Identification of a new bentonite in sediments of Mid-Turonian age from Lower Saxony, Germany and its correlation within NW Europe

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Abstract: A newly discovered bentonite from the Söhlde area of Lower Saxony, northern Germany is described. The bentonite is identified on the basis of geochemical evidence (major, trace and REE data) and has been given the name T_{C2} Trace element discriminant plots indicate that the ash had a trachyitic composition and was derived from a within plate source. With the aid of biostratigraphic and stable isotope ($\delta^{13}C$) data it is demonstrated that T_{C2} is the lateral equivalent of the bentonite Southerham Marl 1 / Melton Ross Marl of the Anglo-Paris Basin and eastern England.

Keywords: Bentonite, Upper Cretaceous, Turonian, Rare-Earth Elements, Söhlde, Lower Saxony

1. INTRODUCTION

Recent geochemical studies in northern Germany have identified four bentonites in Cretaceous sediments of mid- to late-Turonian age. Studies in eastern England and the Anglo-Paris Basin have demonstrated the presence of five bentonites in carbonate sediments of comparable age (see discussion below). This work presents evidence for the presence of a fifth bentonite at Söhlde in Lower Saxony, northern Germany and discusses its correlation with beds already identified in other areas of northwest Europe.

2. GEOLOGICAL SETTING / STUDIED SECTIONS

Dorn & Bräutigam (1959), Valeton (1959) and Bräutigam (1962) first identified bentonites in sediments of Late Cretaceous age (chalks and limestones) in northern Germany. Their original proposals for the Turonian part of the succession were refined and expanded upon by Ernst et al. (1983, fig. 5) who, following Bräutigam (1962), recognised six tuffs [i.e. bentonites] (0, C, D, E, F and G in ascending order) and established a tephrostratigraphic framework for Lower Saxony. Later mineralogical and geochemical

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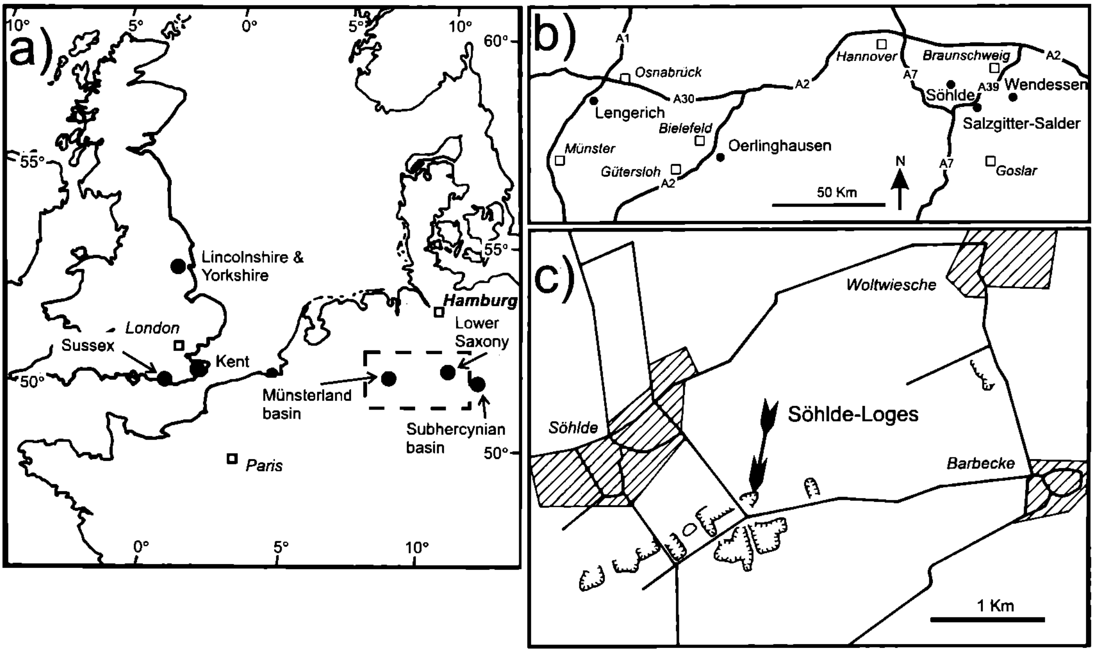

Fig. 1: Location map, illustrating the areas and localities discussed in the text. Figure 1b is a detailed map of the Münsterland / Lower Saxony area as defined by the rectangle in Figure 1a. Figure 1c is a detailed location map for the Söhlde area of lower Saxony, the Söhlde-Loges quarry is identified by an arrow.

studies by WRAY (1995) demonstrated that some of the beds previously identified as bentonites were of detrital origin and that only four of the beds [now designated T(uff)$_C$, T_D, T_E and T_F] were volcanogenic. Identification of the bentonites has been based on both geochemical and mineralogical criteria, in particular the recognition that bentonites display anomalous rare-earth element (REE) profiles, often typified by a negative europium anomaly, in comparison to the approximately straight-line profiles of detrital clay-rich beds above and below them. Studies of major and trace element chemistry and clay mineralogy support this subdivision (see WRAY, 1995, 1999; WRAY & WOOD, 1998).

Subsequent work has further rationalised the tephrostratigraphic scheme, which can now be applied throughout northern Germany. The four bentonites, T_C (Middle Turonian) and T_D, T_E and T_F (Upper Turonian) have been recognised in the Münsterland Cretaceous (Westphalia) and Subhercynian Cretaceous basins (Sachsen-Anhalt), in addition to the original type area between Braunschweig and the Harz in Lower Saxony (Fig. 1; cf. WRAY et al., 1995, 1996). However, not all of the bentonites are recognised in any one section: in particular, bentonite T_C has so far been identified in Westphalia only at one locality (Oerlinghausen; see WRAY et al. 1995) and one of the most widely distributed bentonites (T_F) is not preserved in the Söhlde sections of Lower Saxony, which are the subject of this paper.

In the chalk of eastern England and the Anglo-Paris Basin, a total of five, rather than four bentonites has been recorded through the correlative stratigraphic interval (Wray & Wood, 1998; Wray, 1999). Although the individual bentonites have been given different names in different areas, a correlation of these bentonites between eastern England and the Anglo-Paris Basin has been proposed by Wray (1999), which is supported by both biostratigraphic and geophysical (downhole wire-line log correlation) evidence (Mortimore & Wood, 1986). Geochemical and biostratigraphic evidence can also be used to include within this correlation scheme the four bentonites identified in Germany (cf. Wray, 1999). Central to the England – Germany correlation is the use of the $\delta^{13}C$ carbon stable isotope curves that have been established for the Turonian of the Dover cliff-section in the Anglo-Paris Basin (Jenkyns et al., 1994) and for the Söhlde and Salzgitter-Salder quarries in Lower Saxony (Voigt & Hilbrecht, 1997; Voigt & Wiese, 2000). The similarity in the $\delta^{13}C$ curves between these two regions supports and reinforces the tephro-event correlation (Fig. 2).

At an early stage in the development of the tephro-event correlation scheme it became apparent that the lateral equivalent of one of the five bentonites identified in the Turonian of the Anglo-Paris Basin (Southerham Marl 1) and eastern England (Melton Ross Marl) had yet to be recognised in Germany. This bentonite lies between the first (Glynde Marl 1/Barton Marl 1) and third (Caburn Marl/Deepdale Marl 1) of the English Turonian bentonites, which are inferred to correlate with the German bentonites T_C and T_D respectively. It is also situated very close to the negative $\delta^{13}C$ peak between the positive $\delta^{13}C$ peaks '-2'and '-3' of the isotope correlation framework established by Wiese (1999) and used for long-range correlation. As detailed investigations undertaken in Germany over approximately 45 years had failed to recognise an equivalent of this bentonite, the implication was that either it was not present or, if present, that it was represented by an extremely thin and consequently inconspicuous bed of clay.

The apparent absence of this bentonite in Germany is particularly surprising in view of the fact that the Southerham Marl 1/Melton Ross Marl bentonite is one of the best developed, thickest (up to 0.15 m in eastern England) and most distinctive of the five bentonites in the English tephrostratigraphic framework. However, a detailed lithostratigraphic description and graphic log of the succession in the Söhlde-Loges Quarry in Lower Saxony (Böttcher, 1996 and Fig. 1) revealed the presence of several clay-rich beds in the middle of the T_C – T_D interval that had not previously been sampled for geochemical analysis. Moreover, these beds approximately coincided with an apparent equivalent of the negative $\delta^{13}C$ peak between the positive $\delta^{13}C$ peaks '-2'and '-3' of Wiese (1999), supporting their potential as a location for the missing bentonite (details kindly supplied by Dr. Silke Voigt, Köln, subsequently published as part of Voigt & Wiese, 2000, fig. 2). It must be emphasised, as pointed out by Wiese (pers. comm., 2001), that the positive excursions in question are quantitatively insignificant and cannot safely be identified as the peaks used for long-range correlation. In fact, Wiese (1999) had already stated that the succession at Söhlde was anomalous, involving significant re-sedimentation, and that peaks -2 and -3 were probably missing due to an hiatus.

Southerham Marl 1/Melton Ross Marl is also inferred to correlate with the Fognam Marl in the condensed Chalk Rock succession at Fognam Farm Quarry (Bromley & Gale, 1982). At this locality there is a horizon of phosphatised intraclasts situated below the Fognam Marl and above a phosphatised hardground (the Pewsey Hardground). The intraclast horizon has yielded a specimen of *Subprionocyclus* intermediate between *S. neptuni* (Geinitz) and *S. branneri* (Anderson). This record represents the lowest occurrence of the genus *Subprionocyclus* in England and, by inference, the approximate FAD of *Subprionocyclus neptuni*, a datum which is taken to mark the base of the Upper Turonian Substage (Bengtson, 1996). An additional species of *Subprionocyclus*, *S. hitchinensis* (Billinghurst), has been collected from the interval between Southerham 1 & 2 at Dover (Gale, 1996; Mortimore et al., 2001). From eastern England a specimen of *S.*

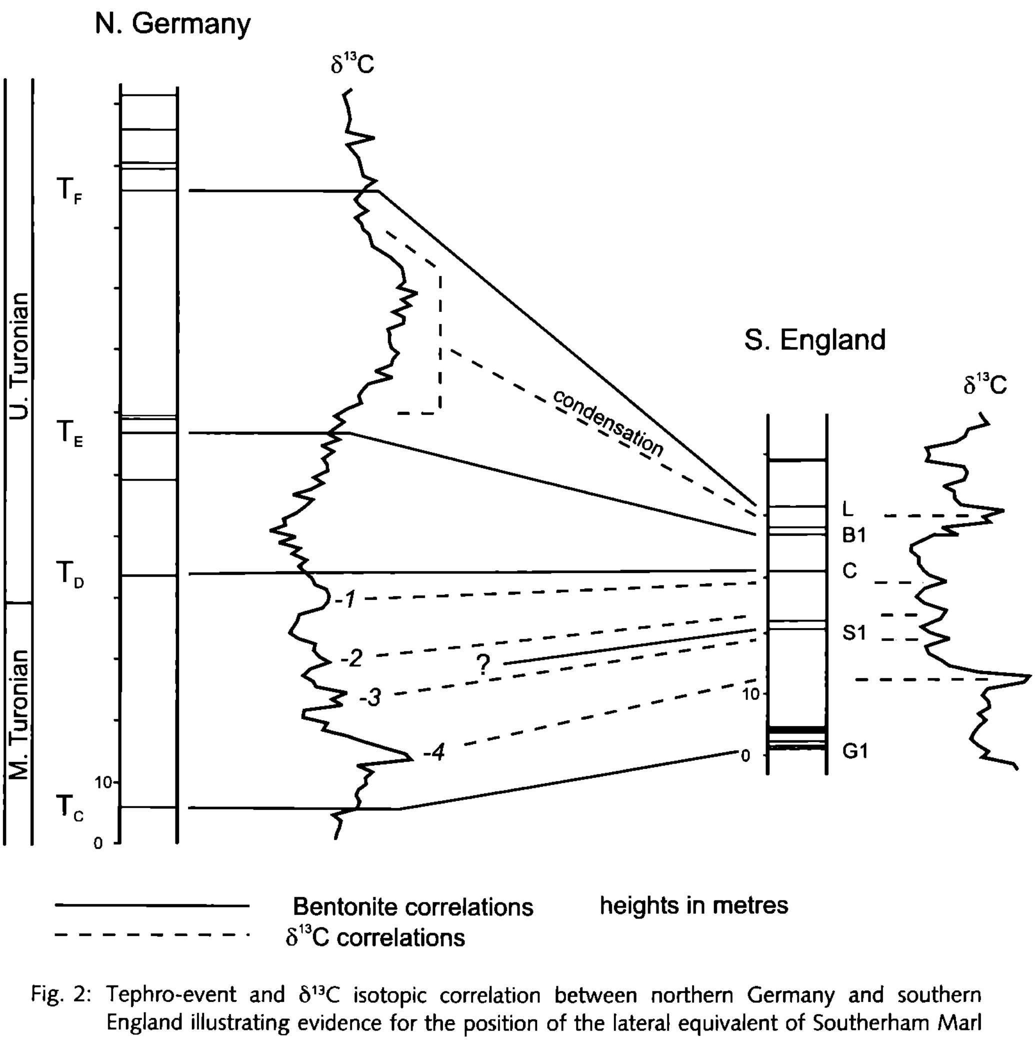

Fig. 2: Tephro-event and $\delta^{13}C$ isotopic correlation between northern Germany and southern England illustrating evidence for the position of the lateral equivalent of Southerham Marl 1 / Melton Ross Marl bentonite in northern Germany. *–1* to *–4* refer to the $\delta^{13}C$ excursion numbering system of Wiese (1999). G1= Glynde Marl 1; S1 = Southerham Marl 1; C = Caburn Marl; B1 = Bridgewick Marl 1; L = Lewes Marl (adapted from Wray, 1999).

neptuni was collected below Deepdale Marl 1, the inferred correlative of the German bentonite T_D. This record is inferred to indicate the approximate position of the *costellatus/plana* event of the German scheme (WOOD in WRAY, 1999: p. 369; MORTIMORE et al., 2001).

3. SAMPLING AND ANALYTICAL METHODOLOGY

Examination of the section in the Söhlde-Loges Quarry by one of us (CJW) in 1998 resulted in the sampling of three clay-rich beds at the top of the Upper Rotpläner [red limestone] lithostratigraphic unit (for stratigraphy see ERNST et al., 1998). A generalized section, modified from VOIGT & WIESE (2000) is presented in Fig. 3 and details of the re-logged section (by CJW) are given in Fig. 4. In ascending order, these clay-rich beds comprised a 10.0-mm grey-green clay terminating a basal unit of pinkish griotte; a

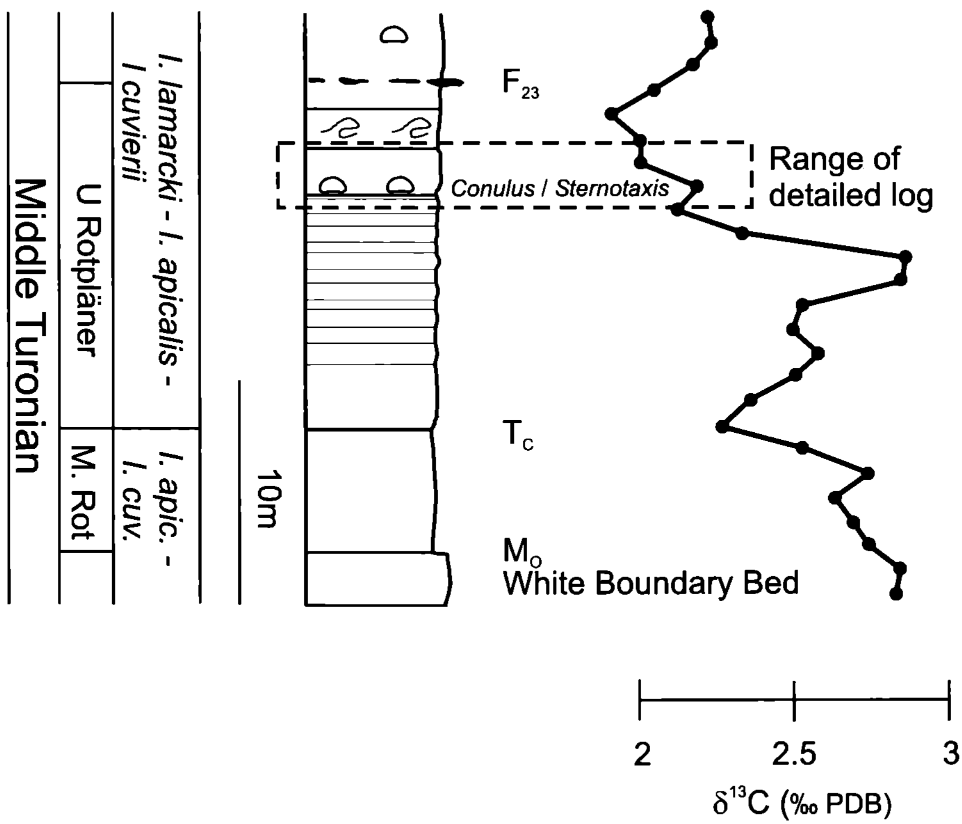

Fig. 3: Stratigraphic log and $\delta^{13}C$ isotope curve for the middle Turonian of Söhlde (adapted from VOIGT & WIESE, 2000).

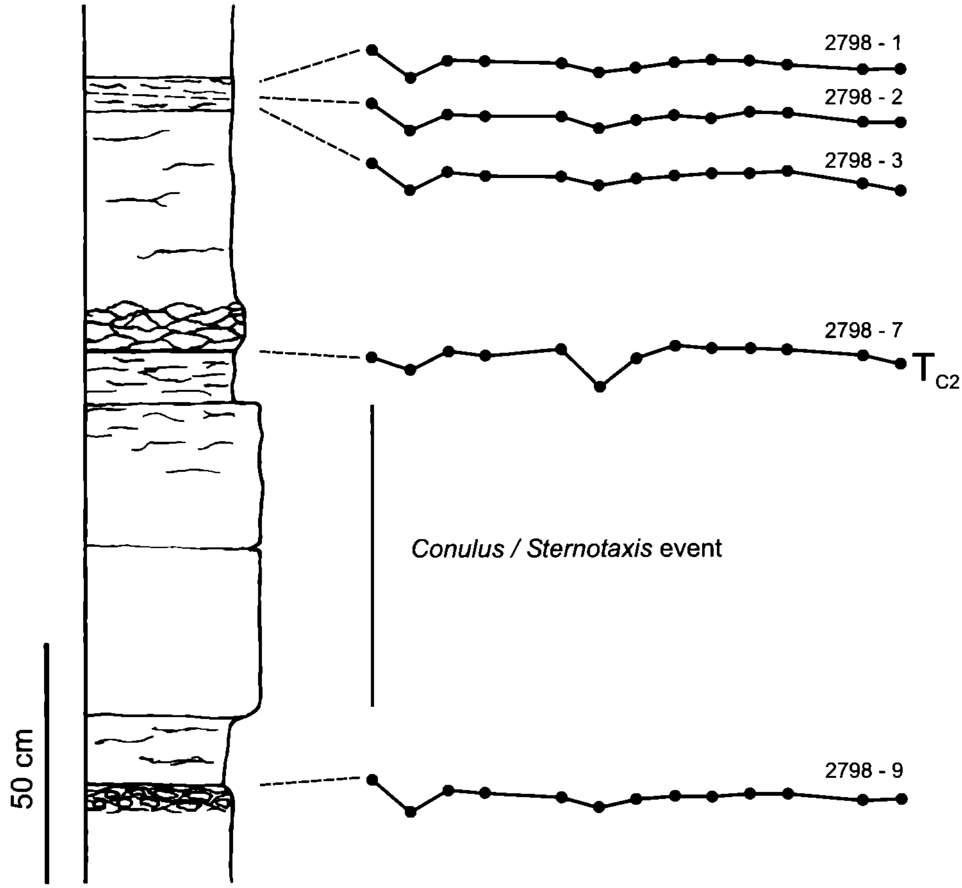

Fig. 4: Detailed stratigraphic log of the studied section in the Söhlde-Loges quarry and shale-normalised REE profiles of all beds collected. The REE profiles are all sub-horizontal with the exception of one bed that displays a significant negative Eu anomaly, this we propose is a bentonite which we name T_{C2} and correlate with Southerham Marl 1 / Melton Ross Marl in England.

10.0-mm- yellowish-green clay with a sub-conchoidal fracture; and a 70.0-mm greenish grey argillaceous bed with a central sub-horizontal orange streak. The second of these, which lay only 0.1 m above a prominent 0.65-m white limestone bed, exhibited all the field characters of the (much thicker) bentonites T_D and T_E in this and in the adjacent Söhlde quarries. The prominent limestone bed marks the *Conulus/Sternotaxis* event of the event-stratigraphic framework (for further details see Ernst et al., 1998, p. 115).

Samples were dried, and ground to a fine powder using an agate ball mill. Subsamples were dissolved using a lithium metaborate fusion prior to analysis by ICP-AES and ICP-MS. Where levels of REE in samples were below the limit of quantification a second preparation was undertaken using a hydrofluoric / perchloric acid digestion, a procedure which results in a ten-fold increase in the concentration of analytes as presented to the instrument (for a detailed description of the methods see WRAY & WOOD, 1998). As with previous studies the REE data are normalised to U.S.G.S. Certified Reference Material SCo-1 (Cody Shale; see JARVIS & JARVIS, 1985 for discussion).

4. RESULTS AND DISCUSSION

Results from all beds sampled are displayed in Tab. 1, Shale normalised REE profiles are displayed stratigraphically in Fig. 4; shale and chondrite normalised REE profiles are also displayed graphically in Fig. 5. All beds display a slight cerium anomaly most probably due to the presence of a variable quantity of fish-derived phosphate and marine carbonate (see WRAY, 1995 for further discussion). Discounting the variable Ce anomaly, of the beds analysed all but one display near horizontal shale normalised REE profiles whilst one displays an anomalous profile characterised by a significant negative Eu anomaly. On the basis of earlier discussions we propose that this bed is a bentonite and, with the support of isotopic data, we also propose that it is the lateral equivalent of Southerham Marl 1 / Melton Ross Marl of England. Whilst it is tempting to suggest that this bed also be titled Southerham Marl 1 in recognition of its 'type area' in the Anglo-Paris Basin, in order to maintain the systematics of the local nomenclature we propose that this bed be referred to as T_{C2}, pending the establishment of a pan-NW Europe nomenclature. The position of T_{C2} has been included in a recent publication by NIEBUHR et al. (2000, fig. 36).

	SiO_2	TiO_2	Al_2O_3	Fe_2O_3t	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	Ba
DW2798 1	17.29	0.202	5.36	1.71	0.029	0.81	38.46	0.06	1.04	0.09	105.2
DW2798 2	15.75	0.180	4.76	2.05	0.036	0.78	39.38	0.07	0.89	0.11	118.9
DW2798 3	16.00	0.180	4.96	1.76	0.033	0.78	39.19	0.05	0.93	0.10	86.6
DW2798 7	29.40	0.286	9.29	2.92	0.029	1.77	28.48	0.07	0.79	0.06	95.1
DW2798 9	17.45	0.208	5.56	1.91	0.021	0.88	37.27	0.09	1.15	0.11	134.6

	Cr	Cs	Hf	Nb	Ni	Rb	Sr	Ta	Th	U	V	Y	Zr
DW2798 1	35.2	3.4	1.3	4.6	42.7	50.8	678.6	0.4	3.8	0.7	54.4	10.9	29.5
DW2798 2	27.7	3.4	0.8	4.1	48.3	46.4	625.5	0.2	3.4	0.6	64.5	11.7	36.5
DW2798 3	33.9	3.2	0.9	4.3	39.5	44.0	622.5	0.3	3.4	0.6	66.6	10.6	32.4
DW2798 7	21.3	2.2	8.4	28.9	78.8	37.0	472.5	3.7	11.3	0.5	35.3	12.2	253.1
DW2798 9	34.4	4.1	1.3	5.0	33.7	52.7	520.4	0.3	4.0	0.6	36.4	8.3	24.4

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Yb	Lu
DW2798 1	17.1	25.8	3.68	13.4	2.60	0.50	1.63	0.30	2.10	0.42	1.08	0.97	0.15
DW2798 2	16.9	25.4	3.60	12.9	2.54	0.48	1.62	0.30	1.96	0.43	1.12	0.96	0.15
DW2798 3	17.1	25.7	3.67	13.1	2.55	0.50	1.66	0.30	2.11	0.43	1.16	0.96	0.14
DW2798 7	22.2	38.7	5.66	19.7	4.23	0.60	2.53	0.51	3.34	0.68	1.78	1.58	0.22
DW2798 9	17.7	25.0	3.76	13.3	2.52	0.49	1.65	0.30	2.00	0.42	1.11	0.98	0.15

Tab. 1: Geochemical data used in this study. Major elements are expressed in oxide weight percent, trace elements are expressed in μg/g. See Figure 4 for the stratigraphic position of each sample.

Major and trace element discrimination diagrams are frequently used to characterise tectonic setting and original magma composition (e.g. WINCHESTER & FLOYD, 1977; PEARCE et al., 1984; ROBERTS & MERRIMAN, 1990; HUFF et al., 1993). Data from other Turonian bentonites has already been presented by WRAY (1999) and the results obtained from T_{C2} are incorporated into this data set in Fig. 6 (a–d). Data from T_{C2} plot close to data from other previously identified bentonites. A plot of Zr/TiO_2 vs Nb/Y (Fig. 6a) implies that T_{C2} has a trachyitic composition. As previously noted by WRAY (1999) there is an interregional, systematic shift in data from correlative bentonites with those from eastern England generally displaying elevated Zr/TiO_2 values and those from northern Germany displaying enhanced Nb/Y values. This has been ascribed to sorting during atmospheric transportation. Additional trace and major element plots (Fig. 6b–d) demonstrate that T_{C2} has similar magmatic affinities and tectonic provenance to that of the other bentonites, adding support to the proposed correlation of T_{C2} with Southerham Marl 1 / Melton Ross Marl. WRAY (1999) proposed, on the basis of geochemical and palaeogeographic data that the most likely source of the original ash was vulcanism associated with the early stages of rift formation in the North Atlantic (for further discussion see WRAY, 1999).

Sampling at other localities has been undertaken in an attempt to locate T_{C2} elsewhere in Lower Saxony. To date this has met with no success, most notably at Wendessen in Lower Saxony, where two thick clay-rich beds were sampled from the top of the Rotpläner but both produced sub-horizontal (detrital) REE profiles. This apparent absence of T_{C2} at other localities in Lower Saxony is disappointing and also somewhat surprising given that the Söhlde succession is somewhat anomalous (for example T_F is absent) and contains slump horizons close to the level of T_{C2} (ERNST et al., 1998). The

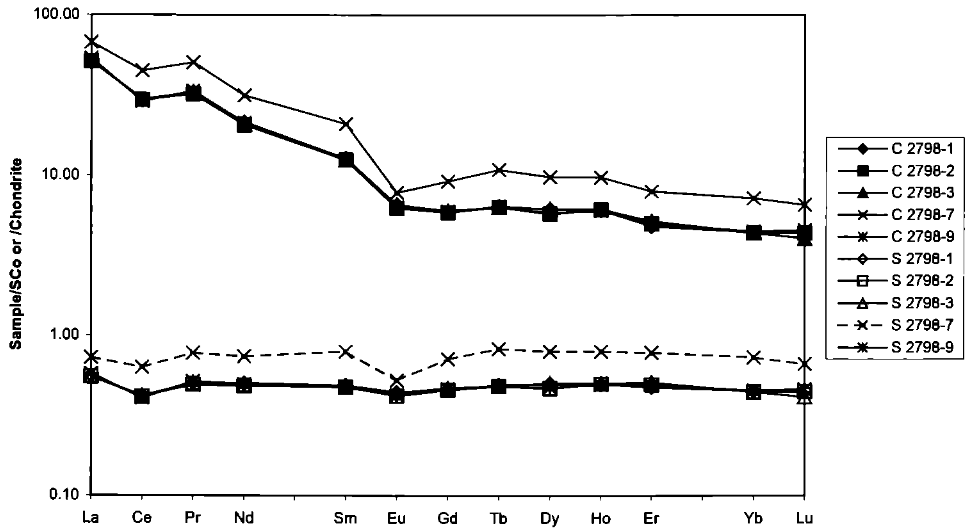

Fig. 5: Chondrite (C) and shale (S) normalised REE profiles of clay beds collected in this study; see Figure 4 for stratigraphic heights.

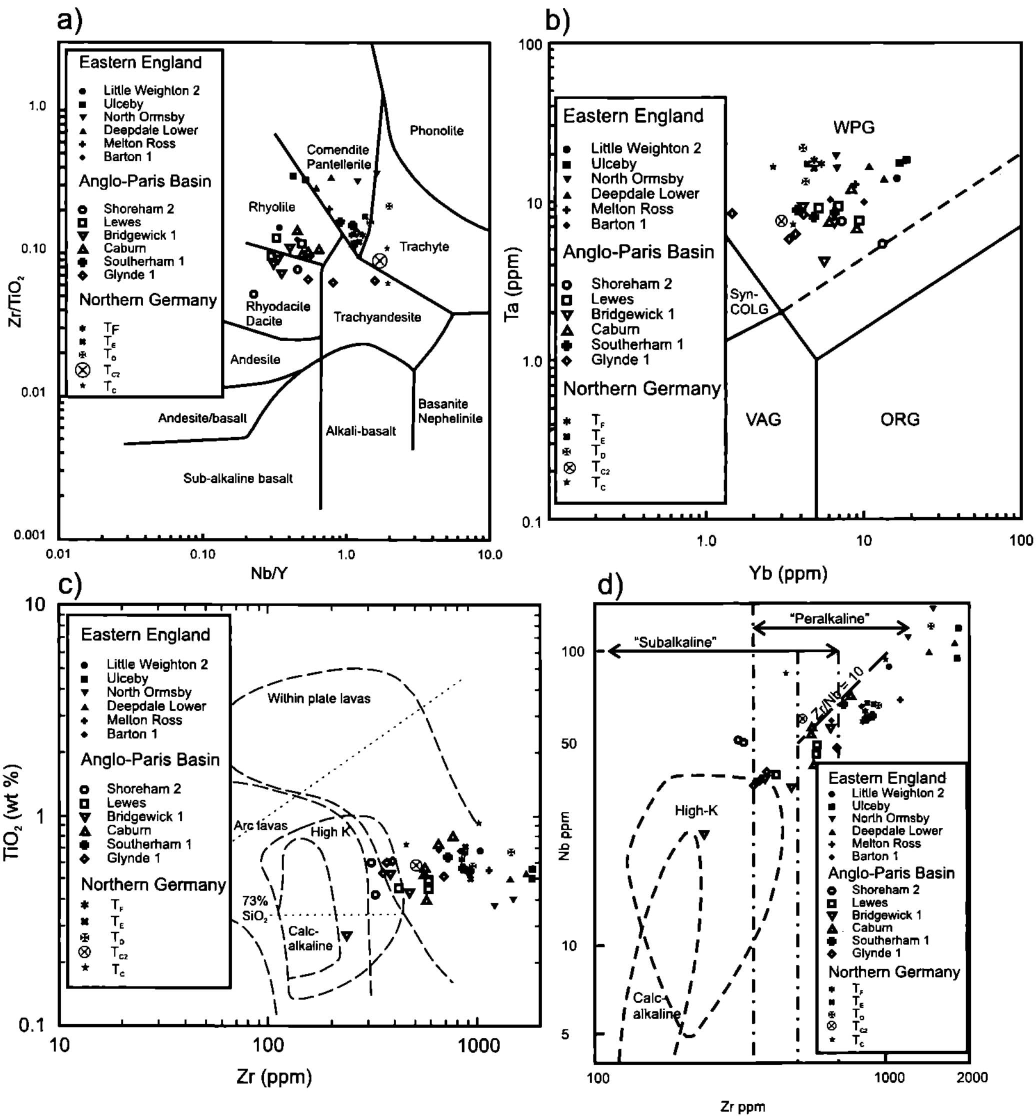

Fig. 6a: A plot of Zr/TiO_2 against Nb/Y for Turonian-Coniacian bentonites of north-west Europe (after WINCHESTER & FLOYD, 1977).

Fig. 6b: A plot of Ta against Yb for Turonian-Coniacian bentonites from north-west Europe after re-calculation to a carbonate free basis (after PEARCE et al., 1984). WPG = within plate granites; Syn-COLG = syn-collision granites; VAG = volcanic arc granites; ORG = ocean ridge granites.

Fig. 6c: a plot of TiO_2 against Zr for Turonian-Coniacian bentonites from north-west Europe after re-calculation to a carbonate free basis (after LEAT et al., 1986).

Fig. 6d: A plot of Nb against Zr for Turonian-Coniacian bentonites from north-west Europe after re-calculation to a carbonate free basis (after LEAT et al., 1986).

apparent absence of T_{C2} across the region is probably a reflection of primary transportation processes, principally wind direction; its occurrence at Söhlde may simply represent a chance concentration of relatively distal ash due to current action.

Current biostratigraphic (ammonites and inoceramid bivalves) and isotope stratigraphic investigations (WIESE & KAPLAN, 2001) of the expanded Turonian section in the Lengerich Quarry, Westphalia, suggest that the *Conulus/Sternotaxis* event of Lower Saxony (i.e. the prominent white limestone beneath the clay-rich bed now identified as T_{C2}) may mark the base of the Upper Turonian, rather than the *costellatus/plana* event, a short distance between bentonite T_D, which had hitherto been taken as the basal boundary marker datum. Although clay-rich beds from this locality have been examined for their REE profiles by one of us (DSW), all of the beds analysed to date have proved to be detrital marls. However, the revised interpretation of the base of the Upper Turonian in German successions supports the correlation of the new German bentonite with Southerham Marl 1 of the Anglo-Paris Basin, since the entry of *Subprionocyclus* immediately below the inferred lateral equivalent (Fognam Marl) of this marl seam in the condensed Chalk Rock successions is taken to mark the base of the Upper Turonian in the UK (see discussion in GALE, 1996; MORTIMORE et al., 2001, WIESE & KAPLAN, 2001).

5. CONCLUSIONS

Using a combination of meticulous field collecting and advanced geochemical analysis it has proven possible to locate and characterise the lateral equivalent of bentonite Southerham Marl 1 / Melton Ross Marl from England at one locality in northern Germany. This bed we name T_{C2}, in keeping with the regional nomenclature. Trace element discriminant plots indicate that the ash had a trachyitic composition and was derived from a within plate source. Its general absence from most localities in this region is problematic but is probably in turn related to original atmospheric distribution of the ash. Attempts to locate this bentonite at other localities in northern Germany are continuing.

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