

# Late Permian limestones and the Permian–Triassic boundary: new biostratigraphic, palaeobiogeographical and geochemical data in Caucasus and eastern Europe

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**Abstract:** This paper presents biostratigraphical and palaeogeographical correlations, in a post-Hercynian and pre-Cimmerian tectonic framework, between stratigraphic sections of Late Permian age in two important and remote areas, with some considerations concerning neighbouring countries. It concerns mainly the Nikitin sequence (Kuban, Russia) and the Bükk Mountains (Hungary), and describes the carbonate environments, microfauna diversity, foraminiferal assemblages, calcisponge and brachiopod constructions, and gymnocodiacean accumulations. This study is extended to former Transcaucasia (southern Armenia, Georgia and Adzerbadjan), the Alborz Belt in northern Iran, Italy and the Carnic Alps. It emphasizes a relatively simple biosedimentary evolution, which permits a confident palaeogeographic reconstruction. New geochemical results provided some additional markers, in particular small microspherules consisting of Cr/Ni spinels of cosmic origin. They occur in several sections in a defined position at the Permian–Triassic boundary based on biostratigraphic correlations (conodonts, foraminifers, last Permian reefal phenomena). These geochemical data might be related to a possible meteorite impact. Nevertheless, another global alternative phenomenon occurs. From the Latest Permian to the Earliest Triassic, the carbonate production or biomineralization is preferentially concentrated in the confined, intertidal or lagunal zones, and its evolution is relatively progressive from gymnocodiacean accumulations of the Latest Permian to the microbialites of the Earliest Triassic.

The Late Permian, prelude to the great biological crisis of the Permian–Triassic boundary (PTB), is located between two huge losses of the global carbonate production, respectively, from 89 and 99.99% (Weidlich 2002). Nevertheless, some sponge (sphinctozoans, inozoans, sclerosponges/chaetetids) or brachiopod (richthofenids) reef-mounds (see definition in Riding 2002) are known during this period, especially in Greece (Skyros and Chios Islands) and South China (Sichuan, Hubei, and Guangxi) (e.g. Flügel & Reinhardt 1989; Weidlich 2002). Bioaccumulations, dominated by gymnocodiaceans red algae (*Permocalculus* with subordinate *Gymnocodium*) and dasycladales green algae *Mizzia*, are locally well known in the Middle East (southern Iran, UAE and Saudi Arabia: e.g. Okla 1992; Vachard *et al.* 2005; Vaslet *et al.* 2005) and western Europe (Bellerophon Limestones: e.g. Noé 1987). The stromatolitic limestones associated with the Zechstein facies in the UK, Germany and Poland are also well known (Kiernowski *et al.* 1995; Smith 1995). Other interesting areas with Late Permian carbonates are located between the

Bükk Mountains (Hungary) and the Transcaucasia in Armenia. These two key points for the palaeogeography of this sector of Palaeo-Tethys and/or Neo-Tethys were studied during the French programme of reconstruction of the northern Peri-Tethys at the PTB. More recently, we have also investigated other Late Permian segments exhibiting the PTB, in Greece (Eubea, Attica, Hydra), Turkey (eastern Taurus: Hazro section), Iran (Zagros: e.g. Koh-e Surmeh and Koh-e Dena sections) and South China (Guangxi: Laren section). The preliminary results (see Gaillot 2006) are congruent with the conclusions exposed in this work.

The Late Permian is also particularly interesting because of the diversity of its physical and geological events, notably the assemblage of the Pangea (e.g. Erwin 1995; Weidlich 2002). Hence, the biotools permitting the control of the migration of the tectonic plates are very important to characterize the orogenic timetable of the successive accretions of terranes or plates. The benthic foraminifers are the most important of these biotools because they have no pelagic stages or

pelagic larvae (e.g. Debenay *et al.* 1996), and need a continuous expansion of shelves, plate-forms or ramps to migrate from plate to plate. Moreover, foraminifers provide the highest resolution biostratigraphy in the Carboniferous–Permian carbonate series because they are more abundant and evolve more rapidly than the conodonts. The problems of chronology concern principally the southern boundary of Armenia (Transcaucasia) and the Turkish Pontides, whose geohistory is still very controversial (Robinson *et al.* 1995). It is still questionable if Iran, as an archipelago of microplates or an independent plate, was accreted on Transcaucasia at the end of the Norian in a pre-Cimmerian orogenesis or only in the Middle Jurassic; the latter based on the age dating of the granites known from sutures.

The purpose of this paper is to show some palaeobiogeographical correlations between western Palaeo-Tethys and western Neo-Tethys in eastern Europe thanks to some bioconstructions of richthofenids and calcisponges, some microflora of gymnocodiaceans and brief considerations about the foraminiferal content. Principal investigated areas are NW Caucasus, Transcaucasia and the Bükk Mountains, occasionally compared with neighbouring plates, microplates or tectostratigraphic terranes. A second topic is to mention the discoveries of microspherules, as possible evidence for a meteoric event at the PTB. This phenomenon could be related with the meteoritic impacts known at Araguinha, Brazil (Crosta *et al.* 1981; Théry *et al.* 2003), or at Bedout, NW Australia (Becker *et al.* 2004). The last point of discussion is to consider the Late Permian–Early Triassic interval, as a replacement period of gymnocodiacean bioaccumulations by stromatolitic constructions, i.e. as a relatively continuous phenomenon, despite the loss of the carbonate production and the recorded geochemical shifts.

## Nikitin section, NW Caucasus (Russia)

### Previous work

The Permian–Triassic succession at Nikitin is relatively well known, taking into account the numerous Russian palaeontological publications in the last 50 years (e.g. Miklukho-Maklay 1954; Kotlyar *et al.* 1999b; Pronina-Nestell & Nestell 2001). A good summary was given by Gaetani *et al.* (2005).

Miklukho-Maklay (1954) divided the Late Permian series, from base to top, into: (1) the Kutani Formation; (2) the Nikitin Formation,

with three biozones; (3) the Urushten Formation; and (4) the Abag Formation, now considered to be Triassic in age. In fact, the three first formations are coeval and updated as late Changhsingian (Kotlyar *et al.* 1999b; Pronina-Nestell & Nestell 2001) and correspond, respectively, to terrigenous, calcareous and reefal facies, laterally equivalent.

The late Changhsingian foraminifers were described by Miklukho-Maklay (1954) and recently redefined and/or re-illustrated by Pronina-Nestell & Nestell (2001). The fauna was revised by Kotlyar *et al.* (2004).

### The Nikitin section

The field section at Nikitin is upstream from the Malaya Laba River, tributary of the Kuban River (Figs 1a, b & 2a). It is located in the Perodovoy Chain in the mountains of NW Caucasus (Kuban province, Russia) (Kotlyar *et al.* 1994, 1997, 1999b). At the base of the ravine at Nikitin, upstream from the Malaya Laba River (Fig. 2a), some leaf imprints *Sphenophyllum oblongifolium* Gemar & Kaulfuss, and *Pecopteris polymorpha* Brongniart (determination Broutin) were collected in the black shales by Mikerina and Pinchuk during our 1999 field trip. In western Europe they are generally dated as Westphalian D, but here they correspond to the Gzhelian stage, which is considered as equivalent to the late Stephanian. These black shales are overlain by few metres of Asselian red shales, followed by Asselian–Autunian conglomerates (Aksuatskaya Formation) with some carbonate remains (Fig. 2a). According to Kotlyar *et al.* (1997), this series corresponds to the German Lower Rotliegend. These conglomerates, approximately 10 m thick, are topped by alternations of limestone with shales of Murgabian age. This last zone of conglomerates corresponds to a nick point and cascade in a water torrent (Fig. 2a).

The overlying Dorashamian–Changhsingian (i.e. the ‘Kutani’, ‘Nikitian’ and ‘Urushtenian’ facies) is approximately 105 m thick (Kotlyar *et al.* 1997). The ‘Kutani’ sandstone overlies the Early Permian Red Beds or older formations unconformably with an important stratigraphic gap. This unconformity corresponds to a Saalian swell, stretching along the former Hercynian Cherskyi suture (Fig. 1, and see also Fig. 4 later).

The Nikitian facies is composed of black bioclastic limestones, rich in microfauna, alternating with shales and algal limestones. The smaller foraminifers are represented by the genera *Neoendothyra*, *Dagmarita*, *Paraglobivalvulinoides*, *Hemigordius sensu lato*, *Agathammina*, *Nodosinelloides*, *Geinitzina*, *Pachyphloia*,

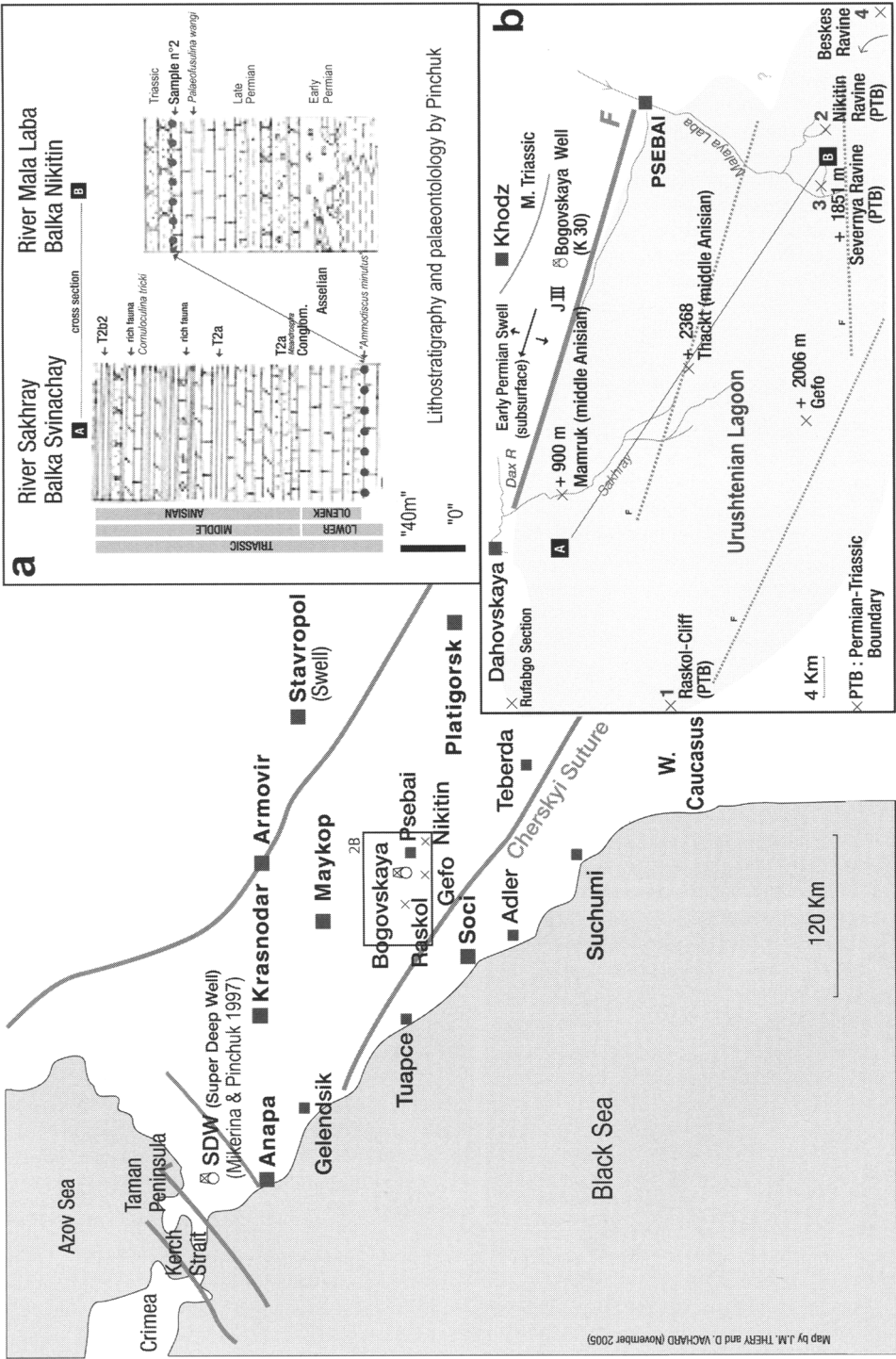
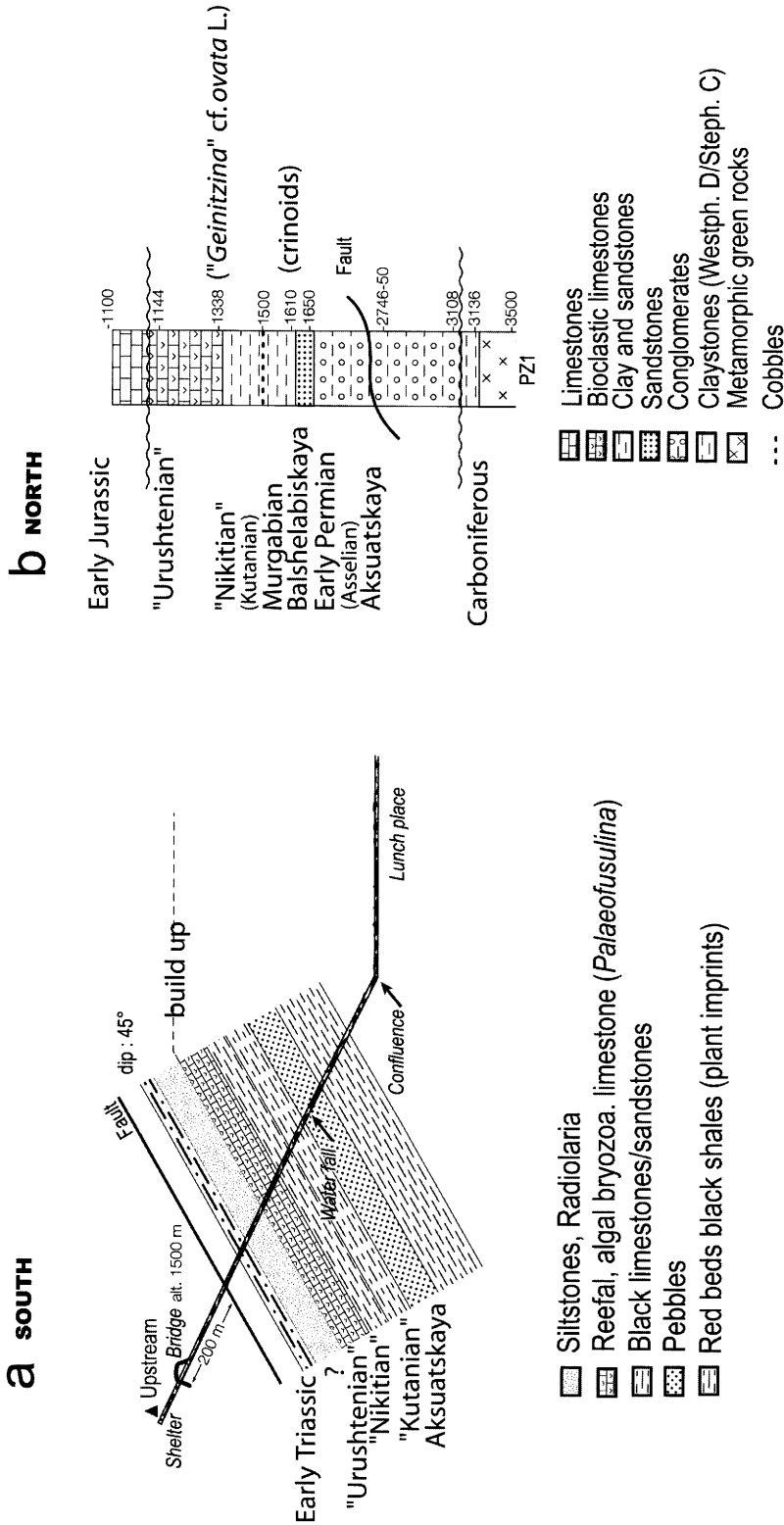


Fig. 1. Map of studied area in Kuban (Russia). (a) Lithostratigraphy and palaeontology with correlation between Balka Svinachay and Balka Nikitin within the Early Permian and Middle Triassic. (b) Urushtenian lagoon extension downstream of the Nikitin field section.



**Fig. 2.** Comparative schemes of (a) the Nikitin field section, log carried out Proshliakov *et al.*; and (b) the Bagoyskaya borehole (K30) Kuban, Russia (Borehole K30 – Diakonov 1962) (SW of Psebai, Nikitin refinery), log carried out by Pinchuk & Mikerina (location in Fig. 1). The distance between the two sections is 14 km.

*Robuloides*, *Lingulina*, *Pseudolangella*, '*Fronidina*' and advanced *Colaniella*; and the fusulinids *Palaeofusulina nana* Likharew, *P. wangi* Sheng, and *P. sinensis* Sheng with also species of *Reichelina*, *Codonofusiella* and *Parananlingella* (Kotlyar *et al.* 1999b; Pronina-Nestell & Nestell 2001). Our samples contained bituminous bioclastic packstones with *Diplosphaerina* ex gr. *inaequalis* (Derville), *Paraglobivalvulina* sp., *Pseudovermiporella nipponica* (Endo), *Midiella zaninettiae* (Altiner), *Reichelina media* Miklukho-Maklay, *Palaeofusulina wangi* and *Nodosinelloides* sp., with more than 60% of the gymnocodiacean red algae (predominant *Permocalculus* sp., at the stage *Dzhulfanella*, and subordinate *Gymnocodium exile* Mu). The Nikitian facies contains also some sponge mounds (Gaetani *et al.* 2005).

The Urushtenian facies consists of bioclastic limestones with abundant algae *Permocalculus* and brachiopods. The microfauna is rich and diversified, and, compared with the Nikitian limestone, is characterized by *Lasiodiscus*, *Pseudomidiella*, *Graecodiscus*, *Neodiscus*, *Multidiscus*, *Hubeirobuloides*, *Nankinella* and *Parareichelina* (Pronina-Nestell & Nestell 2001). One of our samples at the top of the Urushtenian facies ('sample n° 2' in Fig. 1a) contains *Gymnocodium exile*, *Shamovella obscura* (Maslov) and *Permocalculus fragilis* (Pia), *Palaeofusulina wangi*, *Pseudovermiporella nipponica*, *Hemigordiellina* sp., *Midiella zaninettiae* and *Nodosinelloides* sp. This sample demonstrates definitively the contemporaneous character of the Nikitian and Urushtenian facies (*Palaeofusulina wangi* has not been discovered in the Urushtenian facies by Pronina-Nestell & Nestell 2001, table 1 p. 211), and indicates, at least locally, stable palaeoecological and, consequently, geochemical conditions up to the PTB. The brachiopod assemblage of this facies is composed of bioherm-building genera, especially *Leptodus*, *Richthofenia* and *Permianella* (Kotlyar *et al.* 1999b). The colonial rugose coral *Waagenophyllum* is also mentioned (Kotlyar *et al.* 1999b). The top of Urushtenian facies consists of burrowed mudstones. Our samples show local pyritizations and only one undetermined *Nodosinelloides*.

### *The Changhsingian Lagoon*

The facies are generally rich in organic matter and were preserved in a restricted environment. They could correspond with a bay or lagoon, on a rimmed carbonate ramp (Burchette & Wright 1992). In particular, the boreholes associated

with the field sections revealed a lagoon protected in the south (Fig. 1a, b). This lagoon stretches for at least 50 km towards the NW from the Belaya to Raskol-Cliff (Fig. 1b). It generally exhibits an assemblage of algae, bryozoans, brachiopods, sponges, *Shamovella obscura*, *Gymnocodium exile*, *Reichelina media* and *Geinitzina* spp. Pronina-Nestell & Nestell (2001) described similar assemblages of foraminifers dominated by *Palaeofusulina nana* at Gefo, west of Nikitin (Fig. 1b). The lagoon is limited towards the north by an emerged zone that was made clearly visible by the drilling at Bagovskaya (Figs 1b & 2b). According to Pinchuk (pers. comm.), in this borehole the Jurassic deposits (1044 m thick) rest on Permian deposits biostratigraphically characterized up to the Murgabian (middle Middle Permian) crinoidal sandstone by *Platycrinites* ex gr. *laevis* Millot. They were deposited on a sandy shoal where phyllitic components from the Precambrian metamorphic substratum and conglomeratic sandstones are also present. These metamorphic Proterozoic green slates (Fig. 1) were penetrated at the base of the drill hole up to -3500 m (Fig. 2b).

Nevertheless, the presence of the palynomorph *Protohaploxylinus* sp. and the smaller foraminifer *Geinitzina* cf. *ovata* Lange (Pinchuk & Mikerina pers. comm.), just below the Jurassic, would indicate some Late Permian deposits before the emergence and erosion (Fig. 2b). We agree with this hypothesis as we consider that '*Geinitzina*' *ovata* is not a true *Geinitzina* but most probably a *Pachyphloides* or a very primitive *Colaniella*, both taxa whose FAD (first appearance datum) is Late Permian in age (Gaillot & Vachard unpublished data). Consequently, although limited by a fault (Fig. 1b), the northern extension of the lagoon is probably entirely preserved. As another piece of evidence of the coastal line, we observed a reddish sandy molasse with granite and Palaeozoic components in the Rufabgo ravine, tributary of the Belaya River (Fig. 1b). The horizon is dated as Early Triassic in the transgressive Yatyrgvart Formation. Pinchuk & Kotlyar (pers. comm.) have observed *Ammodiscus minutus* Dunn here (Fig. 1a) and a perhaps locally characteristic *Nodosaria*, as in the neighbouring section at Balka Svinachay near the Sakhray River (Fig. 1a, b). We suppose that these two foraminifers might be, respectively: (a) some primitive, planispirally, undivided, tubular cornuspirid miliolids, which are the first to reappear after the PTB, probably *Rectocornuspira kahlari* Brönnimann, Zaninetti & Bozorgnia, mentioned as occurring immediately on the PTB in several localities of southern Turkey and

southern Iran; and (b) a nodosarioid, relatively common in the same levels, the genus *Polarisella* (see Vachard *et al.* 2005; Gaillot 2006).

### *The reefal phenomenon*

An important reefal barrier stretched for a length of at least 50–70 km south of the lagoonal area. It settled there with up to 70–100 m of buildup, between the Belaya, Bolshaya and Malaya Laba river basins. The reefal sequence spread out into the Urushtenian facies with bioclastic, biogenic limestones with algae, foraminifers, sponges, bryozoa and reef-building brachiopods. Two field sections of late Changhsingian correspond to the back-reef area at Nikitin ravine and at Raskol-Cliff, west of the Belaya River at the presumed end of the lagoon. Some field sections have been studied at Khuko in the Main Range, 36 km NNW of Soci; we found there in an off-reef area olistolites of late Changhsingian sediments. Near the Nikitin section, Severnaya ravine already corresponds to an off-reef field section only 2 km SSE from Nikitin (Fig. 1b). The Urushtenian facies provides the best classification concerning the reefal phenomenon as a result of our field sampling at Nikitin ravine. There, beds of bioclastic Urushtenian limestones are massive, layered and about 5 m thick. The limestones have inclusions of marl limestone that contain accumulations of small foraminifers. Associated brachiopods bioherms of *Richthofenia*, often with *Crurithyris* or *Leptodus*, are repeated in association with sponges, and bryozoa in most of the beds. Some accumulations of algae *Gymnocodiaceae* (*Permocalculus*, *Gymnocodium*) and Dasycladales *Mizzia* form another characteristic biota.

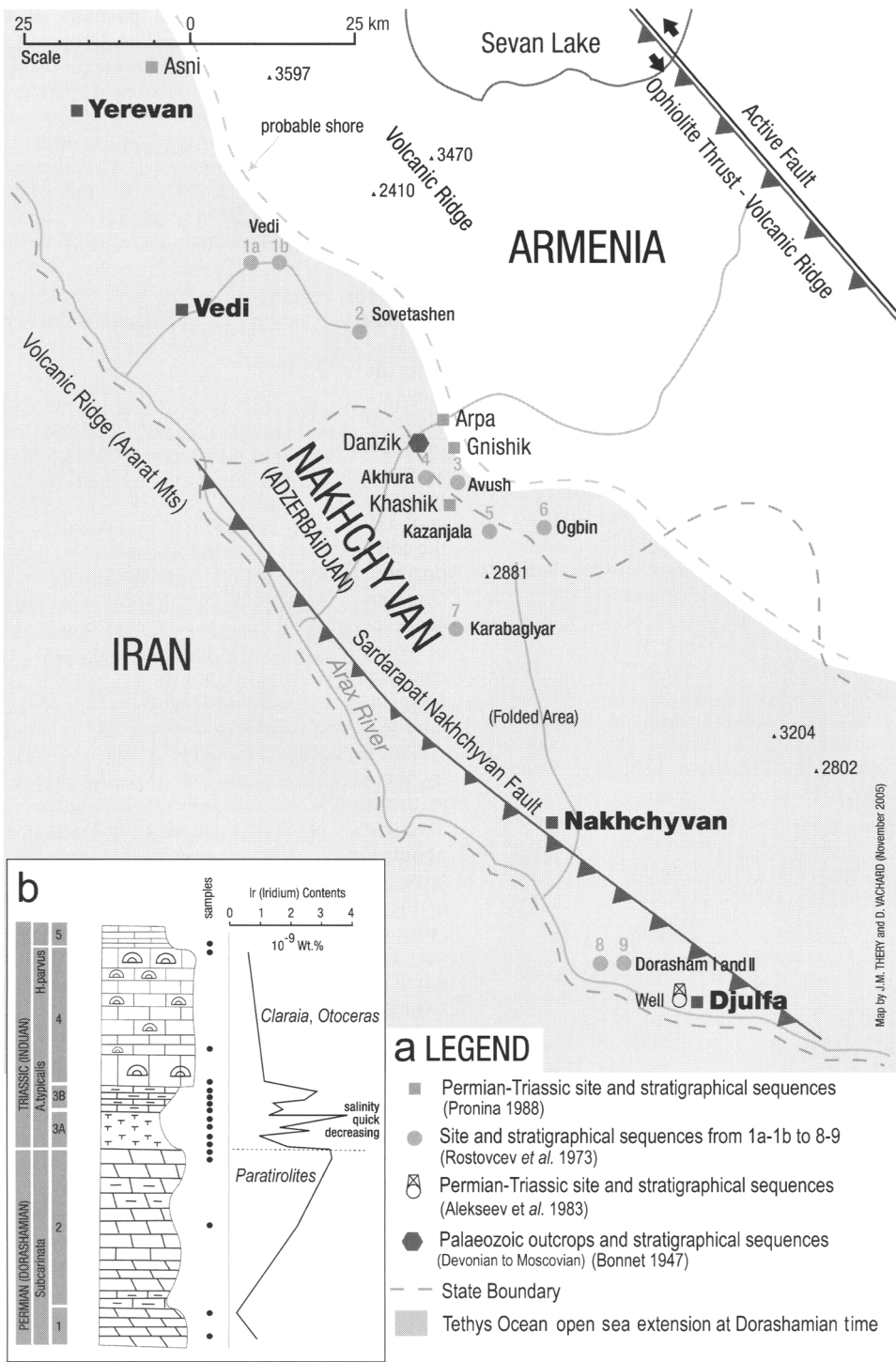
### *Palaeobiogeographic comparison with Transcaucasia and southern Crimea*

The best known Middle–Late Permian Transcaucasian sections are those at Arpa (southern Armenia), Sovetashen (Armenia) and Djulfa (Azerbaijan) (Figs 3 & 4). The top of the Dorashamian–Changhsingian contains cherts and silicifications at Arpa and Khashik, and red marls at Sovetashen (Rostovtsev & Azaryan 1973; Alekseev *et al.* 1983; Zakharov *et al.* 1996). The different taxa of foraminifers clearly suggest the different palaeobiogeographical assignments of NW Caucasus and Transcaucasia during the whole of the Permian. In particular, the fusulinids *Orientoschwagerina abichi* Miklukho-Maklay and *Eopolydiexodina persica* (Kahler) mentioned by Akopian (1974) and Kotlyar *et al.*

(1989) in Armenia also exist in Iran (Abadeh: see Kobayashi & Ishii 2003a, b), many species of *Codonofusiella* are common between Armenia (Kotlyar *et al.* 1984) and Abadeh (Iranian–Japanese Research Group 1981), and the genus *Pseudodunbarula* is known both in Transcaucasia (Kotlyar *et al.* 1984) and in the Abadeh area (Mohtat-Aghai & Vachard 2005). The smaller foraminifers identified by Pronina (1988) and Mohtat-Aghai & Vachard (2005) are also similar. Contrary to NW Caucasus, Changhsingian reef mounds are apparently lacking in Transcaucasia. Stromatolites are known in Armenia at the base of the Triassic, in all probability correlatable with those of Abadeh recently re-described by Heydari *et al.* (2000, 2003). During the Triassic a phase of rifting is particularly well known from the Carnian (*Trachyceras* Zone) during which, according to Vuks (2000), the subsidence is at a maximum, as previously supposed by Nikishin *et al.* (1998a, b). This pre-Norian phase precedes the collision of the Transcaucasian plate with the northern boundary of the Caucasian chain of the Cimmerian orogenesis. Subsequent to an emergence, creating an unconformity, a Jurassic suite of volcanoclastic sediments was deposited. The emergence is even more pronounced south of the Caspian, in the Alborz Mountains, by a layer of laterite (Stampfli 1978).

Another important field section was studied by the first author at Dizi (Fig. 4, see later), in the region of Svaneti Kedi in Georgia, NE Transcaucasia. It is located at an altitude of about 3000 m on the banks of the high Inguri River, 80 km east of Suchimi. Located south of the Main Range of the Greater Caucasus, it appears to belong to the northern boundary of the Transcaucasian Terrane (Georgian Block: Khain 1982). The section shows a continuous sequence from the Eifelian to the Triassic epochs and is separated from the Jurassic by an unconformity.

According to the work of the Oceanological Institute of Moscow (Kazmin pers. comm.), these series are folded and were overturned to the north, as at Nikitin, during the pre-Jurassic Cimmerian orogeneses, and are here metamorphosed to the greenschist facies. In the lower series, the jaspers and marbles are dated by conodonts as Devonian and Early Carboniferous. These horizons correlate with the levels known in southern Armenia at Danzik near Arpa (Fig. 3) and dated by Bonnet (1947). This upper part of the sequence also contains sandstones, often coarse grained, undoubtedly belonging to the Triassic. They cover a lower complex of Palaeozoic, which presents a chaotic facies of



**Fig. 3. (a)** Recent geological structures with an attempt at a palaeogeographical extension of Tethys Ocean during Dorashamian time in South Armenia area. **(b)** Sovetashen Permo-Triassic section according to Aleskeev *et al.* (1983).

slides and relics of mudflows formed at the continental slope (Kazmin & Sborshchikov 1989). Their Permian olistolites are similar to those of the Taurida Formation of the Crimea, recently re-examined by Kotlyar *et al.* (1999a). Moreover, Taurida of Crimea and Transcaucasia have many palaeobiological points in common during the Middle–Late Permian owing to: (a) the diversity of the *Parafusulina* sensu lato (i.e. *Skinnerella*, *Paraskinnerella* and rare true *Parafusulina*) (compare Kotlyar *et al.* 1999a and Akopian 1974); (b) the presence of the neoschwagerinids genera: *Cancellina*, *Armenina*, *Neoschwagerina* ex gr. *simplex* and *Praesumatrina* (compare Kotlyar *et al.* 1999a and Leven 1998); (c) the diversity of *Eopolydioxodina* (compilation in Vachard & Bouyx 2002); and (d) the absence of Changhsingian reef mounds, although richthofenids and calcisponges have been present in Crimea since the Midian (Kotlyar *et al.* 1999a).

The Dizi zone may mark the margin of the Georgian block and the proximity of the Hercynian suture of the Caucasus with the Russian platform (Fig. 4). Consequently, the Hercynian sector of NW Caucasus appears biogeographically separated from the microplate Crimea–Taurida–Georgian Block–Lesser Caucasus–Armenia–Djulf–Alborz. This microplate was initially named ‘Extragondwan Realm’ by Vachard (1980), but is most generally described in the literature under the name of ‘Cimmerian Terranes’.

The microplate Crimea–Transcaucasia–Alborz is also characterized by Palaeozoic–Triassic olistolites present in Armenia at Sevan Lake, where a Permo–Triassic rift appears to exist (Bonnet 1947; Stampfli & Pillevuit 1993). Here a thin crust (Ershov *et al.* 1998) was formed, which was uplifted in front of a Cimmerian magmatic belt. A back-arc Permian–Triassic basin extended south of Sevan Lake, at the northern margin of the Neo-Tethys Ocean. This area showed a great seismic and volcanic instability, which even expressed itself in Permian–Triassic sedimentation. This instability was again perceptible in Holocene times by intense volcanism (Karakhanian *et al.* 2002, fig. 3).

The Armenian and Georgian blocks have aggraded against one another since the Bajocian (Khain 1982) and, in turn, against the Russian platform, north of the Dizi area.

The Cimmerian Orogeny is thus recognized more or less at the base of the Norian in the three regions studied above: Kuban, Georgia and Armenia. It corresponds to an extension of the Neo-Tethys before its major expansion during the Bajocian–Callovian (second phase of the Cimmerian Orogeny). We suggest that the

Palaeotethys probably closed partially at the base of the Late Permian (Saalian Orogeny), as indicated by the pre-Murgabian conglomerates observed in the Nikitin section, in Bulgaria (Yanev 2000), south of the Caucasus, and in the Alborz Mountains (Stampfli 1978; Stampfli *et al.* 1991). In the Nessen Formation (Latest Permian) in this region (Lys *et al.* 1978), the microfauna and algae appear to be very similar to those in certain southern Armenian sections (Khashik: Pronina 1988).

### Bükk Mountains (Hungary) and neighbouring countries

In Hungary, the PTB is known from the Bükk Mountains and the Transdanubian Range (e.g. Haas *et al.* 2006 with bibliography) (Figs 5 & 6a). The Bükk Mountains are located in NE Hungary, near the border with Slovakia and Ukraine (Fig. 6). There, Balogh (1980) divided the Late Permian–Early Triassic series, respectively, into Nagyvisnyó and Gerennavár limestones. The Nagyvisnyó Limestone (250–280 m thick) consists of black and dark grey, thin-bedded limestones with shaly intercalations. The Gennevár Limestone (110–140 m thick) contains, at its base, successively 50 cm of mudstones or *Earlandia* wackestones (with the conodont *Hindeodus parvus* recognized as characteristic of the PTB) and 8.5 m-thick stromatolites (Hips & Haas 2006).

We have studied several field sections in the Bükk Mountains (Fig. 6a). Other good exposures of the PTB are located in Serbia, west of Belgrade, as well in a bore core at Gartnerkofel 1 (Austria) (Fig. 6a). The latter corresponds to the Bellerophon Formation, which appears in the Latest Permian as a significant bioclastic limestone with gymnocodiacean algae.

In the Bükk Mountains (Nagyvisnyó), the microfauna were accurately described from black bituminous limestone by Bérczi-Makk (1992) and Bérczi-Makk *et al.* (1995). We found in our samples accumulations of *Permocalculus* with rarer *Gymnocodium*, and foraminifers *Earlandia*, *Paraglobivalvulina*, *Septoglobivalvulina?* ex gr. *decrouezae* Köyüoglu & Altiner, *Dagmarita*, *Paradagmarita*, *Shindella?*, *Pseudovermiporella*, *Hemigordius*, *Multidiscus*, *Geinitzina*, *Pachyphloia* and *Robuloides*. Finally, we found only Changhsingian assemblages in our samples from the Bükk Mountains, contrary to Bérczi-Makk (1992), which emphasized a Midian age for the series, or a very reduced Dorashamian–Changhsingian part (Bérczi-Makk *et al.* 1995). This Changhsingian age is indicated by: (a) the

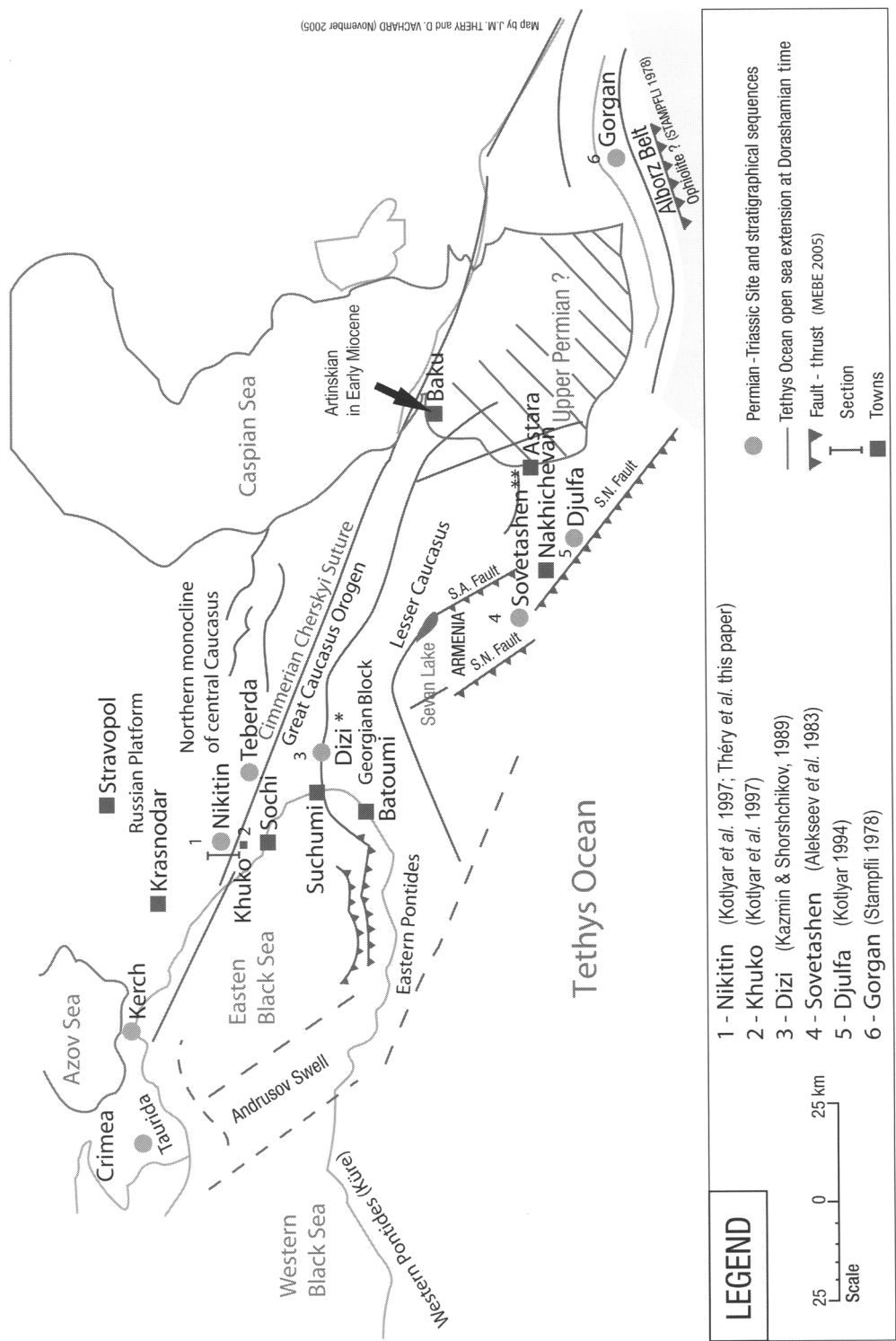


Fig. 4. Recent geological structures with an attempt at a paleogeographical extension of the Tethys Ocean during Dorashanian time between Crimea and Elburz Belt.

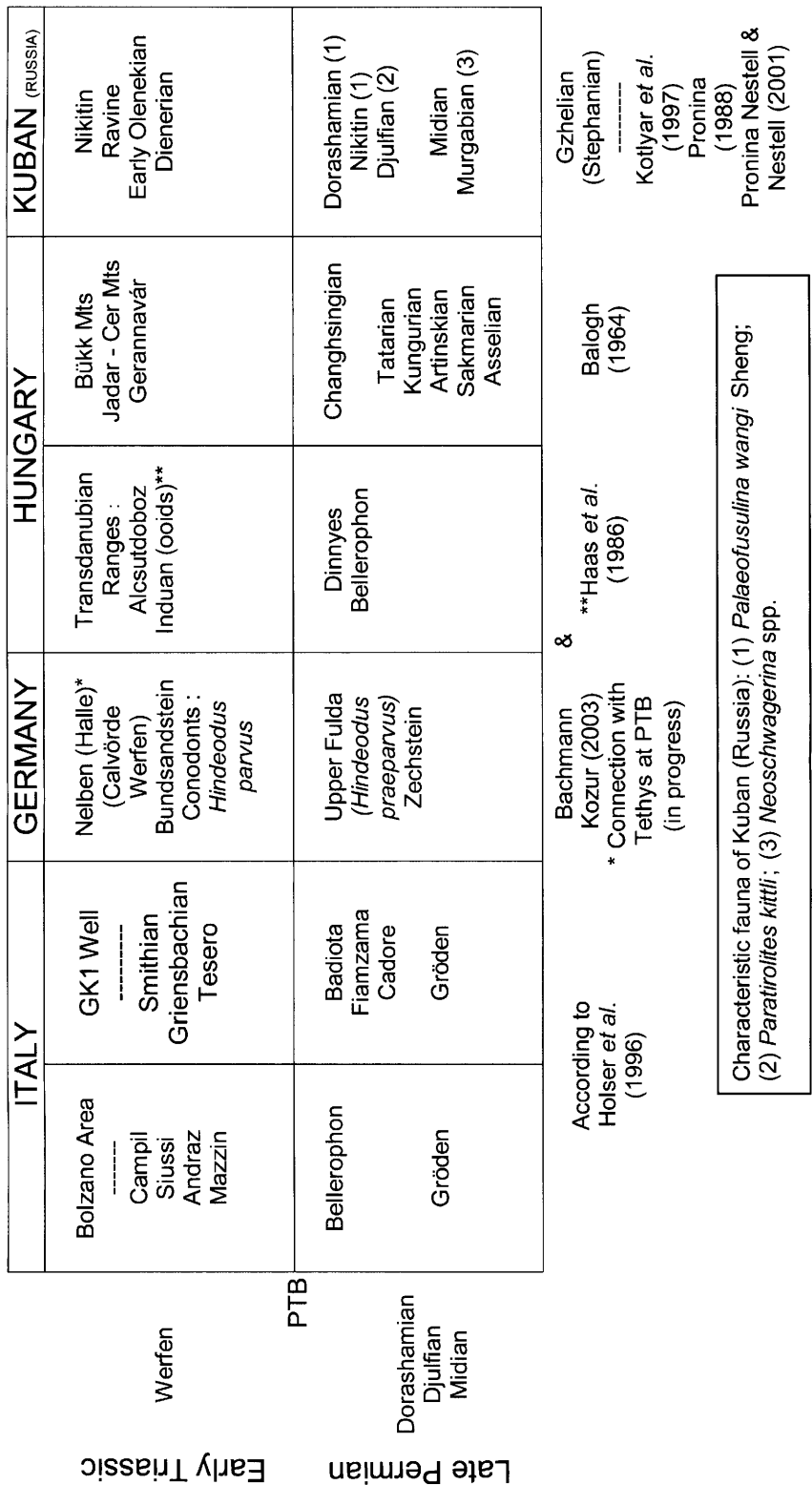
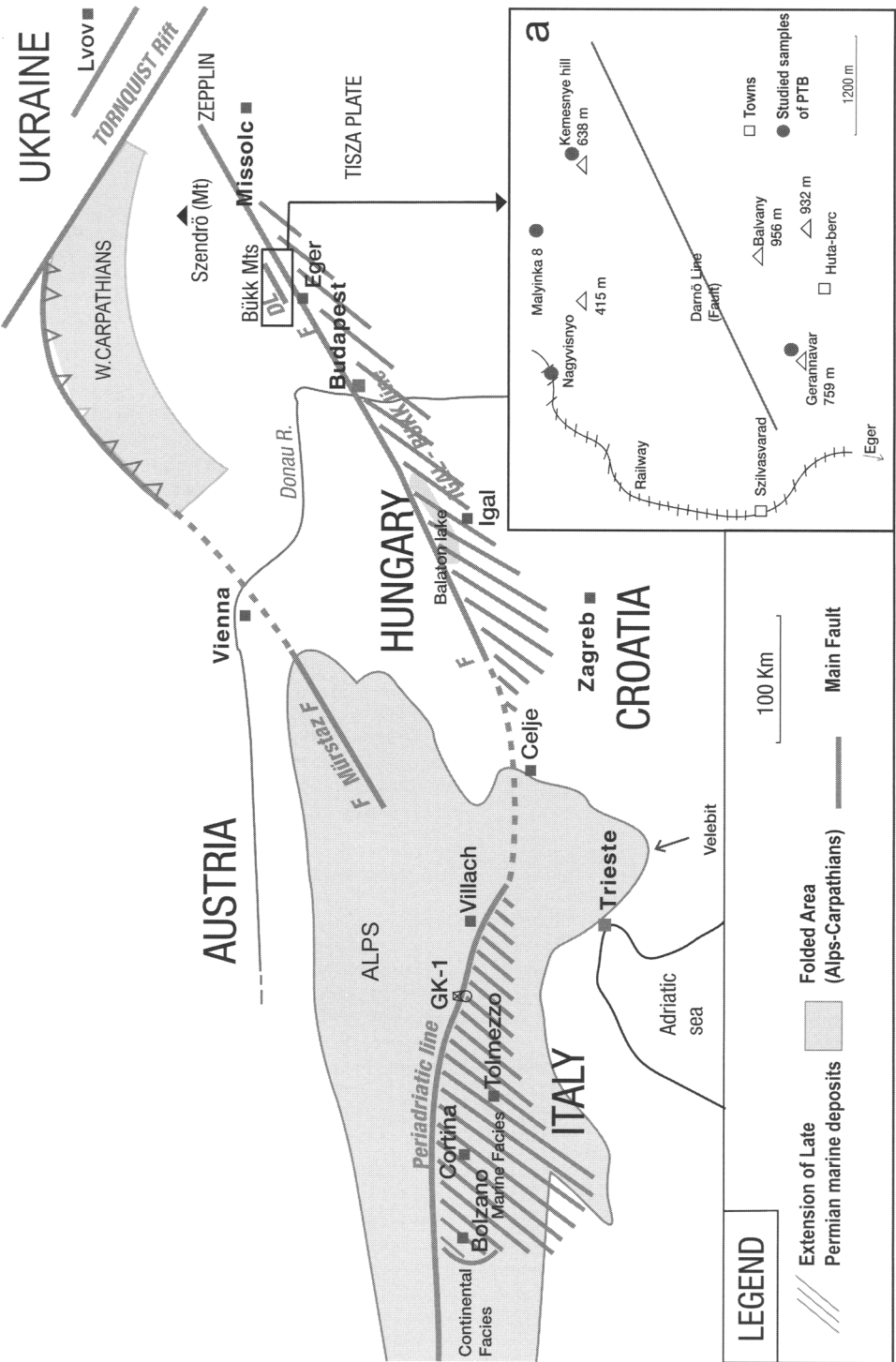


Fig. 5. Stratigraphical correlation charts between Bolzano area (northern Italy) and the Bükk Mountains (NE Hungary) at the PTB.



**Fig. 6.** Recent geological structures and palaeogeographical map of Late Permian and Early Triassic between the Bükk Mountains and the Bolzano area (GK-1) (western end of the Tethys Sea), with (a) the location of the sampled area in the Bükk Mountains.

presence of a primitive *Paradagmarita* (denominated *Globivalvulina cyprica* by Bérczi-Makk *et al.* (1995, plate 6, fig. 4); (b) *Shindella?* sp. (juvenile or dwarf specimens identified as *Codonofusiella nana* Erk by Bérczi-Makk *et al.* 1995, plate 10, figs 1–6, and *Codonofusiella* spp., plate 11, figs 1, 2?, 5 & 6?) since the base of the series; (c) advanced representatives of *Globivalvulina decrouzeae* that look like *Paraglobivalvulina nitida* Lin, Li & Sun from South China (Bérczi-Makk *et al.* 1995, plate 6, figs 1, 2, 3?, 5, plate 7, figs 1–5); and (d) *Multidiscus* with striated walls (Bérczi-Makk *et al.* 1995, plate 16, fig. 3 & 4, plate 20, figs 1, 2), plate 21, fig. 3) previously only observed by us in the late Changhsingian of Greece (Vachard *et al.* 1993, plate 8, figs 16–18). Nevertheless, two other Changhsingian markers: *Colaniella* (Bérczi-Makk *et al.* 1995, plate 1, fig. 12) and the *Kamurana?* sp. (Bérczi-Makk *et al.* 1995, plate 14, figs 1–3) seem to be misinterpreted. According to Balogh (1964), the brachiopod reefs with *Tchernyschevia* are shared by both areas, Hungary and NW Caucasus.

Although some authors have previously correlated the Bükk Mountains with the NW Caucasus in the Changhsingian (Balogh 1964), more similarities appear between the Hungarian foraminiferal and algal assemblages and those of Taurus, Zagros, Saudi Arabia (Vachard *et al.* 2005; Gaillot 2006) than those of NW Caucasus. These similarities are as follows: (a) *Hemigordiopsis renzi* Reichel should be associated with *Rectostipulina quadrata* Jenny-Deshusses (Bérczi-Makk *et al.* 1995, text-fig. 10, p. 212); as this later species is considered by all the authors as characteristic of the Late Permian, '*Hemigordiopsis renzi*' is most probably a new genus discovered by Gaillot (2006) in the Taurus and Zagros; (b) '*Globivalvulina cyprica*' is, in fact, a very primitive *Paradagmarita*, early Wuchiapingian in age (Gaillot 2006); (c) *Paraglobivalvulina mira* is part of the group *Septoglobivalvulina?* *decrouzeae*, well known in the Taurus and Saudi Arabia (e.g. Vachard *et al.* 2005); and (d) the return of the old genus *Climacammina* at the end of the Changhsingian (Gaillot 2006).

Nevertheless, the bioconstructions with richthofenids and calcisponges similar to NW Caucasus are present in Bükk Mountains, as well as in Skyros Island (Greece). Hence, we suggest that Greece and Bükk constitute microplates situated in the centre of the Palaeo-Tethys, but submitted to a northern system of currents, allowing communication with South China because of the very limited, on the world scale, late Changhsingian reef development. Another

marker of the links between South China, NW Caucasus and Greece is the fusulinid genus *Parareichelina* Miklukho-Maklay emend (Rauzer-Chernousova *et al.* 1996). Indeed, it is known only from South China (Wang 1974), NW Caucasus (Rauzer-Chernousova *et al.* 1996) and in the Salamis Island in Greece (Altiner & Özkan Altiner 1998, under the synonym name *Baudiella*) (Fig. 7).

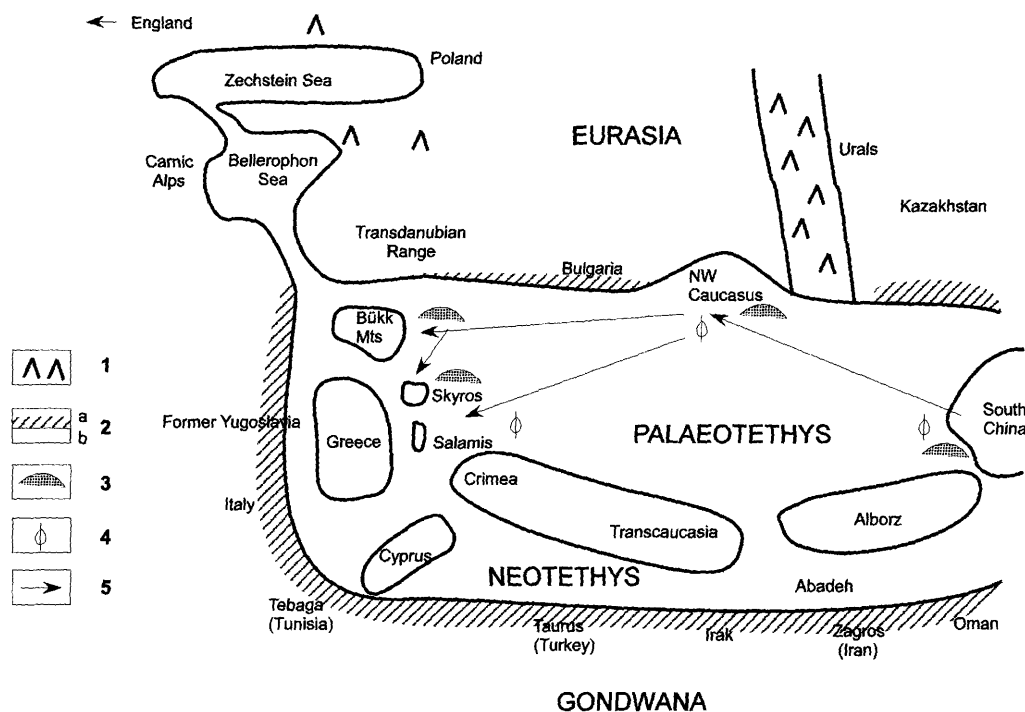
West of the Bükk Mountains, the biodiversity of the Late Permian microfauna is poor (or at least poorly known). But some algae can be palaeogeographical markers of the Perihercynian Domain, e.g. *Macroporella preromangica* Praturion (see Noé 1987, plate 29, fig. 4). Data are given from the sections of NE Serbia (Pantic-Prodanovic 1996) at Krupanj, as well as at Jadar (Pesic *et al.* 1986; Pantic-Prodanovic & Radosevic 1981); in the Vlasic zone, in the Panica Cave, and at Gaj, where the reefal coquinas with the brachiopod *Richthofenia* are overlain by the same abundant assemblage with *Geinitzina* and *Permocalculus* spp. at the end of the Permian.

West of Villach (Carnic Alps, Austria), the drill core of Gartnerkofel 1 (Figs 5 & 6) clearly shows the PTB (Holser *et al.* 1991). At the top of the Tesero horizon, a bioturbated biomicrite and wackestone–mudstone are present in an internal platform with *Hemigordius* and *Globivalvulina*. As in Serbia, this level changes at the base of the Triassic into oolitic beds, as found in NE Hungary (Haas *et al.* 1986). The same facies is found at Gerennavár in the Bükk Mountains, but there the microspherules are of cosmic origin.

## New geochemical data at PTB

### Cosmic microspherules

If compared to the K–T (Cretaceous–Tertiary) crisis, a catastrophe on a global scale that has led to the well-known mass extinction in a relative short time, the PTB would contain, in its deposits of many localities, microspherules of a cosmic origin. In our samples of Nikitin, the first ones were found by EMTT in the Urushtenian limestones at the top of the Late Permian. They are small agglomerates of microspherules consisting of Ni or Cr spinels (Fig. 8). They could be the result of the fusion at the surface of a giant meteorite, such as the one known from Araguinha in Brazil or two candidates of the same period at Bedout in Australia (Becker *et al.* 2004) or at Kursk in Russia (Masaitis 1999). The latter one is at a distance of 940 km from the Kursk impact and provides a remarkable layer of shocked minerals, traces of which we ought to find at



**Fig. 7.** Palaeobiogeographical map of Late Permian plates and microplates: 1, mountains; 2a, mainlands; 2b, seas; 3, late Changhsingian reefs; 4, *Parareichertina* localities; 5, possible migration ways.

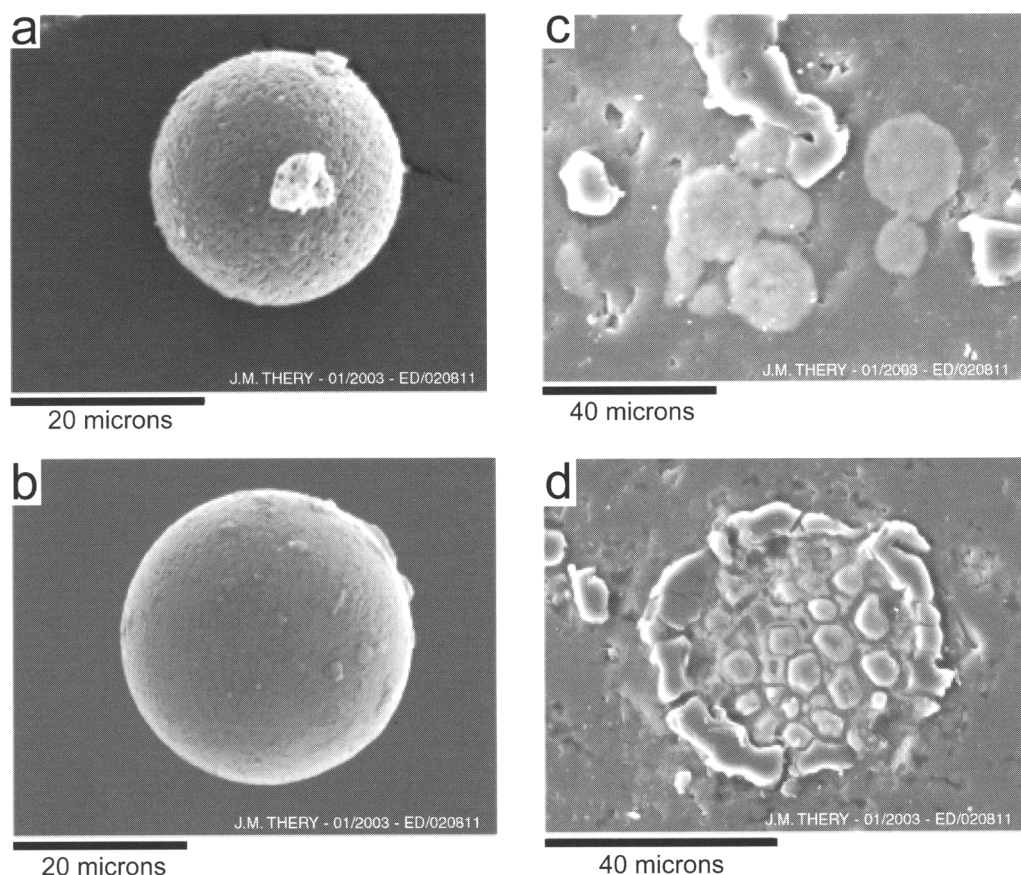
Nikitin. The hypothesis of a meteoritic fall at the PTB has generally been abandoned (see Weidlich 2002), but is it still advocated by some authors (Retallack *et al.* 1998; Farley & Mukhopadhyay 2001; Kaiho *et al.* 2001; Becker *et al.* 2001, 2004; Basu *et al.* 2003; Erwin 2003; Koeberl *et al.* 2004).

These microspherules can also be observed in Transcaucasia and the Raskol-Cliff in the NW of the Caucasus (sample 1, Kotlyar *et al.* 1997; see also Zakharov *et al.* 1996). Similarly, Bachmann & Kozur (2003) discovered microspherules of cosmic origin at Nelben (Germany). Some consist of spinels with 2% Ni and 2% Cr, and up to 0.17% Ir. They are coeval with the FAD (first appearance datum) of the conodont *Hindeodus parvus*, which is the main marker of the base of the Triassic (Kozur 1981, 1999). In Hungary we have also collected a sample in the reefal limestone located at the top of the Changhsingian stage. Fluorescence analyses reveal a content of 17 ppm Ni and 65 ppm Cr. Magnetic particles were separated by EMTT from the spinel microspherules. The oxide concentrations are: FeO=86%, Al<sub>2</sub>O<sub>3</sub>=6%, SiO<sub>2</sub>=1%, Cr<sub>2</sub>O<sub>3</sub>=3% and NiO=4%. These spinels were formed during the fusion of a meteorite while crossing the

atmospheric layers (Robin & Rocchia 1998), and whose impact must have taken place exactly at the PTB.

### Isotopic anomalies

Important geochemical and isotopic anomalies, revealed by our samples, concern particularly the organic  $\delta^{13}\text{C}$  and the Ca/Mg ratio. At Raskol-Cliff (west of the Belaya River), Ca/Mg reaches a maximum of 193 200 at the top of the Urushtenian facies. This maximum is comparable with that in Transcaucasia. The highest value of  $\delta^{13}\text{C}$  is reached near Djulfa, in the Araxoceras zone, with 2.5% against -0.1%, with a maximum of 0.1%, in the Induan. This would translate, at the PTB, in an abrupt decline in the  $\delta^{13}\text{C}$  and with this a decline in the photosynthesis and bioproductivity of the sea with a deficiency in heavy oxygen ( $\delta^{18}\text{O}$ ). After a brief period of a cold climate, without doubt owing to a gigantic basaltic eruption in Siberia (Norilsk), with a maximum  $\delta^{13}\text{C}$ , one observes in the late Induan substage an abrupt increase in temperature. According to recent data (Schultz 2005), the Middle Triassic would have been one of the hottest periods governing the Earth.



**Fig. 8.** Microspherules consisting of Cr or Ni spinels at Nikitin (Kuban, Russia) and in the Bükk Mountains (Hungary) sampled in the PTB deposits. (a) & (b) External view of spherules found at Nikitin. (c) & (d) Polished cut-out of the internal structure of spherule from the Bükk Mountains.

Several investigations of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  have led to the same conclusions at the PTB (especially at the base of the Mazzin Formation) (Fig. 5), as in Transcaucasia, Kashmir and Nepal (e.g. Holser *et al.* 1991; Baud *et al.* 1996). The variation of their content falls to a minimum during a period close to 3 Ma. This would be the result of an increase in aridity, accompanying a lowering of ocean levels, followed by a flow of carbon gas in the atmosphere coming from Siberia. In the upper Mazzin Formation, an abrupt increase in temperature of 5 °C and a rise in sea level took place in a transgression, which occurred worldwide. These different phenomena would have been the only ones recognized as responsible for the greatest extinction of the Phanerozoic.

#### *Carbonate productivity*

Correlatively, a palaeoclimatic proxy can be provided by the accumulations of *Permocalculus*

remains. They are already present in the Midian microfacies, e.g. in Djebel Tebaga (Tunisia) (Glantzboeckel & Rabaté 1964; Termier *et al.* 1977; Vachard & Razgallah 1993). In fact, they are present from the Kubergandian–Roadian in Aghanistan (Vachard 1980; Vachard & Montenat 1981; with the so-called *Dzhulfanella*). The presence of these *Permocalculus* accumulations in the Lopingian, after the important loss of carbonate production mentioned by Weidlich (2002), is puzzling. *Permocalculus* are very littoral algae (Vachard *et al.* 2003). Our hypothesis is that, whereas the carbonate rate of the sea waters greatly decreased in the ocean, far off the coasts, the innermost platform remained relatively favourable to the carbonate production. Hence, after the disappearance of carbonate microfauna and microflora at the PTB, the carbonate environments were confined to the intertidal zone, dominated by stromatolites.

The conditions were similar to those of the Early Palaeozoic rather than an environment for crisis survivors of the microbial reefs or 'anachronistic facies' (contrary to Sepkoski *et al.* 1991; Schubert & Bottjer 1992; Baud *et al.* 1997), although these are present in many bases of Triassic sequences from SW Turkey to South China (Heydari *et al.* 2000, 2003; Baud *et al.* 2005; Mohtat-Aghai & Vachard 2005). We prefer the hypothesis of Riding & Liang (2005). These authors explain that the abundance of microbial carbonate is inversely proportional to that of the metazoans or, in this case, of the advanced red algae. These conditions existed first in the Zechstein carbonate equivalents with their stromatolites (Kiersnowski *et al.* 1995; Smith 1995). Riding (2005) indicated that the reefal microbial carbonates were already abundant prior to the end-Permian period owing to an elevated seawater saturation state. In the stromatolitic zone, i.e. upper intertidal–mediolittoral zone, stromatolites, thrombolites and other microbialites are associated with particular cements (Heydari *et al.* 2000, 2003; Heydari & Hassandzadeh 2003; Baud *et al.* 2005). The Triassic system appears in this case as a reconquest of the oceans by the carbonate production. This progressive change of the carbonate geochemistry can be accelerated by other shifts (Magaritz *et al.* 1988; Heydari *et al.* 2000; Heydari & Hassandzadeh 2003), and the influence of diverse falls: meteorite, sea level, temperature or oxygenation (see the summary of Heydari *et al.* 2003); or gaps: reef, chert or coal (see the summary in Pruss *et al.* 2005).

### Palaeobiogeographical correlations

According to the geodynamic syntheses about Bulgaria, Slovakia, Hungary and Serbia (Balogh 1964; Pesic *et al.* 1986; Vozar & Vozarova 1988; Pantic-Prodanovic 1996; Yanev 2000; Bachmann & Kozur 2003), correlations exist between these areas and the zone NE of the Caucasus. The work of Lemaire *et al.* (1998) on Poland and the Tornquist rift, as well as that of Nikishin *et al.* (1998a, b) on the Caucasus, show the tectonic relations with the neighbouring countries of the Black Sea of Sengör *et al.* (1984), assuring good correlations on the northern periphery of the European Peri-Tethys. Balogh (1964) considered the Lvov (L'viv, Ukraine) Gulf the most likely connection; moreover, the Teisseyre–Torquist Gulf could fulfil the same role. The studies by Vozar & Vozarova (1988), Karamata *et al.* (1994), Lamarche *et al.* (1998) and Yanev (2000) show the impossibility of this interpretation for tectonic and magmatic reasons, and because of

the presence of evaporites at the two ends of these gulfs. Near Varna in Bulgaria and at Zemplicum in the NE of Slovakia, close to the Bükk Mountains in Hungary, the same types of volcano-sedimentary strata (rhyolites, latites) were deposited during the Latest Permian. According to Yanev (2000), the Rhodope, Moesia and Tisza terrains or plates were converged together north of Gondwana at the end of the Devonian and entered into collision much later during the Late Permian subsystem. The final tectonic phase was the pre-Cimmerian equivalent to the one south of the Russian platform. According to Kotlyar *et al.* (pers. comm.), the closest relationships start from the Late Permian and become more refined during, or at the base of, the Norian stage. The species *Miliolipora cuvillieri* Brönnimann & Zaninetti, found by Vuks (2000) in the Balka Svinachay (Sakhray River) with *Involutina* of the Norian, can be correlated with the Balkans (Budurov & Trifonova 1994). As already indicated by Banks & Robinson (1997), based on strike-slip faults that traverse the Black Sea from NW to SE, the pre-Norian and Cimmerian tectonic phases could correspond to those in the Balkans at Algöl (Pontides) followed by the Taurides and those in turn with the NW Caucasus (Kotlyar *et al.* 1999a).

Nevertheless, these correlations are not demonstrated during the Late Permian. Hence, our work attempts to provide some palaeogeographical data (Fig. 7). The NW Caucasus, which belongs to the Peri-Hercynian Domain (Vachard 1980), is closely related with South China in the late Changhsingian, but its foraminiferal algal and foraminiferal population differ considerably from those of Transcaucasia, which are correlable with southern Crimea and Alborz Mountains. This unit belongs to the Extragondwanian Domain (Vachard 1980; equivalent to the Cimmerian blocks of the authors).

The Bükk Mountains and Greece are poorly constrained, but seem to belong to one or two independent microplates. The Perigondwanian Domain is considered here following the interpretation of Vachard *et al.* (2005). It extends to the Tebaga in Tunisia. The eastern border of the Palaeo-Tethys–Neo-Tethys confluence is constituted by Italy and the former Yugoslavia. Within the Peri-Hercynian Domain two confined seas existed: the Zechstein Sea and the Bellerophon Sea.

The proposed palaeogeography is consistent with the distribution of the Permian markers firstly emphasized by Sengör *et al.* (1988), namely *Eopolydixodina*, *Shanita*, *Palaeofusulina* and *Colaniella*.

## Conclusions

- The discovery of new representatives of *Palaeofusulina wangi* confirms the coeval character of the Nikitian and Urushtenian facies of the Malaya Laba River (NW Caucasus, Russia), Nikitin (Russia) and their assignment to the late Changhsingian. The 'Nikitian' facies corresponds to a large lagoon, behind the 'Urushtenian' small reef-mounds with sponges and/or brachiopods. Similar bioconstructions are only known in the Greek Islands and South China.
- Owing to the presence of very particular late Changhsingian reefs and some foraminifers, like *Parareichelina* (= *Baudiella*), the correlations of NW Caucasus assemblages extend further towards the east in a large part of the Palaeo-Tethys, up to South China (Meishan section) and to the south up to Greece (Salamis Island).
- Late Changhsingian reefs are lacking in Transcaucasia, and the foraminiferal micro-fauna of NW Caucasus and Transcaucasia differ palpably. Those of Transcaucasia have more in common with the assemblages from Alborz and Abadeh areas (Iran), and prove the discontinuity of the carbonate platform southwards, and consequently the independence of the blocks.
- The identity of the Permian biological assemblages can be extended from Crimea to Alborz. This unit is the Permian Extragondwanian Domain, characterized by the identity of the populations and the absence of Hercynian orogenesis.
- The series of the Bükk Mountains is probably only Changhsingian in age, and no evidence of the Midian age can be provided. The Bükk Mountains appear as a transitional territory between NW Caucasus and Transcaucasia because they possess Changhsingian reefs, but their foraminifers resemble more closely the Perigondwanian assemblages.
- In the studied areas, microspherules are often discovered at the PTB and can provide arguments against the meteorite hypothesis.
- In our Nikitin samples, agglomerates of microspherules consisting of Ni or Cr spinels were found at the top of the Urushtenian limestones. They can be caused by fusion at the surface of a giant meteorite, such as the ones known from Araguinha in Brazil, at Kursk in Russia or Bedout in Australia, and in this case the PTB is very abrupt.
- Another common characteristic is the location of carbonate bioaccumulations. The

gymnocodiacean *Permocalculus* accumulations are common everywhere from NW Caucasus to Hungary, and correspond to prolific carbonate production, quite puzzling during a period of crisis for limestone deposits elsewhere.

- Comparison between the very littoral *Permocalculus* bioaccumulations of the Late Permian and the microbialites of the Early Triassic, allows one to enunciate the hypothesis that, during this very critical period, only the innermost platforms remained favourable to carbonate production.
- Consequently, the PTB should be only conventional along a sedimentological and geochemical continuum affecting the carbonate production and/or carbonate biomineralization.
- The palaeogeographical reconstruction indicates four groups of terranes in the studied area, from north to south: Peri-Hercynian Domain; Group Bükk-Greece; Extragondwanian Domain; and Perigondwanian Domain. The individuality of these areas is complete up to the PTB, and no element allows clear discrimination between the Palaeo-Tethys and Neo-Tethys in this area.

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