3.3.2. Locality 9 – Kuhjoch

This text is mainly taken from HILLEBRANDT et al. (2013) and RICHOZ et al. (2012).

Fig. 38. Triassic – Jurassic boundary sections of the western Karwendel Syncline (modified after HILLEBRANDT & KMENT, 2009).

Within the western part of the Eiberg basin, the Karwendel Syncline is a local, East-West trending synclinal structure, approximately 30 km long, within the Inntal nappe of the western Northern Calcareous Alps, extended E-W. The syncline is wide and relatively flat near the Achensee in the east (Fig. 37) and narrows towards the west with increasingly steep to overturned flanks at its western end close to Mittenwald (Fig. 38). Triassic-Jurassic boundary sections south of the Karwendel Syncline are classical localities and have been studied by various authors (Fig. 38; references in KUERSCHNER et al., 2007). The boundary sections of the Karwendel Syncline have been much less studied and detailed biostratigraphic information about the Tiefengraben Member is only known for some years past. Most of the recently-studied outcrops belong to the southern flank of the Karwendel Syncline, and at least five of them (Hochalplgraben, Rissbach, Schlossgraben, Ochsentaljoch and Kuhjoch) have become important as a result of the findings of a new psiloceratid (*Psiloceras spelae tirolicum*) distinctly older than the well-known earliest Psiloceras from England (*P. erugatum*, *P. planorbis*) and the Alps (*P. calliphyllum*).

The continuously subsiding Eiberg basin reached 150-200 m water depth in late Rhaetian time and was, therefore, less affected by the end-Triassic sea level drop which led to a widespread and longer-lasting emersion of the surrounding shallow water areas. Instead, marine conditions prevailed in the basin across the system boundary, though a distinct and abrupt lithological change from basinal carbonates of the Eiberg Member to marls and clayey sediments of the lower Kendlbach Formation (Tiefengraben Member, corresponding to the British Preplanorbis Beds) occured. Within the Eiberg basin, between Lake St. Wolfgang (Kendlbach) and Garmisch-Partenkirchen all sections show the same sedimentary record across the Triassic-Jurassic boundary with varying carbonate vs. clay content depending on their more marginal or more distal position within the basin. A general increase in thickness of the Tiefengraben Member can be observed from east to west, nearly double in the Karwendel syncline compared with the eastern Kendlbach and Tiefengraben sections. With a thickness of more than 20 m, the Karwendel Syncline exposes one of the most expanded Triassic-Jurassic boundary successions of all known sections worldwide.

Among the diverse Triassic-Jurassic boundary sections of the Western Eiberg basin (Fig. 38), the pass of the Kuhjoch (Fig. 40) was selected as GSSP for the base of the Jurassic because it presents the best continuously available and most complete Triassic-Jurassic boundary sections of the area. Only the topmost part of the boundary sequence, with the transition to the *P. calliphyllum* horizon, 10 to 18 m above the GSSP level, has been studied

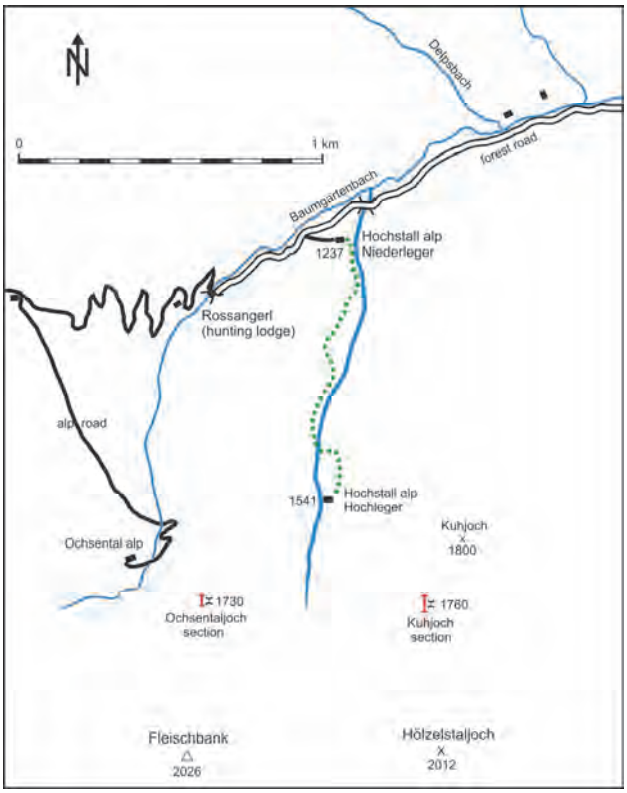

Fig. 39. Way to Kuhjoch and Ochsentaljoch sections (from HILLEBRANDT & KMENT, 2009).

Among the diverse Triassic-Jurassic boundary sections of the Western Eiberg basin (Fig. 38), the pass of the Kuhjoch (Fig. 40) was selected as GSSP for the base of the Jurassic because it presents the best continuously available and most complete Triassic-Jurassic boundary sections of the area. Only the topmost part of the boundary sequence, with the transition to the P. calliphyllum horizon, 10 to 18 m above the GSSP level, has been studied in more detail at a neighbouring locality (Ochsentaljoch) about 750 m to the west of Kuhjoch (Fig. 39), where this interval is better exposed.in more detail at a neighbouring locality (Ochsentaljoch) about 750 m to the west of Kuhjoch (Fig. 39), where this interval is better exposed.

The Kuhjoch section starts 3.8 m below the top of the Kössen Formation/Eiberg Member with a band of well-bedded and variably thick (up to 50 cm) grey bioturbated limestones (bioclastic wackestones) overlying 5 m black marls with pyrite nodules and rare thin (5-10 cm) limy mudstone intercalations (Figs. 41, 42). The 20 cm thick topmost bed (= T in Fig. 41, 43) of the Eiberg Member differs by darker colour and platy weathering; due to an increased clay content and is softer than the pure limestone below, and thinly laminated in its upper half. The top of this bed (~ 1 cm thick and also thin-bedded) is black and bituminous, rich in bivalves and fish remains (scales). Above, the Kendlbach Formation is divided in the lower 22 m thick terrigenous Tiefengraben Member and the following 3 m thick calcareous Breitenberg Member.

Grey to brownish marls (up to 13 cm thick) with concretions of pyrite and worm-shaped traces constitute the base of the Tiefengraben member and are overlain by yellowish weathering, partly laminated marls (ca. 30 cm thick) passing into reddish, partly laminated, argillaceous marls approximately 2.8 m thick (Fig. 42) and comparable with also reddish, argillaceous marls which are known as Schattwald Beds from the Allgäu basin. Grey intercalations characterise the transition to the overlying main part of the Tiefengraben Member, 19 m thick. Ammonite level (2) with *P. spelae tirolicum* (Fig. 44) is located 3.2 m above the Schattwald beds, ammonite level (3a) with *P.* ex gr. *P. tilmanni* 2 m higher and ammonite level (4) with *P.* cf. *pacificum* 4 m higher up in the section (HILLEBRANDT & KRYSTYN, 2009) (Fig. 42).

Approximately 8 m above the Schattwald Beds, the marls become more silty and from 10 m upwards also finely arenitic. A first arenitic bed (15 to 20 cm thick) occurs at around 11 m above the Schattwald Beds. The remaining part of the Tiefengraben Member, with the transition to the Breitenberg Member ("Liasbasiskalk" of ULRICH, 1960), is not well exposed. A naturally well exposed outcrop of this part of the section is found at Ochsentaljoch (750 m west of Kuhjoch).

Fig. 40. View to the West on Kuhjoch section with the main lithological Formations.

The exposed part of the Breitenberg Member consists at Kuhjoch (Fig. 42) of grey thin-bedded (glauconite-rich bioclastic packstone) limestones with thin black hard marl layers and a top bed (10 to 15 cm) that contains, in the middle and upper part, a condensed fauna of the *Calliphyllum* Zone, including a hardground layer enriched in ammonites partly preserved as limonitic moulds. At Kuhjoch and several other sections of the southern and northern flank of the Karwendel Syncline the next two or three limestone beds contain condensed ammonites of middle and late Hettangian age (KMENT, 2000; HILLEBRANDT & KMENT, 2009, 2011). At Kuhjoch follows above the *Calliphyllum* horizon a grey, sparry limestone (8 cm thick), a brownish, micritic limestone bed (10 cm thick), an ochre coloured, micritic limestone with grey clasts and *Alsatites* cf. *liasicus* of middle Hettangian age (= Enzesfeld limestone) (8 cm thick) and a brownish, sparry limestone (15 cm thick) with a limonitic crusts at the top and *Alpinoceras haueri* (marmoreum horizon) of late Hettangian age. On the western slope of Kuhjoch, a limonitic crust with concretions yielding reworked middle Hettangian ammonites (*Megastomoceras megastoma* and *Alsatites proaries*) was found. On the eastern slope, a loose rock of the Enzesfeld

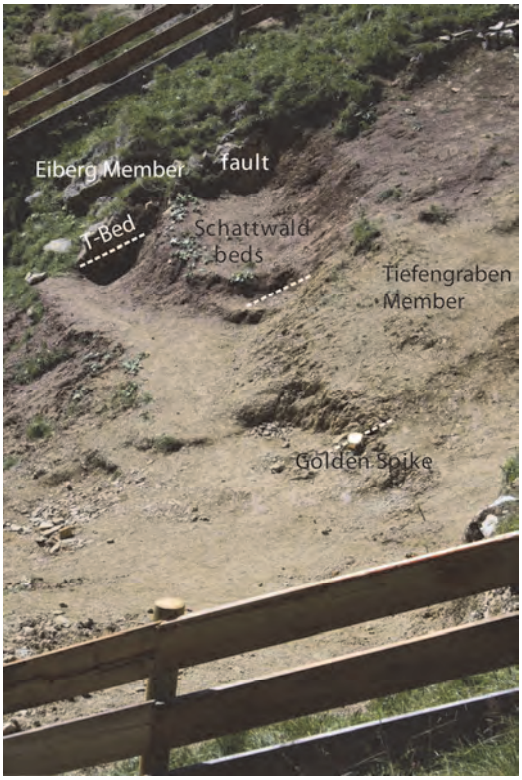

Fig. 41. Section Kuhjoch East with "Golden Spike" at Triassic-Jurassic boundary.

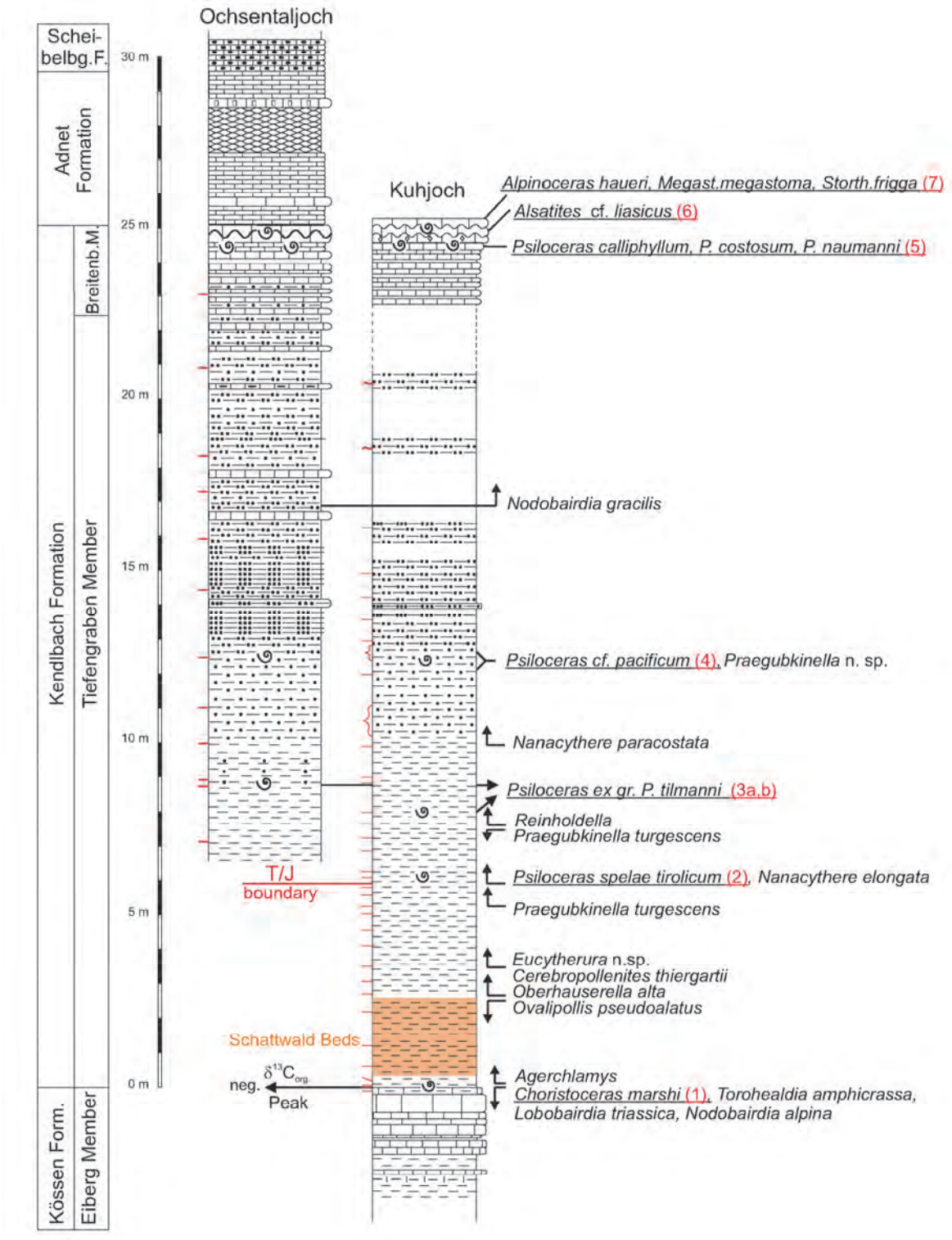

Fig. 42. First and last occurrences of biostratigraphic important fossils at GSSP Kuhjoch West (from HILLEBRANDT et al., 2013).

limestone (10 cm thick) contained middle Hettangian ammonites (e.g. *Megastomoceras megastoma* and *Storthoceras frigga*). The superimposed beds are nodular limestones of the Adnet formation with a Sinemurian age.

A broad spectrum of marine invertebrate groups is recorded, although brachiopods are rare. Macrofossils (Figs. 44, 45, 46) are represented by biostratigraphically (ammonites) as well as palaeoecologically important groups (bivalves, echinoderms). Microfossils (Figs. 44, 45, 46) constitute a major portion of the calcareous biomass except for the Schattwald Beds where only a depauperate foraminifer record is present. Ostracods are usually less frequent than foraminifera. Nannofossils are present in many samples, though coccoliths unfortunately are very rare and extremely small. Most samples were rich in well preserved palynomorphs which have a palynomorph colour of 1-2 on the thermal alteration scale (TAS) of BATTEN (2002). The microfloral record across the Triassic–Jurassic boundary is characterised by significant quantitative changes in the terrestrial and marine components of the assemblages with a few notable palynostratigraphic events, which are very similar to those described from the Tiefengraben section in the eastern part of the Eiberg basin (KUERSCHNER et al., 2007).

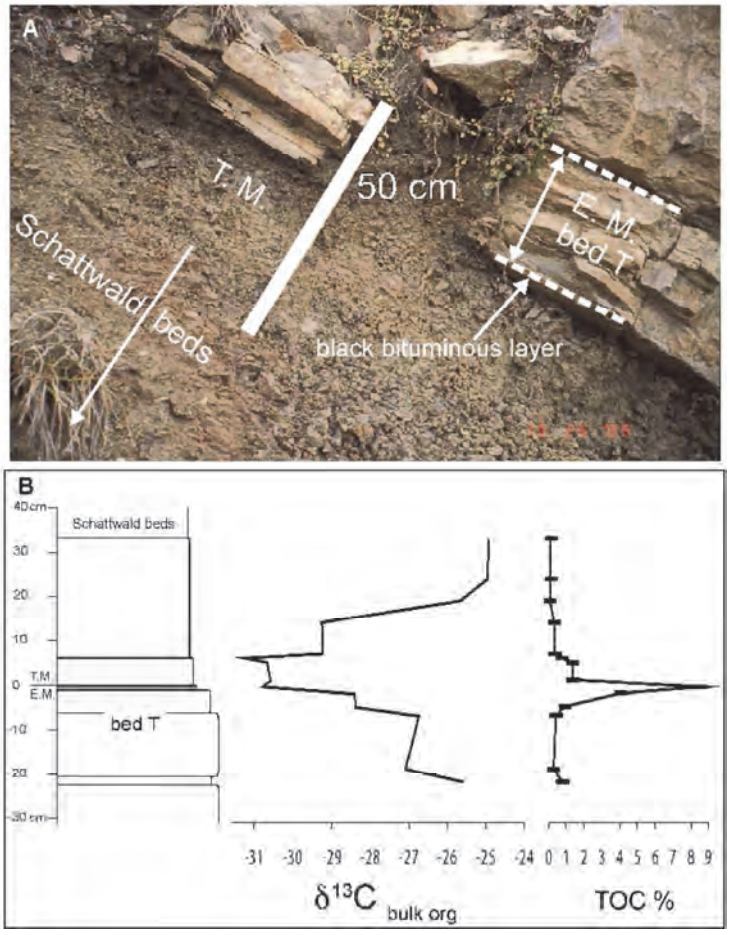

Fig. 43. A) Boundary between Eiberg (E.M.) and Tiefengraben members (T.M.) (Kuhjoch West section). Beds overturned; B) $\delta^{13}C_{org}$ and TOC curves of the Eiberg – Tiefengraben members (Kuhjoch West section) (RUHL et al., 2010) (from HILLEBRANDT et al., 2013).

At the Kuhjoch section no overprint is observable. Ammonites, bivalves and some calcareous foraminifers (in part hollow) are preserved with an aragonitic shell. There are absolutely no signs for regional or local metamorphosis of the rocks (Kuhjoch, Hochalplgraben, Schlossgraben and also Tiefengraben and Kendlbach to the East). From the preservation of palynomorphs, notably the colour, it is evident that this material was never heated above about 50°C (see also KUERSCHNER et al., 2007); conodonts again show a low Conodont Alteration Index (CAI) 1 value. Carbon-isotopes of bulk sedimentary organic matter (Figs. 43, 47) have been studied (RUHL et al., 2009). In addition, compound-specific C-isotope measurements (n-alkanes) have been carried out (RUHL et al., 2011), as detailed mineralogical studies (PÁLFY & ZAJZON, 2012; ZAJZON et al., 2012).

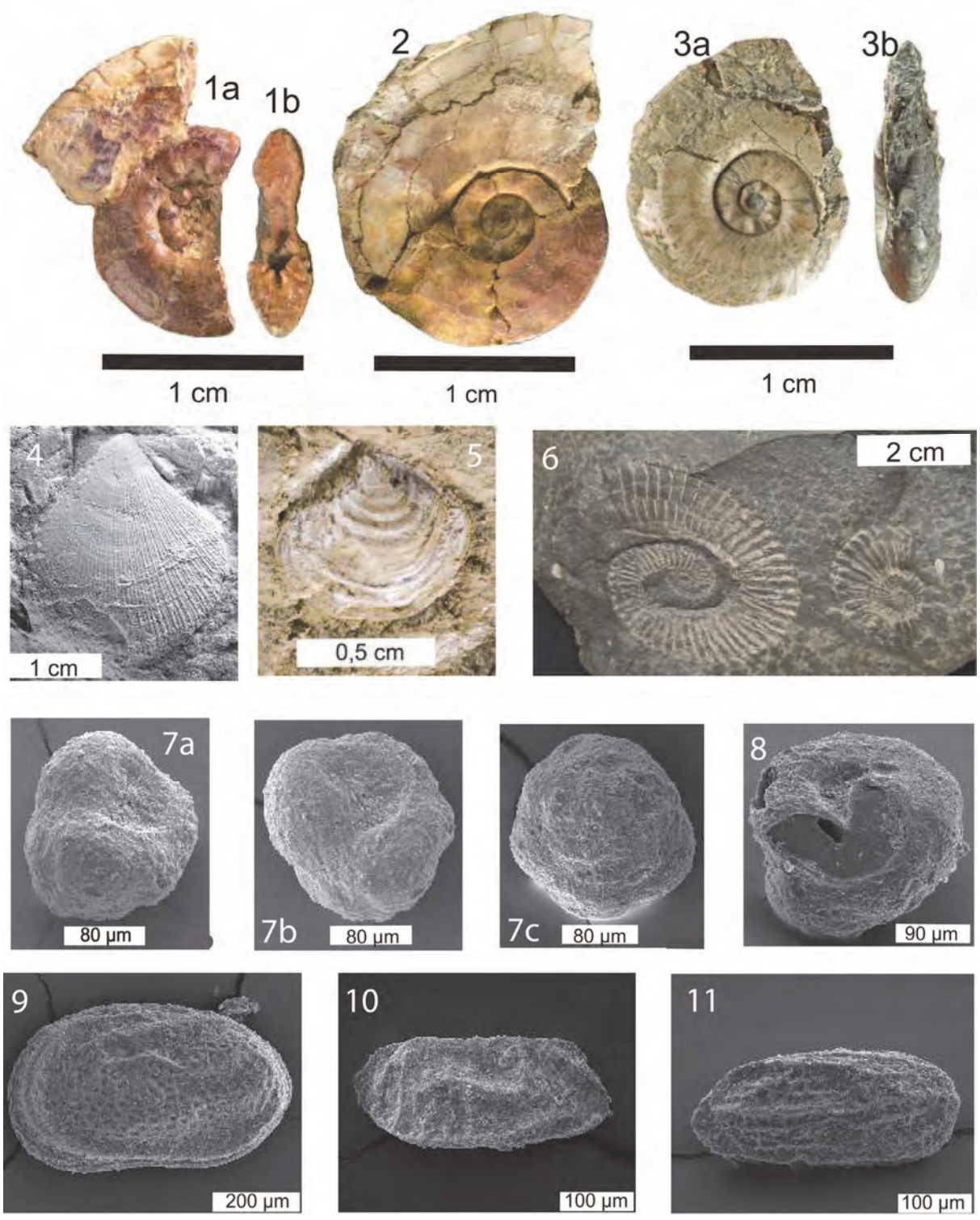

Fig. 44. Important guide fossils at the Triassic – Jurassic boundary of GSSP Kuhjoch. 1-3) *Psiloceras spelae tirolicum* HILLEBRANDT & KRYSTYN, 1a,b, 2) Kuhjoch, 3) Hochalplgraben; 4) *Agerchlamys* sp., Hochalplgraben; 5) *Astarte* sp., Kuhjoch, *spelae* horizon; 6) *Choristoceras marshi* HAUER, Kuhjoch, top T bed; 7a-c) *Praegubkinella turgescens* FUCHS, Kuhjoch, *spelae* horizon; 8) ?*Reinholdella* sp., Kuhjoch, cf. *pacificum* horizon; 9) *Cytherelloidea buisensis* DONZE, lv, Kuhjoch, *spelae* horizon; 10) *Eucytherura sagitta* SWIFT, rv, Hochalplgraben, cf. *pacificum* horizon; 11) *Eucytherura* n.sp., lv, Kuhjoch, latest Rhaetian. rv = right valve, lv = left valve (from HILLEBRANDT et al., 2013).

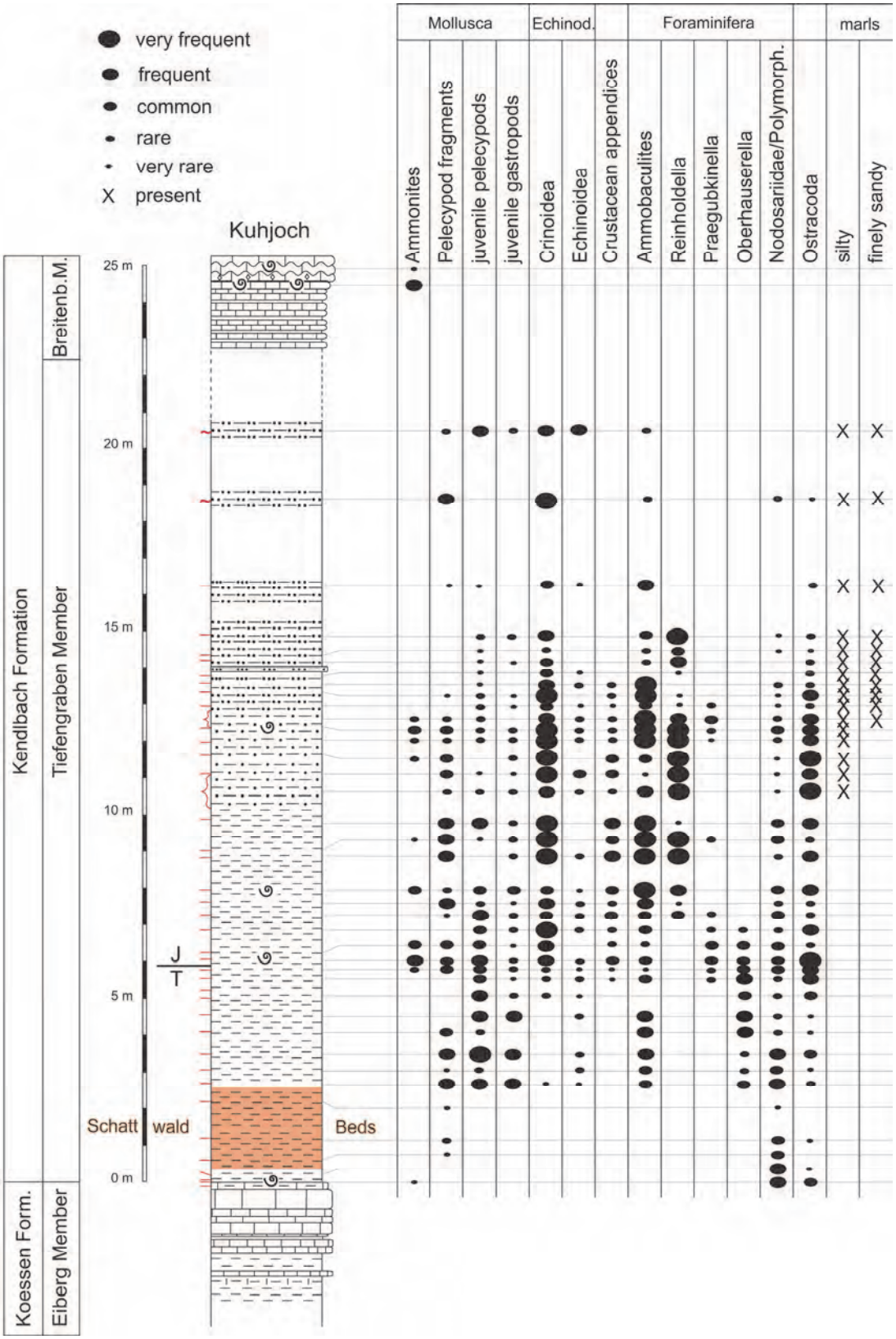

Fig. 45. Fossil at Kuhjoch section (from HILLEBRANDT & KMENT, 2009).

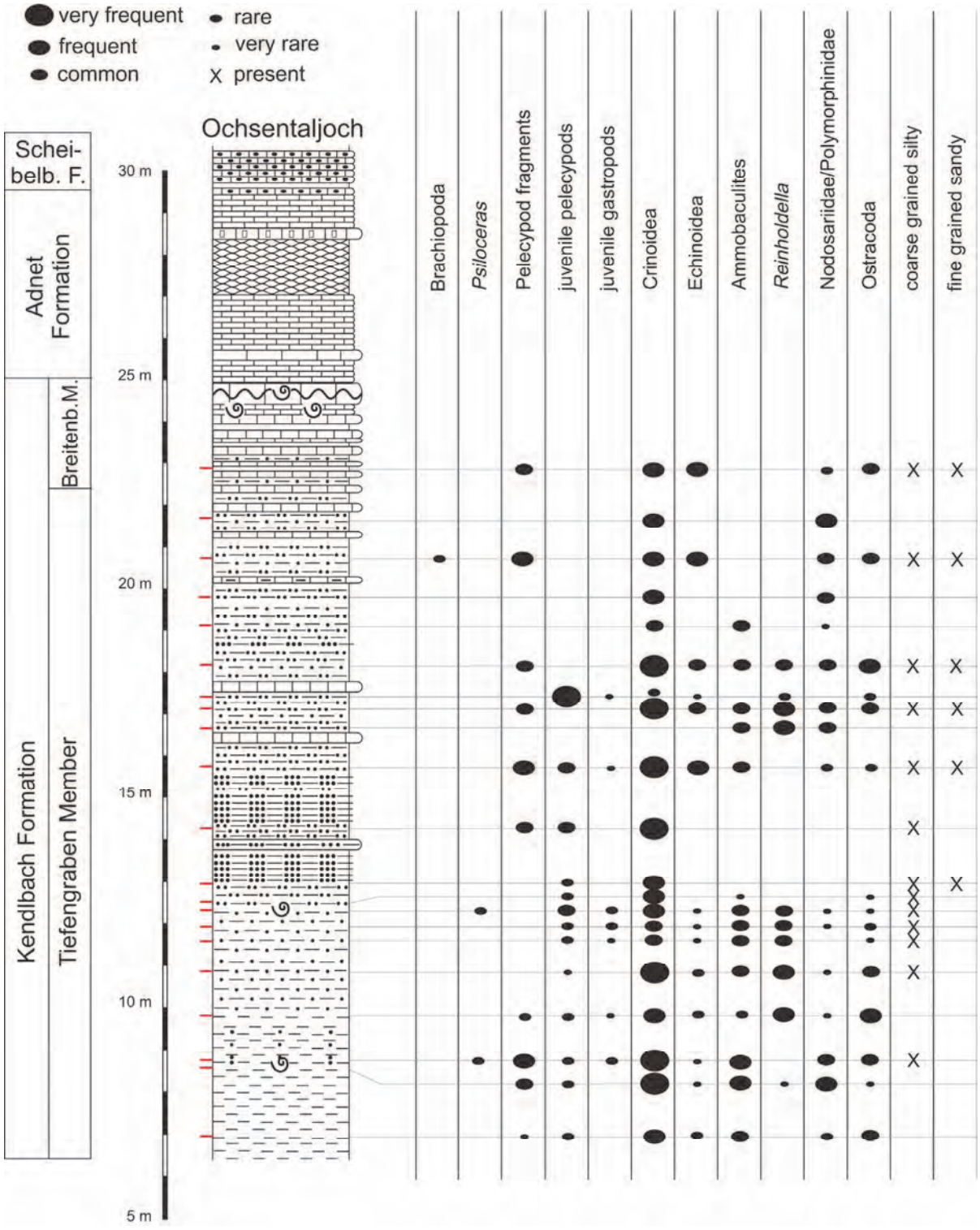

Fig. 46. Fossil at Ochsentaljoch section (from HILLEBRANDT & KMENT, 2009).

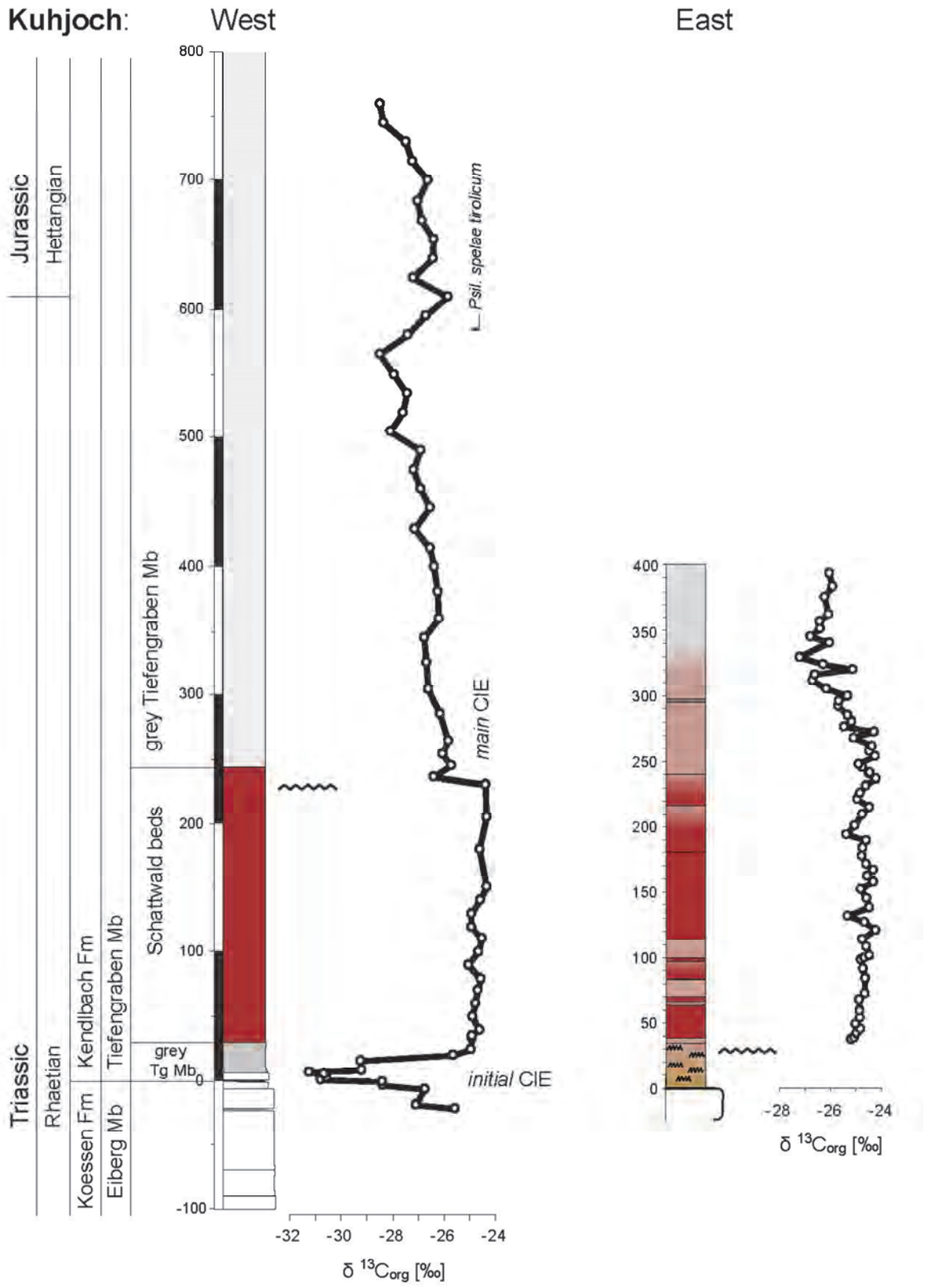

Fig. 47. Detailed C-isotope curves from the Kuhjoch West and the Kuhjoch East sections, data for Kuhjoch West are from RUHL et al. (2009), data for Kuhjoch East are from HILLEBRANDT et al. (2013).