Arc-continent collision in the Southern Urals

Dennis Brown

Institute of Earth Sciences "Jaume Almera", CSIC, Barcelona, Spain

Acknowledgements

Joaquina Alvarez-Marron (CSIC, Spain)

Francisco Fernandez (University of Oviedo, Spain)

Yelena Gorozhanina (Ufimian Geoscience Center, Russia)

Richard Herrington (NHM, UK)

Ralf Hetzel (Wilhelms-Universität Münster, Germany)

Chris Juhlin (Uppsala University, Sweden)

Andres Perez-Estaun (CSIC, Spain)

Victor Puchkov (Ufimian Geoscience Center, Russia)

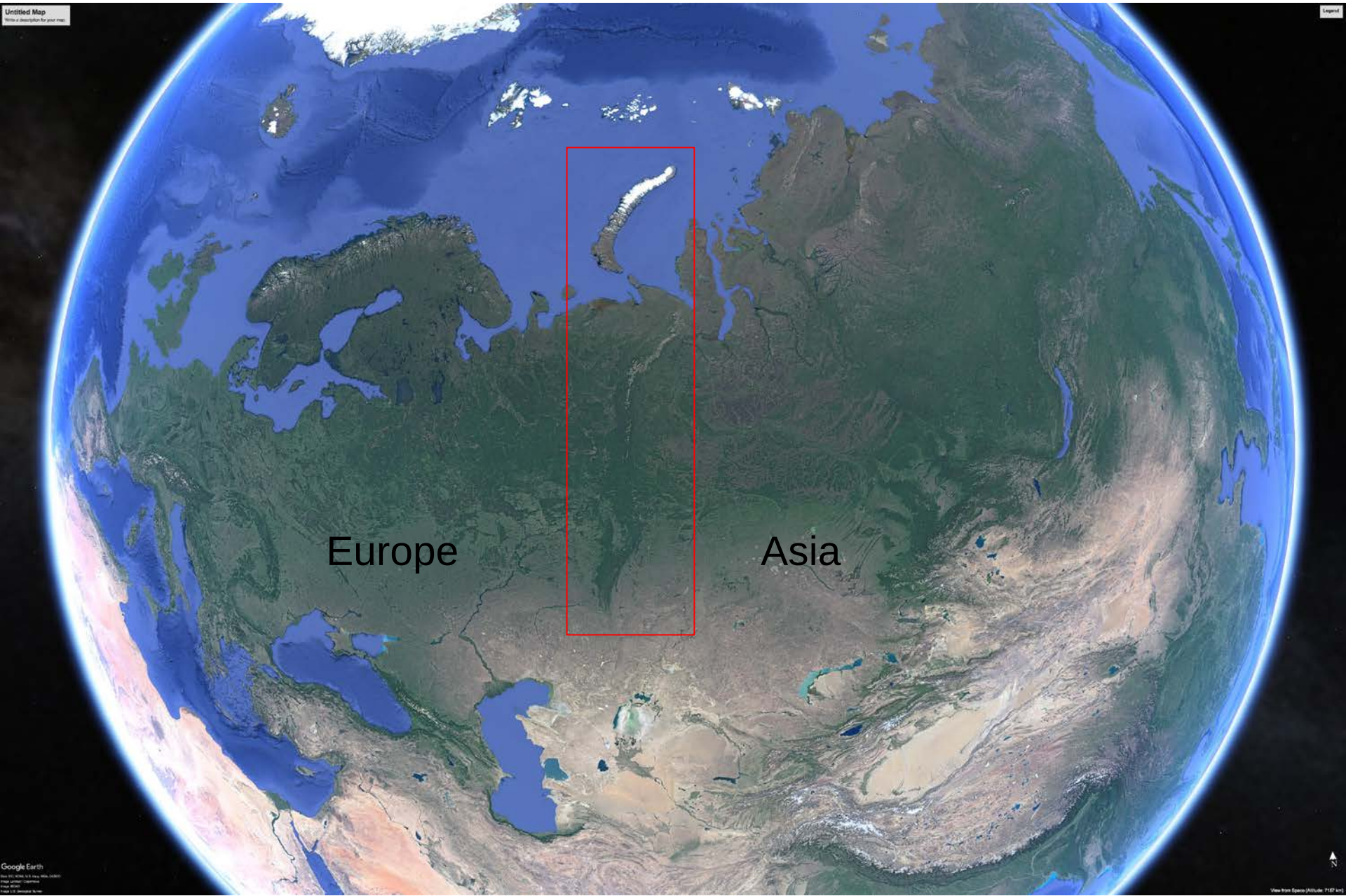
Jane Scarrow (University of Granada, Spain)

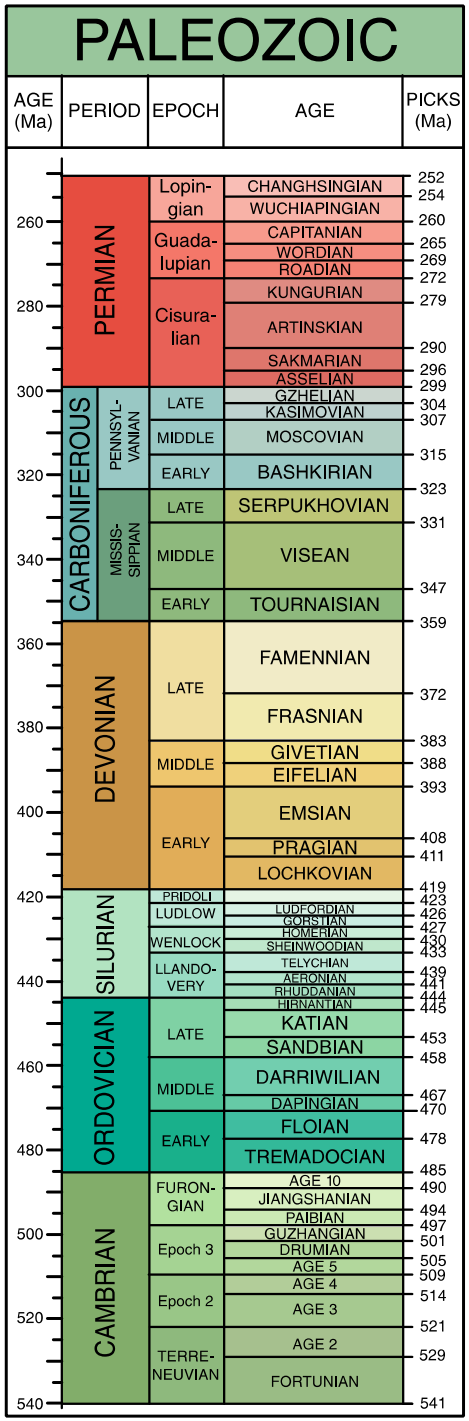
Piera Spadea (University of Udine, Italy)

Ari Tryggvason (Uppsala University, Sweden)

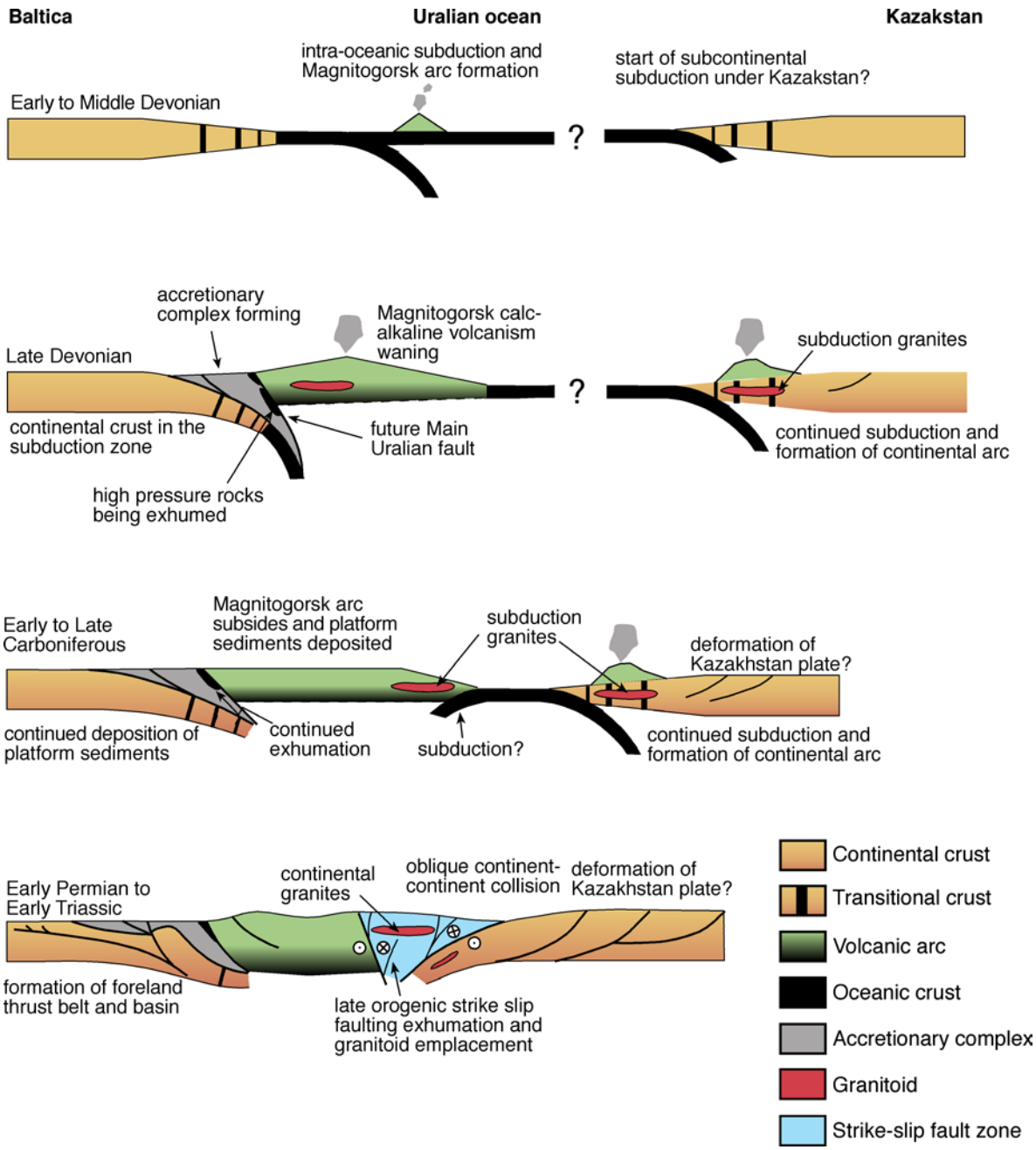
Arne Willner (Insitut für Geologie, Germany)

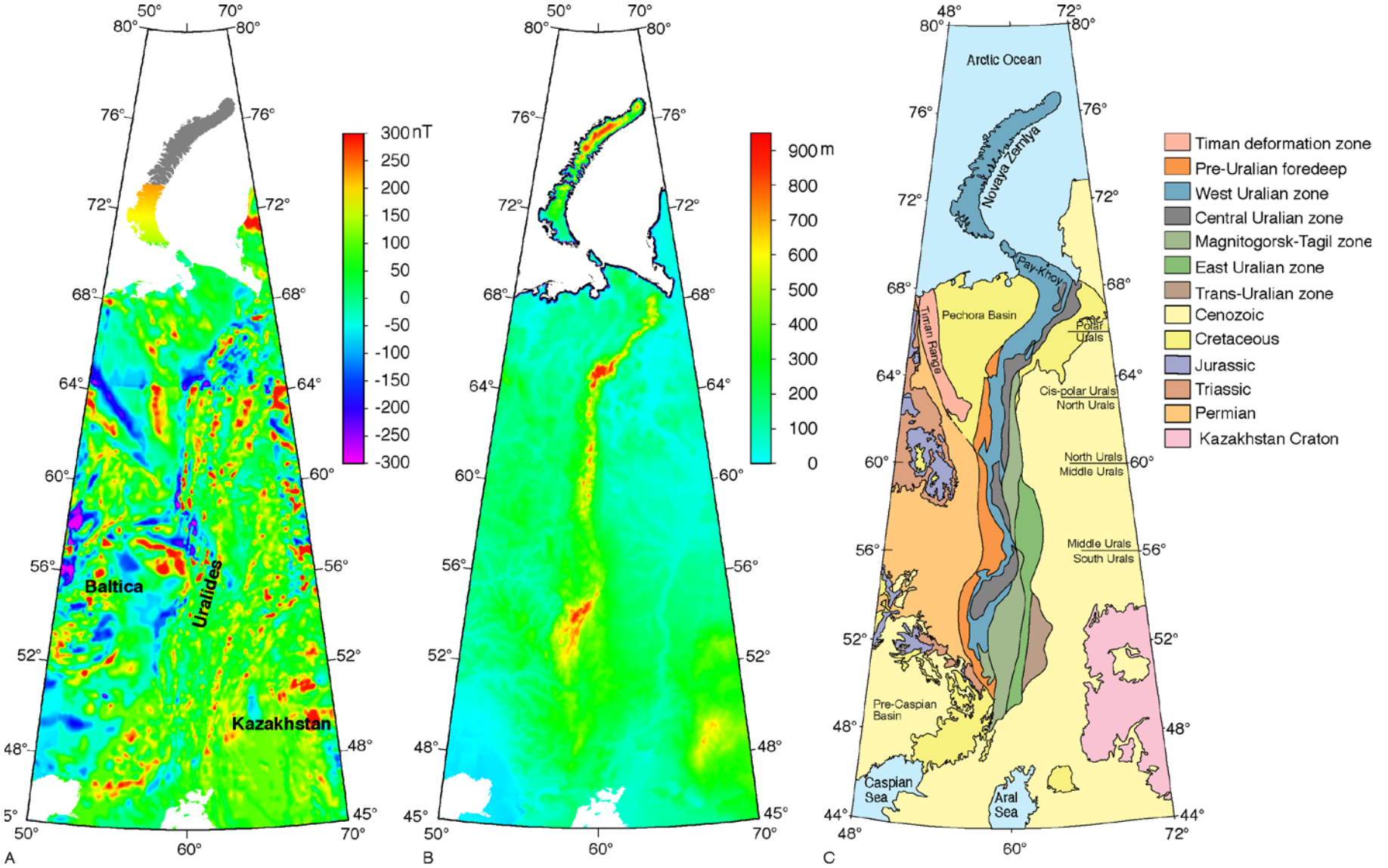
Where is the Uralide Orogen?

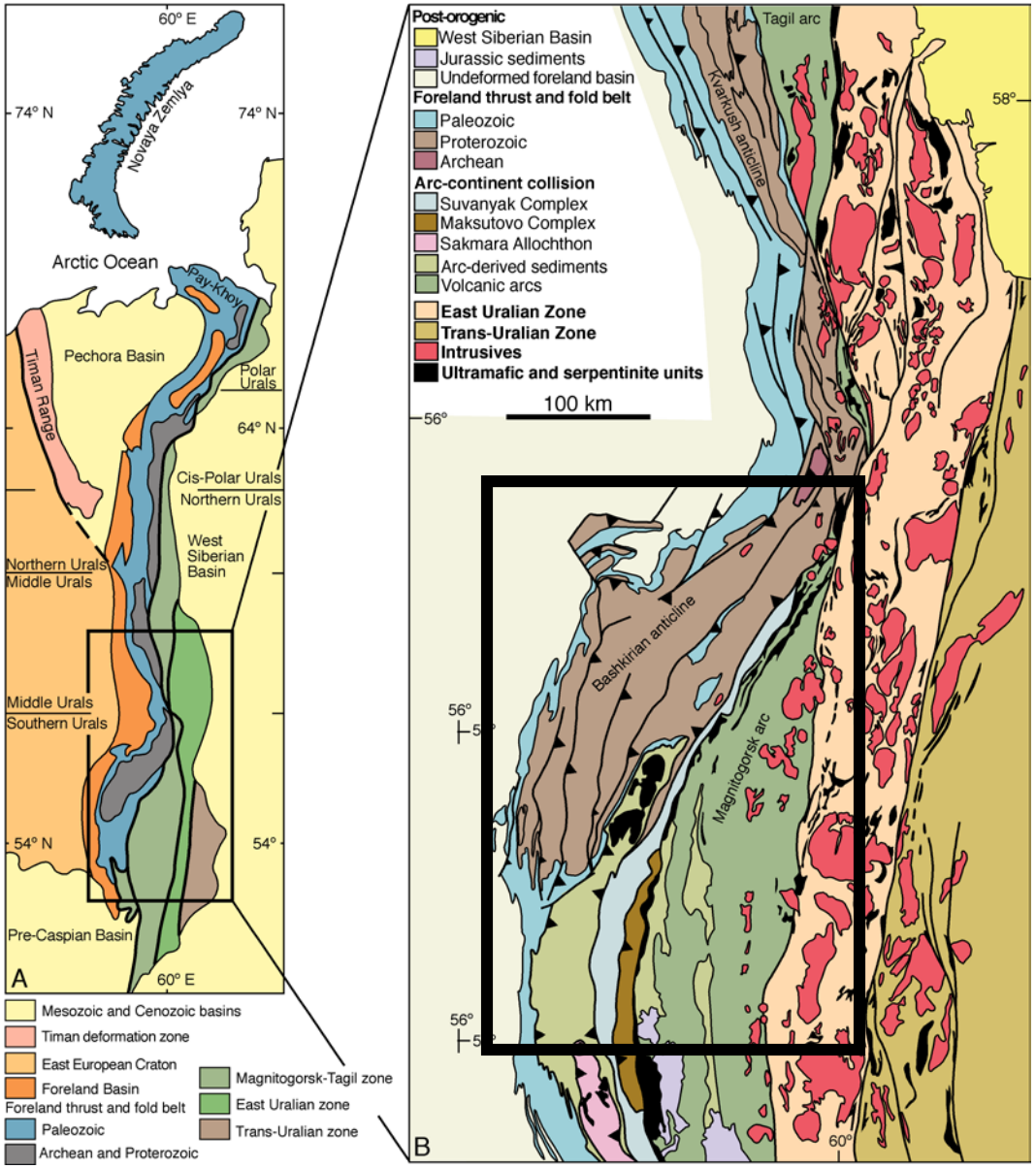


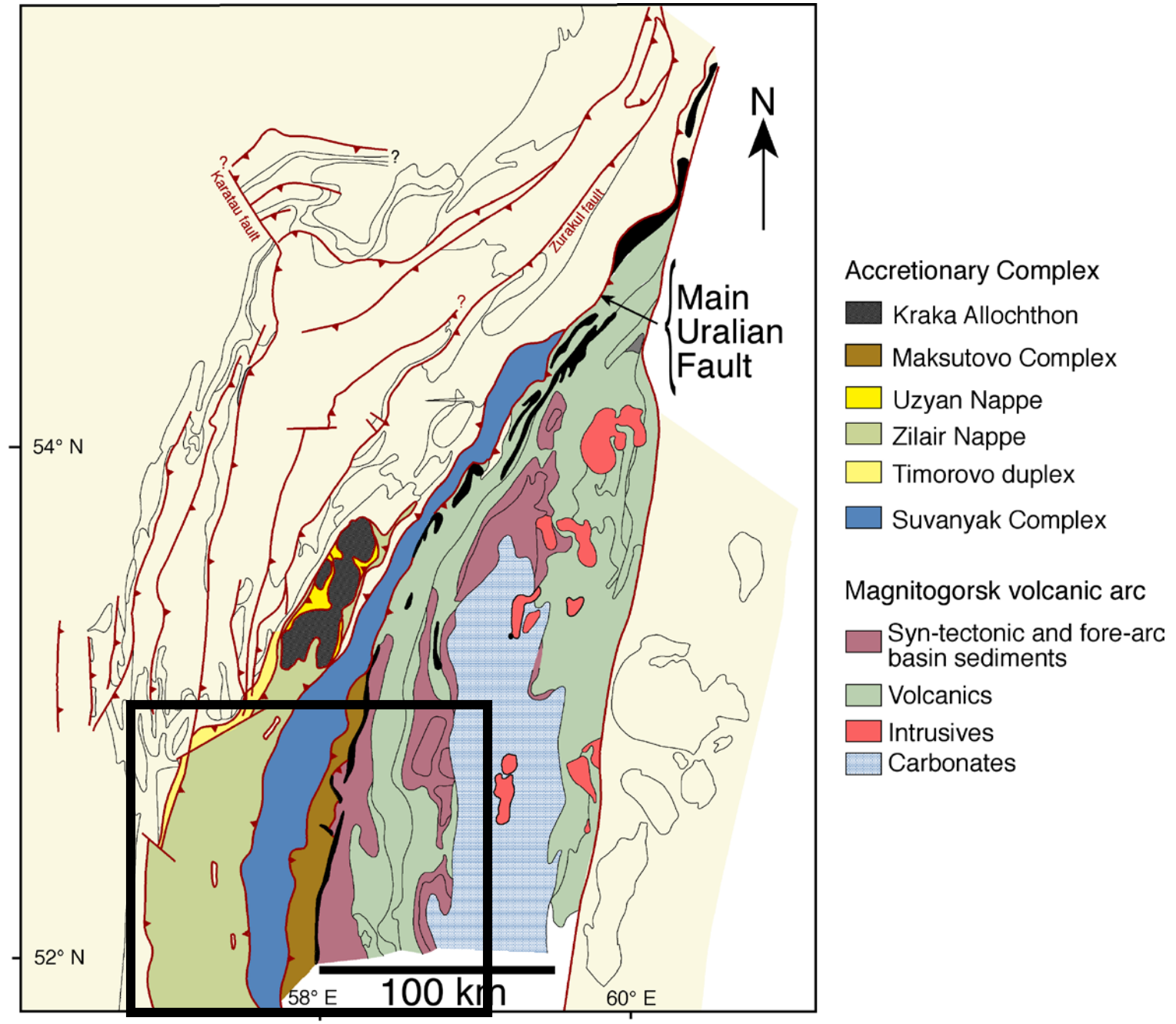


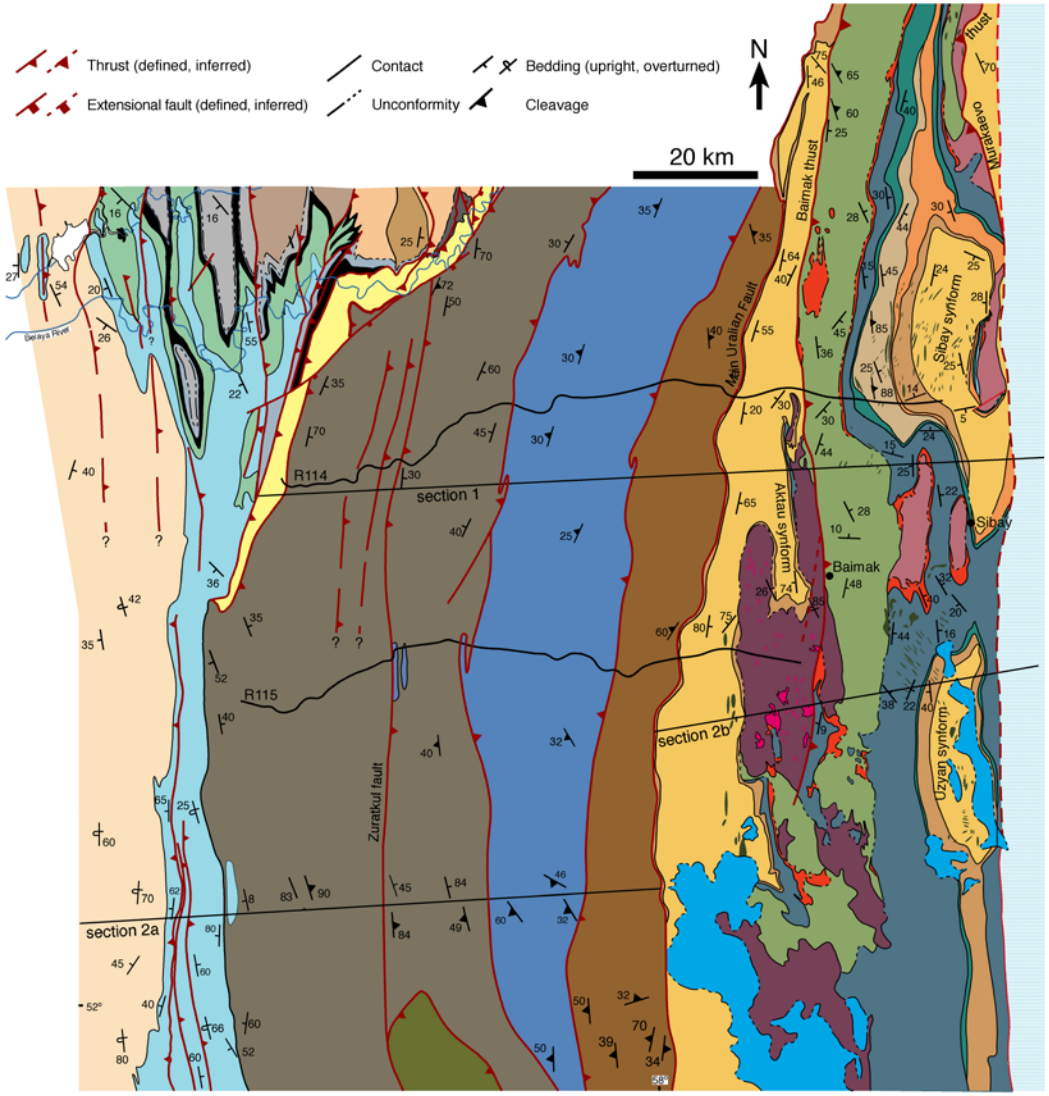
From: C.R. Scotese, PALEOMAP Project


Baltica
Uralian ocean
Kazakstan
intra-oceanic subduction and Magnitogorsk arc formation
start of subcontinental subduction under Kazakstan?
Early to Middle Devonian
?
accretionary complex forming
Magnitogorsk calc-alkaline volcanism waning
subduction granites
Late Devonian
?
continental crust in the subduction zone
future Main Uralian fault
continued subduction and formation of continental arc
high pressure rocks being exhumed
Magnitogorsk arc subsides and platform sediments deposited
subduction granites
deformation of Kazakhstan plate?
Early to Late Carboniferous
continued deposition of platform sediments
continued exhumation
subduction?
continued subduction and formation of continental arc
continental granites
oblique continent-continent collision
deformation of Kazakhstan plate?
Early Permian to Early Triassic
formation of foreland thrust belt and basin
late orogenic strike slip faulting exhumation and granitoid emplacement
Continental crust
Transitional crust
Volcanic arc
Oceanic crust
Accretionary complex
Granitoid
Strike-slip fault zone


A
B
C
300 nT
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
900 m
800
700
600
500
400
300
200
100
0
Baltica
Uralides
Kazakhstan
Arctic Ocean
Novaya Zemlya
Pay-Khoy
Pechora Basin
Timan Range
Polar Urals
Cis-polar Urals
North Urals
North Urals
Middle Urals
Middle Urals
South Urals
Pre-Caspian Basin
Caspian Sea
Aral Sea
Timan deformation zone
Pre-Uralian foredeep
West Uralian zone
Central Uralian zone
Magnitogorsk-Tagil zone
East Uralian zone
Trans-Uralian zone
Cenozoic
Cretaceous
Jurassic
Triassic
Permian
Kazakhstan Craton


60° E
74° N
74° N
Novaya Zemlya
Arctic Ocean
Pay-Khoy
Pechora Basin
Timan Range
Polar Urals
64° N
Cis-Polar Urals
Northern Urals
West Siberian Basin
Northern Urals
Middle Urals
Middle Urals
Southern Urals
54° N
54°
Pre-Caspian Basin
A
60° E
Mesozoic and Cenozoic basins
Timan deformation zone
East European Craton
Foreland Basin
Foreland thrust and fold belt
Paleozoic
Archean and Proterozoic
Magnitogorsk-Tagil zone
East Uralian zone
Trans-Uralian zone
Post-orogenic
West Siberian Basin
Jurassic sediments
Undeformed foreland basin
Foreland thrust and fold belt
Paleozoic
Proterozoic
Archean
Arc-continent collision
Suvanyak Complex
Maksutovo Complex
Sakmara Allochthon
Arc-derived sediments
Volcanic arcs
East Uralian Zone
Trans-Uralian Zone
Intrusives
Ultramafic and serpentinite units
100 km
Tagil arc
Kvarkush anticline
58°
56°
Bashkirian anticline
Magnitogorsk arc
56°
56°
60°
B


N
Karatau fault
Zurakul fault
Main
Uralian
Fault
54° N
52° N
58° E
60° E
100 km
Accretionary Complex
Kraka Allochthon
Maksutovo Complex
Uzyan Nappe
Zilair Nappe
Timorovo duplex
Suvanyak Complex
Magnitogorsk volcanic arc
Syn-tectonic and fore-arc basin sediments
Volcanics
Intrusives
Carbonates



Foreland thrust and fold belt

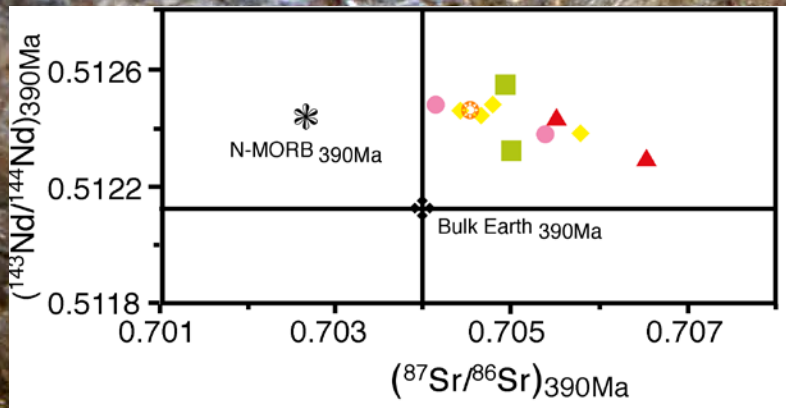
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

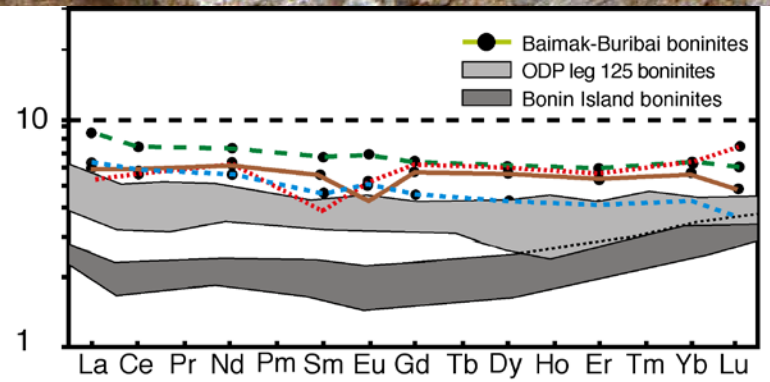
Accretionary complex

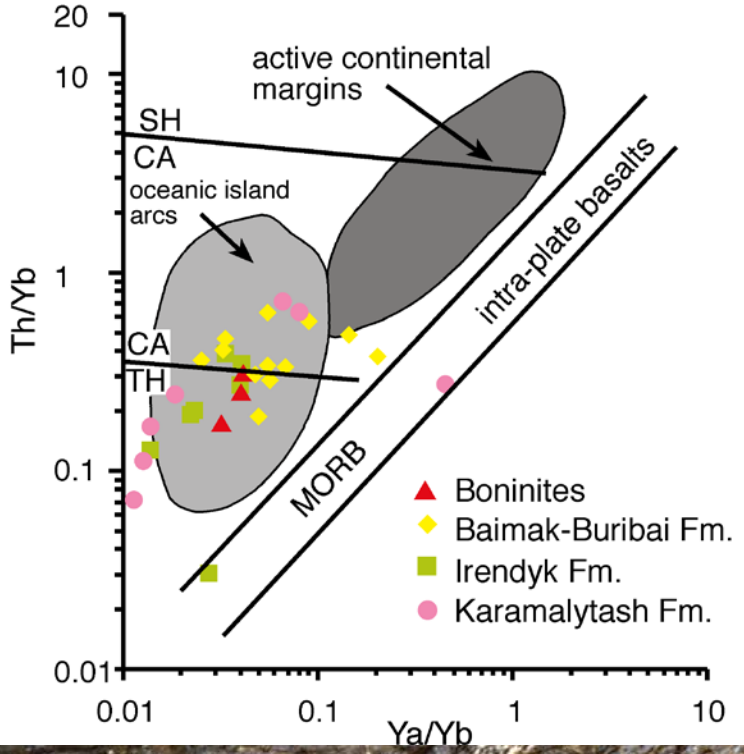
- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

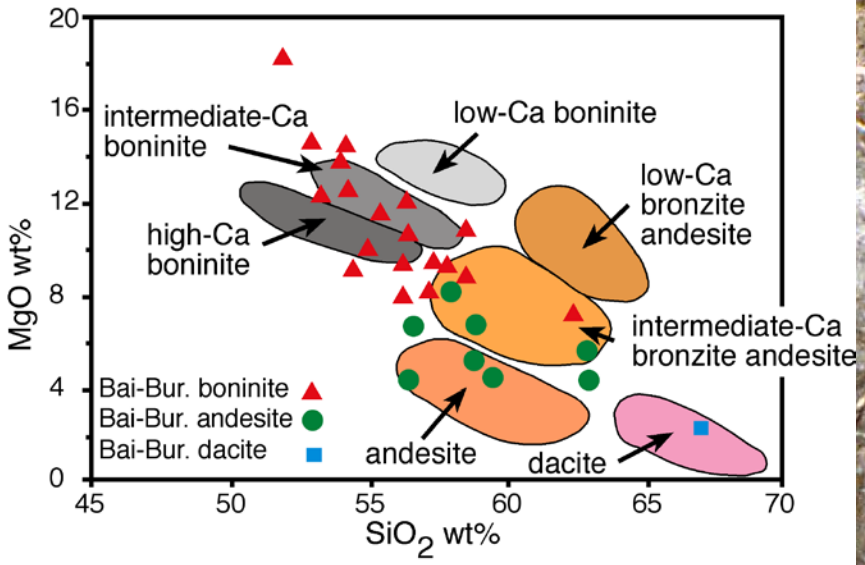
Magnitogorsk arc

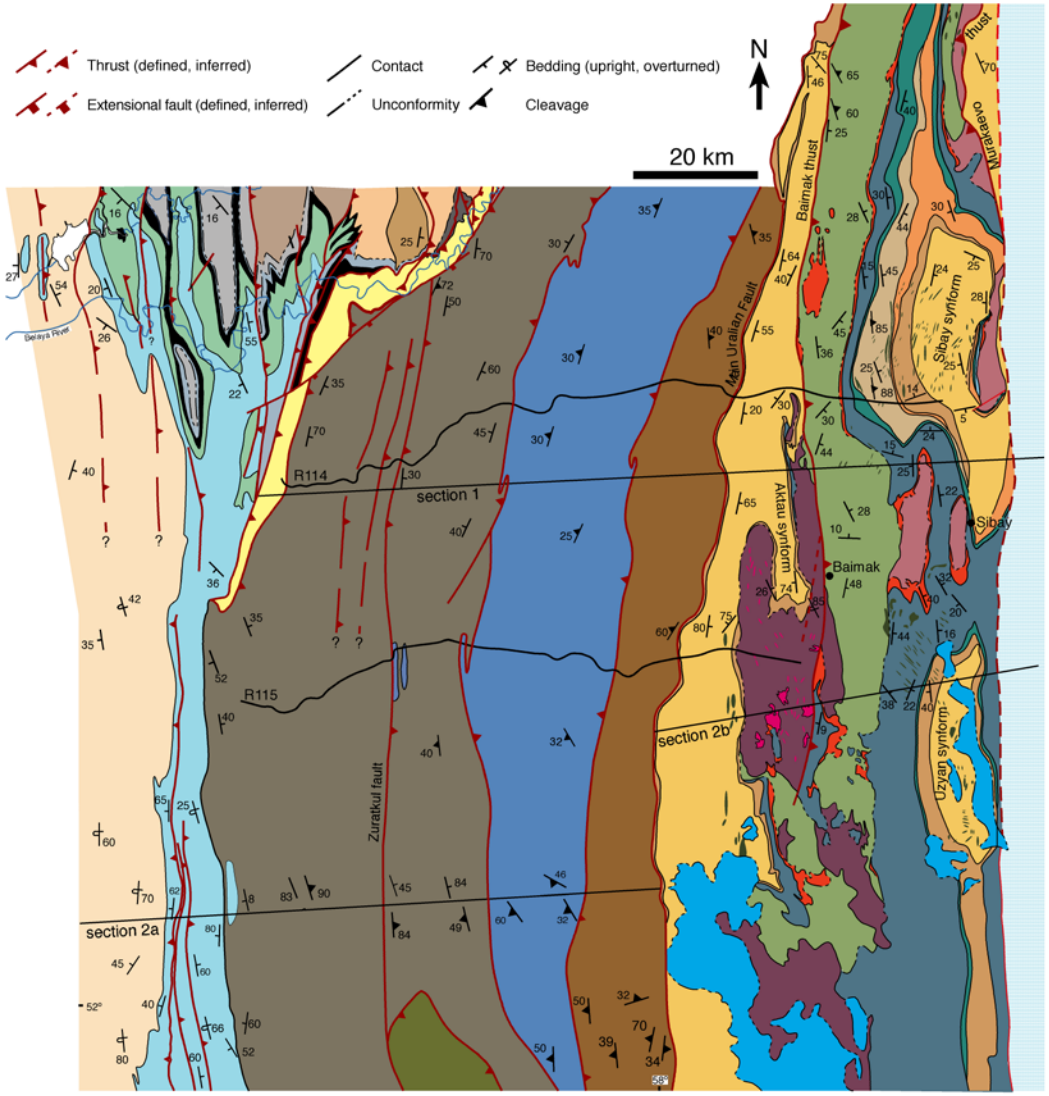
- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)


0.5126
0.5122
0.5118
0.701
0.703
0.705
0.707
N-MORB 390Ma
Bulk Earth 390Ma
(143Nd/144Nd)390Ma
(87Sr/86Sr)390Ma


Baimak-Buribai boninites
ODP leg 125 boninites
Bonin Island boninites
10
1
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu


20
10
1
0.1
0.01
0.01
0.1
1
10
Th/Yb
Ya/Yb
active continental margins
SH
CA
oceanic island arcs
CA
TH
intra-plate basalts
MORB
Boninites
Baimak-Buribai Fm.
Irendyk Fm.
Karamalytash Fm.


20
16
12
8
4
0
45
50
55
60
65
70
MgO wt%
SiO2 wt%
intermediate-Ca boninite
low-Ca boninite
high-Ca boninite
low-Ca bronzite andesite
intermediate-Ca bronzite andesite
Bai-Bur. boninite
Bai-Bur. andesite
Bai-Bur. dacite
andesite
dacite



Foreland thrust and fold belt

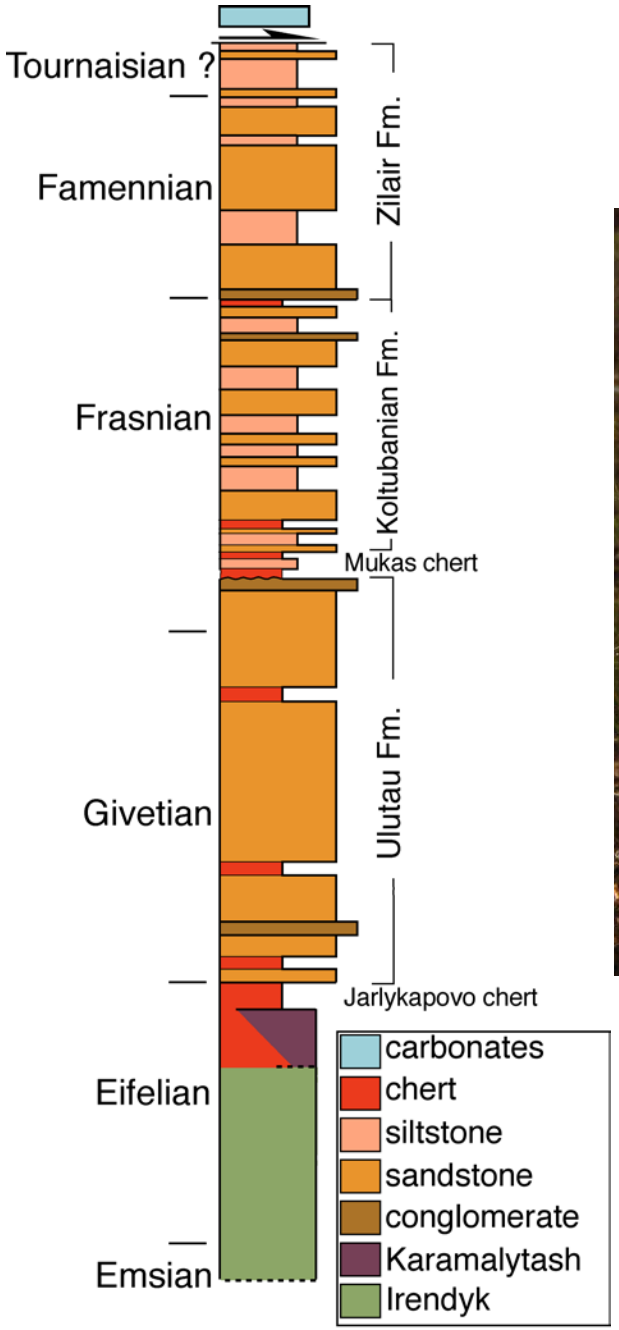
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

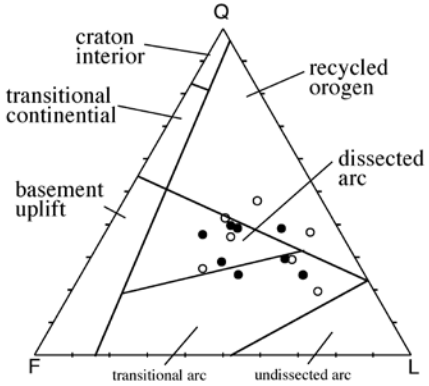
Accretionary complex

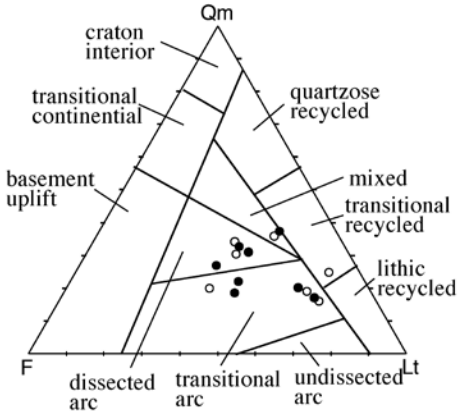
- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

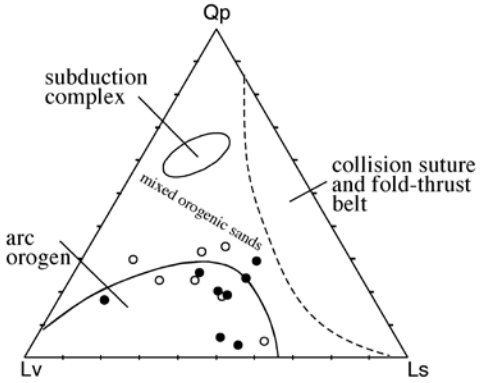
Magnitogorsk arc

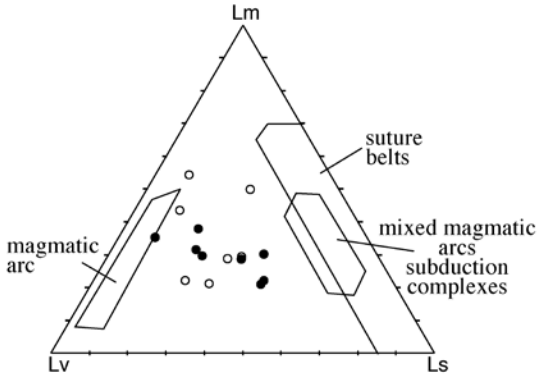
- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)

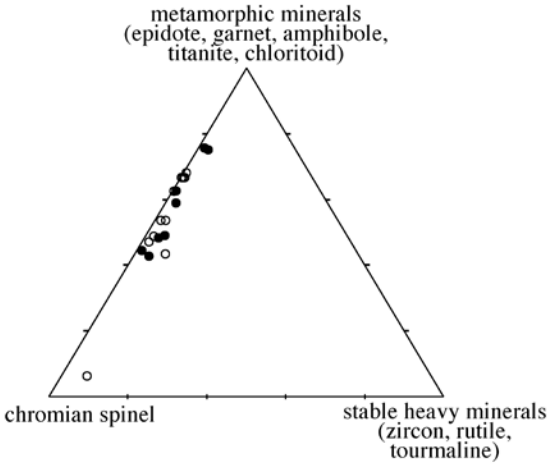

Tournaisian ?
Famennian
Frasnian
Givetian
Eifelian
Emsian
Zilair Fm.
Koltubanian Fm.
Mukas chert
Ulutau Fm.
Jarlykapovo chert
carbonates
chert
siltstone
sandstone
conglomerate
Karamalytash
Irendyk









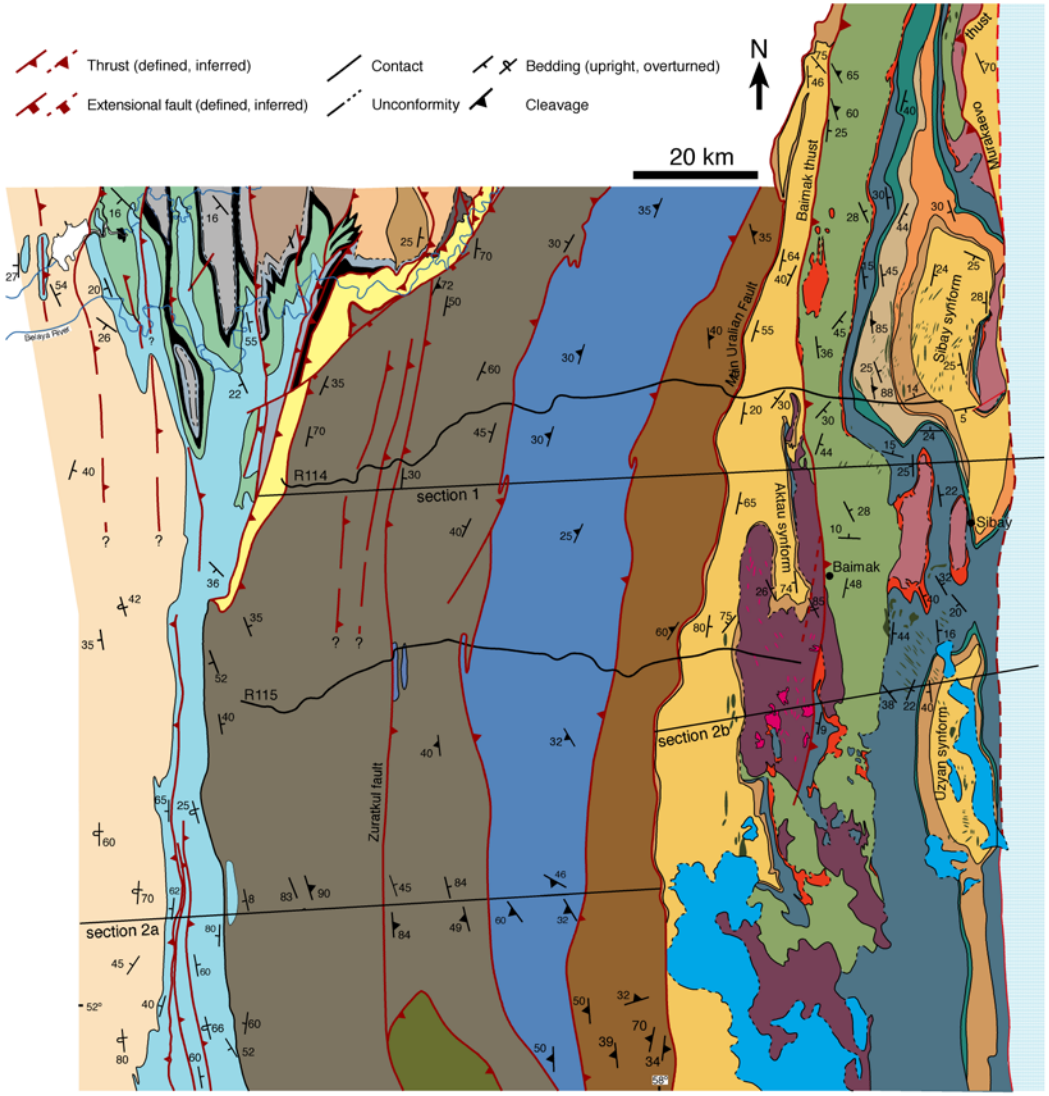


Magnitogorsk arc

● Middle Zilair

○ Lower Zilair

Data from: Willner et al., AGU Geophysical Monograph 132, 2002



Foreland thrust and fold belt

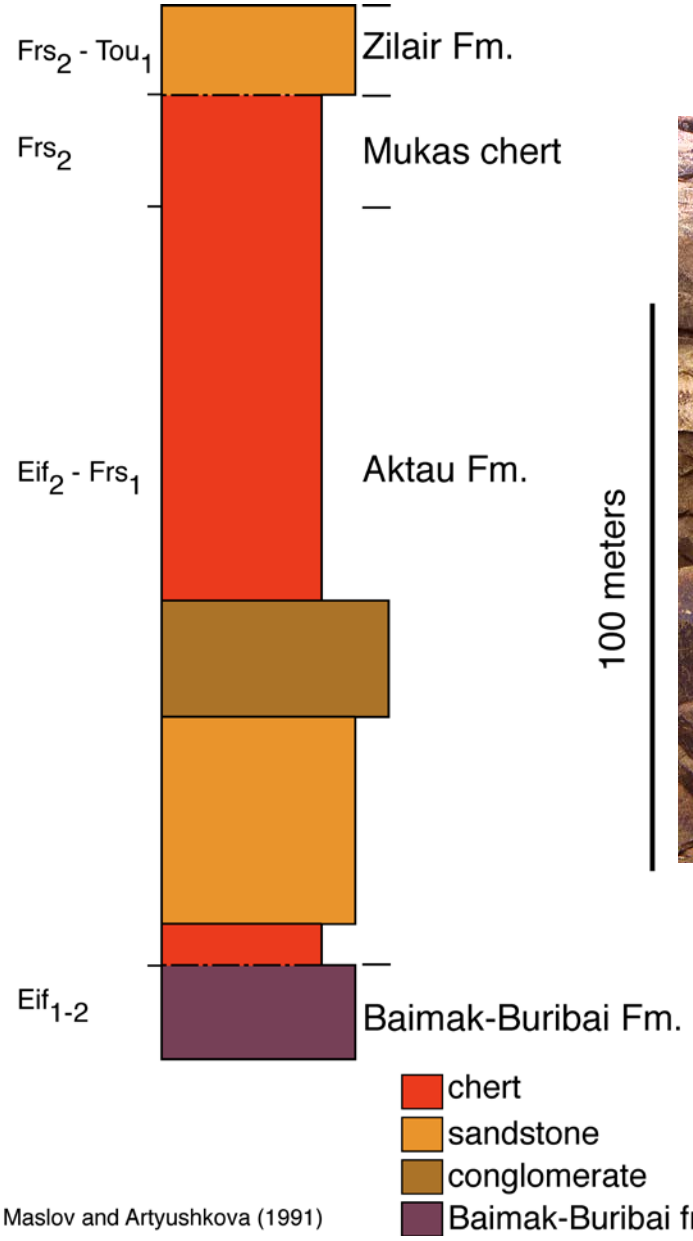
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

Accretionary complex

- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

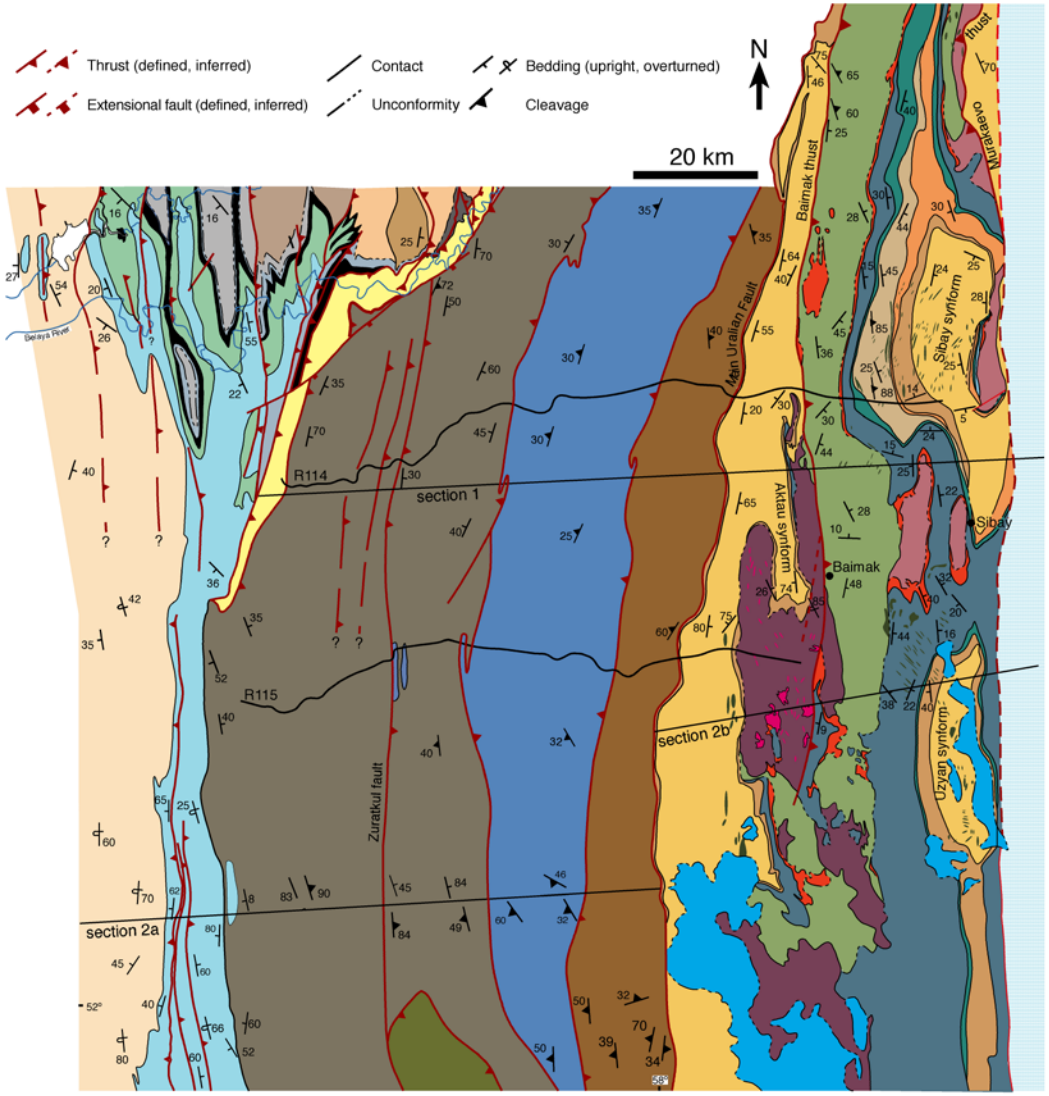
Magnitogorsk arc

- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)



From Maslov and Artyushkova (1991)

100 meters



Foreland thrust and fold belt

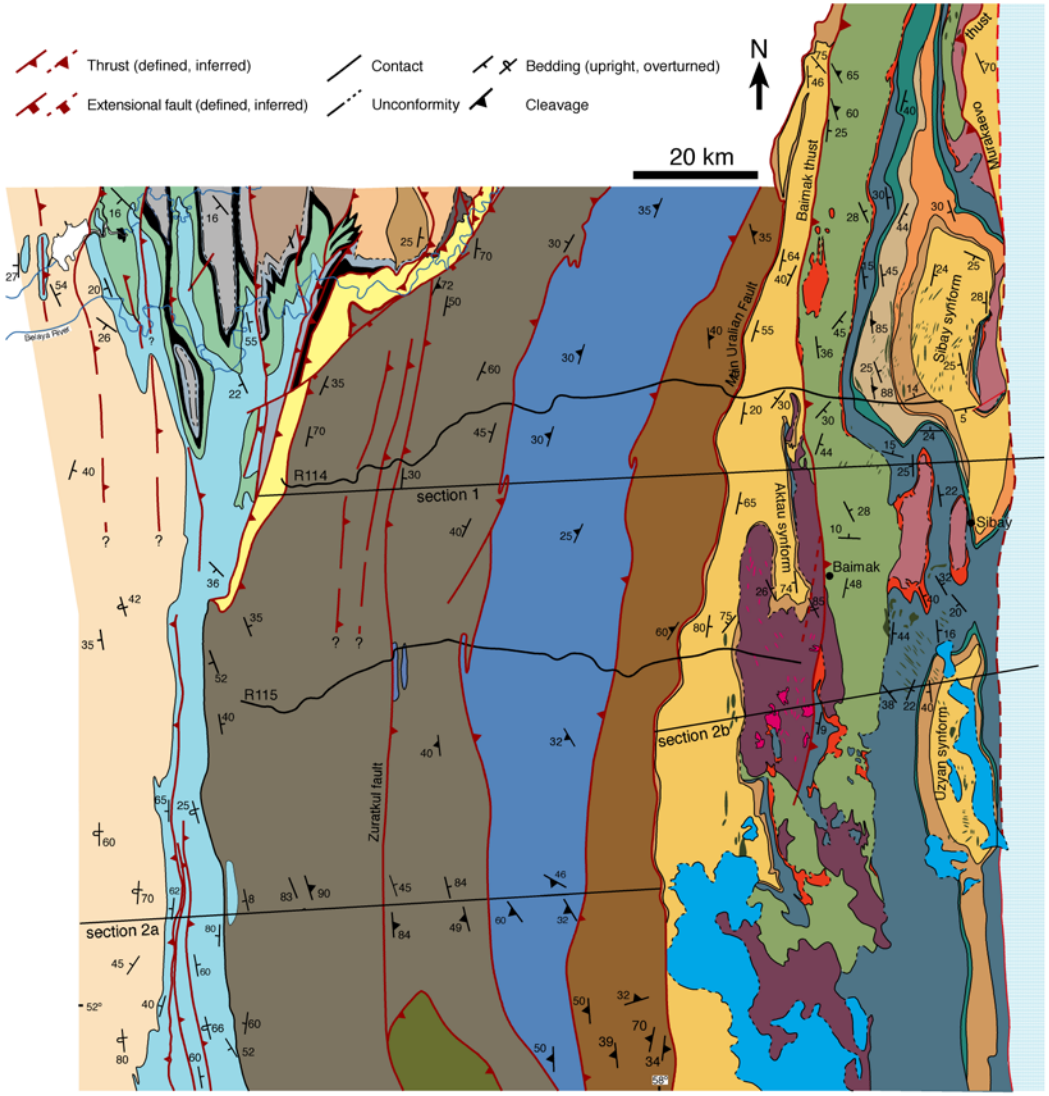
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

Accretionary complex

- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

Magnitogorsk arc

- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)



Foreland thrust and fold belt

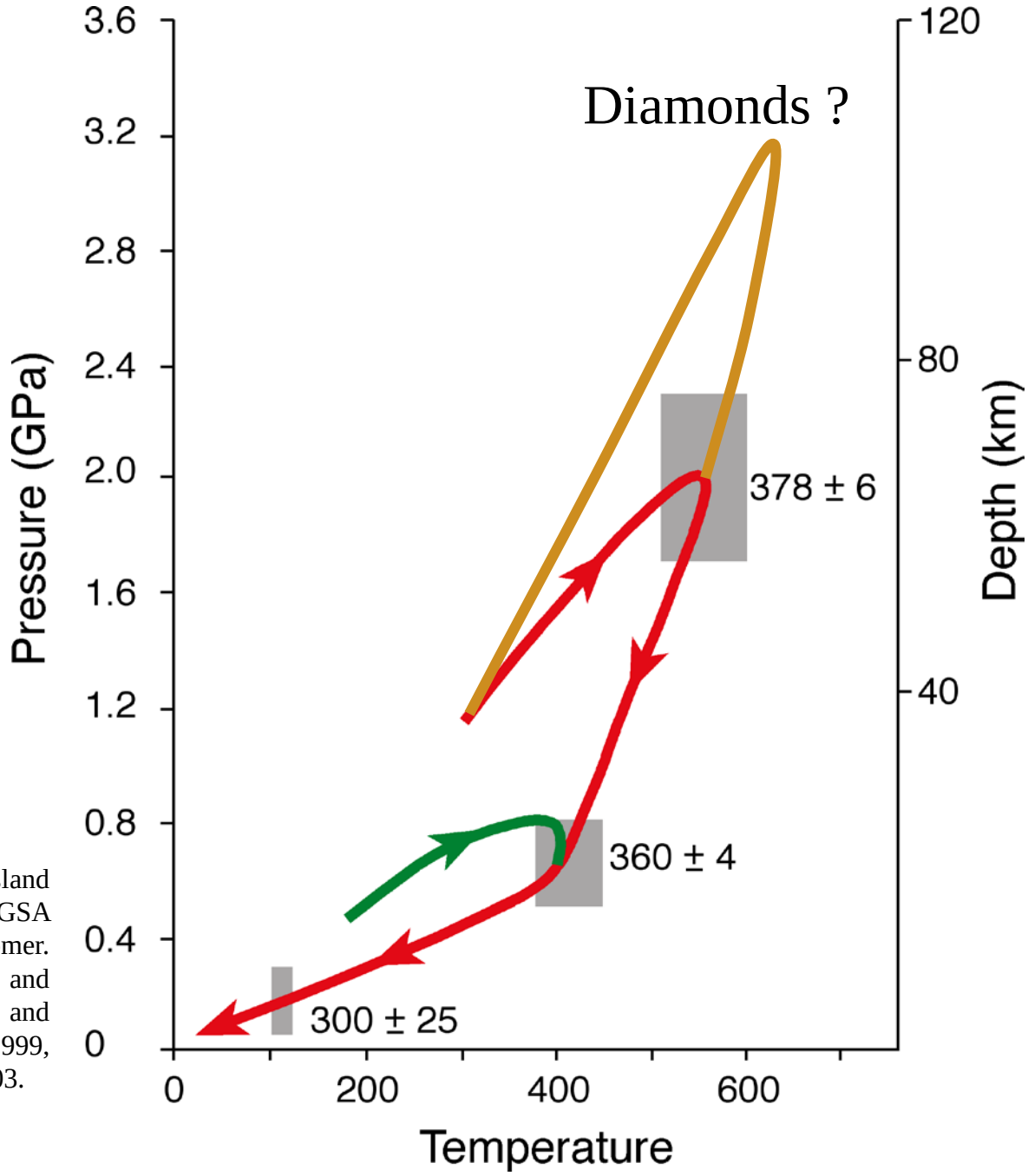
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

Accretionary complex

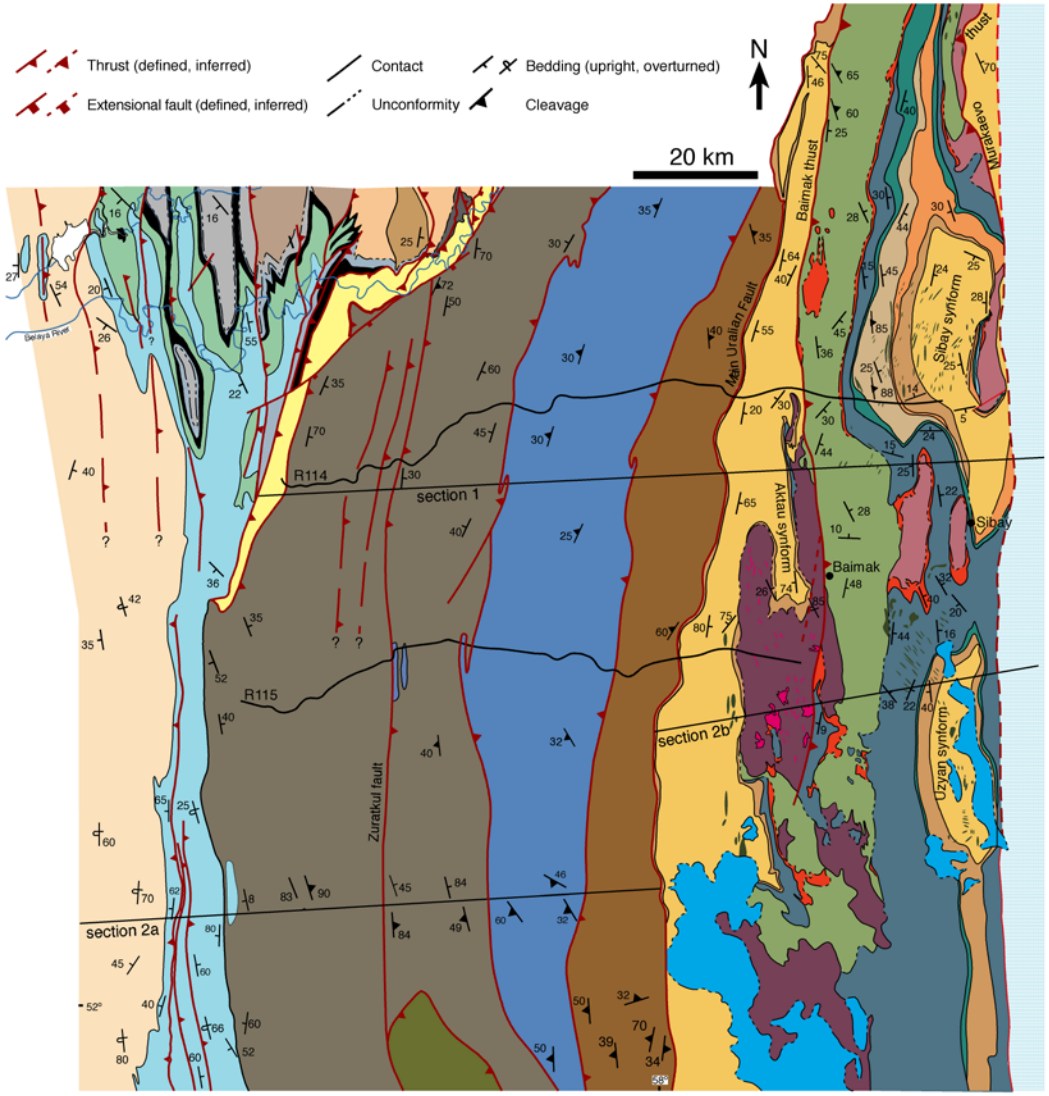
- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

Magnitogorsk arc

- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)



Data from: Beane et al., Island Arc, 1995, Hetzel et al., GSA Bull., 1998, Hetzel and Romer. Geol. J., 2000, Leach and Stockli, 2000; Shulte and Blümel, Geol. Rund., 1999, Bostick et al., Am. Min., 2003.



Foreland thrust and fold belt

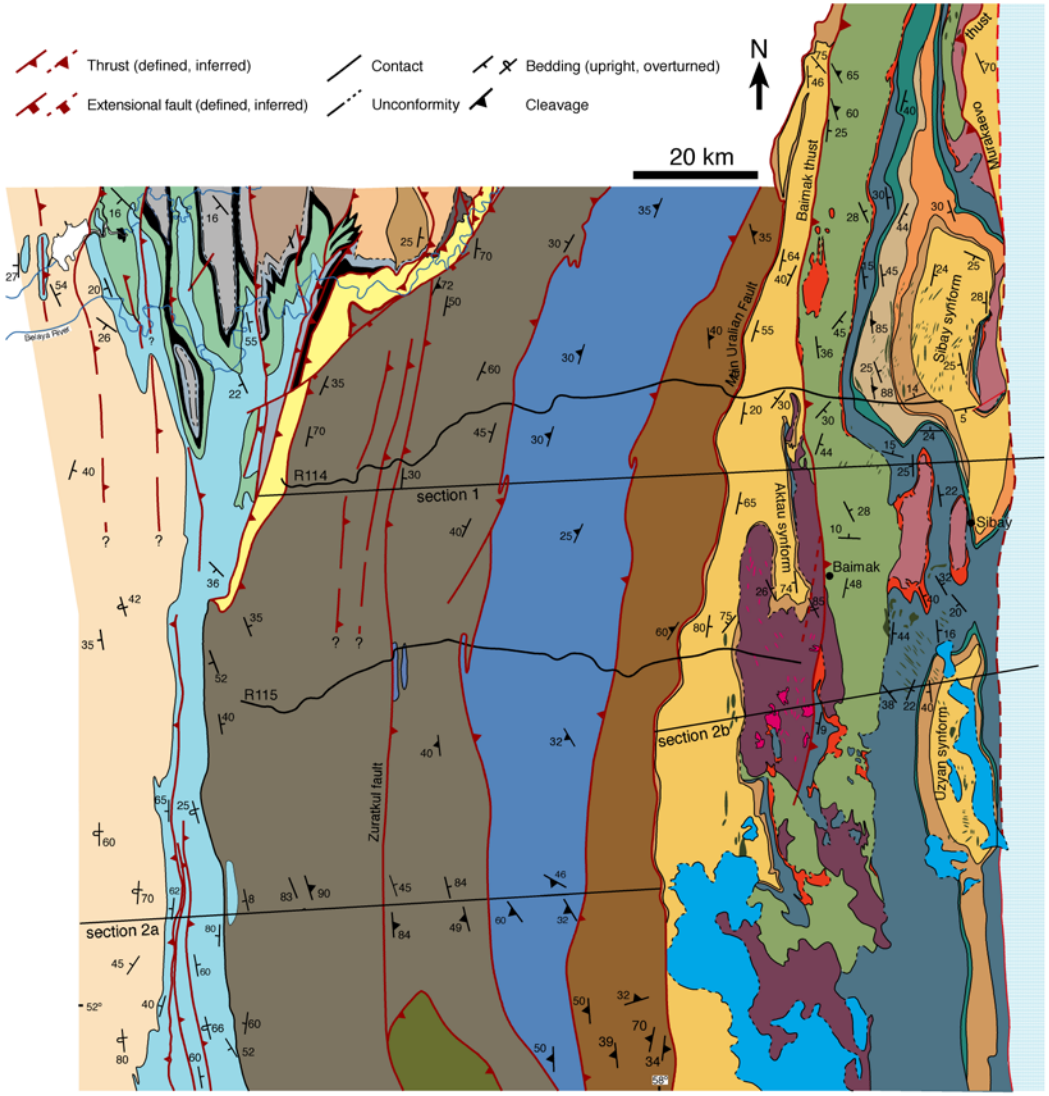
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

Accretionary complex

- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

Magnitogorsk arc

- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)



Foreland thrust and fold belt

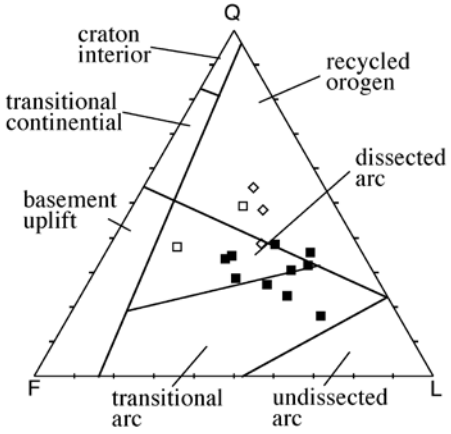
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

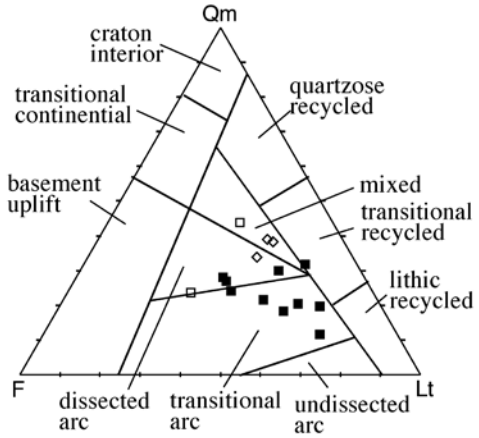
Accretionary complex

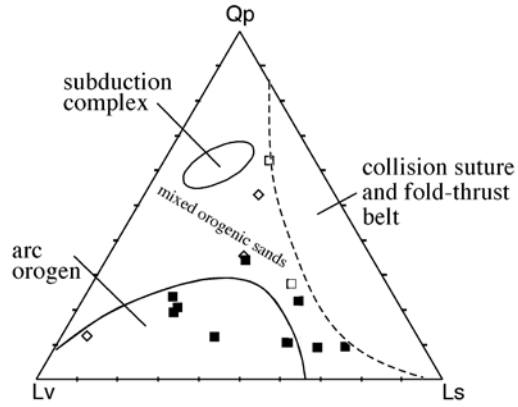
- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

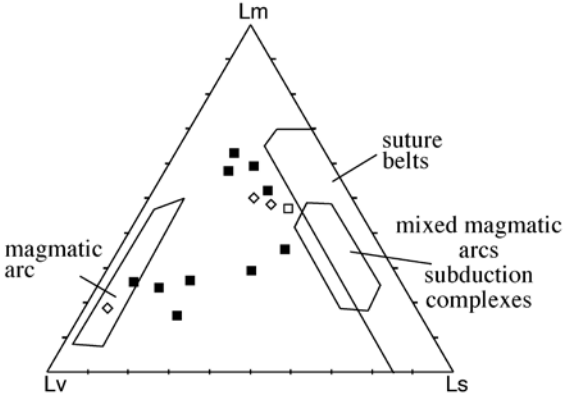
Magnitogorsk arc

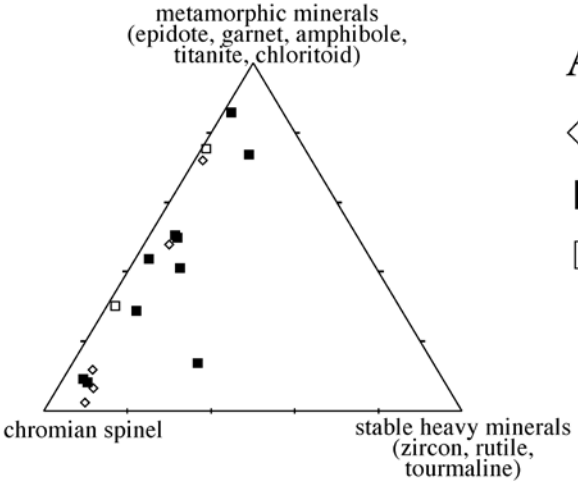
- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)











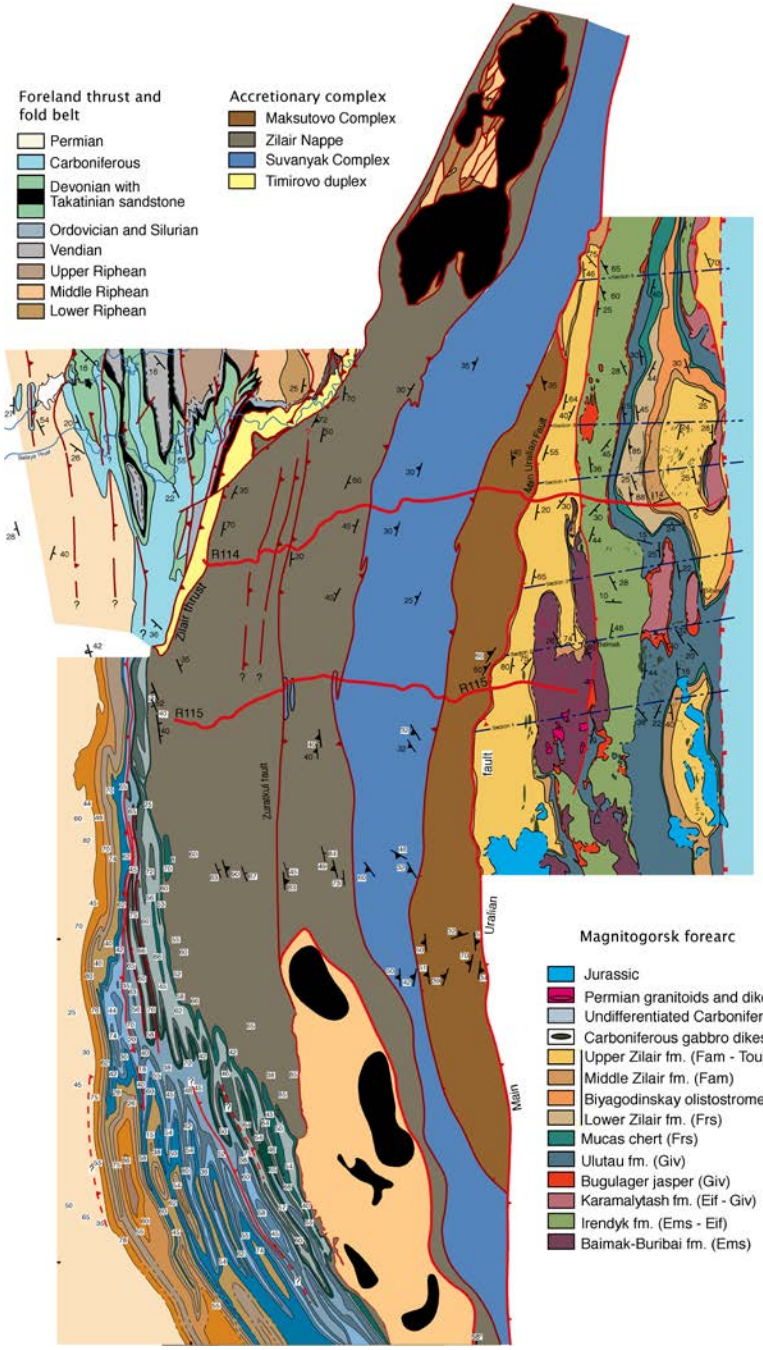
Accretionary complex

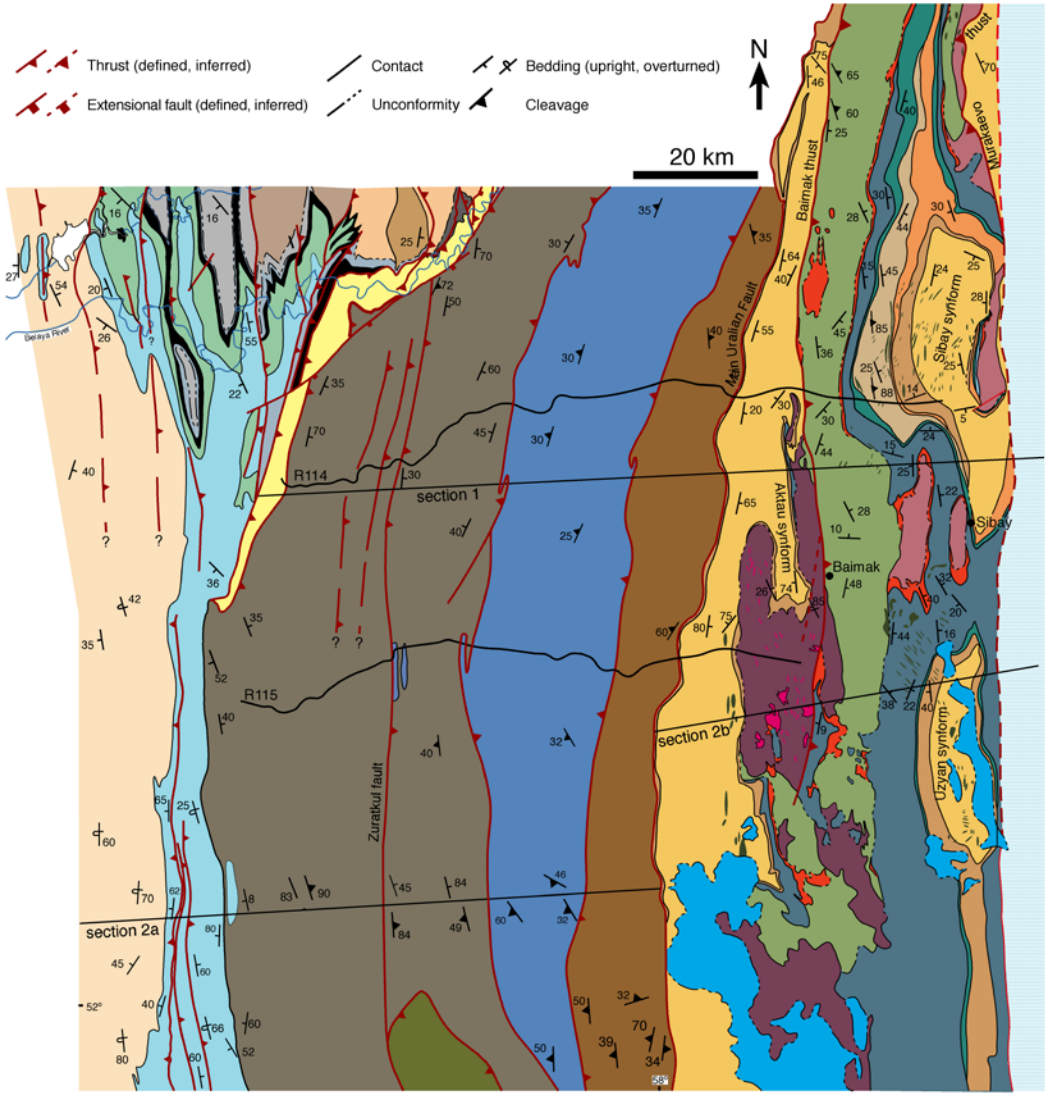
◇ Upper Zilair

■ Middle Zilair

□ Lower Zilair

Data from: Willner et al., AGU Geophysical Monograph 132, 2002.


Foreland thrust and fold belt
Permian
Carboniferous
Devonian with Takatinian sandstone
Ordovician and Silurian
Vendian
Upper Riphean
Middle Riphean
Lower Riphean
Accretionary complex
Maksutovo Complex
Zilair Nappe
Suvanyak Complex
Timirovo duplex
R114
R115
Zilair Thrust
Zuraikul fault
Main Uralian Fault
Uralian
Main
Magnitogorsk forearc
Jurassic
Permian granitoids and dikes
Undifferentiated Carboniferous
Carboniferous gabbro dikes
Upper Zilair fm. (Fam - Tou)
Middle Zilair fm. (Fam)
Biyagodinskay olistostrome
Lower Zilair fm. (Frs)
Mucas chert (Frs)
Ulutau fm. (Giv)
Bugulager jasper (Giv)
Karamalytash fm. (Eif - Giv)
Irendyk fm. (Ems - Eif)
Baimak-Buribai fm. (Ems)



Foreland thrust and fold belt

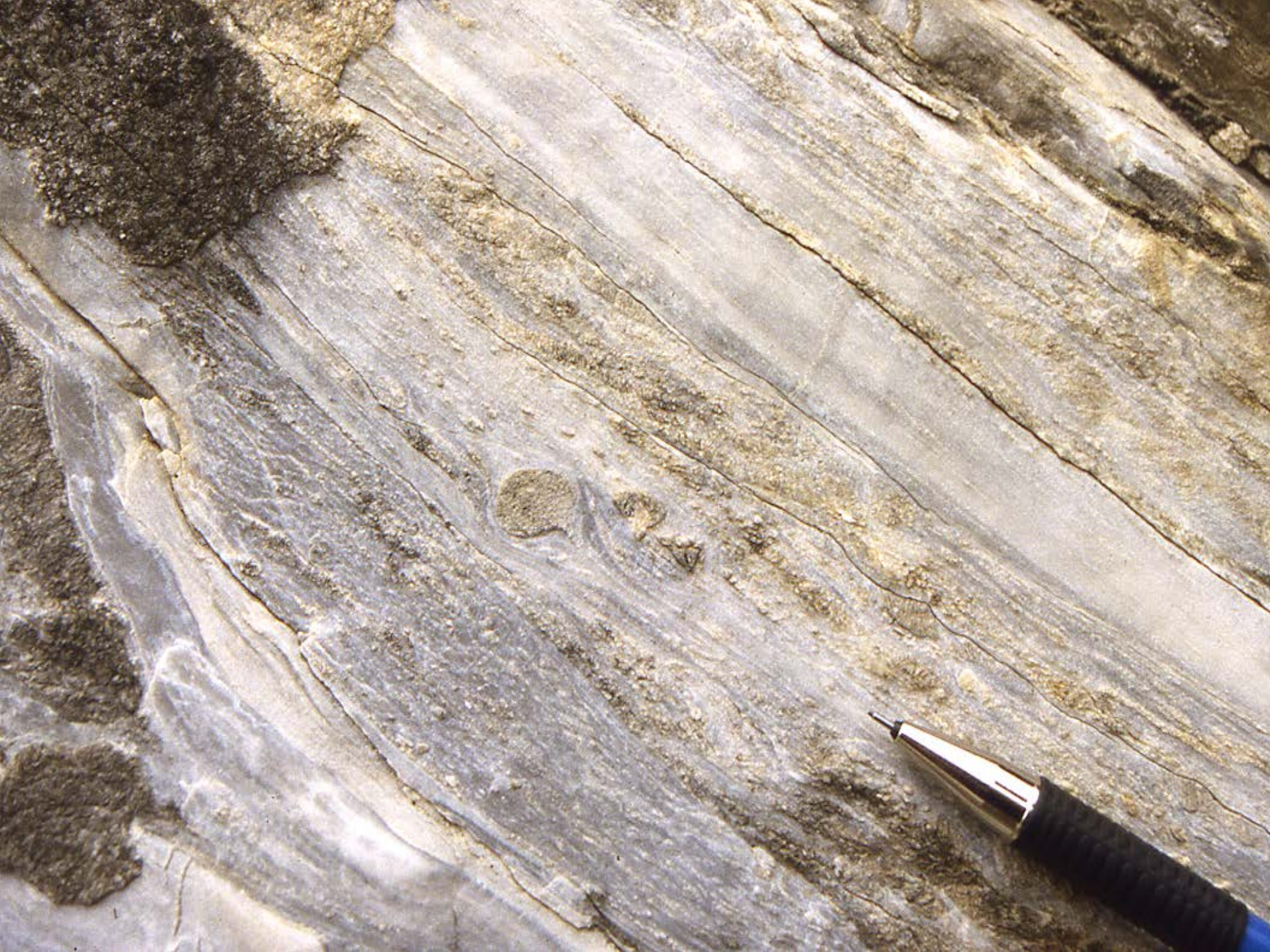
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

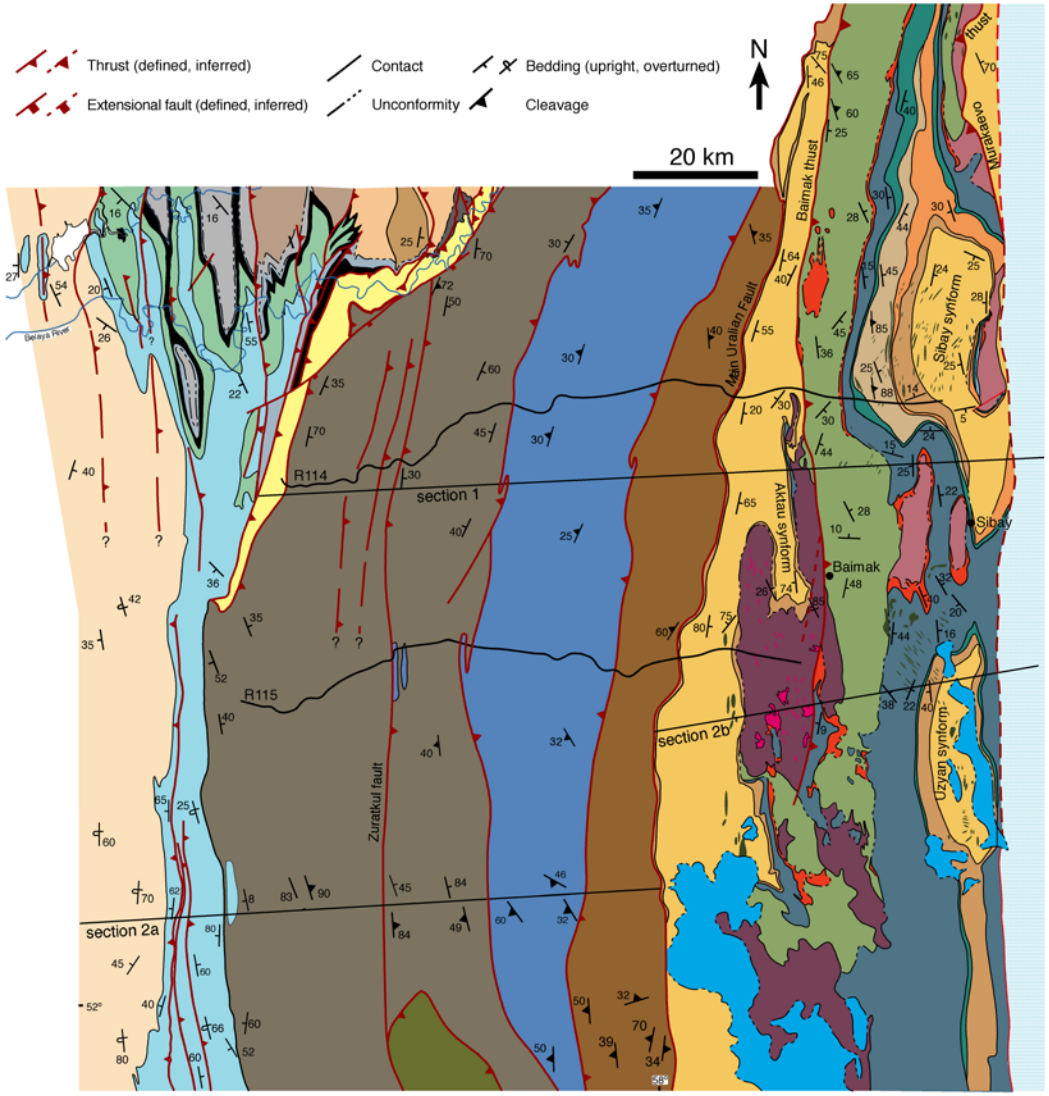
Accretionary complex

- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

Magnitogorsk arc

- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)





Foreland thrust and fold belt

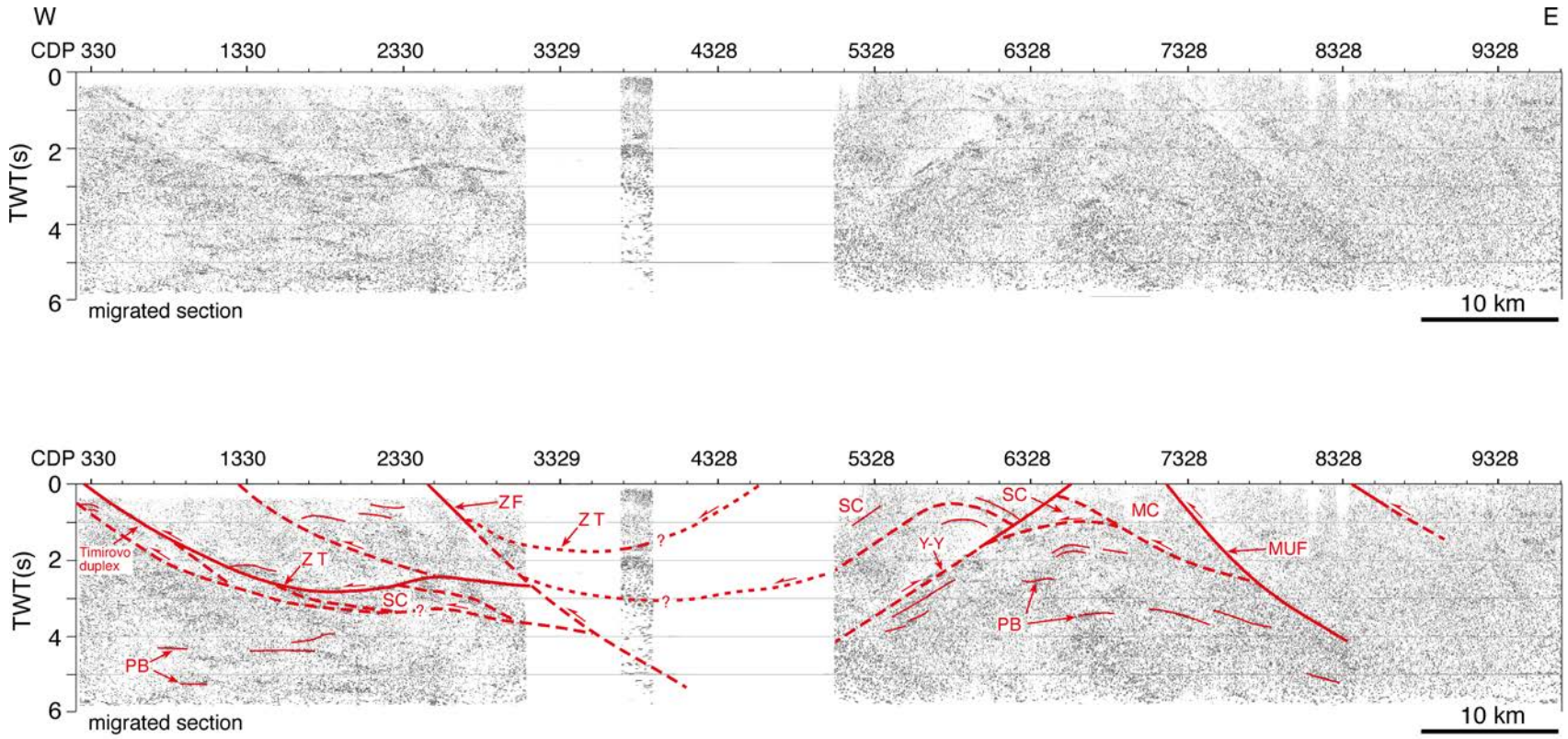
- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

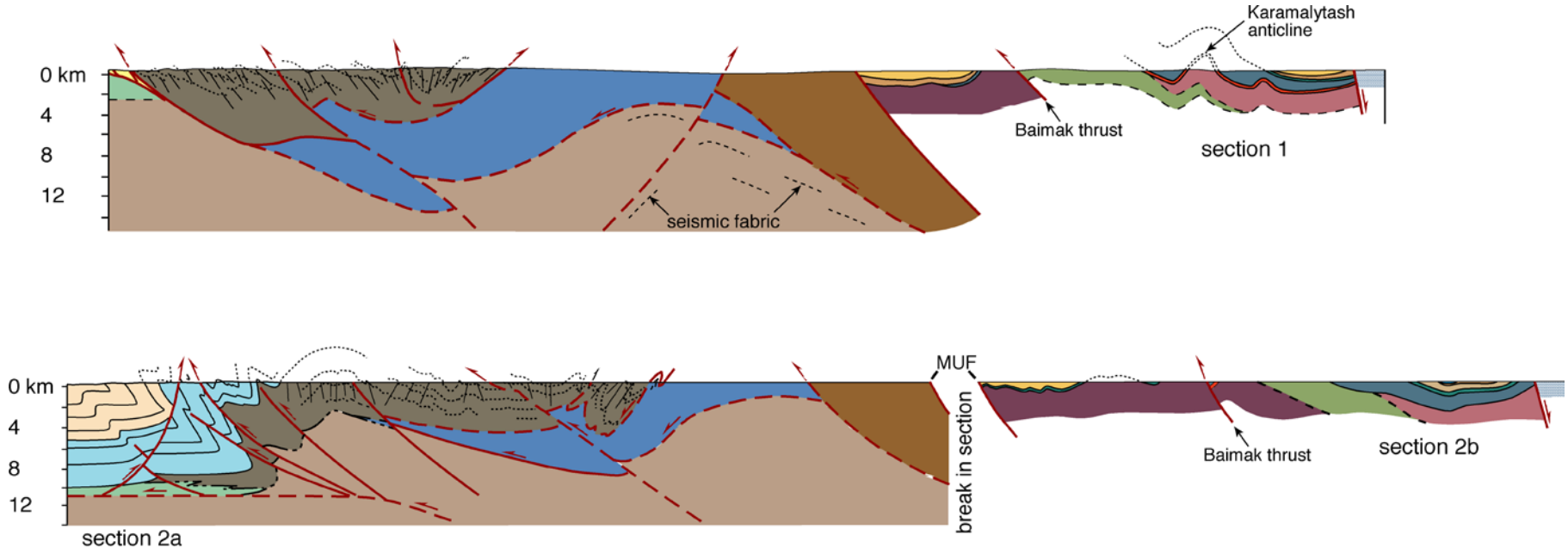
Accretionary complex

- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

Magnitogorsk arc

- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)


W
E
CDP 330
1330
2330
3329
4328
5328
6328
7328
8328
9328
TWT(s)
0
2
4
6
migrated section
10 km
Timirovo duplex
ZF
ZT
SC
PB
MC
MUF
Y-Y
?



Foreland thrust and fold belt

- Permian
- Carboniferous
- Devonian with Takatinian sandstone
- Ordovician and Silurian
- Vendian
- Upper Riphean
- Middle Riphean
- Lower Riphean

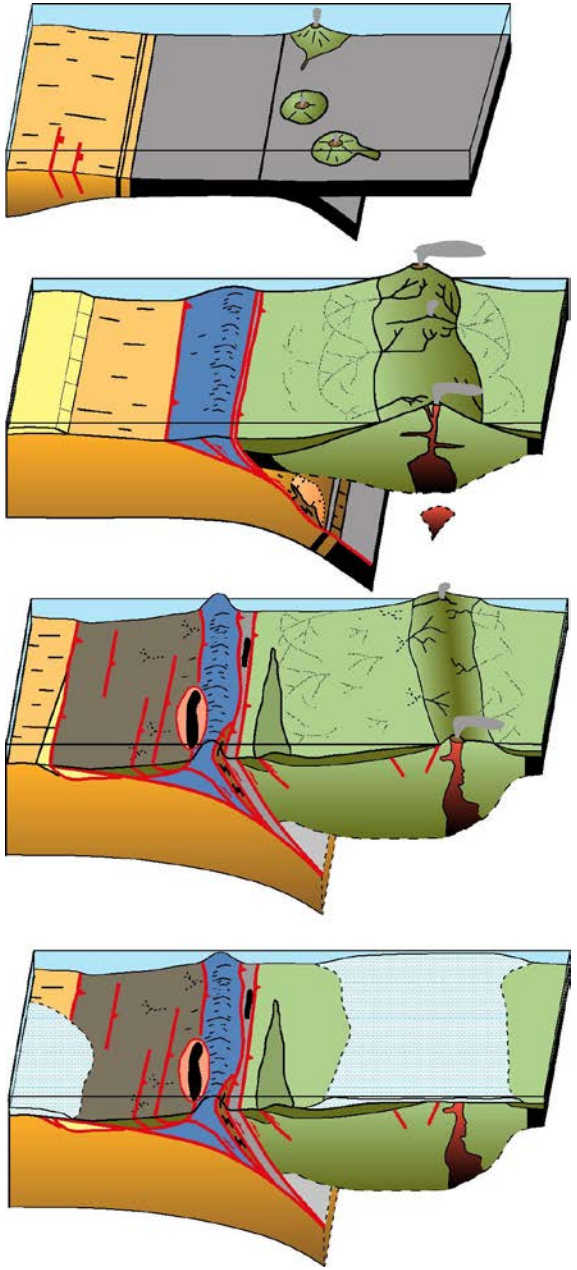
Accretionary complex

- Maksutovo Complex
- Zilair Nappe
- Suvanyak Complex
- Timirovo thrust system
- Sakmara allochthon

Magnitogorsk arc

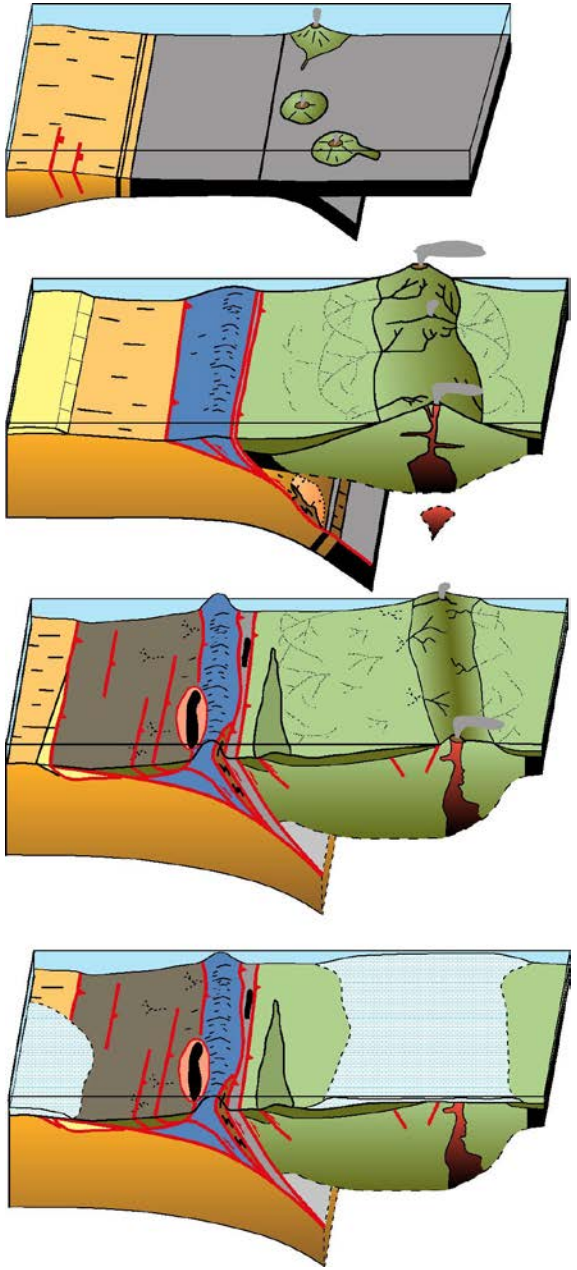
- Jurassic
- Permian granitoids and dikes
- Undifferentiated Carboniferous
- Carboniferous gabbro dikes
- Upper Zilair fm. (Fam)
- Lower Zilair fm. (Frs)
- Biyagodinskay olistostrome
- Koltubanian fm. (Frs)
- Mucas chert (Frs)
- Ulutau fm. (Giv)
- Bugulager jasper (Giv)
- Karamalytash fm. (Eif - Giv)
- Irendyk fm. (Ems - Eif)
- Baimak-Buribai fm. (Ems)

Arc-continent collision processes: Arc



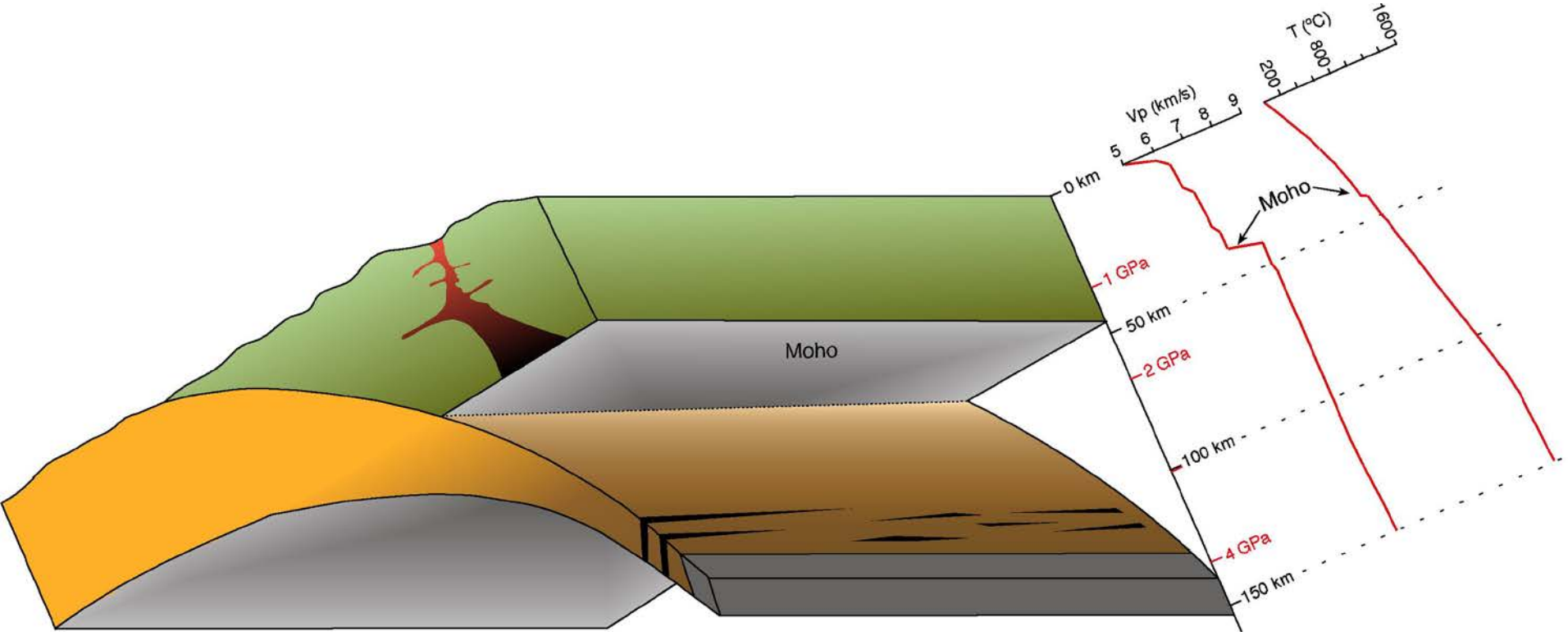
- Eruption of boninites into the forearc early in the subduction history.
- Volcanism shifts away from the subduction zone forming new volcanic fronts.
- Interarc tectonism.
- Erosion and sedimentation forming forearc and intra arc basins.
- Widespread synsedimentary deformation (seismites) at one stratigraphic level may evidence the arrival of the full thickenss of the continental crust at the subduction.

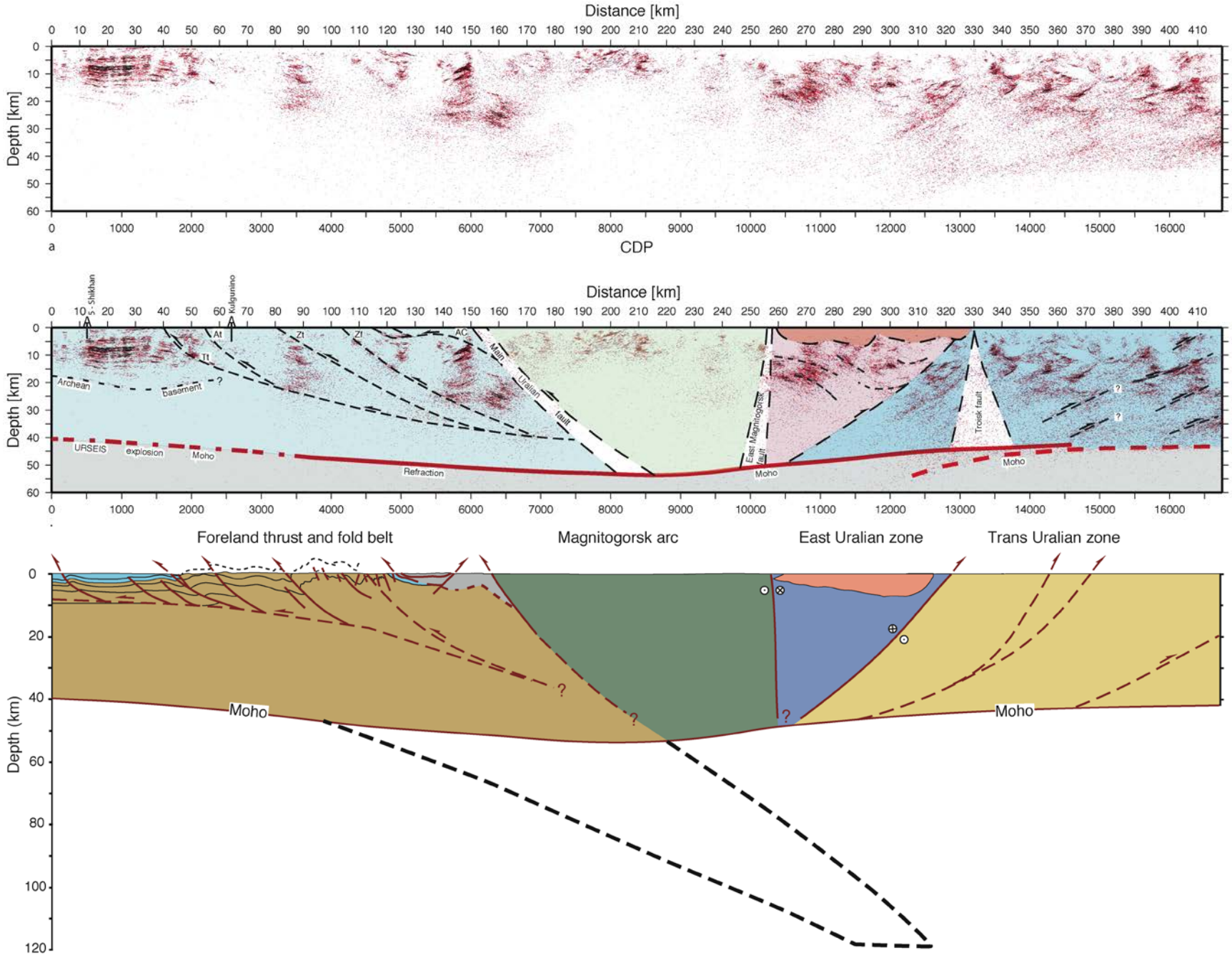
Arc-continent collision processes: Accretionary complex



- Off-scraping and exhumaton of shallowly subducted continental crust.
- Emplacement of ophiolites.
- Deep subduction of the continental margin and exhumation of HP rocks. Flux of material in the subduction channel.
- Formation of a foreland basin in front of, and incorporation of the basin sediments into, the accretionary complex.
- Imbrication of continental margin sediments.

Growth and destruction of the continental crust




Distance [km]
Depth [km]
CDP
a
S. Shikhan
Kulgunino
At
Zt
Zt
AC
Main Uralian fault
East Magnitogorsk fault
Troisk fault
Archean
basement
URSEIS
explosion
Moho
Refraction
Foreland thrust and fold belt
Magnitogorsk arc
East Uralian zone
Trans Uralian zone
Depth (km)

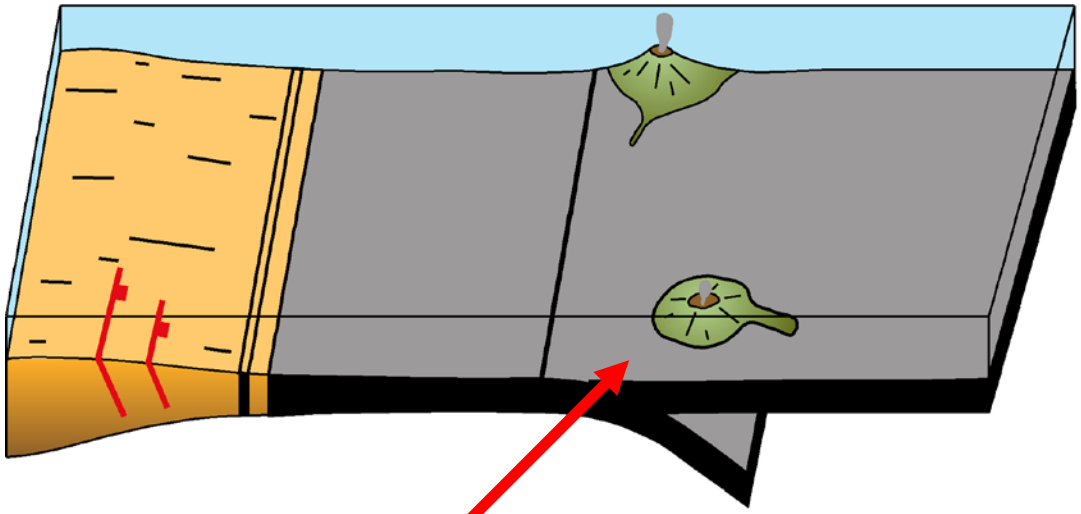
- If we assume an average thickness of 10 km of the Laurussia margin was subducted to around 120 km depth along the entire c. 400 km length of the presently exposed collision zone (with only minor return of material to the surface as high-pressure rocks) and a current Moho depth of c. 50 km, then about 280,000 km^3 of continental crust has been lost to the present day mantle.

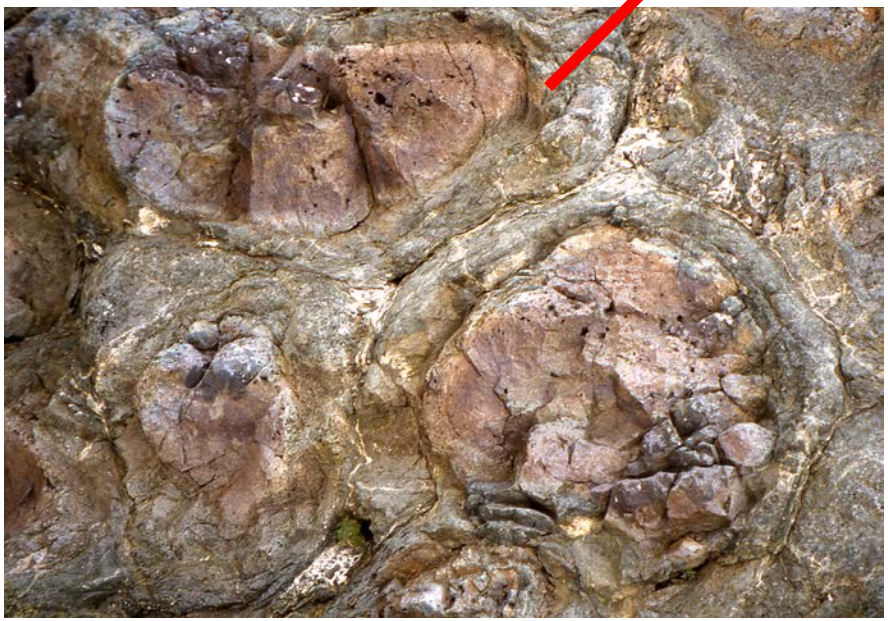
- If a crustal thickness of 20 km is assumed for the Magnitogorsk arc, and a width of c. 100 km, then approximately 800,000 km^3 of new material accreted to the margin.

- This rough calculation suggests that a net volume of around 520,000 km^3 of material was added to the Laurussia margin during its collision with the Magnitogrsk arc.


Thank you for your attention

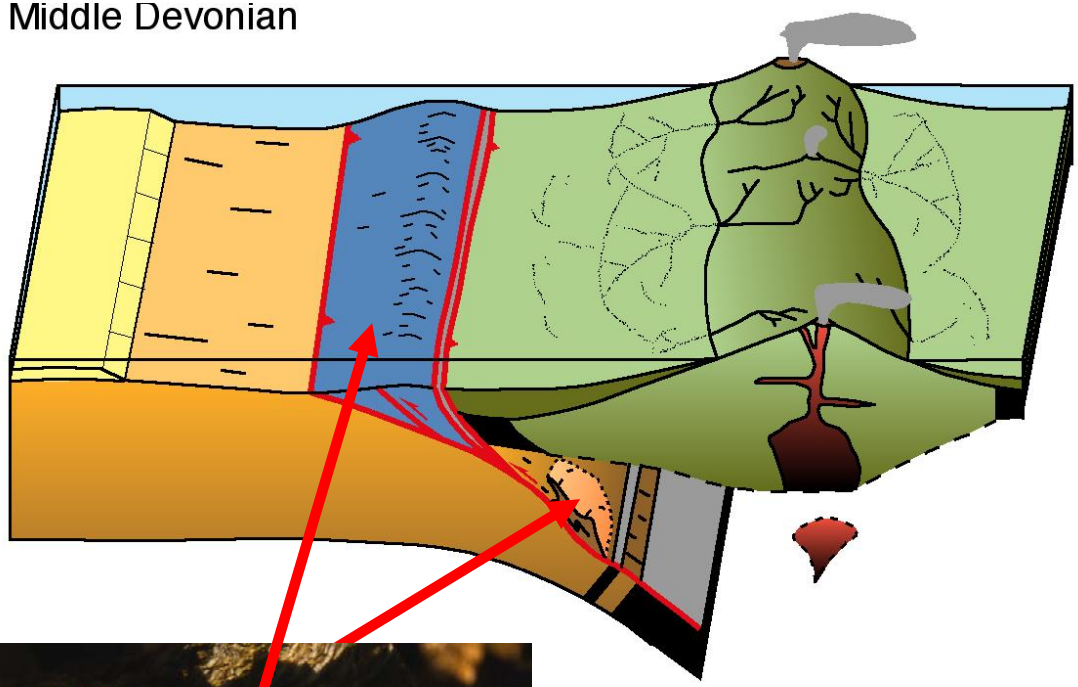
Early Devonian

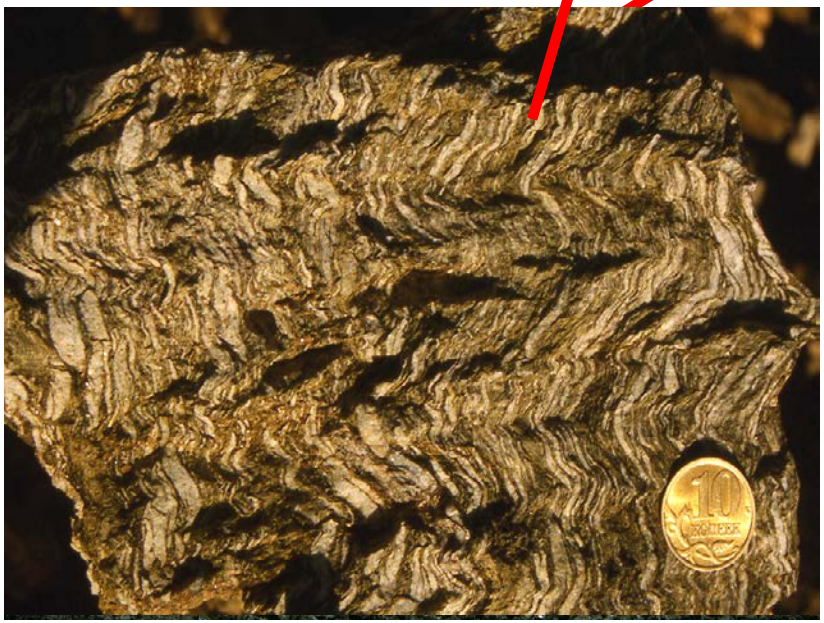




oceanic crust
continental crust
transitional crust
volcanic arc

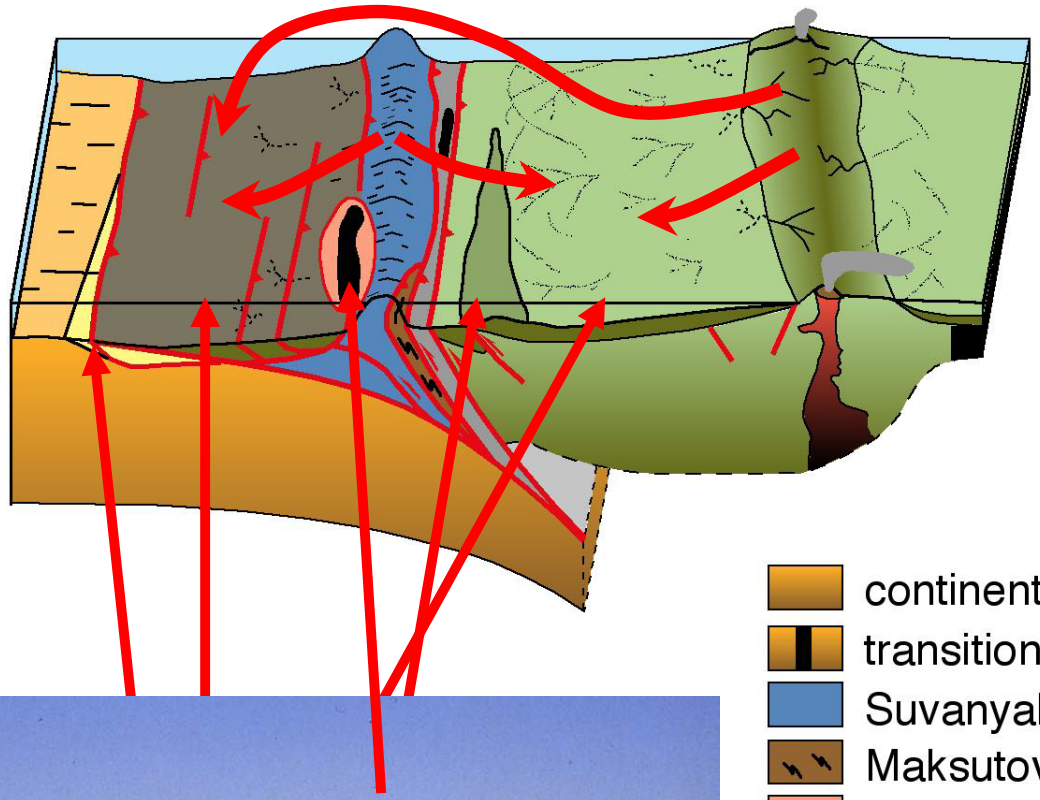
Middle Devonian

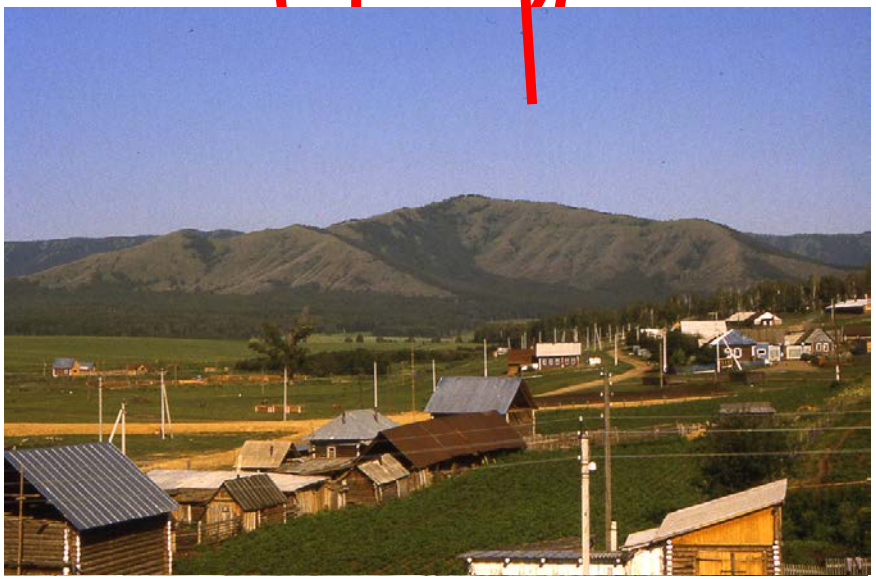




continental crust
transitional crust
Suvanyak Complex
Maksutovo Complex
Uzyan Allochthon
Magnitogorsk arc
intrusive suites

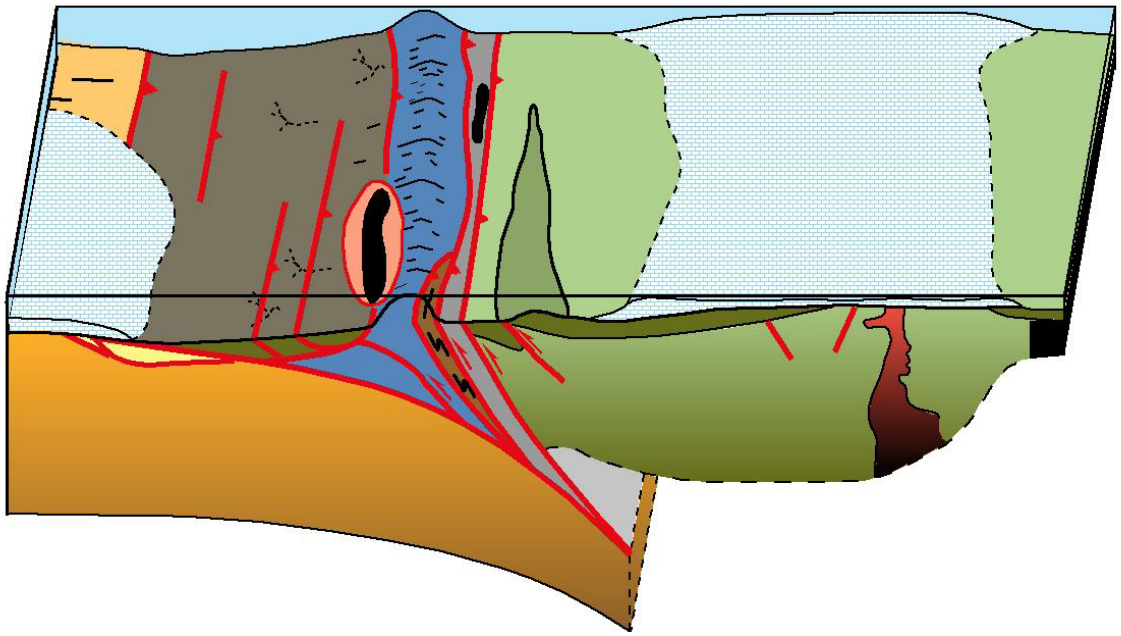
Late Devonian





continental crust
transitional crust
Suvanyak Complex
Maksutovo Complex
Uzyan Allochthon
Magnitogorsk arc
intrusive suites
Timirovo Duplex
Zilair Nappe

Early Carboniferous



continental crust
transitional crust
Suvanyak Complex
Maksutovo Complex
Uzyan Allochthon
Magnitogorsk arc
intrusive suites
Timirovo Duplex
Zilair Nappe
Lower Carboniferous