CAMBRIAN CORRELATION WITHIN THE PERIGONDWANA FAUNAL REALM

Wen T. CHANG

Nanjing Institute of Geology and Palaeontology. Academia Sinica. Chi-Ming-Ssu. 39 East Beijing Road. Nanjing. 210008. P. R. China.
E-mail: wtchang@juno.com

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ABSTRACT

Stratigraphic positions of Redlichioidea trilobites found in the Lower Cambrian of Morocco, Spain, South France, Sardinia, Jordan, Doberlug and Görlitz (both in Germany), and those from Central Asia, Himalayan region, Australia and Antarctica are correlated with that of the Chinese biostratigraphic scheme.

During the Middle Cambrian, biostratigraphic correlation between the Mediterranean region (including Morocco and Central Europe) and China is very difficult because of the complete absence of *Paradoxides*-fauna in China. Based on shallow-shelf and open-shelf trilobite faunas, the Middle and Upper Cambrian biostratigraphy of the Near East, Central, South and Southeast Asia, Australia and Antarctica are correlated with that of both China's shallow-shelf and open-shelf biostratigraphic schemes. Late Cambrian trilobite faunas of eastern Asiatic affinities also occur in Morocco, Spain, South France and Turkey. So far, there is no trilobite fauna of the Late Cambrian Fengshanian Stage found in Europe.

Key words: Cambrian, trilobites, biostratigraphic correlation, Perigondwana Faunal Realm.

RESUMEN

Se correlacionan las posiciones estratigráficas de los trilobites Redlichioidea del Cámbrico Inferior de Marruecos, España, sur de Francia, Cerdeña, Jordania, Doberlug y Görlitz (ambos en Alemania), así como las de Asia central, Himalaya, Australia y la Antártida, con el esquema bioestratigráfico de China.

Dada la completa ausencia de la fauna de *Paradoxides* en China, la correlación bioestratigráfica entre el área mediterránea (incluyendo Marruecos y España) y China es muy difícil para el Cámbrico Medio. Por medio de trilobites de facies nerítico-sublitoral somera y nerítico-sublitoral abierta se correlaciona la bioestratigrafía del Cámbrico Medio y Cámbrico Superior de Oriente próximo, Asia central, meridional y suroriental, Australia y la Antártida con las escalas bioestratigráficas de China, tanto para facies someras como abiertas. También aparecen faunas de trilobites del Cámbrico Tardío de afinidades asiáticas orientales en Marruecos, España, sur de Francia y Turquía. Hasta el momento, no se han encontrado en Europa trilobites del Piso Fengshaniense del Cámbrico Tardío.

Palabras clave: Cámbrico, trilobites, correlación bioestratigráfica, Reino faunístico de Perigondwana.

INTRODUCTION

In Southwest China the Lower Cambrian succession with rich trilobite faunas has been divided into 14 zones within four stages, which may be used as a correlation standard for the Lower Cambrian of the Redlichian Realm. It seems impossible to discuss the precise Middle Cambrian correlation between China and the Mediterranean region, because the Paradoxidid fauna which dominated over this area is absent in China, southern Asia, Australia and Antarctica. During the Late Cambrian a few Upper Cambrian trilobite genera of eastern Asiatic affinities occur in Morocco, Spain, southern France, Turkey, Iran, Oman, Afghanistan, the Himalayan region and Thailand.

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(Fig. 1). The Precambrian-Cambrian boundary beds of Morocco have been studied in detail by Hupé (1953) and Sdzuy (1978) and many important earliest Cambrian fossils including trilobites have been collected. Among them *Lemdadella* is the oldest Cambrian trilobite so far known from the Lemdad area of Morocco. This genus is intimately related to *Eoredlichia* (Chang, 1984), which is a senior synonym of *Pararedlichia*, which occurs in the *Fallotaspis tazemmourtensis* Zone of Morocco (Pillola, 1991). *Lemdadella* occurs in the basal part of the *Calcaire Supérieur*, or in the uppermost part of the *Série Lie de Vin*. It seems reasonable that the *Fallotaspis tazemmourtensis* Zone together with *Calcaire Supĕrieur* should be equivalent to the *Eoredlichia-Wutingaspis* Zone in China. Genera referred to the Gigantopygidae and Saukiandidae (*Saukianda*, *Longianda*) from Amouslekien up to Tasousekhtien (upper Issendalen to Bani Stages of Geyer, 1990) in Morocco fall within the Chinese Tsanglangpuan Stage. The Moroccan Aguilizien (Tissafin Stage of Geyer, 1990) may be correlated with the Lungwang-miaoan Stage in China, but there is no palaeontological evidence. The Toushamian and Tissafinian Stages (Geyer and Landing, 1995) in Morocco include so many *Paradoxides* and ptychoparioid trilobites having typical European affinities, that the exact correlation of the Middle Cambrian between Morocco, Spain, South France, Sardinia, Bohemia, Turkey and China is very difficult. The *Bailiella* and *Olentella* Zones of Morocco mentioned by Geyer and Landing (1995) may tentatively be correlated with the *Bailiella* Zone of the Middle Cambrian Hsuchuangian Stage and the Upper Cambrian Changshanian Stage respectively.

In Spain, *Pararedlichia* is found in Hermida (province of Lugo) and Concha de Artedo (province of Oviedo), northern Spain (Liñán and Sdzuy, 1978); *Dolerolenus*, *Lunolenus* and *Metadoxides* from the *Niveau I* in Los Barrios de Luna (León province), also northern Spain (Lotze, 1961); and *Lemdadella linaresae* from the Pedroche Formation of Córdoba; they are very similar to the *Lemdadella-Pararedlichia* fauna of Morocco. Therefore Zone I of Hupé (1953) together with the *Calcaire Supérieur* of Morocco should be equivalent to the Pedroche Formation of Córdoba and to *Niveau I* of Lotze (1961: 466) in Spain. Both are regarded as correlative with the Lower Cambrian Chiungchussuan Stage of China. The *Perrector* and *Saukianda* faunules from Alanís (Sevilla province), south-western Spain, can more reliably be correlated with the B3 of the Banian Stage in Morocco (Geyer and Landing, 1995), which is equivalent to the Chinese Tsanglangpuan Stage. The presence of *Redlichia* at Huérmeda, near Calatayud (Zaragoza province), north-eastern Spain, suggests a late Tsanglangpuan age. A faunule comprising *Pagodia*, *Lajishanaspis*, *Langyashania* and *Maladioidella* from NE Spain (Shergold, Liñán and Palacios, 1983; Shergold and Sdzuy, 1991) indicates regional affinities with the Upper Cambrian Changshanian Stage.

Lower Cambrian sediments of the Montagne Noire, southern France, consist of the *Grès de Marcory* (base) overlain by the *Alternances gréso-calcaires* which in turn is overlain by the *Masse carbonaté*. Trilobites, *Galloredlichia*, *Granolenus* and *Limouolenus* occur in the three clastic members of the *Alternances gréso-calcaires*. These trilobites are Chiungchussuan because *Galloredlichia* is a junior synonym of *Eoredlichia* (Chang, 1984; Pillola, 1991). *Ferralsia* Cobbold, 1935 from the late Lower Cambrian in South France is intimately related to *Palaeolenus*, or *Pseudoprotolenella* of Southwest China in cranidial and glabellar shape and in the glabellar furrows and may be a junior synonym. *Palaeolenus* is widely distributed in the late Tsanglangpuan Stage in Southwest China. Therefore the bed yielding *Ferralsia* in South France is of Tsanglangpuan age. *Chelidonocephalus* in the Middle Cambrian of South France is of both stratigraphic and biogeographic significance, because it is a genus of slope biofacies in the late Middle Cambrian of North Iran and because it also occurs in association with *Paradoxides* in Southeast Turkey. It is very interesting to note that *Bergeronites* and *Prochuangia* have been reported and illustrated in South France (Feist and Courtessole, 1984). The writer has already pointed out that specimens found from South France should be referred to *Palaeadotes* Öpik, 1967 rather than to *Bergeronites* Sun *in* Kuo, 1965 (Chang, 1989; 1996). *Bergeronites* is a shallow water endemic genus and is confined to the North China Platform, whereas *Palaeadotes*, a pandemic genus, appeared in the slope biofacies of Antarctica, Australia, North and South Europe, Turkey, Iran, Kazakhstan, Northern Siberia and China. With regard to *Prochuangia*, we do not know whether this genus occurs in association with *Palaeadotes*, or whether its stratigraphic position may be slightly higher than *Palaeadotes*. In China, *Prochuangia* usually occurs in the basal part of the Upper Cambrian Changshanian Stage. The bed yielding *Palaeadotes* in South France should be of Kushanian age.

The Lower Cambrian biostratigraphy and the trilobite fossils of Sardinia have been studied in detail (Rasetti, 1972; Pillola, 1991). Three groups, six formations and five trilobite zones are in descending order as follows:

3. Iglesias Group
    Cabitza Formation
    Campo Pisano Formation
2. Gonnesa Group
    San Giovanni Formation
    Santa Barbara Formation
1. Nebida Group
    Punta Manna Formation
        Dolerolenus bifidus Zone
        Dolerolenus zoppii Zone
        Dolerolenus longioculatus Zone
    Matoppa Formation
        Dolerolenus aff. *courtessolei* Zone
        Iglesiella ichnusae Zone

CHINA	MOROCCO (Geyer & Landing, 1995)	SPAIN (Liñán & Sdzuy, 1978; Shergold *et al.*, 1983; Shergold & Sdzuy, 1991)	S. FRANCE (Courtessole & Jago, 1980; Courtessole *et al.*, 1971, 1988; Feist & Courtessole, 1984)	SARDINIA (Rasetti, 1972; Pillola, 1991)	GERMANY (Sdzuy, 1962; Geyer & Elicki, 1995)	TURKEY (Dean, 1982; Shergold & Sdzuy, 1984; Dean & Özgül, 1994)
FENGSHANIAN	▨	?	?	?	?	?
CHANGSHANIAN	▨ *?Olentella*	*Pagodia, Lajishanaspis, Langyashania, Maladioidella, Parachangshania*	*Prochuangia*			*Maladioidella*
KUSHANIAN	▨	?	*Palaeadotes*			*Prochuangia* *Palaeadotes*
CHANGHIAN	▨	*Paradoxides*-Ptychoparioid fauna of southern Europe	*Chelidonocephalus*	?	?	SOSINK Fm. *Peronopsis, Conocoryphe, Dorypyge, Badulesia, Chelidonocephalus, Derikaspis, Paradoxides, Eccaparadoxides* (SE Turkey) *Protolenus, Acadoparadoxides mureroensis, Latoucheia* (SW Turkey)
HSUCHUANGIAN	*Bailiella* TOUSHAMIAN Stage					
MAOCHUANGIAN	TISSAFINIAN Stage					
LUNGWANGMIAOAN			*Ferralsia*	*Protolenus*		?
TSANGLANGPUAN *Megapalaeolenus* Zone *Palaeolenus* Zone *Drepanuroides* Zone *Yunnanaspis* Zone *Yiliangella* Zone *Malungia* Zone	BANI Stage *Gigantopygus* (B3) *Longianda* (B3) *Richterops* (B3) *Resserops* (B3)	*Redlichia* (Huérmeda, NE Spain) *Perrector, Saukianda* (Sevilla)		PUNTA MANNA Fm. *Lungduia, Sardaspis, Yiliangella, Metadoxides, Dolerolenus*	*Lusatiops*, "*Holmia*", *Ferralsia* (Görlitz)	
CHIUNGCHUSSUAN *Eoredlichia-Wutingaspis* Zone *Parabadiella* Zone	ISSENDALENIAN Stage *Abadiella* (A4) *Pararedlichia* (A2) *Lemdadella* (A1 ?)	*Lunolenus, Metadoxides, Dolerolenus* (L. B. Luna) *Eoredlichia* (Oviedo and Hermida, N Spain) *Lemdadella* (Córdoba)	*Galloredlichia* (=*Eoredlichia*)	MATOPPA Fm. *Iglesiella, Metadoxides, Eoredlichia, Wutingaspis*	*Dolerolichia* (Doberlug)	
MEISHUCUNIAN						

Figure 1. Cambrian correlation between China, the Mediterranean region and Central Europe.

The Gonnesa and Nebida Groups are Lower Cambrian, while the Iglesian Group represents the Middle and Upper Cambrian (Pillola, 1991). The boundary between Lower and Middle Cambrian is drawn at a level within the lower part of the Campo Pisano Formation because specimens of typical Lower Cambrian trilobite *Protolenus* occur in the basal part of this formation. Judging by the stratigraphical range of those Lower Cambrian trilobites, the Punta Manna and Matoppa Formations fall within the late Chiungchussuan and early Tsanglangpuan or from *Eoredlichia-Wutingaspis* Zone up to the *Drepanuroides* Zone. *Iglesiella* closely resembles Chinese *Metaredlichia*, and *Dolerolenus (Malungia)* first appears in the upper part of the *Eoredlichia-Wutingaspis* Zone and goes up as high as the basal Tsanglangpuan. Genera such as *Sardaspis*, *Longduia* and *Yiliangella* in the Punta Manna Formation of Sardinia, are members of the *Yiliangella* to *Drepanu-roides* Zones of the early Tsanglangpuan. The Gonnesa Group and the basal part of the Campo Pisano Formation may be correlated with the late Tsanglangpuan and the whole Lungwangmiaoan, but direct palaeontological evidence is absent.

Dolerolichia from Doberlug ca. 90 km south of Berlin (Sdzuy, 1962) is closely related to *Eoredlichia* in the outline of cranidium and presence of preocular facial lines, but differs from the latter in having longer (exsag.) palpebral lobe and a larger multisegmented pygidium. This genus should be referred to the Saukiandidae and is of the same age as the *Lemdadella-Pararedlichia* fauna in Morocco. Doberlug is the northernmost occurrence of Redlichioid trilobites in Europe. At Görlitz, near the border between Germany and Poland, Richter and Richter (1941a) described a Lower Cambrian trilobite faunule which contains *Lusatiops* and *Serrodiscus*. Little was known of the age relationship of this faunule until Geyer and Elicki (1995) discovered *Ferralsia* and *"Holmia"* in association with the *Lusatiops* faunule at Görlitz (ca. 100 km southeast of Doberlug). As mentioned above, *Ferralsia* is similar to *Palaeolenus*, and the trilobites from Görlitz should be Tsanglangpuan.

In Turkey, Lower Cambrian trilobites are unknown. In southwest Turkey, early Middle Cambrian *Acadoparadoxides mureroensis*, *Protolenus*, *Latoucheia* and *Corynexochella* occur (Dean and Özgül, 1994). In southeast Turkey, the Sosink Formation contains *Paradoxides*, *Eccaparadoxides*, *Dorypyge*, *Chelidonocephalus*, *Derikaspis*, *Badulesia*, *Peronopsis* and *Conocoryphe*, which indicate a late Middle Cambrian age (Shergold and Sdzuy, 1984). *Palaeadotes* and *Prochuangia*, which also occur in Turkey (W. T. Dean, personal communication) have close affinities with the same faunule in South France, indicating the Kushanian. The *Maladioidella* and *Pseudagnostus* faunule of Shergold and Sdzuy (1984) is Changshanian.

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(Fig. 2). *Redlichops* from the Dead Sea shore (Richter and Richter, 1941b) probably occurs in the same horizon as *Lemdadella* or *Pararedlichia* from Morocco or Spain because the posterior tip of the palpebral lobe of this genus is distant from the glabella, the palpebral lobe shorter than that of *Redlichia*, and the anterior section of facial suture relatively short and divergent, which are the primitive characters of the Redlichiidae. In the Dead Sea area, trilobites younger than *Redlichops*, such as *Resserops*, *Myopsolenus*, *Kingaspis* and *Strenuella* (Parnes, 1971) show affinities with the Mediterranean region, and are probably Tsanglangpuan or Lungwangmiaoan or both, but direct palaeontological evidence is lacking. The Lower Cambrian trilobite fauna from Jordan and Israel is different from that of Iran, Pakistan, Himalaya and China.

A late Cambrian trilobite succession from the Sultanate of Oman (Fortey, 1994), contains Fauna A, B, and C. Fauna A comprises *Dipyrgotes* and *Torifera.* Judging from the illustrations, the fragmentary specimen of a spinose pygidium should be referred to *Fengduia* (Zhu *in* Lu *et al.*, 1974) rather than *Dipyrgotes. Fengduia* is a typical Damesellidae and occurs in the Kushanian of eastern Sichuan and southwestern Hubei (Lu *et al.*, 1974: 106, pl. 42, figs. 5-9). Fortey's Fauna B contains *Afghanocare*, *Prochuangia*, *Yokusenia* and *Maladioidella*, of which the first three genera fall within the *Chuangia* Zone (*s. l.*) and the last within the younger *Maladioidella* Zone, both referred to the Changshanian. The *Eosaukia* trilobites of Fauna C are regarded as being pre-Tremadoc Fengshanian in age by Fortey.

The Cambrian trilobites of Iran have been studied by King (1930, 1937), Kushan (1973), Wolfart (1974a, b), Fortey and Rushton (1976) and Wittke (1984). Lower Cambrian deposits crop out in the Isfahan region and Kerman areas, of southwestern and southeastern Iran respectively. Middle and Upper Cambrian rocks occur in the Alborz Mountains, northern Iran. To the east of the Sultanate of Oman and Iran, the Cambrian faunas are all of east Asiatic affinities, including the Middle Cambrian. Therefore, it seems easy to correlate the Iranian Cambrian trilobite sequences with those of the current Chinese Cambrian biostratigraphic scheme. The Cambrian trilobite sequences of Iran are briefly summarized here, proceeding from the youngest faunas to the oldest as follows: 1. *Saukia* Zone, 2. *Alborsella* Zone, 3. *Maladioidella* Zone, 4. *Prochuangia-Paracoosia* Zone, 5. *Palaeadotes-Torifera* Zone, 6. *Dorypyge-Chelidonocephalus* Zone, 7. *Iranoleesia* Zone, 8. *Kermanella* Zone and 9. *Redlichia* Zone. Of which Zones 1 and 2 are regarded as Fengshanian; Zones 3 and 4 Changshanian; Zone 5 Kushanian. It seems necessary to point out that *Spinopanura* (Kushan, 1973) is a junior synonym of *Palaeadotes.* According to the range of *Dorypyge*, Zone 6 is late Changhian. With regard to Zone 7, the nominate *Iranoleesia* (Reed, 1934; Kobayashi, 1967: 493) is very similar to the Chinese *Proasaphiscus* (Resser and Endo *in* Endo and Resser, 1937). This Chinese genus has a stratigraphic range from Hsuchuangian to basal Changhian. Therefore Zone 7 is provisionally correlated with the late Hsuchuangian. Based on *Kermanella kuhbananensis* as the type species, Wolfart (1974a)

CHINA	DEAD SEA (Richter & Richter, 1941b; Parnes, 1971)	OMAN (Fortey, 1994)	IRAN (King, 1937; Kushan, 1973; Wolfart, 1974a, b; Wittke, 1984)	AFGHANISTAN (Wolfart, 1974b)	PAKISTAN (Schindewolf & Seilacher, 1955)	KASHMIR and SPITI (Reed, 1910; Jell, 1986; Whittington, 1986; Kumar & Verma, 1987)	THAILAND and MALAYSIA (Kobayashi, 1957; Shergold *et al.*, 1988)
FENGSHANIAN	?	*Eosaukia*	*Saukia* *Alborsella*	?	▥	?	*Eosaukia*, *Lophosaukia*, *Shergoldia*, *Micragnostus* (base not exposed)
CHANGSHANIAN		*Maladioidella* *Yokusenia* *Prochuangia*	*Maladioidella* *Prochuangia*				
KUSHANIAN		*Torifera* *Fengduia*	*Torifera* *Palaeadotes*	*Torifera*, *Airaspis* *Blackwelderia*		*Blackwelderia* *Monkaspis*	
CHANGHIAN	?	?	*Chelidonocephalus-Dorypyge*	?		*Lejopyge laevigata* *Fuchouia*	
HSUCHUANGIAN			*Iranoleesia*			*Bailiella* *Tonkinella* *Hundwarella* *Pagetia* *Oryctocephalus*	?
MAOCHUANGIAN			*Kermanella*		*Chittidilla*		
LUNGWANGMIAOAN	*Kingaspis* *?Myopsolenus* *Comluella* *Myopsolenus* *Strenuella* *Resserops* *Redlichops*	?	*Redlichia*	?	Neobolus Shale *Redlichia* Purple Sandstone	*Redlichia* *Paokannia* ?	
TSANGLANGPUAN							
CHIUNGCHUSSUAN					Saline Series ?		
MEISHUCUNIAN			Middle Dolomite Mb. (Soltanieh Fm.)				

Figure 2. Cambrian correlation between China, Near East and South Asia.

erected the genus *Kermanella* in the Ptychopariidae. In addition to the type species, *K. lata* is also referred to *Kermanella* (Wolfart, 1974a). Judging from the illustrations of Wolfart (1974a: pl. 8, figs. 1-2), *K. lata minuta* is close to *Chittidilla* of the Salt Range, Pakistan, and specimens of the same genus (Wolfart, 1974a: pl. 7, figs. 4a, 5a) are characteristic of the Chinese *Kunmingaspis*. Because both *Chittidilla* and *Kunmingaspis* are important component members of the early Middle Cambrian Maochuangian Stage, the *Kermanella* Zone is correlated with this stage. The oldest *Redlichia* Zone so far known in Iran may be regarded as late Tsanglangpuan. Cambrian fossils including trilobites and small shelly fossils which are older than the *Redlichia* fauna occur in northern parts of Iran. If the trilobites *Eoredlichia* and *Wutingaspis* occur in the Upper Shale Member of the Soltanieh Formation in the Dalir-Valiabad region, north of Tehran, the beds yielding those trilobites may correspond with the Chiungchussuan Stage; the Middle Dolomite Member, underlying the Upper Shale Member of the same formation, may be regarded as Meishucunian (Hamdi, 1989; Hamdi *et al.*, 1989).

In the Kohe Taraka and Surkh Bum areas, Afghanistan, Cambrian trilobites including *Torifera*, *Airaspis* and *Blackwelderia* (Wolfart, 1974b) resemble Kushanian faunas in eastern Sichuan, southwestern China (Zhu *in* Chang *et al.*, 1980).

The Cambrian sequences in the Salt Range, Pakistan and in Yunnan, Southwest China correspond closely lithologically and contain the same sequence of fossils (Chang, 1981). The Salt Pseudomorph Beds are composed of purple shales and sandstones and contain *Chittidilla plana* King, 1941 and some brachiopods. The Douposi Formation of Maochuangian age, well exposed in the Wuting and Luquan areas East Yunnan, is also composed of purple sandy shales yielding many specimens of *Chittidilla* (Chang *et al.*, 1980). The Magnesian Sandstones (=dolomite) (Schindewolf and Seilacher, 1955), like the Shanyicun Formation (Luo *et al.*, 1994) of Lungwangmiaoan Stage is dolomite to dolomitic limestone. The upper part of the *Neobolus* Shale contains *Ptychoparia geei* King, 1941, *P. sakesarensis* King, 1941 and *Redlichia noetlingi* (Redlich, 1899) and several different brachiopods including *Botsfordia* (King, 1941). The two species of *Ptychoparia* have been transferred to the late Early Cambrian Chinese *Yuehsienszella* (Chang, 1964). The Wulongqing Formation of the Upper Tsanglangpuan Stage consists of green sandy shales yielding serveral species of *Redlichia* and inarticulate brachiopods. The Hongjiangshao Formation, corresponding to the Purple Sandstone of Salt Range, is composed of purple sandstone and green shales and represents the lower Tsanglangpuan Stage in Southwest China. The only mismatch is between Heilinpu Formation (Luo *et al.*, 1994) and rocks of the Meishucun Stage, which do not contain evaporites, and the Saline Series of Pakistan. Otherwise these two sections exhibit an extremely close correlation on lithologies, thickness and fossil contents (Chang, 1981: tab. 1).

The Cambrian trilobites of Spiti and Kashmir, Himalayan region, were described by Reed (1910, 1934). Lower, late Middle and early Upper Cambrian trilobites have been discovered from Kashmir and Ladakh by Whittington (1986), Jell (1986) and Kumar and Verma (1987). Based on the modern taxonomy of Cambrian trilobites and the current Chinese Cambrian biostratigrapic scheme, seven successive assemblages or faunules in descending order are revised as follows: 7. *Blackwelderia*, 6. *Lejopyge laevigata*, 5.*Bailiella*, 4. *Tonkinella*, 3. *Oryctocephalus-Pagetia*, 2. *Redlichia* and 1. *Paokannia*. The *Blackwelderia* Zone, which contains *Blackwelderia*, *Monkaspis* and *Cyclolorenzella* is reported from the Trahagam Formation near the village of Trahagam, Hundwara, Tehsil, Kashmir. This fauna occurs in green shales and provides the first unequivocal Kushanian in the Himalayan region (Jell, 1986). The *Lejopyge laevigata* Zone contains *Lejopyge laevigata*, *Diplagnostus* cf. *humilis*, *Fuchouia* and *Cyclolorenzella*, and occurs in Zanskar, Ladakh, northern India, ca. 300 km southeast of Trahagam village. This fauna occurs in neighbouring areas, such as Malyj Karatau, southern Kazakhstan; Qurugtagh and Huocheng, both in Xinjiang, western China; western Hunan and western Zhejiang, South China. Undoubtedly it represents a fauna of slope biofacies and of late Middle Cambrian age (Whittington, 1986). *Bailiella* occurs in the Hundwara district, Kashmir, and it has a wide distribution in the late Hsuchuangian on the North China Platform and near the North Vietnam-southeastern Yunnan border (Reed, 1934; Chang, 1988). It is very interesting to note that *Tonkinella* has a wide geographic distribution in Utah, Nevada and Newfoundland (Sundberg, 1994), Kashmir (Reed, 1934; Kobayashi, 1934), North Vietnam (Mansuy, 1912, 1916), southeast Yunnan (Mansuy, 1912, 1916; Luo, 1984), central Shandong, western Henan and southern Liaoning (Chang, 1957; 1988; Chang *et al.*, 1995), North and South Korea (Kobayashi, 1935) and Siberia (Tchernysheva, 1962). In North China the *Poriagraulos* Zone contains species of *Tonkinella*. The superjacent *Bailiella* Zone contains *Ptychagnostus sinicus* Lu, 1957. According to Robison (1984) this agnostoid species is a junior synonym of *Ptychagnostus intermedius* which is an important member of the *Ptychagnostus gibbus* Zone of North America. Judging from the palaeontological evidences mentioned above, the *Bailiella* and *Poriagraulos* Zones should be equivalent to the *Ptychagnostus gibbus* Zone. It should be also mentioned that species of *Tonkinella* from Siberia and North America occur in the same agnostid zone. Therefore species of *Tonkinella* found from Kashmir and Vietnam are of the same age. In eastern Guizhou the beds overlying the *Bathynotus-Redlichia* bearing rocks contain *Oryctocephalus* and *Pagetia* and represent the typical slope bio- and lithofacies in the eastern marginal part of the Yangtze Platform. The beds yelding *Oryctocephalus*, *Pagetia* and ptychoparioids in Kashmir are the equivalent beds of eastern Guizhou, of the *Oryctocephalus* beds in North Korea and central and northern Australia, and of the *Oryctocephalus* Zone of eastern Nevada and western

MALYJ KARATAU S. Kazakhstan (Abdulin *et al.*, 1984)	CHINA	AUSTRALIA (Shergold, 1995)	ANTARCTICA (Cooper & Shergold, 1991)
ORDOVICIAN	ORDOVICIAN	ORDOVICIAN	
		Datsonian Payntonian	Fauna 7
Kazakhstanian Aksaian	Fengshanian	Iverian 4 3 2 1	Fauna 6
Sackian	Changshanian 4 3 2 1	Idamean	Fauna 5
Ayusokkanian	Kushanian	Mindyallan	Fauna 4
Zhanaarykian Tyesaian	Changhian	Boomerangian Undilian Floran	Fauna 3
Amydaian	Hsuchuangian Maochuangian	Templetonian	Fauna 2
Toyonian (*Redlichia*)	Lungwangmiaoan	Ordian	
Botoman (*Palaeolenus*) (*Ushbaspis*)	Tsanglangpuan	*Pararaia janeae* *Pararaia bunyerooensis* *Pararaia tatei* *"Abadiella" huoi*	Fauna 1
Atdabanian (*H. orientalis*)	Chiungchussuan		
Tommotian	Meishucunian		

Figure 3. Cambrian correlation between China, Kazakhstan, Australia and Antarctica. • Fengshanian: 3. *Mictosaukia* Zone; 2. *Changia* Zone; 1. *Tsinania-Ptychaspis* Zone. • Changshanian: 4. *Kaolishania* Zone; 3. *Maladioidella* Zone; 2. *Changshania* Zone (=*Irvingella* Zone); 1. *Chuangia* Zone. • Iverian: 4. *Lophosaukia* Zone; 3. *Hapsidocare* Zone; 2. *Peichiashania* Zone; 1. *Irvingella* Zone.

Canada. The *Oryctocephalus* beds in Kashmir and other parts of the world are early Middle Cambrian. In the Himalayan region the *Redlichia* Zone is regarded as the late Tsanglangpuan Stage and the *Paokannia* Zone (Kumar and Verma, 1987) is the oldest Early Cambrian trilobite zone in the region. *Paokannia* from the Vel Member of the Lolab Formation, Anantnag, 70 km southeast of Srinagar, Kashmir, which occurs in beds underlying *Palaeolenus* Zone in Southwest China, is regarded as early Tsanglangpuan.

Cambrian fossils were discovered in sandstone beds, known as the Tarutao Sandstone, or Formation (=Machinchang Formation in Malaysia) on Tarutao Island, Thailand (Kobayashi, 1957; Shergold *et al.*, 1988). This formation is chiefly composed of purple, brown and micaceous sandstone, with intercalations of thin, argillaceaous tuffaceous beds and light brown siltstone, which represent very shallow waters of a tropical barrier-beach complex, where frequent storms redistributed much of the fauna and sediment. The thickness of Tarutao Sandstone has been estimated at 850 m, but the base is not exposed. The trilobites including species of *Micragnostus*, *Prosaukia*, *Eosaukia*, *Hoytaspis*, *Lichengia*, *Quadraticephalus*, *Parakoldinioidia*, *Szechuanella* and *Shergoldia* (Shergold *et al.*, 1988) are terminal Late Cambrian based on the occurrence of saukiid and leiostegiid genera. The exact age is regarded as equivalent to the *Neoagnostus quassibilobus*/*Shergoldia nomas* Zone of the middle Payntonian, or of the lower part of the *Mictosaukia* Zone of the Fengshanian.

CAMBRIAN CORRELATION BETWEEN CHINA, KAZAKHSTAN, AUSTRALIA AND ANTARCTICA

(Fig. 3). We have discussed the correlation of Cambrian between China and Australia earlier (Chang and Jell, 1987; Chang, 1986). Based on the description of the Early Cambrian trilobites from South Australia (Jell *in* Bengtson *et al.*, 1990), four trilobite zones have been proposed for the Lower Cambrian (in descending order), namely *Pararaia janeae* Zone, *Pararaia bunyerooensis* Zone, *Pararaia tatei* Zone and "*Abadiella*" *huoi* Zone, of which the lower zone could be correlated approximately with the Chiungchussuan Stage of China, while the upper three zones with the Tsanglangpuan Stage. The highest trilobite occurrence at the top part of Wirrealpa Limestone in South Australia is of *Redlichia* *guizhouensis*, that resembles *Redlichia chinensis* Walcott, 1905 in many respects, and *Onaraspis* from the Moodlatana Formation may correlate with the Lungwangmiaoan Stage of China and most probably with the *Redlichia chinensis* Zone (Bengtson *et al.*, 1990: 16-18). This correlation is approximately the same as the correlation proposed by Chang and Jell (1987). Moroccan *Abadiella* is different from Chinese *Parabadiella* in not only cranidial features but also stratigraphical occurrence (Chang *et al.*, 1997: 461-462). Specimens from Australia referred to *Abadiella* (Jell *in* Bengtson *et al.*,1990: 277-280) are similar to *Wutingaspis* rather than *Abadiella*. *Dolerolenus* sp. (Öpik, 1975: pl. 7, fig. 2) from the Parara Limestone near Kulpara, Yorke Peninsula, South Australia should be referred to *Parabadiella*. *Redlichia* beds in Antarctica and the Emu Bay Shale of Kangaroo Island, South Australia, are late Tsanglangpuan, whereas *Redlichia chinensis* and other species of *Redlichia* in western Queensland and Northern Territory are Lungwangmiaoan. With regard to the correlation of the Lower and Middle Cambrian boundary between China and Australia, some important evidences have been given by Kruse (1990). There are two fossiliferous intervals within the Tindall Limestone of the Daly Basin, Northern Territroy, Australia, of which the upper fauna is characterized by *Xystridura*, *Gunnia* and *Tongshania*; the lower fauna by *Redlichia*. According to Kruse, the upper fauna is correlated with the early Templetonian *Peronopsis longinqua* Zone, while the lower fauna with the late Ordian *Redlichia chinensis* Zone, and this same faunal succession is present also in the Thorntonia Limestone of western Queensland. Kruse also noted that *Gunnia* is close to *Probowmania* Kobayashi or *Probowmaniella* Chang of the early Maochuangian. A cranidium of *Gunnia lutea* Gatehouse (Kruse, 1990: 18, pl. 5) resembles closely the Chinese *Kaotaia*, which is an index genus confined to the Maochuangian in Southwest China. Thus the boundary between Templetonian and Ordian Stages in Australia is equivalent to the boundary between Maochuangian and Lungwangmiaoan (or Manto) Stages in China.

With regard to the age of *Redlichia chinensis* Walcott, 1905, a few palaeontologists suggest that it is early Middle Cambrian rather than late Lower Cambrian. Australian palaeontologists consider that there is faunal overlap of *Redlichia* and *Xystridura* in the Ordian Stage of Northern Territory. Succeeding the Ordian Stage is the Templetonian which has been divided into the upper *Triplagnostus gibbus* Zone and the lower *Xystridura templetonensis* Zone. Considering the xystridurid trilobites as a standard for the early Middle Cambrian in Australia, therefore, *Redlichia chinensis* or other species of *Redlichia* which occur in association with *Xystridura*, should be of early Middle Cambrian. I think this is the only reason why the Ordian is considered to be of early Middle Cambrian age (Öpik, 1975; Shergold *et al.*, 1990). Within Australia, most species of xystridurids, oryctocephalids, ptychopariids (*Gunnia*, *Tongshania*) and *Pagetia* occur in the Templetonian, which represents the early Middle Cambrian of Australia. *Xystridura* and *Galahetes* from Hainan Island, western Kansu and from western Xinjiang, do not coexist with *Redlichia*. Öpik (1975: 8) correlated the Ordian with the upper Botoman and Lenian (=Toyonian) Stages of Russia which has long since been considered Lower Cambrian by Russian geologists and also by Shergold *et al.* (1990). Xystridurid trilobites probably evolved from Early Cambrian protolenid trilobites, such as *Hsuaspis*. It seems reasonable that earlier species of *Xystridura* may coexist with some species of *Redlichia*. A similar case occurs in Morocco where the olenellid *Kjerulfia* appears in the Tasousekhtien Substage, and goes up as high as the base of Middle Cambrian, where it coexists with *Acadoparadoxides* and various protolenids, and some endemic olenellids can also be found, in the passage-beds from the Lower to the Middle Cambrian (Hupé, 1960: 75). Chang and Jell (1987) raised the problem whether the Payntonian Stage in Australia is equivalent to all or only the upper part of the Fengshanian. After a comparison of the trilobites within the interval between the Idamean and the Payntonian in Australia and the Changshanian of China, we arrived at the conclusion that the base of the *R. clarki prolatus/C. sectatrix* Zone coincides with the base of the Fengshanian (Chang and Jell, 1987: 32, 34). Some Australian palaeontologists suggest that the Fengshanian is totally equivalent to the Payntonian which includes in descending order the *Mictosaukia perplexa*, *Neoagnostus quasibiloba/ Shergoldia nomas* and *Sinosaukia impages* Zones (Shergold *et al.*, 1990; Shergold, 1995). Based on conodont biostratigraphy, the *Tsinania-Ptychaspis* Zone, the basal zone of the Fengshanian, coincides with the *Proconodontus tenuiserratus* Zone; the superjacent *Changia* (or *Quadraticephalus*) Zone with the *P. muelleri* and *P. posterocostatus* Zone; and the *Mictosaukia* Zone with the *Cambrooistodus minutus* and *Eoconodontus notchpeakensis* Zones. The *Missiquoia* Zone both in China and North America coincides with the *Cordylodus proavus* Zone (An, 1982; Mei, 1993; An and Mei, 1994, Wang, 1984). Based on the trilobite biostratigraphy, Howell (1947) was the first to suggest that the Chinese *Tsinania-Ptychaspis* Zone may be correlative with the *Ptychaspis-Prosaukia* Zone of the late Franconian Stage in Wisconsin, USA. According to Miller (1969) and Miller *et al.* (1982), this trilobite zone is also equivalent to the *Proconodontus tenuiserratus* Zone. In Australia, the upper part of the *P. muelleri* Zone to the top of the *Eoconodontus* Zone are equivalent to the Payntonian Stage; the *Lophosaukia* Zone of the top of the Iverian Stage is correlated with the lower part of the *P. muelleri* Zone and upper part of the *P. posterocostatus* Zone; the *Hapsidocare* Zone is said to be equivalent to the lower part of the *P. posterocostatus* Zone and probably the *P. tenuiserratus* Zone, in the text, but not in column 6 of the conodont biostratigraphic sequence on the correlation chart (Shergold, 1995). The base of the Fengshanian, or the base of the *Tsinania-Ptychaspis* Zone, is correlated with the base of the *Hapsidocare* Zone rather than within the middle part of this Zone (Chang and Jell, 1987: 34). If this is the case, the late Cambrian conodont and trilobite biostratigraphies in China, Australia and North America are all coincident. For instance, the first appearance of saukiid and ptychaspid trilobites is in the *Tsinania-Ptychaspis* Zone of the Fengshanian in China, the *Hapsidocare* Zone in Australia and the *Prosaukia-Ptychaspis* Zone of the late Franconian in North America. In North America, Eastern Asia and Australia, the late Upper Cambrian conodont biostratigraphy is also similar. The Idamean of Australia can be correlated with the *Chuangia* Zone; the succeeding *Peichiashania* Zone may be regarded as the equivalent with the Chinese *Maladioidella* and *Kaolishania* Zones. The *Lophosaukia* and *Hapsidocare* Zones of late Iverian age should be correlated to the lower part of the *Changia* Zone and the *Tsinania-Ptychaspis* Zone respectively. The Payntonian Stage is equivalent to the upper part of the *Changia* Zone and the *Mictosaukia* Zone of the late Fengshanian Stage in China. It should be mentioned that *"Tsinania" nomas* (=*Shergoldia nomas*) differs from *Tsinania canens* not only in cranidial and pygidial features but also in different stratigraphic position.

The Karatau Range in southern Kazakhstan is the westernmost extension of the Tienshan Mountains which extends more than 2,000 km in an east-west trend between Chinese Xinjiang and Kazakhstan. Cambrian rocks are well exposed in the Malyj Karatau area, southern Kazakhstan. Since the publication of the Cambrian trilobites and biostratigraphic sequence from the sections of the Batyrbay and Kyrshabakty areas (Ergaliev, 1980), it deserves special attention by the Cambrian geologists and palaeontologists around the world. The lower and upper boundaries of the Cambrian System in Malyj Karatau, southern Kazakhstan are the same as those in southwestern China; the Cambrian zonal scheme of southern Kazakhstan can be correlated with those in Xinjiang, Hunan and Zhejiang, western and southern China respectively. Because of lack of fossil evidence from Malyj Karatau, it is impossible to discuss the Lower-Middle Cambrian boundary between China and southern Kazakhstan. The Middle-Upper Cambrian boundary in southern Kazakhstan is slightly different from that of China, but the trilobite sequence is the same. The Tremadocian biostratigraphy and the early Lower Cambrian phosphorite deposits in southern Kazakhstan are also the same in southwest China. From the facts mentioned above, I was surprised to find the great similarity of both the Cambrian biostratigraphy and trilobite faunas within the slope biofacies in China and southern Kazakhstan. *Metaredlichioides*, an Early Cambrian redlichioid from southwest and west China, is a junior synonym of *Ushbaspis* from southern Kazakhstan. Kazakhstan should be included within the Redlichian Realm during the Early Cambrian, and within the same faunal province as China in the Middle and Late Cambrian. A brief Cambrian correlation for the stages in China and Kazakhstan is shown in figure 3.

The correlation of the Cambrian Fauna 1-7 in Antarctica has been discussed in great detail by Cooper and Shergold (1991); it seems not necessary to repeat it here.

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