Part 1. Geology and Biostratigraphy of the Carboniferous of the Southern Urals

Часть 1. Геология и биостратиграфия карбона Южного Урала

STRUCTURE OF THE URALS (WITH A SPECIAL REFERENCE TO THE CARBONIFEROUS COMPLEXES)

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СТРУКТУРЫ УРАЛА (СО СПЕЦИАЛЬНЫМ АКЦЕНТОМ НА КАМЕННОУГОЛЬНУЮ СИСТЕМУ)

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The Urals are a Late Palaeozoic orogenic belt. It is located at the western flank of a huge (more than 4000 km long) intracontinental Uralo-Mongolian mobile belt. The orogen developed mainly between the Late Devonian and the Late Permian, with a brief resumption of orogenic activity in the Lower Jurassic and Pliocene – Quaternary time. Although its evolution is commonly related to the Variscides of Western Europe, its very distinctive features argue against a simple geodynamic connection. To a first order, the evolution of Uralian orogen shows similarities with the "Wilson cycle", beginning with epi-continental rifting (Late Cambrian – Lower Ordovician) followed by passive margin (Middle Ordovician – Late Devonian and partly Early Carboniferous) development, onset of subduction and arc-related magmatism (Late Ordovician) followed by arc-continent collision (Late Devonian in the South and Early Carboniferous in the North) and continent – continent collision (beginning in the mid-Carboniferous). In detail, however, the Uralides preserve a number of rare features. Oceanic (Ordovician to Lower Devonian) and island-arc (Ordovician to Lower Carboniferous) complexes are particularly well preserved as is the foreland belt in the Southern Urals, which exhibits very limited shortening of deformed Mesoproterozoic to Permian sediments. Geophysical studies indicate the presence of "cold", isostatically equilibrated root. Other characteristic features include a Silurian platinum-rich belt of subduction-related layered plutons, a juxtaposition of orogenic and rift-related magmatism, a succession of collisions that are both diachronous and oblique, and a single dominant stage of transpressive deformation. The end result is a pronounced bi-vergent structure. The Uralides are also characterized by Meso-Cenozoic post-orogenic stage and plume-related tectonics. The evolution of the Uralides is consistent with the development and destruction of a Paleouralian ocean to form part of a giant Uralo-Mongolian orogen, which involved an interaction of cratonic Baltica and Siberia with a young and rheologically weak Kazakhstanian continent. The Uralides, oppositely to Variscides, are characterized by recurrent and much more protracted orogenesis, interrupted in the Early Triassic by tectonothermal activity associated with the Uralo-Siberian superplume.

The relics of earlier orogens are traced in the basement of the Uralides. In particular, the Late Neoproterozoic pre-Uralian (Timanian) orogen is reconstructed and identified as a counterpart of the Late Precambrian Cadomian orogen. The Timanian orogen was partly destroyed by Late Cambrian – Early Ordovician epicontinental rifting and formation of the Paleo-Uralian ocean whose remnants are Palaeozoic ophiolites. Calc-alkaline volcanites and plutons, typical of island arcs and active margins, are widely developed in the eastern Urals.

The Uralian foldbelt results from oblique collision between the East European (Laurussia) passive margin and the active margin on the Kazakhstanian continent. Collision began in the south of the Urals and moved, wave-like, to the north. The eastern and northern parts of the Urals have been also affected by the Pre-Middle Jurassic Cimmerian intracontinental (intra-Pangaean) shortening. The Uralian – Cimmerian mountain belt (Uralides) was eroded and partially inundated by seas in the Late Jurassic – Early Cretaceous times and has been reactivated since the Pliocene in response to a recent intracontinental shortening.

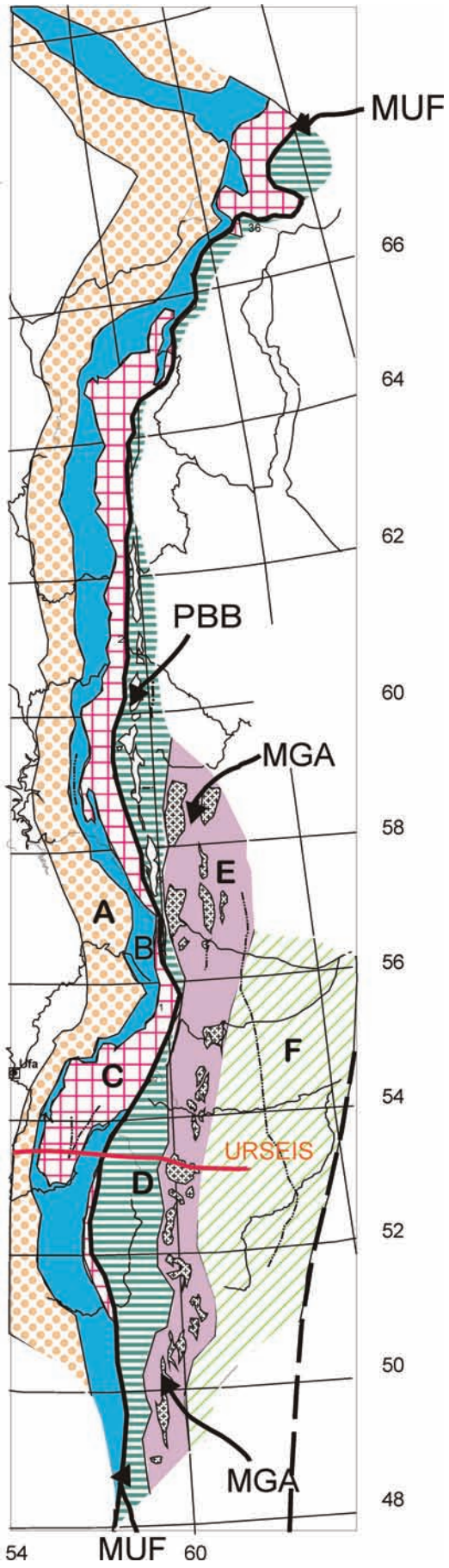
The Uralian foldbelt is one of the oldest and richest mining regions of Russia. Therefore, it has attracted attention of many geologists among whom one should mention Murchison (the founder of the Permian system), Karpinsky, (the proponent of the contractionist ideas who suggested that the changes in the Ural's strike were influenced by the outline of the rigid Russian plate) and Shatsky (who established the Riphean system in the Urals, discovered relics of a Late Proterozoic foldbelt and developed a theory of relationships between geosynclines and platforms). In the early 1970s, in light of the introduction of plate tectonics, Hamilton, Peyve and Ivanov proposed that the Urals represent a closed Palaeozoic ocean.

The north-south-trending mountain range, approximately 2000 km long, is the geographic Europe – Asia boundary and is commonly divided into the Polar, Cis-Polar, Northern, Central and Southern Urals (Fig. 1 at colored inset). The characteristic feature of the fold belt is a distinct, though disturbed, linearity of tectonic zones. Thanks to Late Cenozoic tectonic movements the tectonic zones are all exposed in the Southern Urals. In the north, the Mesozoic and Cenozoic sediments of the West Siberian basin cover the easternmost zones. The Urals are divided into six sub-longitudinal zones that differ both in their structure and stratigraphy (see Fig. 1). From west to east they are (1) the Uralian Foredeep, (2) the West Uralian, (3) the Central Uralian, (4) the Tagilo-Magnitogorskian, (5) the East Uralian and (6) the Transuralian zones. Zones 1, 2 and 3 represent the former passive margin of the East European (Laurussia) continent [Puchkov, 1979]. This margin formed from the Late Cambrian to Early Ordovician and was stable during the Ordovician, Silurian and Devonian times. In the Late Palaeozoic, the platform was deformed to become a part of the Uralian foldbelt.

The Uralian foredeep, 50–75 km wide, is filled with Permian flysch and molasse of eastern provenance, up to 6 km thick [Nalivkin 1949; Chuvashov, Dyupina 1973], underlain by 4–7 km thick Ordovician – Carboniferous shelf deposits, which, in turn, unconformably cover Precambrian sedimentary, metamorphic and magmatic complexes.

The western boundary of the foredeep is marked only in the Southern Urals by a chain of barrier reefs of Early Permian age (Asselian to Early Artinskian [Chuvashov, Nairn 1993]) (Fig. 2). The terrigenous facies of the eastern provenance are spread far onto the platform, and the western boundary of the foredeep is usually expressed only by a more or less pronounced downward bend of the top surface of carbonates underlying the molasse and in a corresponding eastward increase in the molasse thickness. Facies changes of the foredeep sediments are complex; but the main steps in the foredeep development are the same at all latitudes. The foredeep began with the establishment of a "preflysch" deep-water basin on shelf sediments, west of the orogenic front. The basin was filled then by flysch and molasse sediments grading westward into deep-water facies and still further west into reefs and biostromes (see Fig. 2). The basin was filled with depositional evaporites of Kungurian (latest Early Permian) age. In the north the evaporites are replaced by terrigenous sediments with paralic coals. The Late Permian is represented in the foredeep by shallow marine and continental sediments, mostly terrigenous, red-colored and variegated in the south, grey-colored and coal-bearing in the north. The eastern boundary of the foredeep was affected by westward thrusting. To the east the molasse and flysch are preserved in some deep synclines of the West Uralian fold zone.

The outer (western) subzone of the foredeep is characterized mostly by smooth, open, nonlinear folds typical for platform areas; the inner (eastern) subzone is characterized by thrusts and folds of a thin- to medium-skinned type [Puchkov, 1997; Yudin, 1994].



To article by Viktor N. Puchkov "Structure of the Urals (with a special reference to the Carboniferous complexes)"

Fig. 1. Tectonic zoning of the Urals
Zones: A — Preuralian foredeep, B — West Uralian zone, C — Central Uralian zone, D — Tagilo-Magnitogorskian zone, E — East Uralian zone, F —Transuralian zone; MUF — Main Uralian Fault, MGA — Main granitic Axis of the Urals, PBB — Platinum-bearing belt, URSEIS — the seismic line shown in the Fig. 3

The West Uralian zone comprises predominantly intensely folded and thrusted Lower and Middle Palaeozoic sediments characterizing the former passive margin of the East European continent. There is no conspicuous facies change at the boundary between the Uralian foredeep and the West Uralian zone. Such a change, partially affected by later thrusts, occurs further to the east within the zone, as an abrupt transition from shelf to bathyal sediments. Such sedimentary facies changes occur across the passive margin as well as along its 2000 km length.

Shelf sediments are up to 2.5–3 km in the Middle and Southern Urals. In the western sections of zone, Ordovician, Silurian and Lower Devonian sediments are absent, so the Middle Devonian strata unconformably overlie Riphean and Vendian (Meso- and Neoproterozoic) sediments. The Lower Devonian regressive succession of argillaceous limestones, dolomitic marls, siltstones and shales, are followed by Emsian transgressive quartzites, sandstones and siltstones grading upwards mostly into shallow-water open-sea limestones.

The longest Lower Devonian barrier reef is traced along the margin of the shelf zone from the Polar to the Southern Urals. In the south Middle Devonian basinal shales, marls and cherts (so-caled infradomanik) are developed. In the Latest Mid-Devonian a new transgresive series was deposited with thin quartzites and shales in the bottom. Over area of development of the Upper Givetian terrigenous facies and open-sea limestones, the so-called Kama – Kinel system of deep-water troughs was established in the Mid Frasnian time in the eastern part of the Laurussia continent.

The basinal, "domanik" facies in the axial parts of the troughs is represented by a starved, condensed unit of marls, cherts and oil shales. Reef limestones border the troughs. This type of sediment distribution persisted through the Famennian and Tournaisian, related to the high stand of sea level across platform. The regressive Lower Viséan and transgressive Upper Viséan sediments are characterized by the wide development of terrigenous and carbonate-terrigenous facies, including quartzites, shales and siltstones with coal layers. The Kama – Kinel troughs were filled with Early Viséan sediments and ceased to exist.

The outer part of the continental margin was marked by a formation of bathyal facies which are contemporary to the shelf ones (Ordovician to Devonian). They are represented mainly by turbidites of the western provenance alternating with condensed shaly-carbonate and cherty sediments [Puchkov, 2002].

Starting with the Late Frasnian – Early Famennian, the passive margin of the continent in the territory of the future Southern Urals, firstly bathyal and then shelf zone, was affected by orogenic movements as a result of a collision between the Magnitogorsk arc and passive margin of the Laurussia continent [Puchkov, 2009]. The collision was accompanied by a formation of an accrettionary complex with exhumed HP-LT metamorphics, Main Uralian Fault (MUF), west-vergent thrust-and-fold system of the footwall of MUF and a deposition of Famennian – Tournaisian greywacke flysch of eastern provenance, prograding to the west onto the marginal shelf of Laurussia continent.

The Early Carboniferous, Late Viséan – Serpukhovian as well as the Upper Carboniferous Bashkirian stage in the platform and partly in the Preuralian foredeep and West Uralian zone, are represented mostly

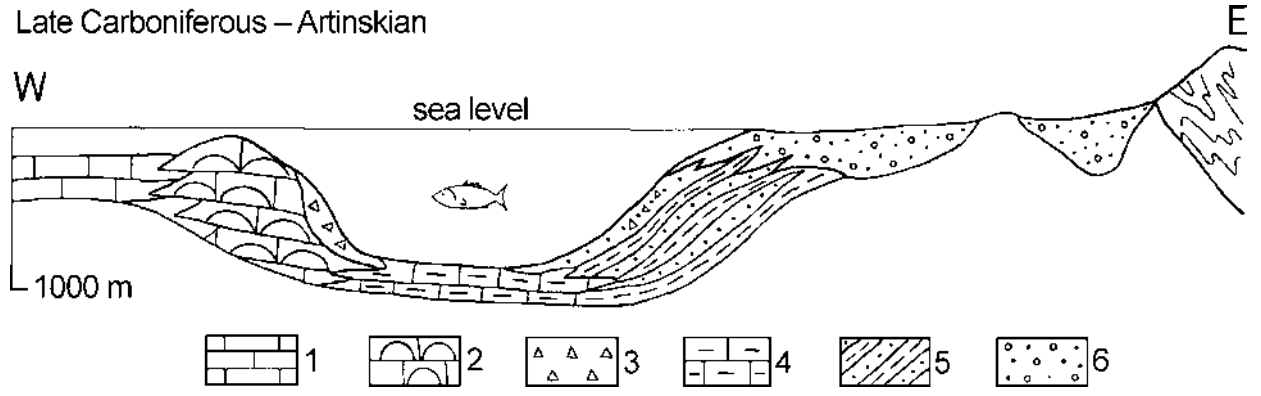


Fig. 2. Cartoon summarizing the principal lithofacies across the Late Carboniferous – Artinskian Uralian foredeep (after [Nalivkin, 1949] and [Chuvashov et al., 1984]).

Legend: 1 — shallow-water sediments, mostly bedded carbonates; 2 — reef limestones; 3 — carbonate olistostrome; 4 — basinal (preflysch) shales, cherts, marls; 5 — turbidites; 6 — molasse

by pure shallow-water limestones. A very important transgressive – regressive boundary of the stratigraphic sequences, marked by unconformity and the deposition of terrigenous sediments is within the Moscovian, but in the West Uralian zone this unconformity is not pronounced due to a general eastward inclination of the shelf. The Upper Carboniferous is represented in the West Uralian zone predominantly by shallow-water limestones, restricted above, in many places, by a stratigraphic unconformity.

However the Carboniferous of the southern part of the West Uralian zone displays again the signs of the westward terrigenous influx, which started in the Famennian. From this time on, the area of flysch sedimentation influenced by the eastern source of terrigenous material was present and widening in the western zones of the Urals, and finally the Preuralian foredeep in its modern boundaries was formed above the shelf zone. During the whole time since the Famennian till the Early Permian, flysch trough was prograding to the west, being preceded by a deep-water preflysch and heralded by barrier reefs.

The modern structure of the West Uralian zone is characterized by thin-skinned to thick-skinned thrusts and folds of western vergency, with detachment surfaces under them [Brown et al., 2006]; Fig. 3 at colored inset, the western part.

The Central Uralian zone up to 70–75 km wide is characterized by well-exposed Precambrian sedimentary, metamorphic and magmatic rocks which are, in some places, thrust over the rocks of West Uralian zone. The core of the Bashkirian anticlinorium, an exhumed Precambrian basement of the Palaeozoic continental margin, includes crystalline complexes, produced by two or more stages of deformation and metamorphism, sedimentary sequences of Riphean aulacogens and Vendian molasse of the Late Precambrian Timanide orogen.

The Tagilo-Magnitogorskian, East Uralian and Transuralian zones belonged to the active margin of the Kazakhstanian continent [Yazeva et al., 1989; Puchkov, 1996]. They are less uniform compared the first three zones. What unites them, is a wide development of magmatic complexes, indicators of subduction.

The Central Uralian and Tagilo-Magnitogorskian zones are thought to be divided by an east-dipping major suture zone called the Main Uralian Fault. A considerable part of it is marked by serpentinitic mélanges.

The Tagilo-Magnitogorskian zone is composed of Lower-Middle Palaeozoic complexes of oceanic crust, island arcs, flysch troughs, covered by Carboniferous shallow-water sediments: limestones, coal-bearing terrigenous sequences and widespread rift and subductional volcanics. The development of subductional complexes was finally stopped in the Bashkirian time. From this moment on, the subduction was changed by a collision, resulted in a formation of the Uralian orogen.

The East Uralian zone is distinguished by the presence of sialic, microcontinental complexes, fragments of Precambrian continental crust. This is a collage of microcontinental blocks with relics of an autochthonous Palaeozoic sedimentary and volcano-sedimentary cover and allochthonous Palaeozoic ophiolite and island-arc formations. The distinct feature of the zone is also a chain of granite intrusions (Main Granitic Axis of Urals), developed during the last stages of subduction (Tournaisian to Bashkirian) and later stages of collision (Moscovian to Permian). The relicts of collision-induced intermontane depressions, traced in the East Uralian zone, were filled by Moscovian flysch-like deposits and a Gzhelian – Kasimovian molasse.

The Transuralian zone. This, the easternmost, most poorly exposed and least studied zone, has a rather controversial eastern boundary separating the Uralides from the Kazakstanides (Caledonides). The zone has accretionary features, including Precambrian blocks, Ordovican rift complexes and ophiolites, Silurian and Devonian shallow and deep-water complexes. The most important are calc-alkaline volcano-plutonic subductional) complexes of the Tournaisian to Bashkirian age.

The modern structure of the Uralian orogen. The complex geological and geophysical studies at URSEIS-95 and SB-ESRU profiles demonstrated a well-preserved bi-vergent structure of the Uralian orogen ([Puchkov, in print], and references therein).

The origin of the modern Ural mountains. The Late Palaeozoic mountain belt rejuvenated by the Old Cimmerian dislocations existed only for a short time, due to rapid erosion. By the end of the Jurassic and during the Cretaceous the Urals were low hills and partially a lowland ingressed and covered by seas [Papulov, 1974]. Only since the Pliocene have Ural mountains started to grow again. These processes are still active,

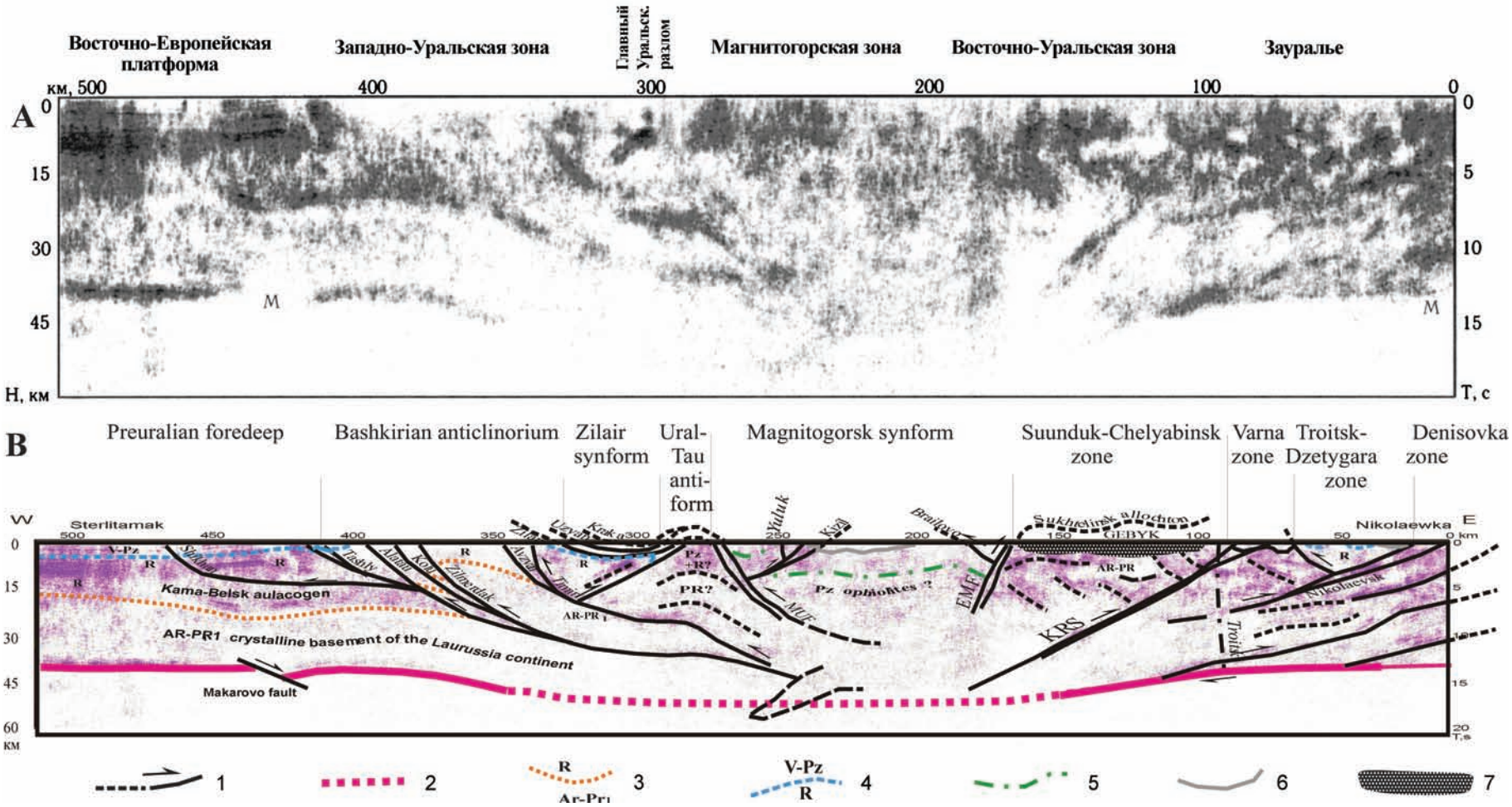


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Fig. 3. A — uninterpreted combined (vibro- and explosion) seismic section along the URSEIS-95 geotraverse profile Sterlitamak – Nikolayevka). The seismic data after [Suleimanov, 2006], SpetsGeofizika. B — geological interpretation, overlain on the profile. The symbols belong to this part of the picture

Legend: 1 — Faults and directions of movements; 2 — Moho boundary after the wide-angle seismics; 3 — Top of the Archean – Paleoproterozoic basement; 4 — Top of the Riphean (Meso-Neoproterozoic minus Ediacarian) sequence; 5 — Top of the island-arc crystalline (ophiolitic) basement; 6 — Base of the Lower Carboniferous; 7 — Gebyk granites

proved by geodetic and horizontal stress measurements as well by weak to medium earthquakes. This orogeny probably results from an intracontinental process, a far-reached alpine deformation of a continental crust, that followed favorable, weak directions in the lithosphere of Eurasia [Puchkov, 1988; Puchkov, Danukalova, 2009]. The Shikhans (hills, representing Lower Permian carbonate reefs) were uplifted and devoid of their evaporitic envelope during this late orogeny, in the Pliocene – Quaternary time.

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