Towards a Definition of the Permian – Triassic Boundary

by Edward Timothy Tozer

The boundary between the Paleozoic and Mesozoic eras has long been a focus for attention by the IUGS International Commission on Stratigraphy. The only method of dating with adequate precision is provided by biochronology, for there are problems with radiometric ages for the beds in question, and the magnetic polarity time scale does not extend back to the Triassic Period. This article summarizes the progress towards a chronostratigraphic definition and stratotype. Taking a rather different approach from that expressed in the Commission's own guidelines, the author advocates placement at the base of the *Otoceras* beds, regarded as the oldest Triassic division. (Ed.)

Historical Background

The type area for the Triassic System is in Germany (Fig. 1), where there are three major divisions: Buntsandstein, Muschelkalk and Keuper, which are more or less synonymous with Lower, Middle and Upper Triassic rocks, respectively. Because it lacks distinctive faunas, the non-marine Buntsandstein, the base of which defines the Permian-Triassic (P-T) boundary, is not a chronostratigraphic datum that can be recognized world wide. However, for over 100 years it has been known that in many parts of the world marine strata occupy the position of the Buntsandstein. These beds have generally been regarded as a standard for the Lower Triassic rocks.

In the Italian Alps the Werfen Formation is in the position of the Buntsandstein. It overlies the Bellerophon Limestone, and the boundary since well back into the 1800s has been regarded as that between the Permian and the Triassic (Assereto et al., 1973). A distinctive bivalve - *Claraia* - occurs in the lower (but not lowermost) Werfen; whereas the

Bellerophon contains faunas universally regarded as Permian. Recognition of the boundary at this level is still considered to be more or less justified (Perri and Andraghetti, 1987), although there is now evidence that beds at the very base of the Werfen (the Tesero horizon) contain fossils of Permian age (Pasini, 1985; Neri and Pasini, 1984, Noé, 1987).

In the 1870s, C.L. Griesbach of the Geological Survey of India discovered in the Himalayas another very distinctive fossil in association with *Claraia*, the ammonoid *Otoceras*, above unquestioned Permian and below agreed Triassic. Whether the *Otoceras* beds were Permian or Triassic became the subject of lively debate. The argument for a Triassic age was based mainly on the presence of *Claraia*, indicating a correlation with the Werfen. That for a Permian age was based on similarities between the Himalayan *Otoceras* and ammonoids assigned to the same genus from undisputed Permian beds near Dzshulfa in Armenia (cf. Fig. 2). Dzshulfa is on the Araks River, which today is the frontier between the U.S.S.R. and Iran. Beds with Permian otoceratids are now known on both sides of the river.

Eventually, there was agreement that the Himalayan and Armenian otoceratids, although undoubtedly related, were not sufficiently similar to justify a correlation. The Armenian forms are today placed in other genera, the name *Otoceras* being restricted to the Triassic species. By about 1910, it was generally accepted that the Himalayan *Otoceras* beds should be taken to typify the basal Triassic. For about 50 years the question was considered settled, but the issue has now been raised again by a few contemporary workers who regard the *Otoceras* beds as Permian, not Triassic.

Until the 1920s, *Otoceras* was known only from the Himalayas. Since then it has been discovered in eastern Greenland, Siberia, Alaska, Axel Heiberg Island, Ellesmere Island and Spitsbergen (Figs. 1,3F). In all these places the *Otoceras* beds lie between unquestioned Permian and unquestioned Triassic strata.

Recent Work by the PTWG

Since the formation of the Permian-Triassic Boundary Working Group (PTWG) in 1981, the writer has studied key exposures in the Verkhoyansk Mountains of Siberia, in Soviet Armenia, Italy, and Turkey, the Salt Range of Pakistan and at Guryul Ravine and Pahalgam in Kashmir (Fig. 1). The visit to Kashmir was in 1987, with three PTWG and Triassic Subcommittee colleagues - Aymon Baud (Switzerland), Maurizio Gaetani (Italy) and Jean Marcoux (France). Here, at the famous Guryul Ravine section, we chose to place the P-T boundary at the Zewan-Khunamuh contact, not at the higher level within the Khunamuh, the commonly accepted position. More will be said about this below.

Another famous section, the Salt Range in Pakistan, was visited in 1987 during a field conference for IGCP Project 199 (Rare Events in Geology). At one time this section was believed to shed light on the precise chronology and nature of the P-T boundary. Its significance in this regard is now diminished with the recognition that there is a substantial hiatus in the sequence, with both latest Permian and earliest Triassic (by any definition!) missing.

Figure 1: Critical localities for the P-T boundary. O: *Otoceras* above Permian, P: *Paratirolites* below Triassic. Crosses: P-T boundary without O and P. Localities mentioned in text: 1) Axel Heiberg Island, 2) Ellesmere Island, 3) East Greenland, 4) Spitsbergen, 5) Setorym River, Siberia, 6) Northern Alaska, 7) Dzshulfa, U.S.S.R. and Julfa, Iran, 8) Salt Range, Pakistan, 9) Guryul Ravine and Pahalgam, Kashmir, 10) Selong, Tibet, 11) Zhejiang Province, China.

The most recent field trip (May 1988) was to southern Tibet, where the writer and Walter Nassichuk (Canada) together with Chinese colleagues visited the P-T boundary section at Selong, at an elevation of 4650 m, 130 km northwest of Mount Everest. This, the only known occurrence of *Otoceras* in Tibet, is located in the Tethys (Tibetan) Zone of the Himalayas, north of the crystalline rocks that form the high peaks. This section was discovered in 1967 by Wang Yigang, and a description of the stratigraphy and ammonoids has been published (Wang and He, 1976). Conodonts have also recently been recorded from this locality (Yao and Li, 1987).

The Selong section (Fig. 3B,C) is of outstanding interest, both for the P-T boundary and the stratigraphy of the Lower Triassic. The structure is simple, with beds dipping to the north at 40°. The boundary beds are perfectly exposed and can be traced along the strike for about 1 km. The main *Otoceras* bed, 8-30 cm of brown dolomitic limestone, rests with a distinct, wavy boundary on a thin (6-17 cm) bed of grey limestone from which our Chinese colleagues have now identified tiny brachiopods, which they interpret as Changhsingian (Fig. 2), that is latest Permian (Wang et al., 1988). Beneath this bed, separated by another abrupt contact, is limestone with large crinoid columnals, rugose corals and assorted brachiopods.

The *Otoceras* bed in the Selong section is overlain by a fully exposed limestone sequence containing a succession of Griesbachian, Dienerian, Smithian and Spathian ammonoids (Fig. 2). Two specimens of *Otoceras* were found immediately above the main bed, indicating that here, as in the Arctic, *Otoceras* is not restricted to a single level. The nearly complete Lower Triassic section here is only 6 m thick, and the base of the *Otoceras* bed is a good candidate for the P-T boundary stratotype.

Biochronology of the Boundary Interval

Ideally a biochronological scale is based on sections that reveal all relevant faunas in sequence. For the P-T boundary interval, however, it is not certain that this condition can be met. The problem can be illustrated by working backwards from an interval of undisputed Triassic time. The *Anasibirites* beds and their correlatives make a good starting point because they are known from many localities and provide several testing situations. In biochronological nomenclature these beds are late Smithian (Fig. 2).

There are good sections in Arctic Canada, Spitsbergen, Siberia and the Himalayas where these late Smithian beds overlie more or less continuous sequences of ammonoid

faunas extending downwards to the *Otoceras* zones. In every section, however, continuity is obviously broken at the base of the *Otoceras* beds, which rest on Permian rocks of several different ages. An unconformity is clearly present.

Most workers consider that the youngest Permian faunas are typified by the Changhsingian of south China and the Dorashamian of Soviet Armenia and Iran (Fig. 3E). Exact correlations have not been settled but there is general agreement that these two stages are at least partly contemporaneous. The Dorashamian and Changhsingian have ammonoid faunas that are unknown in the Arctic and Himalayas, the only places where *Otoceras* has been identified with certainty. They also contain fusulinaceans, rugose corals and productacean brachiopods, which give the rocks a distinctive Paleozoic stamp.

One of the youngest and most distinctive ammonoids is *Paratirolites*, which occurs at the top of Dorashamian strata in the Armenian sequence, in Madagascar, and probably in the Changhsingian of China (Tozer, 1979). Until 1969, it was believed that *Paratirolites* was Triassic in age and that it occurred in a continuous marine sequence covering the P-T boundary interval in Armenia (Ruzhentsev and Sarycheva, 1965). The *Paratirolites* bed and some underlying strata contain what was regarded as a transitional Permian-Triassic fauna that was dated as Early Triassic. There is now universal agreement that the so-called transitional beds are Permian (Tozer, 1969; Teichert et al., 1973). Indeed, they form the stratotype of the latest Permian Dorashamian Stage (Rostovstev and Azaryan, 1974).

Some otoceratids have been described from *Paratirolites* beds of Iran (Bando, 1980), but they are clearly different from the true *Otoceras* of the Himalayas and Arctic, having simpler and presumably more primitive suture lines. Otoceratids are more common in the somewhat older Dzhulfian beds, and they are very similar to those in the Dorashamian.

The Dorashamian beds of Armenia and the Changhsingian strata of China are overlain by beds with *Claraia* (Stepanov et al., 1969; Zhao et al., 1981; Yang et al., 1987). These *Claraia* beds are universally accepted as Lower Triassic. They are Griesbachian, but not necessarily as old as *Otoceras*. Well preserved, unquestioned *Otoceras* have never been found above certain Dorashamian or Changhsingian strata. There are possible occurrences of *Otoceras* above the Changhsingian in Zhejiang Province, southeast China, but the fossils are too poorly preserved to be identified with certainty (Tozer, 1988; Wang, 1984).

Positioning the *Otoceras* beds as younger than Dorashamian-Changhsingian is thus not demonstrable in a stratigraphic sequence. It nevertheless has biological support, Dorashamian otoceratids being plausible ancestors for Griesbachian *Otoceras*. Moreover, the Dorashamian and Changhsingian beds are the youngest anywhere that contain a host of indigenous characteristic Paleozoic fossils. Such fossils are nowhere known in the *Otoceras* beds.

More than one zone is distinguished within the *Otoceras* beds of Greenland, Canada and Siberia (Trümpy, 1969; Tozer, 1967, 1988; Dagys et al., 1979), but the basal *Otoceras* zones of the Arctic and the Himalayas are essentially correlative.

Unconformity Below *Otoceras* Zones

Wherever the *Otoceras* beds are exposed they appear to be concordant with the underlying strata, at least within the confines of a single outcrop. The underside of the formation with the lowest *Otoceras* is nevertheless a distinct bedding plane. Mapping on Ellesmere and Axel Heiberg islands shows that this bedding plane defines a low-angle unconformity (Nassichuk et al., 1972). A distinct boundary is also well displayed at the Zewan-Khunamuh contact of Guryul Ravine, Kashmir; and at Setorym River, Siberia (Fig. 3D).

Figure 2: Standard chronostratigraphic divisions for the Upper Permian and Lower Triassic series, showing the stratigraphic position of key fossils.

A

D

B

E

C

F

Figure 3: Key boundary sections, at each of which Permian and Triassic beds are distinguished by lithology and separated by a distinct bedding plane (arrow). Earliest Triassic with *Otoceras* occurs at Selong (B,C), Setorym River (D) and Raanes Peninsula (F). At Meishan (A) and Julfa (E), the Permian beds are the youngest known, but the overlying Triassic strata appear to be slightly younger than those with *Otoceras*.

Despite the absence of obvious angularity, interpretation of these boundaries as unconformable is supported by the fact that at these localities the beds below the *Otoceras* zone, although Permian, are generally not as young as Dorashamian. The sub-*Otoceras* bed in the Selong section may be as young as Dorashamian, but even here the sharp, wavy boundary suggests an interruption in sedimentation.

Many Chinese scientists consider that the sections in southeast China record uninterrupted marine sedimentation across the P-T boundary. They have advocated the Meishan section as the Permian-Triassic stratotype (Sheng et al., 1987). Unfortunately, as mentioned earlier, certain proof of an *Otoceras* zone here is lacking.

Mixed Faunas and Their Significance

In many parts of the world fossils generally regarded as characteristic of the Paleozoic have been found in close association with Triassic fossils. Some of these have been interpreted as Paleozoic forms redeposited in Triassic sediments. Others have been interpreted as relics of the Paleozoic fauna that lived in earliest Triassic time. Implicit in the second interpretation is that the beds in question are of an age close to that of the P-T boundary, and that they may indicate that sedimentation between the two periods was continuous (Sheng et al., 1983, 1987; Yin, 1985).

One such occurrence is the brachiopod fauna described by R.E. Grant (in Kummel and Teichert, 1970) from the Kathwai Member of the Salt Range, Pakistan. Kummel and Teichert, who were the first to investigate this member, believed that the brachiopods, although of Permian aspect, were short-lived survivors of Triassic age. This interpretation found little support, and there is now general agreement that the fossils are Permian, not Triassic (Tozer, 1971; Nakazawa and Dickens, 1985).

Another occurrence is in unit E1 at the base of the Khunamuh Formation of Guryul Ravine, Kashmir. This 2.6 m-thick unit rests abruptly on the Permian Zewan Formation and is followed by E2, with *Otoceras woodwardi*. E1 contains *Claraia bioni* Nakazawa, productacean and other brachiopods and is generally, but not universally, dated as Permian (Sheng et al., 1984). Dickens (1987), excludes E1 from the Permian on the grounds that the brachiopods are derived from the underlying Zewan.

There are also occurrences of mixed faunas in the "Transitional Bed" at the base of the Chinglung Formation of south China (Yin, 1985). The Chinglung rests abruptly on the Changhsing (Fig. 3A), the contact being interpreted as the P-T boundary. One of the best documented sections is at Meishan where three successive beds with mixed faunas, with a combined thickness of 2.4 m have been distinguished within the Transitional Bed (Sheng et al., 1984). The Permian-type fossils are brachiopods, nearly all of which are Changhsingian relics, according to Yin (1985). The fossils indicating a Triassic age are crushed ammonoids and *Claraia*, which makes its first appearance in the upper mixed bed.

Most Chinese workers (e.g. Yang et al., 1987) consider that nearly all the fossils in the Transitional Bed are autochthonous, and that sedimentation was continuous between the Permian and Triassic. The writer, however, maintains that the brachiopods in the Chinglung are derived from the underlying Changhsing and that the abrupt lower contact of the Chinglung indicates that sedimentation was not continuous (Tozer, 1979).

Triassic ammonoids are also associated with productacean brachiopods and bryozoans in east Greenland. At one time it was thought that this association was natural, but the study by Teichert and Kummel (1976) leaves no doubt that Permian fossils have been incorporated into Triassic sediments here. None of these occurrences thus provide good evidence that Paleozoic life continued into *Otoceras* time.

Disputed Correlations

Correlation of the beds with *Otoceras*, a distinctive, easily identified ammonoid with a short time range, and a wide geographic distribution, does not present problems. Although it is sometimes suggested that it is too rare to be useful as a biochronological index, particularly for defining the earliest Triassic, this fossil is widely distributed in the Arctic and Himalayas where it characterizes the Lower Griesbachian (Fig. 2). Its absence from Lower Triassic sections around the Pacific and the main part of Tethys indicates Lower Griesbachian beds are not present in all places where the Triassic overlies the Permian. In this sense the Lower Griesbachian *Otoceras* beds may be described as rare. But these beds are nevertheless testimony of an interval of time easily recognized by its distinctive fauna. The fact that this interval of time has not left its record everywhere does not disqualify it from defining the start of the Triassic Period.

There are also other correlations and interpretations. Kozur and Sweet claim that Dorashamian rocks are at least partly correlative with Griesbachian. Kozur and Gaetani (1979) bases this argument on his belief that *Otoceras* is present in the Dorashamian of Iran. The specimens in question were described by Bando (1980), and as already mentioned the suture lines are not the same as those of *Otoceras*. Bando identified the specimens as a different genus - *Julfo-toceras*. There are thus no grounds for correlation here.

Sweet (1979) employed a graphic technique in an attempt to refine correlations between P-T sections in Iran, the Salt Range, and the Himalayas. This technique uses data on the range of all fossils, but only those present in two or more of the sections contribute to the correlation. This necessitates the exclusion of *Otoceras* and *Paratirolites* but allows the inclusion of the long-ranging gastropod *Bellerophon*. It is difficult to see from Sweet's interpretation of the data from these three sections a case for correlating any part of the Dorashamian with the Griesbachian. At the level of species there are only three, all conodonts, common to the Permian and Triassic formations. Is it not possible that these conodonts, like the brachiopods in China and Kashmir, have been reworked from older to younger beds? If so they are presumably useless for precise correlations.

An Alternative Boundary Position

Norman Newell (1973, 1984, 1988), unlike Kozur and Sweet, does not dispute that the *Otoceras* beds are younger than the Changhsingian and Dorashamian, but he considers they should be regarded as Permian from his belief that the fauna of the *Otoceras* beds has an intrinsically Paleozoic character. In an earlier paper, Newell (1973) included the *Otoceras* zones in the Permian because he believed that an extensive brachiopod fauna of distinctly Paleozoic aspect lived at the same time. The principal faunal association that led him to this conclusion, that of the boundary beds in the Salt Range, is now known to be spurious, as already mentioned. The brachiopods in question not only look Permian but are clearly Permian!

The fact that *Otoceras* has obvious Paleozoic ancestors and is a Paleozoic relic also fuels Newell's argument. But all Triassic animals must have had Paleozoic ancestors. The ammonoids came close to complete extinction just before *Otoceras* time. *Otoceras* itself did not last long, and contemporary with it were the xenodiscid ammonoids, but there are few if any brachiopods of Paleozoic aspect. All the younger ammonoids are descended from the xenodiscids.

Summary

As a level for defining the P-T boundary, the merits of the earliest *Otoceras* zone are superior to any other. Wherever it is recorded, *Otoceras* time seems to have been preceded by an interruption in sedimentation. But because the earliest beds with *Otoceras*, in both the Arctic and the

Himalayas, are biochronologically synchronous, they have excellent attributes for a stratotype to define the P-T boundary.

Objections have been made to defining boundaries at unconformities by J.W. Cowie and others (1986). But if the beds above the unconformity are synchronous they are entirely suitable as a chronostratigraphic datum. For the P-T interval there seems to be compelling evidence that no continuous record is recognizable in the marine facies. Probably the only preserved marine P-T sequences are those of shelves and seamounts. Continuous sequences may have formed in the deep sea, but have not been found. They would probably have been swept into oblivion by subduction.

The universal unconformity below the *Otoceras* zones must signify a world-wide geological event. Its nature is still a matter for speculation. The existence of the Dorashanian and Changhsingian faunas suggest that Paleozoic life persisted nearly as late as *Otoceras* time but the last rich and varied Paleozoic faunas were extinct before *Otoceras* appeared on the scene. The *Otoceras* zones mark a world-wide event in the history of the oceans. They form a chronostratigraphic division both useful and significant to define the Paleozoic-Mesozoic boundary.

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