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The importance of *Hindeodus parvus* (Conodonta) for the definition of the Permian–Triassic boundary and evaluation of the proposed sections for a global stratotype section and point (GSSP) for the base of the Triassic

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Abstract

The biostratigraphic Permian/Triassic (P/T) boundary is defined by the first appearance of *H. parvus*. The first appearance of *H. parvus* within the cline *H. latidentatus-H. parvus* is a globally recognizable event in the conodont evolution. The first appearance of *H. parvus* is not facies related and can be observed both in ammonoid-free shallow-water deposits and in ammonoid-bearing pelagic deposits. *H. parvus* is a common, easily determinable species known so far from the entire Tethys, Japan, western North America, Boreal realm (Greenland) and the Tethyan margin of Gondwana. *H. parvus* is the first species with world-wide distribution to appear after the absolute minimum in the faunal diversity indicated by the minimum in $\delta^{13}C$.

The Meishan section (South China) contains a continuous, pelagic sedimentary record across the P/T boundary without stratigraphic gaps. It is nearly unaltered thermally (CAI = 1-1.5). Its fossil content (ammonoids, conodonts, foraminifers, bivalves, brachiopods, sporomorphs etc.) and event succession have been thoroughly studied. Absolute age and magnetostratigraphy have also been subjected to intensive studies. The section is readily accessible and under protection of the government. This section is best suitable as a global stratotype section and point (GSSP) for the base of the Triassic. No other section in the world is known to be qualified for defining the P/T boundary in a GSSP. *H. parvus* made its earliest appearence in the middle part of Boundary Bed 2 (Bed 27) at Meishan. It evolved within Bed 27 from *H. latidentatus* within a phylomorphogenetic continuum in a continuous and monofacial stratum. The biostratigraphic P/T boundary lies very close to the event boundary (15 cm above the event boundary at the base of Boundary Bed 1 = Bed 25, and a few centimetres above the minimum in $\delta^{13}C$ in the lower Boundary Bed 2).

Introduction

The faunal change at the Permian/Triassic (P/T) boundary has been often overestimated. The disappearance of about 96% of the fauna at this boundary (Raup, 1979) is a summary estimation over a longer time interval. Bed by bed investigations have shown that the disappearance of faunal and floral elements occurred over a certain interval with accelerated extinctions at several levels (Kozur, 1977a, 1989, 1994b). Nevertheless, the faunal incision near the P/T boundary was very strong. Some fossil groups (plankton, shallow-water, warm-water benthos) were so strongly affected that even some sediment types (e. g. radiolarites) globally disappeared at the P/T boundary and did not re-appear before the late Olenekian. The minimum of faunal diversity is indicated by a minimum in $\delta^{13}C$ near the P/T boundary.

Most of the faunal groups that disappeared near the P/T boundary re-appeared in the late Olenekian or in the Middle Triassic (Kozur, 1977a, 1994b). The mode of extinction, the affected groups and the later re-appearance of most groups that disappeared at the P/T boundary lead Kozur (1989, 1994b) to the conclusion that the faunal incision was caused by a short-lasting, rapid cooling also in low latitudes caused by dense aerosols (similar to the calculated nuclear winter). The causes for these dense aerosols were probably extremely strong volcanic activities in the areas of the Siberian Trap (more than 2 million km^2) and other eruptive centres (e.g. in China, where several thin, exactly correlatable tuffitic layers near the P/T boundary cover an area of about 2 million km^2). The recovering of the fauna was hindered by wide-spread anoxia in the lowermost Triassic (Wignall & Hallam, 1993; Kozur, 1994b).

Despite the considerable faunal incision near the P/T boundary, the exact level of the P/T boundary is not yet finally defined. Ammonoid workers used mostly the first appearance of *Otoceras* for defining this boundary. However, despite more than 100 years intensive search, nowhere a section has been found, in which *Otoceras* evolved in a phylomorphogenetic cline from ist forerunner. Even the direct forerunner of *Otoceras* is unknown. The Araxoceratidae, forerunner of the Otoceratidae, are restricted to the pre-Changxingian Wuchiapingian Stage. *Julfotoceras* as the oldest representative of the Otoceratidae occurs in the type late Dzhulfian and type basal Dorashamian, equivalent to the late Wuchiapingian and basal Changxingian (Changshingian).

If *Otoceras* is post-Changxingian as assumed by most ammonoid workers, then the largest part of the Changxingian has not yielded Otoceratidae and Araxoceratidae. No section with undoubtedly determined *Otoceras* has yielded ammonoids in strata immediately below beds with the first *Otoceras*. With "special creations", however, we cannot define a biostratigraphic Permian/Triassic boundary.

This special situation of the distribution of *Otoceras* has lead Tozer (1971) to a curious opinion. He assumed that the *Otoceras* faunas follows always after a gap above pre-Changxingian beds, whereas in all areas with ammonoid-proven Changxingian, the *O. concavum* and *O. woodwardi/O. boreale* zones are missing because of a gap immediately above the Changxingian. However, such situation is hardly explainable because even in shallow-water Werfen facies continuous P/T boundary sections without stratigraphic gaps are present, e.g. in the Southern Alps (Broglio Loriga et al., 1988; Kozur, 1989, 1994c). In some sections there is a genuine gap between the base of *Otoceras*-bearing beds and pre-Changxingian beds, e.g. at Selong. However, there are also many continuous pelagic sections across the P/T boundary. According to Kozur (1980a, 1989, 1994b), Bando et al. (1980), Gupta and Kozur (1983), Li and Yao (1984) the mutual exclusion of *Otoceras* and Changxingian faunas (perhaps with the exception of Meishan, where Changxingian ammonoids, conodonts and brachiopods occur together with doubtful *Otoceras*) is caused by provincialism. They concluded that a large part of the *Otoceras* faunas is contemporaneous with the Changxingian.

Because the ammonoids have failed to provide a reliable base for definition of the P/T boundary, conodonts were used recently to define this boundary. There is now an agreement among most conodont workers to use the first appearance of *Hindeodus parvus* for definition of the base of the Triassic. *H. parvus* evolved in a phylomorphogenetic cline from *H. latidentatus* and has a global distribution in marine sediments, where it occurs both in shallow-water and pelagic deposits. It is not influenced by provincialism and has a far wider distribution than ammonoids.

In the present paper the advantages and disadvantages of using the first appearance of *Otoceras* and *Hindeodus parvus* are discussed. The significance of the 4 sections proposed as GSSP for the Permian-Triassic boundary, and of some other boundary sections are also discussed.

Definition of the P/T boundary with the appearance of *Otoceras*

Since Mojsisovics et al. (1895) the *Otoceras* faunas traditionally have been mostly placed into the Triassic. For Tozer (1988), this priority is important. In other cases the Triassic ammonoid workers (including Tozer) reject the priority. For instance, Tozer (1994a) continues to place the Rhaetian into his Norian s.l. despite a clear voting of the International Subcommission on Triassic Stratigraphy in favour of the Rhaetian Stage, which has clearly the priority as the first established Triassic Stage (Gümbel, 1861). Brack and Rieber (1994, p. 29) pointed out in connection with the Anisian-Ladinian boundary that any priority argument "can hardly be a constructive contribution to the boundary problem". We do not agree with this argument and regard priority as an important principle for stability of stratigraphic classification. If there is a clear priority, it should be followed. However, there are two main reasons to exclude the application of the priority: (1) if the priority is not clear because of original statements that exclude each other; (2) if two biostratigraphic units, between which a boundary is defined, overlap each other in a considerable scale or if a long time gap is present between these two units.

Both cases for exclusion of application of the priority are given in the case of the *Otoceras* faunas. The overlap of the lower part of the *Otoceras* faunas with the late Changxingian is proven by conodonts (Kozur, 1989, 1994b). Moreover, if *Otoceras?* sp. from Boundary Bed 1 at Meishan is a true *Otoceras*, then there *Otoceras* occurs together with Changxingian ammonoids, brachiopods and conodonts. Because of the different faunal provinces of the *Otoceras* faunas and the Changxingian tropical ammonoid faunas (see below), in general both faunas exclude each other. But nowhere in the world *Otoceras* faunas have been observed to overly Changxingian faunas. Where such a situation was assumed, it can be proven now as wrong (see discussion to the Selong section). Mojsisovics et al. (1895) stated that *Otoceras* and *Episageceras* are typical Permian genera but the *Otoceras woodwardi* Zone is Triassic because of the presence of such genera, as *Danubites, Flemingites, Hungarites, Kingites, Koninckites, Medlicottia, Meekoceras* and *Nannites*. Even after revision of the ammonoids assigned to these genera, they are undoubtedly Triassic, but likewise undoubtedly, they do not occur in the *Otoceras* faunas, but above them. Consequently, according to the priority, the Triassic age of the *Otoceras* faunas was determined by Triassic genera that do not occur in the *Otoceras* faunas (except *Ophiceras* in the upper *Otoceras* faunas), but only above them.

This was already recognized by Noetling (1901). He subdivided the *O. woodwardi* Zone sensu Mojsisovics et al. (1895) into the *O. woodwardi* Zone s. str., the *Ophiceras tibeticum* Zone and the *Meekoceras noetlingi* Zone. He placed the *O. woodwardi* Zone s. str. (in the modern scope!) in the Permian, in agreement with the statement by Mojsisovics et al. (1985) that *Otoceras* is a Permian genus. The *Meekoceras noetlingi* Zone was assigned to the Triassic and the *Ophiceras tibeticum* Zone was regarded as transitional between the Permian and Triassic. Diener (1909, 1912) rejected the Permian age of the *O. woodwardi* Zone s. str. and placed it again into the Triassic. His arguments were: (1) complete absence of Permian brachiopods in *Otoceras*-bearing beds; (2) correlation of the *Otoceras* faunas with the Triassic basal Werfen Beds of the Southern Alps. Tozer (1988) fully agreed with the arguments of Diener. However, they are both considered to be incorrect. Permian brachiopods are known from several places together with *Otoceras*, or from beds correlated with the *Otoceras* faunas. These brachiopods are surely not all reworked. The basal Werfen lower Tesero Oolite at its type locality contains fusulinids and other Permian foraminifers and a characteristic late Changxingian conodont fauna with *H. typicalis,* typical *H. latidentatus* and *Stepanovites* sp. This fauna is characteristic for the uppermost Changxing (Changhsing) Limestone in the Changxingian stratotype (section D at Meishan). A Late Permian age of these beds is also indicated by mass occurrences of the *Tympanicysta stoschiana* fungal association and by Permian brachiopods, such as *Ombonia* cf. *canavei* Merla, *Crurithyris extima* Grant, *Spinomarginifera* sp.

Consequently, there is no clear priority for assignment of the *Otoceras* faunas into the Triassic, because this assumption was made on the basis of faunas that do not occur in the *Otoceras* faunas. Moreover, if any priority will be regarded, this will only affect the ***O. woodwardi* Zone of the central Himalayas** that was investigated by Mojsisovics et al. (1895) and Diener (1912). But this zone in its present scope was placed into the Permian by Noetling (1901).

Even if the priority of the Triassic age of the *O. woodwardi* Zone is accepted, this would not mean priority of Triassic age for *Otoceras* because this genus was regarded as a typical Permian genus by Mojsisovics et al. (1895), who assigned the *O. woodwardi* Zone to the Triassic. If the P/T boundary will be defined with the first appearance of *H. parvus*, then this boundary is near to the assumed priority boundary at the base of the *O. woodwardi* Zone and probably identical with the base of the *O. woodwardi* Zone in central Himalayas, where this zone was established. *H. parvus* begins in the middle part of the *O. woodwardi* Zone s. l. (Matsuda, 1981). According to all the present data, *H. parvus* begins about in the same level as *Ophiceras*. This species first appears in the upper *O. boreale* Zone of the Arctic and in the upper *O. woodwardi* Zone of the Gondwana margin of the Tethys. In central Himalayas, *Ophiceras* is present at the base of the *O. woodwardi* Zone. Therefore, the type *O. woodwardi* Zone corresponds only to the upper subzone of the *O. woodwardi* Zone (Dagys, 1994). Despite the fact that the conodont fauna of the *O. woodwardi* Zone in central Himalayas is not yet well studied, it is possible that there *H. parvus* begins at the base of the *O. woodwardi* Zone representing in the central Himalayas only the upper subzone of the *O. woodwardi* Zone. The ammonoid-based correlations of the *Otoceras* faunas by Dagys (1994) confirm therefore the view of Kozur (1994b) that the type *O. woodwardi* Zone is younger than most of the Arctic *Otoceras* faunas as clearly indicated by conodonts (see below).

The *Otoceras concavum* Zone is older than even the lower *O. woodwardi* Zone s. l. as assumed by most ammonoid workers and once more demonstrated by Dagys (1994). Primitive *Otoceras* with distinctly flattened ventral side during all stages of ontogeny, as characteristic for the *O. concavum* Zone, are missing even in the lower *O. woodwardi* Zone s. l. where only advanced *Otoceras* with distinctly acute venter is present. The base of the Triassic defined by first appearance of *Otoceras* at the base of the *O. concavum* Zone would be therefore one and a half ammonoid zones below the assumed priority base at the base of the *O. woodwardi* Zone of central Himalayas.

Independently from these priority questions, the first appearance of *Otoceras* is unsuitable for definition of the P/T boundary for the following reasons:

(1) Both at the base of the *O. concavum* Zone and of the *O. woodwardi* Zone, the first occurrence of *Otoceras* marks a migration event. The immediately underlying beds are in all cases free of ammonoids. Biostratigraphic definition of the base of the Triassic by the first appearance of *Otoceras* at the base of the *O. concavum* Zone of the Arctic or at the base of the *O. woodwardi* Zone of peri-Gondwana Tethys is not possible, because such boundary must be defined by a phylomorphogenetic cline between two species. In the case of the first occurrence (not first appearance!) of *Otoceras* this boundary would be even not situated between two ammonoid zones and therefore not be a biostratigraphic boundary. The first occurrence of *Otoceras* in any section must not be identical with the first appearance of *Otoceras*. In the case of the *O. woodwardi* Zone this is obvious. In the type area of this Zone, *Otoceras* begins together with *Ophiceras*. Therefore, this level cannot be older than the upper *O. boreale* Zone in the Arctis (Dagys, 1994). This is in full agreement with the conodont correlations (Kozur, 1994b). Where the *Otoceras* beds begin with *Otoceras* of the *O. woodwardi* group (with acute venter and a single keel in adults) without *Ophiceras*, their exact position within the lower *O. woodwardi* Zone and the lower *O. boreale* Zone is unknown. Therefore the base of the *O. woodwardi* Zone cannot be exactly correlated with the *O. boreale* Zone in most cases. Only in those sections, where *O. woodwardi* begins together with *Ophiceras* (e.g. in the type *O. woodwardi* Zone in central Himalayas), an approximate correlation can be made (not older than upper *O. boreale* Zone).

The first occurrence of *Otoceras* is either related to a transgression (e.g. base of the Upper *O. woodwardi* Zone in the central Himalayan type area, base of the *O. woodwardi* Zone at Selong, see under discussion of this section) or by immigration because of cooling or other, not yet known reasons, e.g. first occurrence of *Otoceras* in Kashmir above pelagic, but *Otoceras*-free beds. At the base of the *O. concavum* Zone, *Otoceras* begins distinctly above the transgression surface. This may be related to a deepening of the basin. Only where the *O. boreale* zone succeeds the *O. concavum* Zone, a definable biostratigraphic boundary is present, but this boundary was never proposed as the base of the Triassic and would be really not a suitable P/T boundary (recognizable only in very few sections of the world).

(2) The first occurrence of *Otoceras* is strongly diachronous. This can be clearly proven by ammonoid and conodont data. Bando (1971, 1973), Zakharov (1971) and Dagys (1994) have shown that *O. concavum* retains some features inherited

from the Araxoceratidae, including a flattened ventral side. It is more primitive than *O. woodwardi* and *O. boreale* that have both in early ontogenetic stages distinctly flattened ventral sides with three keels, but in later ontogenetic stages the venter is acute with only a single keel (Kummel, 1972; Bando, 1981). The more primitive *O. concavum* is regarded as the ancestor of the advanced *Otoceras* of the *O. woodwardi* group. This is in full agreement with the succession of *O. boreale* above *O. concavum* in the Arctic, with seemingly some overlap as demonstrated in the Setorym River section of the Verkhoyansk region (see below).

In peri-Gondwana Tethys, primitive *Otoceras* of the *O. concavum* group with flattened ventral side are missing, and only the advanced *O. woodwardi* group is present. Consequently, the view of Tozer (1988, 298) that the base of the *O. woodwardi* Zone of the Himalayas is correlative with the base of the *O. concavum* Zone in the Arctic is unsubstantiated on ammonoid evidence. The type *O. woodwardi* Zone of the Himalayas corresponds only to the upper *O. woodwardi* Zone with *Ophiceras* (Dagys, 1994). Consequently, it is the youngest *Otoceras* fauna of the world.

Nakazawa (1992) and Yin (1993) correlated the *O. latilobatum* "Zone" of Selong (Tibet) with the *O. concavum* Zone of the Tethys. As pointed out by Dagys (1994), *O. latilobatum* is a badly preserved *Otoceras* that surely does not belong to the *O. concavum* group, because it lacks flattened ventral flanks. He concluded that "*O. latilobatum* must really be identified as *Otoceras* ex gr. *woodwardi*" (Dagys, 1994, 39). Also the *Otoceras* fauna of Selong belong to the upper *Otoceras* fauna that is also indicated by conodonts (see under discussion of the Selong section).

The ammonoid correlations by Dagys (1994) are largely in agreement with the conodont correlations by Kozur (1994a, b, 1995). Sweet (1976) reported from Greenland one of the richest conodont faunas of *Otoceras*-bearing beds. According to the taxonomy in that time, he assigned the species from the *Otoceras* faunas to *H. typicalis* and *Neogondolella carinata*. From these determinations and the figures it was clear that *H. parvus* was not present in this very rich fauna. Re-studies of the material by Kozur and Sweet (in prep.) confirmed these original results. *H. parvus* is absent in the very rich *Hindeodus* faunas of the *Otoceras* beds of Greenland, as already recognized by Sweet (1976), who did not determine any *Isarcicella isarcica* to which *H. parvus* was assigned in that time by Sweet and all other conodont workers (because *H. parvus* was not yet separated from this species!). In the lower part of the Greenland *Otoceras* faunas only *H. typicalis* is present, whereas in the upper part *H. latidentatus* is additionally present. Very primitive *H. parvus*, in an evolutionary stage like those of the middle part of Boundary Bed 2 in Meishan, have been found in *Ophiceras*-bearing beds. Two explanations can be given for this fact: (1) The upper part of the *O. woodwardi* Zone is younger than the *O. boreale* Zone (Kozur, 1994b) and corresponds to the lower *Ophiceras commune* Zone. This interpretation seems to be confirmed by the fact that Nakazawa et al. (1987) reported from Svalbard a slab with *O. boreale* and *Claraia stachei*, a guide form of the *Ophiceras commune* Zone. (2) The *Ophiceras*-bearing beds with very primitive *H. parvus* from Greenland may belong to the uppermost *Otoceras* faunas of this area in which *Ophiceras* is already present (Dagys, 1994). In this case *Claraia stachei* would begin in the upper *Otoceras* fauna what is, however, unproven so far.

In any case, *H. parvus* does not begin before *Ophiceras* in the Arctic, because the Greenland specimens are the most primitive forms of that species (see above). For this reason, the largest part of the Boreal *Otoceras* faunas is older than the type *O. woodwardi* Zone (= *Ophiceras*-bearing upper *O. woodwardi* Zone of the Himalayas), as pointed out by Kozur (1994b). This is exactly the same correlation as given by Dagys (1994) on ammonoid evidence. If the base of the Triassic is defined by the first appearance of *H. parvus*, the largest part of the Boreal *Otoceras* faunas will belong to the Permian (Kozur, 1974, 1989, 1994b, c, 1995).

(3) The occurrences of *Otoceras* are restricted by provincialism. *Otoceras* is restricted to cool-temperate to cold-water areas (Wang, 1984; Yin, 1985; Yin et al., 1988; Kozur, 1989, 1994b), whereas the Changxingian faunas occur in the tropical realm. The *Otoceras* faunas display a very low faunal diversity; all warm-water faunas are absent and except marginal parts of the distribution area of *Otoceras* (Greenland, peri-Gondwana Tethys, seemingly with temperate climate), limestones are missing or sparse in *Otoceras*-bearing beds. Only in Greenland and peri-Gondwana Tethys, limestones are common in the *Otoceras*-bearing beds. According to Kozur (1994b), *Otoceras* migrated in the latest Permian toward the equatorial realm because of cooling at that time. In the *O. concavum* Zone it was restricted to the central parts of the Boreal realm (Arctic Canada and Siberia). Within the upper part of the *O. boreale* Zone, *Otoceras* started in the cool to temperate peri-Gondwana Tethys and during a shortlasting strong cooling near the P/T boundary *Otoceras* may have immigrated to part of the Tethys (doubtful *Otoceras* in Boundary Bed 1 of Meishan together with Changxingian ammonoids, brachiopods and conodonts). According to Kozur (1989, 1994b) this rapid, short-lasting cooling in the tropical Tethys was the cause of the faunal incision. Whereas the temperature on the Tethyan marginal sea dropped below the lethal level for warm-water faunas, insular regions in the Panthalassa ocean preserved warm-water conditions. From there, many faunal elements that disappeared in the Tethys at the P/T boundary, migrated back into the Tethys during the Olenekian and Middle Triassic.

Whereas the view that *Otoceras* is a cool-water form is generally accepted, Tozer (1994b) rejected this view and explained furthermore the absence of *Otoceras* in Transcaucasia, Central Iran and perhaps in South China by a gap above the Changxingian or Dorashamian. Whereas he regarded data and graphic correlations by Sweet (1992) that show partial overlap of the *Otoceras* faunas with the Changxingian (independently recognized by Kozur, 1989, 1994b without using graphic correlation) as unproven, he really used unproven statements. The sections at Meishan and Shangsi and of Transcaucasia and Central Iran have been investigated by numerous specialists of different countries and all came to the conclusion that there is no gap above the Changxingian or above the Dorashamian. The idea of a gap was only expressed by those authors (especially Tozer) who have not worked on the detailed sedimentology in these sections and who concluded from the absence of *Otoceras* that a gap existed. The data for continuous sedimentation around the P/T boundary have been summarized by Yin (1993, results of the Chinese working group). In the Sovetashen section of Transcaucasia, overlapping samples were taken from the base of the *Paratirolites* beds up to the first occurrence of *H. parvus*. No sedimentologic indications of a gap could be found in these pelagic beds nor a stratigraphically condensed sequence is present. Also the faunal evidence indicates a step by step evolution. In the type section of the Dorashamian the water depth is still greater, as indicated by sedimentological data and ostracod faunas. The sequence is continuous across the P/T boundary (Kotlyar et al., 1984). The graphic correlation by Sweet (1992), regarded by Tozer (1994b) as "interpretations, not demonstrations", is far better founded by an original set of facts than the unproven hypothesis of Tozer that the absence of *Otoceras* in Transcaucasia, central Iran and possibly South China is caused by a gap above the Changxingian (or Dorashamian). This hypothesis by Tozer (1994b and earlier papers) is in direct contradiction to the facts in these sections, and it is hardly credible that numerous sedimentologists and paleontologists from China, Russia and elsewhere had all overlooked the gap that Tozer postulated by the absence of *Otoceras* without any sedimentologic evidence.

The evidence by Tozer against a cool-water (to temperate) restriction of *Otoceras* compared with the tropical Changxingian fauna are likewise vague. Several times he explained that the view about the cool-water restriction of *Otoceras* is an attempt by Kozur (1989) to influence other people. However, as stated by Kozur (1989), this view was already expressed earlier in papers of Chinese colleagues (Wang, 1984; Yin, 1985; Yin et al., 1988) that all continue to maintain this view. Tozer (1994b, 34) stated: "In making this interpretation of the paleoclimatic significance of the otocerataceans Kozur seems to overlook the fact that otocerataceans occur in the Dorashamian, i.e. in the Tethyan province... Thus otocerataceans cannot be regarded as an exclusively cool water group". However, neither Kozur nor any other scientist, who has regarded ***Otoceras*** as a genus restricted to cool and temperate waters, has ever written that **otocerataceans** have this zoogeographic restriction. The presence of Araxoceratidae in the Dzhulfian and doubtfully in the basal Dorashamian of the tropical-subtropical Tethyan province does not exclude the possibility that a genus of the successor family Otoceratidae may have a zoogeographic restriction to cool and temperate waters. Many recent animals or fossils restricted to the Boreal zoogeographic province have tropical relatives in a different family of the same superfamily. There are living genera with species restricted to cool water and other species that also occur in warm water (e.g. within the Bairdiidae). Moreover, ammonoids of Dzhulfian to earliest Changxingian age are practically unknown from the Arctic. Therefore, it cannot be concluded that **all** Araxoceratidae of this age are restricted to the Tethyan province.

The other argument against the exclusive occurrence of *Otoceras* in cool and temperate water is the possible occurrence of *Otoceras* in China, **above the Changxingian.** An explanation for this occurrence is given by Kozur (1989, 1994b, see above). Just at the level, where doubtful *Otoceras* have been recorded, all stenotherm warm water faunal elements are missing. Moreover, if true *Otoceras* is present in Boundary Bed 1 of China, this would document the contemporaneous occurrence of *Otoceras* with Changxingian ammonoids, brachiopods and conodonts, being incorrect according to Tozer (1994b). The fauna of Boundary Bed 1 was in the original biostratigraphic definition of the type Changxingian included in this stage as an unnamed zone (Zhao et al., 1978). Only the assumed Triassic age of the doubtful assumed *Otoceras* specimens has lead to the conclusion that these beds are younger than Changxingian (Zhao et al., 1981). Those specialists, who recognized the Permian character of the ammonoid, brachiopod and conodont faunas from the Boundary Bed 1, but assumed a Triassic age of *Otoceras,* rejected the presence of *Otoceras* in these beds (Dagys & Dagys, 1987). Today, the Permian age of Boundary Bed 1 is again generally accepted, also by the most ammonoid specialists and not only by authors that define the base of the Triassic with the first appearance of *H. parvus* in the middle part of Boundary Bed 2 (Dagys & Dagys, 1987; Kozur, 1989, 1994b, 1995; Yin et al., 1994; Wang et al., 1987). The mixed Permian-Triassic character of this fauna was assumed by the co-occurrence of Permian ammonoids, brachiopods and conodonts with "Triassic" ammonoids tentatively assigned to *Otoceras.* The repeatedly expressed view of Tozer (1994b) that Boundary Bed 1 lies **above** the Changxingian is neither correct with respect to the original definition of the Changxingian in its type locality, nor with respect to the present general assignment of these beds. It reflects the view of Tozer that a fauna, which contains or perhaps contains *Otoceras* must be younger than Changxingian.

Tozer (1994b, 35) stated that "the ammonoids of the Dorashamian and Changxingian give absolutely no grounds for a correlation with the Lower Griesbachian." Because the Lower Griesbachian below the upper *Otoceras boreale* and upper *O. woodwardi* faunas with *Ophiceras* contains only *Otoceras*, this sentence means nothing else than the absence of *Otoceras* in the Dorashamian and Changxingian (if the doubtful specimens of *Otoceras* from Boundary Bed 1 of Meishan do not belong to *Otoceras*). This situation is normal for the entire Permian, where the Boreal (and Notal) cool-water faunas have totally different ammonoid faunas as the Tethyan warm-water faunas. The discussion of the Dorashamian ammonoid faunas that preceded the above-mentioned sentence adds nothing to this problem. Tozer pointed out that *Pleuronodoceras occidentale* is based on a poorly preserved specimen, the generic affinity of which is far from certain. However, the ammonoid-based late Changxingan age determination of the *Pleuronodoceras occidentale* fauna (Zakharov, 1988, 1992) can be confirmed by conodonts. The lower part of the *P. occidentale* Zone belongs to the lower *Clarkina deflecta-C. changxingensis* fauna, in which *C. subcarinata* is still present, but no more dominant as in older Changxingian beds. In the upper part of the *P. occidentale* Zone, *C. subcarinata* is absent, but *C. changxingensis, C. deflecta, C. dicerocarinata, H. typicalis* and *H. latidentatus* are present. This conodont succession is the same as in the type late Changxingian confirming the assignment of the *P. occidentale* Zone in the late Changxingian by Zakharov and Rybalka (1987).

Furthermore, Tozer (1994b) pointed out that *Iranites* is probably a synonym of *Shevyrevites* and *Dzhulfites* is a synonym of *Paratirolites*. This view of Tozer is not shared by the Russian ammonoid workers (Kotlyar et al., 1984; Zakharov, 1985, 1988, 1992), who have studied this fauna. The discussion of these taxonomic questions are beyond the topic of this paper. These questions have nothing to do with the question of the partial overlap of the *Otoceras* faunas with the Changxingian, because *Dzhulfites, Iranites* and *Shevyrevites* occur below the *Paratirolites* beds of the Dorashamian and even these beds are not latest Changxingian that is present in the *P. occidentale* Zone. The only taxonomic problem in ammonoid taxonomy that was related to the correlation of the *Otoceras* faunas with the Tethyan scale was the misidentification of *Koninckites* as *Otoceras* by Tozer (1979). He concluded on the basis of this misidentification that *Otoceras* occurs considerably above the type Changxingian in South China (Tozer, 1979). Sheng et al. (1982) and Wang (1984) proved that this "evidence" is without background, because *Otoceras* of Tozer (1979) belongs to *Koninckites* that is, of course, considerably younger than the Changxingian. After the publication of these papers, Tozer (1988) pointed out "that the specimens are too poorly preserved to identify the genus". However, at least the age determination, which results from an assignment of these specimens to *Koninckites*, is correct. *Neospathodus* occurs in this level indicating that the horizon with ammonoids determined by Tozer (1979) as *Otoceras* and by later authors as *Koninckites* is several conodont zones younger than the *H. parvus* fauna of the upper *O. woodwardi* Zone.

Definition of the Permian-Triassic boundary with the first appearance of *Hindeodus parvus*

Conodonts belong to the stratigraphically most important groups of fossils in the Paleozoic and in the Triassic. Rapid evolution of often globally distributed guide forms makes conodonts very suitable for definition of stratigraphic boundaries in that time interval. The base of many stages in the Paleozoic and in the Triassic is defined by the conodonts.

Kozur (1972, 1974, 1977a) used conodonts for the first time for the definition of the P/T boundary. He used the base of the *Isarcicella isarcica* Zone as the base of the Triassic. The base of this zone was also preferred by Sweet (e.g. 1992) and Kotlyar (1991). Yin (1985) preferred the first appearance of *H. parvus*, because of the discovery of this form in the middle part of Boundary Bed 2 at Meishan. As shown by Kozur (1994b) both boundaries are by definition very near to each other or identical. Sweet included for a long time *H. parvus* into *Isarcicella isarcica*, following Staesche (1964). Therefore the base of his *I. isarcica* Zone was identical with the base of the *H. parvus* Zone. Kozur defined the base of the *I. isarcica* Zone with the first appearance of *Isarcicella* s. str. (specimens with thickened cup and at least one lateral denticle on the thickened part of the cup). As shown by dissolving large samples from the P/T boundary level in different parts of the world, these forms began very rarely near the base of the *H. parvus* Zone. Consequently, also the base of the *I. isarcica* Zone s. l. was nearly identical with the base of the *H. parvus* Zone. For this reason, and because of the wider distribution of *H. parvus* also Gullo and Kozur (1993) and Kozur (1994a, b) accepted the base of the *H. parvus* Zone as the base of the Triassic. The *I. isarcica* Zone was redefined with the first appearance of *I. isarcica* and regarded as a range zone. The advantage of the base of the *H. parvus* Zone against all other possible conodont boundaries is discussed below.

At the P/T boundary only gondolellids and *Hindeodus* are common. In shallow-water deposits *Stepanovites* (Permian) and *Ellisonia* (Triassic) may be common. *Merrillina* is very rare. The platform conodonts are exclusively represented by the smooth *Clarkina*. In contrast to the opinion of Orchard (1994b), Orchard et al., (1994) and Dagys (1994, referring to Orchard, 1994b), these platform conodonts are not suitable for definition of the P/T boundary for the following reasons: The P/T boundary level is marked by successive disappearance of *Clarkina* species in the latest Changxingian. Two species characteristic for the basal Triassic, *Clarkina carinata* (Clark) and *C. tulongensis* (Tian), have their first appearance in the uppermost Changxing Limestone of the Meishan sections or equivalent undoubtedly Changxingian beds immediately below the Boundary Beds in the Shangsi section; they straddle the Permian-Triassic boundary. These species, especially the common *C. carinata* have during their entire range from the latest Changxingian to earliest Scythian a very high intraspecific variability (width and outline of the platform, degree of upward turning of the platform margins, size of the cusp, denticulation of the carina). Extreme forms of *C.* cf. *carinata* are very similar and almost inseparable from *C. deflecta, C. changxingensis, C. tulongensis.* A large part of the different determinations of the conodonts of the Selong section is caused by this intraspecific variability. Independent from this high intraspecific variability, the smooth *Clarkina* species are difficult to separate. Only very rich, well preserved faunas allow an exact separation of different species, but even in these faunas the high intraspecific variability brings a lot of problems for taxonomy. Basic questions of the taxonomy are open that are related to this intraspecific variability, e.g. *C. carinata* s. l. versus *C. carinata* s. str., *C. planata* and *C. nevadensis* for the same populations. *C.* cf. *carinata* cannot be clearly separated from *C. carinata*. Despite the fact that most specimens are different, the transitional field between these two species is always strongly occupied from the latest Changxingian to the earliest Triassic. Only in the *I. isarcica* Zone of the Tethys both species are distinctly separable, whereas in the cool and temperate climatic zones the high variability of *Clarkina* continued in the same stratigraphic level. *Clarkina* cf. *changxingensis* from the *H. parvus* Zone is nearly inseparable from *C. changxingensis* of the Changxingian. Single specimens of *C.* cf. *carinata* from the *H. parvus* Zone are nearly inseparable from *C. changxingensis* and *C. deflecta*, some are even similar to *C. orientalis* and *C. transcaucasica*. In this situation, the determination of stratigraphically important forms may be influenced by pre-existing opinions about the age of the fauna. For instance, the latest type Changxingian *Clarkina* fauna of the Meishan sections with *C.* cf. *carinata*, *C. changxingensis*, *C.* cf. *deflecta*, but without *C. subcarinata* and *Clarkina* faunas from earliest Triassic *H. parvus* Zone are nearly inseparable.

Moreover, the pelagic gondolellids have near the P/T boundary the same or even more patchy distribution than the ammonoids. Pelagic beds are rare near the P/T boundary and therefore also sections with *Clarkina* are rare near this boundary. Moreover, even sections with very rich *Clarkina* faunas in the latest Permian and earliest Triassic display often a short interval, where only *Hindeodus* is present, e.g. Sosio Valley in Western Sicily (Gullo & Kozur, 1993), most of the Transcaucasian sections (Kozur et al., 1978), some of the Chinese sections (Tian, 1993, 1994), Guryul Ravine, Kashmir (Matsuda, 1981). No direct correlation of the few pelagic sequences across the P/T boundary with the wide-spread shallow water facies (Werfen facies of the Tethys and in western North America) at the P/T boundary is possible with any *Clarkina* species, because they are absent in all shallow-water deposits. None of the basal Triassic *Clarkina* species appeared at the base of the Triassic, independent from the level in which this boundary will be finally placed. All these species appeared in undisputed Changxingian strata. The distinct differences between tropical Changxingian and Triassic *Clarkina* faunas are exclusively caused by disappearance of Changxingian species, but disappearance is not a useful base for definition of the base of the Triassic.

The *Clarkina* species near the P/T boundary are strongly temperature dependent. All typical late Changxingian *Clarkina* species, such as *C. deflecta*, *C. dicerocarinata*, *C. postwangi* and *C. xiangxiensis* are stenotherm warm-water species. The *C. carinata* group is eurytherm, but prefered temperate and cool-water environments and became in tropical areas only dominant after disappearance of the stenotherm latest Permian warm-water gondolellids. For this reason, the *C. carinata* group began earlier in cool-water and temperate environments. For instance, it began in the Guryul Ravine section (Kashmir) already 22.6m below the first appearance of *Otoceras*.

On the other hand, *Hindeodus* is very common in the shallow-water Werfen facies, but also occurs in pelagic deposits (mostly rarer). It is an eurytherm genus that is common both in Boreal cool-water and in tropical warm-water shallow-water seas. *H. parvus* is globally present in different facies. It is much wider in its distribution than ammonoids and platform conodonts. Despite the fact that the denticulation of the blade of *H. parvus* is variable (two morphotypes), the main difference against its forerunner *H. latidentatus,* the large cusp, is invariable and always recognizable, if the specimens are not broken. Both *H. parvus* and *H. latidentatus* are well determinable and easily to distinguished, both by their Pa element and by their Sb ramiform elements (see Kozur, 1995 and in press).

Only the transition forms that occur in a very short interval (e.g. in the middle 8–12 cm of Boundary Bed 2 (Bed 27) in the Meishan section) must be separated by arbitrary definition: All specimens, in which the cusp is more than two times longer than the following denticles are assigned to *H. parvus.* In general, also the denticulation of *H. latidentatus* and *H. parvus* is rather different. But the transitional forms display already the long cusp of *H. parvus,* but still the typical denticulation of *H. latidentatus* with 2–3 narrow denticles behind the cusp followed by broad, often wide denticles. The presence of perfect transition forms is, on the other hand, a good evidence for the derivation of *H. parvus* from *H. latidentatus* in a continuous phylomorphogenetic cline. Arbitrary separation of two species of a cline in the transitional field of the two species is generally necessary in phylomorphogenetic lineages.

H. latidentatus is a very characteristic form of the uppermost Changxing Limestone, rarely present also in the Boundary Bed 1 and 2 of the Meishan sections. It occurs in the same stratigraphic level in the Transcaucasian sections and is a common species of the lower Tesero Oolite of the Southern Alps. It occurs also in the *Otoceras* faunas of Greenland, but there the specimens are often not so typical as in the Tethys and more reminiscent of small advanced *H. typicalis*, but they fall within the intraspecific variability of the Tethyan forms. *H. latidentatus* is a characteristic latest Changxingian conodont species. Its derivation is not yet clear. According to Wardlaw (discussion in Guiyang) it has been derived from *H. julfensis* (Sweet); according to Kozur (in press) it may be the successor of *H. typicalis* or of *H. julfensis*. This question does not touch the problematic of the P/T boundary, because the first appearance of *H. latidentatus* is in the uppermost Changxing Limestone within unquestionable Changxingian.

In a special meeting at the Guiyang Symposium (August 1994) hindeodid conodont material (among them type material of *H. parvus*) was shown and discussed. Full agreement was reached about the scope of *H. parvus*, its derivation from *H. latidentatus*, intraspecific (especially ontogenetic) variability, character of the apparatus and generic assignment.

The apparatus of *H. parvus* that was found in a monospecific fauna in Sicily, but was also recognized in the material of the Chinese workers during the Guiyang meeting, correspond to the apparatus of *Hindeodus*. A very similar apparatus is present in *H. latidentatus* found in monospecific faunas in the Tesero Oolite of the Tesero section (Kozur, 1995 and in press) and by Wardlaw (pers. comm.) in the Salt Range. Except the Pa element only the Sb element is different in these two species. Because of the presence of a *Hindeodus* apparatus and the *Hindeodus* type Pa element, all participants agreed that *H. parvus* belongs to *Hindeodus.* However, Sweet (1992), Orchard (1994a, b) and Orchard et al. (1994) assigned *H. parvus* tentatively to *Isarcicella.* So far, *Isarcicella* is regarded by all authors as Pa element of a single element apparatus. If this can be definitely proven, *H. parvus* cannot be assigned to *Isarcicella.* However, the ramiform element of *H. parvus* are distinctly shorter than those of typical *Hindeodus.* If *Isarcicella* displays the same apparatus, an assignment of *H. parvus* to *Isarcicella* would be possible. However, *H. parvus* has never a thickened cup as characteristic for the Pa elements of all *Isarcicella* species. Thus, all forms of the *Hindeodus-Isarcicella* cline, in which the cup is thickenend in 50% or more of its width, are assigned to *Isarcicella* and forms, in which the thickend part is narrower than 50% of the cup width or in which the cup is unthickend, are assigned to *Hindeodus*.

According to Sweet (pers. comm.) the apparatus of *Hindeodus* may be identical with that of *Subbryantodus*. If this can be definitely proven, *Hindeodus* Rexroad & Furnish, 1964 would be a junior synonym of *Subbryantodus* Branson & Mehl, 1934.

These problems of the generic status of *H. parvus* (and of the genus *Hindeodus*) do not touch the stratigraphic value of this species for definition of the base of the Triassic. Full agreement was also reached at the Guiyang meeting that the first appearance of this species is better suitable for the definition of the base of the Triassic than any other biostratigraphic event.

The definition of the base of the Triassic with the first appearance of *H. parvus* within the phylomorphogenetic cline *H. latidentatus – H. parvus* has the following advantages:

(1) *H. parvus* is easily determinable and readily separable by its large cusp (more than two times longer than the following denticles) from its forerunner *H. latidentatus*. Two morphotypes have been discriminated by Kozur (1990). Morphotype 1 display small uniform denticles behind the big cusp and a steeply dipping to nearly vertical posterior end of the blade that is undenticulated in juvenile specimens, but displays in general a small denticle in its upper part in adult specimens. In morphotype 2 the posterior third of the blade is occupied by small, strongly inclined denticles.

(2) The derivation of *H. parvus* is well established and the forerunner *H. latidentatus* and *H. parvus* can be found in several shallow-water and pelagic sections in superposition connected by transition forms.

(3) *H. parvus* has a far wider distribution than any other conodont or ammonoid species near the P/T boundary, which could be used for definition of the base of the Triassic. It is so far known from the Southern Alps, Dinarides, Hungary, Sicily (Italy), Crete (Greece), Transcaucasia (with the type locality), northwestern and Central Iran, Elburz, Kashmir, Salt Range, China, Japan, Greenland, western North America, i.e. from the entire Tethys, Circum-Pacific realm, cratonal North America, Boreal realm and the margin of Gondwana.

(4) *H. parvus* is not restricted to a narrow facies zone. It occurs both in ammonoid-free shallow-water Werfen facies and in ammonoid-bearing pelagic deposits.

(5) *H. parvus* has no zoogeographic restriction and occurs in the high latitude Boreal realm, temperate peri-Gondwana Tethys and in the tropical central and western Tethys.

(6) *H. parvus* is the first globally distributed species that appears immediately after the minimum in faunal diversity indicated by the minimum in $\delta^{13}C$. At Meishan, it begins 5cm above the minimum in $\delta^{13}C$.

(7) The first appearance of *H. parvus* is near to a lithostratigraphic event boundary, where such a boundary is recognizable. In the Meishan section, it begins 15cm above the event boundary.

(8) The first appearance of *H. parvus* is near to the traditional base of the Triassic. It lies in the middle part of the *O. woodwardi* Zone. In the central Himalayan type area of the *O. woodwardi* Zone, where *Otoceras* begins together with *Ophiceras* at the base of the (upper) *O. woodwardi* Zone, *H. parvus* probably begins at the base of the (upper) *O. woodwardi* Zone. The traditional P/T boundary above the Changxingian was in China either placed somewhat above or somewhat below the first appearance of *H. parvus*. Until Zhao et al., 1978, this boundary was placed at the

base of the *Claraia wangi* Zone, at Meishan 12 cm above the first appearance of *H. parvus*. Since Zhao et al. (1981) this boundary was placed at the base of Boundary Bed 1 that is 15 cm below the first appearance of *H. parvus*. Later the lower part of Boundary Bed 1 ("White Clay", Bed 25) was again placed in the Permian and the P/T boundary was placed at the base of the "Black Clay" (Bed 26, upper part of Boundary Bed 1), 11 cm below the first appearance of *H. parvus* (Yin et al., 1988; Yang et al., 1993). Yin (1993) and Yin et al. (1994) placed the P/T boundary at the base of Boundary Bed 2, about 8 cm below the first appearance of *H. parvus*, but defined the P/T boundary with the base of the *H. parvus* Zone in our sense.

Advantages of the Meishan section as GSSP for the Permian-Triassic boundary

The Meishan section consists of 7 quarries at the southern slope of the Meishan hill (Changxing County, Zejiang Province, South China, location see fig. 1) at 70 to 400 m from each other. They are named quarry A, B, C, D (Baoqing quarry, stratotype of the Changxingian Stage), E, F and Z (Zhongxin Dadui quarry). The beds of these quarries have identical thickness, facies and fossil content and because they are laterally traceable, they have been numbered around the P/T boundary in all quarries in the same manner. The Permian-Triassic Boundary Beds (Transitional Beds) are exposed in all of these quarries, the exposed part of the Changxing Limestone and of the overlying Lower Triassic beds is different. Quarry D exposes the entire Changxingian, the other quarries only the middle and upper part of the Changxing Limestone. Best studied are quarries D and Z, and the GSSP should be fixed in one of these two quarries by the Chinese colleagues. The large lateral extent of the Meishan

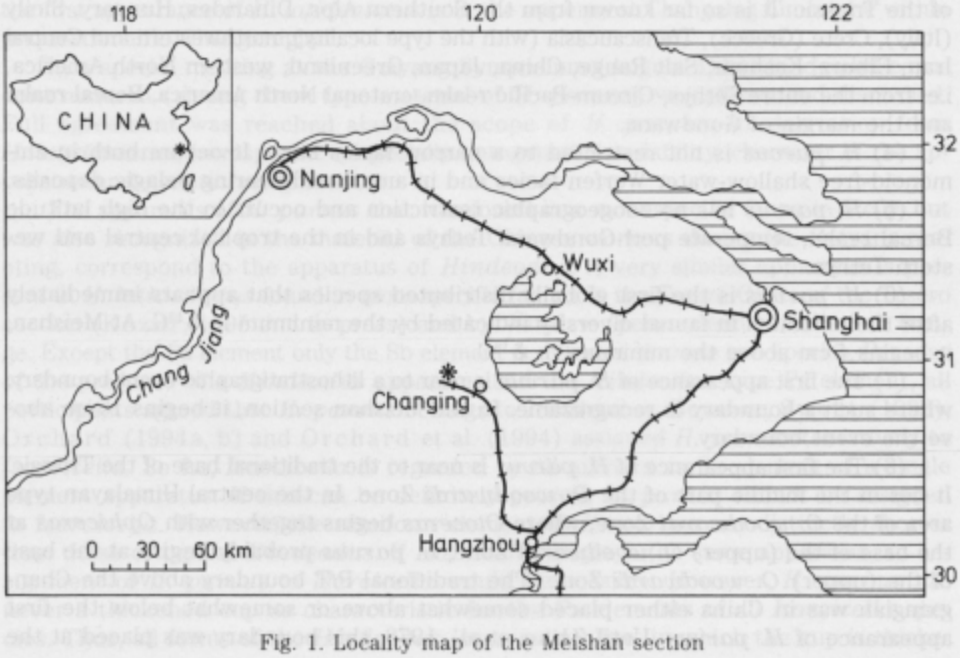

Fig. 1. Locality map of the Meishan section

section allows to take very large samples and to find also larger ammount of rare fossils, such as ammonoids.

As pointed out by Kozur (1989), the Meishan section is more suitable for definition of the base of the Triassic than all other P/T boundary sections in the world. After further studies of the faunas and physical events around the P/T boundary and very fruitful discussions on the excellent Guiyang Symposium (August, 1994) connected with excursions to the most important P/T boundary sections of China, Yin et al. (1994) and Wang (1995) proposed independently to use the Meishan as GSSP for the Permian-Triassic boundary. Yin et al. (1994) proposed to fix the GSSP for the base of the Triassic in quarry D, the stratotype of the Changxingian Stage, following Yang et al. (1987). Wang (1995) proposed the Zhongxin Dadui quarry, 500m east of quarry D as GSSP for the base of the Triassic. He followed the first such proposal by Sheng et al. (1984).

We agree with the proposal to choice the Meishan section as GSSP for the base of the Triassic (defined with the first appearance of *H. parvus*), independently from the question in which of the two quarries (D or Z) of the Meishan section the GSSP will be finally fixed.

In the following, the advantages of the Meishan section at Meishan as GSSP for the base of the Triassic are discussed.

Definition of the biostratigraphic base of the Triassic in the Meishan section

Our studies in South China, Central and northwest Iran, Transcaucasia of Armenia and Azerbaidzhan, Salt Range, Kashmir, Southern Alps, Hungary, Sicily, Greenland and additional published data from western North America (Paull & Paull, 1994) and Japan (IGO, lecture at the First Asian Conodont Symposium in Nanjing, September 1994) have shown that the first appearance of *Hindeodus parvus* within the cline *H. latidentatus – H. parvus* is the most suitable and globally recognizable boundary marker. The advantages of this boundary have been shown above.

To facilitate exact definition of the conodont boundary in the Meishan section, 162kg of samples from Boundary Beds 1 and 2 and immediately adjacent Permian and Triassic rocks have been processed for conodonts. The two 3–6cm thick layers of Boundary Bed 1 were sampled separately. The 16cm thick Boundary Bed 2 was divided to 4 samples, each of ca. 25kg per 4cm (AEL 882-1–882-4).

Hindeodus parvus (both morphotypes) appears first in the middle part of Boundary Bed 2 (AEL 882-3), 8cm above the base of this bed, and it is present as typical specimen also in sample 882-4 and in younger beds. This biostratigraphic boundary lies 15cm above the lithostratigraphic event boundary and a few centimetres above the minimum of $\delta^{13}C$ in the lower part of Boundary Bed 2. Supplementary biostratigraphic criteria, which occur at the above biostratigraphic boundary or a little below or above it, are the extinction of the last Changxingian ammonoids *Pseudogastrioceras, Pseudotirolites, Pleuronodoceras*, the extinction of Permian conodonts *Clarkina deflecta, C. dicerocarinata, C. changxingensis, H. latidentatus, H. typicalis*, and of the Upper Permian albaillellacean radiolarian fauna (most of them at the top of Boundary Bed 1, some a little later), and the development of *Ellisonia* from *Stepanovites* as well as the first appearance of *Ophiceras, Claraia wangi* and *I.? turgida* (the last two events somewhat after the first appearance of *H. parvus*). Also important is the disappearance of the marine fungal association with *Tympanicysta*

Table 1. Distribution of conodonts around the P/T boundary in the Zhongxin Dadui quarry of the Meishan section

Sample / Conodonts	874	875	876	877	878	879	880	881	882 -1	882 -2	882 -3	882 -4	883	884	885	886	887
Weight (kg)	1.1	0	2.1	1.5	1.2	1.2	5.5	7.4	25.1	23.3	29.7	23.8	4.9	10.2	4.2	3.1	7.1
Clarkina carinata									1	1	2					1	1
Clarkina cf. *carinata*	1		2	3	1	2	5	21									
Clarkina changxingensis	1		4	6	6	4	3	5	2		6	3					
Clarkina deflecta			1	1				8		1							
Clarkina dicerocarinata								1									
Clarkina meishanensis							4	5									
Clarkina subcarinata	1		9	2	2												
Clarkina xiangxiensis				1	2	4	2	3	7								
Clarkina sp.			7					14	2			3	1				
Hindeodus changxingensis sp. nov									1		1						
Hindeodus latidentatus									1		1						
Hindeodus typicalis	1		1			1			10	11	4	3					
Hindeodus parvus M. 1											1?	2		2	1	1	
Hindeodus parvus M. 2											3	2	2	1			
Isarcicella ? turgida														4	5	1	
Hindeodus julfensis											1						
Hindeodus sp. (Fragments)											13	27			7	1	
Ellisonia spp.									2		12	6		10	5	2	
Stepanovites sp.										1							
Merrillina longidentata										3							
Ramiform elements	14		2					2		6	16	31			4		
Fish teeth and scales	6		2	3	2	3	1	2	6	11	13	2	1				2

stoschiana, which is very characteristic world-wide in Late Changxingian marine deposits, especially near-shore occurrences. In Meishan it is common to the top of the Changxing Limestone, and very rare in the Boundary Beds 1 and 2 (Ouyang & Utting, 1990). In the Boreal realm, beds with mass occurrences of marine fungi have been placed in the Triassic, because they occur in the *Otoceras* faunas. But the largest part of the Boreal *Otoceras* faunas belong to the Permian (Kozur, 1989, 1994b). *Clarkina meishanensis* n. sp. is restricted to Boundary Bed 1 and *Hindeodus changxingensis* may also be possibly restricted to the Boundary Beds.

Correlations of the biostratigraphic base of the Triassic in the Meishan section on the global scales

Evolution of *H. parvus* from *H. latidentatus* is gradual and occurs in one monofacial bed. It is therefore not influenced by facial changes. Because of the gradual transition perfect transitional forms were found that were assigned either to *H. latidentatus* or to *H. parvus*. Zhang (1987) figured such a transitional form as *H. parvus* from Boundary Bed 2 of Meishan. It displays the typical denticulation of *H. latidentatus* with mostly 2 small denticles behind the cusp followed by large and broad, often widely separated denticles. If the cusp is largely broken as in the specimen figured by Zhang (1987), the separation of *H. latidentatus* and *H. parvus* may be difficult or impossible. In well preserved specimens the transition forms can be easily assigned to *H. parvus* if the cusp is more than two times larger than the largest denticles of the blade.

The same succession from *H. latidentatus* to *H. parvus* can be observed in different continents and faunal provinces, e.g. in Transcaucasia (Kozur et al., 1975, 1978), Kashmir (Matsuda, 1981), the Salt Range (Wardlaw, pers. comm.), in the Southern Alps (Schönlaub, 1991; Kozur, in press) and in Greenland (Kozur & Sweet, in prep.). *H. parvus* is present in all investigated conodont-bearing sections of the lowermost Triassic of the world (see III.). It occurs both in shallow-water ammonoid-free and in pelagic beds. It can therefore be correlated readily within different shallow-water and pelagic fossil associations. Rich sporomorph associations of the Meishan sections allow a correlation with continental beds, at least within the Cathaysian floral province.

Several kinds of biostratigraphic and event data serve as auxiliary signals that facilitate recognition of proximity of the biologically-defined P/T boundary (biostratigraphic auxiliary signals see above). For example, the "Boundary Clay", the base of which marks the lithostratigraphic event boundary, can be recognized as a marker horizon in the Meishan section and those other sections where deposition was below the storm wave base in the level of Boundary Bed 1. It lies in the Meishan sections 15 cm below the proposed biostratigraphic boundary. This "Boundary Clay" is present in the huge area from SE Siberia in the N to Meishan in the S and Shangsi in the W (about 2 million km^2). It represents fall-out of volcanic ash and was therefore deposited very rapidly. In sections deposited above storm wave base it is not preserved. We cannot agree with the view of Jin et al. (1994) that this bed represents residuum on the non depositional surface containing a condensed fauna of the few 100 m Greenland *Otoceras* beds. Moreover, it does not represent a transgression surface, equivalent to the *Otoceras* transgression in the Arctic and at the Tethyan margin of Gondwana. As shown by conodonts, the *Otoceras* transgression in the Arctic is considerably older and even in the Meishan sections the transgression was not at the base of the "Boundary Clay", but deeper, within the upper Changxing Formation between beds 24c and 24d. In Transcaucasia and in Sicily a distinct regression took place at the base of or within the *H. parvus* Zone and in the Southern Alps the base of the *H. parvus* Zone lies within the lower Mazzin Member in a level without transgression or regression. Thus, there was no world-wide transgression at the P/T boundary as assumed by Jin et al. (1994). World-wide transgression is recognizable only for the level of the *Paratirolites* fauna within the Changxingian, but it is too far from the P/T boundary to be used as an auxiliary marker for this boundary.

The minimum for $\delta^{13}C$ is also recognizable near the biostratigraphic P/T boundary. It indicates the minimum in organic diversity. In all sections, where both the conodonts and the $\delta^{13}C$ values are known, the $\delta^{13}C$ minimum pre-dates the first appearance of *H. parvus* only slightly. In the Meishan section this minimum lies about 5 cm below the first appearance of *H. parvus* (see above). One exception to this generalisation was reported from the Carnian Alps, where *H. parvus* was recorded slightly below this event boundary (Schönlaub, 1991). But this inversion of the event and biostratigraphic succession is caused by misidentification of advanced *H. latidentatus* as *H. parvus* as judged from the figured specimens. True *H. parvus* also begins in this section a little above the minimum in $\delta^{13}C$.

An additional important event is the beginning of the Lower Scythian anoxia (Wignall & Hallam, 1993) that began almost globally near the base of the *H. parvus* Zone (exceptions include the Salt Range, Transcaucasia and Abadeh; Kozur, 1994b).

A further important event is the nearly total drop in organic silica production by Radiolaria. As a consequence, radiolarites are absent world-wide in the lower Scythian. In the Dalong Formation, siliceous rocks (and radiolarians) disappear at the base of the event clay.

The foregoing two types of auxiliary data for recognition of the P/T boundary are important for the radiolarite deep-sea sequences of the Circum-Pacific realm. These are the only marine sediments that do not contain *H. parvus* (and mostly no conodonts at all). Such deep-sea sediments do not contain ammonoids or other macrofaunas as well. But the position of the P/T boundary can be recognized easily by the sudden change of radiolarites (often red coloured) into black shales (e.g. in Japan and SE-Siberia, Suzuki et al., 1993; Kozur, 1994b).

The originally tuffitic "Boundary Clay" at Meishan contains zircon, which allows radiometric age determinations (see 8, herein), which can be used for correlations as well (e.g. with the Siberian Trap volcanism). The presence of a layer of volcanic origin in the fossil-rich pelagic P/T boundary section at Meishan offers a unique opportunity to correlate the biostratigraphic and numerical time scales.

Location of the proposed GSSP

The Meishan section is situated at the southern slope of the Meishan hill in Changxing County, Zhejiang Province, South China (fig. 1). It is under the administrative jurisdiction of Huaikan township in Changxing County. The land where the section is located is owned by the Changxing cement factory, but the most important quarries (D = Changxingian stratotype and Z = Zhongxin Dadui) are protected by government. The detailed lithostratigraphic succession of the Boundary Beds is shown in text-fig. 2. All faunas and lithofacies in the Changxingian Stage and in the lowermost Triassic (especially those of the Boundary Beds) of the Meishan section have been thoroughly studied. The section is favourable both for biostratigraphic and event studies.

Description of the Boundary Beds and immediately adjacent strata of the Meishan section

The stratotype section of the Changxingian Stage (quarry D = Baoqing section at Meishan in Changxing, Zhejiang) had been described fully by Zhao et al. (1981), whereas the lithology as well as the biostratigraphy of the Changxingian to lowermost Triassic and especially of the Boundary Beds in quarry Z (= Zhongxin Dadui section) were described by Sheng et al. (1984). Recently, intensive studies of conodonts of the Meishan section have been carried out (Wang, 1994a, b; Yin et al., 1994; Kozur & Wang, in prep.). As representative for the Meishan section, lithology and fossil content of the Boundary Beds and immediately under- and overlying strata are described below. The lithological descriptions with listing of megafossils are based on Sheng et al. (1984). New additions are those for conodonts (see also table 1). The conodont determinations were made by Cheng-Yuan Wang and H. Kozur

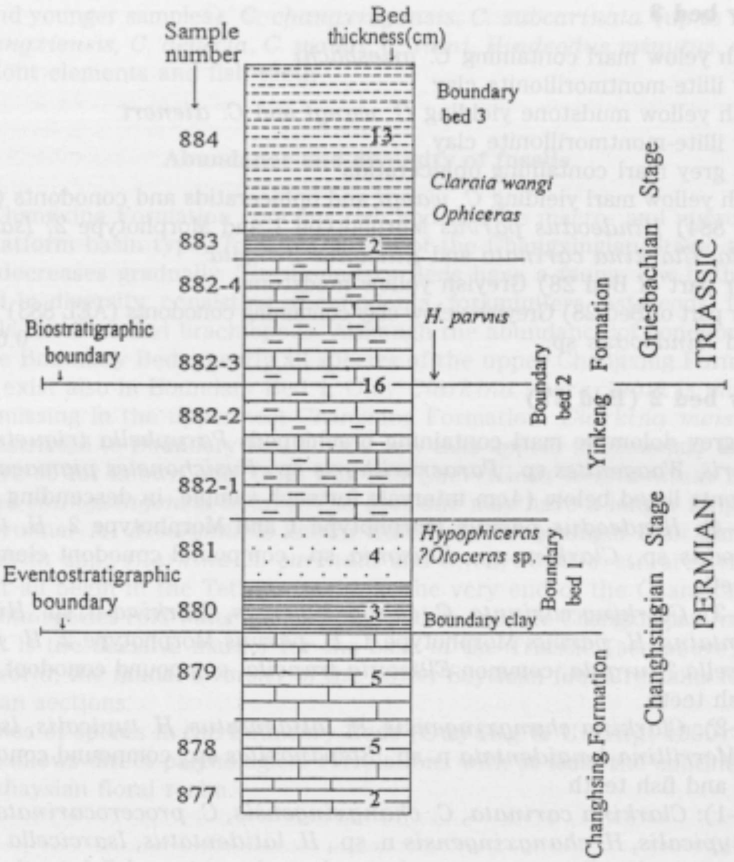

Fig. 2. Eventstratigraphic and biostratigraphic boundaries of the Meishan section at Zhongxin Dadui quarry, Changxing County, Zhejiang Province, South China. The exact thickness of each bed is indicated within the column

(unpublished data). The new species will be described by Kozur and Wang (in prep.). The following stratigraphic sequence is described in descending order (bed numbers only indicated for the Boundary Beds and adjacent strata):

Lower Triassic – Lower Qinglong Formation (Chinglung Fm. according to a different transcription) = Lower Yinkeng Formation

15. Greyish green mudstone intercalated with thin-bedded argillaceous limestone (limestone increasing upward), containing bivalves *Claraia fukenensis, C. longyenensis*, ophiceratid ammonoids, including *Lytophiceras* sp. >2 m
14. Greyish yellow mudstone with limestone concretions, in the lower part with *Palaeonucula* sp. and *Claraia* sp., in the middle part with *C. stachei* 6 m
13. Yellow illite-montmorillonite clay 0.02 m

Boundary bed 3

12. Greyish yelow marl containing *C. griesbachi* 0.30 m
11. Yellow illite-montmorillonite clay 0.02 m
10. Greyish yellow mudstone yielding *C. wangi* and *C. dieneri* 0.98 m
9. Yellow illite-montmorillonite clay 0.04 m
8. Bluish grey marl containing ophiceratids 0.46 m
7. Greyish yellow marl yielding *C. wangi* and ophiceratids and conodonts (AEL 886 – AEL 884) *Hindeodus parvus* Morphotype 1 and Morphotype 2, *Isarcicella? turgida, Clarkina carinata* and *Ellisonia transita* 0.36 m
6. (Upper part of Bed 28) Greyish yellow mudstone 0.02 m
5. (Lower part of Bed 28) Greyish yelow clay containing conodonts (AEL 883) *Clarkina* sp. and *Hindeodus* sp. 0.01–0.02 m

Boundary bed 2 (Bed 27)

4. Light grey dolomitic marl containing brachiopods *Paryphella triquetra, P. orbicularis, Waagenites* sp., *Paracrurithyris* sp., *Fusichonetes pigmaea*, and the conodonts listed below (4 cm intervals for each sample, in descending order):

(AEL 882–4): *Hindeodus parvus* Morphotype 1 and Morphotype 2, *H. typicalis, Hindeodus* sp., *Clarkina* sp., *Ellisonia* sp., compound conodont elements and fish teeth

(AEL 882–3): *Clarkina carinata, C. changxingensis, Clarkina* n. sp., *Hindeodus latidentatus, H. parvus* Morphotype 1, *H. parvus* Morphotype 2, *H. julfensis, Isarcicella ? turgida*, common *Ellisonia transita*, compound conodont elements and fish teeth

(AEL 882–2): *Clarkina changxingensis, H. latidentatus, H. typicalis, Isarcicella* ? sp., *Merrillina longidentata* n. sp., *Stepanovites* sp., compound conodont elements and fish teeth

(AEL 882–1): *Clarkina carinata, C. changxingensis, C. procerocarinata, Hindeodus typicalis, H. changxingensis* n. sp., *H. latidentatus, Isarcicella* ? sp., *Ellisonia transita*; *E.* sp., compound conodont elements and fish teeth 0.16 m

Boundary bed 1

3. (Bed 26) Greyish yellow mudstone with small crystals of pyrite, purple-red in weathering colour, yielding ammonoids *Otoceras* ? sp., *Hypophiceras* cf. *martini, H. changxingense, Tompophiceras* sp., *Metophiceras* sp. and *Pseudogastrioceras* sp.; bivalve *Peribositra baoqinensis*; brachiopods *Paracrurithyris pygmaea, Waagenites barusiensis, Paryphella sulcatifera, Neowellerella pseudoutah* and *Araxathyris minuta*; conodonts (AEL 881) *Clarkina* cf. *carinata, C. changxingensis, C. dicerocarinata, C. deflecta, C.* cf. *sosioensis, C. xiangxiensis, C. meishanensis* n. sp. and *Hindeodus latidentatus* 0.04–0.06 m
2. Yellow or purple illite-montmorillonite clay containing conodonts (AEL 880): *Clarkina* cf. *carinata, C. changxingensis, C. deflecta, C.* cf. *meishanensis* n. sp. and *C. xiangxiensis* 0.03–0.06 m

Changxing (Changhsing) Formation

1. (Bed 24e) Grey thin-bedded limestone with chert nodules, bearing *Palaeofusulina* sp. and conodonts (AEL 879 – AEL 872): *Clarkina* cf. *carinata* (from AEL

876 and younger samples), *C. changxingensis*, *C. subcarinata* (up to AEL 878), *C. xiangxiensis*, *C. deflecta*, *C. wangi*, *C. tiani*, *Hindeodus minutus*, compound conodont elements and fish teeth 0.20 m

Abundance and diversity of fossils

The Changxing Formation contains rich and diverse macro- and microfaunas of an intraplatform basin type. Toward the end of the Changxingian Stage, the faunal diversity decreases gradually. The Boundary Beds have a fauna, low both in abundance and in diversity, consisting of conodonts, foraminifers, ostracods, fish teeth, ammonoids, bivalves and brachiopods. Although the abundance of conodonts decreases in the Boundary Beds, nearly all species of the upper Changxing Formation are known to exist also in Boundary Bed 1. Only *Clarkina subcarinata* is missing, but it is also missing in the uppermost Changxing Formation. *Clarkina meishanensis* n. sp. is restricted to Boundary Bed 1. Few new taxa appear in Boundary Bed 2. Two of them are so far known only from this bed (*Merrillina longidentata* n. sp. and *Hindeodus changxingensis* n. sp.). The first one may have a longer range, because its forerunner *M. divergens* is known from beds not younger than Early Dzhulfian. *Ellisonia* spp., *Clarkina* cf. *carinata* and *C. carinata* s. str. are Triassic elements, but all begin in the Tethyan realm at the very end of the Changxingian, the two *Clarkina* species cold-water faunas in the middle and late Changxingian respectively. *H. parvus* is the decisive marker for the base of the Triassic (see above). Like all over the world, the faunal diversity of the Lower Scythian fauna remains low also in the Meishan sections.

Presence of spores in the Boundary Beds (Ouyang & Utting, 1990) is significant, as it allows direct palynological correlations with at least the continental beds of the Cathaysian floral realm.

Favourable facies for widespread correlation

Studies on the Meishan sections reveal that the Changxing Limestone originated on a gently dipping slope. It is characterized by both pelagic and shallow-water fossils. Boundary Bed 1 was deposited below the storm wave base, allowing preservation of the tuffitic layer (Boundary Clay). The fauna consists predominantly of pelagic fossils (pelagic ammonoids, gondolellid conodonts), shallow-water fossils *(Hindeodus)* are subordinate. In Boundary Bed 2 a slight shallowing is indicated by increasing amounts of shallow-water conodonts *(Hindeodus, Ellisonia).* However, *Clarkina* is still present in the Boundary Beds 2, indicating a normal salinity pelagic facies deposition. This association of both pelagic and shallow-water conodonts is highly desirable for world-wide correlations. Moreover, *Hindeodus* occurs not only in shallow-water deposits, but also less abundantly in pelagic beds. Presence of sporomorphs also allows direct correlation with continental beds.

Important is also the low thermal gradient without thermocline. Permian cold bottom-water conodont faunas from open tropical seas are very different from warm-water faunas. Near the thermocline a sudden change in the conodont faunas occurred that sometimes has caused difficulties in stratigraphic interpretations (e.g. in the Luodian section in southwest China, Wang et al., 1994).

Structure and metamorphism

The Meishan section at Changxing is simple in structure, and consists of monoclinal strata without folds or faults. The outcrop is excellent and easily accessible. This section belongs neither to an exotic block nor to a terrane, it is monotonous in lithofacies, its biostratigraphic boundary lies in a successive monofacies horizon without any interruption of sedimentation with minor bioturbation.

The Meishan section displays a very low thermal alteration. The CAI is 1–1.5 and the Thermal Alteration Index (TAI) ranges from 2 to 2⁺, so that spores and acritarchs are well preserved and well studied (Ouyang & Utting, 1990).

Magnetostratigraphy, geochronometry and iridium anomaly

The magnetostratigraphic research data from the Meishan sections can be considered as reliable, because the rocks have not been effected by significant thermal alteration and they display low organic maturity. Li et al. (1989) collected 111 samples at the Meishan sections and according to their studies, the Permian-Triassic eventstratigraphic boundary (15cm below the biostratigraphic boundary) lies 1.2m above the base of normal polarity zone V. This is in good agreement with data on Dorasham 2, Transcaucasia (Zakharov & Sokarev, 1991). The paleolatitudinal position of Meishan was at 12.3 °N in the P/T boundary level. This paleogeographic position within the tropical belt is favourable for biostratigraphic correlations.

The "Boundary Clay" of the Meishan section is of volcanic origin (Yin et al., 1992) and contains zircons that are suitable for absolute geological age determinations. Claoué-Long et al. (1991) and Zhang et al. (1992) calculated the radiometric age of the "Boundary Clay" (Bed 25) as 251.2 ± 3.4Ma (using Shrimp ion-microprobe $^{206}Pb/^{238}U$ dating). Renne (1995) determined a plateau date of 249.91 ± 0.15Ma (using $^{40}Ar/^{39}Ar$ analysis of sanidine grains) and calculated an average age of 250.0 ± 0.2Ma for the boundary tuffs of Meishan and Shangsi. This age corresponds to the age (250 ± 0.3Ma) of the main phase of the Siberian Trap (Renne et al., 1995).

The correlation of the main phase of the Siberian Trap and seemingly contemporaneous post-Tatrian ("Early Triassic" sensu Tuzikova, 1985) basalts in the Urals with the latest Permian and Permian-Triassic boundary was already shown by Kozur (1989, 1994b) on the basis of conchostracans and sporomorphs. This correlation played an important role in the explanation of the Permian-Triassic faunal crisis by a short-lasting strong cooling also in low latitudes caused by dense aerosols (Kozur, 1989, 1994b).

Yin et al. (1994) pointed out that the iridium anomaly at the P/T boundary is in most cases either undetected or of moderate value, and uneven distributions of Ir at the P/T boundary are present in South China and in the Alps, different from the situation at the Cretaceous-Tertiary boundary where the Ir content is consistently and remarkably higher than the background value, thus inferring a different origin. We agree with this statement, but have to add that the iridium peak noted by Brandner et al. (1986) in the Southern Alps was caused by a measurement mistake and is not existing (pers. comm. of the authors). Because also the high Ir values given by Sun et al. (1984) for the Meishan section were not confirmed by later investigations (Clark et al., 1986), it can be concluded that there was no iridium anomaly near the P/T boundary.

Accessibility and conservation

The Meishan section is conveniently accessible from Shanghai, Hangzhou (capital of Zhejiang Province) as well as from Nanjing (capital of Jiangsu Province). The area is known as China's economically developed region and provides suitable facilities for communications, travel and conduct of international geological field studies. Favourable climatic conditions make the section accessible throughout entire year.

The most important and best investigated quarries of the Meishan section, the stratotype section of the Changxingian Stage (quarry D, known also as Baoqing section) and the quarry Z (Zhongxin Dadui quarry) have now been placed under protection of the Provincial Government of Zhejiang and the County Government of Changxing, prohibiting economic exploitation, but allowing scientific studies both for Chinese and foreign scientists.

For the above reasons, several authors recommended the Meishan section as GSSP for the base of the Triassic (Yin et al., 1994; Wang, 1995). Already before the Meishan section was regarded as the best section in the world for defining the Permian-Triassic boundary (Sheng et al., 1984; Yang et al., 1987; Kozur, 1989; Wang, 1994a, b).

In agreement with the opinion of the overwhelming majority of the specialists the biostratigraphic P/T boundary is defined by the first appearance of *H. parvus* in the cline *H. latidentatus* – *H. parvus* within Boundary Bed 2. In the answer to a questionnaire in 1995, 13 members of the PTBWG recommended as base of the Triassic the first appearance of *H. parvus*, 2 members recommended the first appearance of *Otoceras* as base of the Triassic.

Overview of candidates (except Meishan) for the Permian-Triassic boundary GSSP and other important P/T boundary sections

In August, 1993, at the meeting of the Permian-Triassic Boundary Working Group (PTBWG) of the International Commission on Stratigraphy (ICS), four candidate sections for the global stratotype section and point (GSSP) for the base of the Triassic were proposed, Meishan (Changxing County, Zhejiang Province), Shangsi (Guangyuan, Sichuan Province), Selong (Xizang, Tibet) and Guryul Ravine (Kashmir). The Changxing section received the highest ranking.

At the PTBWG meeting at the Guiyang Symposium in August 1994 after visiting the Meishan and Shangsi sections, the vote for the best candidate for P/T boundary GSSP had the following result: 22 participants favoured Meishan, one favoured Guryul Ravine, and none favoured Selong and Shangsi. In a voting in Albrechtsberg, Austria, in which only few member of the PTBWG have taken part, 4 participants voted in favour of Meishan, and 3 in favour of Guryul Ravine. One of each votes for Meishan and Guryul Ravine was made by the same person. Therefore in both votes together 25 were in favour of Meishan and 3 in favour of Guryul Ravine. In the answer to a questionnaire in 1995, 15 members of the PTBWG recommended Meishan and no other section was recommended.

In the following, the different candidates for P/T boundary GSSP (except Meishan, for this section see chapter IV) and other important P/T boundary sections are briefly discussed.

Guryul Ravine (Kashmir)

The Guryul Ravine section contains *Otoceras woodwardi*, but no ammonoids in the beds immediately below the first appearance of *Otoceras*. Therefore no ammonoid-based boundary can be recognized in this section. Conodonts are common in the upper *O. woodwardi* Zone of the outcrop, but nearly absent below it (Matsuda, 1981). The upper *O. woodwardi* fauna belongs surely to the *H. parvus* Zone. It yielded *Hindeodus typicalis, H. latidentatus* (both determined as *H. minutus* by Matsuda, 1981), *H. parvus*, a single specimen of *Isarcicella* sp. and in the upper part also *Clarkina carinata*. Most of the lower *O. woodwardi* fauna[1] of the section cannot be dated by conodonts, because only one sample (upper part of bed 55) immediately below the first appearance of *H. parvus* contains *H. typicalis* and, according to the figured Sb element (Matsuda, 1981, pl. 3. fig.7), also *H. latidentatus*. The remaining part of the lower *Otoceras woodwardi* fauna has no conodonts, but a poor fauna with *H. typicalis* and *C. carinata* occurs also below the first appearance of *Otoceras* (Nakazawa et al., 1975; Matsuda, 1981), both in the E1 Member of the Khunamuh Formation and in upper part of the Zewan Formation (upper Member C and Member D). In temperate to cool-water environments the impoverished *H. typicalis – C. carinata* fauna (consisting in general only of these two species or subordinately additional species of the *C. carinata* group) began therefore considerably earlier (in the Guryul Ravine section in a horizon with *Cyclolobus walkeri* of late Wuchiapingian to early Changxingian age, 22.6m below the first occurrence of *Otoceras*) than in the tropical warm-water faunas, in which the latest Permian contains several other *Clarkina* species, such as *C. changxingensis, C. deflecta, C. dicerocarinata, C. postwangi, C. subcarinata* and *C. xiangxiensis*. The strong change from this typical Permian stenotherm warm-water *Clarkina* fauna to the "Triassic" *Clarkina carinata* fauna (dominant *C. carinata*, subordinately *C. procerocarinata, C. taylorae, C. tulongensis*) in the tropical area is therefore facies related (cooling event) and therefore unsuitable for definition of the base of the Triassic. For the same reason, the pelagic *Clarkina* is absent in the lower *H. parvus* Zone and often also immediately below the base of this zone in most of the tropical pelagic regions. The eurytherm *Hindeodus* species are present both in cool-water and warm-water faunas and therefore not affected by the Permian-Triassic faunal crisis.

The following reasons exclude the use of the Guryul Ravine section as GSSP for the base of the Triassic:

(A) Strong thermal alteration (CAI 4–5) prevents reliable results of magnetostratigraphic and palynologic investigations.
(B) No ammonoid and diagnostic conodont faunas are present in the Late Permian immediately below the *Otoceras* faunas.
(C) The section is not readily accessible at the present time. For political reasons, the visit of foreigners to Kashmir is forbidden at the present time.

The Guryul Ravine section is interesting as auxiliary section for the peri-Gondwana Tethys (temperate to cool-water) because it is the only section of this region,

[1] A part of the lower *O. woodwardi* fauna of the Guryul Ravine section may belong to the upper *O. woodwardi* Zone because *Ophiceras* is present in the top of Bed 52, where it begins about 80cm above the first occurrence of *Otoceras* in this section.

in which the *Otoceras*-bearing beds are not separated from the underlying beds by a gap. However, also in this section no ammonoids are present below the *Otoceras* faunas (*Cyclolobus walkeri* and *Xenaspis* sp. occur 22.6 m below the first appearance of *Otoceras*).

Shangsi (Guangyuan, Sichuan Province)

This excellent Wuchiapingian to Early Scythian sequence is very rich in fossils and the thermal alteration is very low (CAI 1–1.5). Because of the greater water depth, radiolarians are common in the Permian, but disappear suddenly near the P/T boundary. Correlation with Meishan is readily possible. Even the event clay is present. However, near the P/T boundary a 24 cm horizon has not yielded conodonts so far, and only *Hypophiceras* sp., *Claraia* sp. and *Towapteria* sp. were found in this horizon. Consequently, the Shangsi section is unsuitable as GSSP for the P/T boundary. However, this section is very important for studies of deep pelagic sequences in the Late Permian and near the P/T boundary.

Selong (Xizang, Tibet)

This section was proposed by Wang et al. (1989) as potential stratotype of the P/T boundary. It played (and still plays) an important role to "prove" that the *Otoceras concavum* Zone is younger than the Changxingian and contains a Triassic fauna. In this section time equivalents of the *Otoceras* faunas are said to overlie conformably Changxingian and also the "Boundary Clay", and a minimum $\delta^{13}C$ was recognized in the "right place". In this section Orchard (1994a) and Orchard et al. (1994) proved that the *Otoceras* faunas have no Changxingian conodont fauna, and that *H. parvus* begins contemporaneously with *Otoceras*. For Tozer (1994b) this is an important argument against the Permian age of the lower *Otoceras* faunas. However, in Selong only the upper *O. woodwardi* Zone is present (see below). Among the 4 candidates for the GSSP of the P/T boundary, this section is the most unsuitable, and since the Symposium in Guiyang, it is no more taken into consideration as GSSP for the P/T boundary by any scientist (compare above mentioned votings).

As clearly documented by Geldsetzer (lecture at the Guiyang meeting), the formerly assumed "White Boundary Clay" is a horizontal fissure filling of fibrous calcite that disappears laterally within bioclastic pre-Lopingian Permian limestones. The minimum of $\delta^{13}C$ is probably related to this fibrous calcite. The around 7 cm thick "Changxingian" bioclastic limestones above this fissure filling are inseparably connected with the underlying pre-Lopingian limestones. This is also indicated by the presence of Pre-Lopingian corals (upper range in the Middle Permian) in this "Changxingian" limestone (Fedorowski, discussion to the Geldsetzer paper) and by a conodont fauna that contain *Mesogondolella* ex gr. *phosphoriensis* and a new species of the Gondwanide cool-water genus *Vjalovognathus* (Kozur & Wang, Zhi-Hao, in prep.). The overlying *Otoceras latilobatum* bed is separated by a major erosional gap (with subaerial carstification) from these pre-Lopingian limestones. Therefore no Changxingian is present below the *Otoceras*-bearing beds. The basal centimetres of the *O. latilobatum* bed contain very much (partly more than 50%) reworked conodont of Early and Middle Permian ages, e.g. *Mesogondolella idahoensis* and *M.* ex. gr. *phosphoriensis* together with *H. typicalis* and *Clarkina* cf. *carinata* (Kozur & Wang, in prep.).

Nakazawa (1992) and Yin (1993) correlated the *O. latilobatum* beds at Selong with the *O. concavum* Zone in the Arctic. However, as pointed out by Dagys (1994), *O. latilobatum* from Selong is based on a poorly preserved specimen that lacks flattened ventral flank and consequently is not related to *O. concavum*. The holotype is according to Dagys (1994) an *Otoceras* ex gr. *woodwardi*. We fully agree with this determination. This means that the *Otoceras* fauna of Selong begins within any level of the upper *Otoceras* faunas. The presence of *H. parvus* in the *O. latilobatum* bed and the post-Changhsiangian character of the conodont fauna, reported by Orchard (1994a, b) does not mean that *H. parvus* begins together with *Otoceras* and the entire *Otoceras* faunas are post-Changxingian as assumed by Orchard (1994a, b) and above all Tozer (1994b). The conodont data of Orchard (1994a) and Kozur (1989, 1994a, b) are therefore not incompatible with each other as pointed out by Dagys (1994) and Tozer (1994b). The occurrence of *H. parvus* in the upper, *Ophiceras*-bearing *O. woodwardi* Zone is well documented since Matsuda (1981), recognized also by Kozur (1989, 1994a, b). The Changxingian conodont faunas reported by Sweet (1976) and Kozur (1994b) were derived from *Ophiceras*-free older part of the *Otoceras* faunas. If the specimens from the Boundary Bed 1 of China are true *Otoceras*, then also in South China Changxingian conodont faunas occur together with *Otoceras*.

Because *O. latilobatum* is an advanced *Otoceras* that starts after a very long stratigraphic gap, the co-occurrence of *H. parvus* and *O.* ex gr. *woodwardi* reported by Orchard (1994a) and Orchard et al. (1994) adds no new data that are in conflict with the data by Kozur (1989, 1994a, b). However, there are still some sedimentologic and other complications that have to be taken into consideration (see below).

For the following reasons, the Selong section is unsuitable as GSSP of the P/T boundary:

(A) The oldest *Otoceras* of Selong belong surely not to the primitive *O. concavum* group, but to the more advanced *Otoceras woodwardi* group. Because these ammonoids follow after a long stratigraphic gap, it is even unclear to which level of the *O. woodwardi* Zone they belong. Immediately underlying beds do not belong to the Changxingian, but to the early Middle Permian as indicated by corals and conodonts. They do not contain ammonoids. Thus, the P/T boundary cannot be established by ammonoids in this section.

(B) According to Orchard (1994a, b) and Orchard et al. (1994), *Hindeodus parvus* is present at the base of the *Otoceras* faunas of Selong (our lowermost investigated sample yielded *H. typicalis, C.* cf. *carinata*, many reworked Early and Middle Permian conodonts, but no *H. parvus*). If the data by Orchard can be confirmed (different authors presented so far different conodont data), the Permian lower part of the *O. woodwardi* Zone and the equivalents of the Permian Boreal *O. concavum* and lower *O. boreale* faunas (without *H. parvus*, but with *H. typicalis, H. latidentatus* and *Clarkina changxingensis*) are missing in Selong or condensed into the Triassic upper *O. woodwardi* Zone. As pointed out above, basal Triassic beds overlie Middle Permian limestones at a major unconformity and no Late Permian conodonts (and ammonoids) are known below the *Otoceras* faunas. Therefore, the exact position of the P/T boundary in this section cannot be established by conodonts.

(C) Strong thermal alteration (CAI 4–5) precludes reliable results of magnetostratigraphic and palynologic investigations.

(D) Strong stratigraphic condensation and reworking occur in the *Otoceras* faunas of Selong, because *Clarkina* cf. *changxingensis*, *C.* cf. *carinata*, advanced *C. carinata*, *Hindeodus typicalis*, *H. parvus*, *Isarcicella isarcica*, *Mesogondolella idahoensis* and *M. phosphoriensis* (all present in the *Otoceras* faunas of the Selong section) do not occur together in uncondensed and unreworked faunas.

C. tulongensis, also present in this fauna, was originally described from beds of earliest Triassic age, but the listing is a summary of conodont associations, and it is unclear whether the listed conodonts occur exactly in the same level near the P/T boundary. The "earliest Triassic" of the *C. tulongensis* type section contains also the equivalents of the latest Permian Boundary Bed 1 of Meishan. The species figured as *H. typicalis* from the stratum typicum of *C. tulongensis* is a *H. latidentatus*. The only exact age determination for *C. tulongensis* is from bed 27a of the Shangsi section. This bed belongs to the Upper Changxingian immediately below the latest Changxingian "White Boundary Clay".

C. taylorae from the *Otoceras* Beds of Selong is common in cool-water faunas with *H. parvus*, but also in cool-water faunas of the Permian basal Dolomite Unit of the Katwai Member (with the brachiopod *Comelicania* and the fusulinid *Reichelina*) of the Salt Range. Its stratigraphically lowest occurrence is in the White Sandstone Member (of latest Dzhulfian or earliest Changhsingian age) of the Salt Range. Both the Permian and Triassic *C. taylori* of the Salt Range have been so far erroneously assigned to *C. carinata* (Bando et al., 1985).

Another interpretation of the conodont distribution of the Selong section was given by Orchard (1994b) and Orchard et al. (1994). According to these authors, *"Isarcicella"? parva* and *Otoceras* appeared contemporaneously, *Isarcicella isarcica* appeared within the range of *Otoceras* and the Changxingian *"Neogondolella" changxingensis-"N". deflecta* assemblage does not occur in *Otoceras*-bearing beds. None of these assumptions can be confirmed in complete and uncondensed sections. Moreover, these assumptions are based on previous correlations of the *O. latilobatum* beds with the *O. concavum* Zone of the Arctic. As shown by Dagys (1994), this correlation is basically wrong. As pointed out above, Dagys (1994) proved that *O. latilobatum* is an *Otoceras* ex gr. *woodwardi*, because it lacks flattened ventral flanks characteristic for the *Otoceras concavum* group. The *O. latilobatum* beds belong therefore to the *O. woodwardi* Zone and the presence of *H. parvus* in these beds does not indicate that *H. parvus* and *Otoceras* began contemporaneously.

In Kashmir, *H. parvus* begins in the middle part of the *O. woodwardi* Zone, whereas in the lower *O. woodwardi* Zone only *H. typicalis* and *H. latidentatus* are present (see p. 196). Because the *O. woodwardi* Zone is surely younger than the *O. concavum* Zone, *H. parvus* is missing in the largest part of the *Otoceras* faunas. In Greenland, the first primitive *H. parvus* appears above the *O. boreale* Zone or in its uppermost, *Ophiceras*-bearing part (Kozur, 1994b; Kozur & Sweet, in prep.). In the Verkhoyansk region (NE Siberia), the lower *O. boreale* Zone yielded *H. typicalis* and *C. changxingensis*, but no *H. parvus*. But also this is not the oldest *Otoceras* fauna, represented by the *O. concavum* Zone.

A primitive new species of *Isarcicella* is common in Late Changxingian shallow-water deposits, where it occurs together with fusulinids, *H. latidentatus* and *Stepanovites* sp. (Kozur, 1995 and in press). Contemporaneously with *H. parvus* begins the more advanced *Isarcicella* sp. sensu Matsuda (1981), in which the main blade is either bifurcated or a lateral denticle is present and fused with the main blade. True *I. isarcica* begins somewhat above the base of the *Ophiceras tibeticum* Zone, where it evolved from *I. turgida*. If *I. isarcica* s. str. is present in the *Otoceras* faunas of Selong, this would not prove the occurrence of *I. isarcica* within the range of *Otoceras*, but stratigraphic condensation of the Selong section, which is also indicated by other data. The late Changxingian *C. changxingensis–C. deflecta* fauna is a diverse warm-water fauna. Most species of this fauna are consequently missing in the temperate and cool-water *Otoceras* faunas. However, in the basal *Otoceras* faunas of Greenland *C. subcarinata* is present that ends within the lower *C. changxingensis–C. deflecta* fauna. Therefore, the time-equivalent of the entire *C. changxingensis–C. deflecta* Zone are present in the *Otoceras* faunas.

According to Orchard (1994a) and Orchard et al. (1994) all known conodont faunas from *Otoceras*-bearing beds are basically different from Dorashamian and Changxingian conodont faunas that are dominated by *"Neogondolella" subcarinata, "N." changxingensis, "N." deflecta*, and *H. typicalis* (with *H. latidentatus* in the uppermost Permian). According to this statement, the conodont faunas of the upper, *H. parvus*-bearing (post-Changxingian) part of the *Otoceras* faunas were compared with conodont faunas below the latest Changxingian. Both in Meishan (stratotype of the Changxingian) and in Transcaucasia, *Clarkina subcarinata* is no more present in the latest Changxingian. *C. subcarinata* is still present, but no more dominating, in the lower *C. changxingensis – C. deflecta* fauna of Meishan; in the upper part of this fauna *C. subcarinata* is missing. In the lower *Pleuronodoceras occidentale* Zone of Transcaucasia *C. subcarinata* is present, but also no more dominant. In the middle and upper part of this zone, *C. subcarinata* is missing. On the other hand, in this latest Changxingian fauna without *C. subcarinata*, several species of the *Otoceras* faunas are present: *Clarkina* cf. *carinata, C. changxingensis, C. tulongensis, Hindeodus latidentatus* and *H. typicalis*. Decisively important is that *H. parvus* occurs only in the *Ophiceras*-bearing upper part of the *Otoceras* fauna, but not in the *Ophiceras*-free *O. concavum* and lower *O. boreale* Zone, where only *H. typicalis*, and in a short interval in the middle part of the *O. woodwardi* Zone also *H. latidentatus* are present. The same situation is in the tropical Tethyan area, where the latest Changxingian has no *H. parvus* that begins at the base of the Triassic within Boundary Bed 2 (see description of the Zhongxin Dadui quarry of the Meishan section).

Sovetashen and Dorasham 2 (Armenia and Azerbaidzhan in Transcaucasia)

Kotlyar et al. (1993) proposed the sections of Sovetashen and Dorasham 2 (Armenia and Azerbaidzhan in Transcaucasia) as auxiliary boundary sections. These sequences comprise open marine, red pelagic limestones, claystones and marls (Kotlyar, 1991; Zakharov, 1988, 1992) with considerably richer conodont faunas (CAI = 1) in the Changxingian (Dorashamian) part of the section than in the intraplatform basin and slope facies in South China. However, in the *H. parvus* Zone a distinct shallowing occurs and only *Hindeodus* and *Ellisonia* are present in this level, whereas pelagic gondolellids are absent. Unfortunately these sections, especially the most suitable section Dorasham 2, are currently inaccessible for political reasons. However, the same succession as in Dorasham 2 is present on the opposite side of the Araxes River in Joulfa on Iranian territory, and these sections are accessible. These Transcaucasian sections in Armenia, Azerbaidzhan and Iran and the Abadeh sections in Central Iran are the only known pelagic sections in the world, where the basal Triassic *H. parvus* Zone is represented by highly oxidized, bioturbate red marls. All geochemical and isotope investigations along the P/T boundary have been carried out in areas, where benthos-rich Changxingian rocks are overlain by basal Triassic beds with anoxic or disaerobic conditions without or with low diversity benthos. Therefore geochemical and stable isotope investigations need to be conducted in the above area to demonstrate, whether the geochemical signals are independent of the widespread anoxia in the basal Triassic (Wignall & Hallam, 1993).

Sosio Valley area (western Sicily, Italy)

A conodont-rich P/T boundary section (CAI = 1) was found by Gullo and Kozur (1993) in the Sosio Valley (western Sicily, Italy, detailed description in Kozur et al., in prep.). This section has a rich late Changxingian deep-water conodont fauna with *C. changxingensis, C. deflecta, C. sosioensis* as well as rich radiolarian faunas (Kozur, 1993a) and benthic foraminifers (*Bathysiphon* deep-water fauna) that can be washed from red soft claystones. The basal Triassic is marked by a 2m thick anoxic soft claystone that contains a rich *H. parvus* fauna, mostly juvenile specimens, especially in intercalated laminated limestones. In the lower *I. isarcica* Zone advanced *Clarkina carinata* (including *I. planata*), *Isarcicella ? turgida, H. parvus anterodentatus* and *Ellisonia transita* are common in slope limestones. In contrast to the very rich microfauna of this section, there are very few macrofaunas in the Changxingian and Lower Scythian.

Southern Alps

The well exposed Tesero section of the Southern Alps displays late Changxingian and earliest Triassic shallow-water conodont faunas. All pelagic elements (ammonoids, pelagic conodonts) are missing, but *Hindeodus* is common. The Tesero Oolite yielded rich associations with *H. latidentatus, Isarcicella prisca* and some *Stepanovites* (Kozur, 1995). Conodonts are rare in the lower Mazzin Member, but the transition from *H. latidentatus* to *H. parvus* is recognizable. This section can be used as auxiliary boundary section for shallow-water faunas near the P/T boundary in the western Tethys.

Boreal realm

The most suitable auxiliary sections for the P/T boundary in the Arctic are those in East Greenland and of the Verkhoyansk region. In Greenland, conodont faunas are extraordinary rich (Sweet, 1976), an exceptional situation for the Arctic. The sections are partly obscured by solifluction, but the conodont samples (investigated by Sweet, 1976 and re-investigated by Kozur & Sweet, in prep.) are taken from matrix of ammonoids or from ammonoid-bearing beds, so that the stratigraphic control is good. The *Otoceras* faunas of Greenland represent exclusively the *O. boreale* Zone (Dagys, 1994). In its lower part *H. typicalis, Clarkina* cf. *carinata* and *C.* cf. *chan-*

gxingensis are present and the basal part also contains *C. subcarinata*. This fauna is characteristic of the late Changxingian below the Boundary Beds. In the upper *Otoceras* faunas *H. latidentatus* successively replaces *H. typicalis*, whereas the gondolellid conodont fauna consists furthermore of *C.* cf. *carinata* and *C.* cf. *changxingensis*, with *C. carinata* in the uppermost part. This fauna is characteristic for the latest Changxingian just before the Boundary Beds and especially for the Boundary Beds (except the absence of Tethyan warm-water elements, like *Clarkina deflecta*). In *Ophiceras*-bearing beds above the *Otoceras* beds (or in the upper part of the *Otoceras* faunas) the first very primitive *H. parvus* begins (as primitive as *H. parvus* of the middle part of Boundary Bed 2 of Meishan). This conodont succession can be interpreted in two ways. According to Kozur (1994b, c) most of the Boreal *Otoceras* fauna is older than the upper *O. woodwardi* Zone of the Tethys. This would indicate that the upper range of *O. woodwardi* is in younger beds than the general upper range of *O. boreale*. In this case the upper *O. woodwardi* Zone would be correlative with the lower *Ophiceras commune* Zone. In favour of this interpretation is the discovery of a slab with *O. boreale* and *Claraia stachei* (guide form of the *Ophiceras commune* Zone) in Svalbard by Nakazawa et al. (1987). The second interpretation is that *H. parvus* from *Ophiceras*-bearing beds of Greenland was derived from the upper *O. boreale* Zone, in which *Ophiceras* is already present.

The conodont succession of Greenland indicates that *H. parvus* occurs only in beds, in which *Ophiceras* is already present, independently, whether these beds belong to the upper *O. boreale* Zone or to the *Ophiceras commune* zone. Because these specimens of *H. parvus* are very primitive, like in the middle part of Boundary Bed 2 in Meishan, they surely represent the lowermost occurrence of this species in Greenland. This is also indicated by the presence of *H. typicalis* and *H. latidentatus* in the upper *Otoceras* fauna of Greenland. The first appearance of *H. parvus* is therefore not related to an immigration of the genus *Hindeodus* by shallowing, but lies within a phylomorphogenetic lineage.

These conodont data do not confirm the assumption that the entire *Otoceras* beds of the Arctic are younger than the Changxingian. As these conodont data were mentioned in the discussion of the P/T Boundary Working Group in Calgary (Permian-Triassic Boundary Working Group Newsletter, 1993), the stratigraphic data of the Greenland *Otoceras* fauna published in Teichert and Kummel (1976) were immediately regarded as unreliable during the discussion. According to Tozer in this discussion, the stratigraphic succession in East Greenland is unclear because of solifluction. As mentioned above, the conodonts studied by Sweet (1976) have been largely solved from the bedrocks of *Otoceras*. For the question, whether these *Otoceras* fauna has a Permian or Triassic character, these samples are therefore well dated.

Dagys (1994, 41) wrote that Sweet (1976) described the conodonts of the "oldest Triassic" of Greenland and few sentences later in the same paragraph that "conodont faunas from the lowermost Triassic of Arctic Canada and Greenland have not been described in the literature". However, the paper of Sweet (1976) was published in the literature and the conodonts were documented in a photo plate. Moreover, Henderson (1993) reported *C. subcarinata* from beds in Arctic Canada, so far regarded as basal Triassic. These results are in full agreement with the conodont data of Greenland, where *C. subcarinata* occurs also near the very base of the *Otoceras* faunas. From the paper of Sweet (1976) it was clear that *H. parvus* is absent in the rich *Hindeodus* association of the *Otoceras* fauna in Greenland. Insofar, the restudy of the material by Kozur and Sweet (in prep.) has not brought a new result. Very primitive *H. parvus* were found in beds with *Ophiceras* above those *Otoceras* beds from which Sweet (1976) has described the conodonts. There may be an objection that *H. parvus* was not yet described at time when the paper of Sweet (1976) was given in press. However, Sweet placed in that time, like all authors before, *H. parvus* into *Isarcicella isarcica*, and this species in its former wide sense (including *H. parvus*) was not found by Sweet in the *Otoceras* fauna of Greenland.

A further famous fossil locality of the Boreal *Otoceras* faunas is the Permo-Triassic sequence of Setorym River (Verkhoyansk region, NE Siberia). *Otoceras* is there present in an 18m thick interval at the base of the Nekuchan Formation. So far, the lower part of the *Otoceras* faunas, 0.7–7m above the base of the Nekuchan Formation, was placed so far in the *O. concavum* Zone. However, in this interval *O. boreale* occur together with forms determined as *O. concavum*. For this reason, Zakharov (1994) regarded this lower interval of the *Otoceras* fauna at Setorym River as lower (or basal) *O. boreale* Zone. 5m above the base of the Nekuchan Formation both forms of *Otoceras* are abundant. In this level also *Tomponautilus setorymi* Sobolev and *"Claraia"* sp. are present. From this level a conodont fauna with *H. typicalis* and *C.* cf. *changxingensis*, a typical Late Changxingian association, has been found (Kozur & Zakharov, in prep.). By this, the conodont data of Greenland have been fully confirmed for the lower *O. boreale* Zone. In the 13m thick upper *Otoceras* faunas of the Setorym section conodonts have not yet been found. In this level *O. boreale* is associated with rare *Tomponautilus setorymi* and extremely rare *Ophiceras* sp. Overlying sediments of reliable Triassic *Tompophiceras pascoi* Zone yielded numerous *Tompophiceras* and rare *Vishnuites* and *Ophiceras*. Abundant Triassic ophiceratids of this or a little younger level were recognized in the neighbouring Burgagandzha River region.

If we regard all known conodont data from the Boreal *Otoceras* faunas, we can state that up to the lower *O. boreale* Zone the conodonts indicate clearly Changxingian age. Only the youngest occurrences of *O. boreale* are of Triassic age (association with *O. boreale* and *C. stachei*), but it cannot be excluded that these occurrences belong to the basal *Ophiceras commune* Zone.

Dalongkou (Sinkiang, NW China)

An important auxiliary section for the base of the Triassic in continental beds is the Dalongkou section in Sinkiang. This section has complete conchostracan and vertebrate faunas records across the P/T boundary and is rich in sporomorphs. The conchostracan faunas can be correlated readily with those of the Tunguska Basin and those of the Germanic Basin, which in turn can be correlated with the marine scale (Kozur, 1993b). They indicate the beginning of the Siberian Trap within the Lopingian with maximum activities around the P/T boundary (Kozur, 1989, 1994b).

Systematic part

The systematic of the Late Permian *Hindeodus* and *Isarcicella* is discussed by Kozur (in press). For the better understanding of the problems discussed in this paper and especially for the separation of *H. latidentatus* and *H. parvus*, it is necessary to publish also in the present paper the descriptions and discussions to *H. latidentatus* and *H. parvus* and some remarks to the genus *Hindeodus*.

Genus *Hindeodus* Rexroad & Furnish, 1964

Type species: *Trichonodella imperfecta* Rexroad, 1957 (= *Spathognathodus cristulus* Youngquist & Miller, 1949).

Synonym: *Anchignathodus* Sweet, 1970.

Remarks: *Hindeodus* displays a seximembrate apparatus with Pa, Pb, M, Sa, Sb, Sc elements. Beside the Pa element especially the Sb element is very diagnostic.

During the Late Permian Lopingian Series rapid changes of the Pa element and Sb can be observed that are very important for the definition of the P/T boundary.

Isarcicella Kozur, 1975, is distinguished by a thickening of the cup that bears mostly one or more denticles or a denticulated side blade on one or both sides of the cup. Important are the denticles or the secondary side blades on the cup. The taxonomic importance of the thickenings of the cup are not clear. They are present in all typical *Isarcicella* with denticles or side blades on the cup, but it cannot be excluded that the thickenings of the cup are ecologically controlled. For this reason, forms with thickening of the cup, but without denticles on it, are only tentatively assigned to *Isarcicella*. According to Sweet and Clark in Moore and Robison (1981), *Isarcicella* is probably unimembrate (only Pa element). However, *Isarcicella* faunas contain always some ramiform elements similar to those of *Hindeodus*. A reconstruction of the *Isarcicella* apparatus is not yet possible, because all known *Isarcicella* faunas contain also Pa elements of *Hindeodus*. Therefore it is unknown, whether the ramiform elements belong all to the accompanying Pa elements of *Hindeodus*, or whether *Isarcicella* has a similar apparatus as *Hindeodus*.

Hindeodus latidentatus (Kozur, Mostler & Rahimi-Yazd, 1975)
Pl. 1, figs. c, d, f

1975 *Anchignathodus latidentatus* n. sp. – Kozur et al., p. 4–5, pl. 2, fig. 6.

?1976 *Anchignathodus typicalis* Sweet, pars – Sweet, only the specimen on pl. 16, fig. 7.

?1979 *Anchignathodus parvus* Kozur & Pjatakova – Wang & Wang, p. 116, pl. 1, fig. 20.

1981 *Hindeodus minutus* (Ellison, 1941), pars – Matsuda, p. 78–91, pl. 1, figs. 1 (morphotype 1), ?6, ?8, 9, ?10; pl. 3, figs. 7, 8, 10.

1987 *Hindeodus typicalis* (Sweet, 1970), pars – Perri & Andraghetti, p. 308–309, pl. 32, fig. 3.

1991 *Hindeodus typicalis* (Sweet, 1970), pars – Perri, p. 40–42, pl. 3, figs. 2, 5, ?6, non ! pl. 3, figs. 1, 3, 4.

1991 *Hindeodus* cf. *latidentatus* (Kozur, Mostler & Rahimi-Yazd) – Schönlaub, pl. 1, fig. 9.

1991 *Hindeodus parvus* (Kozur & Pjatakova, 1975) pars – Schönlaub, only pl. 1, figs. 8, 18 (several specimens are undeterminable, as those on pl. 1, figs. 12–14).

Description: Seximembrate apparatus. Pa element relatively short, with 5–7, rarely 8–9 triangular, mostly broad denticles, at least in the terminal part often widely separate. In the rare morphotype 1 the denticles are nearly of equal length and width, relatively narrow, straight and the high posterior end of the posterior blade is undenticulated. In the common morphotype 2, to which belongs also the holotype, the denticles are broadly triangular, widely separated, almost of equal length, but the first 2–3 denticles after the cusp are often distinctly narrower and somewhat closer spaced. The denticulation reaches near to the posterior end of the blade. Both morphotypes are connected by transition forms, in which all mentioned features may be transitional. The cusp is in both morphotypes broader and considerably longer (often around two times) than the denticles on the posterior blade. Cusp and denticles are strongly striated. The cup is wide, but not thickened.

The ramiform elements (Pa, M, Sa, Sb, Sc) are similar to those of *H. typicalis*, but the blade of the Sa element is higher. The anterior bar of the Sb element is immediately in front of the cusp curved strongly inward, the posterior blade is high and bears 3–5 large denticles in the posterior half and 3–4 small denticles in the anterior half.

Occurrence: Late Changxingian, transitional forms to *H. parvus* range up to the *H. parvus* Zone of the basal Triassic. World-wide.

Remarks: The holotype is a rather extreme form with respect to the widely separated denticles. Similar forms, however, are common in the Late Changxingian of Southern Alps (Tesero Oolite), South China, Transcaucasia and Iran. They are characterized by two, rarely three, somewhat more slender denticles after the cusp and 3–4 broad, triangular, widely separated denticles on the middle and posterior part of the blade. The denticulation is rather variable, but always the cusp is considerably longer than the following denticle (mostly 1.5–2× longer).

Most probably *Hindeodus julfensis* n. subsp. (forms with denticulated hump on the Pa element) is the forerunner of this species, because this form displays also a large cusp on the Pa element and the ramiform element are nearly identical. Only the denticulation of the posterior bar of the Sb elements in *H. julfensis* is more similar to *H. typicalis* (10–12 denticles on the posterior bar with lesser size differences between the anterior and posterior denticles on this bar).

A derivation of *H. latidentatus* from *H. typicalis* (forms with somewhat larger cusp) cannot be excluded. In this species the Pa element displays more denticles (9–15) that are generally more slender and not so widely separated as in morphotype 2 and not so uniform in length as in morphotype 1. The blade of the Sa element and mostly also of the Sc element is lower, the Sb element displays a short flat posterior portion of the anterior blade with 1–3 denticles between the cusp and the inward curved part.

Morphotype 1 of *H. latidentatus* is the forerunner of morphotype 1 of *Hindeodus parvus* (Kozur & Pjatakova, 1976), whereas morphotype 2 of *H. latidentatus* is the forerunner of morphotype 2 of *H. parvus*. In this species the cusp is considerably longer (more than 2× longer than the following denticles) and in generally also more slender. The ramiform elements of *H. parvus* are distinguished by shorter and relatively higher bars in all elements. In the Sb element, the cusp and mostly also one denticle behind the cusp lies on the inward curved part of the unit.

Hindeodus parvus (Kozur & Pjatakova, 1976)
Pl. 1, figs. a, b, e, g

1964 *Spathognathodus isarcicus* Huckriede, 1958, pars – Staesche, p. 288–289, only figs. 60, 61.

1975 *Anchignathodus parvus* Kozur & Pjatakova n. sp. – Kozur, p. 7–9, pl. 1, figs. 17, 21, 22.

1976 *Anchignathodus parvus* n. sp. – Kozur & Pjatakova, p. 123–125, figs. 1a, b, e, h.

1977 *Isarcicella isarcica* (Huckriede), pars – Sweet in Ziegler, p. 229–230, morphotype 1 in text-figure "Terminology of *Isarcicella* Kozur, 1975" at p. 225.

1981 *Hindeodus parvus* (Kozur & Pjatakova, 1975) – Matsuda, p. 91–93, pl. 5, figs. 1–3.

Description: Seximembrate apparatus. Pa element small, with very big, rather slender, erect or slightly backward inclined or curved cusp. The following 4–9 denticles are considerably smaller (more than twice smaller). In morphotype 1 the denticles are slender, small, erect, all nearly of the same size. The posterior part of the blade is steeply dipping and in juvenile forms undenticulated. In adult forms a small denticle is present in the upper part of the posterior margin. Morphotype 2, to which the holotype belongs, displays erect, but a little longer denticles, their upper edge is slightly downward directed away from the cusp. The posterior third of the blade is occupied by small, strongly inclined denticles. Cup moderately wide to wide, not thickened.

The ramiform elements are typical for *Hindeodus*, but the bars are relatively short and high. In the Sb element the strongly inward curved part comprises not only the anterior bar or its anterior portion, like in all other *Hindeodus* species, but also the cusp and sometimes even the first denticle of the posterior bar.

Occurrence: *Hindeodus parvus*- and *Isarcicella isarcica* zones of the basal Triassic. World-wide.

Remarks: Staesche (1964) regarded *H. parvus* as undenticulated morphotype of *Isarcicella isarcica*. Kozur (1975) and Kozur and Pjatakova (1976) recognized that this form begins earlier than *I. isarcica* and established the new species *Anchignathodus parvus* which was later placed into *Hindeodus*. Sweet (1977) regarded *H. parvus* again as morphotype of *I. isarcica*, but he was only followed by Perri and Andraghetti (1987) and Perri (1991). Sweet (1992) agreed that *H. parvus* is an independent species, but he assigned it to *Isarcicella* ? *parva*. He was followed by Orchard (1994a, b) and Orchard et al. (1944). The discovery of a rich monospecific fauna with *H. parvus* in Sicily containing the entire apparatus of *H. parvus*, has confirmed the view of Kozur (1977b) that *H. parvus* has a *Hindeodus* type apparatus. This fauna was found in a Permian-Triassic boundary section 500 south of Pietra dei Saracini (Sosio Valley area, Sicily, Italy, see Gullo & Kozur, 1993) in a 2m thick anoxic clay just at the base of the Triassic. All elements have shorter and relatively higher bars than the Carboniferous and Permian *Hindeodus* species. Otherwise the ramiform elements are similar to those of *H. typicalis, H. latidentatus* and *H. julfensis*.

H. parvus has evolved from *H. latidentatus* by development of a smaller Pa element with bigger cusp and by development of shorter and relatively higher bars in all ramiform elements. Moreover, the inward curved part of the Sb element is still larger than in *H. latidentatus* and comprises also the blade below the cusp and sometimes also below the first denticle of the posterior bar. Like in *H. latidentatus*, two morphotypes can be distinguished in *H. parvus* (see description). Morphotype 1 has a rather stable denticulation (with only a slight change during the ontogenesis), whereas morphotype 2 is variable in size and width of the denticles, like in the two morphotypes of *H. latidentatus*.

Isarcicella isarcica is distinguished from *H. parvus*, morphotype 1 by a thickened cup and the presence of a denticle or a secondary blade on one or both sides of the thickened part of the cup.

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Plate 1

a *Hindeodus parvus* (Kozur & Pjatakova), morphotype 2, primitive form, transitional to *H. latidentatus* (Kozur, Mostler & Rahimi-Yazd), cusp large as in *H. parvus*, denticulation still of *H. latidentatus* type, × 160, upper half of Boundary Bed 2, Meishan, refigured from Zhang (1987)

b *Hindeodus parvus* (Kozur & Pjatakova), morphotype 1, × 120, Zhongxin Dadui quarry of Meishan section, sample 882–4, upper part of Boundary Bed 2 (12–16 cm above its base), *H. parvus* Zone of basal Triassic, rep.-no. 4011

c, d, f *Hindeodus latidentatus* (Kozur, Mostler & Rahimi-Yazd, Tesero Oolite of the Tesero type section (Southern Alps)

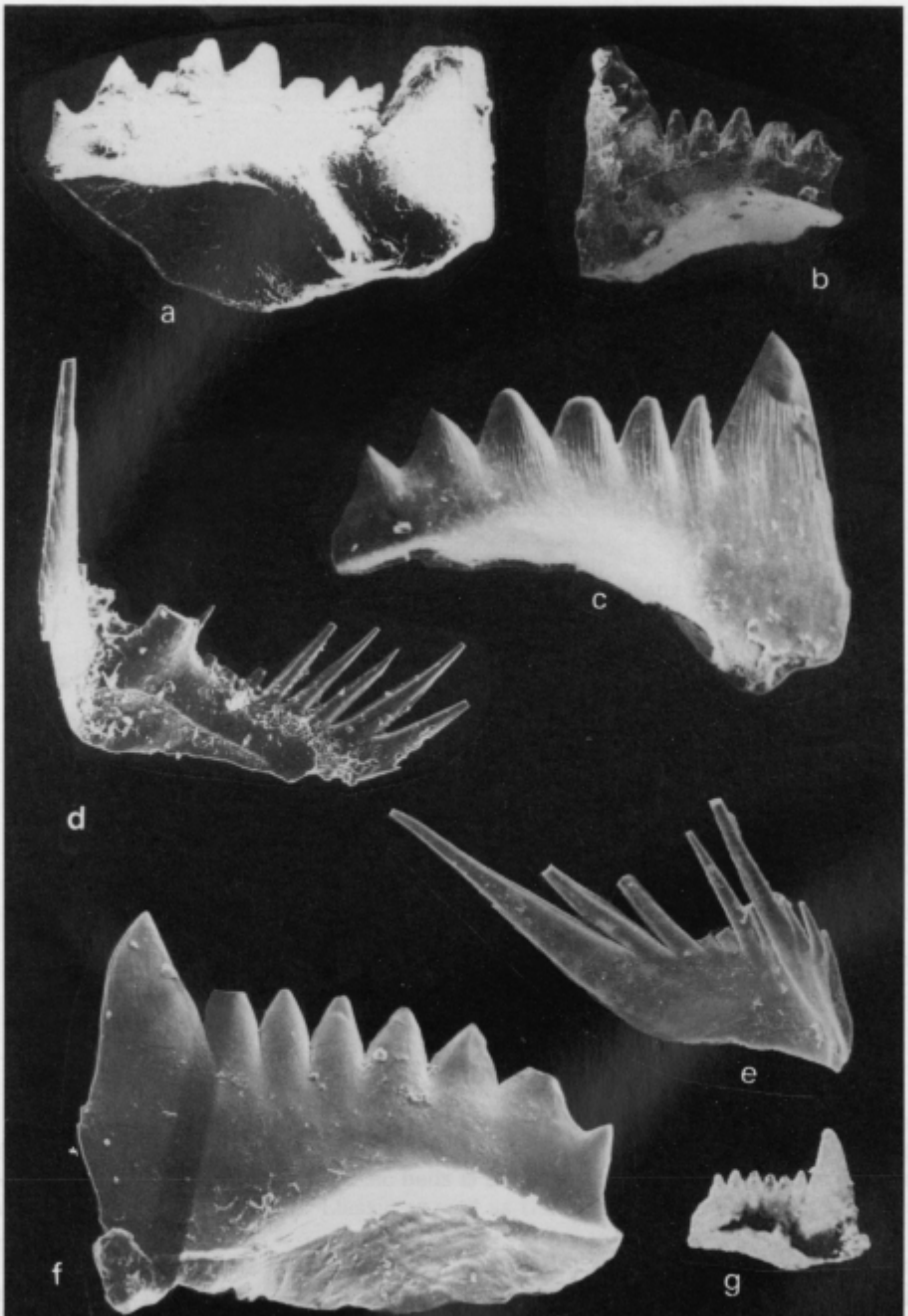
c Pa element, specimen very similar to the holotype (such morphotypes are characteristic for the Late Changxingian of Transcaucasia and China, in Meishan they occur above all in the uppermost Changshing Limestone), × 150, rep.-no. Ko 8992, sample T 7 (2 m above the *Bellerophon* Limestone), horizon with Changxingian brachiopods, latest Changxingian *H. latidentatus* Zone of the shallow-water conodont zonation

d *Sb element,* × 160, rep.-no. Ko 9208

f Pa element, × 200, rep.-no. Ko 9003, sample T 4, 1.5 m above the *Bellerophon* Limestone, latest Changxingian *H. latidentatus* Zone of the shallow-water conodont zonation

e *Hindeodus parvus* (Kozur & Pjatakova), Sb element, × 140, P/T boundary section 350 south of Pietra dei Saracini (Sosio Valley, Sicily, Italy), sample 14 (thin laminated limestone intercalation in 2 m thick yellowish-brown weathered, laminated, originally pyritic anoxic claystone, *H. parvus* Zone of basal Triassic, rep.-no. Ko 1994/I-1

g *Hindeodus parvus* (Kozur & Pjatakova), Pa element, morphotype 1, adult specimen, × 60, Achura (Transcaucasia, Azerbaidzhan), sample 10/13 a-1, ca. 1.5 m above the *Paratirolites* beds, base of the *Hindeodus parvus* Zone, immediately above the last Permian conodonts, rep.-no. PK 1–4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