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Conodont Survival and Low Iridium Abundances Across the Permian-Triassic Boundary in South China

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The Permian-Triassic sedimentary sequence of China includes one of the most complete and fossiliferous Paleozoic-Mesozoic boundaries known. Closely spaced sampling across the boundary, which is an important extinction event for most organisms, has produced good conodont faunas that show little diversity change. A drop in conodont abundance is the only apparent response to the extinction event. A low concentration of iridium in the boundary clay (0.002 part per billion ±20 percent), as well as in samples immediately below and above, that range from 0.004 to 0.034 part per billion do not support the proposal of an extraterrestrial impact event at this boundary in China.

THE PERMIAN/TRIASSIC BOUNDARY (P/Tr) (245 million years ago) has been characterized as the most profound extinction event of the Phanerozoic even though certain organisms may have been relatively unaffected. Recently, the possibility of an extraterrestrial influence for the Late Permian event has been suggested by the reports of iridium anomalies at two localities in China (*1, 2*). This raises the question of how conodonts were able to escape what might have been a major worldwide catastrophe. New conodont and Ir data from an excellent stratigraphic sequence in the Meishan, Changxing area of China, indicate that conodont abundance (but probably not species diversity) was affected at the P/Tr boundary and that the concentration of Ir in the boundary clay is extremely low (0.002 ppb). The environmental factors contributing to the Late Permian extinction event were only effective in reducing conodont abundance and, furthermore, did not involve any increase in Ir abundance.

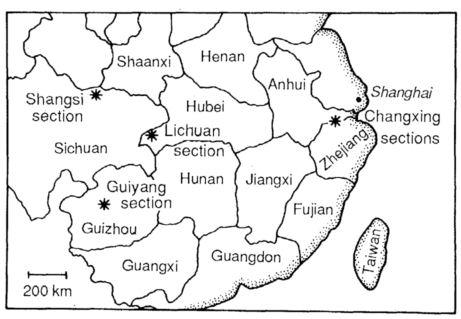

Fig. 1. Localities of P/Tr sections in South China referred to in this report. Data on Changxing sections are from this report and (*1, 5*); on the Lichuan section from this report; on the Shangsi section, from (*2*); and on the Guiyang section, from (*5*), Table 2.

The discovery of an Ir anomaly at the Cretaceous/Tertiary (K/T) boundary (*3*) with its associated mass extinctions has led to investigations of Ir abundances at other biologic extinction events (*4–11*). It is reported that the Late Permian event resulted in the elimination of approximately 50% of the preservable marine families in the World Ocean, and it is estimated that between 77 and 96% of the marine invertebrate species were affected (*12*). There was a significant decrease in the world terrestrial reptilian faunas at this time as well (*13*). Because the Late Permian extinction "stands alone as the most devastating collapse of the marine ecosystem" (*12*), studies of possible geochemical anomalies, similar to those at the K/T boundary have followed naturally at the P/Tr boundary. An Ir abundance of 8 ppb has been reported for the 4 cm of P/Tr boundary clay in the Meishan area of Changxing (*1*), and an abundance of 2 ppb was reported for the P/Tr boundary in the Shangsi section, Guangyuan County of Sichuan Province (*2*) (Fig. 1). Both occurrences were considered evidence of an extraterrestrial event at the end of the Permian.

The Changxing report is of particular interest because the section at this locality may represent the best of the few uninterrupted Permian-Triassic marine intervals worldwide. Complete sequences in Kashmir, the Salt Range, South China, central and northern Iran, and the Kap Stosch area of East Greenland have been reported, but recent work indicates that the relation between the Permian and Triassic in at least some of these areas is disconformable (*14*). Because of this, the Changxing section has been recommended as the world stratotype for the Late Permian (*15*) and is of particular importance for documentation of the validity of an extraterrestrial (terminal) Permian event.

A novel aspect of the Late Permian extinction, known for more than a decade, is that Late Permian conodont species studied in Iran and elsewhere range across the P/Tr boundary relatively unaffected (*16*). During the whole of the Late Permian interval there were at least 50 species and eight genera of conodonts although there probably were never more than five to eight species living at one time (*17*). In the Salt Range, Kashmir, and northern and central Iran, five or six conodont species, the total number known in the Late Permian, all range across the P/Tr boundary (*16*). Because five species are within the range of normal Late Permian conodont population levels (*17*) the occurrence of this number of the same species on either side of the P/Tr boundary suggests that the factors responsible for the devastating collapse of the marine ecosystem at this time had little effect on conodont diversity.

The report of an Ir anomaly at the Chinese P/Tr boundary renewed our interest in this extinction event and the survival of conodonts. In order to determine a precise conodont sequence in what may be the best P/Tr section (and from the same sediment layers reported to show the Ir anomaly), detailed sampling for conodonts was undertaken in 1984–85 by C. Y. Wang. In South China, the marine P/Tr boundary occurs in many places, but the most important is the Changxing area of Zhejiang Province (Fig. 1). This section has been studied in detail by a joint Chinese-Japanese team (*15*).

Among the several sections documented in this study is the section in Meishan at Changxing, the stratotype of the Changshing Stage (latest Permian). Section D of

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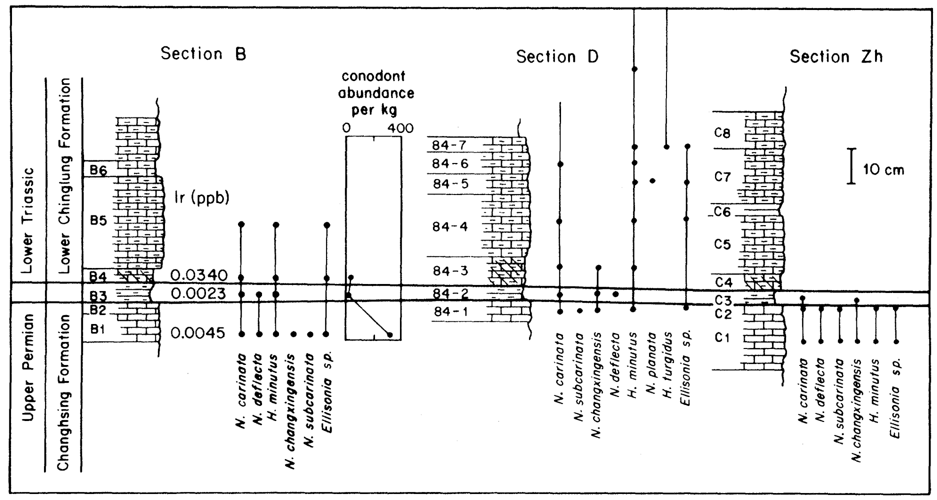
Fig. 2. The P/Tr intervals and range of conodont species in three sections in Changxing area of Zhejiang Province. Section B is in Baoqing Quarry, Meishan, approximately 370 m west of section D. Iridium and conodont element abundance shown. Section D is the stratotype of the Changhsingian Stage, Baoqing Quarry of Meishan. Section Zh is located approximately 0.5 km east of section D at the west end of Meishan. This section has been suggested as the stratotype section of the P/Tr boundary in South China. Triassic conodonts from this section were not studied. Bed B3 and its equivalents in sections D and Zh is the boundary clay. In China this is regarded as post-Changhsingian. We interpret it to represent the terminal Permian event.



this study at Baoqing Quarry of Meishan (Fig. 2) has been recommended as the P/Tr boundary stratotype (*15*). The P/Tr sequence is characterized by a "mixed layer" fauna above the Changxing Formation (Fig. 2) that contains Permian-type brachiopods and Triassic ammonoids and bivalves.

Three sections across the boundary of the Baoqing Quarry were measured and sampled for conodonts (Figs. 1 and 2). Conodonts occur in every layer including the illite-montmorillonite boundary clay that has no other fossils. Most important for this study is section B (Fig. 2). The range of conodonts indicates that three or four of the six species present in the Late Permian Changhsingian survived into the Early Triassic. Whether it is three or four depends on the interpretation of bed B3 as Permian or Triassic (Fig. 2). At section D (Fig. 2), an additional species (*Neogondolella changsingensis*), present in the Late Permian of section B but not in the Early Triassic of that section, also crosses the boundary. Thus, four or five of six species range across the Chinese P/Tr boundary, and this is similar to the survival of Permian species in Pakistan, the Salt Range, and Iran (*16*).

Whatever devastation affected up to 96% of the preservable marine species at this time in the Paleozoic did not affect conodont species diversity as far as we can determine. However, the Chinese material studied to date shows a dramatic reduction in the abundance of conodonts across the P/Tr boundary. This includes a reduction of from 322 specimens per kilogram of carbonate in section B (Late Permian B1) to six specimens per kilogram of carbonate in the Early Triassic sample (B4). This low abundance also characterizes the Triassic carbonates for several meters higher in the section. Both Permian and Triassic carbonates are mudstones and wackestones. The boundary clay has an abundance of four specimens per kilogram but this may represent a much shorter time interval if it represents a single event and is not comparable to the carbonate abundances. Thus, the environmental

Table 1. Elemental abundances from section B samples across the P/Tr boundary, Changxing. All abundances in parts per million, except for Ir which is parts per billion. Errors quoted (except Ir) are only for counting statistics. Stratigraphic position of samples is shown in Fig. 2.

Element	Section B1	Section B3	Section B4
Na	196 ± 22	291 ± 29	1,019 ± 70
Mg	5,030 ± 710	16,900 ± 1,400	11,900 ± 2,800
Al	6,370 ± 450	123,200 ± 7,600	76,800 ± 10,000
Cl	< 94	< 26	< 94
K	< 3,500	37,400 ± 3,300	25,900 ± 4,400
Ca	395,000 ± 27,000	8,020 ± 750	73,000 ± 10,000
Ti	< 2,900	1,970 ± 180	3,990 ± 560
V	19.9 ± 2.1	12.8 ± 2.1	122.0 ± 8.8
Mn	441 ± 30	25.3 ± 2.0	536 ± 36
Cu	< 130	< 130	< 240
Sr	420 ± 100	< 130	< 330
In	< 0.12	0.11 ± 0.03	< 0.20
I	< 28	< 18	< 41
Ba	< 3,500	< 1,200	294 ± 60
Dy	2.57 ± 0.45	10.9 ± 1.1	5.42 ± 0.81
U	3.90 ± 0.18	8.55 ± 0.39	4.26 ± 0.20
Ga	< 9.6	30.4 ± 7.3	< 23
As	2.66 ± 0.33	11.2 ± 1.2	15.0 ± 1.6
Br	1.77 ± 0.23	< 1.6	< 1.4
Mo	2.0 ± 1.2	4.8 ± 1.9	< 87
Sb	0.52 ± 0.05	2.4 ± 0.2	1.1 ± 0.01
La	11.53 ± 0.54	76.0 ± 4.2	42.2 ± 2.2
Sm	1.72 ± 0.09	14.0 ± 0.6	6.32 ± 0.29
Yb	1.3 ± 0.01	5.4 ± 0.5	2.9 ± 0.2
W	1.9 ± 0.4	< 3.8	2.0 ± 0.9
Au	≤ 0.003	≤ 0.008	≤ 0.006
Sc	1.01 ± 0.06	13.2 ± 0.7	13.7 ± 0.7
Cr	15.9 ± 1.1	< 2.7	66.6 ± 4.3
Fe	3,500 ± 190	28,100 ± 1,400	38,000 ± 2,000
Co	0.83 ± 0.12	0.19 ± 0.14	26.0 ± 1.4
Zn	229 ± 30	227 ± 29	48 ± 11
Se	1.9 ± 0.6	< 3.9	1.4 ± 0.7
Rb	6.0 ± 1.6	105 ± 7	129 ± 9
Zr	< 88	251 ± 59	204 ± 72
Ag	< 1.3	< 4.0	< 3.6
Cs	0.77 ± 0.07	22.1 ± 1.3	9.8 ± 0.6
Ce	15.4 ± 1.1	135 ± 6	88 ± 4
Nd	< 12	58 ± 12	32 ± 12
Eu	0.25 ± 0.01	1.16 ± 0.05	1.13 ± 0.06
Tb	0.309 ± 0.032	1.95 ± 0.18	0.756 ± 0.083
Lu	0.18 ± 0.02	0.51 ± 0.04	0.42 ± 0.04
Hf	0.42 ± 0.04	12.2 ± 0.5	4.54 ± 0.38
Ta	< 0.24	1.76 ± 0.12	1.03 ± 0.10
Th	2.10 ± 0.1	46.3 ± 2.1	14.0 ± 0.6
Ir*	0.004	0.002	0.034

*The error on Ir at the 95% confidence level is ±20%, and this includes all counting, weighing, chemical, and possible systematic errors. Calibration is with University of California–Berkeley, University of California–San Diego, and laboratories in the Soviet Union. All other elements calibrated using USGS and NBS standard rock samples.

factors affecting other organisms at the P/Tr boundary had relatively little effect on conodont species diversity but resulted in a significant reduction in conodont abundance.

This reduction in abundance may be taphonomically produced but the latest Permian and earliest Triassic carbonates (Fig. 2) have many similarities. The abundance change probably represents the conodont response to the P/Tr mass extinction event. Conodont life-style may be a factor in their immunity to the extinction event but even recent discovery of impressions of whole conodonts (*18*) does not aid in such interpretations. Most conodonts probably were nektonic and soft bodied, probably surface or upper water heterotrophic organisms and likely shared space with a large number of invertebrate and vertebrate animals that were affected by the Late Permian extinction event. We do not know what characteristics of conodonts shielded them from the fate of associated organisms at the time of extinction.

It is important to note that recent conodont work on several P/Tr sections in China includes descriptions of form-species whose numbers are not directly comparable to the species numbers reported here (*19*). We used multielement reconstructions that should be closer to true biologic species numbers (*20*). The Chinese work also included sampling intervals of one to several meters whereas that we report is at the centimeter level. Although the Chinese work (*19*) is at a different scale and uses different species numbers, the conclusions support this report.

In order to confirm the magnitude of the previously reported Ir anomaly (*1*), elemental abundances in duplicates of the same samples as those studied for conodonts in section B were measured by neutron activation analysis, with radiochemical isolation of Ir (Table 1). We measured eight samples from the boundary clay at different localities including four samples from the same locality. Contrary to the earlier report of 8 ppb (*1*), we observed a mere 0.002 ppb ± 20% in the boundary clay and slightly higher amounts above and below (Fig. 2). In general, earth crustal abundances range from about 0.005 to 0.080 ppb. Furthermore, the P/Tr boundary clay observed across south China exhibits a rather unusual trace element pattern, and in Table 2 we show a comparison of our elemental abundances in the Changxing section with those reported by Asaro *et al.* (*5*) and by Sun *et al.* (*1*). We also include the data of Asaro *et al.* (*5*) for a section near Guiyang, of Xu *et al.* (*2*) for the Shangsi section, and data for a section near Lichuan (Hubei Province) (*21*). At these three localities, which are separated from each other by as much as 1300 km, we note a strong enhancement of K, Cs, Hf, Ta, and Th and depletion of Na, V, Cr, Mn, Co, and Ir, relative to average crustal abundances. Although there is a remote possibility that the boundary clay (predominantly illite) resulted from alteration of ejecta dust from a comet impact, the most likely source was ash from a massive volcanic eruption. The trace element patterns (Table 2) indicate the ash or dust was highly silicic (acidic) and the very low ratios of TiO_2 to Al_2O_3 support this conclusion. Spears and Kanaris-Sotiriou (*22*) observed that the TiO_2/Al_2O_3 ratio remains virtually unchanged as a volcanic ash alters to clay and low ratios are associated with acidic ash and high ratios with basic ashes. The extremely low ratios in the boundary clay (0.014 to 0.017) are compatible with highly silicic ash.

Much of the paleontological information concerning the P/Tr boundary is derived from the study of rock formations that were formed on the southern part of the south Chinese landmass which probably was isolated from the earth's supercontinent at the end of the Permian. It is therefore conceivable that a massive volcanic eruption on or near what is now south China scattered enough tephra into the shallow seas to cause the observed effects on the marine organisms.

Table 2. Comparison of elemental abundances in P/Tr boundary clay from localities in China. Data are from this study unless otherwise referenced. Error discussion is the same as for Table 1.

Element	Changxing	Changxing (*5*)	Changxing AG-91 (*1*)*	Lichuan	Shangsi AG-252 (*2*)†	Guiyang (*5*)
Na (%)	0.027	0.024		0.016		0.015
Mg (%)	1.6	3.2		2.0		2.1
Al (%)	11.6	11.9		12.2		10.8
K (%)	4.3	4.4		6.0		4.3
Ca (%)	0.75	0.69	≤0.8	0.17		≤0.4
Ti (%)	0.185	0.199		0.236		0.208
V (ppm)	12	<50		9.0		<66
Cr (ppm)	≤2.7	≤2.7	10.2	≤3.1	7.85	≤1.8
Mn (ppm)	23.7	39.4		6.4		15.0
Fe (%)	3.0	1.73	2.3	1.5	1.63	2.26
Co (ppm)	0.19	4.41	1.9	0.62	2.43	6.06
In (ppm)	0.104	0.174		0.213		0.148
Cs (ppm)	27.2	31.4		18.6	13.4	12.4
La (ppm)	76.0		89.9	51.2		
Ce (ppm)	135		~180(e)	136		
Hf (ppm)	12.2	14.4		17.4	9.69	11.5
Ta (ppm)	1.76	2.23	~2(e)	2.30	1.68	1.82
Ir (ppb)	0.002	≤0.40	8.0	0.0012	ND	≤0.50
Th (ppm)	46.3	59.6	~60(e)	56.2	39.5	46.4
U (ppm)	8.05	7.02		7.39	9.46	5.04
TiO_2/Al_2O3	0.014	0.015		0.017		0.017

*Concentrations with an (e) are estimated from Sun *et al.* (*1*, figure 1). †Xu *et al.* (*2*) assign the P/Tr boundary between layer AG-252 and a superjacent 4-cm-thick gray-black calcareous shale (AG-253). They report an Ir abundance of 2.48 ppb in AG-253, but did not detect (ND) Ir in AG-252.

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