Eastern Europe: The Timanian and Uralian Orogens

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Glossary

Orogenesis The mountain building process resulting from collision between two tectonic plates; can be ocean-continent or continent-continent collision.
Supercontinent Assembly of much of Earth's continental crust into a large single landmass, such as Pangea or Rodinia.
Timanian orogen Latest Neoproterozoic through Cambrian mountain building event resulting from oceanic subduction beneath/accretion to NE Baltica.
Uralian orogen Carboniferous through Permian mountain building event resulting from the subduction of oceanic crust associated with the Uralian ocean and ultimately the collision between eastern Europe and the Kazakhstan plus Siberian plates.
Wilson cycle Divergence (rifting) of continental crust ultimately results in the formation of intervening ocean basin due to spreading; later motion reversal results in the closure of that ocean with associated collision leading to orogenesis.

Introduction

Eastern Europe as seen today is the result of multiple orogenic events, i.e., the mountain building processes associated with collision between tectonic plates. Orogens may be products of the *supercontinent cycle*: continental collision results in orogenesis and fewer but larger continents. Rifting, on the other hand, leads to basins and more, smaller continents. Multiple orogens occurring in the same general location over geological time are not uncommon and can be explained by the *Wilson Cycle*. Orogens represent crustal-scale discontinuities and later deformation often localizes along these pre-existing zone of crustal weakness. In the eastern part of the East European Craton, this relationship is seen in the Timanian and Uralian orogens, where orogenesis is repeated (partly) in the same location.

"Baltica" is the name given to the paleocontinent which formed as the result of Neoproterozoic rifting and disaggregation of the supercontinent Pannotia (a "descendent" of Rodinia). Baltica comprises a significant part of the East European Craton (Fig. 1). After Neoproterozoic rifting, but before amalgamation in the Carboniferous to Permian of the younger supercontinent Pangea, subduction and island arc collision along the modern-day northeast margin of Baltica resulted in Timanian orogenesis. Later collision between the Baltican and Siberian/Kazakhstan plates during creation of Pangea resulted in Uralian orogenesis. Since the breakup of Pangaea in the Mesozoic, what remains of the Uralian Orogen is preserved within the Eurasian Plate. The current extent of these two orogens is clearly seen by their magnetic signatures (Fig. 2).

The Timanides

The Timanian Orogen extended from the southern Ural Mountains northward to the Arctic, via its type section in the Timan Range of Russia, and across the Arctic coastal peninsulas as far west as Varanger, Norway (Fig. 3)—a distance of more than 2500 km. The Timanian Orogen is less well known than other older orogens of Europe because (i) its northern parts were deeply buried by Phanerozoic successions of the Pechora Basin during later extension and subsidence, and (ii) its eastern parts were fragmented and re-worked during Uralian orogenesis (Fig. 3). Rocks with Timanian-age deformation and metamorphism are present throughout the western flank of the Ural Mountains, and as far north as Novaya Zemlya (Fig. 3). The onset of Timanian orogenesis is well constrained in the north. The change from a passive margin at c. 610 Ma (alkaline dike intrusion in the Timan Range) to a convergent margin with arc magmatism at c. 550 Ma resulted in SW-directed thrusting accompanied by deformation and uplift of regionally metamorphosed Neoproterozoic rocks. As thrusting and accretion continued, the active convergent margin migrated

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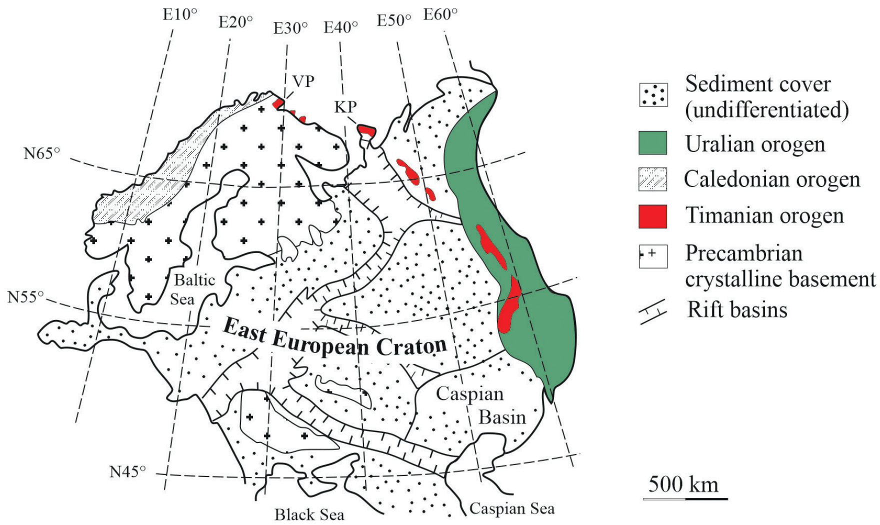

Fig. 1 Orogens of the East European Craton. Relicts of the Timanian Orogen (red) define its inferred extent. It was re-worked in its southern parts by the later Uralian orogeny (green). Both orogens are of similar scale, extending 1000s of kilometers. *KP*, Kanin Peninsula; *VP*, Varanger Peninsula.

outboard (northeastward) through mid- Cambrian time. After orogenesis, Cambrian rifting led to additional uplift and erosion, and a regional unconformity of Cambrian-Ordovician age developed. Deposition along the eastern edge of the East European Craton resumed as mostly passive margin shelf facies, until the onset of Uralian orogenesis in the late Paleozoic.

The Timanian foreland fold and thrust belt

The Timanian foreland is represented by two different Neoproterozoic sedimentary successions. In the north, along the Timan Range to the Varanger Peninsula, a thick turbidite succession was deposited along the margin of the East European Craton in a continental slope/rise environment. This succession was thrust southwest-ward onto platformal facies (shallow marine carbonate and siliciclastic formations), generating upright to SW-vergent folds of lower greenschist facies. Primary sedimentary structures (graded bedding and Bouma sequences) are well preserved. Regional higher-grade (amphibolite facies) metamorphism is only recorded locally (Kanin Peninsula, northernmost Timan). Blueschist has also been reported in northeastern Kanin Peninsula. The turbidite-dominated succession is extensively intruded by pre-tectonic dolerite dykes and, in northern Timan, by an alkaline suite of gabbros, granites, and syenites, often nepheline-bearing, with zircon U/Pb ages of c. 610 Ma. On the Varanger Peninsula and in the Mezen Basin, Late Ediacaran non-marine, siliciclastic successions represent erosional detritus from the uplifting orogen.

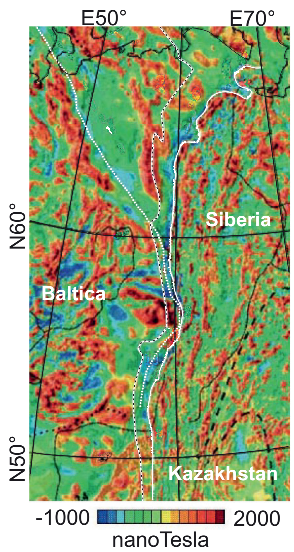

Fig. 2 Magnetic anomaly map of the northeastern East European Craton. Pronounced differences between the magnetic signature of "Baltica" crust to the west (large amplitude magnetic highs) and "Siberia" or "Kazakhstan" crust to the east (discrete smaller amplitude highs). From west to east: Deformation front of the Timanides (dotted white line), deformation front of Uralides (doted black and white line), and the main Uralian fault (solid white line).

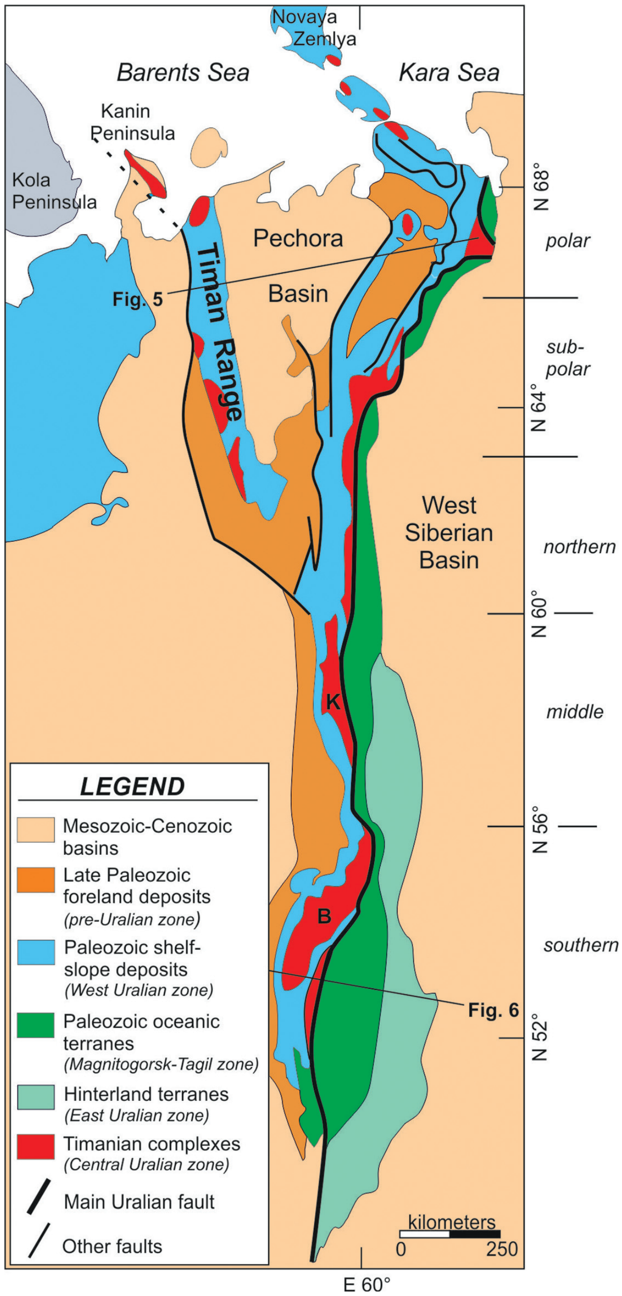

Fig. 3 Distribution of Timanian and Uralian complexes. Timanian-aged complexes are of mostly pre-Paleozoic age and best exposed in the Timan Range. Isolated Timanian fragments occur as far south as the Bashkirian antiform (B) and as far west as the Polar Urals. The Uralian Orogen has a foreland of shelf-slope deposits to the west, a core of allochthonous oceanic terranes thrust eastward onto the Baltica margin, and a hinterland c. 300 km to the east in the north but missing/unexposed in the south. K, Kvarkush anticlinorium (also known as the Kvarkush-Kamenogorsk anticlinorium). Line of sections in Figs. 5 and 6 indicated.

To the south in the Middle and Southern Urals (Fig. 3), thick (up to 15 km) Mesoproterozoic through Cryogenian intracratonic successions are dominated by shallow water siliciclastic and carbonate formations with some rift-related volcanic and sub-volcanic rocks. These successions are overlain by Cryogenian tillites and Ediacaran clastic sediments, a later response to the Timanian orogeny further east. These rocks are well exposed in the cores of two major fold systems associated with the Late Paleozoic fold and thrust belt of the Uralian Orogen: the Bashkirian and the Kvarkush Anticlinoria (Fig. 3). In both areas, Proterozoic successions occur beneath a regional Ordovician (post-Timanian) unconformity. In the Bashkirian Anticlinorium, the folded and faulted Mesoproterozoic through Ediacaran sedimentary rocks beneath the unconformity are overlain by a more deformed and, in part, more metamorphosed (amphibolite facies, locally with eclogite) allochthon known as the Beloretsk Terrane. Ordovician quartzites overlie these Precambrian rocks and structures with major unconformity.

The Pechora basin and Barents shelf

A large part of what is known about the Timan Orogen comes from drill-cores that sample Timanian basement beneath the Phanerozoic cover sequence of the Pechora Basin. From the Timan Range, this cover sequence extends to the east where it reaches thicknesses of 10–15 km in the Uralian foredeep. The character of the underlying basement in the foredeep is unknown, though a few structural windows indicate oceanic associations. Basement highs in the central parts of the Pechora Basin are within a few kilometers of the surface. Drill-core samples, integrated with potential field data, U-Pb zircon dating, and geochemical analyses, recognize three tectonostratigraphic domains: the Izhma, Pechora, and Bolshezemel zones (Fig. 4). These data define our current view of the Timan Orogen.

The turbidite assemblages of the Timan Range can be traced eastward where they are buried beneath the Izhma zone. The Pechora zone is well defined by a broad belt of NW-trending magnetic anomalies which continue offshore onto the Barents Shelf. Drill-core samples show that the Pechora zone is dominated by volcanic and volcaniclastic rocks, extensively intruded by calc-alkaline mafic to intermediate plutons. The calk-alkaline plutonic rocks intruding both the Izhma and the Pechora zones yield zircon U-Pb ages of 550–560 Ma (Fig. 4). Further east, the Bolshezemel zone comprises acid volcanic rocks and granites that give somewhat older zircon U-Pb ages of c. 570 and 620 Ma, along with Grenville-age xenocrysts. The older Russian literature suggests on the basis of limited geophysical data that 'continental' fragments may define the basement beneath the deepest "unknown" part of the Pechora Basin (Fig. 4), but this is as yet unverified.

Timanian units below the Phanerozoic sediments of the Pechora Basin strike northwest into the southern Barents Shelf. Their associated geophysical (deep multichannel seismic, gravity, and magnetic) signature can be traced from on-shore to off-shore and to the more distal parts of the Barents Shelf (near Svalbard). Timanian metamorphism is documented in outcrop on Kanin Peninsula and in southwest Svalbard. Timanian basement has been sampled on Franz Josef Land where a single deep borehole on the westernmost island penetrated the Lower Carboniferous unconformity and reached folded, lower greenschist facies Neoproterozoic meta-turbidites at 2–3 km depth.

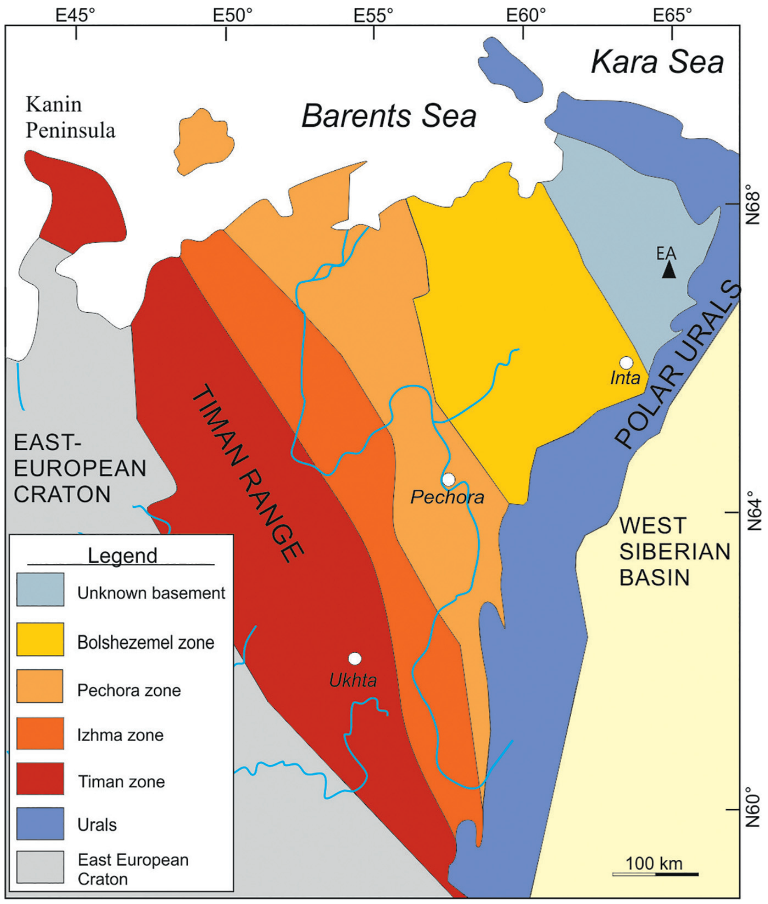

Fig. 4 Distribution of basement complexes beneath the Phanerozoic cover of the Pechora Basin inferred from drill cores. Structural fabric trends NW-SE and basement domains extend NW into the Barents Sea Shelf and SE into the Urals. Evidence from these rocks provides the basis for our understanding of the tectonic evolution of the Timan Orogen. EA, Enganepe anticline (arc association).

The Timanides within the Ural mountains

The Timanian structural fabric trends southeast towards the Ural Mountains (Fig. 3). Along strike from the Pechora zone in the Northern Urals, andesitic volcanic rocks dominate the pre-Ordovician formations in the Uralian fold and thrust belt and lower thrust sheets. In the sub-Polar Urals, the southeast continuation of the Bolshezemel zone, Mesoproterozoic metasediments, granites, Neoproterozoic siliciclastic and carbonate formations, and acid volcanic rocks are well documented. Early Ordovician conglomerates and quartzites overlie the Neoproterozoic successions with marked unconformity. This geological association, along with a limited number of zircon U-Pb ages, suggests that these rocks likely correlate with those of the Bolshezemel zone and that this Precambrian complex is distinct from the Ediacaran calc-alkaline volcanic suites of the Pechora zone.

In the Polar Urals, Neoproterozoic complexes comprise major components of the footwall to the Paleozoic ocean-related Uralian allochthons. In the core of Uralian foreland folds, beneath Ordovician quartzites, the fragmented 670 Ma Enganepe ophiolite is associated with obducted arc volcanic and volcaniclastic rocks. Further east in the Uralian thrust sheets where the Paleozoic metamorphic grade is higher, mafic island-arc related igneous complexes contain 580 Ma old gabbros (Dzela complex) and similar ages characterize the igneous protoliths of Paleozoic eclogite-bearing associations. Thus, in the most easterly exposed hinterland of the Timanide Orogen, the main Neoproterozoic components are represented by rocks of oceanic domain associations.

As in the Polar Urals, further north on Novaya Zemlya major foreland anticlines and thrusts expose Neoproterozoic complexes beneath lower Paleozoic unconformities. On southern Novaya Zemlya Lower and Middle Ordovician quartzite and limestone overlie greenschist facies metaturbidites. U-Pb zircon ages of c. 490 Ma from Cambro-Ordovician intrusive and extrusive rocks, and from sedimentary rocks at the unconformity (maximum age of deposition), indicate that deformation in the region occurred in the late Cambrian. However, central and northerly locations on Novaya Zemlya show pronounced diachroneity, suggesting that the unconformity was transgressive from south to north.

Tectonic evolution

Evidence for Timanian orogenesis provides a basis for the Neoproterozoic to Early Paleozoic tectonic evolution of this part of Baltica. Given its fragmentary character, however, important aspects of its tectonic evolution may be incomplete. For example, it is probable that the Timan Orogen extended further east, but is now lost or buried due to Devonian rifting and later extension. Another problem is the missing Timanian hinterland east of the Urals - it is likely hidden beneath the deep Mesozoic cover of the West Siberian Basin. Using the evidence presented above, a tectonic synthesis (Fig. 5) includes an Early Neoproterozoic passive margin being established along the eastern edge of the EEC, from northern Norway to the Middle Urals. The change from an extensional to a compressional regime in the Ediacaran due to the onset of the Timanian Orogeny is well defined in the foreland fold-and-thrust belt along this part of the EEC margin and extending southwards into the Southern Urals. Deposition of a late Ediacaran molasse facies in foreland basins along the length of the orogen constrains the timing of hinterland uplift and foreland

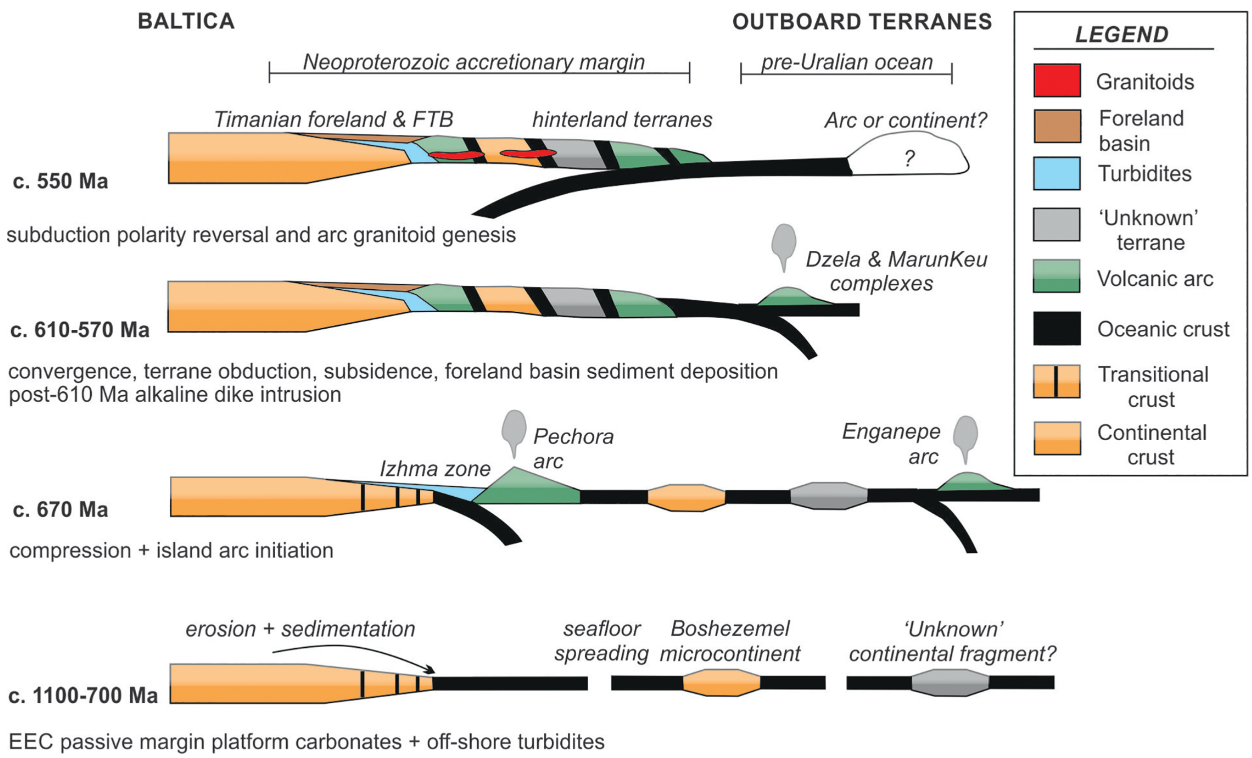

Fig. 5 Tectonic development of the accretionary Neoproterozoic Timanian Orogen. FTB, fold and thrust belt.

deformation. An ocean existed along the eastern margin (present-day coordinates) of the EEC in the Neoproterozoic, allowing deposition of continental margin turbidites and the development of the Pechora magmatic arc and the Enganepe ophiolite and arc association. The informal name for this Neoproterozoic ocean is the pre-Uralian Ocean. Towards the hinterland, the dominance of mafic to intermediate calc-alkaline igneous rocks and volcanogenic sedimentary rocks of the Pechora zone is interpreted to imply thrusting of oceanic domains onto the thickened passive margin turbidites of the EEC margin (Izhma zone). The western contact of the Pechora zone is not well defined, but the presence of Timanian-aged blueschist along strike, both to the southeast in the northern Urals (Kvarkush) and to the northwest in the easternmost Kanin Peninsula, suggests that subduction-related arc magmatism culminated in thrust emplacement onto the EEC margin. The oceanic character of the adjacent Pechora zone favors the interpretation that the further outboard terranes, e.g., the Bolshezemel zone (Fig. 4), were not accreted to the EEC until the Ediacaran. The composition of micro-continents or continental terranes (or blocks) outboard in the pre-Uralian Ocean differ from the EEC in having Grenville-age xenocrysts with a Mesoproterozoic metasedimentary succession intruded by c. 1000 Ma granites. To the east of the Bolshezemel zone, the "Unknown" basement domain of the Pechora Basin (Fig. 4) has been suggested to be a possible micro-continental fragment. However, the Cryogenian Enganepe ophiolite is exposed in a structural window within the Uralian foreland and further east calc-alkaline intrusions occur within some Uralian allochthons—these provide evidence for an oceanic character of the internal parts of the Timanide hinterland. This, combined with the lack of Timanian rocks east of the Urals, has promoted the widely accepted hypothesis that Timanian orogenesis resulted from the subduction and accretion of Neoproterozoic ocean floor and island-arc assemblages. It may have also included some continental fragments, but is unlikely to have involved a major continent such as Siberia.

The Uralides

Our understanding of the Uralian Orogen is derived from the present-day Ural Mountains, a narrow range of low to moderate topography extending for nearly 2500 km from the Caspian Basin in the south to the Arctic Ocean in the north (Fig. 1). East and south of the Ural Mountains, much of the orogen is buried beneath Mesozoic and Cenozoic sediments of the West Siberian and Caspian basins and is not well known. The Uralides are divided geographically into the Southern, Middle, Northern, sub-Polar, and Polar Urals (Fig. 3). Historically, the geology of the Uralian Orogen is defined by a number of longitudinal zones largely based on the ages and rock-types within them. From west to east, these include the pre-Uralian zone, the West Uralian zone, the Central Uralian zone, the Magnitogorsk-Tagil zone, the East Uralian zone, and the Trans-Uralian zone beneath the West Siberian Basin.

Using more modern terminology, these zones represent typical tectonic elements of a collisional orogen: the foreland and re-worked foreland deposits (Pre-Uralian and West Uralian zones), the fold and thrust belt (Central Uralian and Magnitogorsk-Tagil zones), and the hinterland of the orogen (East Uralian and Trans-Uralian zones) (Fig. 3). The Pre-Uralian and West Uralian zones contain Archean and Proterozoic rocks of the East European Craton, Paleozoic platform and slope sediments of the pre-Uralian Baltica margin, and Late Carboniferous to Early Triassic sediments of the Uralian foreland basin. The core of the orogen includes the Central Uralian zone and Magnitogorsk-Tagil zone, while the eastern hinterland part of the orogen includes the East Uralian zone and the Trans-Uralian zone. The Magnitogorsk-Tagil zone is made up of two volcanic arcs: (i) the Magnitogorsk Arc (Southern Urals) comprising Lower Devonian to Middle Devonian basalts overlain by late Devonian volcanoclastic sediments, and (ii) the Tagil Arc (Middle Urals) comprising Silurian to Lower Devonian basalts and volcanoclastic sediments locally overlain by Lower and Middle Devonian sediments. The East Uralian zone is composed predominantly of deformed and metamorphosed volcanic arc fragments with minor Precambrian and Paleozoic rocks thought to represent continental crust. The East Uralian zone is extensively intruded by Carboniferous and Permian granitoids that young northward and document diachroneity from south to north during Uralian collision. The Trans-Uralian zone, only exposed in the southernmost Urals, is composed of Devonian and Carboniferous volcanic and plutonic complexes overlain by terrigenous red beds and evaporites. Ophiolitic material (oceanic crust) and high-pressure rocks have also been reported.

Crustal structure

Surface geology has been integrated with seismic, potential field and thermal data to interpret the crustal structure of the Uralian Orogen. These data show that the Uralides preserve a bivergent collisional architecture and confirms the existence of a crustal root along the central axis of the orogen (Fig. 6). The orogen thickens from c. 40–50 km in the west to c. 50–55 km across the Magnitogorsk-Tagil zone (from the Southern to the sub-Polar Urals) and then thins across the eastern part of the orogen to c. 40–45 km. The East European Craton is imaged by subhorizontal to east-dipping reflectivity extending beneath the Magnitogorsk-Tagil zone in the Southern Urals. The crust-to-mantle transition (the Mohovic discontinuity) is not imaged beneath the Magnitogorsk zone (Southern Urals), but is a fairly sharp transition beneath the Tagil zone (Middle-Northern Urals). In the eastern part of the orogen, the mid- to upper-crustal region has sharp, predominantly west-dipping reflectivity that extends from the mid- to lower-crust and appears to merge with the Moho. The Trans-Uralian zone dips westward beneath the East Uralian zone.

Petrophysical modeling (assigning rock types based on the seismic velocity, density, and thermal data) of Uralian crust along various E-W transects shows clear differences between the composition of the old continental crustal nucleus of the East European Craton and the newly added crust of the accreted arc terranes to the east (Table 1). The crust of the East European Craton is more felsic than that of the Magnitogorsk and East Uralian zones, and the latter two zones have a lowermost crust with characteristics indicating a high garnet content (mafic garnet granulite) and/or the presence of hornblendite. The overall composition of the arc terranes is mafic. The physical properties data suggest that eclogite is not present in the lower crust, or if present exists in such small amounts that it is below the resolution of the dataset.

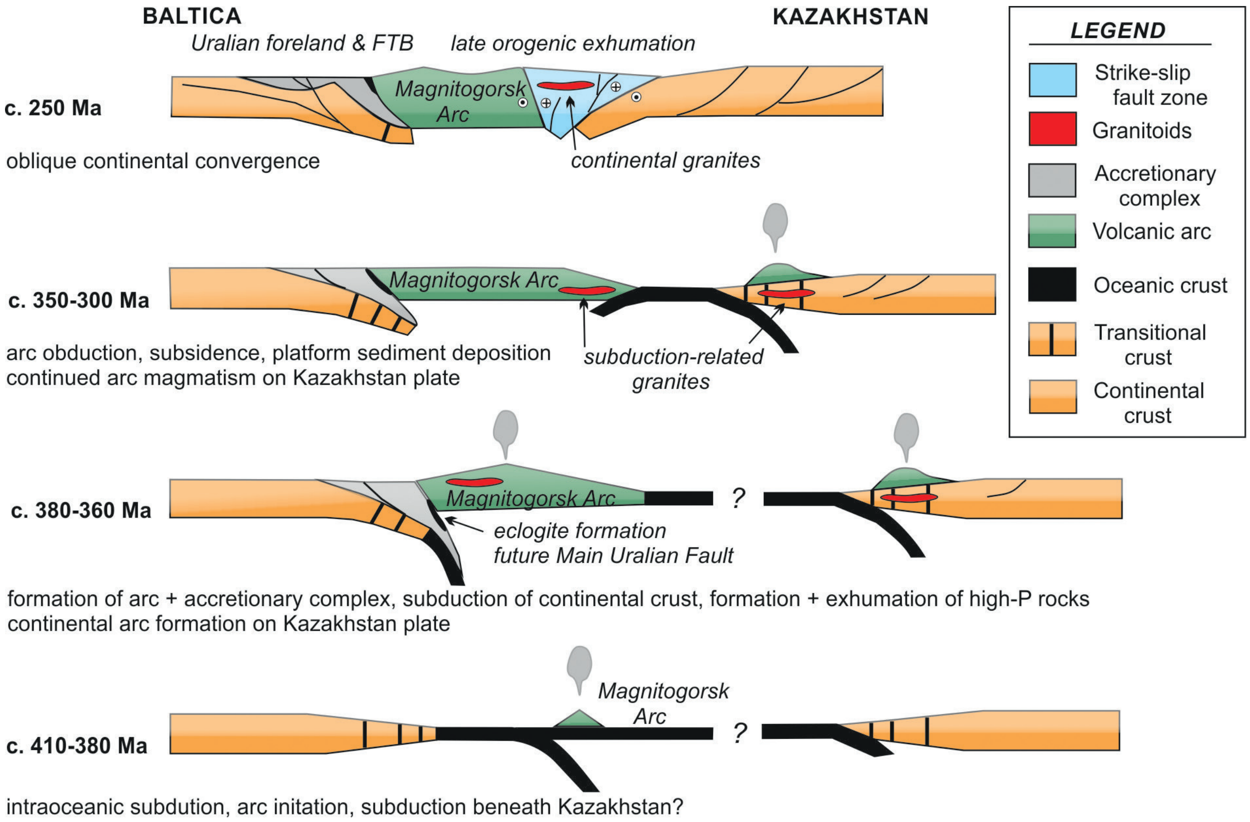

Fig. 6 Tectonic development of the Uralian Orogen across the southern Urals (latitude of the Magnitogorsk Arc). FTB, fold and thrust belt. *Journal of Earth Science* 30(6): 1144–1165.

Tectonic evolution

The tectonic evolution of the Uralides (Fig. 6) began during the Devonian as intra-oceanic subduction formed the Magnitogorsk and Tagil island arcs. This was followed by the partial subduction of the continental margin of Baltica, the emplacement of an accretionary complex over the continental margin, and the exhumation of high pressure (eclogite) rocks along the arc-continent collisional boundary. Simultaneously, the eastward subduction of oceanic crust beneath the continental crust of Kazakhstan resulted in the genesis of volcanic arc magmatism which continued throughout the Carboniferous. At this time deformation

Table 1 Petrophysical properties of the Uralian Orogen[a].

Characteristic	*Western*	*Magnitogorsk (central)*	*Eastern*
Heat flow	$\leq$60 m W m^{-2}	$\geq$10 m W m^{-2}	$\leq$60 m W m^{-2}
Bouguer gravity	–60 to –40 mGal	–40 to 0 mGal	–70 to –10 mGal
Magnetic susceptibility			
Upper crust	0.25–0.5 Am^{-1}		
Mid-, lower-crust	0.5–1.5 Am^{-1}		
Crystalline basement	1.5 Am^{-1}	0 Am^{-1}	
Velocity			
Upper crust	<6.3 kms^{-1} (Vp)	6.3 kms^{-1} (Vp)	<6.3 kms^{-1} (Vp)
	<3.9 kms^{-1} (Vs)	3.9 kms^{-1} (Vs)	<3.9 kms^{-1} (Vs)
Mid-, lower-crust	<6.8 kms^{-1} (Vp)	6.8 kms^{-1} (Vp)	<6.8 kms^{-1} (Vp)
	<3.9 kms^{-1} (Vs)	3.9 kms^{-1} (Vs)	<3.9 kms^{-1} (Vs)
Base of crust	<7.1 kms^{-1} (Vp)	7.1 kms^{-1} (Vp)	<7.1 kms^{-1} (Vp)
	<3.9 kms^{-1} (Vs)	4.0 kms^{-1} (Vs)	<3.9 kms^{-1} (Vs)
Moho	<8 kms^{-1} (Vp)	>8 kms^{-1} (Vp)	<8 kms^{-1} (Vp)
	<4.6 kms^{-1} (Vs)	4.6 kms^{-1} (Vs)	<4.6 kms^{-1} (Vs)

If blank, no data.
[a]Data from geophysical transects across the Middle and Southern Urals.

along the Baltica margin ceased and shallow-water platform margin sedimentation continued undisturbed. By the latest Carboniferous to Early Permian, the Uralian ocean basin had closed completely and the continent-continent collision between the Kazakhstan and Baltica plates had begun. As this collision progressed through the Early Permian to the early Triassic, the western foreland fold-and-thrust belt and the foreland basin of the Uralides developed. Widespread strike-slip faulting took place in the central part of the orogen with exhumation of lower crustal material accompanied by melt generation and granitoid emplacement. An episode of early Triassic extension and volcanism followed in the eastern part of the Middle Urals and northward—by the mid-Jurassic, intraplate deformation (?) led to further uplift of the Timan Range and formation of the Pay Khoy-Novaya Zemlya fold belt.

Arc-Continent Collision. Throughout geological time, intra-oceanic island arc development and its subsequent collision with a continental margin have been important processes in collisional orogenic belts, and among the most important means by which Earth's continental crust has grown. In the case of the Uralides, the Tagil and Magnitogorsk island arcs developed in the Silurian (Tagil) and early Devonian (Magnitogorsk), and began to collide with the margin of Baltica in the mid-Devonian (Magnitogorsk) and the early Carboniferous (Tagil) (Fig. 6). The Tagil Arc was pervasively deformed and metamorphosed to lower greenschist facies, whereas deformation and metamorphism in the Magnitogorsk arc were minor (minor folding and thrusting) and low-grade (prehnite-pumpellyite facies). The Magnitogorsk arc-continent collision resulted in the development of an accretionary (Suvanyak) complex (Fig. 6) that involved continental slope and platform sedimentary rocks detached from, and thrust westward over, the continental margin of Baltica. This accretionary complex was in turn overthrust by *syn*-collisional volcanoclastic sediments sourced from the accretionary complex and the Magnitogorsk arc. These units are flanked to the east by high-pressure eclogite- and blueschist-bearing gneiss (Maksutovo Complex) which record peak metamorphic pressures of 20 ± 4 kbar and temperatures of 550 ± 50 °C, and have a peak metamorphic age of 380–370 Ma. The east-dipping Main Uralian fault, the main suture between arc and continental margin rocks, is a fault melange containing several kilometer-scale fragments of oceanic crust and mantle.

Subcontinental Subduction. Little is known of the margin of the Kazakhstan plate because there are no rocks in the Uralides that can be unequivocally assigned to the Kazakhstan plate. However, studies suggest subcontinental subduction and the development of a continental volcanic arc did occur. In part, the evidence for this comes from Silurian- to Devonian-age mafic to felsic gneiss and volcano-sedimentary rocks in the East Uralian zone (Fig. 3) that appear to represent a volcanic arc complex. The key piece of data for assigning these rocks to a continental arc setting is the presence of subduction-related granitoids that intrude into them. These granitoids are thought to have formed in two subduction zone settings. The first subduction related magmatism occurred from about 370–350 Ma and produced granitoids with a recognizable older continental geochemical component. These granitoids are interpreted to have been related to the development of a continental arc during subduction of oceanic crust under the continental margin of the Kazakhstan plate. A second phase of subduction-related magmatism occurred from about 335–315 Ma and produced granitoids with little continental component. These granitoids are interpreted to have been related to melting of the earlier continental arc during subsequent (or continued) subduction beneath the Kazakhstan plate margin. Magmatic activity directly related to subduction ended after the Carboniferous.

The Foreland Fold and Thrust Belt. The western foreland fold and thrust belt and foreland basin of the Uralides developed from the Upper Carboniferous to the Lower Triassic. The foreland fold and thrust belt trends roughly north and south and is c. 50–150 km wide from the Main Uralian Fault to the deformation front. Rocks involved in folding and thrusting include Proterozoic and Archean basement of the East European Craton, Paleozoic platform sediments of the Baltica margin, the arc-continent collision accretionary complex, and the Permian to Early Triassic foreland basin sediments (Fig. 3). Along its eastern margin, rocks of the Kvarkush (Middle Urals) and the Bashkirian (South Urals) anticlinoria were deformed in the Neoproterozoic and these structures were reactivated with further deformation during Uralian orogenesis. The structural architecture of the foreland fold and thrust belt is that of a west-verging thrust stack developed above a basal detachment within the Proterozoic basement. When balanced cross-section restoration can be performed, the amount of Paleozoic shortening associated with Uralian deformation in the western foreland fold and thrust belt (i.e., the western part of the orogen) is $\leq$20 km.

Late Orogenic Strike-Slip Faulting. A late orogenic strike-slip fault system affects the internal part of the Uralian Orogen. It extends N-S for more than 700 km before it disappears beneath Mesozoic and younger sedimentary cover. Throughout much of the Middle and Southern Urals, this strike-slip fault system coincides with the East Uralian zone (see Fig. 3), although the currently defined Main Uralian fault appears to be its western limit in the Middle Urals, so it therefore includes the Tagil Arc. Estimates of displacement along some strands of this fault system range from a few tens of kilometers to more than 100 km. Isotopic dating on one segment of the fault system indicates an age of 247–240 Ma for the development of fault-related mylonites, and 305–291 Ma for associated metamorphic rocks. The late orogenic strike-slip fault system was extensively intruded by continental-type granitoids, first in the southern part at 292–280 Ma and then in its northern part at 270–250 Ma. These granitoids have unusually primitive Sr and Nd isotopic compositions thought to have resulted from re-melting of the older juvenile continental arc rocks.

Future Work

The fragmentary nature of the Timan Orogen lends itself to the application of modern analytical methods and more comprehensive analyses of the existing limited samples. Future investigations will benefit from higher fidelity geophysical studies, especially in the north where despite being hidden beneath sediment of the Pechora Basin, the greatest volume of Timanian rocks exist at depth. In addition, more work along the western Urals should be a focus of future investigations as the best Timanian exposures occur there.

The Uralides, geophysically well-studied, will benefit from the continued application of modern analytical methods. In particular, detrital mineral studies and the application of multi-method analyses to single-grain samples will advance our understanding of sediment provenance associated with the docking of allochthonous terranes during orogenesis. Additionally, the correlation of terranes now-displaced from the Timanides and the Uralides are critical to unraveling tectonic plate reconstructions at the regional scale across the Arctic.

Further Reading

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