

# 西伯利亚和环西伯利亚地区：古生代时期它们的 识别与古地理

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**提要** 古西伯利亚地体的核心区域包括现今的西伯利亚的大部分，并延伸进入蒙古和中国西北部。环绕它周围的是古生代时期多个单独地体。根据古地磁数据可知西伯利亚的核心地区自从新元古代至三叠纪一直在反转，因此任何靠近它并与其拼合的小地体都应该发生了反转。经过分析，所有位于西西伯利亚盆地和阿尔泰—萨彦岭地区之下的地体，以及巴尔古津地体，图瓦—蒙古地体，蒙古中部地体集合体，鄂霍次克地体和雅库加—科累马地区的大部分，除了个别的以外，可以认为已经形成了环西伯利亚地区的一部分。反之，华北地体，满洲里地区的地体，阿拉善、羌塘—祁连、塔里木、准噶尔以及天山地体和哈萨克斯坦地体集合体并没有成为环西伯利亚的组成部分。据新的古地理学，从寒武纪至二叠纪末的西伯利亚陆块上的陆地、浅海、深水以及大洋分布都已经得到重建。古生代时期的土著分子——包括三叶虫、腕足动物、陆生植物的动物群和植物群序列，说明西伯利亚在古生代绝大部分时期孤立於其它主要的地块，直到在二叠纪才逐渐成为 Pangea 超大陆的一部分这一过程。

**关键词** 古地理，古生代，西伯利亚，环西伯利亚，蒙古，阿尔泰—萨彦岭

## SIBERIA AND PERI-SIBERIA: THEIR IDENTITIES AND PALAEOGEOGRAPHY DURING THE PALAEOZOIC

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### 1 INTRODUCTION

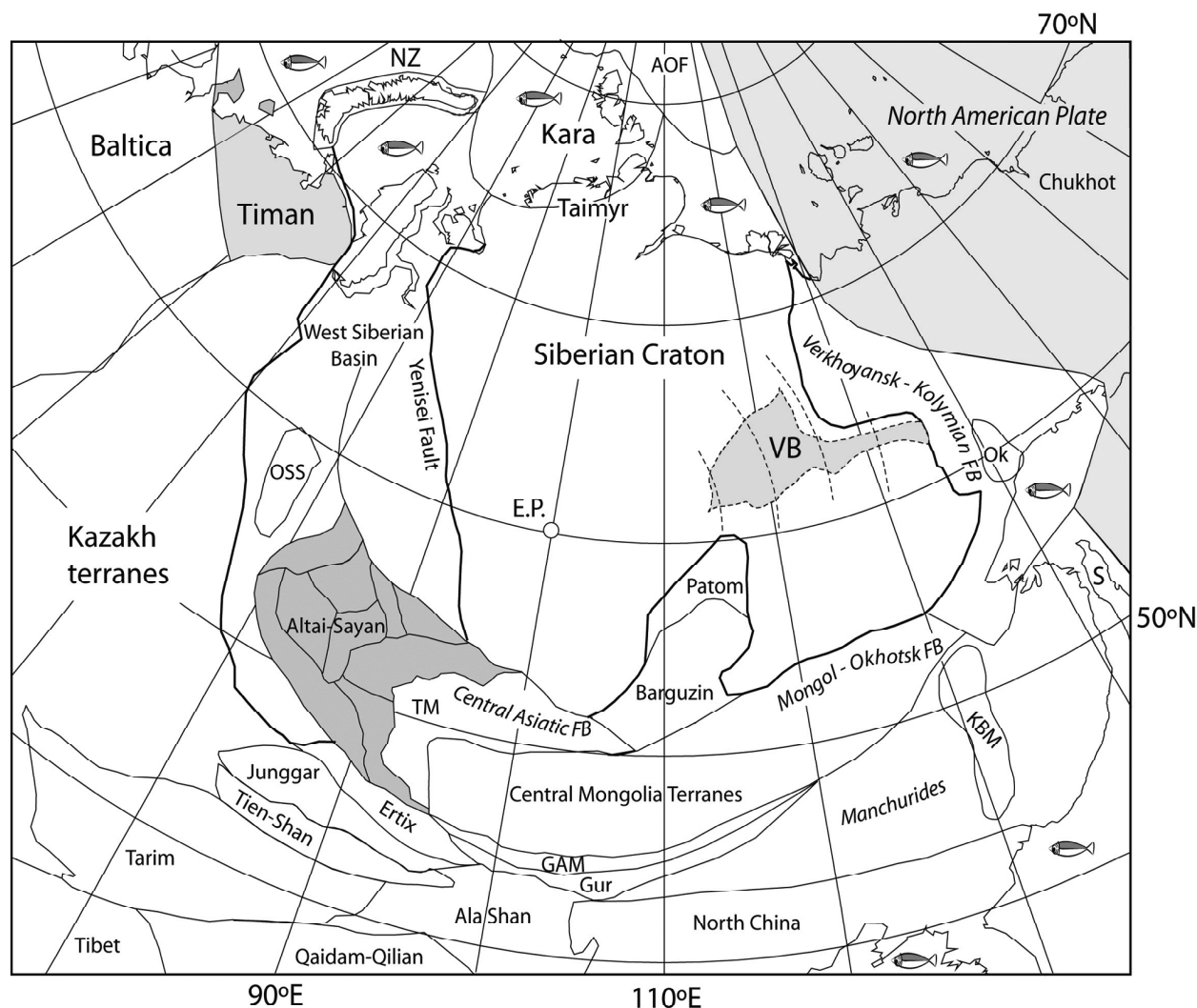
The end-Permian Siberian Traps are the largest known eruptions in Earth history, but they obscure over 40% of the land area of the old Siberian Craton. That craton has flat-lying or shallow-dipping sedimentary rocks from late Neoproterozoic to Recent in age, indicating that there has been little tectonic activity (apart from the Siberian Traps) over most of the craton for over half a billion years. However, in contrast, and surrounding the craton, there are substantial zones of major tectonic disruption. To the west of the craton there is the West Siberian Basin, whose relatively undisturbed Cretaceous to Recent rocks

overlie hidden Palaeozoic terranes of great complexity. To the south of the craton there is the Central Asian Fold Belt, running from the Pamirs to the north of the Himalayas and extending to the shores of the Pacific Ocean. To the east of the Siberian Craton there is the Verkoyansk-Kolymar Fold Belt, which overlies the boundary between two of the largest tectonic plates existing today, the Eurasian and the North American plates. To the north lies the Arctic Ocean. It is our purpose here to present a much shortened version of our analysis (Cocks and Torsvik, 2007) of the Siberian and peri-Siberian Terrane Assemblage through Palaeozoic time.

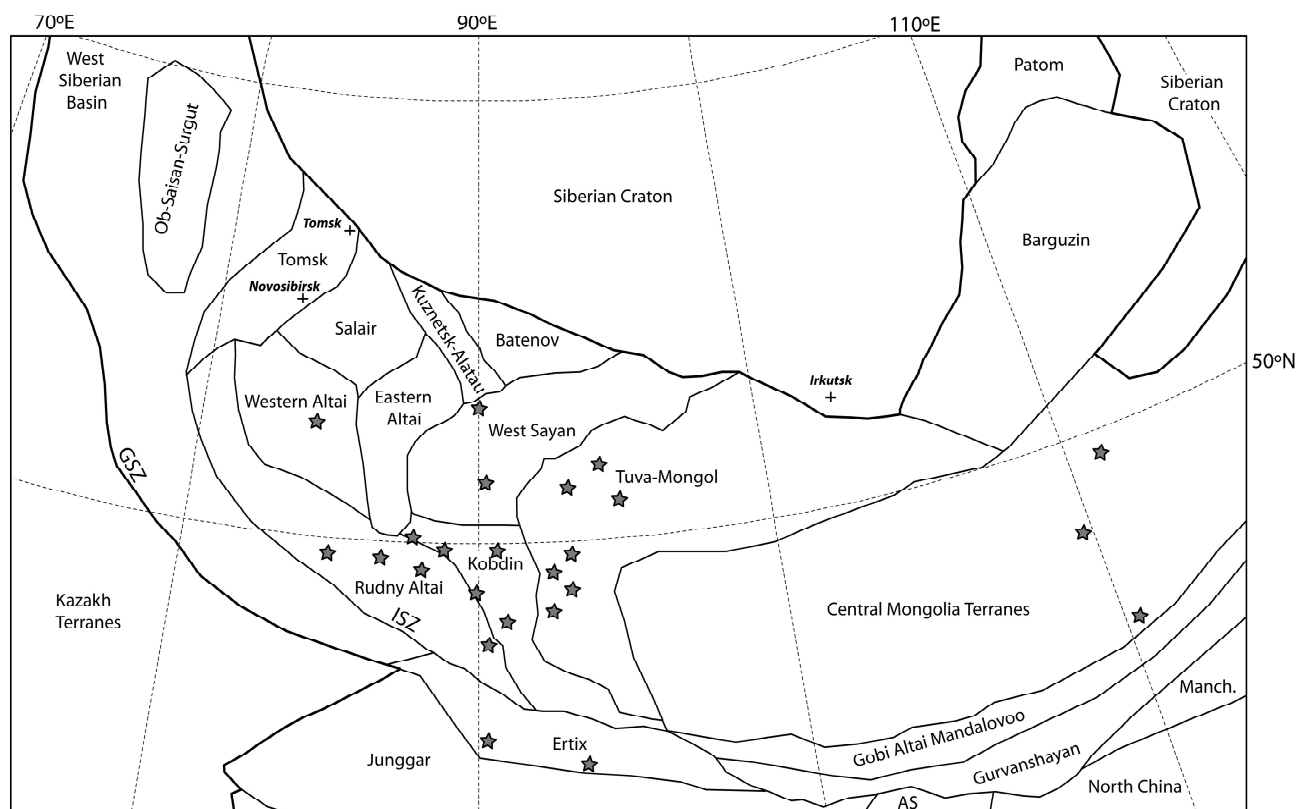
## 2 THE SIBERIAN CRATON

The Siberian Craton occupies most of the modern political Siberia, apart from near the Ural Mountains in the west (the western part of the West Siberian Basin), the Altai-Sayan and adjacent areas such as Barguzin to the south, and the Verkhoyansk-Kolymar Fold Belt, Chukhot Peninsula and areas further to the east. The latter areas underlie the North American Plate today, whilst all of the other areas discussed here form part of the Eurasian Plate. The craton has been little tectonically disturbed since the Neoproterozoic, and as a result reliable

palaeomagnetic results have been obtained from all of the Palaeozoic rocks (Smethurst *et al.*, 1998; updated in Cocks and Torsvik, 2007). These indicate that Siberia was inverted during the Palaeozoic, and progressed slowly from low southern palaeolatitudes in the late Neoproterozoic, across the palaeoequator in the Cambrian and early Ordovician. For the remainder of the Palaeozoic it was one of the few major terranes to lie entirely in the Northern Hemisphere, leading to much endemism in the faunas and floras. An enormous amount of stratigraphical and biostratigraphical data has been published for the Palaeozoic of the area, and it was often



Text-fig. 1 Terrane boundaries of the Siberian Craton and surrounding areas on a modern map. Fish symbols indicate modern oceans. AOF, Arctic Ocean floor; EP, Euler Pole; FB, fold belt; GAM, Gobi Altai and Mandalovoo Terranes; Gur, Gurvanshayan Terrane; KBM, Khingan-Bureya Massif; NZ, Novaya Zemlya; Ok, Okhotsk Massif; OSS, Ob-Saisan-Surgut area; S, Sakhalin Island; SJ Songhuajiang Terrane; TEF, Trans-Eurasian Fault; TM, Tuval-Mongol Terrane; VB, Viljuy Basin.



Text-fig. 2 Map of the SW part of the Siberian Craton and adjacent terranes in southern Siberia, Mongolia, eastern Kazakhstan, and northwestern China. AS, Ala Shan; Manch, Manchurides, GSZ, Gornostaev Shear Zone; ISZ, Irtys Shear Zone. Stars show distribution of the *Tuvaella* Silurian brachiopod fauna, with data points derived from Rong and Zhang (1982) and Rozman (1986).

the centre of provincialism for various biota at successive times.

### 3 PERI-SIBERIA TERRANES

Many tectonically-divided units probably represent previously separate terranes surrounding the core Siberian Craton (Text-figs. 1 and 2) which rotated with it during the Palaeozoic. Many of these small terranes had already accreted to neighbouring microterranes or to the main Siberian Craton before the Cambrian, but this paper starts at the beginning of the Cambrian. A key element in deciding whether or not each terrane was part of peri-Siberia is the presence or absence of the Silurian *Tuvaella* brachiopod fauna within them; and the outcrops containing that fauna (Text-fig. 2) are known from the work of many biostratigraphers, particularly Rong and Zhang (1982) and Rozman (1986). In anti-clockwise order from the Arctic Ocean (Text-fig. 1), these peri-Siberia terranes are as follows.

#### 3.1 The Ob-Saïsan-Surgut area and the Tomsk Terrane

The former is known largely from geophysical and borehole evidence and underlies the Mesozoic to Recent West Siberian Basin: it consists of Devonian and later Palaeozoic rocks. The Tomsk Terrane has a metamorphosed Precambrian core which, with overlying rocks, collided and amalgamated in the Middle Cambrian with island arcs on today's SW margin of the craton (Zonenshain *et al.*, 1990).

#### 3.2 Altai-Sayan Terrane Assemblage

Some of these are well exposed in the Altai-Sayan Mountains and adjacent areas, and from them many Palaeozoic rocks and fossils are known. There was much island arc activity in the Cambrian (Patom Terrane). The first major Palaeozoic series of accretionary events to the Siberian Craton occurred in the Ordovician, when there was also much island arc activity at the periphery of the Siberian Terrane (Batenov, Kuznetsk-Alatau,

Salair, Western Altai and Eastern Altai Terranes). The second major phase occurred in the Devonian, when there was also a huge amount of igneous and tectonic activity and which saw the inclusion of the West Sayan Terrane into the expanding craton, and in the Carboniferous the Kobdin Terrane. In the final Palaeozoic event, the Rudny Altai Terrane finally formed part of the Siberian Terrane in collisional orogeny during the late Carboniferous into the Early Permian.

### 3.3 Ertix Terrane

This is a new term (Cocks and Torsvik, 2007) for the substantial area to the south of the Rudny Altai, Kobdin and Central Mongolian Terranes, whose boundaries are shown on Text-figure 2, and which includes parts of southern Mongolia and the Xinjiang Province of China. The terrane's southern border with the Junggar and Tien-Shan terranes is delineated by the Ertix Fault complex, after which the terrane is known. Because of the occurrence of the Silurian *Tuvaella* brachiopod fauna there, in the Barkol area of NE Xinjiang, the terrane is deduced to have formed part of peri-Siberia and rotated with it.

### 3.4 Barguzin Terrane

Within this vast area (Text-fig. 1) there are Proterozoic metamorphic and ophiolitic rocks overlain by Vendian to Cambrian sediments. It is uncertain whether or not Barguzin formed part of Siberia in the latest Proterozoic, but the Patom Fold and Thrust Belt to its north is of Lower Devonian age, and most of the area is occupied by the enormous Barguzin Batholith of late Devonian age. The batholith may have been post-collisional, so that it seems most likely that the final accretion of Barguzin to Siberia was in the Devonian rather than in the Neoproterozoic.

### 3.5 Tuva-Mongol Terrane Assemblage

The southern margin of peri-Siberia is an arcuate line which bisects Mongolia and lies immediately S of the Gobi-Altai Mountains of Siberia. Badarch *et al.* (2002) have identified 14 different terranes in the area, which is immensely complex. In the latest Precambrian there were at least three terranes independent of Siberia (the

Tsagaanshiveet, Sangelin and Hug-Gargon-Ilchir Terranes). During the Neoproterozoic and Lower Palaeozoic many tectonic events unified all these terranes with each other, but it was not until the Devonian and Early Carboniferous that they became finally united within the main Siberian Terrane. Once again, the presence of *Tuvaella* confirms the positions of the many terranes situated to the then north of the main Siberian Craton prior to their accretion.

### 3.6 Central Mongolia Terrane Assemblage

Like the Tuva-Mongol Terranes described above, there were several Neoproterozoic and Lower Palaeozoic independent terranes in this large area, which have also been characterised by Badarch *et al.* (2002), who identified 14 terrane units there, nine of which have Precambrian cores. Spread across the whole Tuva-Mongol and Central Mongolia terrane collages there are well-documented Cambrian sequences with typical endemic Siberian trilobite faunas (Astashkin *et al.*, 1995), indicating that the whole area again formed parts of the peri-Siberian terrane assemblage and rotated with it during the Palaeozoic.

### 3.7 Gobi Altai and Mandalovoo Terranes

Badarch *et al.* (2002) have again defined these units, which are largely within Mongolia. The Mandalovoo Terrane includes *Tuvaella* in the Silurian (Wang *et al.*, 2005), indicating again that it lay on the northern margins of peri-Siberia, but the terrane also contains island arc rocks of Devonian age, and it probably did not accrete to the main Siberian Terrane until the late Carboniferous. The Gobi Altai Terrane also had a complex history, consisting of Cambrian metamorphic rocks overlain by Ordovician to Triassic largely shallow-marine rocks, but all intruded by Silurian and Upper Palaeozoic granites. However, the two terranes were probably amalgamated before the Devonian.

### 3.8 The Okhotsk Terrane and Verkhoyansk and Kolymar regions

The Okhotsk Massif has a Precambrian core, above which are Cambrian and later sediments (Zonenshain *et al.*,

1990; Astashkin *et al.*, 1995). It is uncertain at what time the Okhotsk Massif was welded to the main Siberian Terrane; it may have been as early as Riphean, but some authors postulate an independent Palaeozoic existence; however, the Lower Palaeozoic trilobite faunas of Okhotsk include typical Siberian endemic genera, for example Cambrian trilobites. The Verkhoyansk and Kolymar regions have no rocks earlier than Permian within them, but elements of them are inferred to have been within the margins of the Siberian Terrane for the preceding parts of the Palaeozoic.

#### 4 SURROUNDING NON-SIBERIAN TERRANES

Other terranes shown on Text-figures 1 and 2 were never part of the old Siberian Terrane, and thus did not rotate with it during the Palaeozoic and later. Chief among these were Baltica (including the Urals and Novaya Zemlya), the North China Terrane, the Manchurides Terranes, the Guransayhan Terrane of Mongolia, the Ala Shan Terrane, the Qaidam-Qilian Terranes, the Tarim Terrane, the Junggar Terrane, the Tien-Shan Terranes, and the various terranes that make up most of Kazakhstan. The Palaeozoic structure and history of the Central Asia area has been the subject of much controversy, with leading early post plate-tectonic papers by Zonenshain *et al.* (1990) and Sengor and Natalin (1996). A modern summary including much of the area is in Windley *et al.* (2007), and they and their relationships with Siberia are also discussed individually in Cocks and Torsvik (2007).

#### 5 PALAEOZOIC HISTORY

The core of Siberia includes Archaean and older Proterozoic rocks of the Anabar Massif and Aldan Shield, but these were united into a single Siberia Terrane before 1.0 Ga, which was independent from the rest of Rodinia before at least 800 Ma (Torsvik, 2003). From the Riphean onwards, the core of Siberia was a stable craton which was overlain at different times by a series of epeiric seas often yielding terrane-diagnostic marine shelly faunas. In the Upper Palaeozoic, the record from the plants is also distinctive. Siberia was inverted in relation to the

present day through the entire Palaeozoic. It lay in the southern hemisphere during all of the Cambrian, but then drifted steadily northwards, crossing the palaeoequator at a relatively high speed during the Ordovician, and by the end Silurian it was entirely confined to the northern hemisphere, where it has remained for the rest of the Phanerozoic; the only major terrane to have been located there. There was much tectonic activity in the peri-Siberian island arcs of Altai-Sayan and elsewhere.

In the Cambrian, the trilobites were very endemic (Astashkin *et al.*, 1991, 1995), but they were less diverse than on other equatorial terranes such as Laurentia (North America). In the Ordovician there were also very endemic faunas; for example, the trilobite family Monorakidae was almost entirely confined to the Siberian Terrane, including the southern part of the Taimyr Peninsula. It was at this time that there was more tectonic activity in many parts of the peri-Siberian adjacent terranes, some concerned with the docking of those terranes to the main Siberian Craton. In the Silurian, although today's central and northern (then southern) areas' shallow-water marine faunas were relatively cosmopolitan, in the north of Siberia and peri-Siberia, including the very substantial Mongolian Terrane Assemblage (which was not then attached to Siberia), there existed the very distinctive relatively low-diversity *Tuvaella* brachiopod fauna (Rong and Zhang, 1982; Rozman, 1986). The latter is particularly striking, since most early and middle Silurian faunas in all the terranes were cosmopolitan, apart from the *Tuvaella* Fauna, which was confined to northerly palaeolatitudes of Siberia and peri-Siberia, and the *Clarkeia* Fauna in high southerly palaeolatitudes of Gondwana and peri-Gondwana.

The Devonian was also a time of great tectonic activity. It seems probable that the Viljuy Basin, within today's east of Siberia (Text-fig. 1), was passing over a hot spot, causing Red Sea type rifting but subsequent closure: there Upper Devonian rocks lie unconformably directly over old oceanic crust. It was at this time also that the very substantial Barguzin Batholith and many other granitic and volcanic rocks were intruded across many parts of the old terrane. In the Carboniferous, Siberia was evidently still at some distance from the other

major global terranes, which gave rise to an endemic Siberian botanical province known as the Angara Province: the floral provinces were reviewed by e.g., Meyen (1987). The boundary between the Angara Province and the Cathaysian Province within Mongolia and China in the Upper Carboniferous is clearly marked (Yue *et al.*, 2001), and it is clear that the two areas and their floral realms were still widely separated from each other at that time. However, by that time other terranes were approaching Siberia. In particular, the Junggar-Tarim area was situated to its south-east, elements of the Kazakh Terrane Assemblage were to the south of Siberia, and the Kara Terrane was not too far from its south-west margin, which, following the steady rotation mentioned above, was by then today's Arctic Ocean margin. In the Permian, for which there is much high-quality palaeomagnetic data, Siberia progressively became part of the immense superterrane of Pangea. This was in contrast to much of the rest of Pangea, notably Laurussia (including the earlier Baltica) and most of the Kazakh Terrane Assemblage and Gondwana, which had already united before the end of the Carboniferous. Whilst the Angaran floral Province was still clearly differentiated from the Cathaysian during the Early Permian (Wordian), by the later Permian (Sakmarian) the distinctions between the two had largely disappeared (Rees *et al.*, 2002). Tectonically the Tunguska Basin, which covers most of the western part of the Siberian Craton, had steadily downwarped, and it was at the very end of the Permian at 251 Ma that the vast volcanic outpourings of the Siberian Traps occurred, which were the main cause of the end-Permian biotic extinction event. From then onwards until the present day, Siberia has remained the eastern component of the Eurasian Superterrane.

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