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Author for correspondence: Peter Hodges, Email: peter.hodges@museumwales.ac.uk

A new ammonite from the Penarth Group, South Wales and the base of the Jurassic System in SW Britain

Peter Hodges

Department of Geology (Palaeontology), Natural Sciences, National Museum of Wales, Cathays Park, Cardiff CF1 3NP, UK

Abstract

Two ammonites have been found in porcelaneous limestones of the White Lias Formation traditionally considered to be of Rhaetian (Late Triassic) age at Lavernock Point, south Wales (ST 181 681). These ammonites, named here *Neophyllites lavernockensis.* sp. nov, are the earliest recorded from the UK. This horizon is located directly above a major negative $\delta^{13}C$ isotope anomaly (CIE1) in the Upper Cotham Member that marks the top of the Triassic System and below another negative $\delta^{13}C$ isotope anomaly (CIE3). Both correlate with negative $\delta^{13}C$ isotope anomalies in the Triassic–Jurassic global boundary stratotype section and point (GSSP) at Kuhjoch, Austria. This establishes the base of the *tilmanni* Chronozone, Hettangian Stage and Jurassic System in SW Britain within the White Lias Formation at Lavernock Point.

1. Introduction

In the absence of an international consensus to designate a type locality for the base of the Hettangian Stage and Jurassic System, the base of the Jurassic System in SW Britain has historically been based on the first occurrence of *Psiloceras planorbis*. To resolve this issue, an international subcommission on Jurassic stratigraphy was established in 1988 with various working groups invited to submit proposals for a global stratotype section and point (GSSP). In the UK, two type sections were proposed: the first is at St Audrie's Bay, Somerset (Warrington *et al.* 1994, 2008) and the second is at Larne, Northern Ireland (Simms & Jeram, 2007). Another candidate section at Kuhjoch, Karwendel Mountains, Tyrol, Austria was also proposed (von Hillebrandt *et al.* 2007). Following much deliberation, the GSSP was awarded to the Kuhjoch section with a 'Golden Spike' ceremony undertaken in 2011 and a detailed description was subsequently published (von Hillebrandt *et al.* 2013). This proposed the first occurrence of *Psiloceras spelae tirolicum* as defining the base of the *tilmanni* Chronozone and Hettangian Stage, but it created a problem for defining the base of the Jurassic System in the UK and NW Europe.

The earliest ammonite species recorded in England was *P.* cf. *erugatum* from Doniford Bay, Somerset and *P.* cf. *erugatum* with *Neophyllites* sp. in bed 8 at St Audrie's Bay, Somerset (Page & Bloos, 1998). However, these specimens were crushed, lacked any detail of sutures and were considered by Warrington *et al.* (2008) to be 'Too poorly preserved to warrant identification'. Elsewhere Page & Bloos (1998) recorded *Neophyllites* above *P. erugatum* and below *P. planorbis* in the Wilkesley borehole. Recognition of ammonite biohorizons below *P. planorbis* in SW Britain is difficult because of a lack of well-preserved specimens. Nonetheless, Page (2003) proposed an ammonite zonation for NW Europe in which *P. erugatum* defined the base of the *planorbis* Chronozone and base of the Jurassic System.

In contrast to Britain, the Larne section in Northern Ireland has yielded well-preserved uncrushed examples of *P. erugatum*, *N. imitans* and *N. antecedens* below beds with *P. planorbis* (Simms & Jeram, 2007). The absence of the *tilmanni* Chronozone in NW Europe has been attributed to differences in water depth compared with the Northern Calcareous Alps of Austria and its deeper Tethyan waters (von Hillebrandt & Krystyn, 2009), but the ammonite record in NW Europe has been augmented recently by the discovery of *P.* cf. *tilmanni* in the Rødby borehole, Denmark (Lindström *et al.* 2017). However, an anomaly in the ammonite record of SW Britain was the discovery of a small psiloceratid ammonite with a simple suture in the Penarth Group at Hampstead Farm Quarry, Chipping Sodbury, England (Donovan *et al.* 1989). This specimen was said to occur in a limestone bed at the top of the Westbury Formation, but re-examination of this section has revealed that this limestone bed actually belongs to the Lower Cotham Formation. An unconformity separates the limestone bed in which the psiloceratid was found from black laminated mudstones of the Westbury Formation beneath. A major negative

δ^{13}C isotope anomaly CIE1 occurs in SW Britain in the Upper Cotham Member above, so this psiloceratid must be of Rhaetian age.

2. Stratigraphy of the Triassic–Jurassic Boundary at Lavernock Point

The earliest ammonite previously recorded in south Wales is *P. planorbis* from the St Mary's Well Bay Formation of the Blue Lias, which is part of the Lias Group (Waters & Lawrence, 1987; Simms *et al.* 2004) *c.* 1.4 m above the Dual Bed at Lavernock Point (ST 181 681) (Hodges, 1994). The pre-*planorbis* beds below (Bull Cliff Member, St Mary's Well Bay Formation) are developed in a shallow-marine facies of limestones and mudstones generally not conducive to occupation by ammonite species, but dominated by the bivalves *Modiolus (M.) minimus* and *Liostrea hisingeri*. In the underlying Penarth Group are a series of breaks in the local stratigraphy caused by tectonic activity related to Central Atlantic magmatic province (CAMP) volcanism and the break-up of the Pangean supercontinent. Evidence for CAMP-related seismicity has been described in Europe by Simms (2003, 2007) and Lindström *et al.* (2015).

The stratigraphy of the Penarth Group in SW Britain was revised by Gallois (2007, 2009) who identified several hiati in the lithostratigraphy related to seabed uplift, sometimes with erosion and desiccation, and marine transgressions due to eustatic sea-level rises; these events are reflected in the boundaries of the formations erected for the Penarth Group (Fig. 1). Recent fieldwork at Lavernock Point has confirmed the work of Gallois and identified an additional erosional boundary immediately beneath the 'Paper Shales' at the top of the Watchet Mudstone Formation, where small-scale desiccation cracks have also been observed (Fig. 2). These hiati in the upper part of sections traditionally treated as Rhaetian have resulted in the absence of beds that could potentially have contained diagnostic ammonite species.

In the Kuhjoch GSSP are several chronostratigraphic markers as represented by a series of major negative δ^{13}C isotope anomalies (Ruhl *et al.* 2009). These isotope anomalies have since been recorded in Triassic–Jurassic sections internationally (Guex *et al.* 2003, USA; Pálfy *et al.* 2007, Hungary; Pienkowski *et al.* 2012, Poland; von Hillebrandt *et al.* 2013, Austria), enabling correlation with the Kuhjoch GSSP. Chemostratigraphy across the Triassic–Jurassic boundary internationally has recently been summarized by Korte *et al.* (2019) and shows the effect of CAMP volcanism on the environment at that time. The significant negative δ^{13}C isotope anomalies at Kuhjoch were designated CIE1, CIE2 and CIE3 by von Hillebrandt *et al.* (2013) (Fig. 3). CIE1, the largest of these, occurs close to the last occurrence of *Choristoceras marshi* and is of Rhaetian (Late Triassic) age. CIE2 occurs just below the first occurrence of *P. spelae tirolicum* that defines the base of the *tilmanni* Chronozone and therefore the Jurassic System. CIE3 occurs *c.* 2 m above this at Kuhjoch, just below the occurrence of *Psiloceras* ex gr *P. tilmanni* (von Hillebrandt *et al.* 2013, fig. 27). CIE1 was recognized in the Upper Cotham Member of the Cotham Formation at Lavernock Point (Suan *et al.* 2012) based on comparisons with St Audrie's Bay (Hesselbo *et al.* 2002), which contains shallow-water ripple-marked sandstones and siltstones with ferruginous staining. This confirms the Upper Cotham Member as being of Rhaetian age.

The base and top of the White Lias Formation above are marked by stratigraphic breaks that might explain the lack

Blue Lias	St Mary's Well Bay Formation	
Penarth Group	Watchet Mudstone Formation	
	White Lias Formation	
	Cotham Formation	Upper Cotham Member
		Lower Cotham Member

Fig. 1. Lithostratigraphy of SW Britain (Gallois, 2007, 2009).

of evidence to date for the *tilmanni* Chronozone here. There is a major negative δ^{13}C isotope anomaly in the Watchet Mudstone Formation above the White Lias Formation at Lavernock Point (Korte *et al.* 2009; Suan *et al.* 2012), which suggested that the Triassic–Jurassic boundary could possibly lie within this formation. Recognized breaks in the lithostratigraphy above and below the White Lias Formation at Lavernock suggest that this negative δ^{13}C is most probably CIE3.

Comparisons between Lavernock Point and the closely studied section at St Audrie's Bay are shown in Fig. 4. The lithostratigraphy of the Penarth Group at St Audrie's Bay is based on Gallois (2009) and the Lower Lias above on Whittaker & Green (1983). The first appearance of *P. planorbis* in this section is based on Hodges (1994). The hiati in the Penarth Group at St Audrie's Bay are identical to those at Lavernock Point (Gallois, 2009) and also result in breaks in the CIE record of St Audrie's Bay (Hesselbo *et al.* 2002) compared with Kuhjoch. These breaks are shown in Figure 4.

3. 'Pre-*planorbis*' ammonites at Lavernock

Fieldwork at Lavernock Point, South Glamorgan, Wales (ST 181 681) led to the discovery of a pyritized ammonite (NMW.83.22G.1459; Figs 5–7) in fallen material at the base of a cliff section (Fig. 2) that exposes rocks of the Penarth Group currently treated as Rhaetian (Late Triassic) in age. A second very worn ammonite (Fig. 8) was also seen on the upper surface of a limestone bed at the top of the White Lias Formation. It was just about possible to make out and measure the diameter and umbilical width of this worn ammonite, allowing comparisons with the ratios of Early Jurassic ammonite species. The location of the pyritized ammonite at the base of the cliff, along with its fragile nature, indicates that it could not have moved far from its original location, but it was not found in situ. Attempts were made using geochemical methods to try and determine the bed from which the specimen originated.

Rock samples collected from each of the beds in the cliff section above where the pyritized ammonite was found were analysed by X-ray diffraction (XRD), as was the limestone adhering to the pyritized ammonite. The results of these XRD analyses (Table 1) suggest a match between the limestone at the centre of the ammonite whorl and the limestone of bed WL1.

Significantly, this bed is also the only one in the cliff section to contain pyrite. The worn ammonite (Fig. 8) seen on the top bed of the White Lias formation (WL1), although impossible to identify, had whorl dimensions similar to those of the pyritized ammonite. It was possible to measure the umbilical width and diameter of the worn specimen, giving an estimated ratio of 0.45. The pyritized ammonite was measured in a similar way, giving an umbilical width to diameter ratio of 0.42.

The position of these ammonites within the White Lias Formation places them 0.5 m above CIE1 and 1.3 m below

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Fig. 2. Section at Lavernock Point (ST 181 681). WM – Watchet Mudstone Formation; WL – White Lias Formation; UCM – Upper Cotham Member; LCM – Lower Cotham Member.

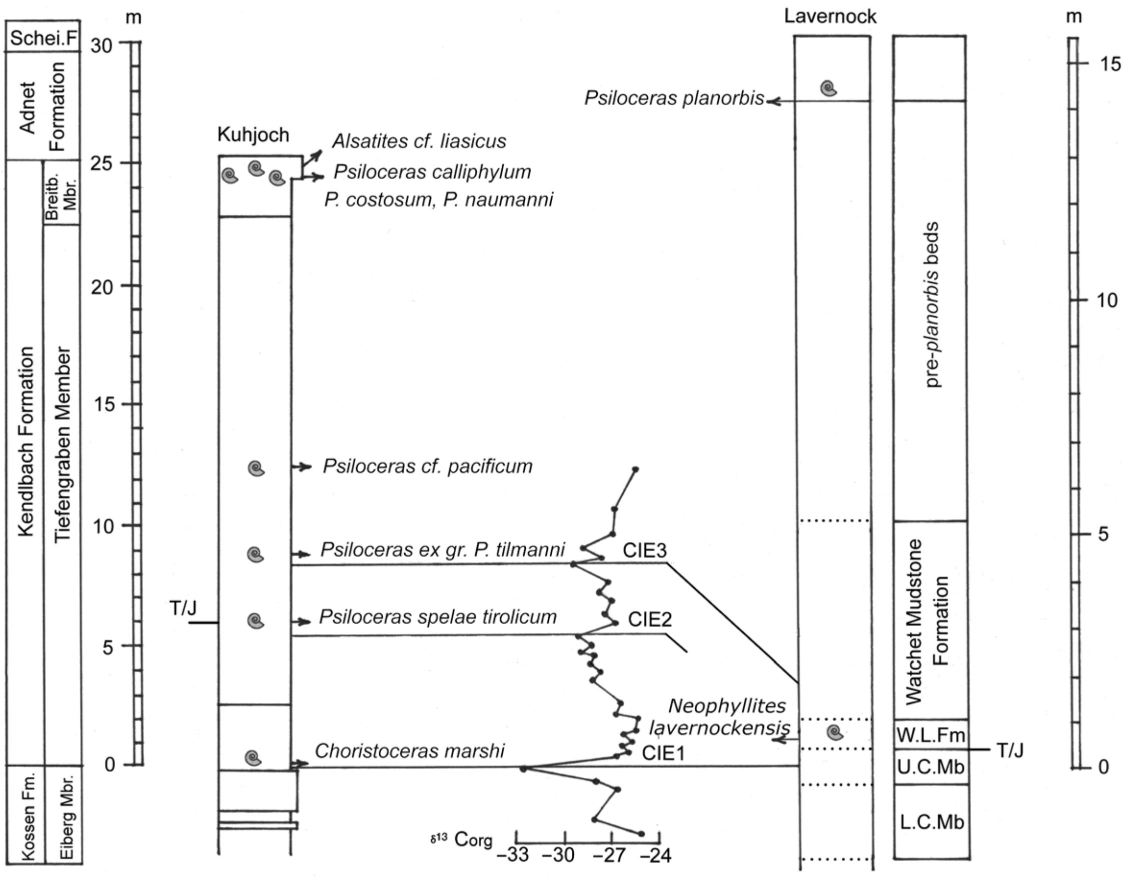

Fig. 3. Comparisons of Kuhjoch type section (Hillebrandt *et al.* 2013) with Lavernock Point section. CIE1-CIE3 – carbon isotope excursions. W.L.Fm. – White Lias Formation. U.C.Mb. – Upper Cotham Member. L.C.Mb. – Lower Cotham Member; T/J – Triassic–Jurassic Boundary.

CIE3. By comparison with the GSSP at Kuhjoch, this is just above the first appearance of *P. spelae tirolicum*. The precise distance of this new ammonite from CIE1 and CIE3 at Lavernock is not critical due to the disconformities that exist above and below the bed in which the ammonite is found. In the absence to date of *P. spelae tirolicum* and *P. tilmanni* at Lavernock, there is no absolute proof of the chronological position of this new species relative to those species; nonetheless, we can be fairly certain

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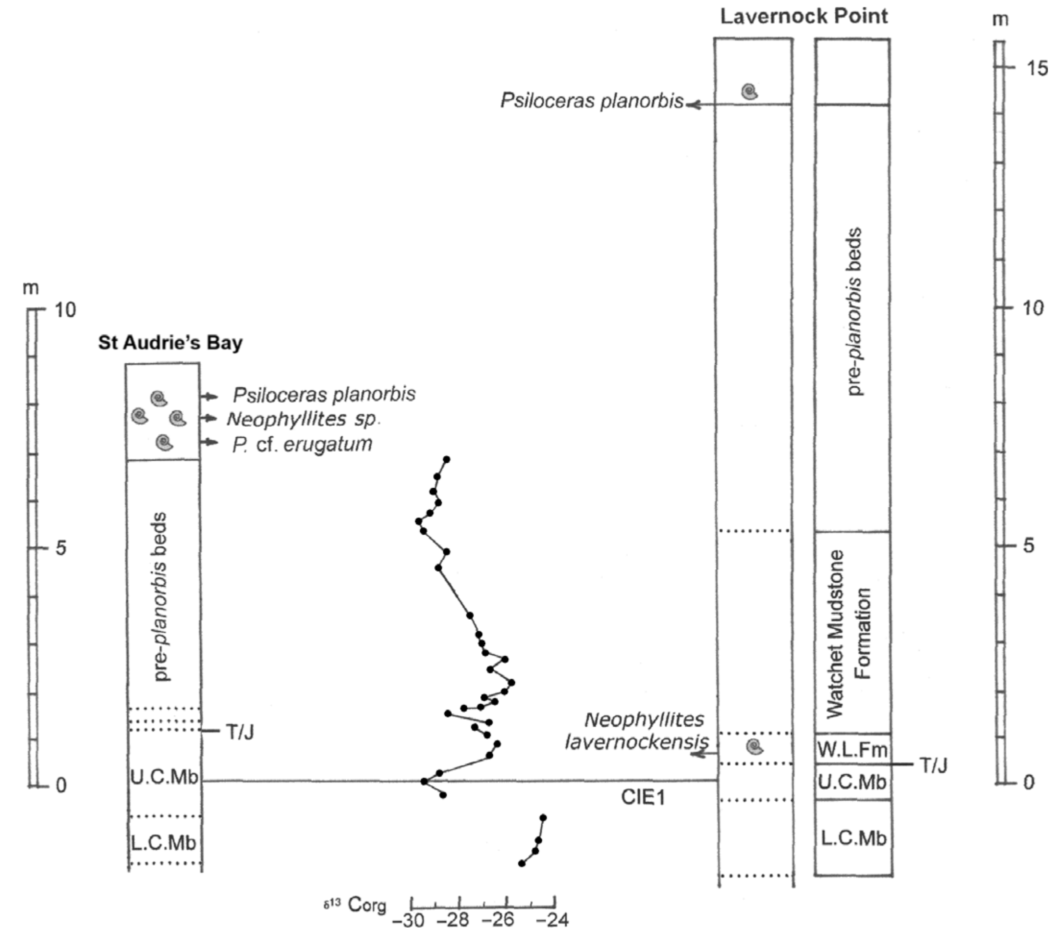

Fig. 4. Comparisons of Lavernock Point section and St Audrie's Bay section (Gallois, 2009). Abbreviations as in Figure 3.

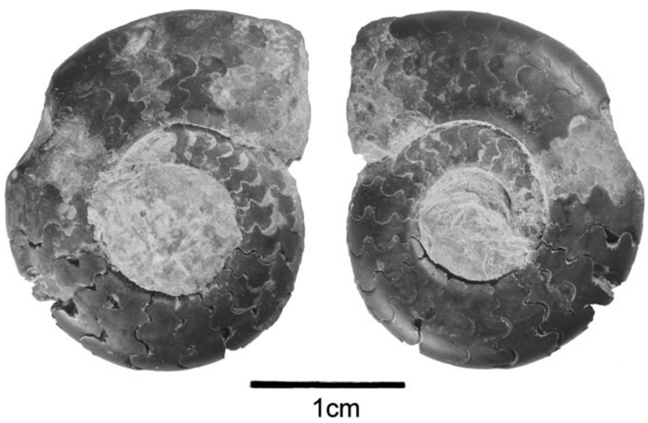

Fig. 5. Pyritized specimen NMW.83.22G.1459 *Neophyllites lavernockensis* sp. nov.

Fig. 6. (Colour online) Detail of nodes on largest whorl.

that the *tilmanni* Chronozone is present at Lavernock. The earliest *P. planorbis* at Lavernock occurs 1.4 m above the Dual Bed, which is *c.* 13 m above this new ammonite species.

4. Ammonite systematics

Superfamily Psiloceratoidea Hyatt, 1867
Family Psiloceratidae Hyatt, 1867

Genus Neophyllites Lange, 1941
Type species. *Psilophyllites antecedens* Lange, 1931
Neophyllites lavernockensis sp. nov

Description. The holotype is an entirely septate pyritic internal cast of 20.8 mm diameter. It is moderately involute, with an umbilical width of 9 mm (0.42 of umbilical diameter) and whorl height of 7.6 mm (0.37 of total diameter). The whorl cross-section is sub-triangular with a rounded venter, and whorl width is greatest (4.6 mm, or 0.6 of whorl height) at the umbilical angle. The flanks are steep, angled at approximately 12° to the vertical. Flanks from umbilical angle to the umbilical seam are relatively flat. The innermost whorls are smooth, but the outer whorl has

Table 1. X-ray diffraction (XRD) analysis of field samples.

	Bed no.	Calcite (%)	Mica (%)	Quartz (%)	Pyrite (%)	Dolomite (%)	Potassium (%)
Watchet Mudstone Formation	WM4	23	45	26	–	6	–
	WM3	68	24	8	–	–	–
	WM2	73	22	5	–	–	–
	WM1	30	51	19	–	–	–
White Lias Formation	WL1	56.6	27.3	11.1	5.1	–	–
Cotham Formation, Lower Cotham Member	LC1	16	25	32	–	12	15
Pyritized ammonite matrix		53	26	15	6	–	–

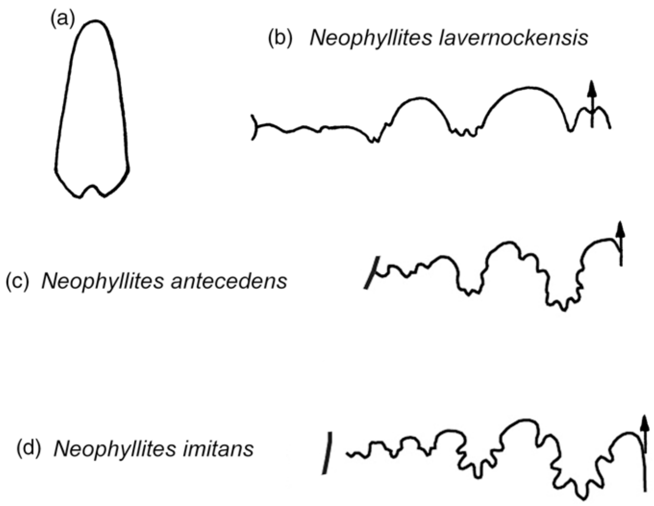

Fig. 7. *N. lavernockensis* (a) whorl section; (b) suture at whorl height 7.6 mm; (c) *N. antecedens*, Larne, Bed 26; and (d) *N. imitans*, Larne, Bed 25.

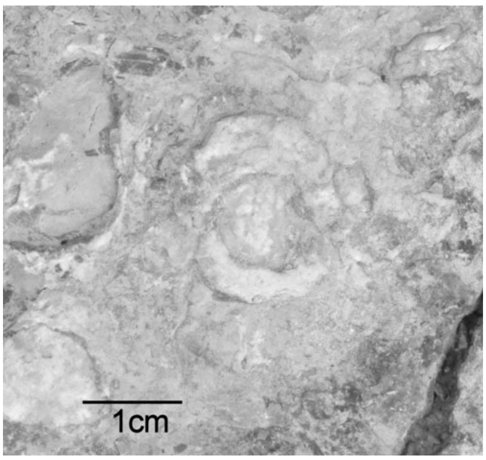

Fig. 8. Worn ammonite on upper surface of limestone bed, White Lias Formation.

nodes located at the second saddle of the suture, elongated and acutely angled to the growth lines. The inner walls of the whorls are marked with fine spiral rills. The sutures are simple (Fig. 7). Four nodes occur in a 30° arc, giving an estimated node density per whorl of 40–48 nodes if present (Fig. 6).

4.a. Comparisons with other Early Jurassic Psiloceratidae

The simple sutures in this specimen are unlike any seen in other Early Jurassic ammonites. Only the protoconchs of juvenile ammonites display such simple sutures as seen in *Psiloceras* ex gr. *tilmanni* (van Hillebrandt & Krystyn, 2009, fig. 13). The sutures of mature *Psiloceras* species are quite complex, whereas those of *Neophyllites* are less so. The spiral rills seen on the inner walls of the whorls are reminiscent of those observed by Bloos (1999) in *Neophyllites sulcifer* Lange, but that species lacks any nodes. The elongated nodes described here are also seen in *Neophyllites neumayri* Lange, but in that species these are parallel to the growth lines, are positioned closer to the umbilical angle and the umbilicus is more open (umbilical width to diameter ratio: 0.48). All of the species of *Neophyllites* described by Lange (1941) were considered by him to occur below *Psiloceras planorbis*, although the exact stratigraphic horizons were unknown at that time. Most of his species are now placed in the *planorbis* Chronozone. *Neophyllites* spp. were described by Guex *et al.* (2003) in the New York Canyon, Gabbs Formation section in Nevada, USA below *P. pacificum* and above *P. tilmanni*, but sutures were not visible in this material and elongated nodes present in one specimen were developed along the umbilical angle.

The best preserved examples of *N. antecedens* and *N. imitans* in the UK were collected at Larne, Northern Ireland (Simms & Jeram, 2007). The sutures are shown for comparison in Figure 7c and d.

Some features seen in species of *Psiloceras* and *Neophyllites* can be seen in this new species, but its suture is unique and very simple. The whorl cross-section and lack of nodes on the inner whorls in *N. lavernockensis* are similar to *P. spelae tirolicum*, but the whorl node density in the latter species is much lower and the suture is more complex.

5. Conclusions

An ammonite found *ex situ* that has been shown to be derived from the top limestone bed of the White Lias Formation at Lavernock Point, and subsequent recognition of a new species *Neophyllites lavernockensis*, demonstrates that beds traditionally considered to be of late Rhaetian age are, in fact, of Jurassic age. The base of the Jurassic System in SW Britain can therefore be defined as the top bed of the White Lias Formation at Lavernock Point, making the Watchet Mudstone Formation above also part of the Jurassic System. The presence of *Neophyllites lavernockensis* at this level also marks the local base of the *tilmanni* Chronozone. Comparisons of negative $\delta^{13}C$ isotope anomalies at Lavernock, St Audrie's Bay and at the Kuhjoch

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GSSP offer further evidence for the position of CIE1 just below the base of the Jurassic System, in the Upper Cotham Member of the Cotham Formation. There is also evidence that CIE3 is represented in the Watchet Mudstone Formation at Lavernock. The White Lias Formation at Lavernock Point represents a local marine transgression and is much condensed, with breaks in the lithostratigraphy above and below; however, on the Devon–Dorset Coast at Pinhay Bay it is much thicker. Hallam (1960) recorded a thickness of 7.84 m with several fossiliferous beds (his beds 3, 6, 10, 11 and 13) containing bivalve species such as *Chlamys (C.) valoniensis*, *Plagiostoma giganteum*, *Liostrea hisingeri*, *Protocardia phillipianum*, *Atreta intusstriata* and *Grammatodon (Cosmetodon) buckmanni*. Diligent searching of this and other exposures of the White Lias Formation may locate additional ammonite evidence for the *tilmanni* Chronozone in Britain.

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Conflict of interest. None.

References

Bloos G (1999) *Neophyllites* (Ammonoidea, Psiloceratidae) in the earliest Jurassic of South Germany. *Neues Jahrb. für Geologie Paläontologie, Abh.* **211**, 7–29.

Donovan DT, Curtis MT and Curtis SA (1989) A Psiloceratid Ammonite from the supposed Triassic Penarth Group of Avon, England. *Paleontol.* **32**, 231–35.

Gallois RW (2007) The stratigraphy of the Penarth Group (late Triassic) of the east Devon coast. *Geoscience south-west Engl.* **11**, 287–97.

Gallois RW (2009) The Lithostratigraphy of the Penarth Group (Late Triassic) of the Severn Estuary Area. *Geoscience south-west Engl.* **12**, 71–84.

Guex J, Bartolini A and Taylor DG (2003) Discovery of *Neophyllites* (Ammonitina, Cephalopoda, Early Hettangian) in the New York Canyon sections (Gabbs Valley Range, Nevada) and discussion of the $\delta^{13}C$ negative anomalies located around the Triassic-Jurassic boundary. *Bull. Laboratoires Géologie, Minéralogie, Géophysique du Musée Géologique l'Université Lausanne* **355**, 247–55.

Hallam A (1960) The White Lias of the Devon Coast. *Proceedings Geologists' Assoc.* **71**, 47–60.

Hesselbo SP, Robinson SA, Surlyk F and Piasecki S (2002) Terrestrial and marine extinction at the Triassic-Jurassic boundary synchronised with major carbon-cycle perturbation: a link to initiation of massive volcanism? *Geol.* **30**, 251–54.

Hodges P (1994) The base of the Jurassic System: new data on the first appearance of *Psiloceras planorbis* in southwest Britain. *Geol. Mag.* **131**, 841–44.

Hyatt A (1867) The fossil cephalopods of the Museum of Comparative Zoology. *Bull. Mus. Comparative Zool.* **1**, 71–102.

Korte C, Hesselbo SP, Jenkyns HC, Rickaby REM and Spotl C (2009) Palaeoenvironmental significance of carbon- and oxygen-isotope stratigraphy of marine Triassic–Jurassic boundary sections in SW Britain. *J. Geol. Soc. London* **166**, 431–45.

Korte C, Ruhl M, Pálfy J, Ullmann CV and Hesselbo SP (2019) 10. Chemostratigraphy across the Triassic–Jurassic Boundary. In *Chemostratigraphy Across Major Chronological Boundaries* (eds AN Sial, C Gaucher, M Ramkumar and VP Ferreira), pp. 185–210. John Wiley & Sons, Inc., New Jersey, USA, Geophysical Monograph no. 240.

Lange W (1931) Die biostratigraphischen Zonen des Lias α und Vollraths petrographische Leithorizonte. *Zentralbl. für Mineral. Geologie Paläontologie* **B**, 349–72.

Lange W (1941) Die Ammonitenfauna der Psiloceras-Stufe Norddeutschlands. *Palaeontographica A* **93**, 1–192.

Lindström S, Pedersen GK, van de Schootbrugge B, Hansen KH, Kuhlmann N, Thein J, Johansson L, Petersen HI, Alwmark C, Dybkjaer K, Weibel R, Erlström M, Nielsen LH, Oschmann W and Tegner C (2015) Intense and widespread seismicity during the end-Triassic mass extinction due to the emplacement of a large igneous province. *Geol.* **43**, 387–90.

Lindström S, van de Schootbrugge B, Hansen KH, Pedersen GK, Alsen P, Thibault N, Dybkjaer K, Bjerrum C and Nielsen LH (2017) A new correlation of Triassic-Jurassic boundary successions in NW Europe, Nevada and Peru, and the Central Atlantic Magmatic Province: A timeline for the end-Triassic mass extinction. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **478**, 80–142.

Page KN (2003) The Lower Jurassic of Europe; its subdivision and correlation. *Geol. Surv. Den. Greenl. Bull.* **1**, 23–59.

Page KN and Bloos G (1998) The base of the Jurassic System in West Somerset, south-west England – new observations on the succession of ammonite faunas of the lowest Hettangian Stage. *Geoscience south-west Engl.* **9**, 231–35.

Pálfy T, Demény A, Haas J, Carter ES, Görög A, Halász D, Oravecz-Sheffer A, Hetényi M, Márton E, Orchard JM, Ozsvart P, Vető I and Zajon N (2007) Triassic-Jurassic boundary events inferred from integrated stratigraphy of the Csővár section Hungary. *Palaeogeogr. Palaeoclimatology, Palaeoecol.* **244**, 1–33.

Pieńkowski G, Niedźwiedzki G and Waksmundzka M (2012) Sedimentological, palynological and geochemical studies of the terrestrial Triassic – Jurassic boundary in northwestern Poland. *Geol. Mag.* **149**, 308–32.

Ruhl M, Kurschner WM and Krystyn L (2009) Triassic-Jurassic organic carbon isotope stratigraphy of key sections in the western Tethys realm (Austria). *Earth Planet. Sci. Lett.* **281**, 169–87.

Simms MJ (2003) Uniquely extensive seismite from the latest Triassic of the United Kingdom; evidence for bolide impact? *Geol.* **31**, 557–60.

Simms MJ (2007) Uniquely extensive soft-sediment deformation in the Rhaetian of the UK; evidence for earthquake or impact? *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **244**, 407–23.

Simms MJ, Chidlaw N, Morton N and Page KN (2004) *British Lower Jurassic Stratigraphy*. Joint Nature Conservation Committee, Peterborough, Geological Conservation Review Series no. 30, 458 pp.

Simms MJ and Jeram AJ (2007) Waterloo Bay, Larne, Northern Ireland: a candidate Global Stratotype Section and Point for the base of the Hettangian Stage and Jurassic System. *ISJS Newsletter* **34**, 50–68.

Suan G, Föllmi KB, Adatte T, Bomou B, Spangenberg JE and van de Schootbrugge B (2012) Major environmental change and bonebed genesis prior to the Triassic-Jurassic mass extinction. *J. Geol. Soc. London* **169**, 191–200.

von Hillebrandt A and Krystyn L (2009) On the oldest Jurassic ammonites of Europe (Northern Calcareous Alps, Austria) and their global significance. *Neues Jahrb. für Geologie Pälaontologie, Abh.* **253**, 163–95.

von Hillebrandt A, Krystyn L and Kuerschner WM (2007) A candidate GSSP for the base of the Jurassic in the Northern Calcareous Alps (Kuhjoch section, Karwendel Mountains, Tyrol, Austria). *ISJS Newsletter* **34**, 2–20.

von Hillebrandt A, Krystyn L, Kuerschner WM, Bonis NR, Ruhl M, Richoz S, Schobben MAN, Urlichs M, Bown PR, Kment K, McRoberts CA, Simms M, Tomašových A (2013) The global stratotype sections and point (GSSP) for the base of the Jurassic System at Kuhjoch (Karwendel Mountains, Northern Calcareous Alps, Tyrol, Austria). *Episodes* **36**, 162–98.

Warrington G, Ivimey-Cook HC and Cope JCW (1994) St Audrie's Bay, Somerset, England: a candidate Global Stratotype Section and Point for the base of the Jurassic system. *Geol. Mag.* **131**, 191–200.

Warrington G, Ivimey-Cook HC and Cope JCW (2008) The St Audrie's Bay – Doniford Bay section, Somerset, England: updated proposal for a candidate Global Stratotype Section and Point for the base of the Hettangian Stage and of the Jurassic System. *ISJS Newsletter* **35**, 1–66.

Waters RA and Lawrence DJD (1987) *Geology of the South Wales Coalfield. Part III, The Country Around Cardiff.* Third edition. Memoir for sheet 263 (England & Wales). London: HMSO, i–xi, 1–114.

Whittaker A and Green GW (1983) *Geology of the Country around Weston-super-Mare.* Memoirs of the Geological Survey of Great Britain, Nottingham. Sheet 279 with parts of 263 and 295, 147 pp.