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Permian chronostratigraphic subdivisions

Names and boundary levels for series and stages of the Permian System, based on marine successions, have been approved by the Permian Subcommission, ICS. These are the Cisuralian, Guadalupian, and Lopingian Series and their constituent stages standardized respectively in the Urals, Southwest USA, and South China for the Lower, Middle, and Upper Permian.

Historic review

The Permian System was proposed by Murchison in 1841 for sedimentologically diverse deposits in the Ural Mountains of Russia. Equivalents had been recognised previously in western Europe as the Dyas or other rock units, but could not be defined satisfactorily as a System because of the paucity of fossil content. The classic Permian succession was extended downward by Karpinsky (1874) and subsequently by Ruzhencev (1936), and became firmly established through extensive twentieth century investigations. Dunbar (1940) provided an excellent review of classification and correlation of the Urals Permian, contributing to its wide acceptance as the international standard (Figure 1).

Problems arose because the depositional sequence in the Urals above the Artinskian is dominated by non-marine sediments, and is thus inadequate for definition of post-Artinskian chronostratigraphic subdivisions. However, post-Artinskian chronostratigraphy can be defined precisely in a number of paleoequatorial marine sequences. Glenister and Furnish (1961) attempted to provide an integrated scheme of marine sequences with substitutions for the traditional Upper Permian Urals standards, and various composite schemes have been proposed subsequently (Stepanov, 1973; Furnish, 1973; Waterhouse, 1976; Kozur, 1977). None of these composite schemes has gained overwhelming acceptance, largely because they are composed of stages with reference areas distant from each other. This separation necessitates determination of stratigraphic superposition of neighbouring stages based on the interpreted evolutionary succession of regionally restricted ammonoid, brachiopod, and fusulinacean faunas, or on previously premature zonation of conodonts. It has therefore become apparent that an integrated standard succession should be simplified to comprise a minimum number of reference areas. The scheme consisting of Cisuralian, Guadalupian, and Lopingian Series and their constituent regional stages proposed by Waterhouse (1982) is a simplified integrated succession that was accepted subsequently in a global time scale (Harland et al., 1990).

Recent refinement of the zonation of Permian conodonts provides an excellent biostratigraphic basis for precise boundary correlation of type sections for the three series. The succession Asselian, Sakmarian, and Artinskian was further documented as a potentially qualified international standard, in connection with the 1991 International Congress on the Permian System of the World (Chuvashov and Nairn, 1993) and the Guadalupian Series of North America also was formally proposed there as a global standard (Glenister et al., 1992). More recently, the faunal successions of the Lopingian Series in South China have been further documented (Jin et al., 1993; Mei et al., 1994b). With support from the updated zonation of conodonts, ammonoids, and fusulinaceans, an operational scheme incorporating these three most promising reference successions was proposed (Jin et al., 1994a; 1994b) as a working template for the Subcommission on Permian Stratigraphy (SPS). However, the Chihsian/Cathedralian Series in the proposed scheme met with reservations, due to uncertainty of correlation between Tethyan and North American successions. SPS meetings early in 1996 suggested the compromise of retaining the name of the Kungurian Stage, but designating the body

Permian Subcommission, 1996				Glenister & Furnish, 1961		Furnish, 1973		Waterhouse, 1982		Harland *et al.*, 1990			Jin *et al.*, 1994	
Series		Stages	Basal conodont zone											
PERMIAN	Lopingian	Changhsingian	*Clarkina subcarinata*	Upper Permian	Dzhulfian	Dzhulfian	Changhsingian	Lopingian	Changhsingian	Zechstein	Lopingian	Changhsingian	Lopingian	Changhsingian
PERMIAN	Lopingian	Wuchiapingian	*Clarkina postbitteri*	Upper Permian	Dzhulfian	Dzhulfian	Chhidruan Araksian	Lopingian	Lungtanian	Zechstein	Lopingian	Lungtanian	Lopingian	Dzhulfian (Wuchiapingian)
PERMIAN	Guadalupian	Capitanian	*Jinogondolella postaserrata*	Upper Permian / Guadalupian	Capitanian	Guadalupian	Amarassian Capitanian	Guadalupian	Capitanian	Zechstein	Guadelupian	Capitanian	Guadalupian	Capitanian
PERMIAN	Guadalupian	Wordian	*Jinogondolella aserrata*	Upper Permian / Guadalupian	Wordian	Guadalupian	Wordian	Guadalupian	Wordian	Zechstein	Guadelupian	Wordian	Guadalupian	Wordian
PERMIAN	Guadalupian	Roadian	*Jinogondolella nankingensis*	Upper Permian / Guadalupian	Wordian	Artinskian	Roadian	Guadalupian	Roadian	Zechstein	Guadelupian	Ufimian	Guadalupian	Roadian
PERMIAN	Cisuralian	Kungurian	*Neostreptognathodus pnevi- N. exculptus*	Lower Permian / Artinskian	Baigendzhinian	Artinskian	Leonardian	Guadalupian	Roadian	Rotliegendes		Kungurian	Chihsian	Kubergandinian Bolorian
PERMIAN	Cisuralian	Artinskian	*Sweetognathus whitei- Mesogondolella bisselli*	Lower Permian / Artinskian	Aktastinian	Artinskian	Aktastinian	Cisuralian	Baigendzinian	Rotliegendes		Artinskian	Uralian	Artinskian
PERMIAN	Cisuralian	Sakmarian	*Streptognathodus postfusus*	Lower Permian	Sakmarian	Sakmarian	Sterlitamakian Tastubian	Cisuralian	Sakmarian	Rotliegendes		Sakmarian	Uralian	Sakmarian
PERMIAN	Cisuralian	Asselian	*Streptognathodus isolatus*	Lower Permian	Asselian	Sakmarian	Asselian	Cisuralian	Asselian	Rotliegendes		Asselian	Uralian	Asselian

***Figure 1** Development of Permian chronostratigraphic scales. This chart is designed to show the succession of chronostratigraphic units in selected scales rather than the correlation between them.*

SERIES		STAGES	SELECTED FOSSIL ZONES: Ammonoids	Conodonts	Fusulinids	Polarity	Ma
Triassic		Griesbachian	*Ophiceras* *Otoceras*	*Hindeodus parvus*			251.1 ± 3.6
PERMIAN	Lopingian	Changhsingian	*Pseudotirolites* *Paratirolites - Shevyrevites* *Iranites- Phisonites*	*Clarkina changxingensis* *C. subcarinata*	*Palaeofusulina sinensis*		253.0 ± 0.3
PERMIAN	Lopingian	Wuchiapingian	*Araxoceras-Konglingites* *Anderssonoceras* *Roadoceras-Doulingoceras*	*C. orientalis* *C. leveni* *C. dukouensis* *C. postbitteri*	*Nanlingella simplex-Codonofusiella kwangsiana*		
PERMIAN	Guadalupian	Capitanian	*Timorites*	*Jinogondolella altudaensis* *J. postserrata*	*Lepidolina* *Yabeina* *Polydiexodina shumardi*		264.1 ± 2.2
PERMIAN	Guadalupian	Wordian	*Waagenoceras*	*J. asserata*	*Neoschwagerina craticalifera*	Illawarra Riversal	
PERMIAN	Guadalupian	Roadian	*Demarezites* *Stacheoceras discoidale*	*J. nankingensis*	*Praesumatrina neoschwagerinoides* *Cancellina cutalensis-Armenina*		
PERMIAN	Cisuralian	Kungurian	*Pseudovidrioceras dunbari* *Propinacoceras busterense*	*Mesogondolella idahoensis* *Neostreptognathodus pnevi-* *N. exculptus*	*Misellina claudiae* *Brevaxina dyhrenfurthi*		272.2 ± 3.2
PERMIAN	Cisuralian	Artinskian	*Uraloceras fedorowi* *Aktubinskia notabilis-Artinskia artiensis*	*N. pequopensis* *Sweetognathus whitei-* *M. bisselli*	*Pamirina* *Charaloschwagerina vulgaris*		280.3 ± 2.6
PERMIAN	Cisuralian	Sakmarian	*Sakmarites inflatus* *Svetlanoceras strigosum*	*S. primus* *Streptognathodus postfusus*	*Robustoschwagerina schellwieni* *Sphaeroschwagerina sphaerica*		
PERMIAN	Cisuralian	Asselian	*S. serpentinum* *S. primore*	*S. constrictus* *S. isolatus*	*S. moelleri- P. fecunda* *S. vulgaris*		290.6 ± 3.0
Carboniferous		Gzhelian	*Shumardites confessus-Emilites plummeri*	*S. wabaunsensis* *S. elongatus*	*Daixina robusta-D. bosbytauensis* *T. stuckenbergi*		300.3 ± 3.2

Figure 2 An integrated chronostratigraphic scheme for the Permian System.

The stratigraphic ranges of fossils zones reflect a general version of respective series and stages but are mainly determined based on zonation in their eponymous regions. However, the Kungurian and Guadalupian fossil zones combine the conodont zones and ammonoid assemblages of Southwestern USA with the fusulinid zones of South China.

stratotype in a paleoequatorial region that contains the open marine communities that are largely absent from the eponymous area (Jin, 1996). In July 1996, usage of Cisuralian, Guadalupian, and Lopingian and correlation of their constituent stages by reference to all eponymous areas, except that for the Kungurian Stage, were approved almost unanimously in a formal postal ballot of SPS Titular Members. Thus, the conclusion of the long journey to integrate suitable marine reference successions into a single Permian chronostratigraphic scheme is near.

Chronostratigraphic subdivisions

The basal boundary of the Permian System and of the coincident Asselian Stage has been officially ratified by the ICS, with the GSSP at Aidaralash Creek, northern Kazakhstan. It is defined by the first appearance of the conodont *Streptognathodus isolatus* slightly below the contact of the ammonoid genozones of *Shumardites-Vidrioceras* below, and *Svetlanoceras–Juresanites* above, and corresponding approximately to the base of the fusulinacean *Sphaeroschwagerina vulgaris–S. fusiformis* Zone (Davydov et al., 1995).

For the upper boundary of the Permian System, both the original definition for the base of the Triassic, the Buntsandstein of Germany, and the top of the Permian in the Urals are non-marine, and therefore unsuitable for worldwide correlation. The functional definition for the base of the Triassic has therefore been the base of the ammonoid *Otoceras* Zone of the Himalayas (Griesbach, 1880). The first appearance of the conodont *Hindeodus parvus* has been proposed as a more widespread and precise basis for primary definition of this boundary level (Yin et al., 1988), and has found general acceptance. Responsibility for formalization of this definition and of the coincident top of the Permian System lies with the Subcommission on Triassic Stratigraphy.

Cisuralian Series

The name Cisuralian was proposed by Waterhouse (1982) to comprise the Asselian, Sakmarian, and Artinskian Stages. In the present scheme, it also includes the Kungurian, and therefore corresponds to the Lower Permian of a Russian proposal (Licharew, 1966; Kotlyar and Stepanov, 1984) and to the Rotliegendes of Harland et al. (1990). The Uralian Series, named by de Lapparent in 1900 and interpreted by Gerasimov (1937) to include pre-Kungurian stages of the Lower Permian, was utilized by Jin et al. (1994a). However, it is a name that is confused by varied historic usage, and we suggest replacement with the Cisuralian Series.

The duration of the proposed Cisuralian Series is much greater therefore than the remaining two higher Permian series, and eustatic and biotic changes near the base of the Kungurian Stage are globally significant (Leven et al., 1996). Consequently, the Cisuralian may be further subdivided into two independent series, or two subseries, of which the upper one might be equivalent to the Chihsian/Cathedralian Series of the preceding scheme (Jin et al., 1994a).

Amongst the constituent post-Asselian Cisuralian stages, the Sakmarian was proposed by Ruzhencev (1950, 1951), based on the Kondurovka Section along the Karamuruntau Range of the Sakmara River Valley. In the absence of ammonoids, the lower boundary was defined at the base of the Karamurunsk Suite by fusulinaceans of the *Pseudofusulina moelleri* Zone and coincides with the *Eoparafusulina* Genozone. In reference to conodont zonation, it is placed at the base of the *Streptognathodus postfusus* (=*S. barskovi*) Zone, which is coincident with the base of the Shikhanskian Horizon. The stage is subdivided into lower (Tastubian) and upper (Sterlitamakian) substages, the boundary between them coinciding in the Southern Urals with the bases of the fusulinacean *Pseudofusulina urdalensis* Zone, the conodont *Sweetognathus primus* Zone, and the ammonoid *Sakmarites inflatus* Zone (Figure 2).

The Artinskian Stage was proposed by Karpinsky in 1874, with the sandstone of the Kashkabash Mountain on the right bank of the Ufa River near Arty Village as the stratotype for its upper part and with the Kondurovka Section for its lower part. Ruzhencev defined the lower part of the stage by reference to ammonoids from the Kondurovk Suite of the Sterlitamakian, but the lower boundary of the Artinskian is now placed above this interval (Chuvashov et al., 1993). It is defined primarily on occurrence of species of *Pseudofusulina*, as ammonoids of the upper Sakmarian (Sterlitamakian) and lower Artinskian are similar. We suggest redefinition of the base of the Artinskian, on conodonts, at the base of the *Sweetognathus whitei* Zone, that is the base of the Bursevsky Horizon.

The Kungurian Stage was restricted formerly to the Philipovian and Irenian horizons of the type area. However, Chuvashov (1994) proposed redefinition of the lower boundary at the base of the Sarginskian Horizon, originally included within the Artinskian Stage. This is a readily correlatable level, marked by the first appearances of the fusulinacean *Parafusulina*. In the present scheme, the base of the *Neostreptognathodus pnevi* Zone of the Saraninsk Horizon is selected for definition, as it represents the first significant evolutionary event following the introduction of *N. pequopensis*, which occurs below a major sequence boundary. The corresponding Tethyan conodont zone is characterized by the occurrence of *N. exsculptus* in the upper part of fusulinacean *Pamirina* Zone of South China (Zhu and Zhang, 1994), and in the basal part of the Cathedralian of North America.

Menning (1993) referred the Permian magnetostratigraphic chrones to two superchrones, the Carboniferous–Permian Reversed Superchrone (CPRS) and the Permian–Triassic Mixed Superchrone

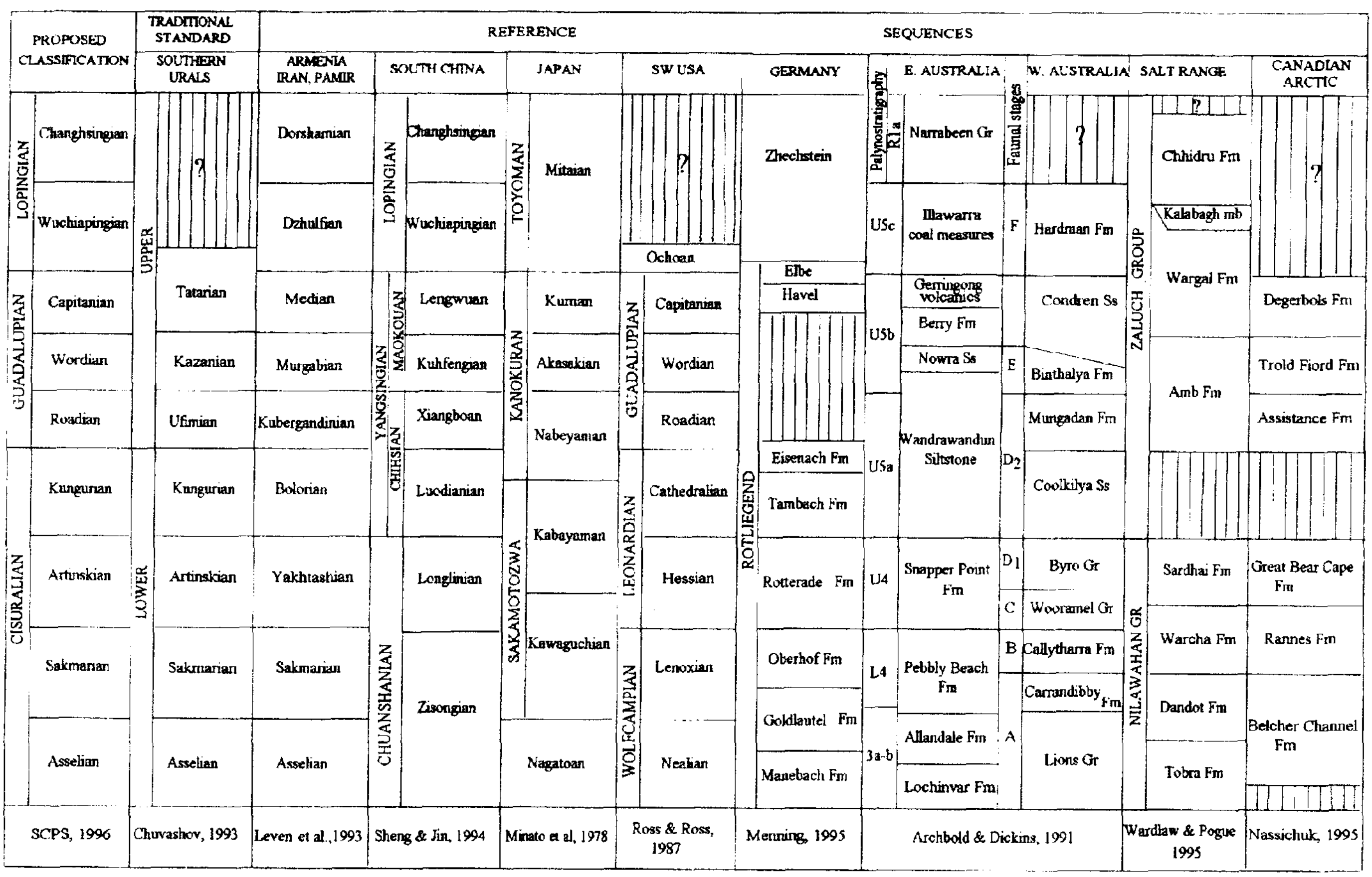

***Figure 3** Correlation of selected Permian successions. The regional successions are adopted from the following authors' contributions: Germany from Menning (1995); Southwestern USA from Ross and Ross (1987); Western and Eastern Australia from Archbold and Dickins (1991); the Urals from Chuvashov (1993), the Salt Range from Wardlaw and Pogue (1995), the Kitakami Mts. of Japan from Minato et al. (1978) and the Arctic from Nassichuk(1995).*

(PTMS). He integrated five normal zones in the Permian part of the CPRS, as shown in the present Figure 2. However, the biostratigraphic control of the integration of three Asselian normal zones cannot be considered as robust. Moreover, no normal zone has been recognized from Asselian strata of the Southern Urals; instead, there are four normal zones from the uppermost Carboniferous (Davydov et al., 1992).

Dating of samples from the Urals suggests that the age of the mid-Asselian is 290.6 ± 3.0 Ma, and that the Sakmarian–Artinskian boundary is 280.3 ± 2.6 Ma. Additionally, samples from the Branxton Formation of eastern Australia, considered early Kungurian, are dated as 272.2 ± 3.2 Ma (Roberts et al., 1996). Based upon the above data, the ages of the basal boundaries of the Asselian, Sakmarian, Artinskian and Kungurian stages are estimated respectively as 292, 285, 280, and 272 Ma.

Guadalupian Series

The base of the Guadalupian Series in West Texas is defined by the first appearance of *Jinogondolella nankingensis* within the evolutionary cline from *Mesogondolella idahoensis* to *J. nankingensis* displayed in the El Centro Member of the Cutoff Formation in Stratotype Canyon, Guadalupe Mountains (Glenister et al., 1992; Lambert and Wardlaw, 1996).

The Guadalupian comprises three stages, Roadian, Wordian, and Capitanian. The proposed boundary for the base of the Wordian Stage is the first appearance of *Jinogondolella aserrata* in the upper limestone beds of the Getaway Member of the Cherry Canyon Formation. This level is slightly higher than the first occurrence of the cyclolobid ammonoid *Waagenoceras* at the base of the Brushy Canyon Formation.

The Capitanian Stage could be defined by the first appearance of *Jinogondolella postserrata* in the upper part of the Pinery Limestone Member of the Bell Canyon Formation (Figure 1). This marks the first significant evolutionary event after the major sequence boundary that divides the Goat Seep from the Capitan reef (shelf) and the Cherry Canyon from the Bell Canyon Formation (slope and basin), and corresponds to the changeover from *Parafusulina*-dominated to *Polydiexodina*-dominated fusulinacean faunas and the occurrence of the ammonoid *Timorites*. Recent studies on the Guadalupian/Lopingian Series boundary have revealed an evolutionary lineage from *Protoclarkina crofti* to *Clarkina postbitteri* (Wardlaw and Mei, in press).

In its type locality in south China, *Jinogondolella nankingensis* was described from the Kuhfeng Formation of Wordian age, occurring with the cyclolobid ammonoid *Shengoceras* (subjective senior synonym of *Kufengoceras*); its lowest occurrence is the *Praesumatrina neoschwagerinoides-Neoschwagerina simplex* Zone, a level corresponding to the base of the Murgabian Stage. The stratigraphic range of the Roadian ammonoid fauna in Central Asia needs clarification, as it has been referred to the Kubergandinian (Bogoslovskaya and Leonova, 1994) as well as the *N. simplex* Zone, the latter generally regarded as basal Murgabian (Kotlyar and Pronina, 1995).

The sequence boundary just below the base of the Guadalupian Series appears to represent a global regression that corresponds to the base of the Ufimian Stage of the Urals. Similarly, the sequence boundary that separates the Cherry Canyon from the Bell Canyon Formation (Wordian/Capitanian) appears to be synchronous with the sequence boundary that marks the junction of the Kazanian and Tatarian Stages. Recognition of the Illawarra Magnetic Reversal near the base of the Capitanian and in the early part of the Tatarian Stage supports this apparent synchroneity.

Magnetostratigraphic sequences of the early Guadalupian represent the upper part of the Carboniferous-Permian Reversed Superchrone, whereas those of the upper Guadalupian belong in the Permian-Triassic Mixed Superchrone. The stratigraphic level of the Illawarra Reversal will eventually serve as a critical marker in global correlation, but to date has been recognized with precise biostratigraphic control in only two marine sections. It is located in the top part of the Maokou Formation in South China (Heller et al., 1995), and in the basal part of the Wargal Formation of the Salt Range (Haag and Heller, 1991), corresponding respectively to the *Neoschwagerina margaritae* Zone and the *Jinogondolella aserrata* Zone of the late Guadalupian. Menning has completed sampling to locate the Illawarra Reversal in the Guadalupian type area. Two and possibly three normal zones are present in the late Guadalupian.

The age of the Guadalupian basal boundary has been estimated as young as 256 Ma by Harland et al. (1990) and 258 Ma by Odin and Odin (1990). Recently Menning (1995) suggested the age to be 272 Ma. New age dates of zircons from a bentonite bed just below the suggested base for the Capitanian proposed stratotype (Wardlaw and Rohr, 1996) have yielded a reliable date of 264 ± 2 Ma (Bowling, personal communication, 1996). The estimates of Harland et al. (1990) and Odin and Odin (1990) are clearly in error. We suggest a more reliable estimation might be between the suggested age for the base of the Kungurian (272 Ma) and the newly established age for the top of the Wordian (264 Ma), approximately 269 Ma.

Lopingian Series

The Lopingian (Huang, 1932), Dzhulfian (Furnish, 1973), Transcaucasian and Yichangian (Waterhouse, 1982), as well as other references, have been proposed for the uppermost Permian series. Of these, the Lopingian appears to be the first formally designated series name to be based on a relatively complete marine sequence. Recent documentation of a comprehensive succession of conodont zones from the Capitanian through the Wuchiapingian Stage in the Lopingian of South China has greatly enhanced the qualifications of the Lopingian and its constituent stages as the international standard for the upper series of the Permian (Jin et al., 1993; Mei et al., 1994a, 1994b, 1994c). The base of the *Clarkina postbitteri* Zone represents the change from *Jinogondolella*-dominated faunas below to *Clarkina*-dominated faunas above, and therefore constitutes a most attractive level for the Guadalupian–Lopingian boundary (Jin et al., 1994c; Wardlaw and Mei, in press). This boundary is to be established within the top part Bed 19 in the Penglaitang section, Laibin County of Guangxi. The *C. postbitteri* conodont zone corresponds approximately to the ammonoid *Roadoceras-Doulingoceras* Zone (Zhou, 1987).

The Lopingian Series comprises two stages, Wuchiapingian and Changhsingian. Zhao et al. (1981) formally proposed the D Section in Meishan of Changxing County as the stratotype of the Changhsingian Stage. The lower boundary is located at the base of Bed 2 that separates the *Clarkina orientalis* Zone below from the *Clarkina subcarinata* Zone above. The basal part of this stage is also marked by the occurrence of the advanced forms of *Palaeofusulina*, and the ammonoid families Tapashanitidae and Pseudotirolitidae. The Dzhulfian and Dorashamian Stages of Transcaucasia correspond respectively to the Wuchiapingian and Changhsingian. However, the successions in the basal part of the Dzhulfian Stage and the top portion of the Dorashamian Stage are not as well developed in their type areas as corresponding intervals in the standard succession of South China (Iranian–Chinese Research Group, 1995).

The Tatarian of the traditional Urals standard corresponds to the uppermost Guadalupian and the Lower Lopingian, since the Illawarra Reversal appears in the basal part of both the Tatarian and the Capitanian (Menning, 1993). Lopingian marine deposits in Pangea are characterized by the occurrence of the *Cyclolobus* ammonoid fauna, as confirmed by associated Lopingian conodonts and foraminifers in the Salt Range (Wardlaw and Pogue, 1995).

The Lopingian part of the PTMS is based on data from South China and the Salt Range. A normal zone is recognised near the base of the Wuchiapingian, and another near the top (Heller et al., 1995). In addition, five distinct normal zones were reported from the Changhsingian strata in both the Meishan and Shangsi sections of South China (Li and Wang, 1989).

The age of Permian–Triassic boundary has been reported as 251.1 ± 3.6 Ma based on a SHRIMP zircon age of the boundary clay of the Meishan Section (Claoué Long et al., 1991), and as 249.9 (1.5 Ma based on $^{40}Ar/^{39}Ar$ dating of sanidine from the same horizon

(Reno et al., 1995). Recent studies show that the age of the tuff beds at the base of the Changhsingian Stage in South China is around 253 Ma (Bowling, personal communication, 1997).

Conclusions

It has taken two decades for the Subcommission on Permian Stratigraphy to achieve agreement on the names and boundary levels of series and stage boundaries. Despite remaining minor differences of opinion, the proposed scheme enables the Subcommission to proceed with the selection of Global Stratotypes for intra-systemic boundaries. It permits correlation of Permian marine sequences, throughout the world, with higher resolution than achievable previously (Figure 3). However, proposed boundary levels will still be subject to change after further test of their correlation potential, which continues to constitute the basic strength of any general scheme.

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