The Jurassic System (199.6–145.5 Ma; Gradstein et al. 2004), the second of three systems constituting the Mesozoic era, was established in Central Europe about 200 years ago. It takes its name from the Jura Mountains of eastern France and northeastern Switzerland. The term ‘Jura Kalkstein’ was introduced by Alexander von Humboldt as early as 1799 to describe a series of carbonate shelf deposits exposed in the Jura mountains. Alexander Brongniart (1829) first used the term ‘Jurassique’, while Leopold von Buch (1839) established a three-fold subdivision for the Jurassic (Lias, Dogger, Malm). This three-fold subdivision (which also uses the terms black Jura, brown Jura, white Jura) remained until recent times as three series (Lower, Middle, Upper Jurassic), although the respective boundaries have been grossly redefined. The immense wealth of fossils, particularly ammonites, in the Jurassic strata of Britain, France, Germany and Switzerland was an inspiration for the development of modern concepts of biostratigraphy, chronostratigraphy, correlation and palaeogeography. In a series of works, Alcide d’Orbigny (1842–51, 1852) distinguished stages of which seven are used today (although none of them has retained its original stratigraphic range). Albert Oppel (1856–1858) developed a sequence of such divisions for the entire Jurassic System, crucially using the units in the sense of time divisions.

During the nineteenth and twentieth centuries many additional stage names were proposed – more than 120 were listed by Arkell (1956). It is due to Arkell’s influence that most of these have been abandoned and the table of current stages for the Jurassic (comprising 11 internationally accepted stages, grouped into three series) shows only two changes from that used by Arkell: separation of the Aalenian from the lower Bajocian was accepted by international agreement during the second Luxembourg Jurassic Colloquium in 1967, and the Tithonian was accepted as the Global Standard for the uppermost stage in preference to Portlandian and Volgian by vote of the Jurassic Subcommission (Morton 1974, 2005). As a result, the international hierarchical subdivision of the Jurassic System into series and stages has been stable for many years.

Ammonites have provided a high-resolution correlation and subdivision of Jurassic strata (Arkell 1956; Morton 1974). For most Jurassic stratigraphers, the stages are groups of zones and have traditionally been defined by the zones they contain in Europe. Ammonites are the primary tools for biochronology and the Standard Ammonite Zones are assemblage zones, not biozones of the nominal species. One should also bear in mind that bioprovincialism of ammonites can influence and complicate biostratigraphical correlations. In that respect, Central Europe provides the most valuable ammonite finds, as in some regions they represent both sub-Mediterranean and Boreal bioprovinces.

The primary criteria for the recognition of chronostratigraphic units and correlation is the precise ammonite biostratigraphy, supplemented by other biostratigraphic criteria, chemostratigraphy, magnetostratigraphy and sequence stratigraphy (Morton 2005). At present, only four of the stages have ratified Global Stratotype Section and Point (GSSP), namely, the Sinemurian, Pliensbachian, Aalenian and Bajocian. The last, seventh International Congress on the Jurassic System held in Cracow, Poland, advanced progress with the establishment of the Pliensbachian/Toarcian (Elmi 2006) and Oxfordian/Kimmeridgian (Wierzbowski et al. 2006) GSSPs. The most difficult Jurassic boundaries to define are the base of the Jurassic System (and Hettangian Stage) and the top of the Jurassic System (and the base of the Cretaceous System). Concerning the former, progress has been made with four GSSP candidate profiles (Bloos 2006). Nevertheless, despite being well subdivided, the Jurassic System is the only one with neither bottom nor top defined.

Jurassic shelf, lagoonal and lacustrine sediments show strong cyclicity observed as sedimentary microrhythms (typically with an alteration of limestone and marl, carbonate-rich and carbonate-poor mudrocks, or more silty and more clayey/organic-rich laminae). Given that these successions represent continuous sedimentation over long periods, they can be used for astronomically calibrated timescales, since the periodicity of these microrhythms is consistent with orbital forcing due to Milankovitch cycles. About 70% of the Jurassic is now covered by floating astronomical timescales based on the recognition of Milankovitch cycles (Gradstein et al. 2004; Coe & Weedon 2006).

Jurassic outcrops occur in several countries of Central Europe
largely sub-Mediterranean bioprovince with elements of the sub-Boreal bioprovince) and the Tethyan Domain would correspond to the Mediterranean province. Assuming the above, the Jurassic system in the studied area of Central Europe is subdivided into the CEBS Domain (including the southern epi-Variscan basins) and the Tethyan Domain.

**Triassic–Jurassic boundary (J.P.)**

The Triassic–Jurassic boundary (TJB) is stratigraphically important but also marks significant global environmental and biotic events. The end of the Triassic is widely regarded as one of the five biggest Phanerzoic mass extinction events (Sepkoski 1996); it coincided with environmental change which included global cooling followed by a warming event (McElwain et al. 1999; Guex et al. 2004), perturbation of the global carbon cycle (Pälfy et al. 2001; Hesselbo et al. 2002; Ward et al. 2004), and significant sea-level changes (Hallam 1997). Causes of these events are widely debated. Radioisotopic dating suggests that marine extinction was synchronous with the formation of the Central Atlantic Magmatic Province at c. 200 Ma (Marzoli et al. 1999, 2004; Pälfy et al. 2000). At present most evidence suggests a scenario that invokes short-lived but intense volcanism as a trigger. The formation of one of the largest Phanerozoic flood basalt provinces may have induced large-scale environmental changes that ultimately led to the latest-Triassic mass extinction (Hesselbo et al. 2002; Pälfy 2003). Alternative hypotheses relate the mass extinction to the effects of a putative bolide impact (Olson et al. 2002) or large and rapid sea-level changes (Hallam & Wignall 1999). Regardless of its cause, the latest-Triassic extinction and contemporaneous environmental events left a distinctive stratigraphic signature that is readily observed in Central European sections.

**Definition**

The TJB has no accepted GSSP yet. At three of the four proposed candidate sections (St. Audrie’s Bay (England), New York Canyon (Nevada, USA) and Utcubamba Valley (Peru), pronounced changes in the ammonoid faunas are used to place the boundary. The first appearance of the smooth, evolute genus *Psiloceras* marks the base of the NW European *Psiloceras planorbis* Zone and the east Pacific *Psiloceras tilmanni* Zone. Ceratitid ammonoids, that dominated the Triassic faunas, did not survive the TJB. The heteromorph *Choristoceras* is regarded as the index fossil of the latest Triassic. In Europe the topmost Rhaetian *Choristoceras marshi* Zone (correlative of the *C. crickmayi* Zone in North America) represents the youngest biochronologic subdivision. At the fourth GSSP candidate, Kunga Island (western Canada), a remarkable turnover in radiolarian faunas offers an alternative biostratigraphic criterion for defining the TJB. Until the GSSP selection is settled, detailed and high-resolution correlation issues will remain hotly debated in the few continuous, fossiliferous marine sections. Generally, however, coarser stratigraphic resolution in most other sections allows unambiguous placement of the TJB as several fossil groups exhibit significant differences between their latest Triassic and earliest Jurassic assemblages.

**The boundary in Central Europe**

Various tectonostratigraphic units in Central Europe represent a broad spectrum of facies types across the TJB. Epicontinental settings prevailed in the Germanic Basin that contrasts with the shelf environments of western Tethys. Sedimentation was discontinuous in the epicontinental areas of the NW part of Central Europe. The bivalve *Rhaetavicula contorta* is the key biostratigraphic marker of the topmost Rhaetian, developed in a marly facies (‘Grès infraliasique’) that overlies the marginal marine Keuper. In the eastern part of the Paris Basin and around the Ardennes Massif, the basal Jurassic is represented by *Gryphaea*-bearing limestones of Early Hettangian age as indicated by ammonoids of the genus *Psiloceras*.

In southern Germany marine Hettangian strata transgressively overlie the fluvial or lacustrine topmost Triassic. A preceding regression is marked in northern Bavaria, where the progradation of sandstone over shale is observed. Fluvial sandstone channel fills that cut into Rhaetian lacustrine shale (‘Hauppton’) (Bloos 1990) is taken as evidence of a significant sea-level fall near the TJB (Hallam 1997, 2001) although its precise timing is not well constrained.

Continuous or near-continuous sedimentation across the TJB is better known from different parts of the western Tethyan shelf. In the Southern Alps, the lower members (1–3) of the Zu Limestone consist of Rhaetian carbonates of platform or ramp facies (Jadoul et al. 2004). Thin-bedded, micritic limestone of the topmost member (Zu 4) marks a transgression and simultaneous platform drowning. Palynological studies suggest that the TJB is located within the Zu 4 Member (Jadoul et al. 2004). A characteristic Triassic foraminiferal assemblage disappears at the top of the Zu 3 Member (Lakew 1990). Also at this level a negative carbon isotope anomaly was observed in several sections in the Monte Albenza area (Galli et al. 2005).

The remainder of the Hettangian is represented by the Conchoodon Dolomite that was deposited on a prograding Bahamian-type platform. Bivalve faunas occur in the Zu and Conchodon formations and show a significant turnover at the system boundary (Alissanz 1992; McRoberts 1994; McRoberts et al. 1995).

Sections in the Northern Calcareous Alps reveal more faeces variability as TJB strata occur from platform through slope to intraplatform basal settings, although a hiatus of varying duration is widespread at the TJB. Large carbonate platforms and reefs existed in the western Tethyan margin during the Late Triassic. The demise of Dachstein-type reefs and the reefal biota at the close of the Triassic is one of the most dramatic aspects of the TJB events and represents one of the major crises in the history of reef ecosystems (Flügel 2002; Kiesling 2002). The spectacular Steinplatte reef in Tyrol (Piller 1981), although its architecture was recently reinterpreted (Stanton & Flügel 1995), exemplifies the vanishing of carbonate buildups.

One of the first recognized and studied TJB sections occurs in an intraplatform basal setting at Kendelbachgraben near the Wolfgangsee in Salzkammergut, near Salzburg (see Fig. 14.39) (Suess & Mojsisovics 1868). Here, and in the nearby Tiefengraben section, the TJB is marked by an abrupt lithological change as the latest Rhaetian Kössen Formation is overlain by the ‘Grenzmergel’ (boundary marl) that grades into alternating marls and limestones (Golebiowski 1990; Golebiowski & Braunsleben 1988; Kürschner et al. 2008). The lack of ammonites resembles the record in NW Europe, hence correlation with the “pre-planorbis beds” was suggested (Hallam 1990). The first Jurassic ammonoid, *Psiloceras planorbis*, was found nearby at Breitenberg in the overlying limestone unit. Palynological turnover supports the presence of the TJB within the Grenzmergel (Morby 1975; Gerben et al. 2004; Kürschner et al. 2007). The lithological change manifests in the Grenzmergel could reflect sea-level rise and/or increased terrigenous influx related to
sudden climate change. A primary stable isotope signal was not preserved in the carbonate due to diagenetic overprint (Hallam & Goodfellow 1990; Morante & Hallam 1996). However, a negative carbon isotope anomaly at the TJB is documented in the organic matter (Kürschner et al. 2007).

Coeasily, in an adjacent, relatively deep-water basin, the Zambach Marl Formation was deposited. Although an offshore facies may be expected to preserve a better ammonoid record, this has been compromised by tectonic deformation and poor outcrops.

Several TJB sections are known from the Western Carpathians, where typically a sharp transition from cyclic, peritidal to shallow subtidal carbonate sedimentation (Fatra Formation) to predominantly terrigeneous dark mudstones and shales (Kopieniec Formation) occurs in the Fatric Unit (Tomašových & Michalík 2000; Michalík et al. 2007). Significant changes across the TJB are documented in the foraminifera (Gaździcki 1983) and bivalve faunas (Kochanová 1967; Michalík 1980).

The Upper Triassic—Lower Jurassic succession of the Transdanubian Range within the Carpathian Basin in Hungary is similar to that in the Northern Calcareous Alps. The TJB transition in carbonate platform facies is well known from the Transdanubian Range in Hungary but the boundary is typically marked by a disconformity. A gap occurs in many sections between the Rhaetian Dachstein Limestone Formation and the underlying Hettangian Kardosfórt Formation in the Bakony Mountains, or the Piszczne Formation in the Gerecse Mountains. In a well exposed section at Tata a sharp erosion surface and a slightly angular unconformity suggest that a break in platform evolution was caused by emergence (Haas & Hámos 2001). The Dachstein Formation is rich in megalodontid bivalves (Vegh-Neubrandt 1982) that do not occur in Hettangian rocks of similar facies. Although not becoming extinct as a group, megalodontids worldwide show a sharp decline in diversity, abundance and size, possibly an effect of the biocalcification crisis at the TJB (Hautmann 2004). The disappearance of the foraminifera Triassina hantkeni is another indicator of the TJB in platform facies.

A small intraplatform basin at Csővár near the northeastern extremity of the Transdanubian Unit preserved a continuous marine TJB transition (Pálfy & Dózstály 2000). Sedimentation occurred in slope, toe-of-slope and basinal settings (Haas & Tardy-Filácz 2004). Interpretation of sea-level history fails to document a significant regression at the TJB; short-term cycles are superimposed on a long-term Rhaetian—Hettangian transgressive trend (Haas & Tardy-Filácz 2004). Ammonoid, conodont and radiolarian biostratigraphy help to constrain the TJB. A stable isotope study of the section yielded evidence of a significant negative carbon isotope excursion at the TJB (Pálfy et al. 2001, 2007). Recently recognized at several localities in Europe and North America, this anomaly is interpreted as a geochemical signature of a major carbon cycle perturbation thought to be related to the environmental change and concomitant biotic crisis.

In the Meesek Mountains of southern Hungary, the TJB occurs within the >1 km thick Meesek Coal Formation that was deposited in a subsiding half-graben, and records the transition from limestones to para-coal-bearing facies and deltaic to marl of marine sedimentation between the coal seams. The TJB is identified based on palynologic evidence but requires further studies. The Hettangian strata are of Gresten-type facies that is also known from the Alps (Lachkar et al. 1984).

Recently, in the Pomerania region in NW Poland (Kamień Pomorski borehole), Pienkowski & Waksmundzka (2005) described a succession of Triassic—Jurassic lacustrine/low-energy alluvial deposits preserved in a small tectonic graben. Palyno-morph content suggests a position close to the Rhaetian–Hettangian transition. Moreover, just below the sequence boundary identified with the TJB, a characteristic fern peak has been observed that calls for further studies (particularly carbon isotope analyses).

**Climate evolution (G.P., M.E.S.)**

Reconstruction of climate change and the related primary causes is exceedingly complex. Numerous factors (e.g. atmosphere composition, ocean circulation, changes in rotational and orbital characteristics of the Earth and the positions of the continents) interact to determine the climate and to make it change in a non-linear way (Page 2004). It is widely accepted that greenhouse effects dominated Jurassic climates worldwide and the Jurassic Period was warm and, for the most part, humid (Chandler et al. 1992). However, Kürschner (2001) placed the Jurassic Period in a relatively cooler phase, between Late Permian and mid-Cretaceous warming periods. Yet, the major features of the simulated Jurassic climate include global warming of 5 to 10°C, compared to the present, with temperature increases at high latitudes five times this global average. Tropical regions reached temperatures as high as 40°C during parts of the summer months, while winters were around 0–20°C. Carbon dioxide levels may have been as much as three to five times higher than those of today, as suggested by the stomatal index studies for Asienian–Bathonian times (Xie et al. 2006).

High-latitude oceans during the Jurassic were certainly warmer than they are today and were mostly ice-free. Results from simulations of the Early Jurassic climate show that increased ocean heat transport may have been the primary force generating warmer climates during the Jurassic (Chandler et al. 1992), with the Early and Late Jurassic appearing to be the warmest. Extensive evaporites and aeolian sandstones suggest that the Jurassic Period (in the western part of Pangaea) was considerably more arid than the present day (Frakes 1979). Abundance of floral remains and coals suggests that the Central European region was much more humid, at least in Early and Middle Jurassic times. Close to the end of the Jurassic, the presence of evaporites, both in England (Purbeck Group) and Poland/ Ukraine, may be related to the spread of an equatorial arid zone across Europe.

The Jurassic climate in Central Europe was controlled by a number of factors, one of them being the paleogeographic position of this region. The Central European region drifted northward from about 35°N at the beginning of the Jurassic to some 45°N at the end (Smith et al. 1994). The most crucial climate change occurred earlier, at the beginning of the Rhaetian, when Norian red-bed sedimentation was replaced by the coal-bearing lacustrine/alluvial facies association with some marine intercalations, suggesting more humid conditions. It seems that the ongoing northward drift of the Central European region was proportionally less significant for the Jurassic climate.

The beginning of the Hettangian was marked by climatic fluctuations indicated by floral changes and isotope compositions. In particular, dramatic changes in pollen floras have long been apparent in Late Rhaetian–earliest Hettangian deposits and suggest pronounced and rather rapid climatic fluctuations in western-central Europe and Greenland (Warrington 1970; Orbell 1973; Hubbard & Boutler 2000). Hubbard & Boutler (2000) proposed a cold episode at the Rhaetian–Hettangian boundary. This view is supported by Guex et al. (2004) who postulated.
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