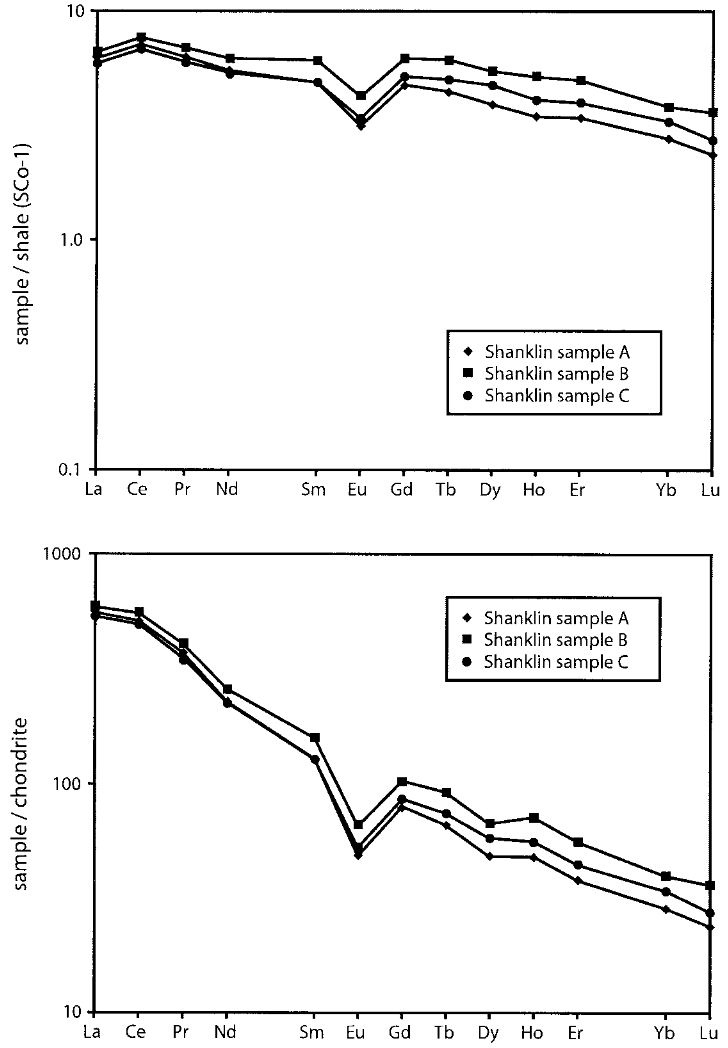

Fig. 5. Shale and chondrite-normalized REE profiles for the Shanklin fuller's earth bentonite (chondrite data from Nakamura, 1974 and Haskin *et al.*, 1968).

Major and trace element data generally fall within the range of values for Lower Cretaceous fuller's earths detailed by previous authors (Morgan 1974; Jeans *et al.*, 1977; Young *et al.*, 1978). Results for SiO_2 are somewhat lower than those commonly obtained from analysis of fuller's earth (Jeans *et al.*, 1977; Wray, unpublished data), probably indicating loss of silica during argillization. Shale-normalized REE plots demonstrate that all REE are more abundant in the bentonite than values normally found in detrital shale (Fig. 5). Shale-normalized REE data also display a relative depletion in europium and a slight depletion in heavy REE relative to light REE.

Major and trace element plots derived from igneous studies are often applied to data from bentonites in order to establish the composition of the source magma and the tectonic setting of the volcanism (e.g. Roberts & Merriman, 1990; Huff *et al.*, 1993). The selective use of relatively immobile elements in such plots ensures that errors due to elemental loss during the alteration of the ash to clays are minimized. A plot of Nb/Y vs Zr/TiO_2 (Fig. 6a) demonstrates that the Shanklin bentonite has a trachytic composition, similar to that of the main fuller's earth seam found at Redhill (Hillbrow Quarry; Wray, unpublished data), and in agreement with the proposal of Jeans *et al.* (1977). A plot of Yb against Ta (Fig. 6b) indicates that the Shanklin bentonite was derived from a within-plate source, again consistent with samples from Redhill. The preliminary identification of K-feldspar from petrography (above) would support a trachytic source.

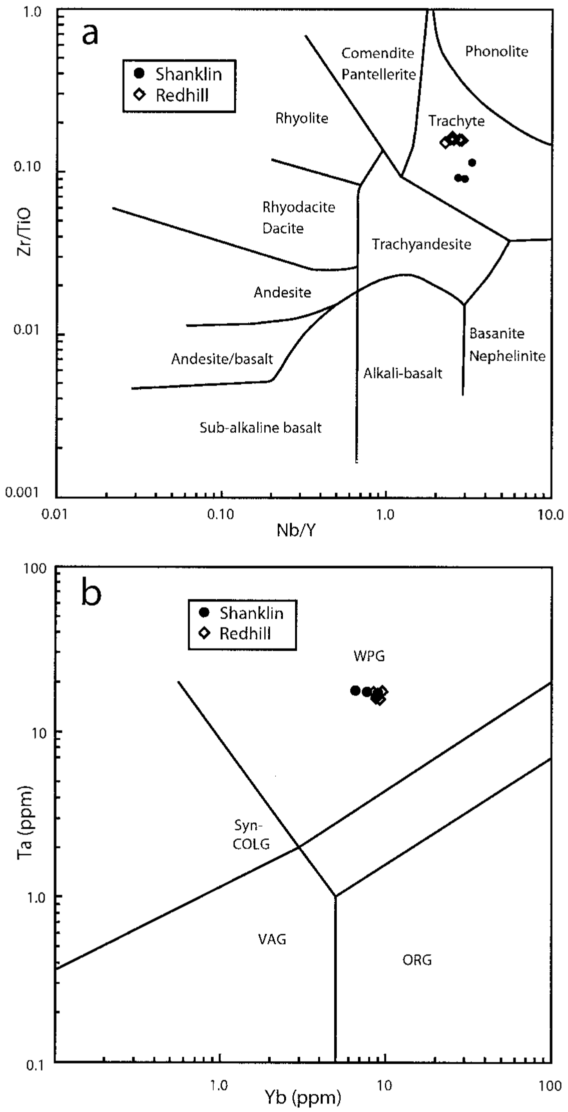

Fig. 6. (**a**) Plot of Zr/TiO$_2$ against Nb/Y for fuller's earths from Shanklin and Hillbrow Quarry, Redhill, Surrey (after Winchester & Floyd, 1977). (**b**) Plot of Ta against Yb for fuller's earths from Shanklin and Hillbrow Quarry, Redhill, Surrey (after Pearce *et al.* 1984). WPG, within plate granites; Syn-COLG, syn-collision granites; VAG, volcanic arc granites; ORG, ocean ridge granites.

7. IMPLICATIONS

The discovery of a fuller's earth bed in the Isle of Wight succession has a number of implications.

1. The palaeoenvironmental conditions pertaining in the Late Aptian of the area were not as exclusive to fuller's earth preservation as implied by previous authors. However, this does not mean that sea-floor conditions were quieter than appears from the presence of cross-stratification; rather it suggests that conditions were much more variable, with episodes of strong current activity, quiescence and faunal activity or ash fall. The mix of feldspar shards, biotite, hornblende and rounded quartz grains, determined from petrography, support the concept of this being neither primary ash fall nor ash completely reworked from land. The ash fall that was preserved as this bentonite could have occurred during a period of current activity as detrital quartz grains are common and the beds below are cross-stratified. It is possible therefore that the fuller's earth was actually much thicker, only to be partially removed by strong currents.
2. The correlation of Lower Greensand Group strata on the Isle of Wight with those of the Weald Basin and 'Northern Outcrops' is contentious. In the absence of fuller's earth beds, Ruffell (1998) correlated beds below the Shanklin fuller's earth (Member XII Foliated Clay and Sand) with the fuller's earth-bearing strata of the mainland. Now it seems that either this correlation is wrong, or else the smectite-rich clays were deposited in the Isle of Wight area of the Channel Basin one ammonite subzone (Ruffell, 1998) after those of the mainland. More accurate methods of correlating each fuller's earth seam, such as Nd isotope stratigraphy or feldspar-separate geochemistry, are needed to resolve this question. The presence of similar clays above firmground horizons both in this section and throughout the Ferruginous Sands Formation (Ruffell & Wach, 1998) may indicate successive ash falls or successive episodes of reworked ash-fall preservation. This suggestion requires confirmation by a full geochemical and mineralogical analysis of each clay bed. Thus there may be correlative horizons to the Weald Basin fuller's earth beds at other horizons in the Isle of Wight that have been reworked: only the peculiar (possibly transgressive) conditions, coupled with possibly high-smectite sediment load allowed preservation in the beds recorded here.
3. The location of the eruptive centre and the type of magma parent is worth reconsidering. Jeans *et al.* (1977) thought that the Netherlands (Zuidwal) and the Western Approaches (English Channel) were likely locations for the Aptian volcano(es). The correct age of the Western Approaches basalts (Bennet *et al.*, 1985), together with the prevailing westerly winds of the Barremian–Aptian (Parrish, 1985) makes this a possibility. However, our geochemical analyses suggest a within-plate, trachytic source. This could still be in the Western Approaches, presuming that ocean-spreading-related magmatism was trachytic. Conversely, the known trachytic nature of the Zuidwal volcano (Jeans *et al.*, 1977) indicates that (geochemically) this type of volcano was a likely source.

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