Cambrian Bradoriida and Phosphatocopida (Arthropoda) of the former Soviet Union

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ABSTRACT - Some 40 bradoriid and phosphatocopid (Arthropoda) species are known from the Cambrian of the former Soviet Union. The faunas occur chiefly in Asia (mostly Siberia and Kazakhstan; also Kirghizia); west of the Urals bradoriid and phosphatocopid faunas are sparse, occurring in the Leningrad region, Belarus and Estonia. Most specimens are recovered as crack-out material from clastic and impure carbonate rocks; acid resistant valves from limestones are a minor component of the known faunas.

Early Cambrian (Atdabanian–Botomian) faunas are widespread; middle and late Cambrian faunas are scarcer and are known largely from Siberia and Kazakhstan. Though many species are seemingly short-ranging, currently most have only local biostratigraphic significance, with only a few having practical international correlative value.

Palaeogeographically, faunas west of the Urals show affinities with those of the Early Palaeozoic Baltica and Avalonia palaeocontinents (Olenellid trilobite realm). Siberian and central Asian (Kirghizia, Gorny–Altay–Mongolian belt) faunas show clear affinities with those of palaeocontinental South China and eastern Gondwana (Redlichid trilobite realm). J. Micropalaeontology, 16(2): 179–191, October 1997

INTRODUCTION
Bradoriids and phosphatocopids are small, bivalved, almost exclusively Cambrian arthropods which first appear coevaly with, or slightly later than the first trilobites (see Siveter et al., 1996 and references therein). In spite of the fact that from the early Cambrian onwards bradoriids and phosphatocopids have worldwide distribution and that they often form abundant elements of Cambrian faunas (e.g. Hou & Bergström, 1991), their use in biostatigraphic and biogeography has largely been neglected. Several recent studies have highlighted their widespread occurrence in the Cambrian of especially Britain (see Siveter & Williams, 1995; Rushton et al., in press; Williams & Siveter, in press), North America (see Siveter & Williams, 1977), Australia (Jones & McKenzie, 1980; Hinze-Schallreuter, 1993a), the Baltic (Hinze-Schallreuter, 1993b, 1993c) and China (see Shu, 1990a, 1990b with nomenclatorial annotations by Malz, 1990; Hou et al., 1991 and references therein) and have demonstrated their biogeographical and regional and international correlatative potential (e.g. Siveter et al., 1993; Williams et al., 1994b; Siveter & Williams, 1995). Bradoriids and phosphatocopids are also known from several parts of the former Soviet Union but a comprehensive account of their geographical occurrence and their biostatigraphic and biogeographic distribution and value remains to be elucidated; these are the primary aims of our paper.

Most of the some 40 bradoriid and phosphatocopid species known from the former Soviet Union are from central and eastern Asia (Fig. 1). Many species were collected as part of geological field reassessment studies and are known from only a few specimens; thus, information regarding exact geographic and stratigraphic provenance is sometimes imprecise. As far as the material at our disposal allows we have, where appropriate, revised the generic assignment of all of the bradoriid and phosphatocopid species of the former Soviet Union.

Small bivalved arthropods of the Cambrian have traditionally been referred to the Order Bradoriida Raymond, 1935 and considered to include the oldest representatives of the ostracod crustaceans (Müller, 1964, 1979; Jones & McKenzie, 1980). Both major groups of bradoriids, the Bradoritina Raymond, 1935 and the Phosphatocopina Müller, 1964, were raised to ordinal level in Müller, 1982 (adopted herein). Because of the problem of convergent evolution, resulting in the possession of a bivalved shell in many otherwise disparate groups of arthropods (as in ostracods, phyllocarids and some Burgess Shale taxa), recognition of the true affinities of such fossil forms ultimately depends on the preservation of appropriate soft parts (e.g. see Briggs, 1983; Müller & Walossek, 1991), rare examples of which are now known from both phosphatocopids and bradoriids (e.g. Müller 1979, 1982; Hou et al., 1996). Thus, some authors now consider the Phosphatocopida to be merely stem-group Crustacea (Müller & Walossek, 1991; Walossek & Müller, 1992; but see also, for example, Hinze-Schallreuter, 1993b, 1993c), and the Bradoriida are regarded as merely a polyphyletic grouping of perhaps several arthropod groups which questionably includes some ancestral ostracods (e.g. Jones & McKenzie, 1980; Siveter et al., 1996; Hou et al., 1996).

Most of the phosphatocopid and bradoriid specimens from the former Soviet Union are preserved on rock slabs, as partly flattened valves and carapaces. Some secondarily (?) phosphatized specimens have been extracted from limestones from Siberia (Müller et al., 1995) and Kazakhstan (Melnikova & Taylor, unpublished). This material is the sort of provenance (see Müller, 1979) which might yield phosphatocopids or bradoriids with soft tissues preserved.

HISTORY OF RESEARCH AND GEOGRAPHICAL DISTRIBUTION
The earliest documentation of bradoriids and phosphatocopids are based on mid- to late 19th Century studies of British and North American faunas (see Rushton et al., in press; Siveter & Williams, 1997; Williams & Siveter, in press). In contrast, these groups were only quite recently recorded from the former Soviet Union, as a result of field and faunal studies in the Cambrian of Asia (Figs 1, 2). From the 1950s onwards finds were made in
Siberia by palaeontologists such as N. P. Suvorova, V. Ye. Savitskii, N. P. Lazarenko, L. N. Repina and E. B. Romanenko. The earliest formal descriptions were of Siberian material from early Cambrian Atdabanian limestones of the Lena-Aldan region (*Cambria sibirica* Neckaja & Ivanova, 1956) and near Chekurovka in the Khara-Ulakh Mountains (*Cambria melnikovi* Ivanova, 1964) and of *Anabarochilina* Abushik, 1960 and *'Leperditia'* from the early late Cambrian of the Kotui River area (Abushik, 1960). Melnikova (1983a, 1983b) documented additional taxa from Siberia.

Later, material was recorded from non-Siberian parts of the former Soviet Union. The middle Asian regions of Kazakhstan, Kirghizia and the Gorny Altay-Mongolian belt have all yielded Cambrian bradoriids and/or phosphatocopids, including the types of *Ushkarella* Koneva, 1978, *Tscholponaella* Melnikova, 1990, *Uskutchiella* Melnikova, 1992 and *Altajanella* Melnikova, 1992 (Koneva, 1978; Melnikova, 1988, 1990a, 1990b, 1992). In contrast, bradoriids and phosphatocopids have been noted only rarely in that part of the former Soviet Union west of the Urals. A few species occur in the Baltic state of Estonia and in the Leningrad region (Melnikova, 1984, 1985, 1987). Unpublished faunas are also known from borehole material from western Belarus.

Most recent studies have either been short general summaries about the bradoriids and phosphatocopids of the former Soviet Union (Melnikova, 1990c, 1990d) or detailed revisions of Siberian species which, in some cases, identify widespread biostratigraphical potential (e.g. Siveter et al., 1993, 1994, 1996; Hinz-Schalreuter, 1993c; Williams et al., 1994a). The possibility of obtaining additional bradoriid and phosphatocopid material from the former Soviet Union is particularly well demonstrated by the acid-resistant faunas obtained from limestones in Siberia (Müller et al., 1995) and from Kazakhstan during the 1980s by Melnikova and Taylor (unpublished manuscript; see herein Pls 3, 4).

**BIOSTRATIGRAPHIC DISTRIBUTION**

In the former Soviet Union bradoriids and phosphatocopids occur throughout the Cambrian but are known chiefly from the early parts of the system (Fig. 2). Many species are short-ranging (Fig. 3), but currently most have only local biostratigraphic significance, with only a few having practical international correlative value.

The Cambrian stratigraphy (Fig. 2) of the southern slope of the Baltic Shield and of Siberia is outlined in Mens et al. (1990), Cowie (1989) and Astashkin et al. (1991). The overall Cambrian stratigraphy in Kazakhstan and Kirghizia is currently under study, but some sequences are documented (e.g. Mambetov & Repina, 1979; Ergaliev, 1980; Brasier, 1989; Melnikova & Taylor unpublished manuscript). The Cambrian stratigraphy of the Gorny Altay-Eastern trans-Baikal regions of Asia is discussed in Astashkin et al. (1995).
Cambrian Bradoriida and Phosphatocopida

Early Cambrian (Pls 1, 2)
Most early Cambrian species are restricted to either the Atdabanian or Botomian stages. The oldest, Atdabanian faunas occur in East Siberia (see Figs 1–3) and are characterized by cambriid bradoriids. These include Cambria melnikovi (= Cambria melnikovae in error in Siveter et al., 1994) from the Tyusser Formation near Chekurovka village and Cambria sibirica and Cambria egorovae Melnikova, 1983 from the Lena-Aldan Region (Neckaja & Ivanova, 1956; Ivanova, 1964; Melnikova, 1983a; see also Siveter et al., 1994; Williams et al., 1994a). The lithostratigraphic provenance for the latter two species is less precise, though they may be from the Pestrotsvet Formation (see Fig. 2), which has subsequently yielded other possible cambriids. Cambriids are amongst the oldest bradoriids, characterizing approximately coeval rocks in Russia, South China (Qiongzhusi Stage, Atdabanian) and North Greenland (Nevadella - Olenellus trilobite Biozones; Siveter et al., 1996). Some of these cambriids may be congeneric or even conspecific, but renewed collection of the Siberian and Chinese taxa is necessary in order to test this and their true correlative value (see also Siveter et al., 1996).

In northern Estonia middle Atdabanian phosphatic sandstones of the Tiskre Formation yield Konicekion kundaensis Melnikova, 1987 and Bradoria (= gen. nov?) estonica Melnikova, 1987. Neither species is known from other Baltic Cambrian faunas (e.g. Wiman, 1905; Hinz-Schallreuter, 1993c).

The Mobergella Beds of Atdabanian age in central Kazakhstan has the bradoriids Houlongdongella sp. (= Alutella sp.), Bradoria sp. 1 (=cambrid? gen. et sp. nov?) and Tsunyiella gridinae Melnikova (1990a). This assemblage is similar to bradoriid faunas from the early Cambrian of China (see Zhang, 1987; Huo & Cui, 1989; Huo et al., 1991), where species of Tsunyiella Zhang, 1974 have been used as indices for the early Cambrian Qiongzhusi and Canglangpu stages (see Huo & Cui, 1989, table 1).

Botomian faunas of Siberia include Bradoria (= gen. nov?) ordinata Melnikova, 1983a, from the Bergeroniellus guarti Biozone of the Sinsk Formation of the Lena-Aldan Region, and Sunella (= gen. nov?) parva Melnikova, 1988, Liangshanelia? sayutinae (Melnikova, 1988) and Alutella usloniensis (Melnikova, 1988) from the Bystraya Formation of the Eastern Trans-Baikal region. In China species of Liangshanelia Huo, 1956 and Alutella Kobayashi & Kato, 1951 also typify the early Cambrian Qiongzhusi and Canglangpu stages (see Huo & Cui, 1989, table 1).

Dabashanella retroswinga Huo, Shu & Fu (in Huo et al., 1983), also a widespread species in the Qiongzhusi Stage (see Zhao & Tong, 1989; Huo et al., 1991), occurs in the Shabakta Formation of Kazakhstan (in association with the hyolith Microcornus parvulus) and the Beshtash Formation of Kirghizia (in associa-
Fig. 3. Biostratigraphic distribution of bradoriids and phosphatocopids of the former Soviet Union. Broken lines denote an uncertain stratigraphic range. The Precambrian–Cambrian boundary is drawn as in Astashkin et al. (1991, 1995).

Abushik, 1960 ranges from the early Cambrian Botomian of the Lena–Aldan Region into the middle Cambrian (Amgan Stage) Kuonamka Formation of the Malaya Kuonamka River Region.

Collections in the Palaeontological Institute, Moscow, include Kunmingella Huo, 1956 from an unspecified, presumed early Cambrian locality in Siberia (Pl. 2, fig. 6). The latter genus characterizes the early Cambrian, especially the Qionghuzsi Stage, of China (Shu, 1990b; Huo et al., 1983, 1991).

**Explanation of Plate 1**

Early Cambrian bradoriids/phosphatocopids of the former Soviet Union. Fig. 1 is a dorsal view; all others are lateral views. Figs 3, 7, 9, 10 are scanning electron micrographs; all other figures are light photographs (methods of Siveter, 1990). Fig. 1, Atdabanian, right side of the Lena River, 5.5 km from the mouth of the Anna-yuriite River, Siberia. Figs 2, 5, 6, 11, Mobergella Beds (Atdabanian), left bank of the Selety River, 9 km S of Bestyube, N Central Kazakhstan. Fig. 3, Beshhast Formation (Botomian; Microcornus parvulus Biozone), left bank of the Beshast River, 1.8 km NE of the mouth of Kaindy Stream, Kirghizia. Fig. 4, Tyuser Formation (Atdabanian), left bank of the Lena River, 4 km S of Chekurovka, Khara-Ulakh Mountains, Siberia. Fig. 7, Tiskre Formation (Atdabanian), Domanplaskii Horizon, Kunda Quarry, N Estonia. Fig. 8, Atdabanian, left bank of the Botoma River, 4 km from the mouth of the Khara-Uryach River, Siberia. Fig. 9, Shabaky Formation (Atdabanian), Berkut River, Maly Karatau, S Kazakhstan. Fig. 10, Tiskre Formation (Atdabanian), Domanplaskii Horizon, Koz-E-Lykatsi outcrop, N Estonia. Fig. 11, Cambria egorovae Melnikova, 1983. Holotype, carapace, PIN N4343/12, length 5.67 mm. Fig. 3. Tscholponaella orientalis Melnikova, 1990. Holotype, carapace, PIN N4344/1, length 5.81 mm. Fig. 2. Tsunyiella griliinae Melnikova, 1990. Paratype, left valve (stereo-pair), PIN N4343/13, length 4.91 mm. Fig. 4. Cambria melnikovi V. Ivanova, 1964. Holotype, left valve, PIN N4343/11, length 6.43 mm (measurement revised from Siveter et al., 1994). Fig. 5. Bradoria sp. 1 of Melnikova, 1990 (= Cambria? gen. et sp. nov.). Right valve, PIN N4343/39, length 3.57 mm. Fig. 7. Konicekion kundaensis Melnikova, 1987. Holotype, right valve (stereo-pair), PIN N4343/30, length 1.19 mm. Fig. 8. Cambria ibericica Neckaja & V. Ivanova, 1956. Holotype, left valve, PIN N117/2, length 5.71 mm (measurement revised from Williams et al., 1994a). Fig. 9. Dabashanella retrouwinga Huo, Shu & Fu, 1983. Carapace, PIN N4343/35, left lateral view, length 1 mm. Fig. 10. Bradoria estonica Melnikova, 1987 (= gen. nov.?). Holotype, carapace, PIN N4343/31, left lateral view, length 1.33 mm. Fig. 11. Indota? sp. Right valve, PIN N4343/98, length 1 cm.
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Middle Cambrian (Pls 2, 3)
Middle Cambrian bradoriid and/or phosphatocopid faunas contain relatively few taxa and are more sparsely distributed and often stratigraphically and geographically more imprecisely defined than the early Cambrian assemblages (Figs 2, 3). *Anabarochilina primordialis* (Linnarsson, 1869) is known from the late middle and late Cambrian of Siberia and the middle Cambrian of southern Britain and Scandinavia (see Siveter et al., 1993). Verification of its full correlative value awaits systematic recollection of Siberian material. *A. primordialis* occurs in the late Cambrian Eyra Formation of the Kotui River region and probably occurs in the middle Cambrian Siligar Formation of the Malaya Kuonamka River region (Fig. 2). The record of *A. primordialis* from the late Cambrian dolomites of the Lapar Formation of the Olenek River region may be in error; more likely it is from limestones of the middle Cambrian Tyussala Formation (see also Melnikova, 1984; Abushik, 1960; herein Fig. 2). The only other named middle Cambrian taxon from Siberia is *Vestrogothia* sp., represented by a single specimen from the Amgan Stage Sekten Formation near Chekurovka in the Khara–Ulakh Mountains (Pl. 3, fig. 10); additional finds comprise indeterminate phosphatocopids from the Kuonamka Formation (Müller et al., 1995).

Several new species are known from the middle Cambrian of southern Kazakhstan (Melnikova & Taylor manuscript; herein Pl. 3, figs 1, 5, 9). They include a late middle Cambrian (*Lejopyge* trilobite Biozone) *Anabarochilina* species, which resembles the middle Cambrian *Anabarochilina australis* (Hinz-Schallreuter, 1993c) from Australia, and a middle to late Cambrian form probably referable to the typically late Cambrian Chinese genus *Euzepaea* Shu (see Shu, 1990a).

West of the Urals the only known middle Cambrian species is *Vojbokalina magnifica* Melnikova, 1984, from the Sablinka Formation of the Leningrad Region.

Late Cambrian (Pls 3, 4)
Possible late Cambrian bradoriid and/or phosphatocopid faunas from west of the Urals are known only from as yet unstudied borehole material from western Belarus (Melnikova, personal observation; herein Pl. 4, fig. 8). In the Asiatic part of the former Soviet Union late Cambrian faunas are documented mostly from Kazakhstan and Gorny Altay (Figs 1–3).

Several apparently short-ranging new species, including beyrichonids, are known from the late Cambrian of Maly Karatau of southern Kazakhstan (Melnikova & Taylor manuscript; herein Pl. 4, figs 1, 2, 6, 9–11). In central Kazakhstan *Anabarochilina kovenae* Melnikova, 1990 is known from sediments of unspecified late Cambrian age and *Monasterium iveshini* Melnikova, 1990, *Monasterium (= gen. nov.?)* *seletiensis* Melnikova, 1990 and an undetermined phosphatocopid (= *Dielymella* sp. of Melnikova, 1990) occur in deposits of Aksayan age (Melnikova, 1990a). *Monasterium iveshini* thus extends the known range of the genus into the late Cambrian (the Chinese *Monasterium bucerum* Zhang, 1987 is early Cambrian and Australian species of *Monasterium* are middle Cambrian; see Zhang, 1987; Fleming, 1973; Hinz, 1992).

In Gorny Altay the upper (Saksian Stage) part of the Tandoshka Formation has yielded *Altajenella costulata* Melnikova, 1992 and *Uskutchiella sulcata* Melnikova, 1992.

**BIOGEOGRAPHIC SIGNIFICANCE**

In the Cambrian the Siberian and Estonian/western Russian areas of the former Soviet Union were positioned on the palaeocontinents of Siberia and Baltica, respectively (Fig. 4). Siberia lay at southerly tropical latitudes and Baltic at about 60° south, within the Bigotinid and Olenellid trilobite faunal realms, respectively (see Scotese & Mckerror, 1990; Mckerror et al., 1992). The sparse bradoriid and phosphatocopid faunas of Estonia and western Russia show some affinities with assemblages from Scandinavia (Baltica) and New Brunswick/Nova Scotia of the Canadian maritimes (situated on Avalonia, a southerly high latitude microcontinent on the northern margin of the Gondwana palaeocontinent). Those of Siberia show affinities particularly with South China, which in the Cambrian was an equatorial continental block on the northeastern margin of Gondwana.

Kazakhstan was once considered to be a discrete continental block or part of the Siberian plate (e.g. Scotese et al., 1979; Scotese & Mckerror, 1990) but it is now thought to be an amalgamation of terranes, many of which may be separated by ophiolites (Mckerror et al., 1992). This so-called Altai tectonic collage, which also includes Kirghizia and Gorny Altay, may have evolved dominantly along a subduction zone which, during the Cambrian, developed along the margin of a unified 'Baltica–Siberia' continent (Sengör et al., 1993). Early Palaeozoic faunas from different parts of Kazakhstan show affinities with Siberia, China and Europe (see summary in McKerrow et al., 1992, p. 603).

**Estonia and western Russia**

Early Cambrian bradoriid and phosphatocopid faunas of Baltica are poorly known (e.g. see Wiman, 1905; Hinz-

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**Explanation of Plate 2**

Early (figs 2–11) and middle Cambrian (fig. 1) bradoriids/phosphatocopids of the former Soviet Union. All valves are figured in lateral view. figs 4, 7 are scanning electron micrographs; all other figures are light photographs (methods of Siveter, 1990). fig. 1, Amgan, Malaya–Kuonamka River, Siberia. figs 2, 5, Botomian, Argaa–Salaa River, Lena–Aldan region, Siberia. fig. 3, Sinik Formation (Botomian; *Bergeronellus gurarii* Biozone), right bank of the Lena River, 1 km from Sinsk, Siberia. figs 4, 7–11, Bystraya Formation (Botomian), watershed between Ernichnaya and Ulolp streams, Georgievsk, E Trans-Baikal Region. fig. 6, Siberia: exact locality and horizon unknown. figs 1, 2, 5, *Lepididiella* concentriculata Abushik, 1960 (= gen. nov.), fig. 1, holotype, right valve, PIN N4342/65, length 7.14 mm. fig. 2, left valve, PIN N4342/80, length 4.05 mm. fig. 5, left valve (stereopair), PIN N4342/81, length 4.19 mm. fig. 3, *Bradoria ordinata* Melnikova, 1983 (= gen. nov.), Holotype, left valve (stereopair), PIN N3456/11, length 6.66 mm. fig. 4, *Walcottella* sp. of Melnikova, 1988. Right? valve, PIN N4372/47, length 1 mm. fig. 6, *Kumingella* sp. Right valve, PIN N4342/70, length 5.48 mm. fig. 7, *Liangshanshuiella* sayutinae (Melnikova, 1988). Holotype, right valve, PIN N4342/48, length 1.38 mm. figs 8, 9, *Alutella usloniensis* (Melnikova, 1988). fig. 8, right valve, PIN N4342/54, length 3.81 mm; fig. 9, holotype right valve, PIN N4342/55, length 4.19 mm. figs 10, 11, *Saniea parva* Melnikova, 1988 (gen. nov.?). Holotype, carapace, PIN N4342/40, right (fig. 10) and left (fig. 11) lateral views, length 1.90 mm.
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Schallreuter, 1993c). Those of western Russia and Estonia show links with Avalonian and Baltica faunal elements. Beyrichona Matthew, 1886 occurs in the late? Cambrian of Belarus and is also a characteristic component of the Cambrian bradoriid faunas of the Avalonian early and middle Cambrian of eastern Canada and middle Cambrian and early Ordovician of southern Britain (Matthew, 1886; Siveter & Williams, 1997; Williams & Siveter, in press). The Estonian ‘Bradoria’ estonica may be congeneric with species from early Cambrian erratic boulders in Schleswig-Holstein, North Germany (see Hinz-Schallreuter, 1993c, figs 16, 17). The poorly known, early Cambrian Konicekion Snajdr, 1975 from Estonia bears some resemblance to the widespread Albrunnicola Martinsson, 1979, a genus found in other Baltica and also Gondwanan and Chinese localities (see Hinz-Schallreuter, 1993c). The middle Cambrian Vojbokalina is endemic, being known only from the Leningrad region.

Siberia

The early Cambrian bradoriid and phosphatocopid faunas of eastern Siberia are dominated by cambriids, a paleoecographically widely widespread group, which span parts of the Redlichiid, Bigotinid and Olenellid trilobite realms, but which were apparently restricted to within tropical/subtropical regions. This suggests possible distributional control by palaeo-latitude factors such as temperature (Siveter et al., 1994 and references therein). The Siberian bradoriid Cambria Neckaja & Ivanova, 1956 is also probably a common element of south Chinese Cambrian faunas (the full biogeographic significance of cambriid species awaits revision of Chinese material such as that of Huo et al., 1991). The presence of Kunmingella confirms this affinity with the Chinese faunas.

The middle and late Cambrian faunas of Siberia include the cosmopolitan Anabarochilina and a vestrogothiid species. Vestrogothids are more typical of the middle and late Cambrian faunas of Scandinavia (Baltica) and southern Britain (Avalonia).

Kazakhstan, Kirghizia and Gorny Altay

The bradoriid and phosphatocopid faunas of central and southern Kazakhstan and possibly Kirghizia suggest a faunal affinity with China and probably Australia, an area synonymous with the Cambrian Redlichiid trilobite realm. Early Cambrian bradoriid and phosphatocopid faunas from northeastern central Kazakhstan include Alutella, Tsunyiella and a possible cambriid species; southern Kazakhstan (Maly Karatau) and Kirghizia yield Dabashanella retroswinga (see Melnikova, 1990a, 1990b). This fauna is very similar to those of contemporaneous deposits in the Tarim and southern (Yangtze Platform) areas of China (see Zhang, 1987; Huo & Cui, 1989; Huo et al., 1991 and references therein). Middle and late Cambrian forms from Maly Karatau, detailed study of which is in preparation (Melnikova & Taylor), includes Monasterium and an Anabarochilina species with affinities to the Australid A. australis Hinz-Schallreuter (Pl. 3, fig. 9).

The bradoriid and phosphatocopid faunas of the Eastern Trans-Baikal region, such as Liangshanella? and Alutella, show obvious affinities with faunas from China (Redlichiid trilobite realm). Ushkarella and Altajanella appear to be endemic to Kazakhstan and Gorny Altay, respectively.

COLLECTIONS

Nearly all bradoriid and phosphatocopid material from the former Soviet Union is housed in the Paleontological Museum of the Paleontological Institute (PIN) of the Russian Academy of Sciences, Moscow, Russia. The collections include material from Estonia, Belarus, the Leningrad Region, Siberia, Kazakhstan, Kirghizia and the Gorny Altay–Mongolian belt and are registered under the prefixes N1117, N2175, N3465, N4341-4344 and N4346.

The Geological Museum of the Institute of Geological Sciences, Alma-Ata, Kazakhstan, houses the small type collection of Ushkarella specimens, registered under N2348. The phosphatocopids from the Kuonamka Formation (Müller et al., 1995) are housed at the Institute of Palaeontology, University of Bonn, Germany.

CONCLUSIONS

From this review we conclude that the Cambrian Bradoriida and Phosphatocopida of the former Soviet Union:

- comprise about 40 species but material is relatively rare, consisting of only about 250 specimens;
- have been recovered mostly as crack-out material from clastic and impure carbonate rocks; acid resistant valves recovered from limestones are a minor component of the known fauna;
- occur chiefly in Asia (Kirghizia and especially Siberia and Kazakhstan); only sparse faunas are known from west of the Urals (Leningrad region, Belarus and Estonia);

Explanation of Plate 3

Middle (figs 1, 5, 8–10) and late (figs 2–4, 6, 7) Cambrian bradoriids/phosphatocopids of the former Soviet Union. fig. 10 is a dorsal view; all others are lateral views. figs 5–7, 9, 10 are light photographs (methods of Siveter, 1990); all other figures are scanning electron micrographs. figs 1, 5, 9, Mayan (Lejopyge trilobite Biozone), Kyrgyzstan, Siberia. fig. 2, Lermontov Horizon (Aksayan), right bank of the Seley River, 11 km E of Bestyube, Kazakhstan. figs 3–4, Shidery Horizon (Aksayan), right bank of the Olenty River, Kazakhstan. fig. 6, Edrei Beds (Aksayan), agyrek Mountains, Kazakhstan. fig. 7, Aysukokhan, vicinity of the River Kotui, Siberia. fig. 8, Sablinka Formation (Mayan), Saryja River, 800 m from Vojbokalo, Leningrad Region, Russia. fig. 10, Sekten Formation (Aman), left bank of the Lena River, 4 km from Chekurovka, Siberia. fig. 1. Eusepaeral?: sp. nov. Left valve, PIN N4343/46, length 0.71 mm. fig. 2. Monasterium seleiensis Melnikova, 1990 (= gen. nov.). Right valve (stereo-pair), PIN N4343/60, length 0.71 mm. fig. 3. 'Dielymella' sp. of Melnikova, 1990. Right valve (stereo-pair), PIN N4343/7, length 0.81 mm. fig. 4. Monasterium inquisitum Melnikova, 1990. Right valve (stereo-pair), PIN N4343/7, length 0.81 mm. fig. 5. Beyrichona sp. nov. A. Left valve (stereo-pair), PIN N4343/57, length 1.90 mm. fig. 6. Anabarochilina konoei Melnikova, 1990. Holotype, left valve, PIN N4343/1, length 5.71 mm. fig. 7. Anabarochilina primordialis (Linnarsson, 1869). Left valve, PIN N4342/60, length 8 mm (measurement revised from Siveter et al., 1993). fig. 8. Vojbokalina magnifica Melnikova, 1984. Holotype, carapace, PIN N4341/6, left lateral view (stereo-pair), length 1.37 mm. fig. 9. Anabarochilina sp. Right valve, PIN N4343/55, length 8 mm. fig. 10. Vestrogothia? sp. Incomplete carapace, PIN N4342/100, length 2.57 mm.

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- are predominantly of early Cambrian age; middle and late Cambrian faunas are scarcer and known largely from Siberia and Kazakhstan;
- include many short-ranging species, a few of which have practical international correlative value but most of which currently have only local biostratigraphic significance;
- west of the Urals show faunal links with those of the early Palaeozoic Baltica and Avalonia palaeocontinents (Olenellid trilobite realm); those of Siberia, and central Asia have links with faunas of palaeocontinental South China and eastern Gondwana (Redlichiid trilobite realm).

A formal systematic and monographic treatment of the Bradoriida and Phosphatocopida of the former Soviet Union ideally requires much more material than is currently available. In particular, the use of acid preparation techniques on limestones should be targeted as a potential high yield mode of recovery of valves, and as a possible source of specimens with soft-part preservation. Such studies would facilitate enhanced evaluation of the taxonomic, biostratigraphic and biogeographic significance of the faunas.

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Explanation of Plate 4

Late Cambrian bradoriids/phosphatocopids of the former Soviet Union (figs 1–11). fig. 5 is a dorsal view; all others are lateral views. figs 6, 8, are light photographs (methods of Siveter, 1990); all other figures are scanning electron micrographs. figs 1, 6, 9–11, Saksian (Issohagnostus isshini Biozone), Kyr-Shabaqty section, Maly Karatau, S Kazakhstan. fig. 2, Aksayan (Eurudagnostus ovaliformis Biozone), Kyr-Shabaqty section, Maly Karatau, S Kazakhstan. figs 3–5, Tandoshka Formation (Saksian), left bank of the Uskutch River, 3 km from its confluence with the Bol’shaya-Isha River, Gorny Altay. fig. 7, Lermontov Horizon (Aksayan), right bank of the Selty River, 11 km E of Bestyube, Kazakhstan. fig. 8, Borehole ‘Brest-1’, Belarus; depth between 903.6 and 905 m (exact horizon unknown). fig. 1. Euzepaera? sp. nov. Right valve, PIN N4343/47, length 0.62 mm. fig. 2. Bradoriid sp. Left valve, PIN N4343/49, length 1.48 mm. figs 3, 4. Alrajanella costulara Melnikova, 1992. fig. 3, Holotype, left valve, PIN N4346/1, length 1.19 mm. fig. 4, silicone rubber cast of right valve (PIN N4346/10), length 1.19 mm. fig. 5. Uskitchiella sulcata Melnikova, 1992. Holotype, incomplete open carapace, PIN N4346/25, length 0.94 mm. fig. 6. Beyrichonda? sp. C. Left valve, PIN N4343/58, length 2.86 mm. fig. 7. Bradoria sp. B. of Melnikova, 1990 (= Lianshankielia?). Carapace, PIN N4343/31, left lateral view, length 1.05 mm. fig. 8. Beyrichona sp. B. Carapace, PIN N4343/101, right lateral view, length 2.57 mm. fig. 9. Gen. et sp. nov. left valve, PIN N4343/48, length 1.00 mm. fig. 10. Beyrichona? sp. nov. D. Carapase, PIN N4343/43, right lateral view, length 2.29 mm. fig. 11. Monasterium sp. nov. Incomplete carapace, PIN N4343/51, right lateral view (stereo-pair), length 1 mm.
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