Permian-Triassic Boundary : a tyro's view

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The major stratigraphic divisions of the Phanerozoic are based on "mass extinction events", a concept that is gradually loosing followers. These divisions are called as systems, and the boundaries between the different systems are often arbitrarily drawn. In continuous sequences it is usually possible to clearly draw the system boundaries, but in case of global stratigraphic gaps, as between the Permian and the Triassic, the placement of the system boundary becomes a difficult task. This paper discusses and analyses information available on the Permian-Triassic transition, both in marine and non-marine sequences, and brings out gaps in information. It has been suggested that the system boundaries are not natural boundaries, and hence instead of focusing on a static PTB, that is, on an abrupt change from Permian to Triassic, more emphasis should be placed on the transition from Permian to Triassic which may be referred to as the PTB Interval.

Key-words—Permian-Triassic Boundary, Global Stratotype Section and Point, Geological Time Boundaries.

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साराँश

परमियन-ट्रायेसिक सीमा : एक नौसिखिये का दृष्टिकोण

हरिकृष्ण माहेश्वरी

फेनरोज़ोइक के मुख्य स्तरिक प्रभाग "व्यापक विलोपी घटनाओं" की अवधारणा पर आधारित हैं। इस संकल्पना के अनुसरण करने वालों की संख्या में क्रमशः कमी हो रही है। इन मुख्य स्तरिक प्रभागों को सिस्टम कहते हैं। विभिन्न सिस्टमों के मध्य सीमाऐं प्रायः मनमाने रूप से निर्धारित की गई है। जो अनुक्रम निरन्तर है उनमें सिस्टम सीमाओं को स्पष्टतः निर्धारित करना प्रायः सम्भव होता है पर उन दशाओं में जब कि विश्वव्यापी स्तरिकीय क्रमभंग हों, जैसे कि परमियन व ट्रायेसिक सिस्टमों के बीच है, सिस्टम सीमा का निर्धारण एक कठिन समस्या बन जाता है। प्रस्तुत समीक्षा में समुद्री एवं असमुद्री दोनों अनुक्रमों में परमियन-ट्रायेसिक संक्रमणकालीन अवधि पर उपलब्ध जानकारी का आंकलन किया गया है तथा जानकारी में जो कमियां हैं उनको उभारा गया है। सिस्टम सीमाऐं प्राकृतिक सीमाऐं न होने के कारण यह सुझाव दिया गया है कि एक नियत परमियन-ट्रायेसिक सीमा के स्थान पर एक परमियन-ट्रायेसिक अंतरावधि की परिकल्पना की जाये जो कि परमियन-ट्रायेसिक संक्रमणकालीन अवधि से सम्बन्धित हो।

BOUNDARIES, be it a political boundary or a geological boundary, are so uncertain a concept that no amount of persuasion or data seems to settle once and for all their limits. I have always been fascinated by the movement of both these boundaries; the only difference between the two is that the political boundaries are moved laterally and usually by brute force whereas the geological boundaries are moved vertically, through seemingly unending arguments. So when the BSIP Golden Jubilee Conference on "Physical and biological changes across the major geological boundaries" was announced, I thought I will initiate a discussion on whether the geological boundaries are or can ever be *Lakshman Rekhas*[1]. But then the Convener of the conference proposed that I give an overview of status of the Permian-

[1] *Lakshman Rekha* is derived from the Indian Epic Ramayana. The epic's hero Prince Ram of Ayodhya, his wife Princess Sita, and brother Prince Lakshman are living in the forest. Sita sites a "golden" deer and asks Ram to get her its skin. Ram goes after it and after a long pursuit is able to put an arrow into it. The deer, which in fact was the demon Maricha in disguise, dies after uttering O'Lakshman, O'Sita. Its cries are heard by Sita who presumes that Ram is hurt and asks Lakshman to go and help Ram. Lakshman pleads that nothing can harm his brother, but Sita is adamant. Lakshman knowing fully well that it may be a ruse of the demons who abounded in that forest, draws a line with his arrow around her hut and requests her not to cross that line so as to remain safe from any mishap. Nothing and nobody will be able to cross the line and enter the encircled area. Outside could be trouble. This line is known as *Lakshman Rekha*.

Triassic Boundary. I accepted the proposal thinking that preparation for this presentation should present no difficulties. After all, I had talked about the Raniganj-Panchet Boundary (in relation to the Permian-Triassic Boundary) way back in 1971 in the Kodaikanal Autumn School, on the occasion of the Silver Jubilee of the Birbal Sahni Institute of Palaeobotany (Maheshwari, 1974). So may be, on the occasion of the Golden Jubilee of the BSIP, another visit to the Permian-Triassic Boundary was in order.

But soon I became disillusioned. Though much literature has poured in on this subject during the past 25 years, yet the final placement of this very important boundary is nowhere in sight. In fact, several new problems have cropped up. I have tried to organise as much data as possible but I am afraid I have been lost in a dark chamber illuminated by infra-red light. I find myself to be a tyro in this respect. Hence, in spite of all my attempts at organisation, this presentation has remained very disorganised.

What actually is a boundary? Webster defines the boundary as "anything marking a limit". So when we talk of a boundary between two geological systems, we actually mean delimitation of upper and lower limits of the older and younger systems, respectively, naturally expecting a sharp line.

GEOLOGICAL SYSTEMS

The Phanerozoic sedimentary sequence is divided into a number of major stratigraphic units on the basis of distinctive lithologies or distinctive fossil contents. Each such unit represents an important time-slice of earth's history and is known as a 'System'. These units as we know today evolved through time not through the efforts of a person or a group, but through independent proposals from a large number of geoscientists, and hence their definitions are being consistently updated. Regardless of how the systems were conceived originally, subsequently they have been recognised in widely separated areas almost entirely on the basis of distinctive fossils, either animal, or plant, or both. Most system boundaries were chosen at apparent breaks in the geological record of the fossils.

The systems of the Phanerozoic are grouped in three eras, namely, the Palaeozoic, the Mesozoic and the Cenozoic, based on the concept of "mass extinction". Thus the boundary between the Palaeozoic and Mesozoic Erathems, consequently the boundary between the Permian and Triassic Systems, should reflect a mass extinction of extraordinary severity. Yang *et alii* (1991) suggest that the mass extinction across the PTB was a result of a number of causes. They have found evidence of frequent volcanic activity across the PTB. One cause commonly mentioned to explain the mass extinction of Permian and Triassic times is an eustatic sea-level drop during which epi-continental seas withdrew from the continents thus leading to large scale loss of ecological niches causing death of most marine life forms. Recently some evidence has come to light about the occurrence of an anoxic event around the PTB (Wignall & Twitchett, 1996). But not every body is enamoured of the idea of mass extinction (Hills & Logan, 1973). As Ager (1987) said in another context 'I find very little evidence for such "mass extinctions" on earth.....In every case I know, there are clear signs of gradual decline in every group of organisms concerned,..... If there was a major break in fossil record.....I would far rather blame it on a gap in the record than on.....'. According to Teichert (1990) "Many authors who fill international journals with papers on "mass extinctions" have little knowledge of fossils and are, therefore, unable to ask simple, pertinent questions: ..... what it was that actually became extinct, and exactly when, and where, and in what order.". According to another view the Permian regression was accompanied by a global climatic change from an Early Permian glacial-maximum condition to a latest Permian-Triassic evaporite-maximum condition. As a consequence to this, the vegetation changed considerably, thus drastically reducing food supply for many herbivorous tetrapods feeding on this vegetation. There was a comparable reduction in both land animals and land plants, which, however, was a far cry from "mass extinction". It is interesting to note that most of the shallow water groups that apparently disappeared around the PTB, reappeared in the Olenekian or in the Middle Triassic. "They all seemingly survived in insular relict areas within the tropical part of Panthalassa" (Kozur, 1996).

Permian System

Before we consider the placement of the Permian-Triassic Boundary, it is important to examine what constitutes the two systems. In Germany, a copper-bearing "Zechstein" group rests on "Red Underlayer" (Rotliegende) of conglomerates, shales and sandstones. In 1808, d'Halloy described the strata between the "Red Underlayer" and the Muschelkalk as *Terrain peneén,* rocks with few fossils (Sherlock, 1947). The term was later (d'Halloy, 1834) restricted to "Red Underlayer", copper shales and Zechstein, only. Murchison (1841) recognised equivalent strata in eastern Russia, near the town of Perm, and named these as Permian, ignoring d'Halloy's term. For long the Permian remained one of the most ill-defined systems. The deliberations of the Subcommission on Permian Stratigraphy (IUGS) during the last two decades have gradually resulted in the establishment of a global time scale for the marine component of the Permian System. Consensus has emerged for a three-fold division of the Permian System. The present position about the divisions and subdivisions of the Permian System is summarised in Table 1 (modified from Jin Yugan, 1996). Such a global time scale is yet to be agreed upon for the Permian System in the non-marine domain.

Triassic System

The term Trias was introduced by Friedrich August von Alberti, the noted salt mining engineer, in 1834 for all the rock units, that is, Bunter Sandstone, Muschelkalk and Keuper, stratigraphically located between the Zechstein and the Lias in Germany. His *"Beitrag zu einer Monographie des Bunten Sandsteins, Muschelkalks und Keupers, und die Verbindung dieser Gebilde zu einer Formation"* deals in detail with the three units. This 'Germanic' system and its classification gradually gained general acceptance, more so in Europe. Later, it was realised that the 'Germanic' classification is not suited for equivalent marine sequences in the Alps and other Tethyan regions. Ammonoid biostratigraphy was found to be a satisfactory criterion for classification of the marine Triassic. Presently, three series, namely, Lower, Middle and Upper, are recognised in the Triassic System. However, as yet there is no agreement on the number of stages, there being no objective absolute criteria for recognition of a stage (Ager, 1987). The Subcommission for Triassic Stratigraphy by a majority decision approved recognition of seven stages, but Tozer (1993) vehemently disagrees with this proposal. The main area of disagreement is the subdivision of Early Triassic. The two views are

Table 1

Series	Stage	Conodonts	Ammonoids	Fusulinids
LOPINGIAN	Changhsingian	*Clarkina subcarinata*	*Paratirolites-Shevrevites*	*Palaeofusulina sinensis*
	Wuchiapingian	*Clarkina postbitteri*	*Roadoceras-Doulingoceras*	*Codonofusiella kwangsiana*
GUADLUPIAN	Capitanian	*Jinogondolella postserrata*	*Timorites*	*Polydiexodina shumardii*
	Wordian	*Jinogondolella aserrata*	*Waagenoceras*	*Neoschwagerina craticalifera*
	Roadian	*Jinogondolella nankingensis*	*Stacheoceras discoedale*	*Cancellina cutalensis*
CISURALIAN	Kungurian	*Neostreptognathodus pnevi* *N. exculptus*	*Propinacoceras busterense*	*Brevaxina dyhrenfurthi*
	Artinskian	*Sweetognathus whitei* *Streptognathodus florensis*	*Uraloceras fedorowii* *Artinskia artiensis*	*Charaloschwagerina vulgaris*
	Sakmarian	*Sweetognathus merrillii* *Svetlanoceras strigosum*	*Streptognathodus barskovii* *Sphaeroschwagerina*	*Sakmarites inflatus* *sphaerica*
	Asselian	*Sweetognathus expansus* *Streptognathodus isolatus*	*Svetlanoceras serpentinum* *Svetlanoceras primore*	*Sphaeroschwagerina vulgaris*

shown in Table 2. According to Kozur (1992) the lower stage in the two-fold classification of the Early Triassic should be named as Brahmanian and not Induan. For reasons not enumerated Lucas (1992, fig. 2) considers Olenekian to be a stage older than the Induan.

Table 2

UPPER	Rhaetian	Rhaetian	
	Norian	Norian	
	Karnian	Carnian	
MIDDLE	Ladinian	Ladinian	
	Anisian	Anisian	
LOWER	Spathian	Olenekian	SCYTHIAN
	Smithian		
	Dienerian	Induan	
	Griesbachian		
	Tozer, 1993	STS, 1984	

PERMIAN-TRIASSIC BOUNDARY PROBLEM

The contact between the Buntsandstein and the underlying Zechstein should normally define the Permian-Triassic Boundary. However, the Buntsandstein, which is non-marine, does not have typical fauna or flora that could be used for global recognition of equivalent strata. In fact on the basis of occurrence of elements of Late Permian palynoflora in the Buntsandstein of the Iberian peninsula, it has been suggested "that Buntsandstein sedimentation began before the end of the Permian in many parts of Spain" (Cassinis *et alti,* 1992). Further, it is now generally agreed that the chronostratigraphic boundaries are best defined in marine sequences.

The Bellerophon/Werfen succession in Dolomite Alps north of Italy, an equivalent of Zechstein-Buntsandstein, was initially used as a supplement. Sedimentologically the contact between the Bellerophon and Werfen Formations is considered to be transitional, though the occurrence of a sedimentary gap at the Bellerophon/Werfen Boundary was suggested (Broglio Loriga *et alti,* 1988). Later, this gap has been found at this level in almost all the areas; this probably could be the result of a major regression.

For the recognition of the PTB a detailed database is needed on the complete succession of biological events at the end of the Permian and beginning of the Triassic, both in the Tethyan and Boreal Realms. However, there is evidence to suggest a regression of the sea from the continental areas during Late Permian culminating at the PTB. At the latter level the hiatus may have been global (Dickins, 1988). The solution of the PTB thus seems to lie with the determination of the base of Triassic.

The sedimentary gap at the Permian-Triassic level is present even in the Gondwanic areas, for example, in Australia (Dickins & Campbell, 1992), Antarctica (Collinson *et alti,* 1994), and India (Fox, 1931; Krishnan, 1960). This naturally has necessitated searching a section where there is virtually no sedimentary gap at the Permian-Triassic boundary level. Many candidates have been proposed, namely,

Meishan Section, south-east China;
Shangsi Section, Sichuan Province, China;
Selong Xishan Section, Xizang; and
Guryul Ravine Section, Kashmir Valley, India

POTENTIAL GSSPS FOR PTB

The arguments advanced in favour of selection of the Meishan Section as GSSP are (Yin, 1996):

1. The section is easily accessible, well exposed, and records continuous marine sedimentation from the Changxingian into the Early Triassic;
2. The base of bed 27c in D Section is characterised by first appearance of conodont *Hindeodus parvus* in the evolutionary lineage of *H. latidentatus — H. parvus—Isarcicella isarcica.* [Ammonoid *Otoceras,* however, is not known].

The Shangsi Section located in Guangyuan County of Sichuan Province is also easily accessible. The section is about 500 m long and is reported to represent a continuous Late Permian-Early Triassic sedimentation. The PTB is drawn just above the 'Black Clay' (Li *et alti,* 1989). The absence of both *Otoceras* and *Hindeodus parvus* in the basal Triassic beds is a major drawback.

In the Selong Section, the first and simultaneous appearance of *Otoceras latilobatum, Hindeodus parvus* and *Neospathodus primitivus* is coincident with the beginning of an anoxic event. This level is proposed as a potential GSSP (Mei, 1996).

The Guryul Ravine Section is located near Khunamuh Village, about 10 km southeast of Srinagar, and is easily accessible. The Permian-Triassic transition is represented by Member D (Zewan Formation) and Member E (Khunamuh Formation). Member E is composed of alternating shale and subordinate limestone and is divided into three units, namely, E_1, E_2 and E_3. E_2 is characterised by the presence of *Otoceras woodwardii* which makes its appearance in Bed 52. *Hindeodus parvus* appears in Bed 56 and *Isarcicella isarcica* in Bed 58. E_1/E_2 contact may be a potential GSSP (Kapoor, 1992).

In most of these areas the Permian and Triassic consist of very different facies and hence a hypostratotype section has also been proposed. Zakharov (1988) reasons that the Permian and Triassic at Meishan consist of very different facies, that is, limestones, clay and mudstones, and as such problems are faced in recognition of continuous succession in marine fauna. He therefore suggests the stratotype section of Dorashamian Stage in the Trans-Caucasia as a Hypostratotype for the PTB interval. In this section the Upper Permian and Lower Triassic strata both comprise similar carbonaceous facies, except for an about 5 m thick clay at the boundary.

EVIDENCES

Several evidences have been used by different workers for deciding the base of the Triassic System, for example:

Ammonoid evidence,
Conodont evidence,
Palynological evidence, and
Geochemical evidences.

Ammonoid evidence

During the 1870s, ammonoids were discovered in certain marine beds in the Himalaya. The most peculiar form was *Otoceras,* and Griesbach (1880) considered the *Otoceras*-Bed as Triassic. Noetling (1905) maintained that all the *Otoceras*-Beds were Permian because similar forms *(Ceratites/Protoceras)* were found in the Permian of Armenia. Diener (1912) reviewed the data and convincingly putforth the argument suggesting a Triassic age for the *Otoceras*-Bed in the Himalaya; which since then has been accepted as forming the base of the Triassic and thus delineating the PTB. *Otoceras* has been reported from the Himalayan region (Spiti, Pahlgam, Guryul Ravine, Barus, Selong, and Nepal), and the Arctic (East Greenland, Axel Heiberg Island, Ellesmere Island, Spitzbergen and North America). Further, the appearance of *Otoceras* coincides with a major transgression. However, there have been a few hiccups, and it has sometimes been suggested to place the PTB at the top of the *Otoceras*-Bed.

Tozer (1988) has reviewed the evidence pertaining to this question. He has concluded that "The most suitable level for defining the base of the Triassic System is the base of the *Otoceras woodwardi* Zone of the Himalayas, with which the base of the *Otoceras concavum* Zone of Arctic Canada and Siberia is correlative.". Type locality for the *O. woodwardii* Zone is the Shalshal Cliff in the Himalaya. Tozer further opines that these zones correlate, albeit only approximately, with the base of the Werfen Formation which is correlatable with the base of Buntsandstein that defines the base of the Triassic. However, at most places the latest Permian (Dorashamian/Changxingian) is absent (Dagys & Dagys, 1988) indicating a global Late Permian regression that may have been the cause of change over from a Palaeozoic to a Mesozoic fauna.

In the Tethyan sequences, *Otoceras woodwardii* and *Ophiceras* Zones have been established in the Lower Griesbachian of Kashmir in the Perigondwana Province. *Otoceras*-Beds have also been reported from central Himalaya and northern slope of Mount Everest in Xizang. In the Boreal Region, the first biological event of significance in the earliest Triassic is the appearance of *Otoceras concavum* followed by the appearance of *Otoceras boreale*. Subsequent event relates to the appearance of the genus *Ophiceras* followed by extinction of the genus *Otoceras* (Dagys & Dagys, 1988). Thus the *Otoceras* Zones (Lower Griesbachian) may be taken as datum for marking the PTB interval.

Newell (1988), however, argues that *Otoceras* and *Ophiceras,* which are relatively rare, belong to a line of Permian ammonoids, and are associated with invertebrate taxa nearly all of which originated in the Permian. He suggests that the PTB be drawn at the top of the Griesbachian Stage which level marks the beginning of a new group of ammonoids, the Meekoceratids, and conodonts *(Neospathodus)*.

Conodont evidence

Conodonts are the second group that is used for zonal subdivision and global correlation of the Triassic sequences. Yin *et alii* (1988, see also Yin,

1994) have recommended replacement of *Otoceras* with *Hindeodus parvus* (Kozur & Pjatakova) Matsuda for drawing the base of the Triassic. The main reasons advanced by them include:

1. The superposition of *Otoceras* Zone upon the *Pseudotirolites* or *Paratirolites* Zone (undoubted uppermost Permian) is possibly known only from Changxing, south-east China;
2. The lower part of *Otoceras woodwardii* Zone in western Himalaya probably overlaps the *Paratirolites* Zone of Iran (Sweet, 1979);
3. Conodonts from the *Otoceras*-Beds of the Spiti Valley include *Gondolella subcarinata* and *G. orientalis,* both index fossils of Late Permian (Bhatt *et alii,* 1981), [a report rejected by Matsuda, 1984];
4. In the Guryul Ravine Section of Kashmir Valley, conodont *Hindeodus parvus* occurs in the upper *Otoceras* Zone, and predates first appearance of *Isarcicella isarcica* (Matsuda, 1985);
5. *Hindeodus parvus* Zone is always superjacent to the latest Permian horizons, for example, in sections at Selong, Meishan and Shangsi (China), Gurvul Ravine (India), Salt Range (Pakistan), Dorasham (Trans-Caucasia), and Hambast Valley (Iran);
6. In China the succession of first appearance of conodont taxa is *Hindeodus minutus—H. parvus — Isarcicella isarcica* (Yin, 1993);
7. *Hindeodus parvus* has a much wider distribution than *Otoceras;* and
8. *Hindeodus parvus* is also known from basal Griesbachian (Dinwoody Formation) of western United States of America (Paull & Paull, 1983).

In south-east China, the *Hindeodus parvus* Zone is delineated from the Permian by a basal boundary clay. It is towards the base of this clay that the biggest mass extinction (trilobites, fusulinids, corals, productids, Permian ammonoids, etc.) is presumed to have taken place. Evidence of catastrophic events (Iridium anomaly, sphaerules, carbon isotopic anomalies, tuffaceous materials, etc.) is also found in this clay. Thus, according to Yin *et alii* (1988), the lower limit of *Hindeodus parvus* Zone coincides with event boundary. Yin (1996) recommends the base of bed 27c in the Meishan Section, south-east China as GSSP for the basal boundary of the Triassic System. This bed is marked by the first appearance of *Hindeodus parvus* in the evolutionary lineage of *H. latilobatus — H. parvus — Isarcicella isarcica.*

Li *et alii* (1996), on the other hand, point out that *Hindeodus parvus* Zone is a Range Zone, and its lower boundary is not defined by the lineage or biotic evolution. The first appearance of the species is in the *Otoceras*-Bed in the Tethyan Realm (Perigondwana), and in the *Ophiceras*-Bed in the Boreal Realm (Greenland). First appearance of the conodont *Isarcicella isarcica* is therefore suggested to mark the PTB. *I. isarcica,* however, made its first appearance only in the upper Griesbachian. Does it mean that the *Otoceras woodwardii* Zone actually lies in the latest Permian? *I. isarcica* is not yet known from the Boreal Realm. In the Guryul Ravine Section, the base of Griesbachian is represented by Bed 52 of Khunamuh E_2 (Nakazawa *et alii,* 1975). This horizon has *Otoceras woodwardii, Hindeodus minutus* and many Permian fossils. *H. parvus* first appears only in Bed 56.

There are some problems even with the conodont evidences, for example,

- Stratigraphical distribution of certain conodont species varies considerably in local sections;
- It is difficult to recognise changes related with evolution from those caused by facies variations and degree of investigation;
- In the Boreal Realm, there are two long ranging species—*Anchignathus typicalis* and *Neogondolella carinata;*
- In the Tethyan Realm, three events, namely, first appearance of *Hindeodus parvus,* first appearance of *Isarcicella isarcica* and extinction of *I. isarcica* have been proposed as candidates for defining the PTB; and
- In the Selong Section of Xizang co-occurrence of *Otoceras, Hindeodus parvus* and *Isarcicella isarcica* has been noticed (Wang *et alii,* 1989).

According to Dagys and Dagys (1988), present knowledge on conodonts is not sufficient for effectively determining the base of the Triassic or for correlating with the Griesbachian ammonoid zones. Stratigraphic distribution of certain conodont species is not uniform laterally; it may be due to variations in facies investigated as well as due to the degree of investigation. Some authors (for example, Sweet, 1992) recommend *Isarcicella isarcica—Ophiceras—Claraia* Assemblage as index for the basal Triassic, thus putting the PTB between lower and upper Griesbachian. Paull and Paull (1994), however, are of the opinion that this assemblage has little value in North America because of the limited distribution of the zone's conodont component, the scarcity of ammonoid specimens, and the long range of *Claraia*. Kotlyar (1991) suggests that the PTB be associated with a complete replacement of Permian biota by the Triassic one.

Palynological evidence

Three better known examples, namely, Bellerophon/Werfen sequence of Italy, marine and non-marine of Hungary, and sub-surface of Israel, are discussed.

In Italy, palynofossils have been recorded from the Bellerophon/Werfen sequence of the southern Alps (Visscher & Brugman, 1988). The silty intercalations in the Bellerophon Formation have yielded palynodebris which, besides pieces of tracheids and cuticles, contain diversified gymnosperm pollen assemblages and a few marine palynofossils. Typical palynotaxa are *Lueckisporites virkkiae, Jugasporites delasaucei* and *Klausipollenites schaubergeri*. Towards the top of the formation, fungal remains appear in relatively high frequencies, and most of the characteristic Late Permian pollen virtually disappear. In the basal part of the Tesero Horizon of the Werfen Formation, *Protohaploxypinus*-type pollen is common, and fungal remains are sometimes overwhelmingly dominant. From the lower part of the Mazzin Member upwards the palynodebris have preponderance of marine acritarchs *Scythiana* Goczan *et alii* and the *Veryhachium—Micrhystridium*-complex. This data is interpreted to indicate that in northern Italy, the PTB interval witnessed replacement of land-derived organic matter by organic matter of marine origin. A 'practical' PTB is drawn at the top of fungi-dominated assemblage which coincides approximately with the disappearance of typical Late Permian pollen taxa *Lueckisporites virkkiae* and *Jugasporites delasaucei*. The "fungal event", reportedly known from latest Permian and/or earliest Triassic sediments of various parts of the Tethyan Realm, the Zechstein Basin of Europe, and various parts of the Boreal Realm, is interpreted to mark "the dramatic collapse of the stable Late Permian ecosystem" (Visscher & Brugman, 1988).

In Hungary, palynofossil assemblages are known from the Permian-Triassic transition both from the marine and non-marine sequences (Haas *et alii*, 1988). In the marine sequences, the PTB is drawn at the level at which characteristic Permian algae and foraminifera disappear and typical Triassic palynofossils appear. The latter include *Lapposisporites villosus* Visscher, *Kraeuselisporites apiculatus* Jansonius, *Anaplanosporites stipulatus* Jansonius, *Endosporites papillatus* Jansonius, *Densoisporites variabilis* (Jansonius), *Lunatisporites novimundii* (Jansonius) and *Spheripollenites elphinstonei* Jansonius. In the continental facies, the PTB is drawn at the level at which the Late Permian palynoflora acquires some so-called Early Triassic palynofossils, such as, *Lueckisporites virkkiae* var. C and *Densoisporites playfordii*.

In Israel, Late Permian-Early Triassic strata are represented by 'Arqov, Yamin and Zafir Formations. The lower part of the 'Arqov Formation contains fusulinids *Codonofusiella, Pseudovermiporella* and *Sargentina* indicating a Dzhulfian (lower Changxingian) age. The uppermost part of the Yamin Formation is unequivocally assigned to the Olenekian Stage on the basis of conodonts *Pachycladina* and *Hadrodontina*, but in Zohar-8 bore-hole this level also has *Lueckisporites virkkiae*, a Late Permian pollen. Elsewhere this taxon does not occur higher than the 'Arqov Formation, and hence the Zohar-8 occurrence may be due to reworking. The Early Triassic *Endosporites papillatus* appears only above the lower third of the Yamin Formation. Thus the PTB interval is presumed to lie within the lower part of the Yamin, slightly above the base of the Formation (Eshet, 1992).

Geochemical evidences

Iridium contents have been recognised at the PTB at Sovetachen in Trans-Caucasia (Alekseev *et alii*, 1983). Iridium anomaly has also been observed at this level at Changxing (Sun *et alii*, 1984; see also Xu & Yan, 1993). Zakharov (1988) reports a high concentration of Iridium in a specimen collected from the base of Triassic at San Antonio, Italy. A relatively high concentration of Iridium (114 ppb) has been reported from a horizon, within the

Productus Shale and 70 cm below the limonitic layer at PTB, in the Lalung section at Spiti, India (Bhandari *et alii*, 1992). Thus, it is possible to speculate on a global Iridium anomaly at or near the PTB.

Oberhänsli *et alii* (1989) have reported a negative $\delta^{13}C$ shift by 2-3‰ in selected bulk samples of finely ground carbonaceous mudstones and siltstones from apparently continuous PTB sections (i) on the east edge of the Schuchert Dal, north of Major Paars Dal on Jameson Land (Greenland) and (ii) at San Antonio (Cadore) in the southern Alps. A similar drop in values of $\delta^{13}C$ has been reported near the PTB in Changxing, south China (Chen *et alii*, 1984). According to Oberhänsli *et alii* (1989) "The carbon isotopic change, which we observe world-wide at the Permian-Triassic boundary, occurs within a few thousand years and may be related to a change in the global carbon cycle".

PTB IN THE NON-MARINE REALM

At the Beijing International Geological Congress 1996 it was proposed to identify GSSP for the PTB in the non-marine sequences also. Some of the candidate sections are (Lozovsky, 1996):

Germanic Basin, west European Platform,
Moscow Syneclise, east European Platform,
Tungusikai Syneclise, Siberian Platform,
Dalongkou Anticline near Jimusar, western China,
Noyon Soon Depression, Mongolia, and
Gondwana Basins, India

In most non-marine sequences too there is a sedimentary gap at the PTB. In the continental series of Eurasia the PTB interval is marked by:

- change of the Upper Permian tetrapod *(Dicynodon)* communities;
- dominance of striate-bisaccate pollen assemblages in the Upper Permian;
- presence of cavate triletes *(Lundbladispora, Densoisporites)*, nonstriate-bisaccate pollen *(Lunatisporites, Klausipollenites)* and taeniate pollen *(Taeniaesporites)* in the Lower Triassic;
- presence of *Lystrosaurus* in the Lower Triassic; and
- distinctive conchostracans in the Lower Triassic.

In the Moscow Syneclise, the most complete section comprising the PTB transition in the Vetluga River Basin too shows a gap in sedimentation at the PTB. Here the Molomskian Member of the Vjaatskian Horizon (latest Permian) has a palynoflora comprising *Brevitriletes* sp., *Apiculatisporites* sp., *Anaplanisporites stipulatus, Densoisporites complicatus, Indotriradites* sp., *Lundbladispora* sp., *Klausipollenites schaubergeri, Ephedripites* spp., and the fungal *Tympanicysta stochiana*. The overlying Vokhmian Horizon (Lower Triassic) contains *Lystrosaurus georgii* (Kalandadze, 1975, in Astschichian Member) and a rich palynoflora comprising *Anaplanisporites stipulatus, Leptolepidites jonkeri, Lycospora imperialis, Propertsporites pocockii, Nevesisporites limatulus, Naumovaspora striata, Densoisporites playfordii, Lundbladispora* sp., *Aratrisporites* sp., *Rewanispora* sp., *Protohaploxypinus jacobii, P. pantii, P. samoilovichii, Striatoabieites richteri, S. multistriatus, Lunatisporites hexagonalis, L. pellucidus, L. noviaulensis, L. transversundatus, Striatopodocarpites* spp., *Ephedripites extensus, E. multistriatus, E. scottii, E. steevesii*, etc. It has been suggested that the palynoflora of the Molomskian Member is transitional from the Permian to the Triassic (Lozovsky & Yaroshenko, 1994).

The Dalongkou Section near Jimusar, Xinjiang (Junggar Basin), China that has been proposed as GSSP for the PTB in non-marine sequences, apparently comprises a continuous deposition across the PTB. A diversity of fossils—vertebrates, conchostracans, ostracods, bivalves, plant megafossils, palynofossils—is known from the section. Distribution of different biotic groups is shown in Table 3 (derived from Zhou *et alii*, 1996).

Table 3

GROUP	FORMATION	
		Lystrosaurus vertebrate assemblage
	Shaofanggou	*Lundbladispora-Taeniaesporites* assemblage
		Conchostraca
	Jiucaiyuan	Ostracods
		Lystrosaurus-Jimusaria vertebrate assemblage
		Limatulasporites-Lundbladispora assemblage
		Falsisca-Cyclotunguzites conchostracan assemblage
		——PTB below 50 m top of formation——
Cangfanggou	Guodikeng	*Striodon magnus*, bivalves, conchostracans
		Limatulasporites-Lueckisporites assemblage
		Zamiopteris-Viatsheslavia assemblage
	Wutonggou	*Callipteris-Comia-Iniopteris* assemblage
		Dicynodontia vertebrate assemblage
	Quanzije	Palynofossils

The PTB in the Dalongkou Anticline is drawn 50 m below the top of the Guodikeng Formation mainly on the basis of ostracods and bivalves. For reasons not specified Esaulova (1995) places the Guodikeng Formation in the upper Kazanian Stage. Though palynofossils are reported from several layers straddling across the PTB, yet these do not provide indubitable evidence for the placement of the boundary. In fact, the palynoassemblages from the northern and southern limbs of the anticline show appreciable differences. The Late Permian sediments contain following palynotaxa: *Cyclogranisporites aureus, Calamospora pallida, *Alisporites sublevis, *A. australis, *Vitreisporites pallidus, Decussatisporites multistriatus, *Trellites* sp., **Triangulatisporites* sp. cf. *T. triangulatus, *Cordaitina rotata, Vesicaspora fusi, Platysaccus alatus, *Limatulasporites fossulatus, Protohaploxypinus ovaticorpus* and *P. samoilovichii*. The taxa marked with an asterisk (*) continue into the Early Triassic beds of the Guodikeng Formation which on the southern limb of the anticline contain: *+Apiculatisporites spinifer, Klausipollenites schaubergeri, +Alisporites australis, +A. sublevis, Vitreisporites pallidus, Pteruchipollenites reticorpus, +Lueckisporites virkkiae, +Limatulasporites fossulatus, +Protohaploxypinus limpidus, +Striatoabieites richteri, Taeniaesporites pellucidus,* and *Hamiapollenites limbatus*. Taxa marked with a plus (+) sign are also present in the Early Triassic on the northern limb along with *Punctatisporties* sp., *Apiculatisporites xiolongouensis, A. decorus, Lundbladispora wantangensis, Kraeuselisporites disparilis, Equisetosporites* sp., *Triangulisaccus* sp., *Treilites* sp., *Triangulatisporites* sp. cf. *T. triangulatus, T. vermiculatus, Verrutriletes* sp., *Maexisporites* sp., *Limatulasporites limatulus, Taeniaesporites noviaulensis*, etc. Among the known plant megafossils from the Early Triassic are *Paracalamites* sp., *Zamiopteris* sp. cf. *Z. glossopteroides, Walchia* sp. and *Samaropsis* sp.

In India, the task is to find in the non-marine deposits, the stratigraphic analogues of the base of *Otoceras—Hindeodus parvus* Zone, the level "accepted" as the PTB in international geological time frame. The transition from marine to non-marine strata of PTB interval can not be traced from the Himalayan basins to the Gondwanan basins. Therefore, correlation can only be made on the basis of palaeontological, palaeomagnetic and geochemical data; and hardly any useful information is available. The best areas to look for the PTB interval are the Damodar and Godavari Grabens. In the Damodar Graben, the PTB is presumed to be astride the Raniganj-Panchet formational boundary (Ghosh *et alii*, 1996) and in the Godavari Graben within the "Kamthi" Formation. An analysis of the available data shows that:

i) there is no marine control for precisely demarcating the PTB interval in basins on peninsular India;

ii) the PTB interval is located somewhere across the Raniganj-Maitur (lower Panchet) transition in the Damodar Graben (Maheshwari, 1974), and within the Kamthi Formation in the Godavari Graben (Srivastava & Jha, 1995);

iii) in most of the sections in the Damodar Graben, possibly except for the Banespati stream section, there is a gap or a pebbly/conglomeratic horizon between the Raniganj and Panchet Formations (Ghosh *et alii*, 1996);

iv) Permian plant taxa, such as, *Schizoneura* and *Glossopteris*, and striate-bisaccate pollen continue into the Maitur Formation (Maheshwari & Banerji, 1975); *Playfordiaspora* and *Lunatisporites* which are characteristic of the Maitur palynoflora are known from the Permian of Salt Range, Pakistan (Balme, 1970); palynological transition from Late Permian into Early Triassic is often gradual;

v) *Dicroidium* and *Lystrosaurus* which mark the advent of the Triassic elsewhere are both absent in the Maitur Formation; the latter is, however, present in the younger Hirapur (upper Panchet) Formation (Tripathi & Satsangi, 1963);

vi) presence of "dicroidia" in the Nidhpuri beds (?Permian) of South Rewa Basin needs verification (Maheshwari & Chandra, 1994), no dicroidia are known from the Panchet Group, definite dicroidia are known only from the Parsora Formation of Rhaetian age (Lele, 1962) and possibly also from the Tiki Formation of Carnian-Norian age; and

vii) the exact horizon where the Triassic conchostracans make their first appearance in the Maitur Formation has yet to be clearly specified;

If the *Lystrosaurus* Zone represents the oldest interval of the Early Triassic (Lucas, 1992), the PTB does not exactly coincide with any lithological boundary; it possibly lies somewhere above the Maitur Formation. The main problem in non-marine sequences is that a definite biota has not emerged as a marker of the base of the Triassic, in spite of the claim that the *Lystrosaurus* Zone represents oldest Triassic. Often the appearance of the genus *Dicroidium* was taken to mark the beginning of the Triassic on the Gondwana Supercontinent at least. However, Dobruskina (1995, chart 1) has come out with a synthesis which shows that the genus *Dicroidium* appeared only in the Olenekian Stage coincident with the changeover from Palaeophytic to Mesophytic on the Gondwana Supercontinent. Then all leaves with forked rachides are not necessarily dicroidia, for example, *Callipteridium changii, Comia* and *Supaia*, all Permian taxa. Even otherwise it should be very difficult to find a fossil plant as a common global denominator for identification of the base of Triassic.

Table 4—Various levels of Permian-Triassic Boundary in southern Israel. Extracted from Hirsch and Weissbrod (1988, figure 1).

FORMATION		
RA'AF	*Balatonites balatonicus* *Noetlingites arifensis* *Noelingites kockeli*	
ZAFIR	*Palynofossils* *Pachycladina*	
YAMIN	*Hadrodontina* Palynofossils	---- PTB (Hirsch, 1975) ---- PTB (Hirsch, 1988) ---- PTB (Hirsch, 1976)
ARQOV	Palynofossils *Codonofusiella*	

IN THE END

I suggest that we seriously ponder over if a sharp Permian-Triassic Boundary, that is, a *Lakshman Rekha* can actually be marked in the global perspective, particularly so when the criteria needed to identify/recognise such a boundary are yet to be agreed upon. With so many imponderables, the available data are subject to differing interpretations. It is too much to expect that with all the climatic zones, different ecological niches and habitats, the biota ever had an uniform global distribution at any given point of time. Taxa of higher metazoans and metaphytes could not have had originated simultaneously all over the globe. Some time lapse must be allowed for their migration to places other than locale of their origin. Similarly such taxa could not have died at the same point of time all over the globe. The genus *Glossopteris* is one such example. While elsewhere on the Gondwana Supercontinent it became extinct by the end-Permian, on the Indian peninsula it continued into the Early Triassic, and possibly even into the Rhaetian (Parsora Formation; Maheshwari, 1992). Bisaccate-striate pollen appeared on the Gondwana Supercontinent in the earliest Permian whereas elsewhere it is mostly known from late Early Permian onwards only. Thus FADs and LADs of different taxa may vary in different regions. It should greatly relieve the confusion if one talks of a Permian-Triassic Boundary Interval rather than of a fixed boundary level, a concept which so far seems to be a mirage and is likely to remain so for long. Alternatively, we consider fixing boundaries in terms of absolute ages; but even these are not that absolute (Claoué-Long *et alii*, 1991). Let us be pragmatic. An objective look at the PTB problem shows that the delimitation of the boundary is so subjective, and that is why the PTB "has been placed by different authors at several stratigraphic levels between the base of the Changxingian.....and at, or close to, the top of the Griesbachian" (Teichert, 1990). Sometimes, even the same author has placed the boundary at different levels in different publications (Table 4). PTB is our invention, not a discovery. He did not say "let there be a PTB" and there it was!

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