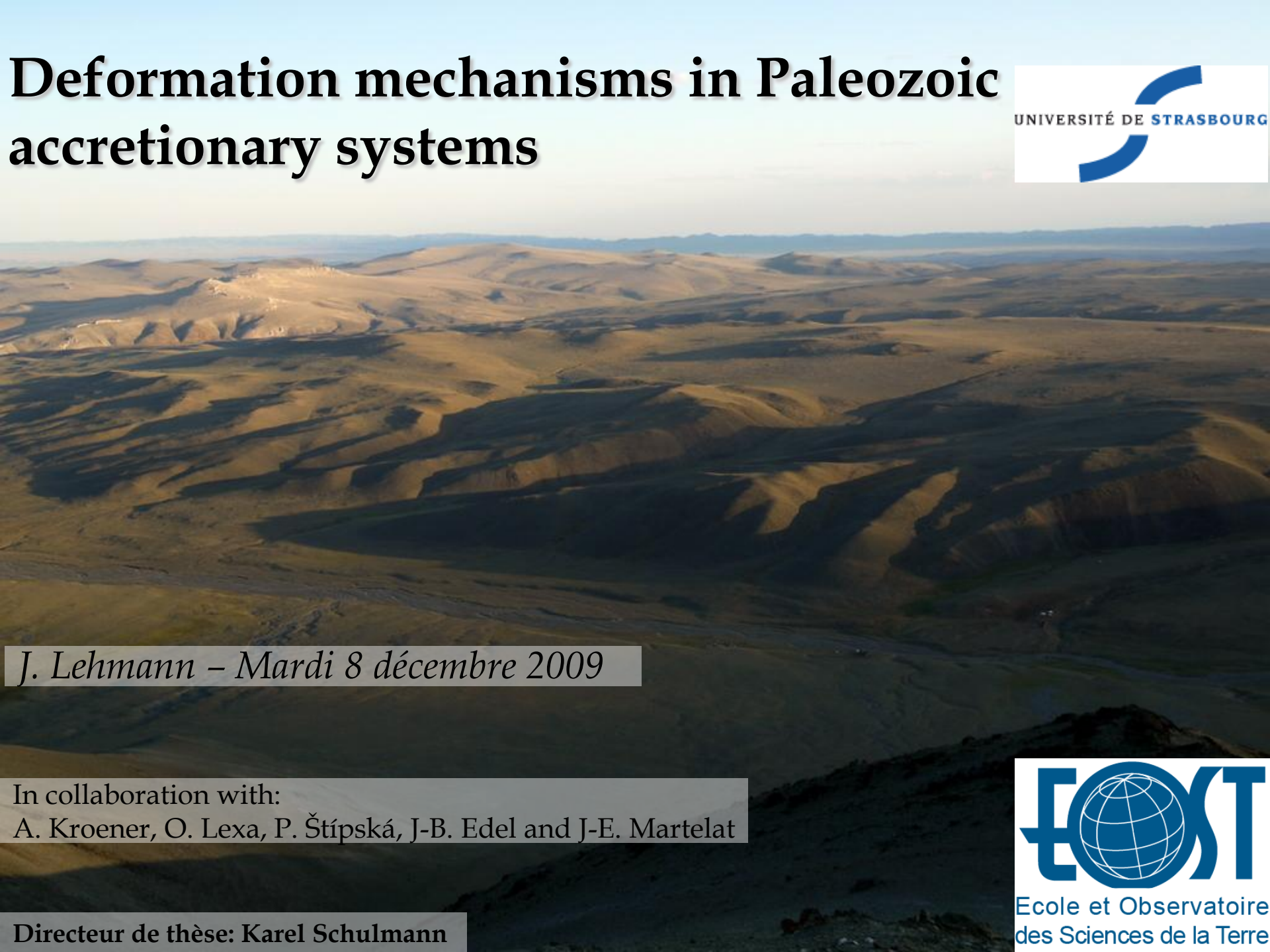
Deformation mechanisms in Paleozoic accretionary systems



J. Lehmann – Mardi 8 décembre 2009

In collaboration with:
A. Kroener, O. Lexa, P. Štípská, J-B. Edel and J-E. Martelat

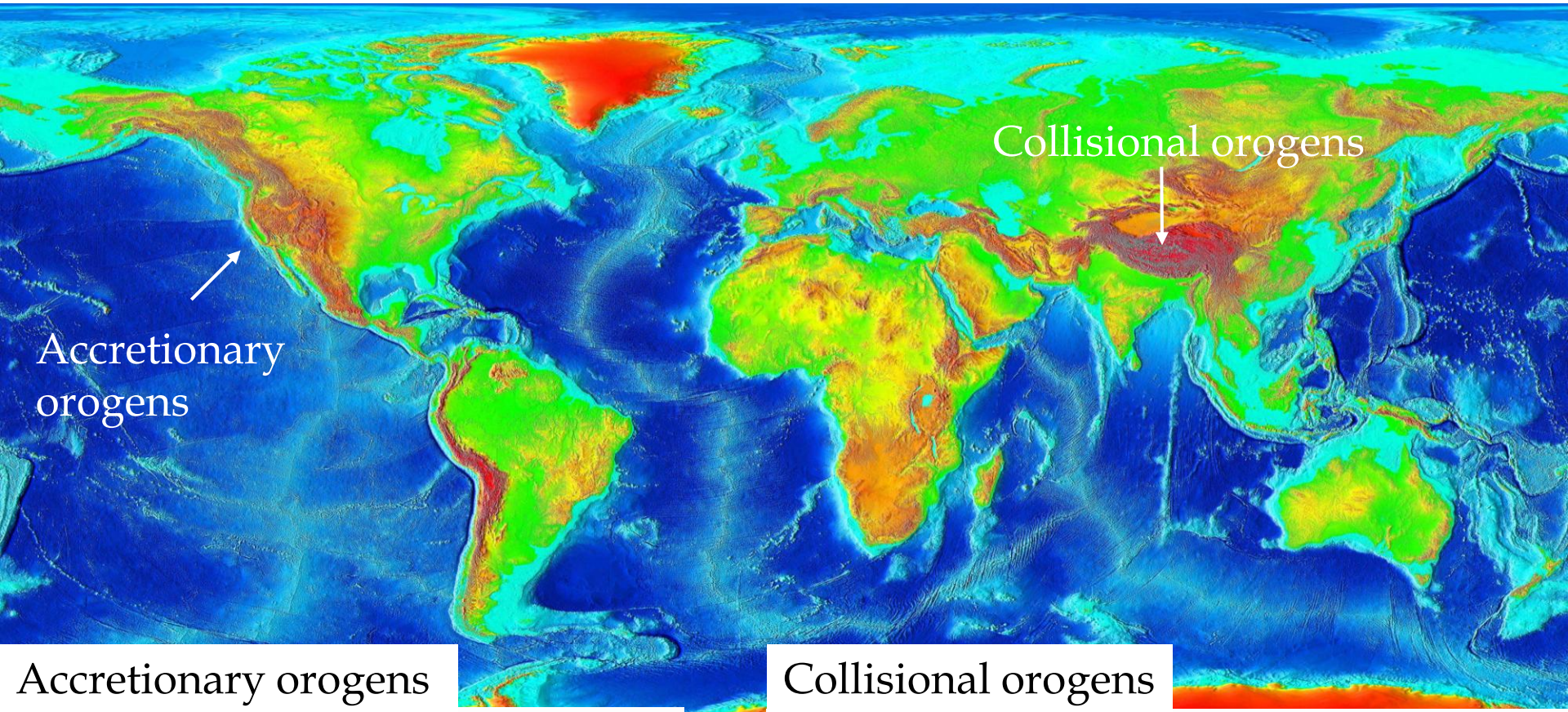
Directeur de thèse: Karel Schulmann

UNIVERSITÉ DE STRASBOURG

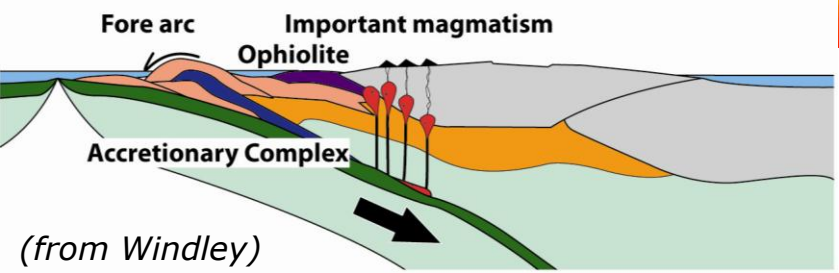
Ecole et Observatoire des Sciences de la Terre

Different types of orogenic belts

Accretionary orogens vs. Collisional orogens

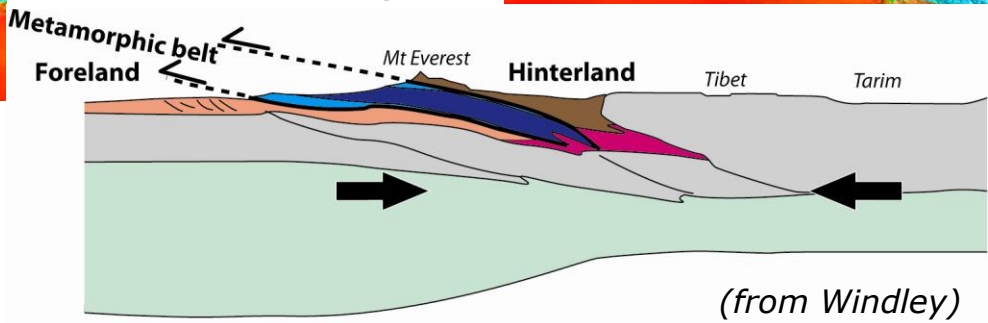


Accretionary orogens



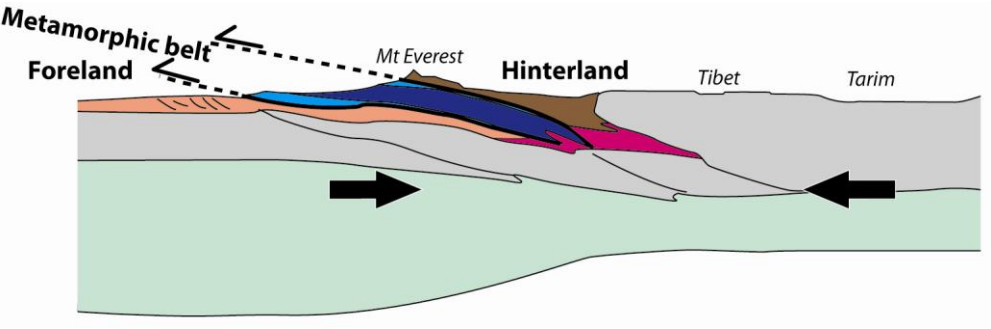
(from Windley)

Collisional orogens



(from Windley)

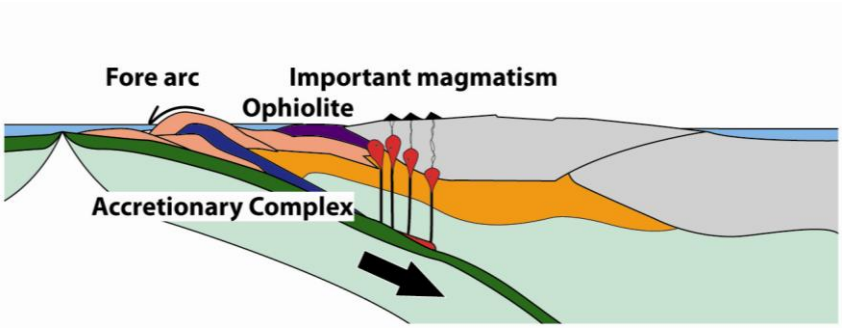
Structural markers for the trend-lines of Orogenic complexes



(from Windley)

Collisonal belts

- Linear and elongated sutures
- Precolllisional magmatic rocks
- Large high PT units
- Continental margin sedimentary prisms in the forelands



(from Windley)

Accretionary belts

- Huge granitoid magmatic belt
- Small high PT units
- Rare large-scale facies continuity & no similar style and orientation of orogenic structures

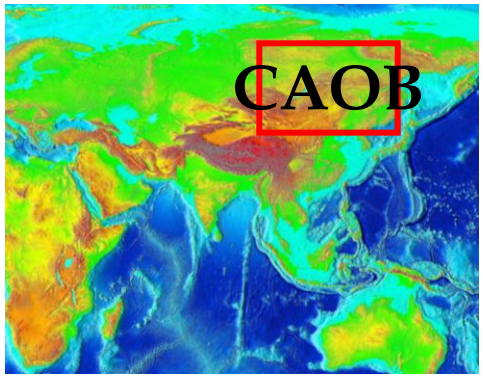
Excellent structural markers

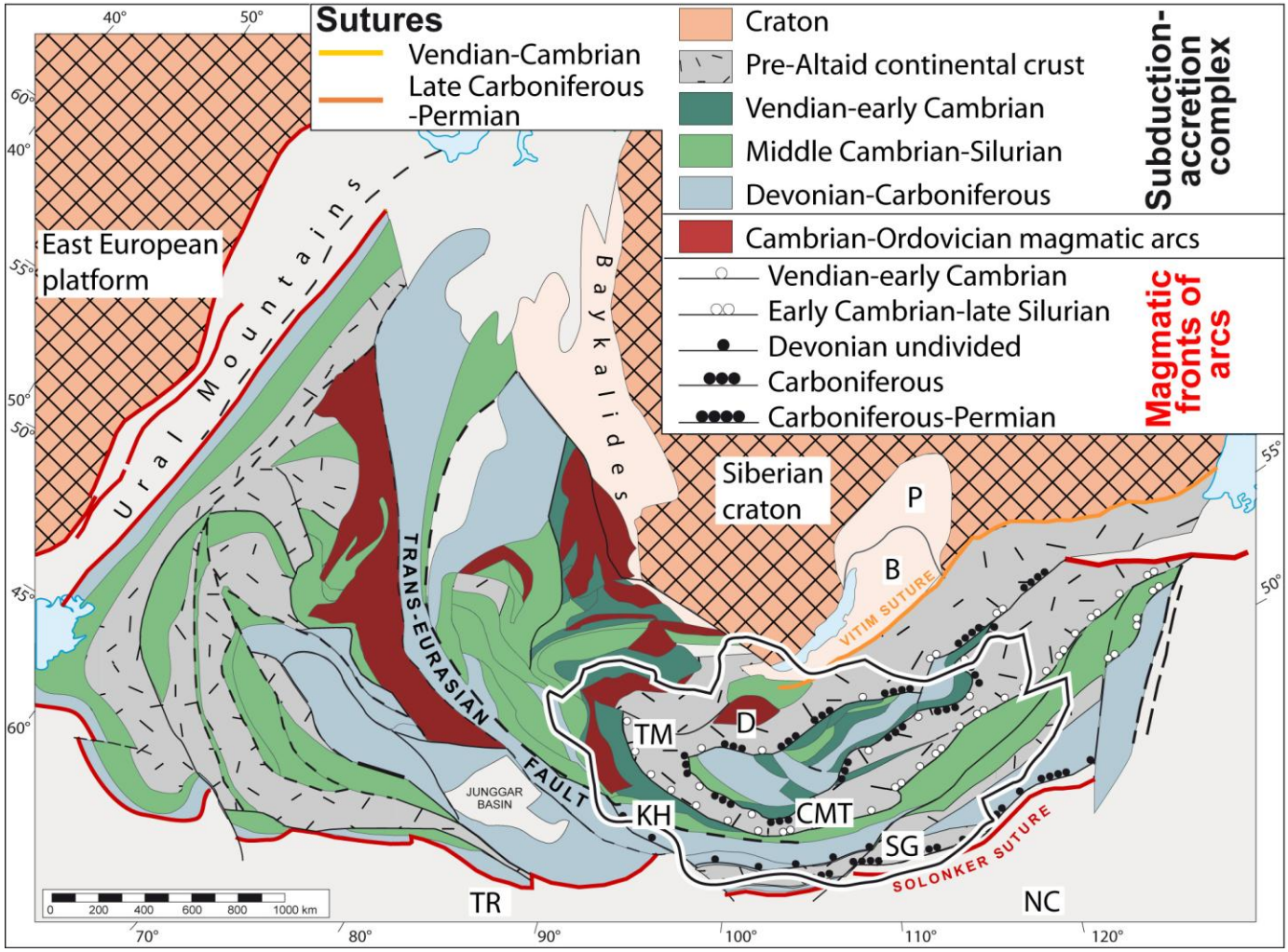
What are the markers?...

The Central Asian Orogenic Belt (CAOB)

How to define polarities?

How this huge crustal domain was accreted?



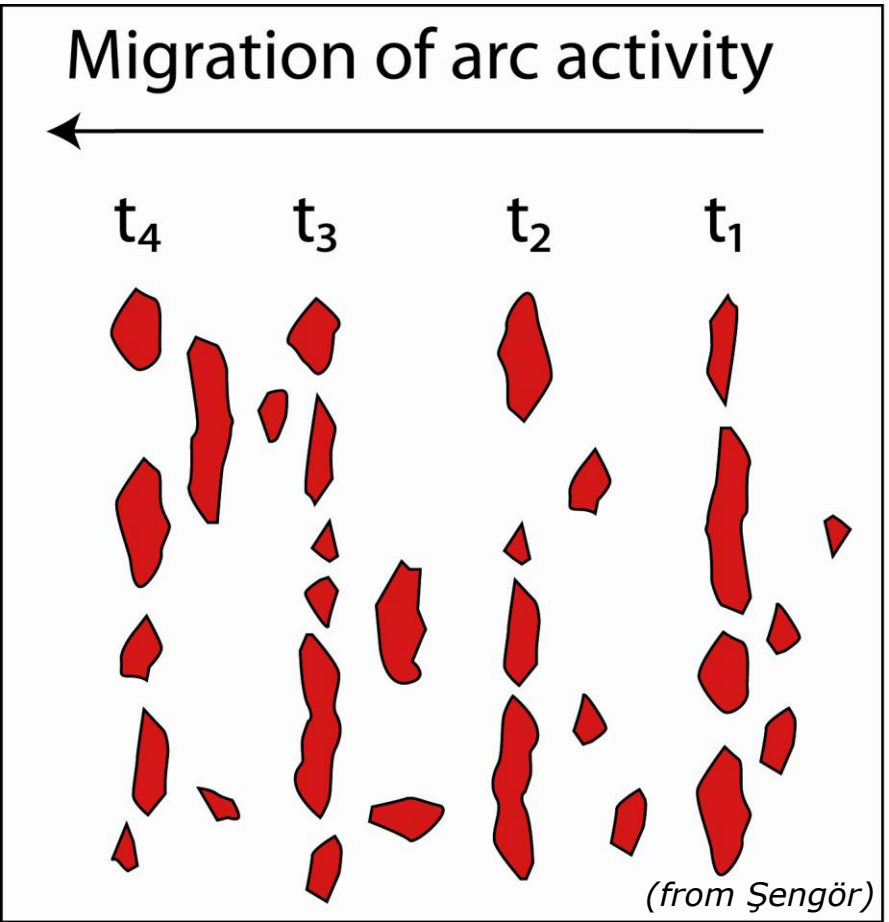


Modified from Şengör et al., 1993

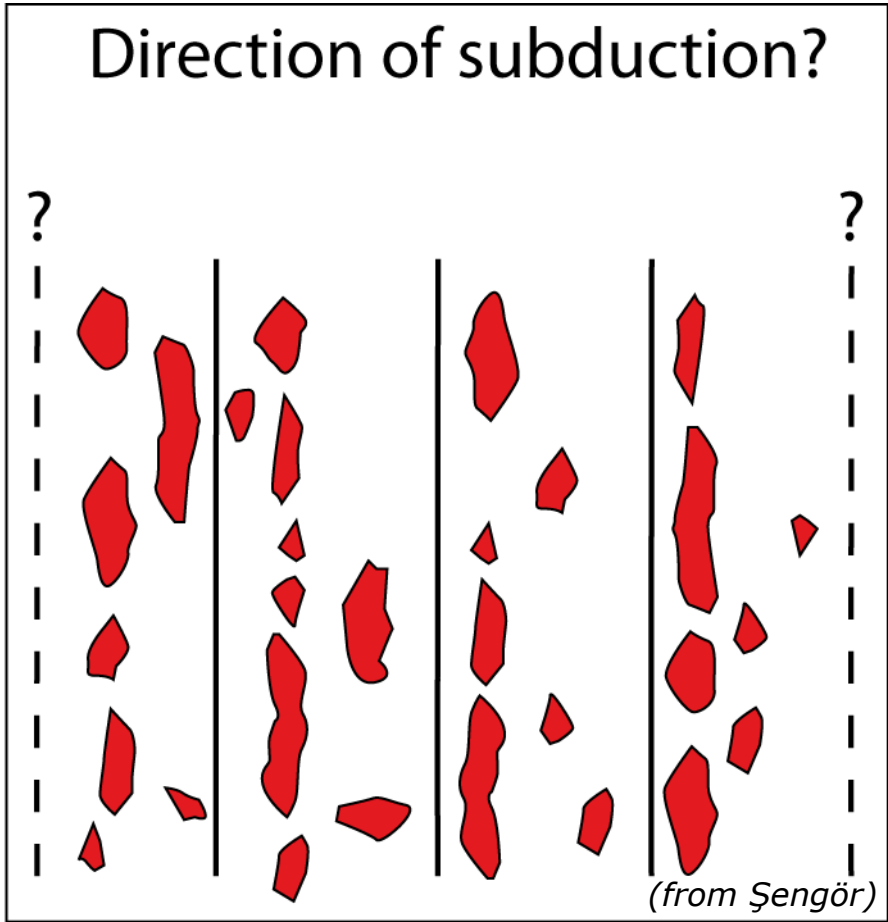
Magmatic fronts as polarity markers in Paleo-accretionary orogens (1)

Trend line of the accretionary system

Map view of a plutonic belt



How to define the polarity?



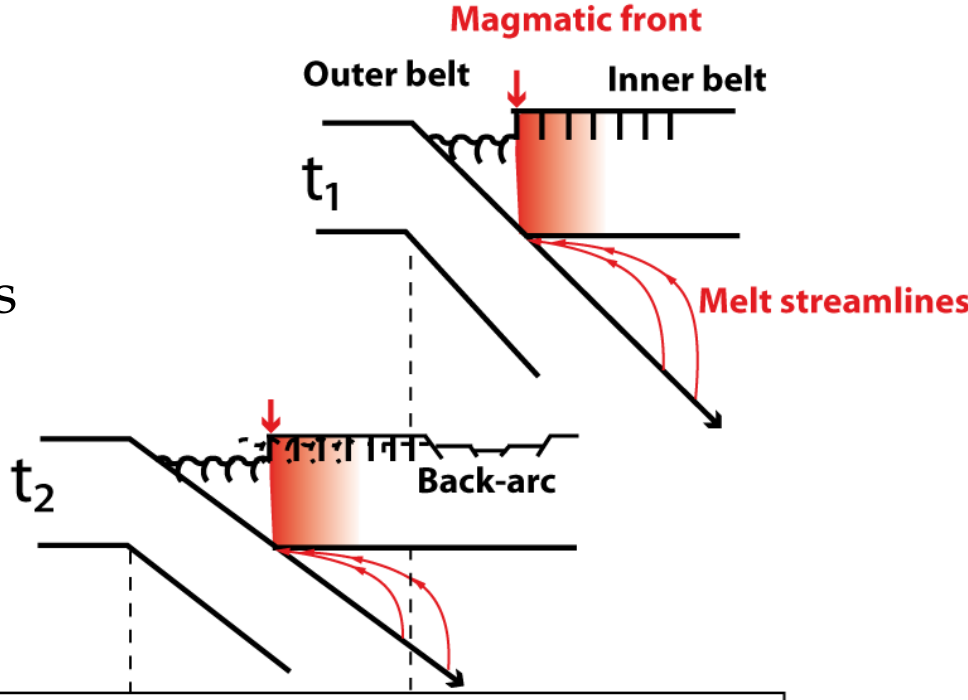
Magmatic fronts (2)

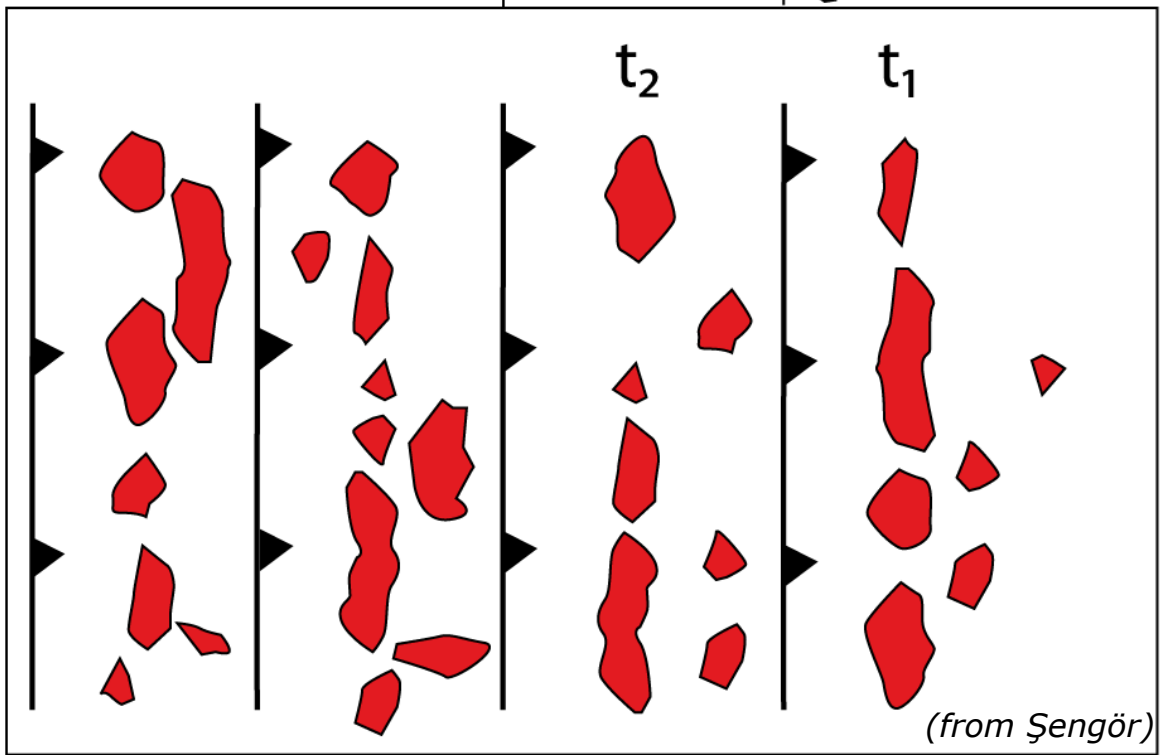
- Very sharp fronts vs. diffuse backs
(Spielgman and McKenzie, 1987)

- Inner belt vs. Outer belt
(Matsuda & Uyeda, 1971)

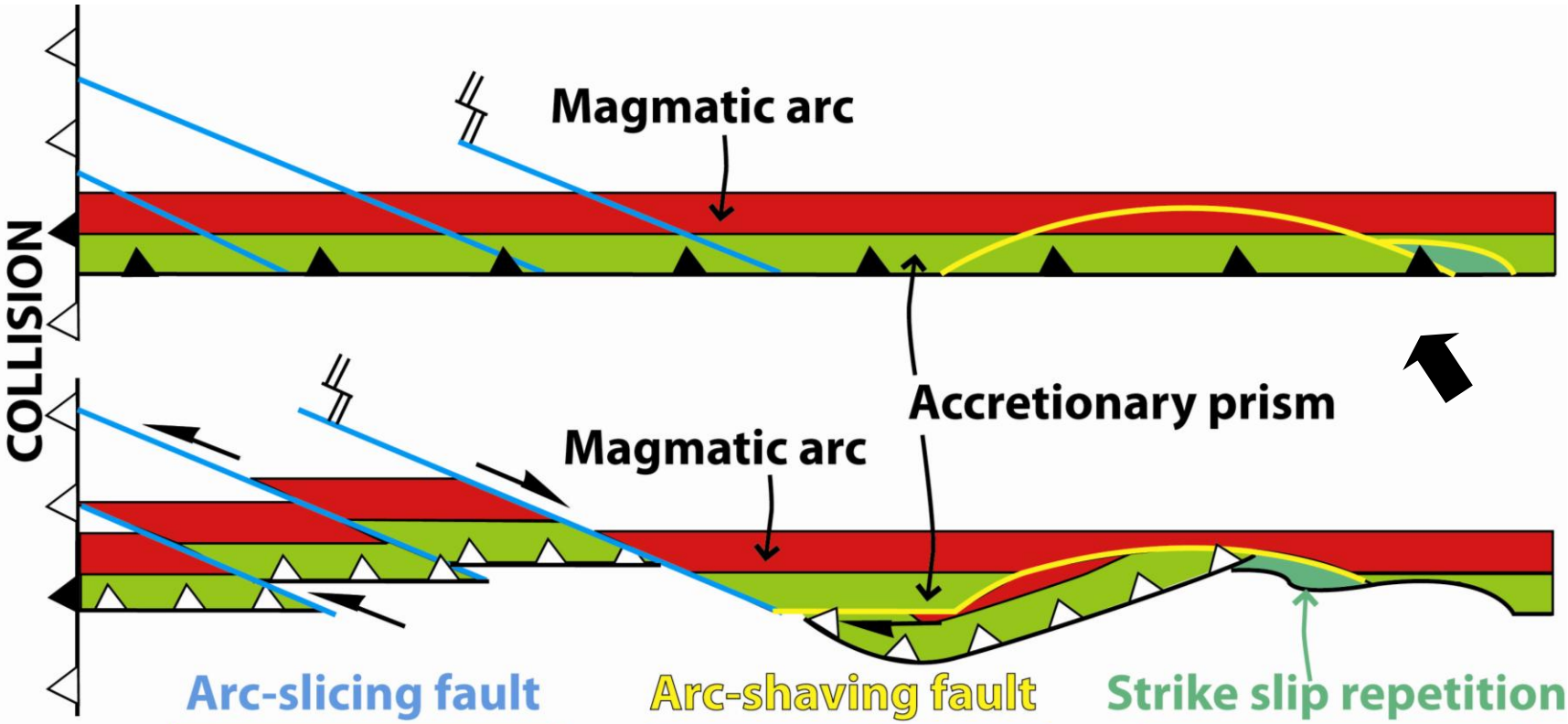
- Polarity of the accretionary system

- Jump outward during growing of the accretionary system

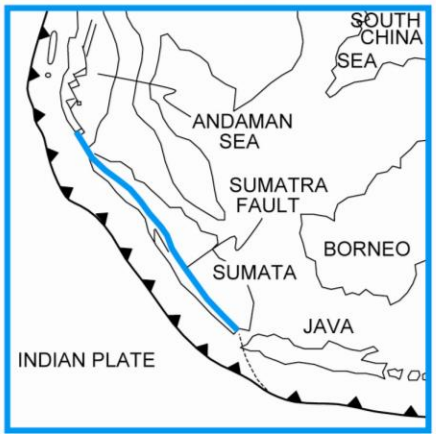




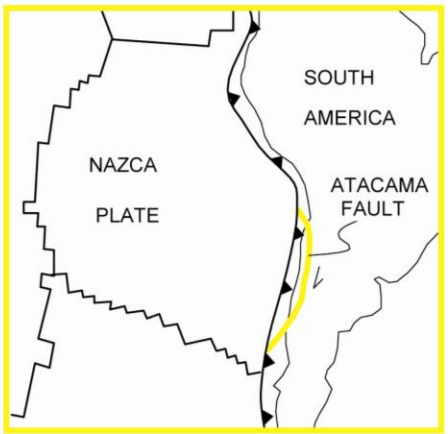
How accretionary systems are deformed during their formations?



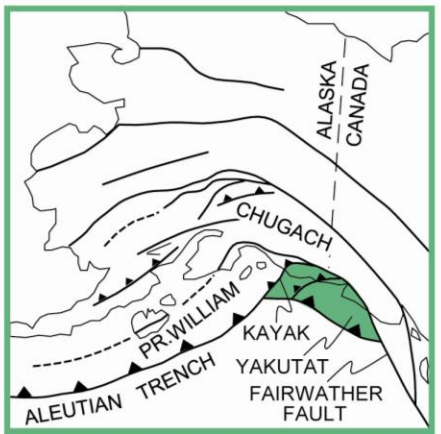
Arc-slicing fault



Arc-shaving fault

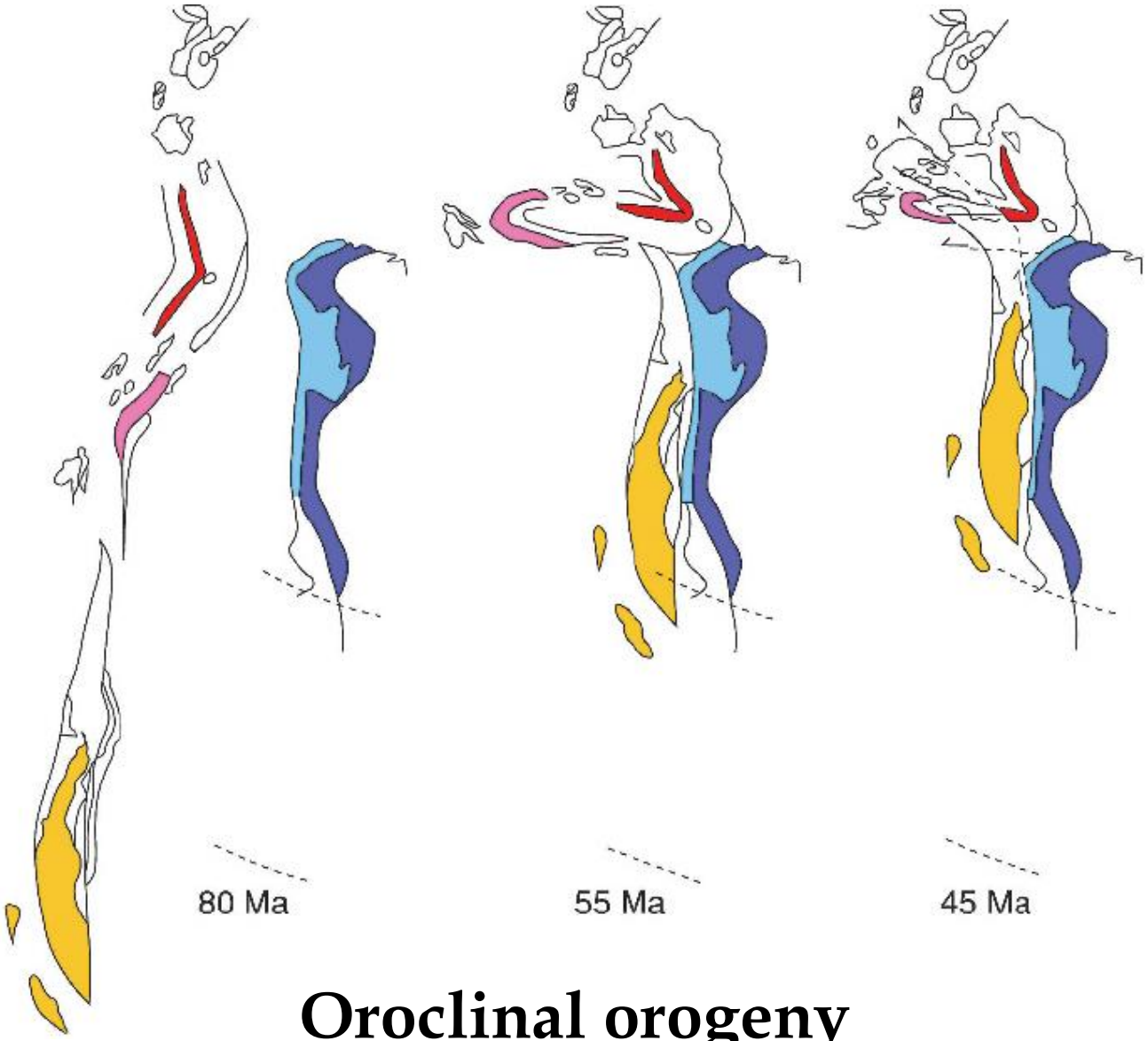


Strike slip repetition



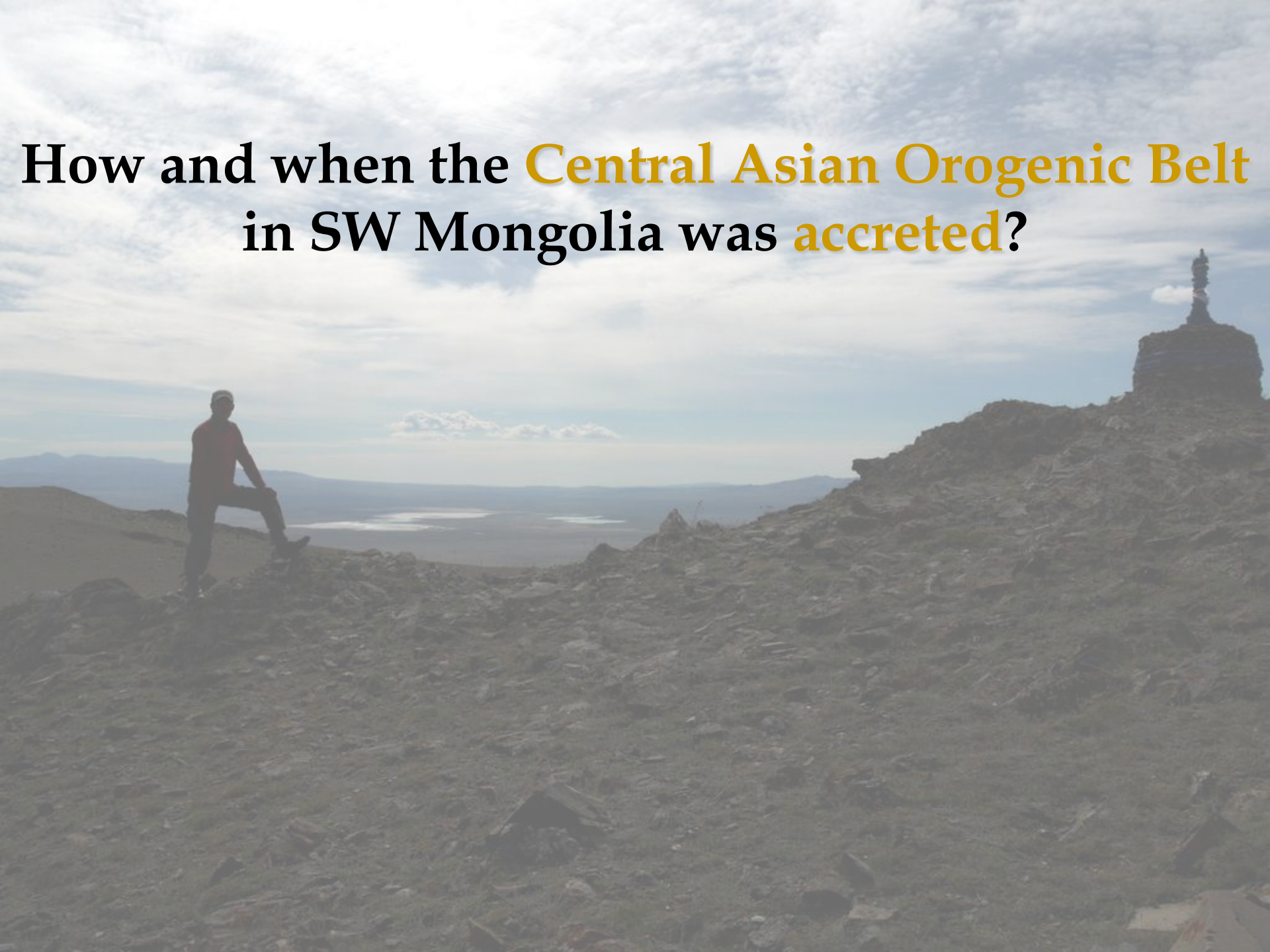
(Hamilton, 1979 - modified from Natal'in and Şengör (2005)

How accretionary systems are deformed during their formations?



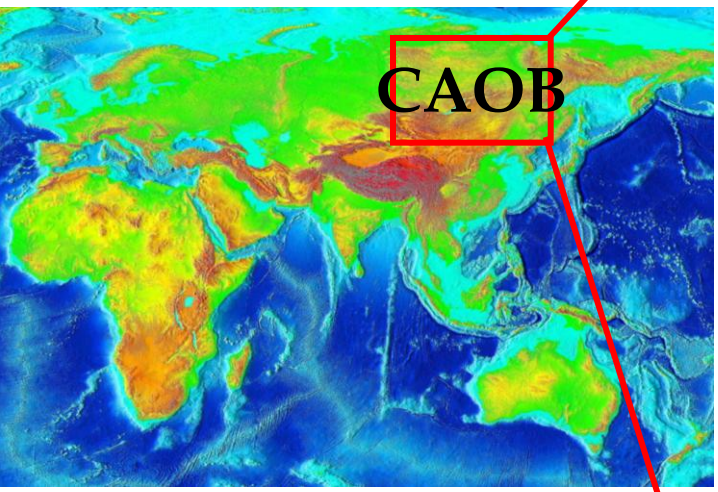
Oroclinal orogeny

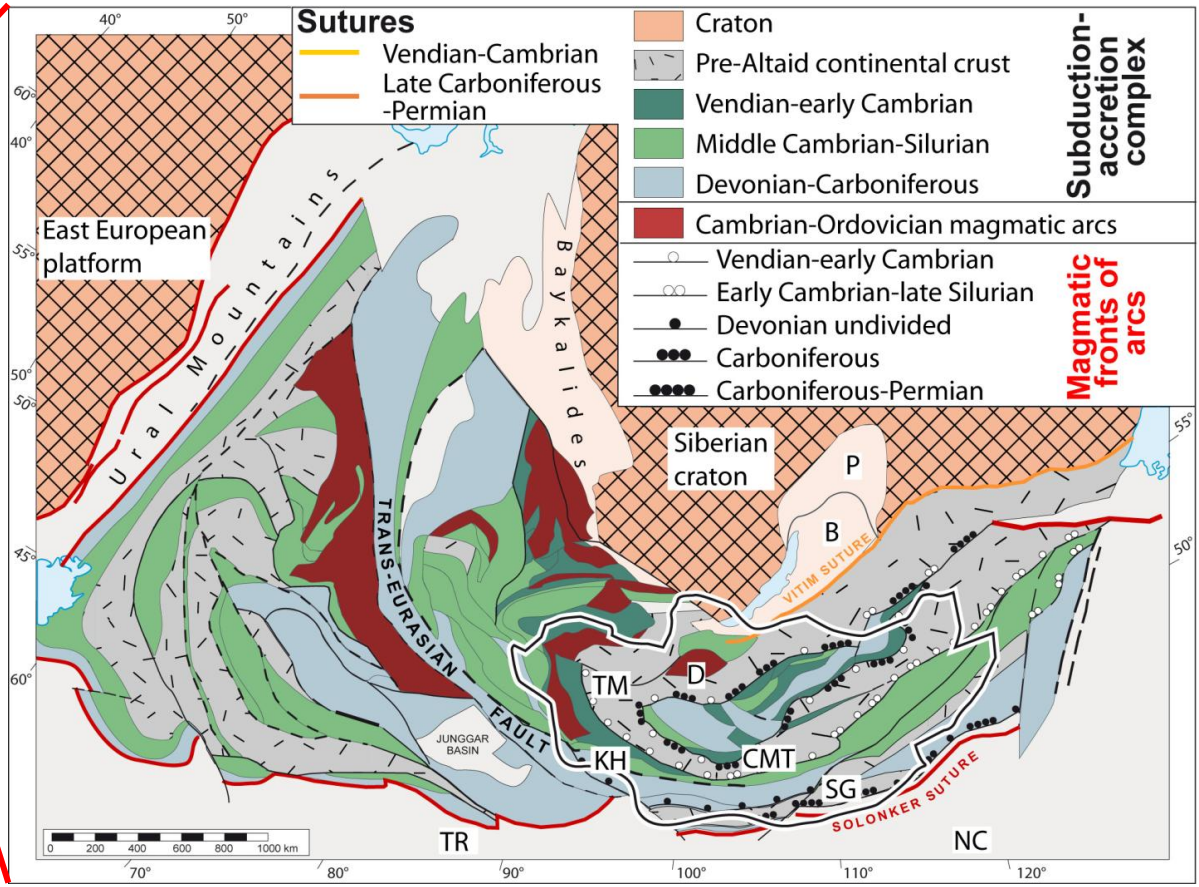
modified from Johnston (2001) in Van der Voo (2004)



How and when the Central Asian Orogenic Belt in SW Mongolia was accreted?

Geological Map of the Central Asian Orogenic Belt

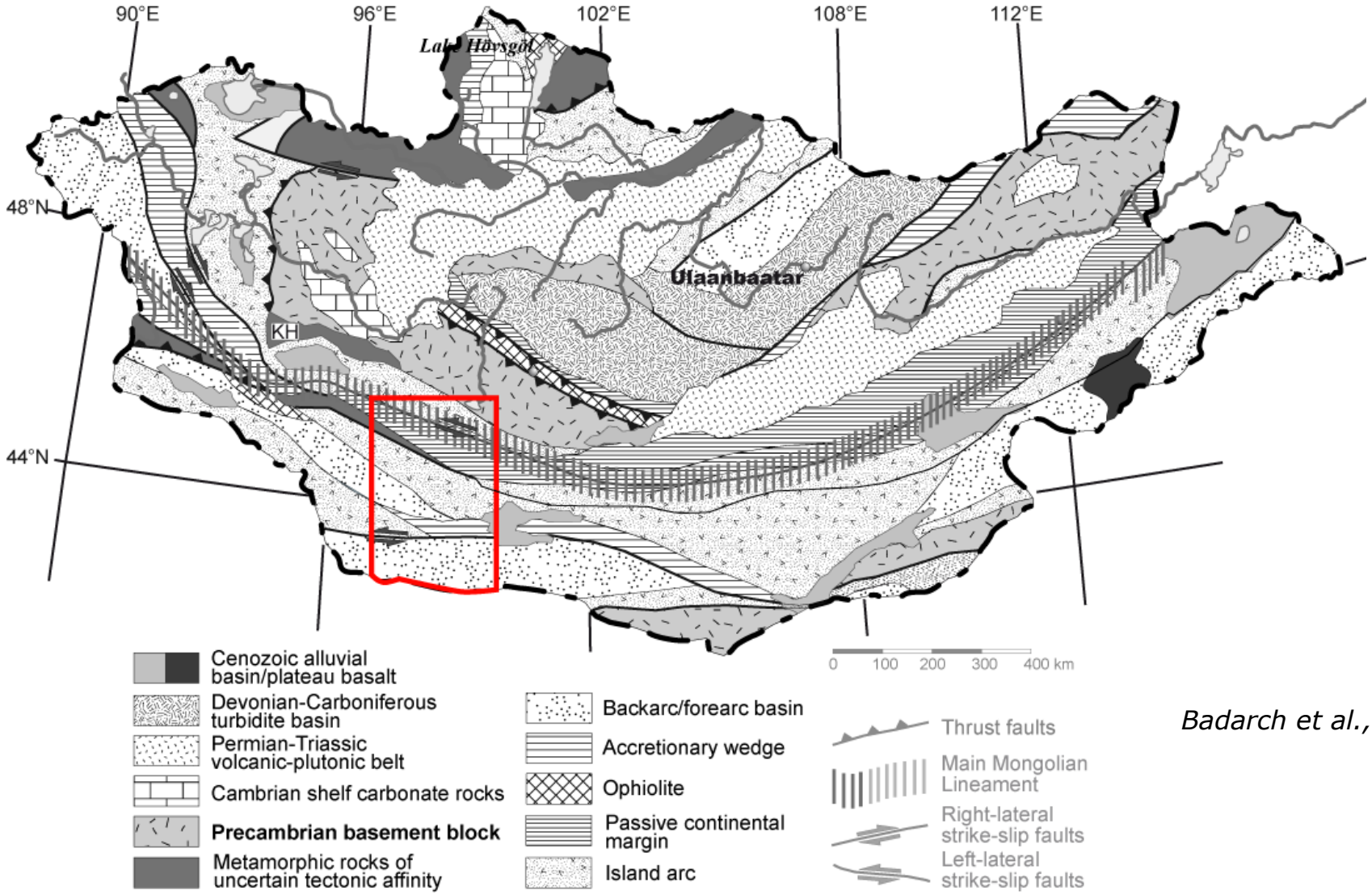




Modified from Şengör et al., 1993

Orogenic System bounded by the Siberian, Tarim and North China Cratons

Tectonostratigraphic terrane map of Mongolia

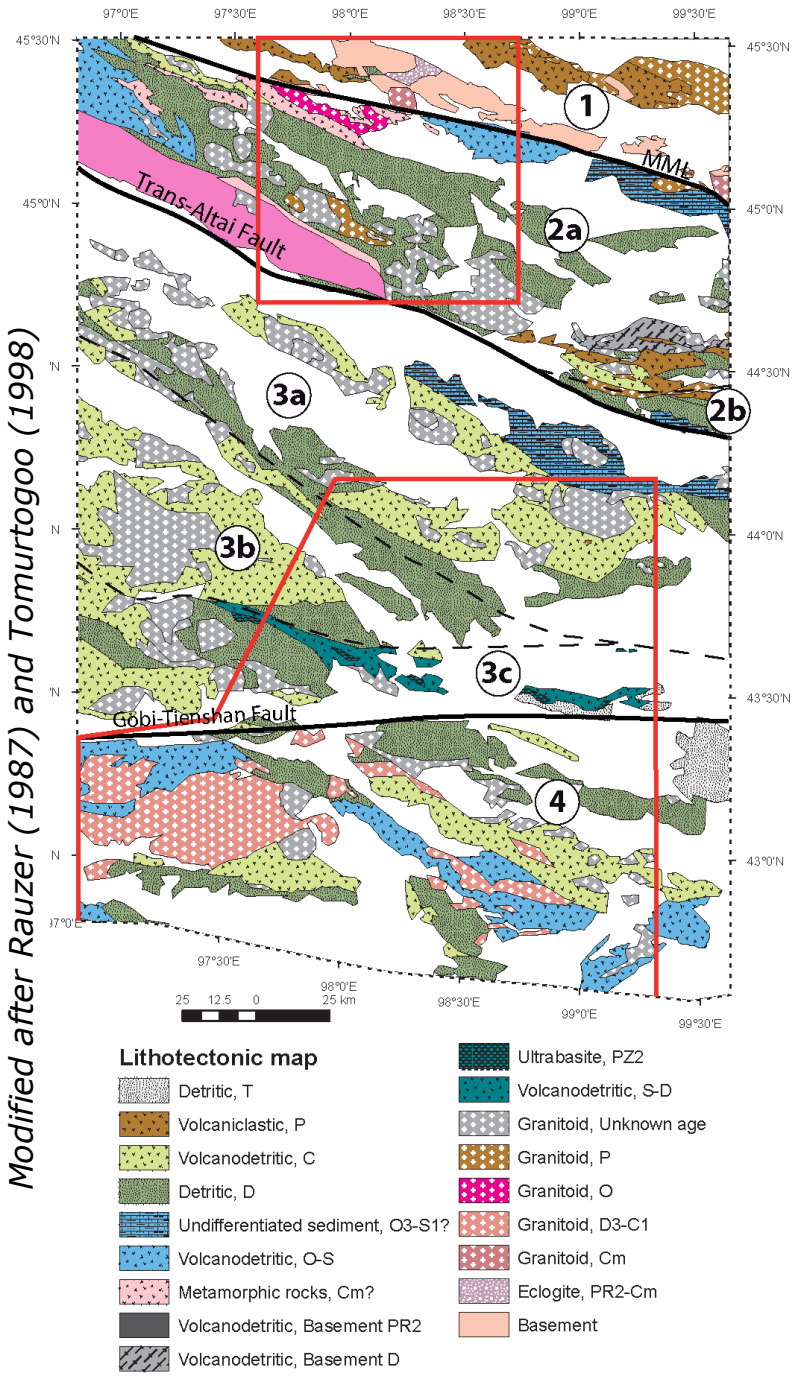


Badarch et al., 2002

Terranes: fault-bounded assemblage or fragment that is characterized by a distinctive geologic history that differs from that of adjacent terranes *(Badarch et al., 2002)*.

The Main Mongolian Lineament or Ikh Bogd Fault

Geological Map of SW Mongolia



Modified after Rauzer (1987) and Tomurtogoo (1998)

Redefine the **lithotectonic** zonation in an unified theory using U-Pb zircon **dating**

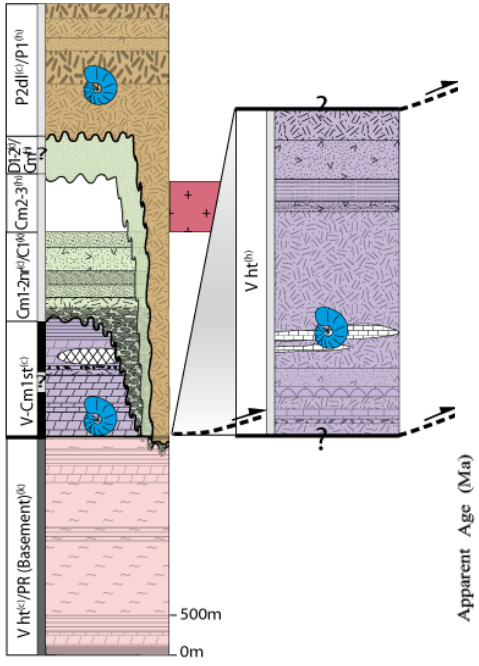
Tectonic evolution using **structural** geology, **Ar-Ar** and U-Pb zircon **dating**

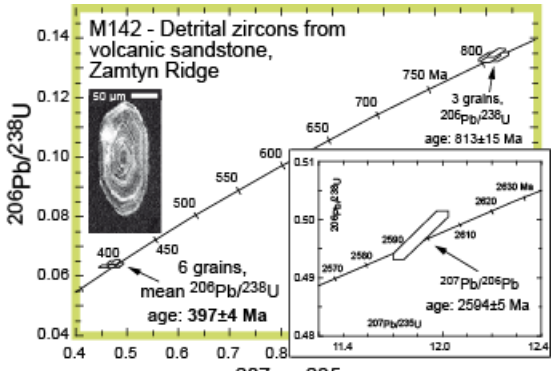
Geodynamic evolution of each zone

Review of **existing geodynamic models**

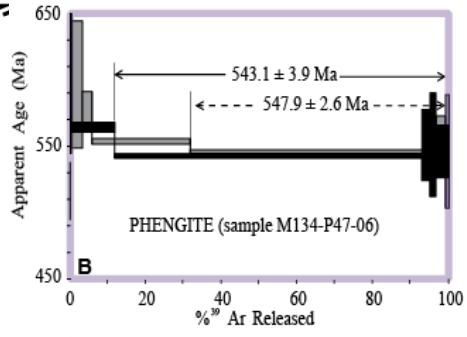
New model of **accretion** through the Paleozoic

Lake Zone

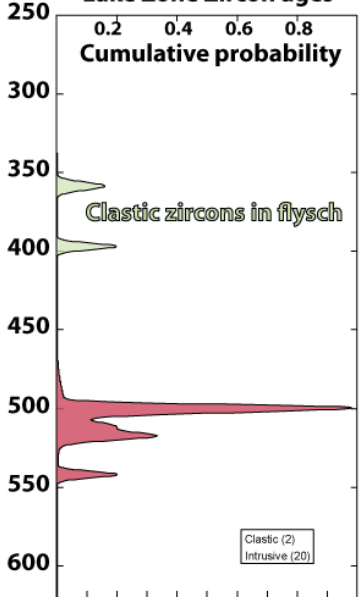




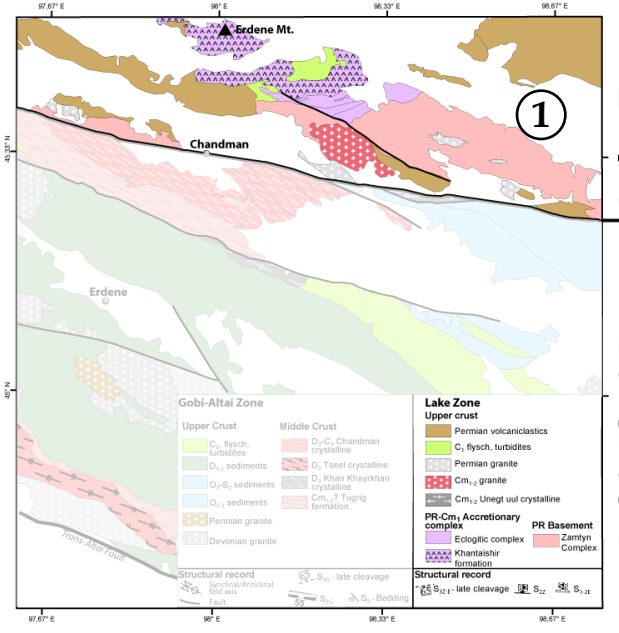
Late Devonian Flysch



Early Cambrian exhumation of a subduction complex

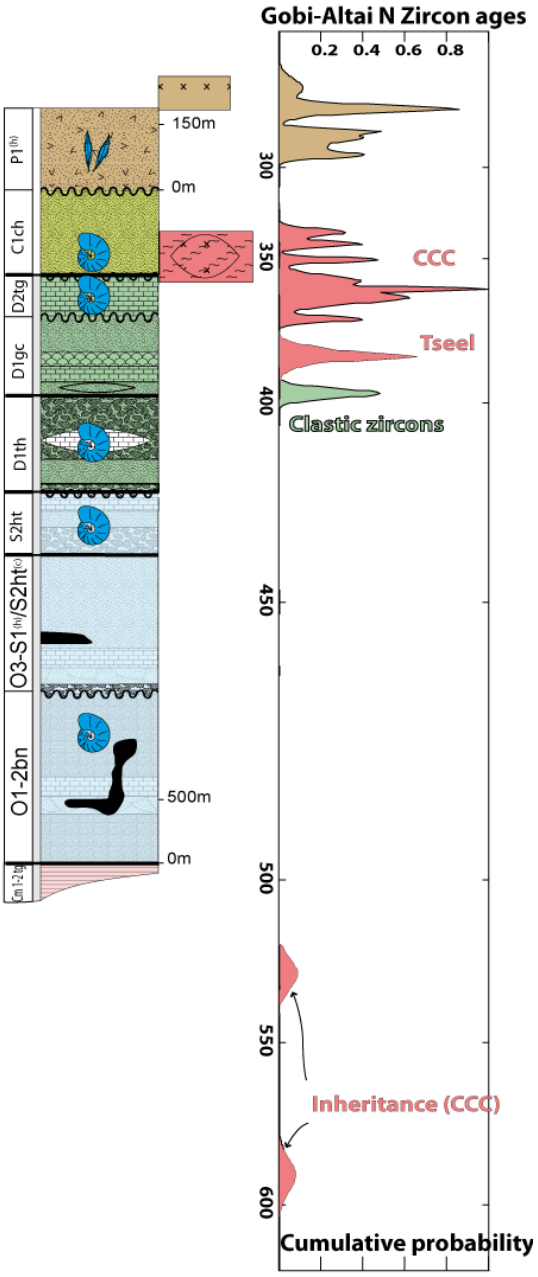


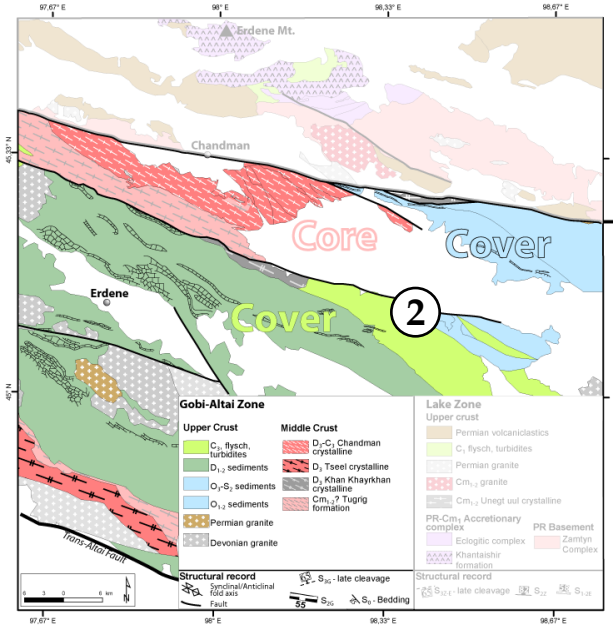
Ca. **900 Ma** basement



Lake Zone
Eclogitized Cambrian passive margin of a Cambrian Oceanic domain Neoproterozoic basement

Gobi-Altai Zone



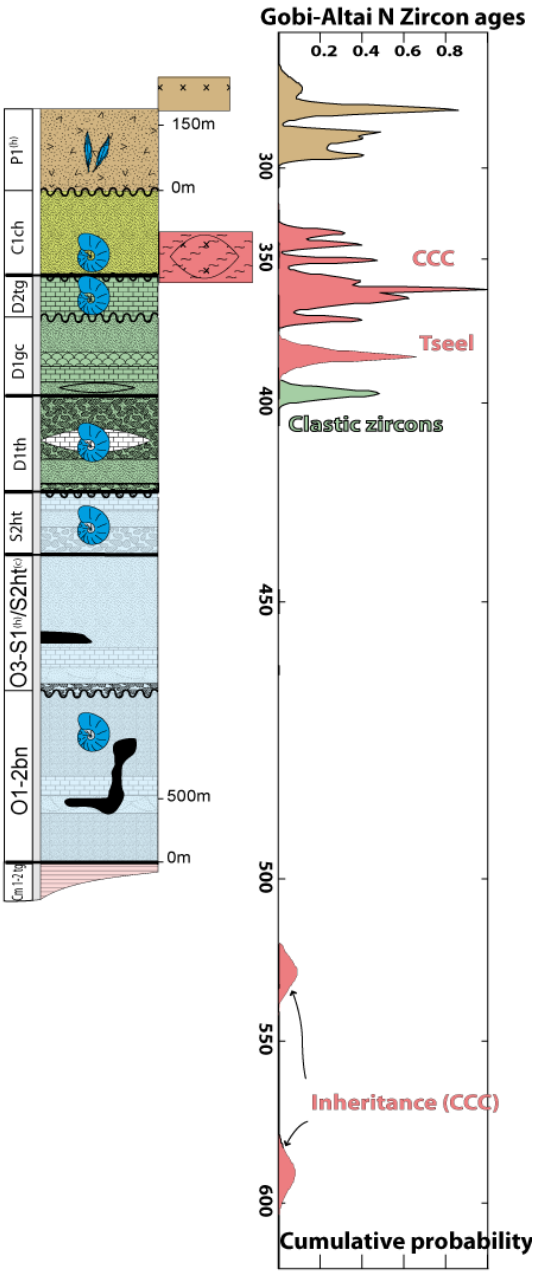


Gobi-Altai Zone

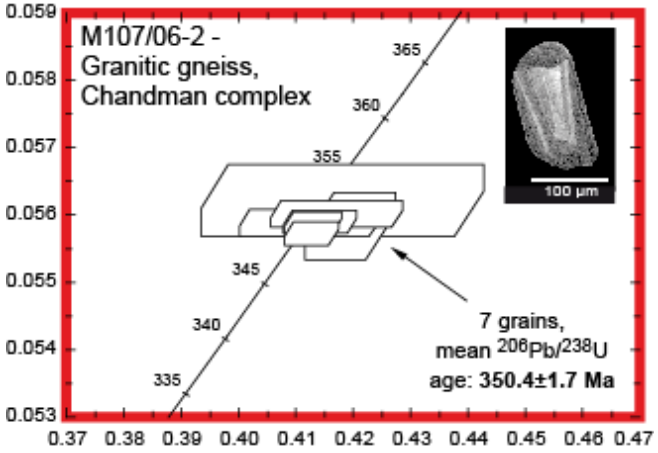
Late Devonian- Early Carboniferous
Japan-type of arc
Siluro-Devonian passive margin
Precambrian basement

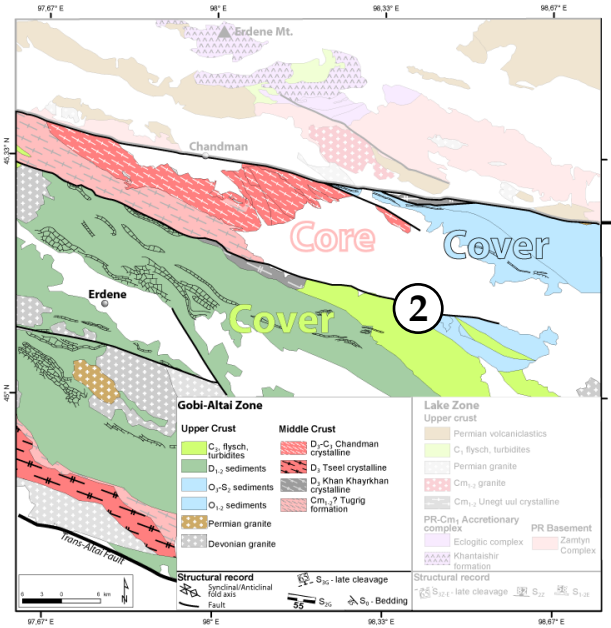

Lower Devonian bioherms

Gobi-Altai Zone



ca. 360 Ma, magmatic arc (CCC)





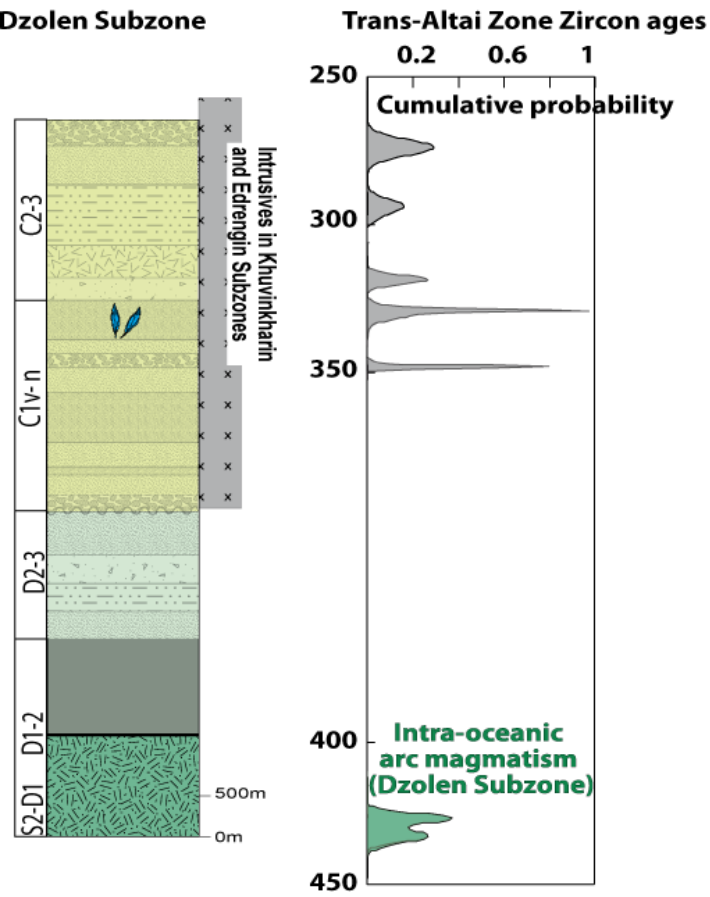
Lake Zone

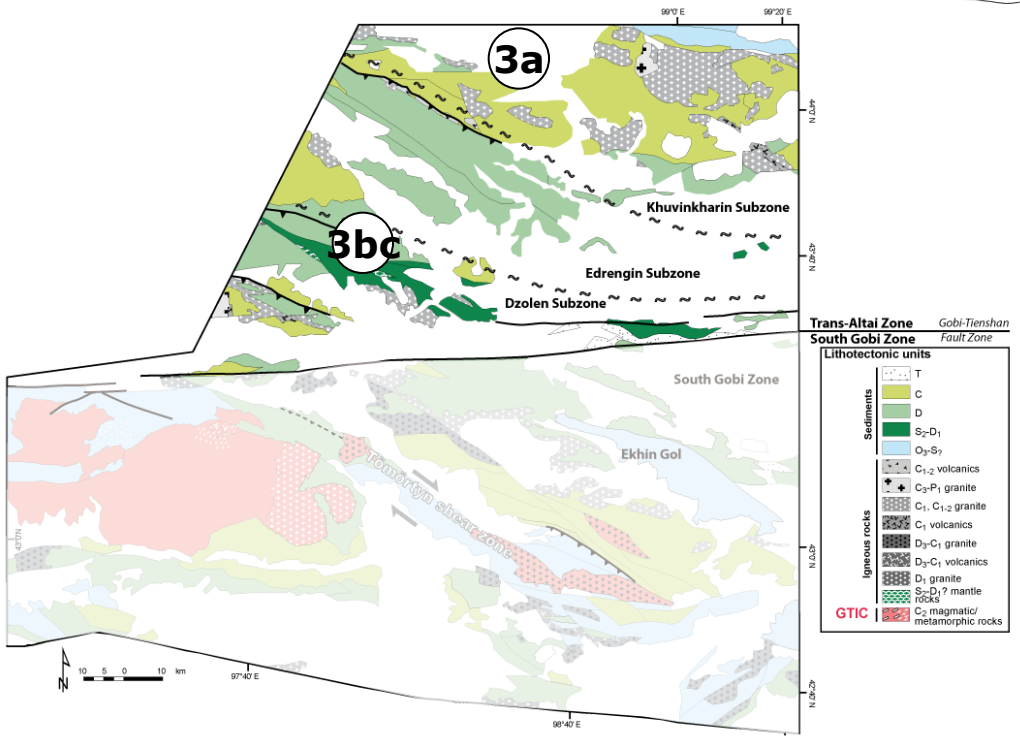
Gobi-Altai Zone

Gobi-Altai Zone

Late Devonian- Early Carboniferous
Japan-type of arc
Siluro-Devonian passive margin
Precambrian basement

Trans-Altai Zone





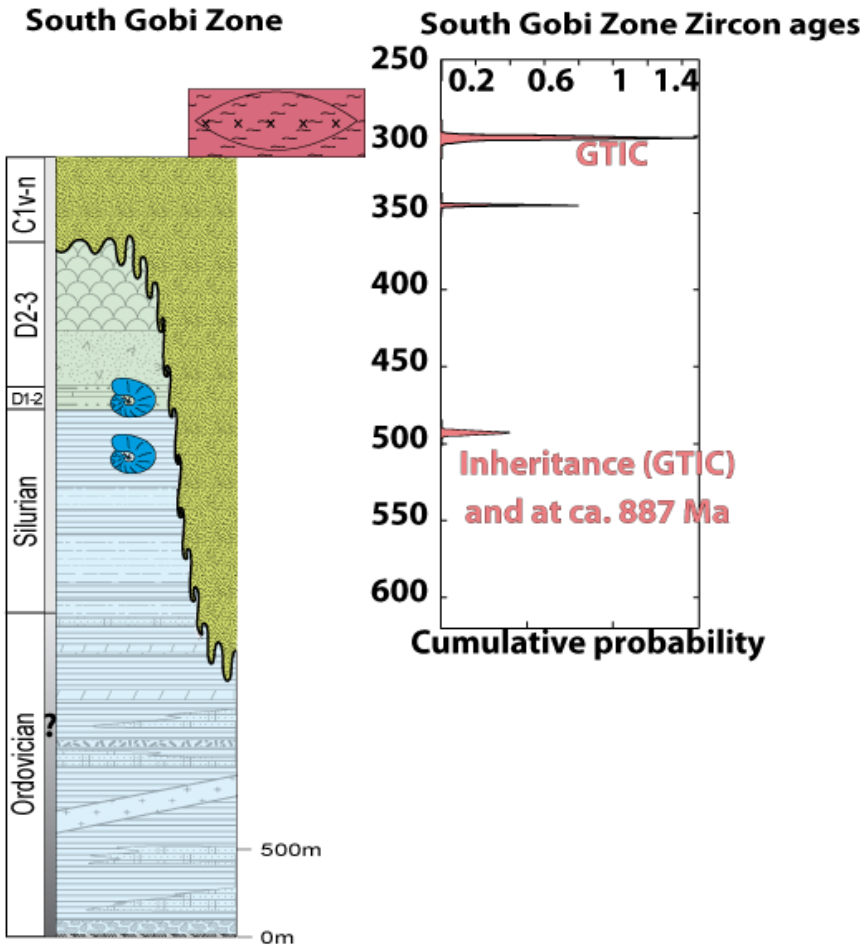
Trans-Altai Zone

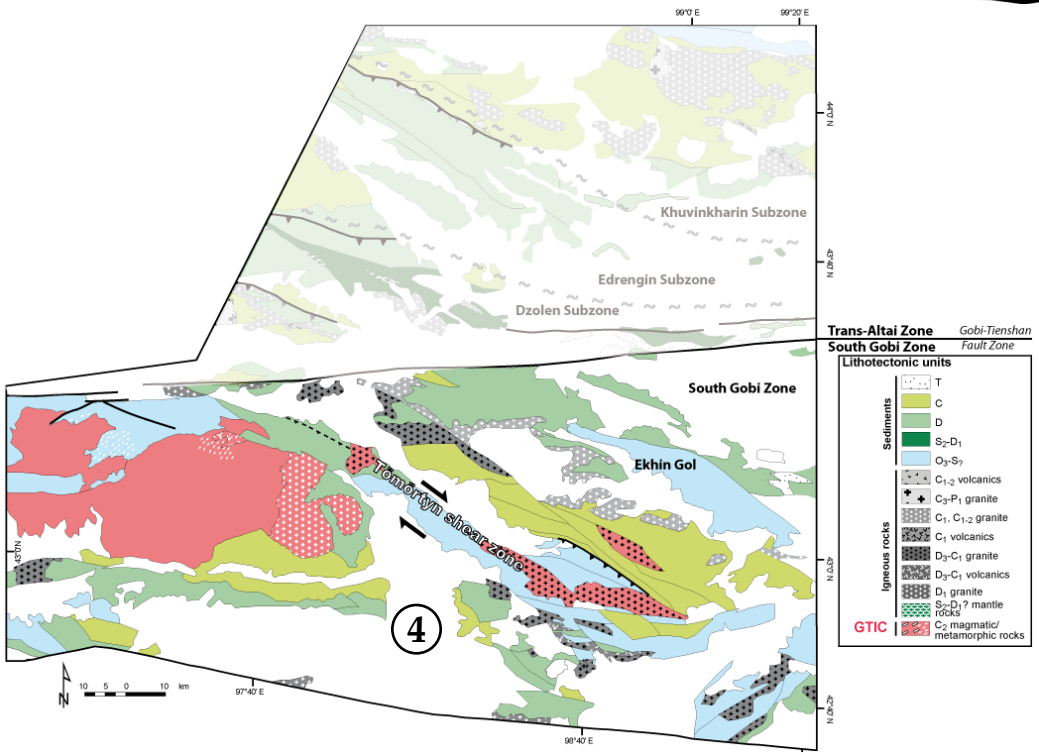
Early Devonian back arc in the North (3a Khuvinkharin Subzone)

Early Devonian island arc in the South 3bc

ca. 420 Ma oceanic basement

South Gobi Zone





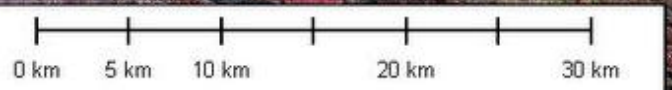
South Gobi Zone:

Late Carboniferous arc magmatism

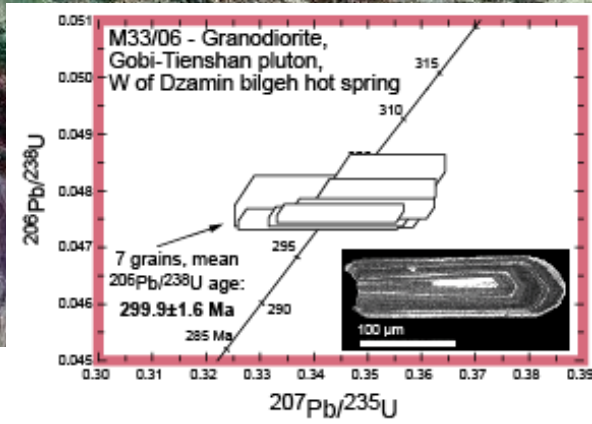
Ante-Silurian continental sedimentation

Precambrian continental basement

The Gobi-Tienshan Intrusive Complex

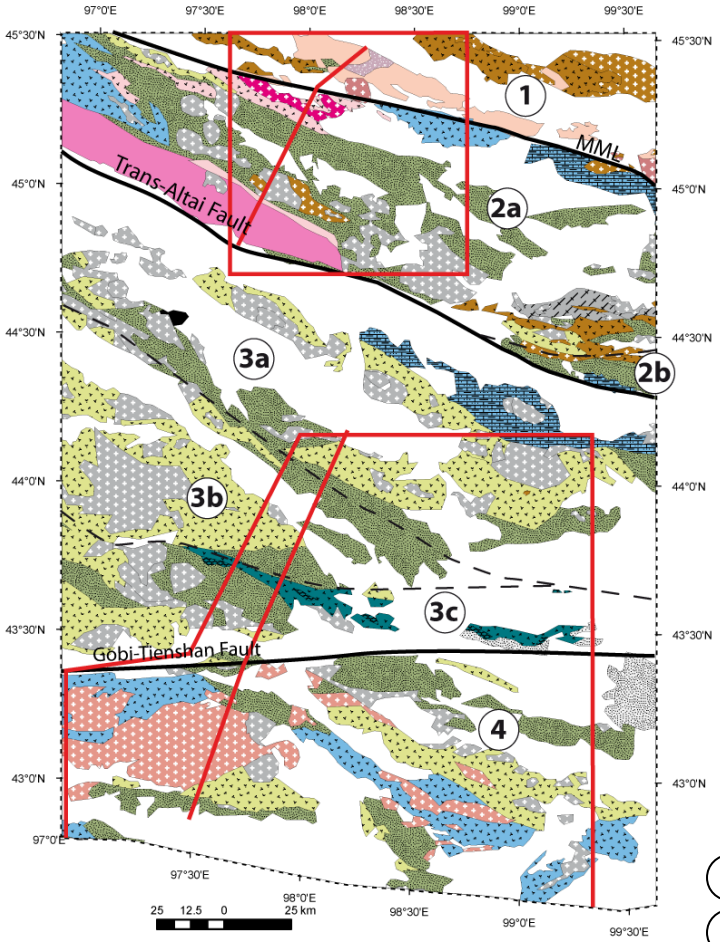


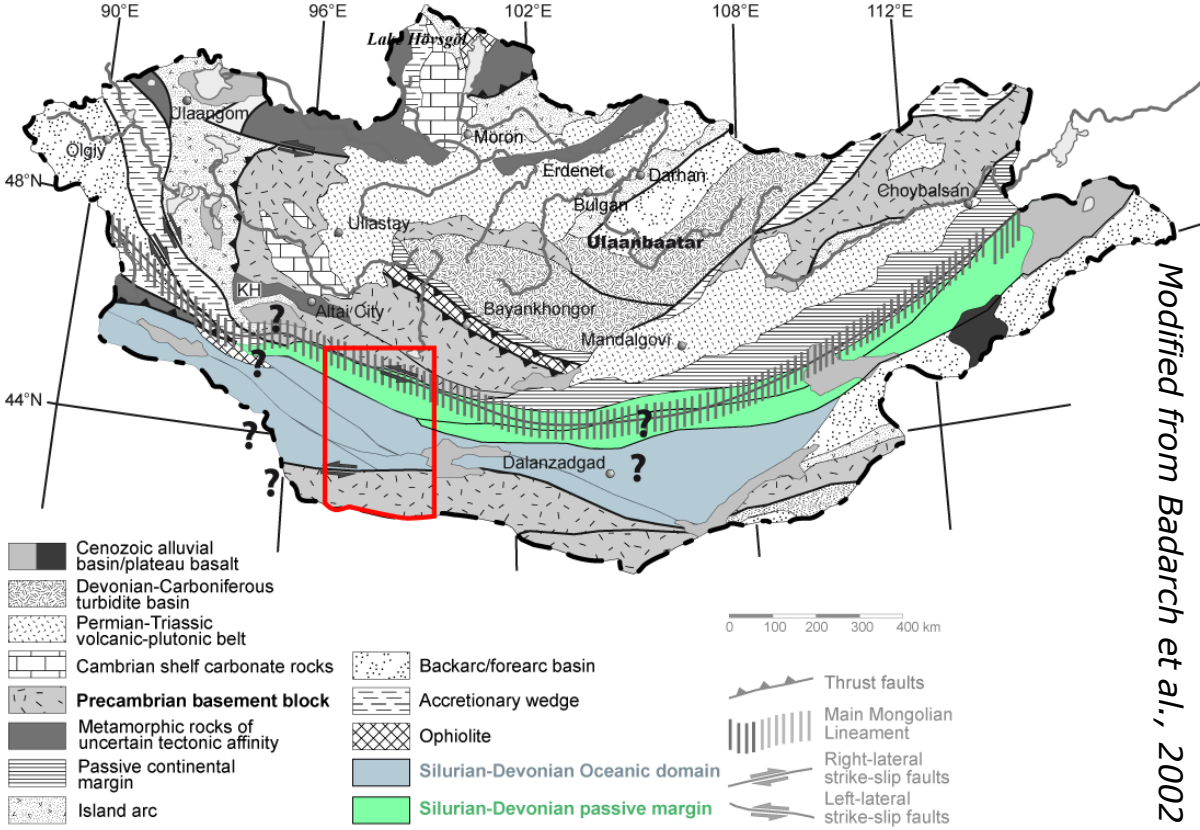
Arc magmatism at ca.300 Ma



The Gobi-Tienshan Intrusive Complex

Modification of the terrane model





Modified from Badarch et al., 2002

Lithotectonic map

- Detritic, T
- Volcaniclastic, P
- Volcanodetritic, C
- Detritic, D
- Undifferentiated sediment, O3-S1?
- Volcanodetritic, O-S
- Metamorphic rocks, Cm?
- **Arc crystalline complex (D3-C1)**
- Volcanodetritic, Basement D
- **Oceanic basement (ante-D1)**
- Volcanodetritic, S-D
- Granitoid, Unknown age
- Granitoid, P
- **Arc crystalline complex (D1-C3)**
- **Arc crystalline complex (C3)**
- Granitoid, Cm
- Eclogite, PR2-Cm
- **Proterozoic basement**

① **Lake Zone: Proterozoic continental basement**

② **Gobi-Altai Zone: Siluro-Devonian Passive margin**

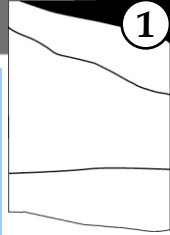
Trans-Altai Zone:

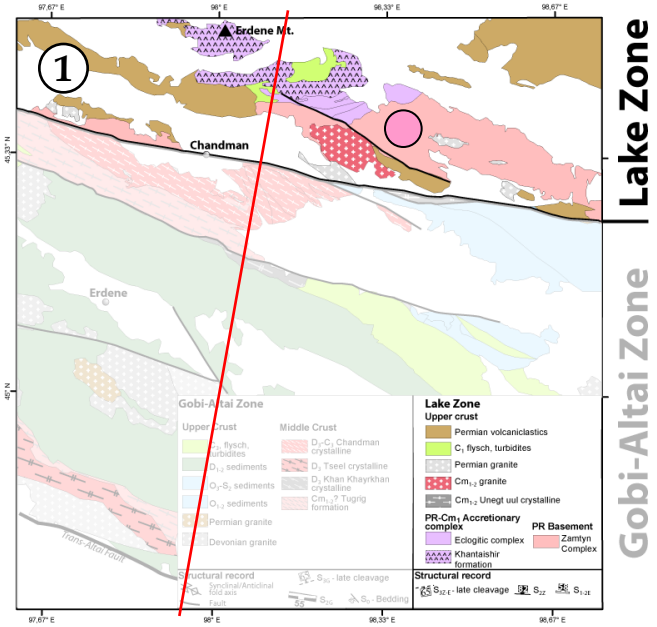
- **3a Back-arc,**
- **3bc Intra-oceanic arc**

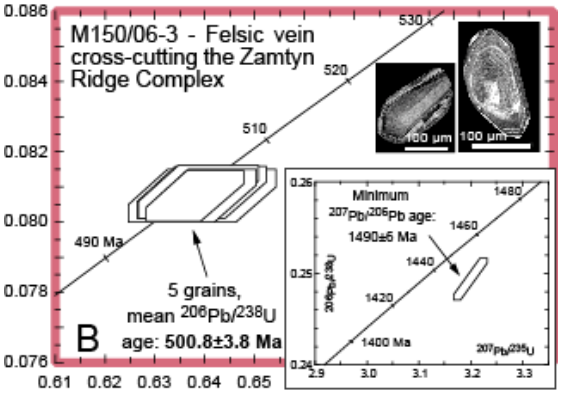
④ **South Gobi Zone: Proterozoic continental basement**

Lake Zone

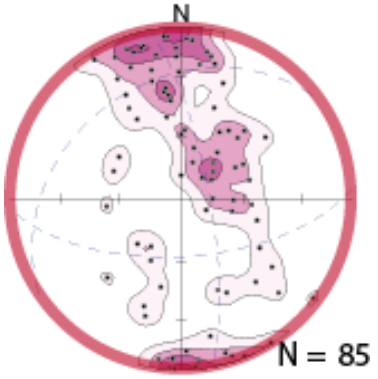
Lake Zone
Top to SW extensional shearing
Amphibolite facies



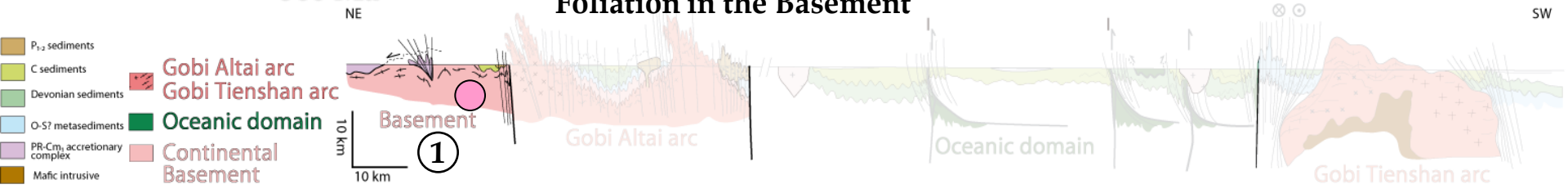




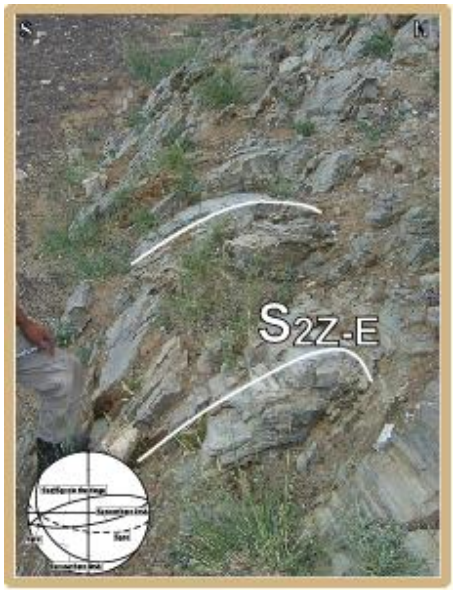
Event dated at *ca.* 500 Ma



Foliation in the Basement

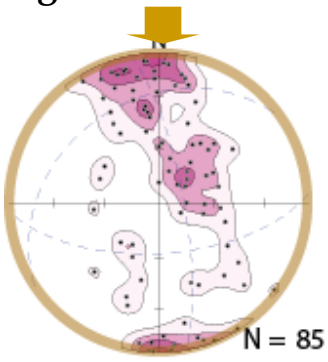


Lake Zone

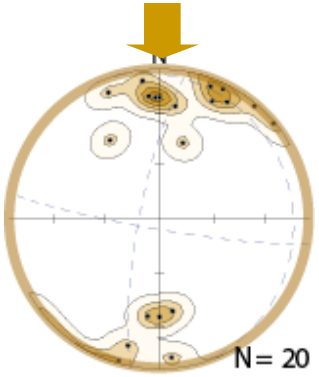


Upright buckle fold

Hinterland duplex

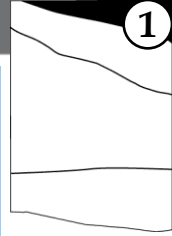


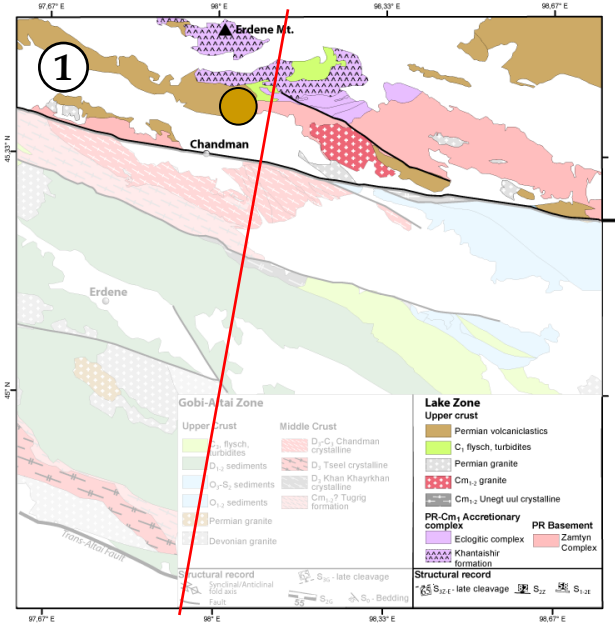
Foliation in basement

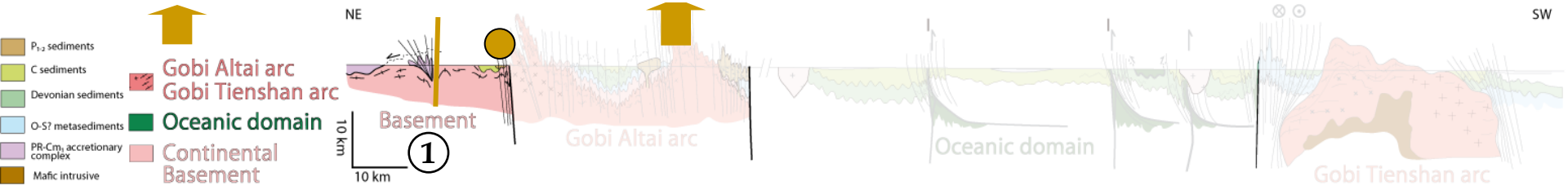


Late cleavage

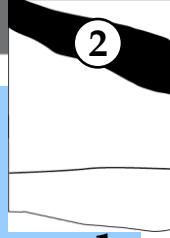
Lake Zone
N-S shortening
Post Lower Permian





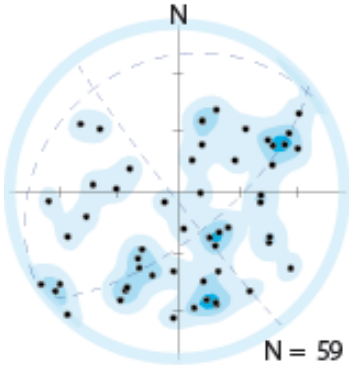


Gobi-Altai Zone

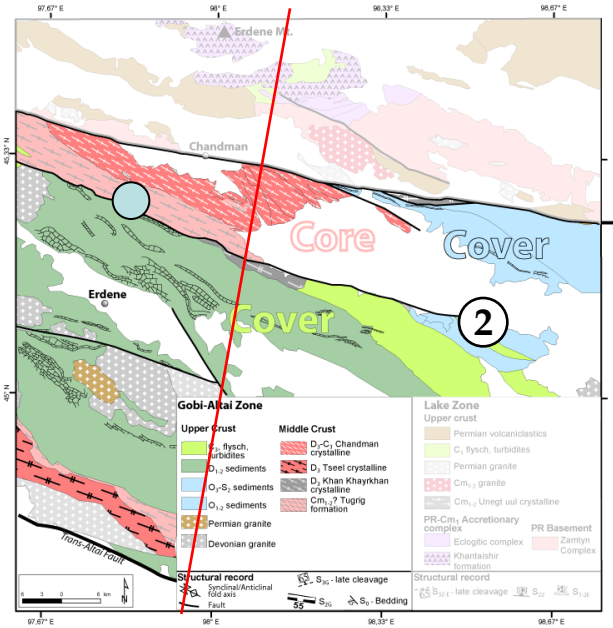


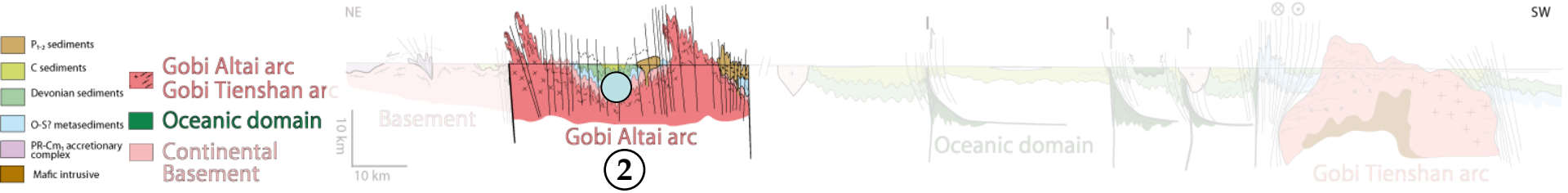
Gobi-Altai Zone
Vertical shortening event
Lower Ordovician not affected

Greenschist facies early fabric



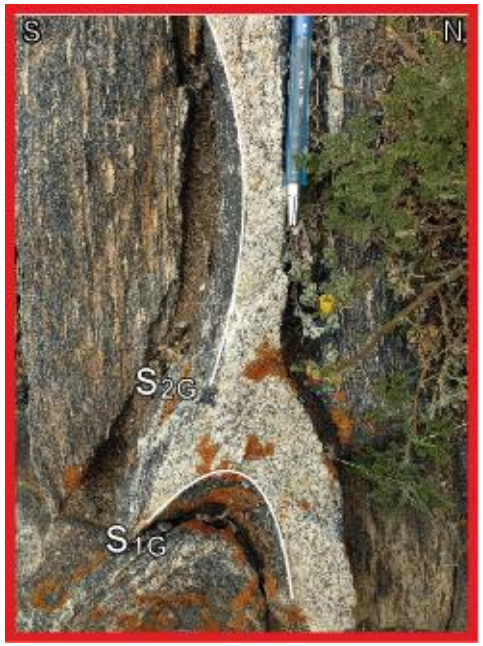
Relics of the early fabric





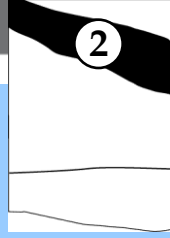
Gobi-Altai Zone

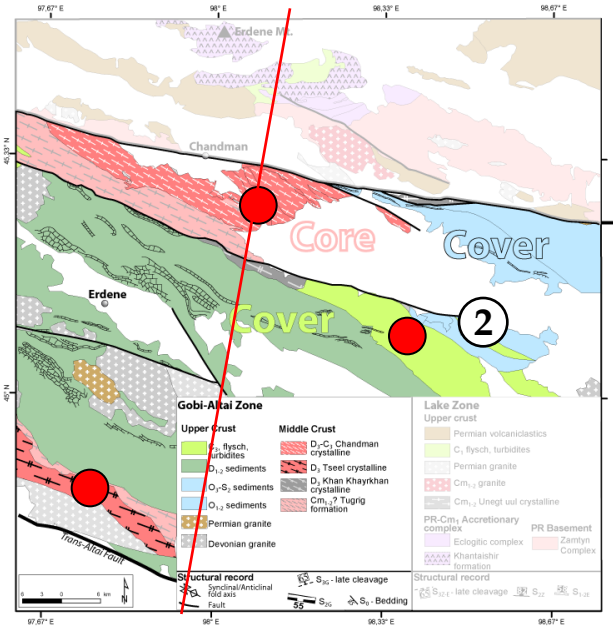
Crenulation cleavage

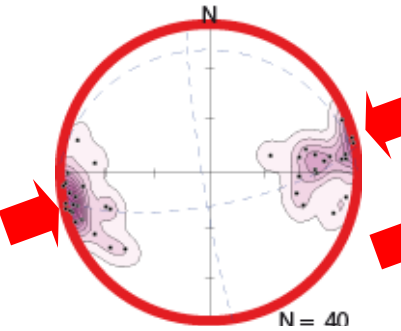


Magma collection

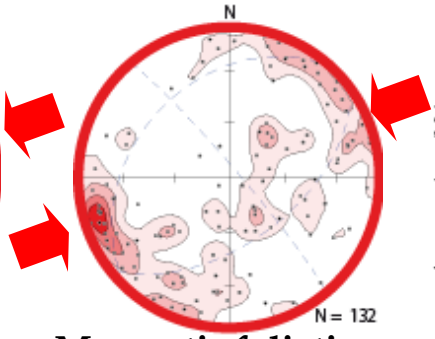
Gobi-Altai Zone
E-W shortening
Late Devonian-Early Carboniferous Compressive arc



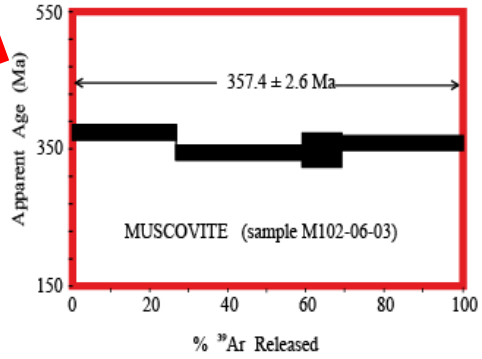


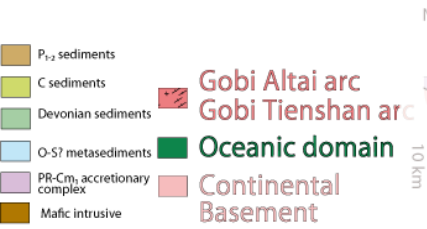


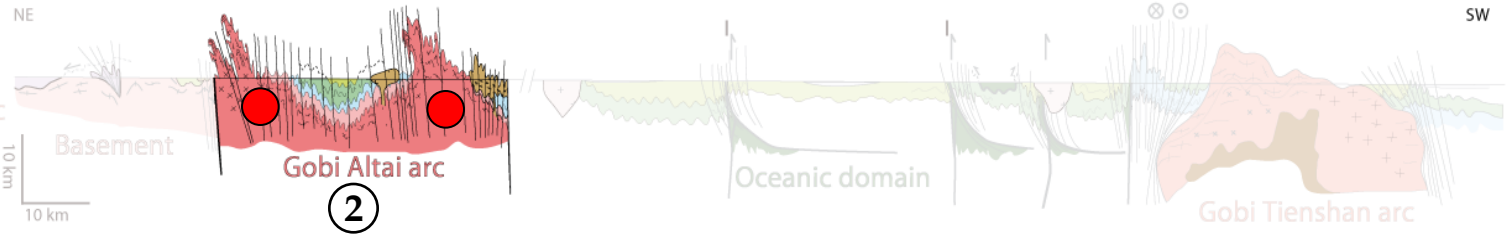
Metamorphic foliation



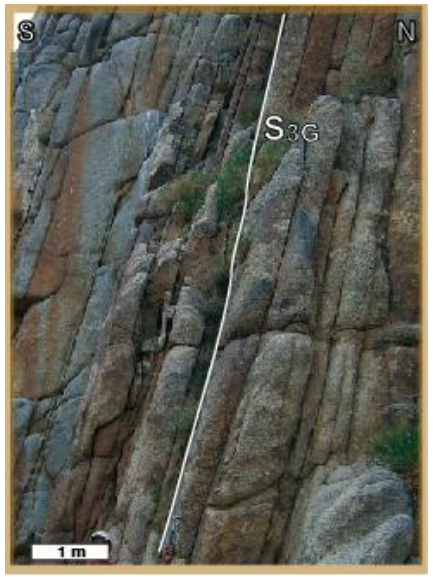
Magmatic foliation







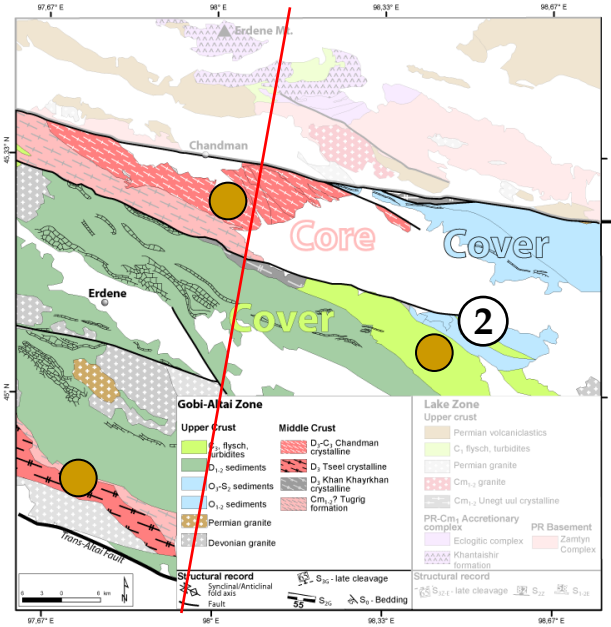
Gobi-Altai Zone

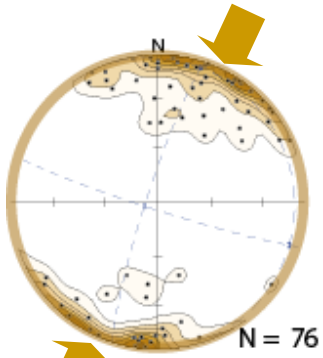


Spaced cleavage

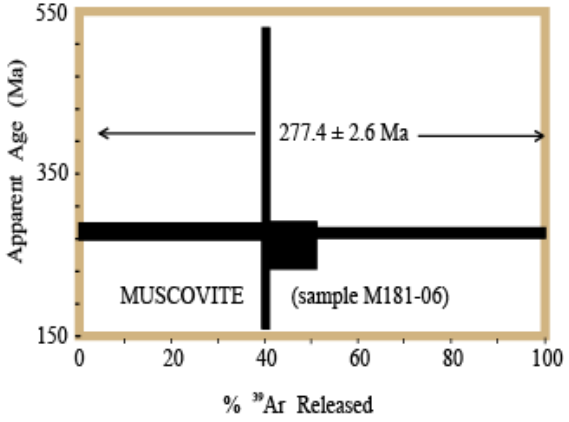
Cleavage refraction

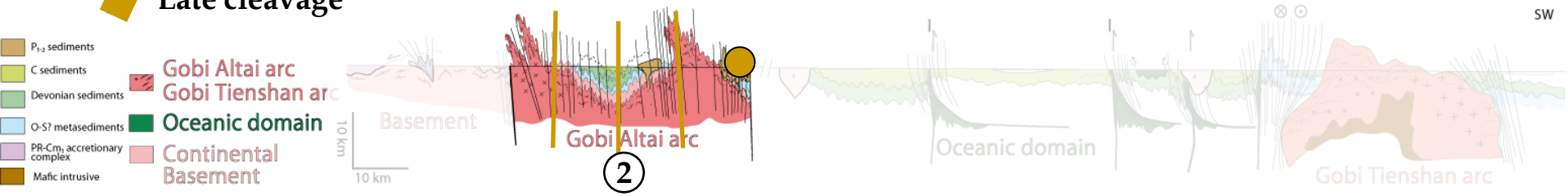
Gobi-Altai Zone
NNE-SSW shortening
Early Permian



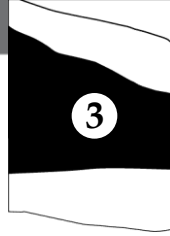


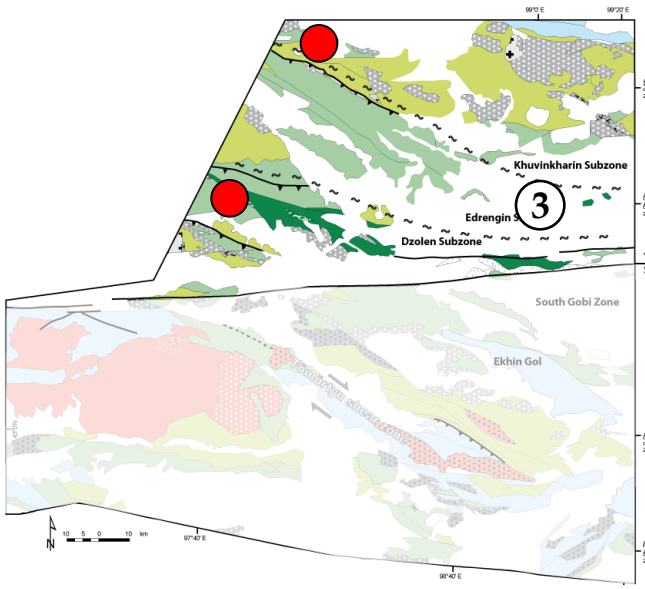
Late cleavage

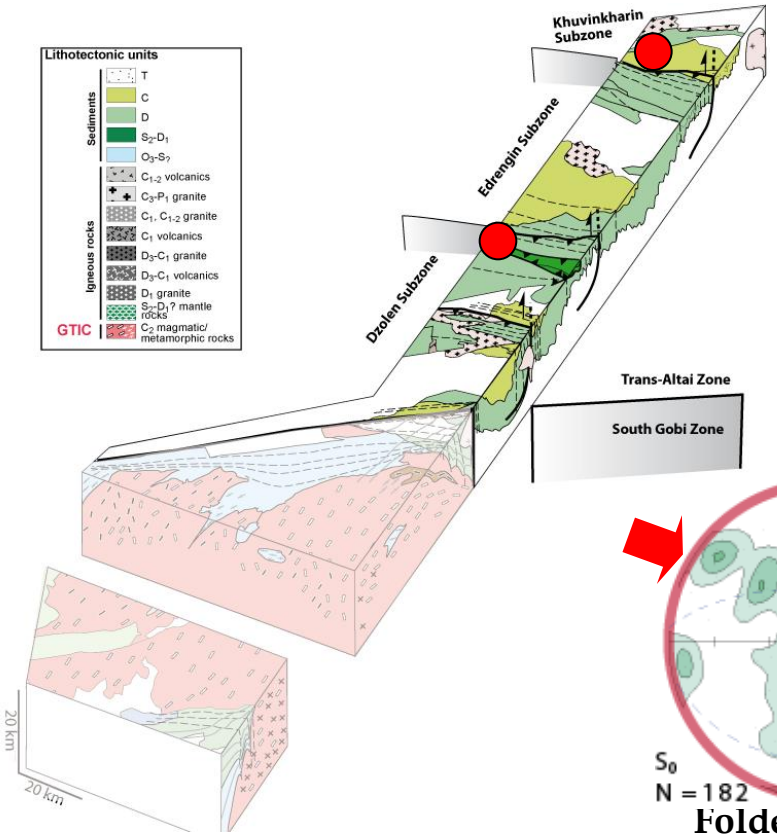


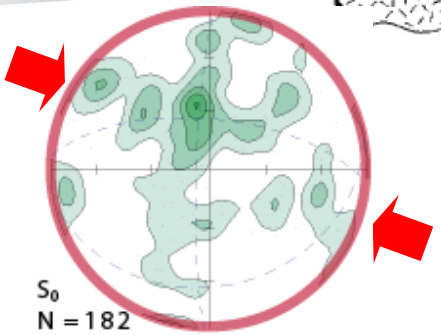


Trans-Altai Zone
E-W shortening
Nappe stacking
Late Devonian to Early Carboniferous

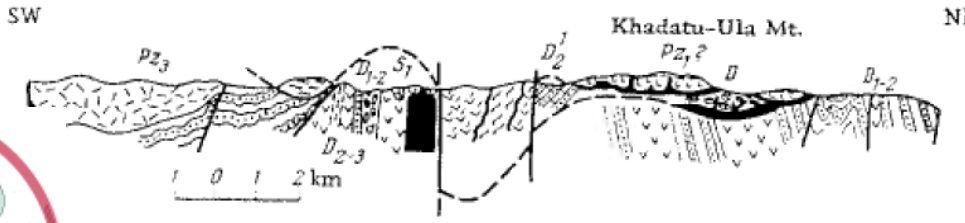




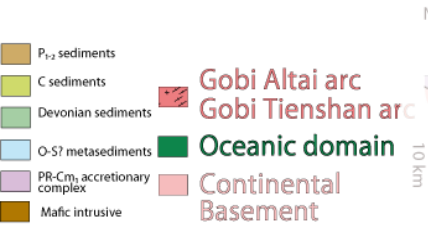


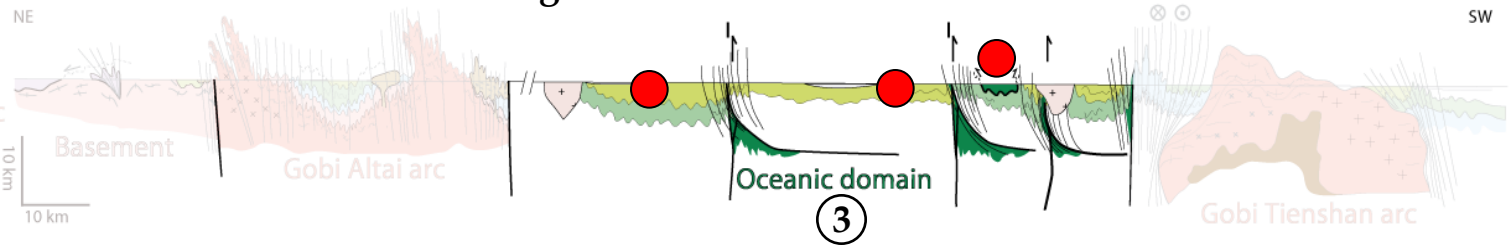


Folded bedding

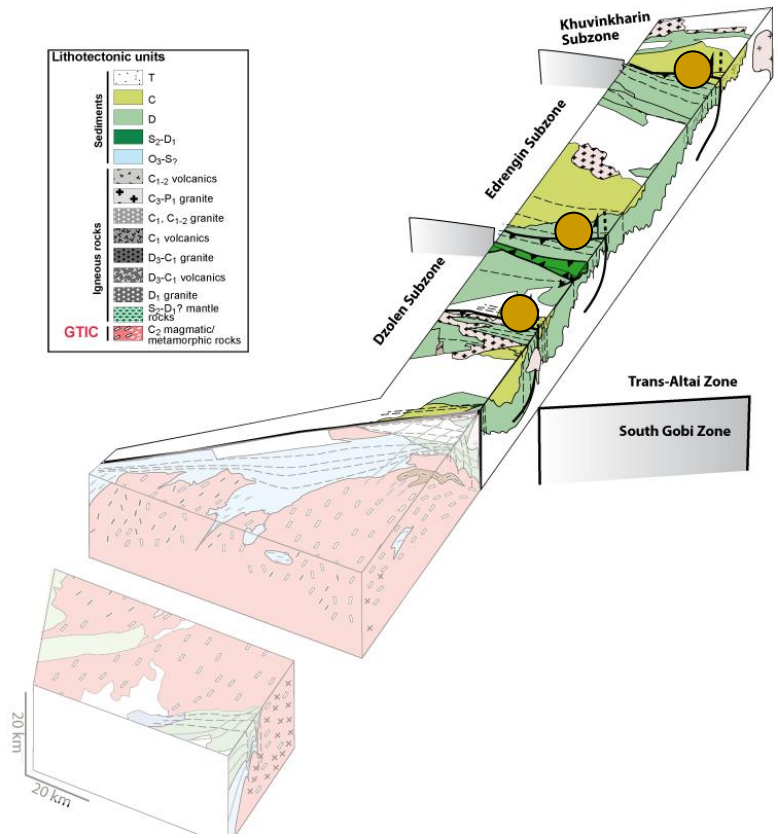


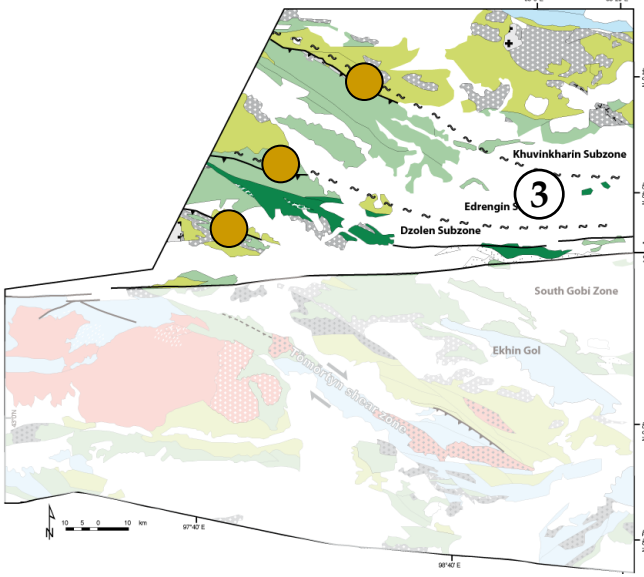
Late Devonian ophiolite thrusting
(*Zonenshain et al., 1975*)

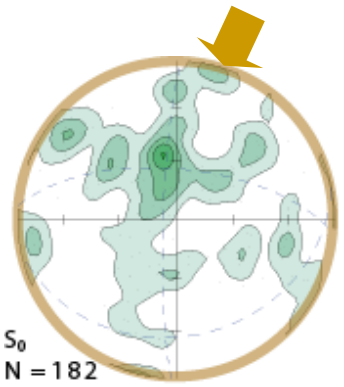




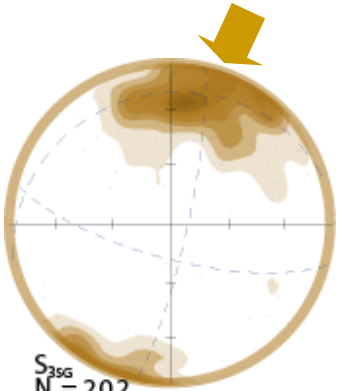
Trans-Altai Zone
NNE-SSW shortening
Deformation fronts
Active after Lower Trias



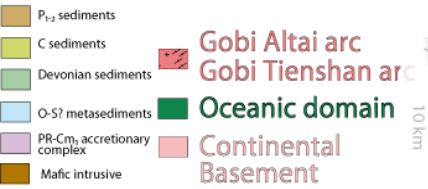


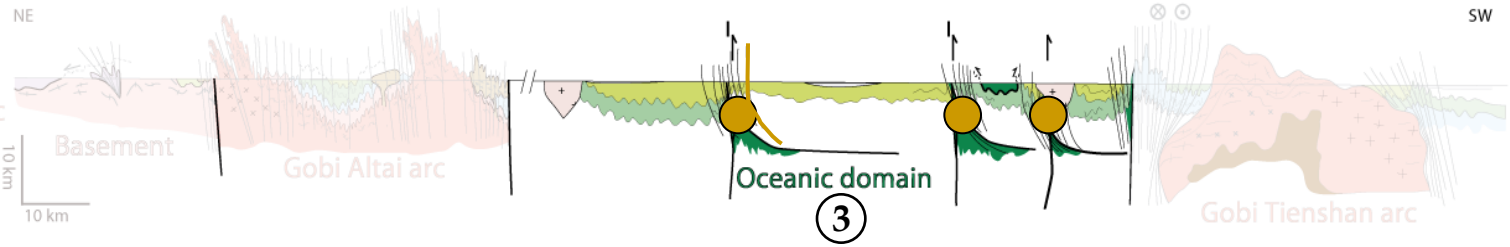


Folded bedding



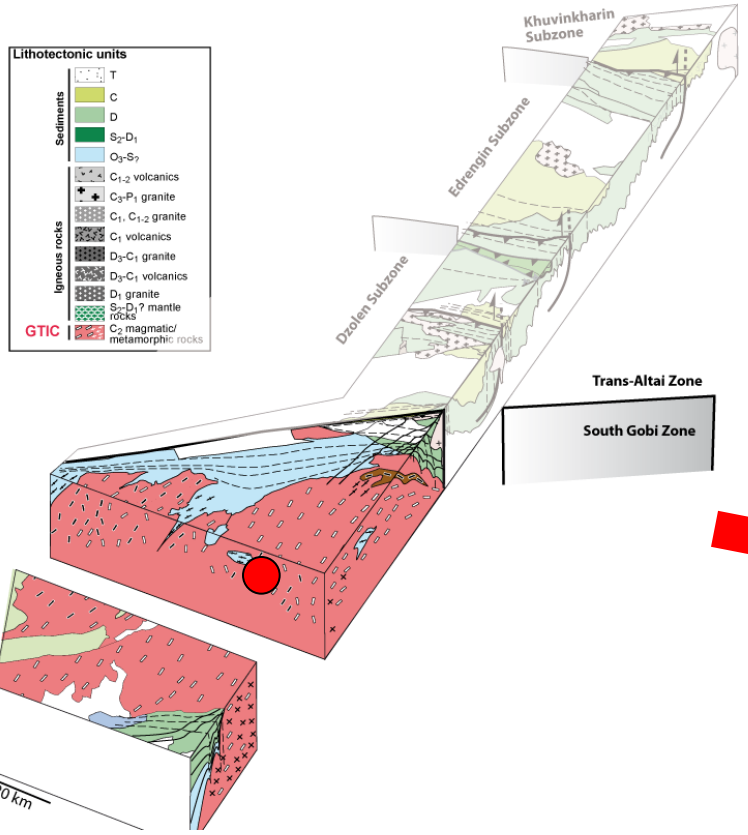
Late cleavage

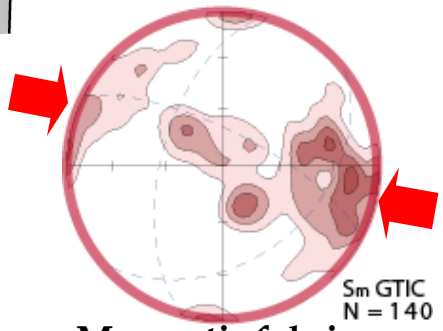




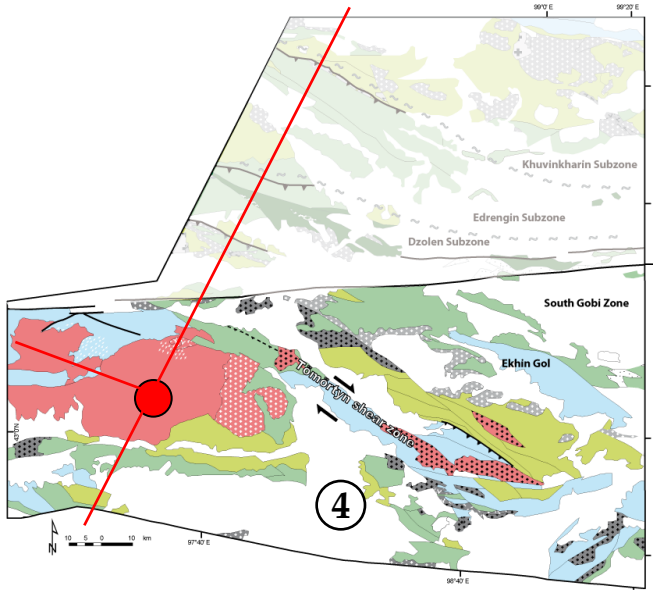
South Gobi Zone

Compressive arc emplacement
During ~E-W shortening
Late Carboniferous time

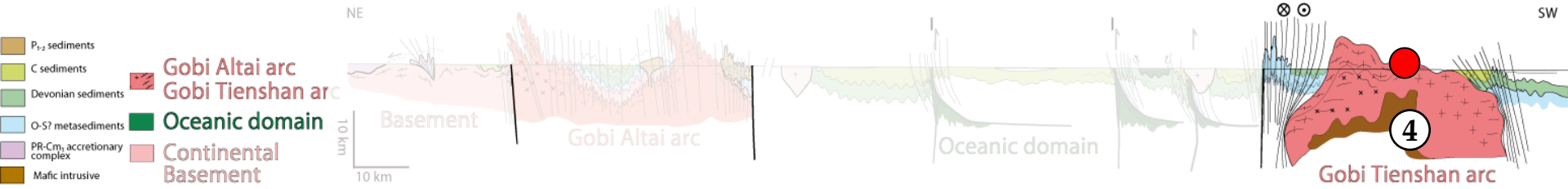




Magmatic fabric

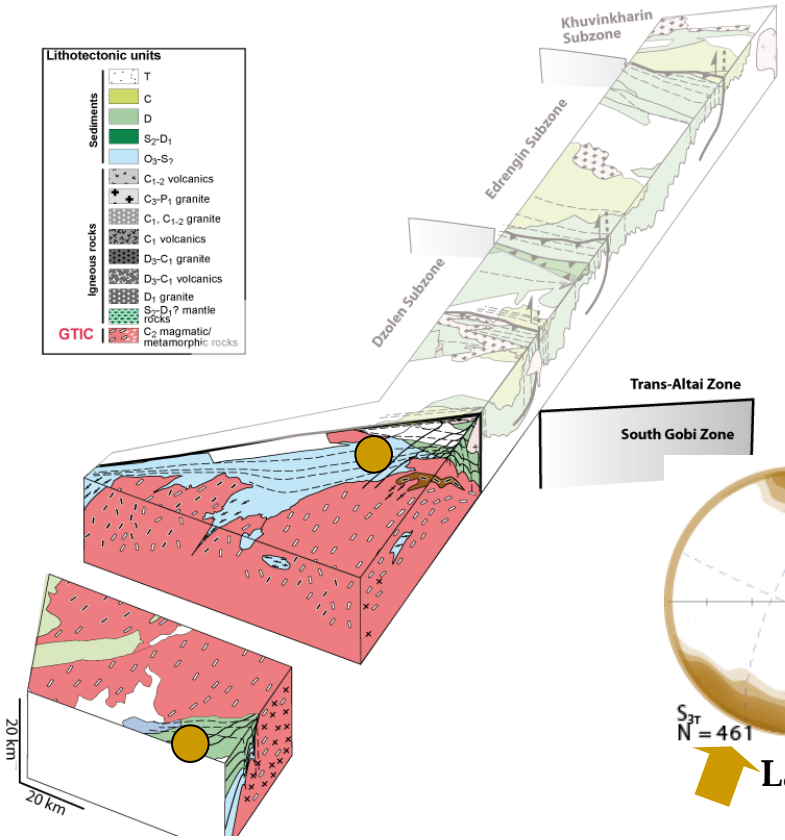


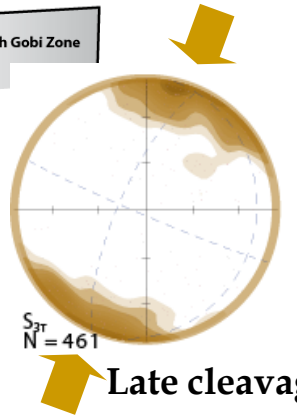
Intense magmatic fabric



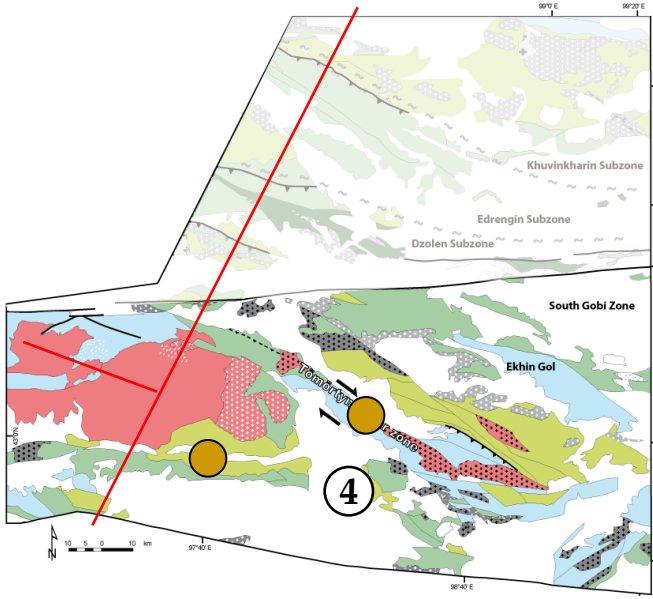
South Gobi Zone

NNE-SSW shortening
Dextral wrenching component
Middle Triassic

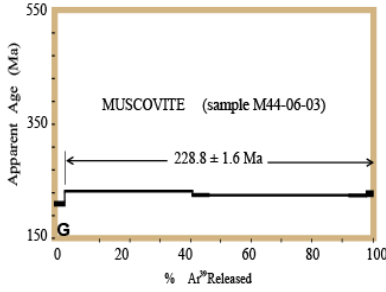


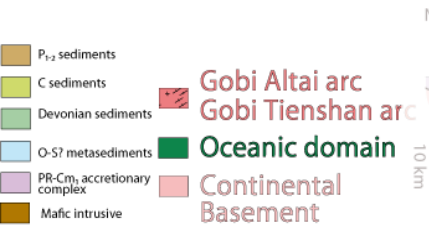


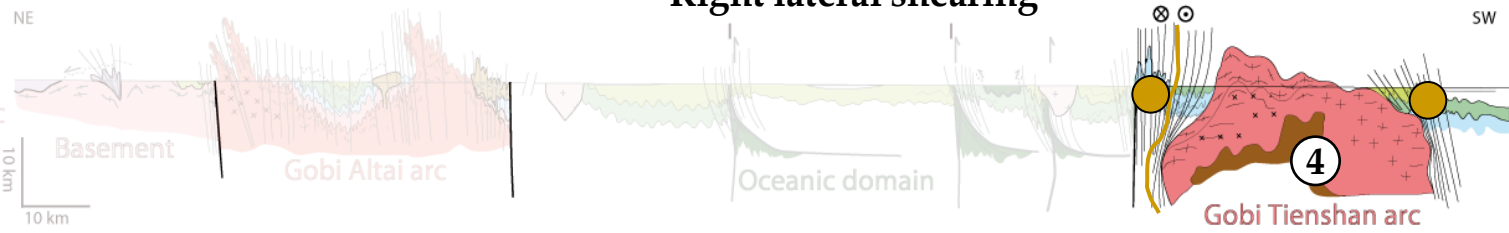
Late cleavage



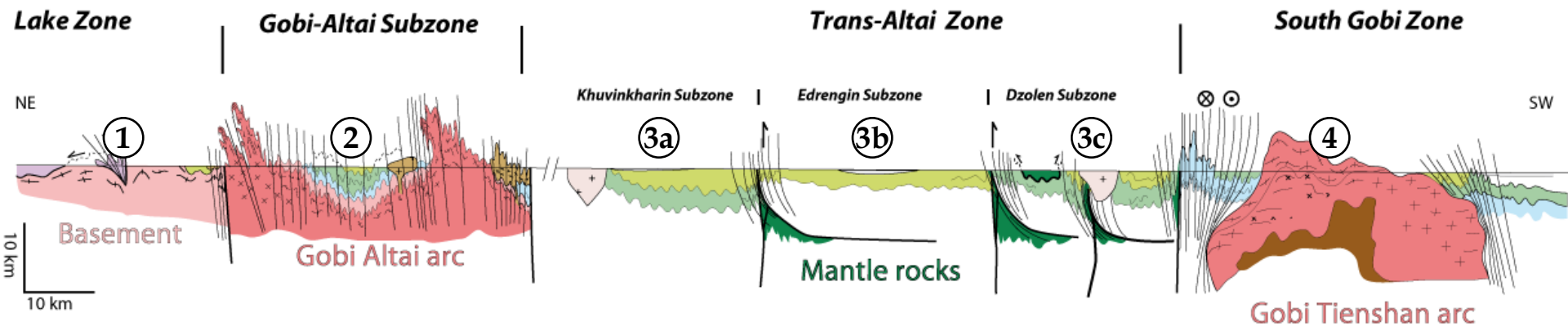
Right lateral shearing







Structural profil accross the 4 zones



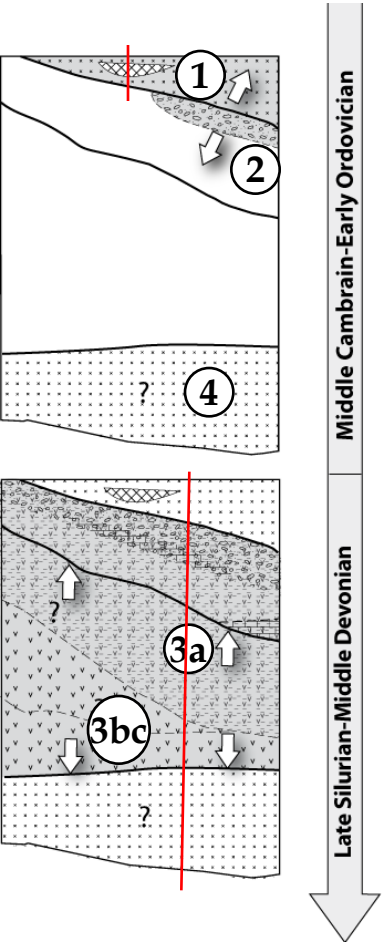
Distinct rheological behaviors during the Permian to Jurassic N-S shortening:

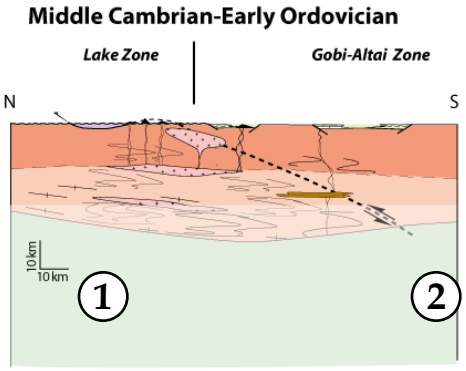
- Lake Zone : upright right folding of the flat multilayer.

- Gobi-Altai Zone : relicts of a N-S striking planar fabrics reworked by a heterogeneous and recurrent E-W striking cleavage.

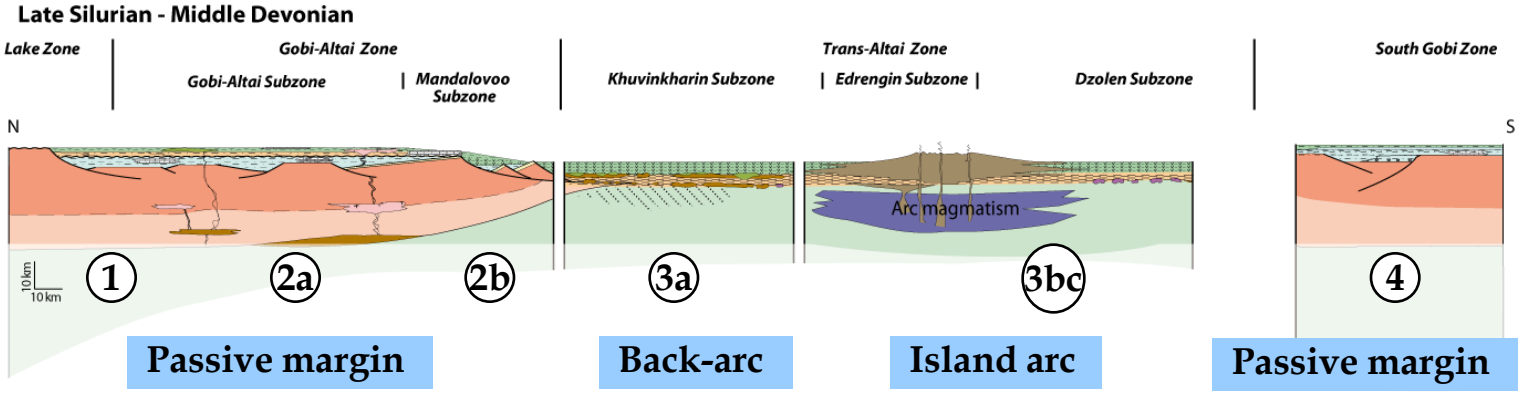
- Trans-Altai Zone : weak deformation related to the N-S shortening located between three deformation fronts where mantle rocks were exhumed.

- South Gobi Zone : Heterogeneous E-W striking cleavage. The Gobi Tienshan arc behaved as a rigid body deflecting ductile shear zones.



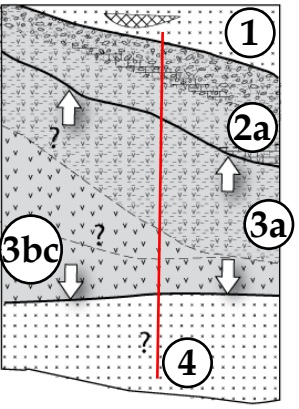


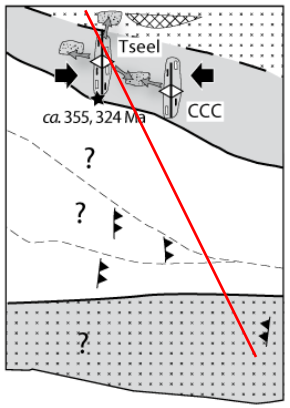
Late Cambrian orogenic collapse



Passive margin | Back-arc | Island arc | Passive margin

Formation of the Trans-Altai crust

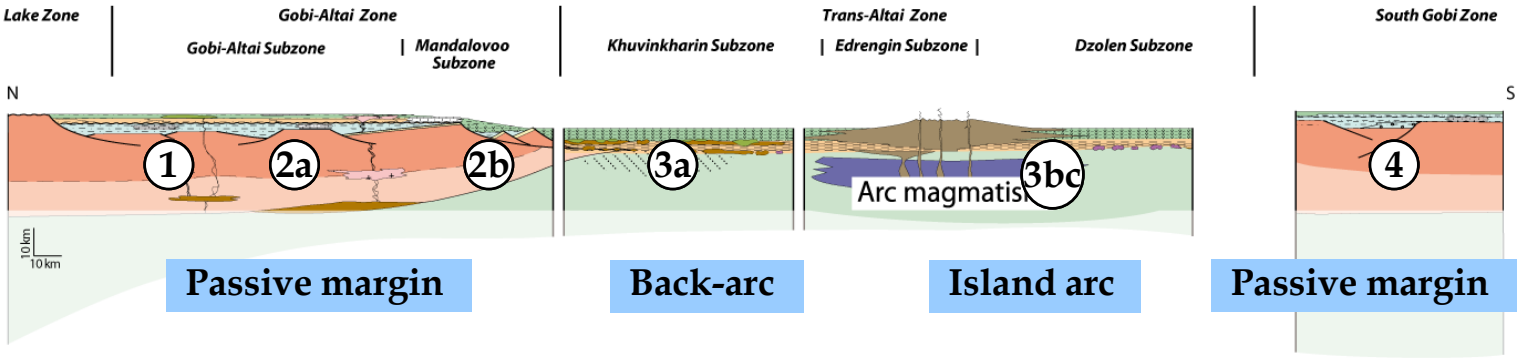




Late Silurian-Middle Devonian

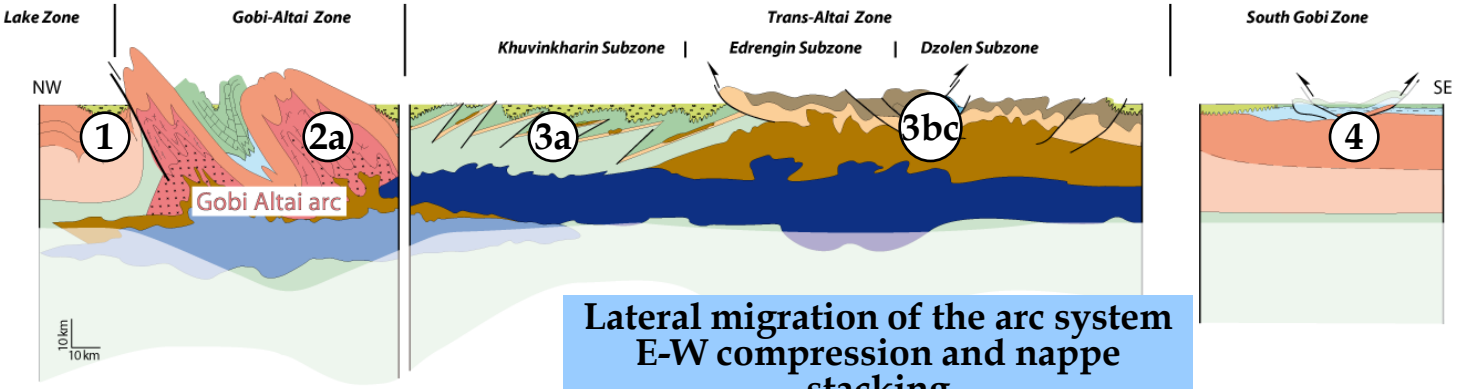
Late Devonian-Early Carboniferous

Late Silurian - Middle Devonian



Passive margin | Back-arc | Island arc | Passive margin

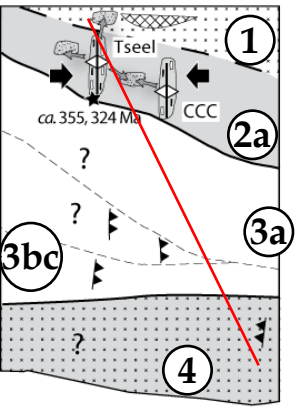
Late Devonian-Early Carboniferous

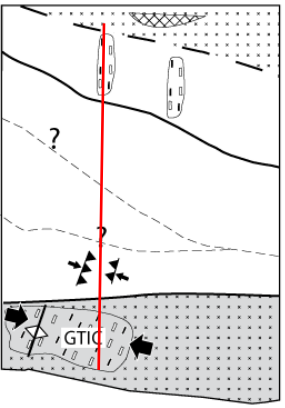


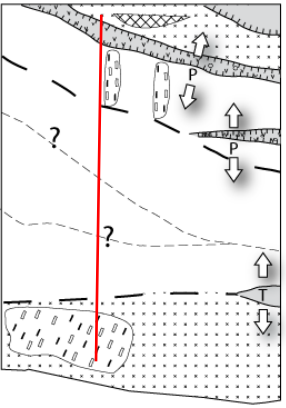
Lateral migration of the arc system
E-W compression and nappe stacking

Japan-type compressive arc during E-W shortening

Stitching of the Lake and Gobi-Altai Zones





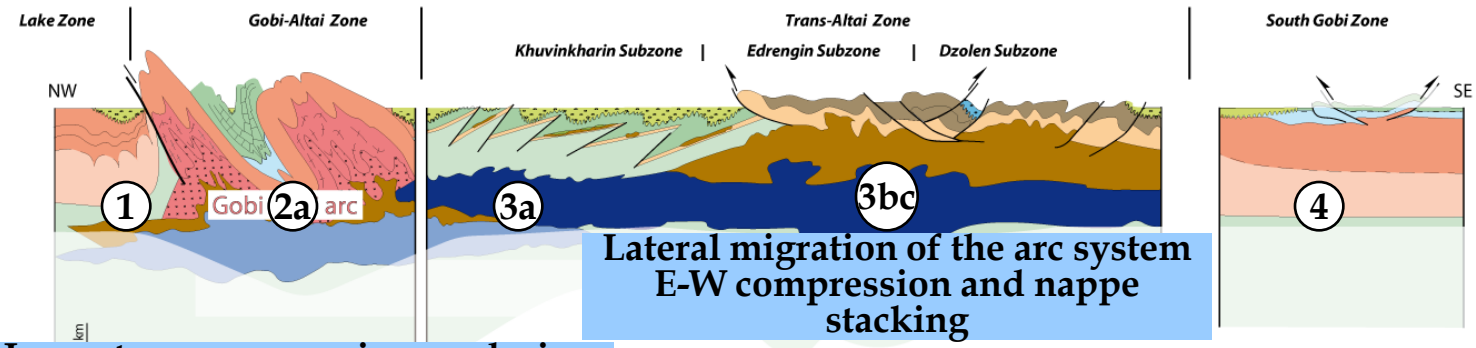


Late Devonian-Early Carboniferous

Late Carboniferous

Permian-Triassic

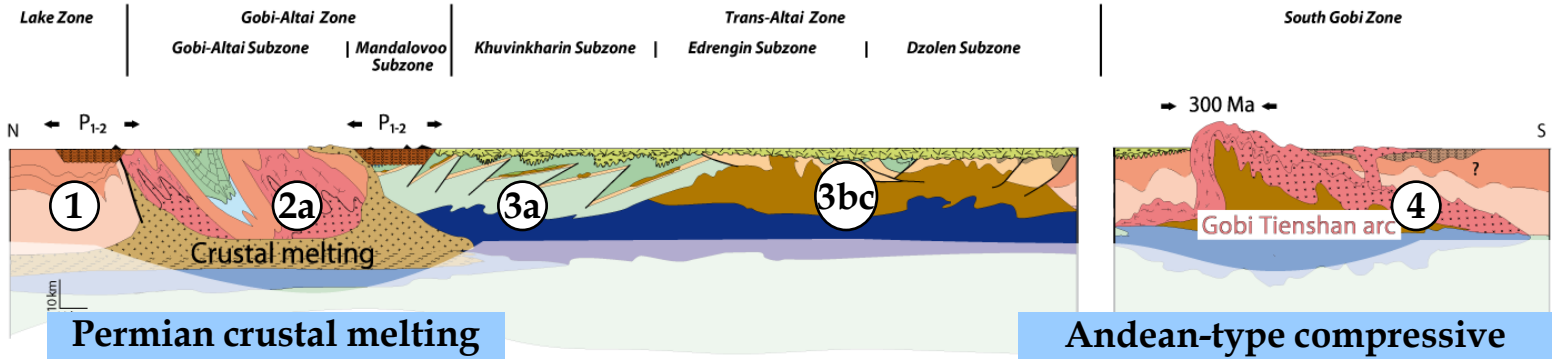
Late Devonian-Early Carboniferous



Lateral migration of the arc system E-W compression and nappe stacking

Japan-type compressive arc during E-W shortening Stitching of the Lake and Gobi-Altai Zones

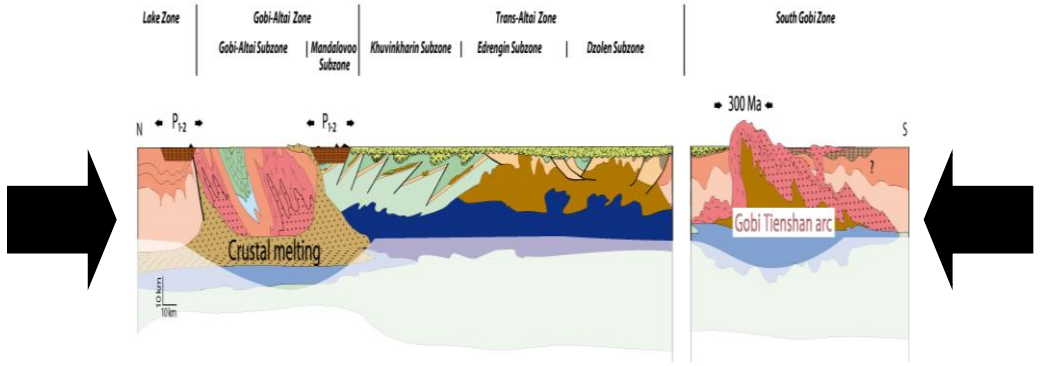
Late Carboniferous, Permian-Triassic



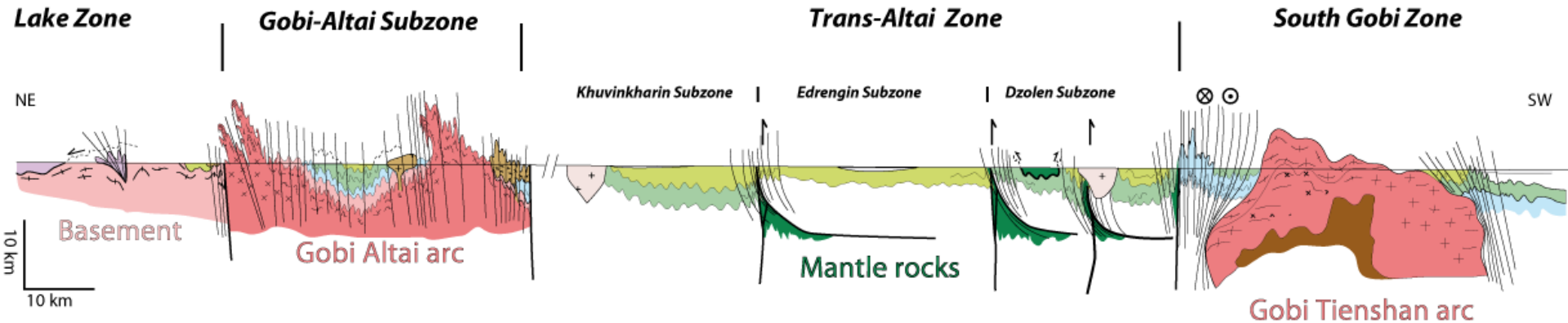
Permian crustal melting

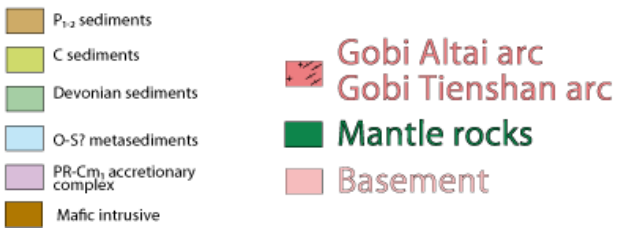
Andean-type compressive arc during E-W shortening

At least 60% of N-S to NNE-SSW bulk shortening



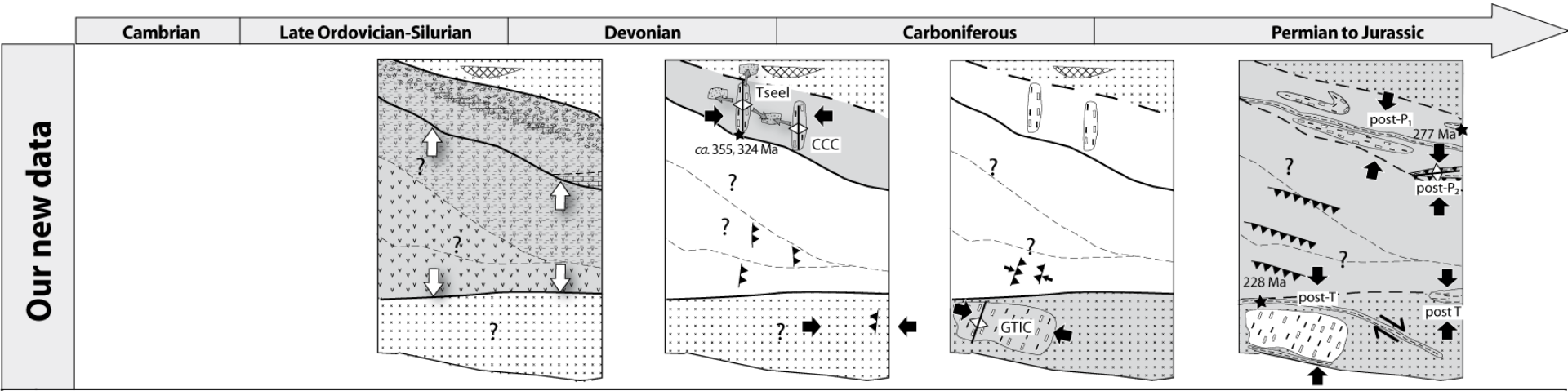
Present day geometry of the orogenic belt

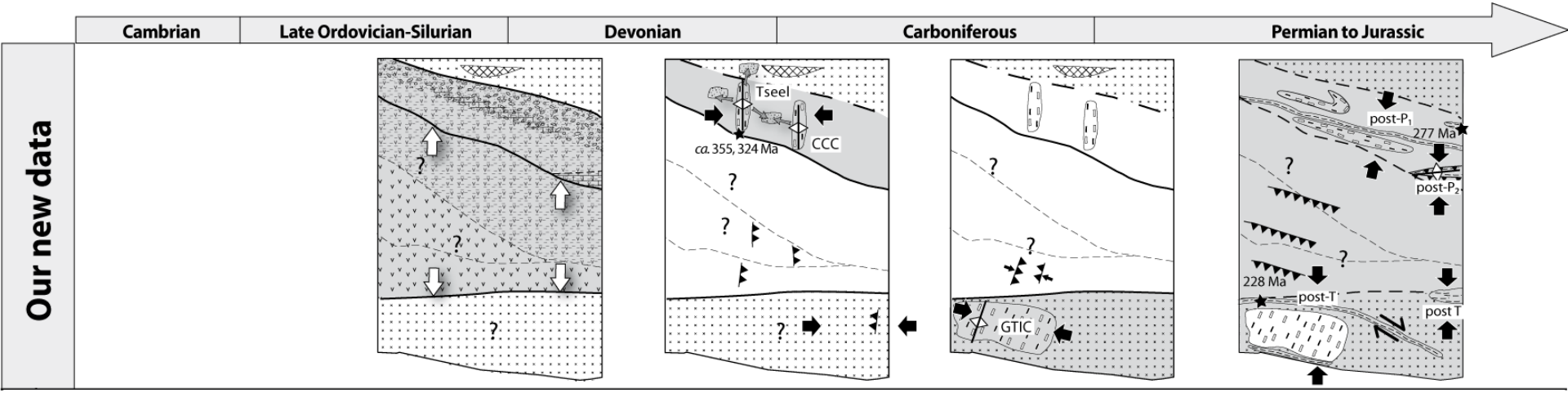




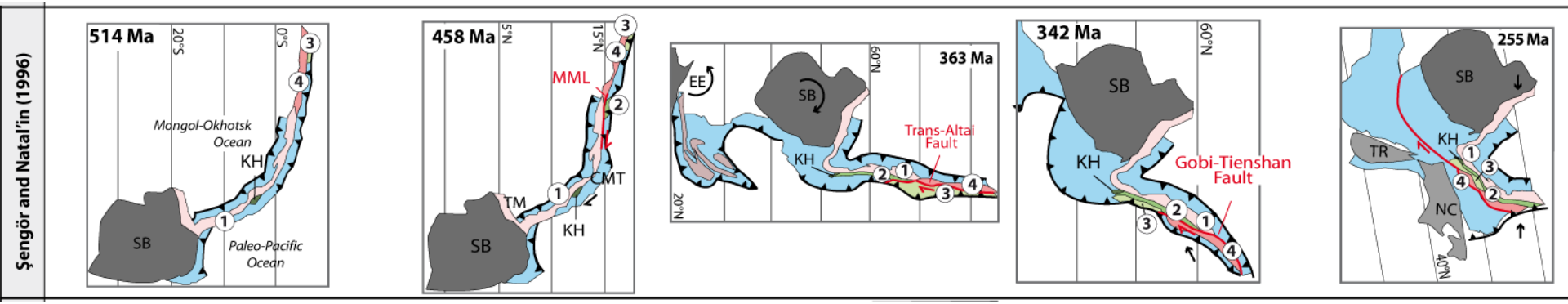
NEW constraints for the accretionary history:

- Late Silurian-early Devonian N-S opening of an oceanic domain in the Trans-Altai Zone.
- Late Devonian-Early Carboniferous E-W shortening in Gobi-Altai , Trans-Altai and South Gobi Zones.
- Late Carboniferous E-W shortening in South Gobi Zone.
- Protracted Permian to Jurassic N-S shortening.



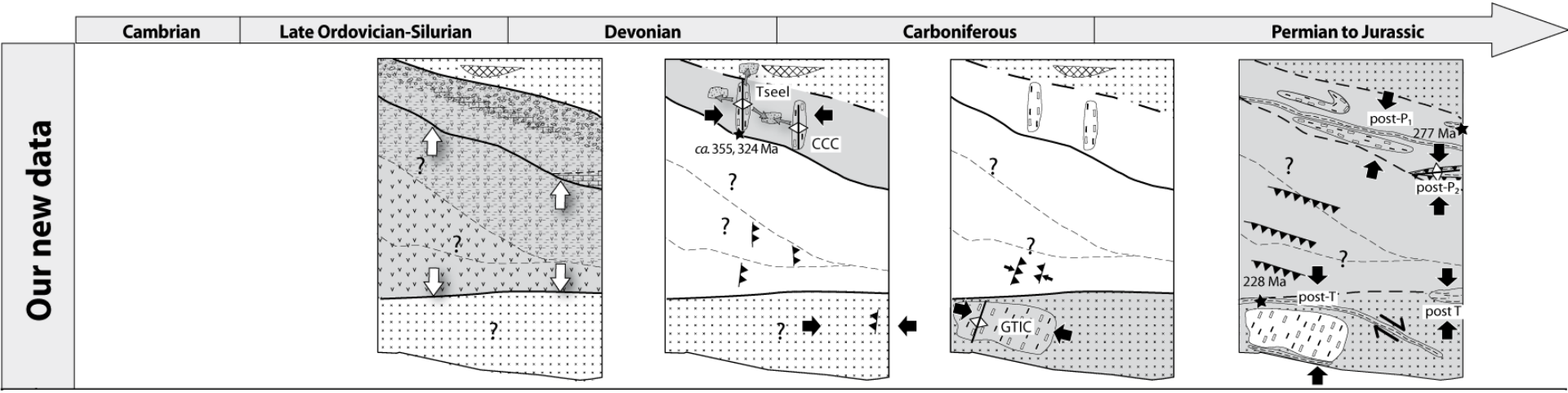


1st model: Şengör et al. 1993

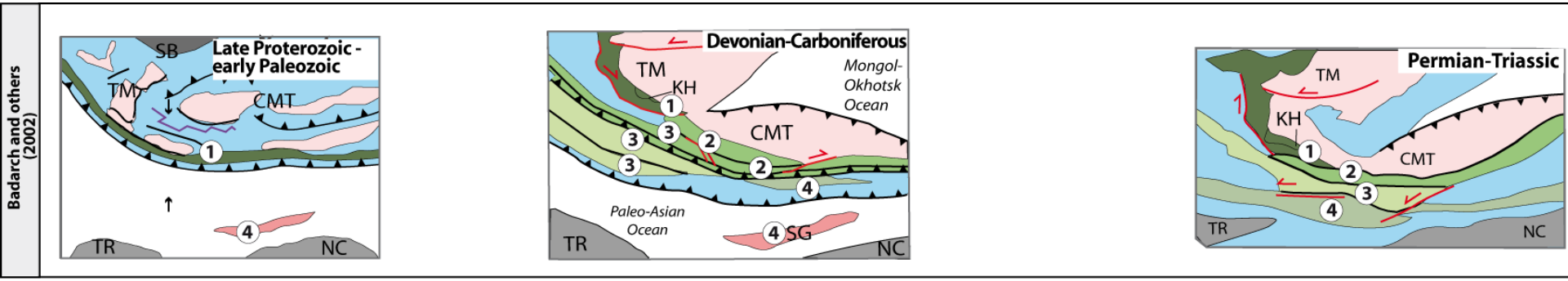


Sequential shaving of the ribbon starting with the Lake Zone and ending with the South Gobi Zone

Structures oriented at high angle possible
BUT not **contemporaneous**



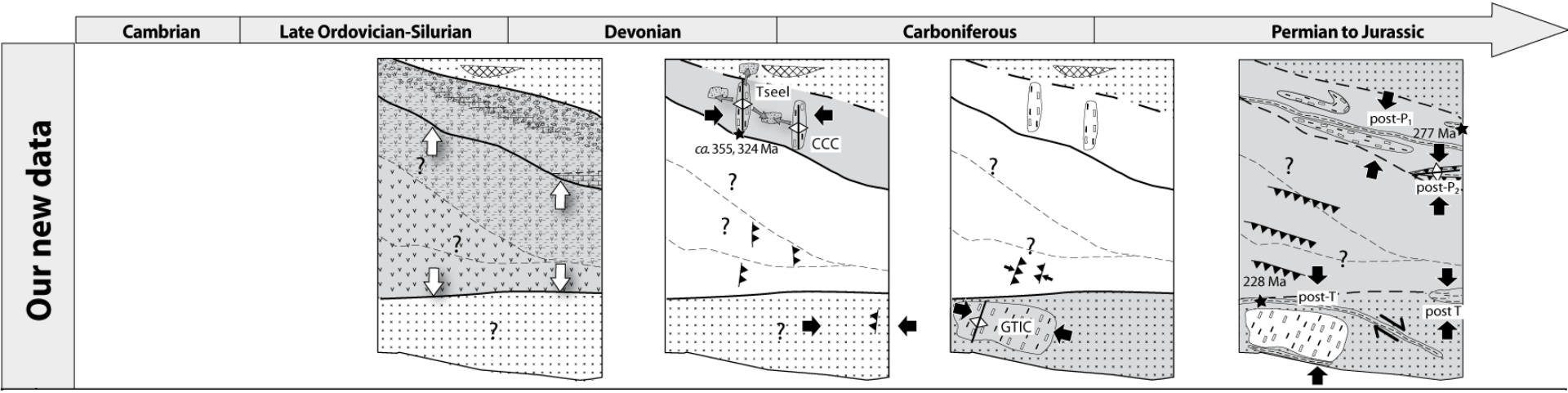
2nd model: Badarch et al. 2002



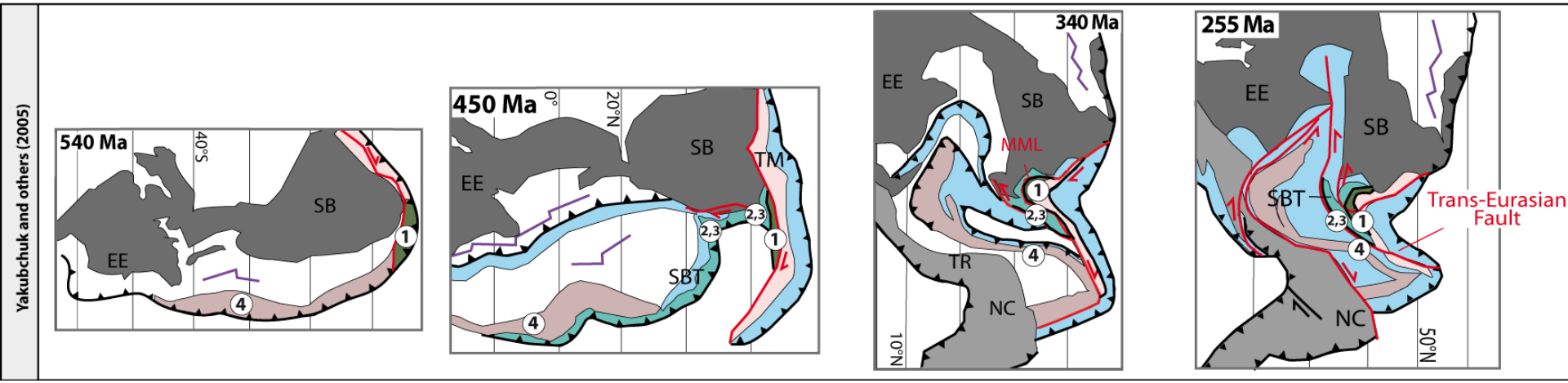
Role of the roll-back of the subduction zone

NO rocks in the field related to two accretionary wedges of Devonian-Carboniferous age

Orthogonality of the structures NOT solved



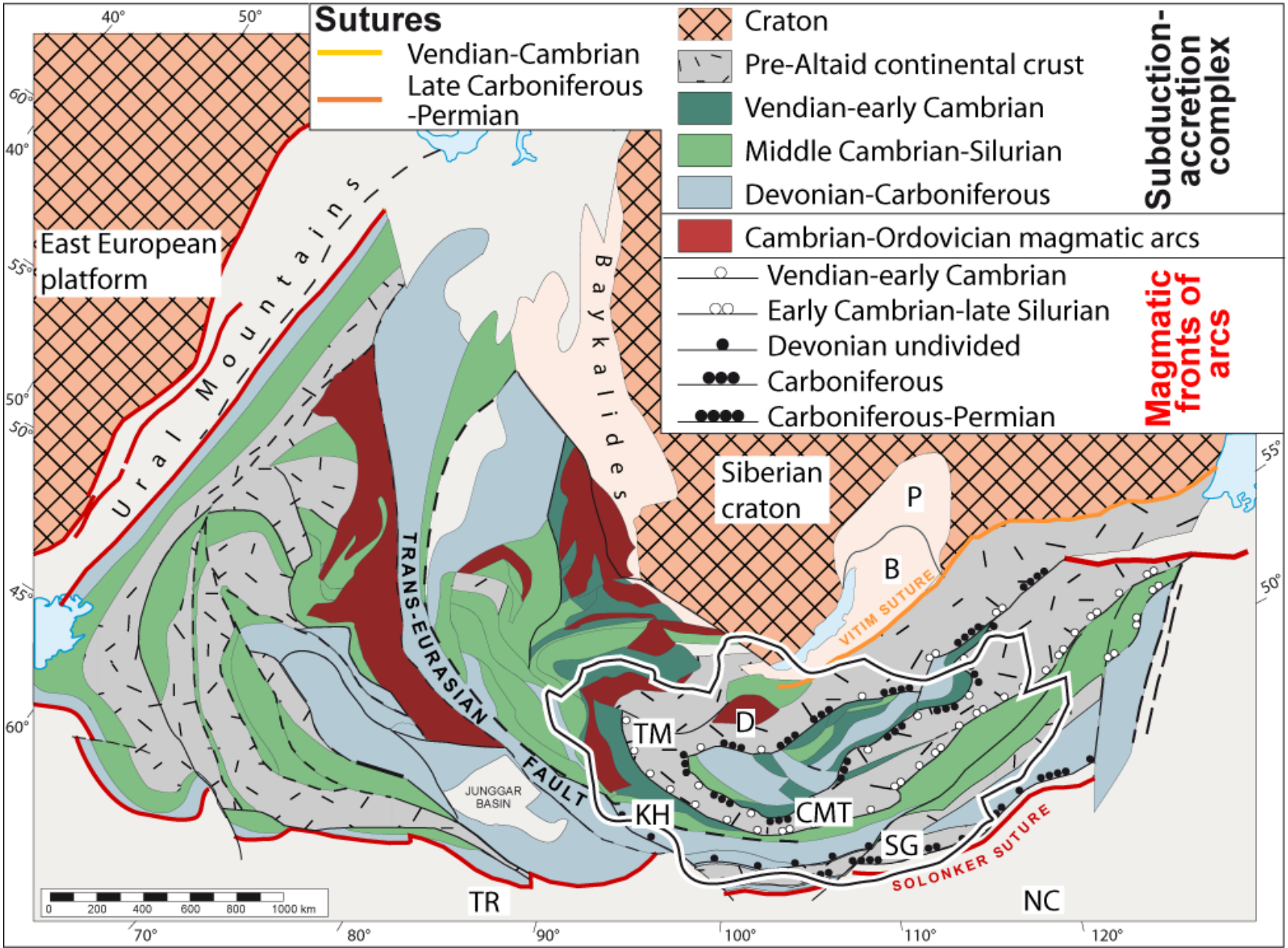
3rd model: Yakubchuk et al. 2005



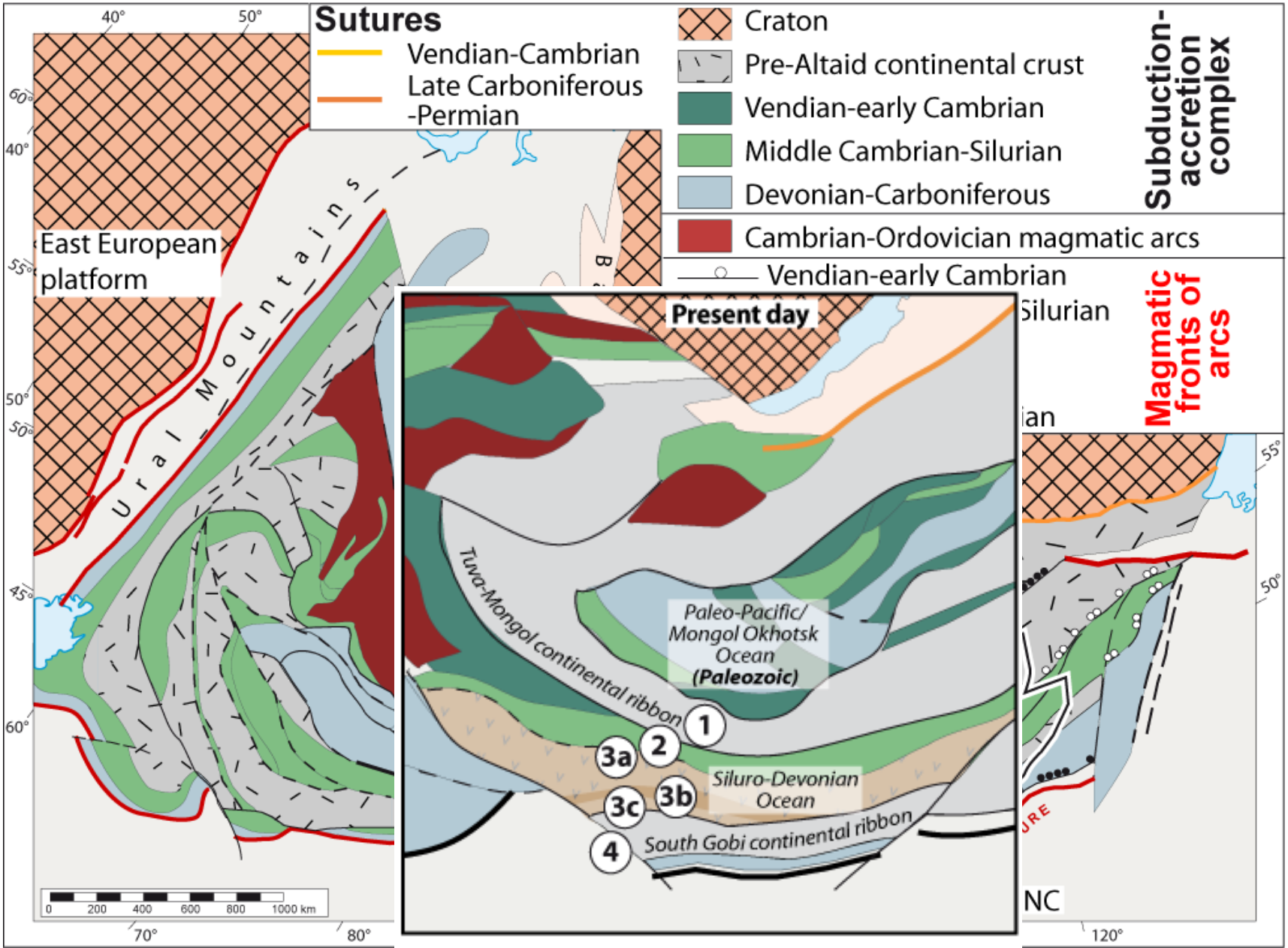
Orthogonality of the structures possible
BUT **timescales not compatible**

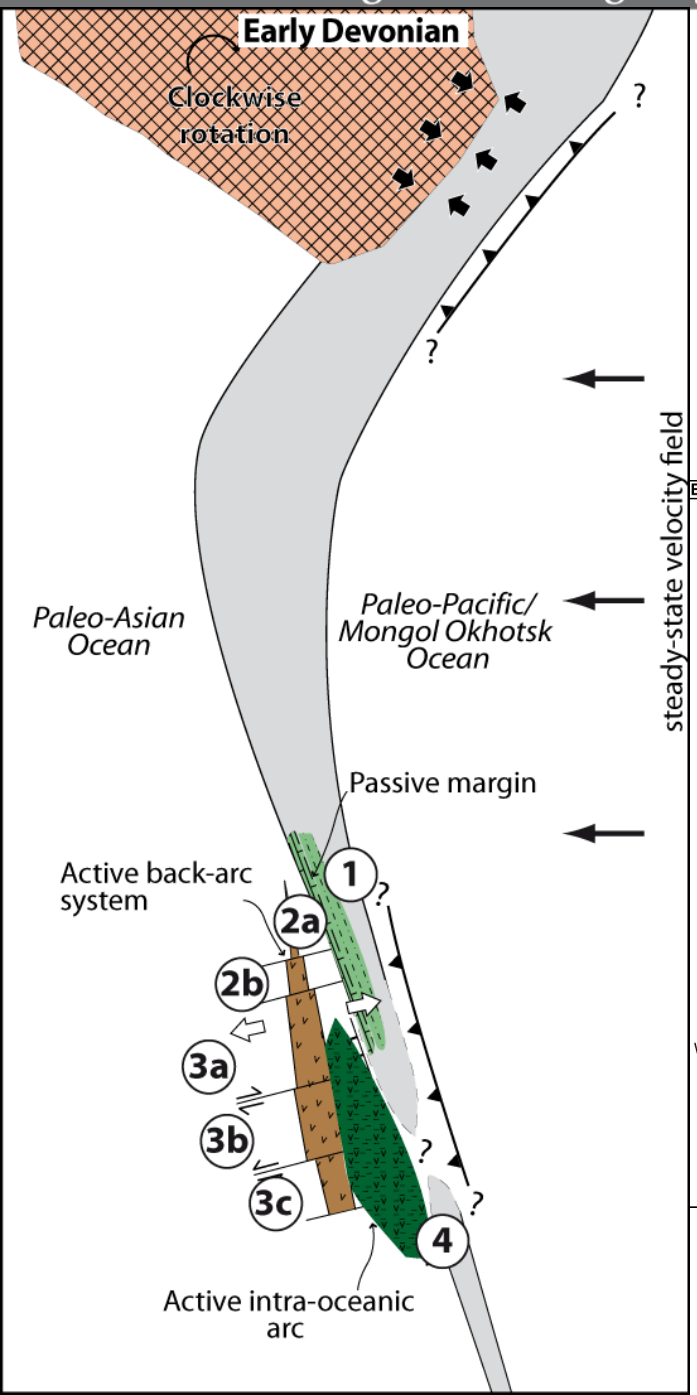
The Gobi-Altai and Trans-Altai Zones **passively** follow the shape of **the fold**

Boundary conditions



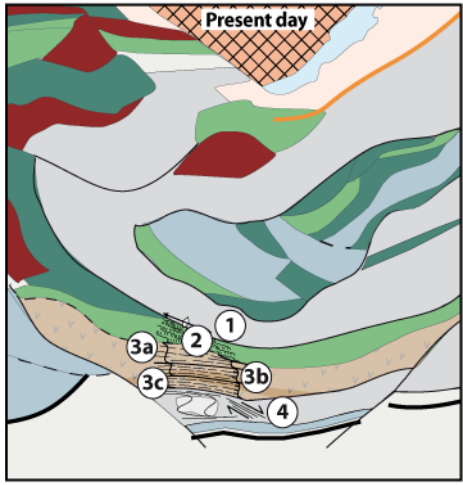
Boundary conditions

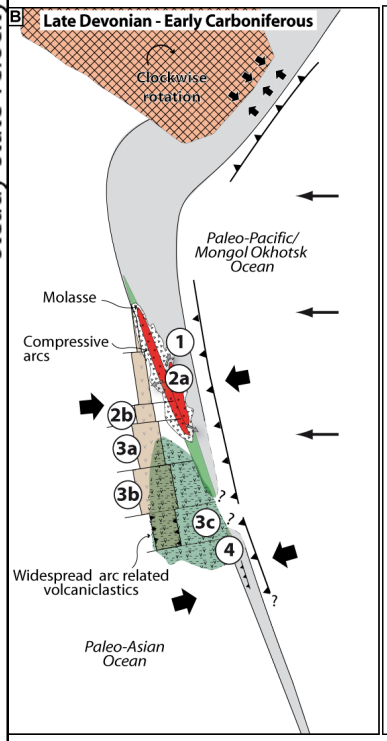


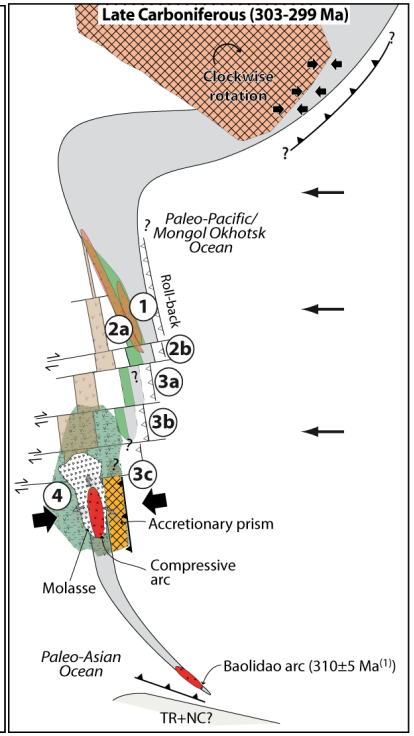


N-S single elongated Precambrian continental ribbon

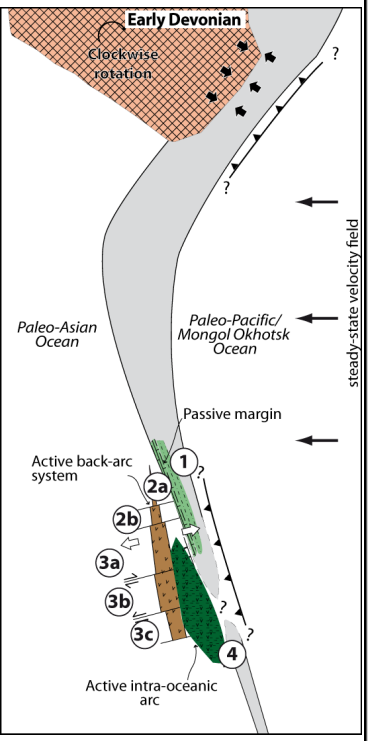
West-dipping subduction zone east of the continental ribbon

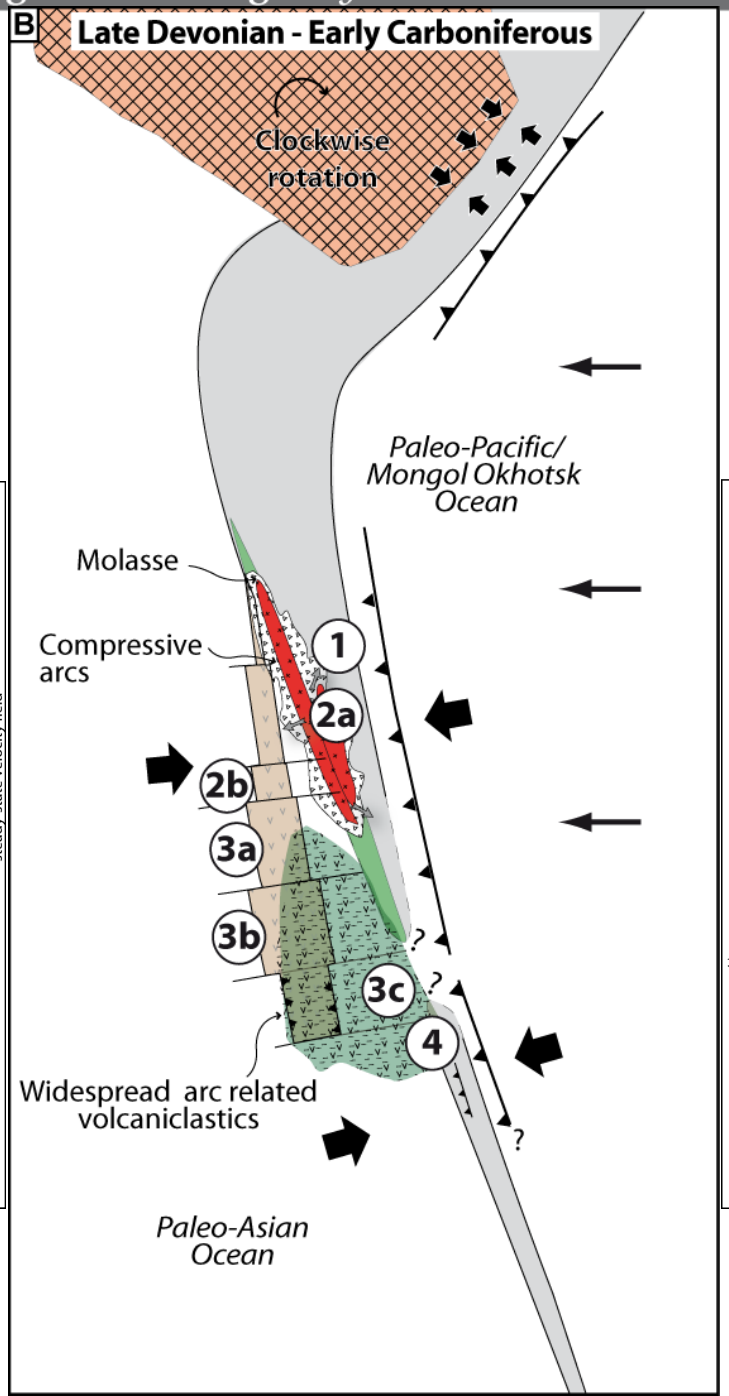


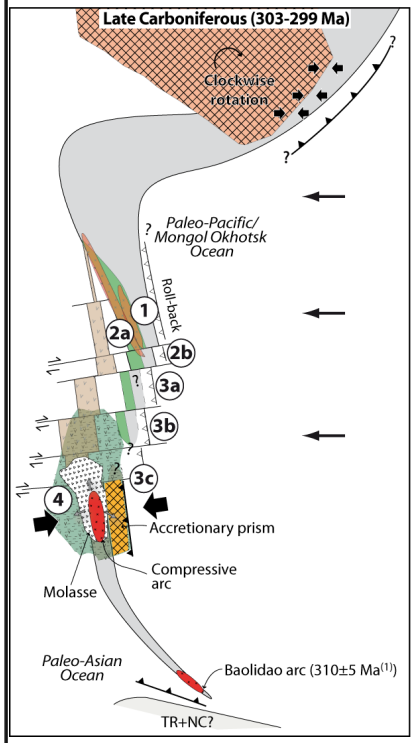


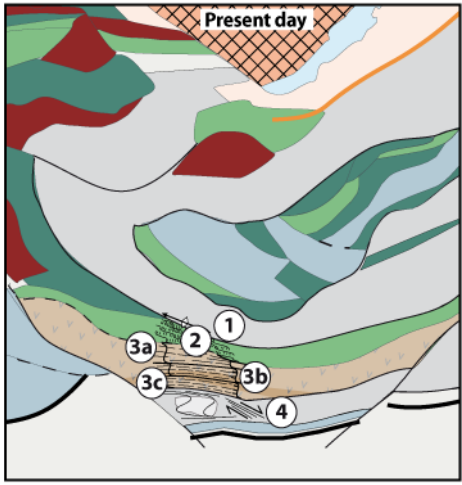


Position of the Tuva-Mongol ribbon in agreement with Delvaux et al. (1995)



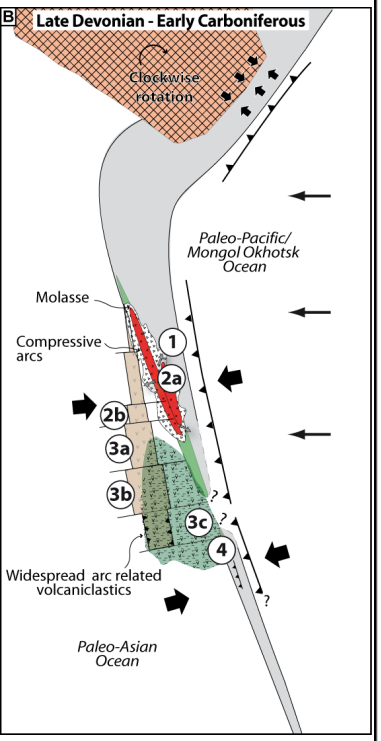


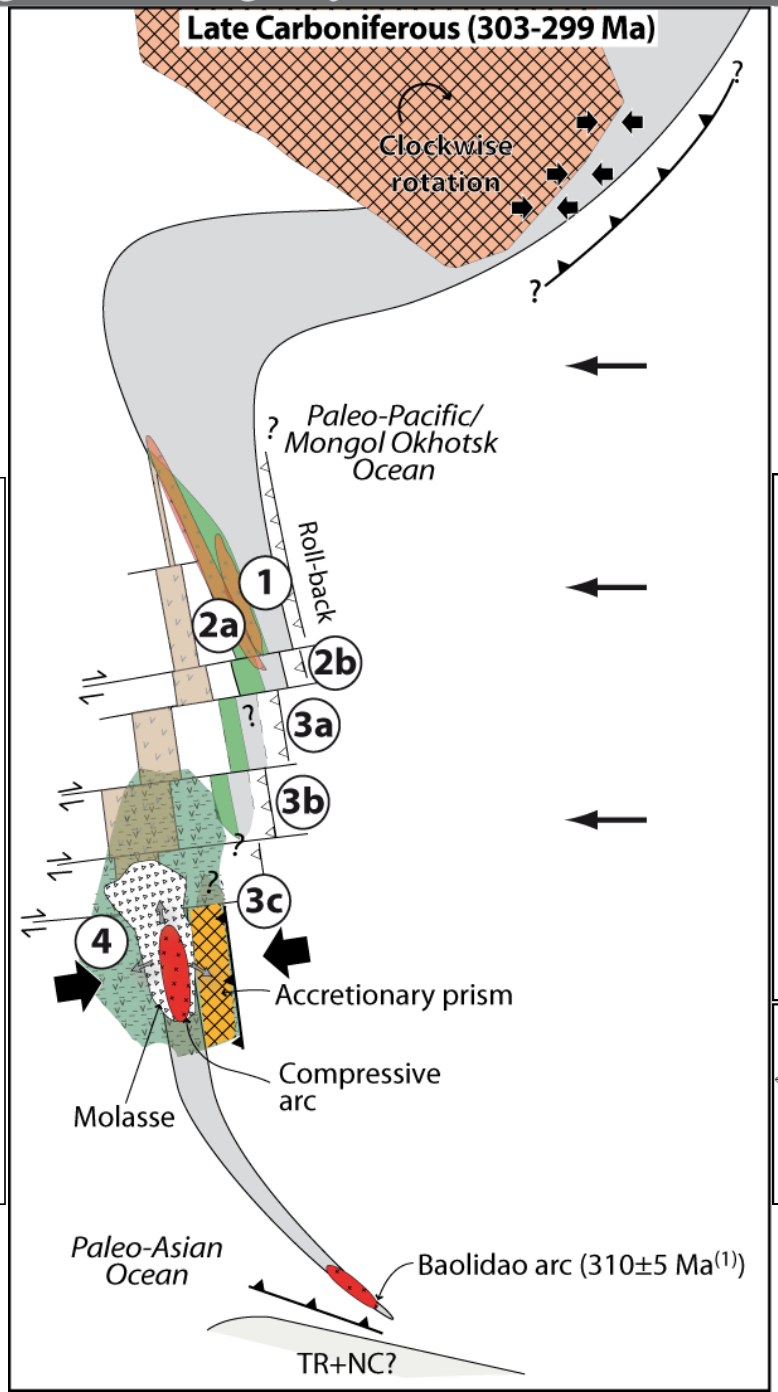


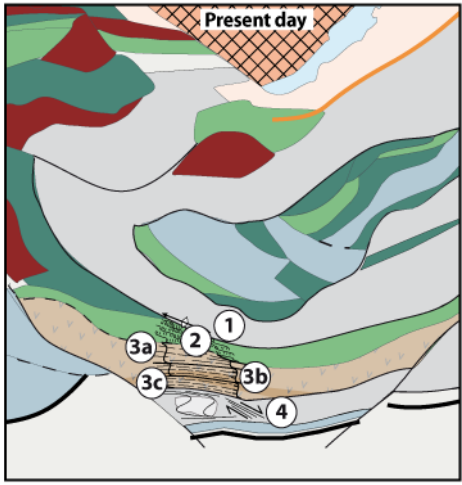


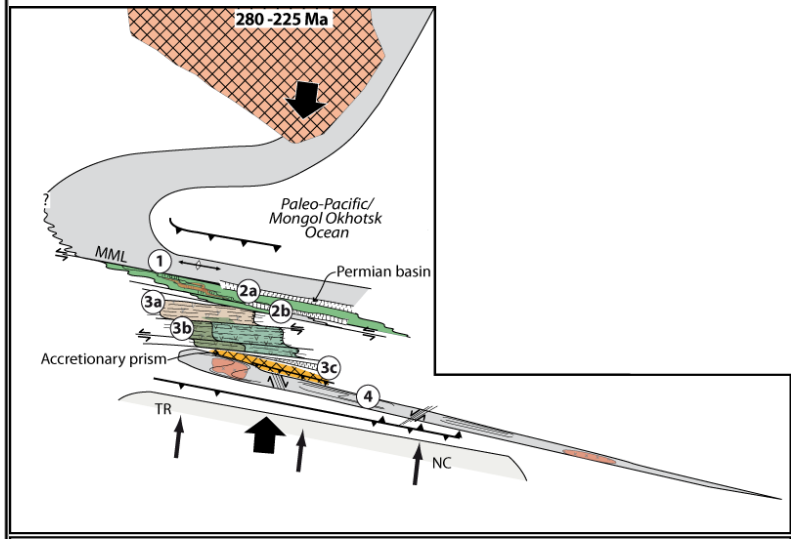
Eastward migration of arc magmatism

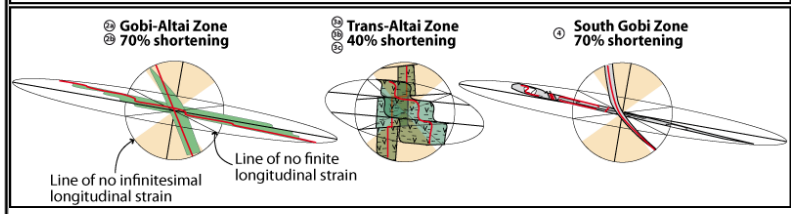
Westward migration of the continental ribbon



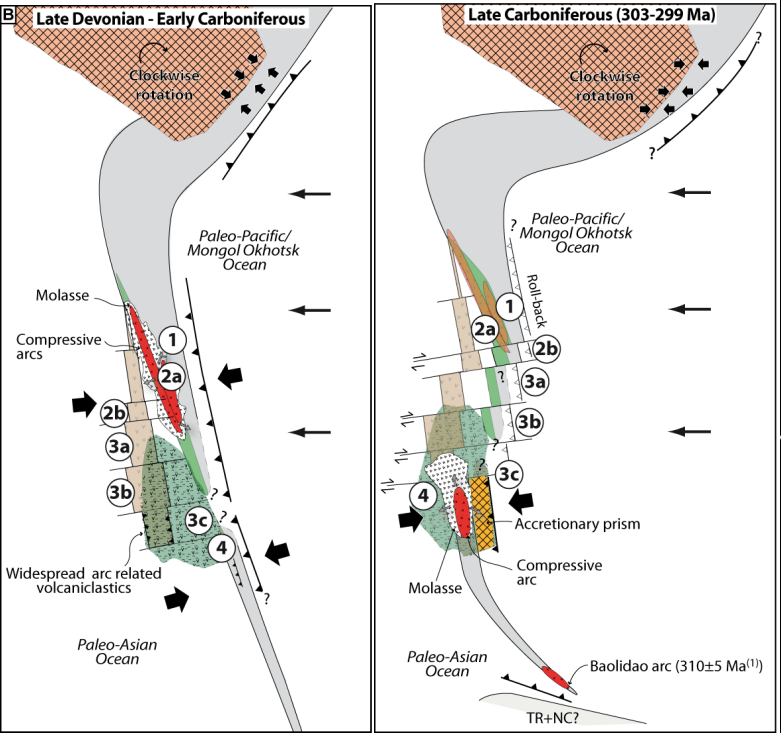


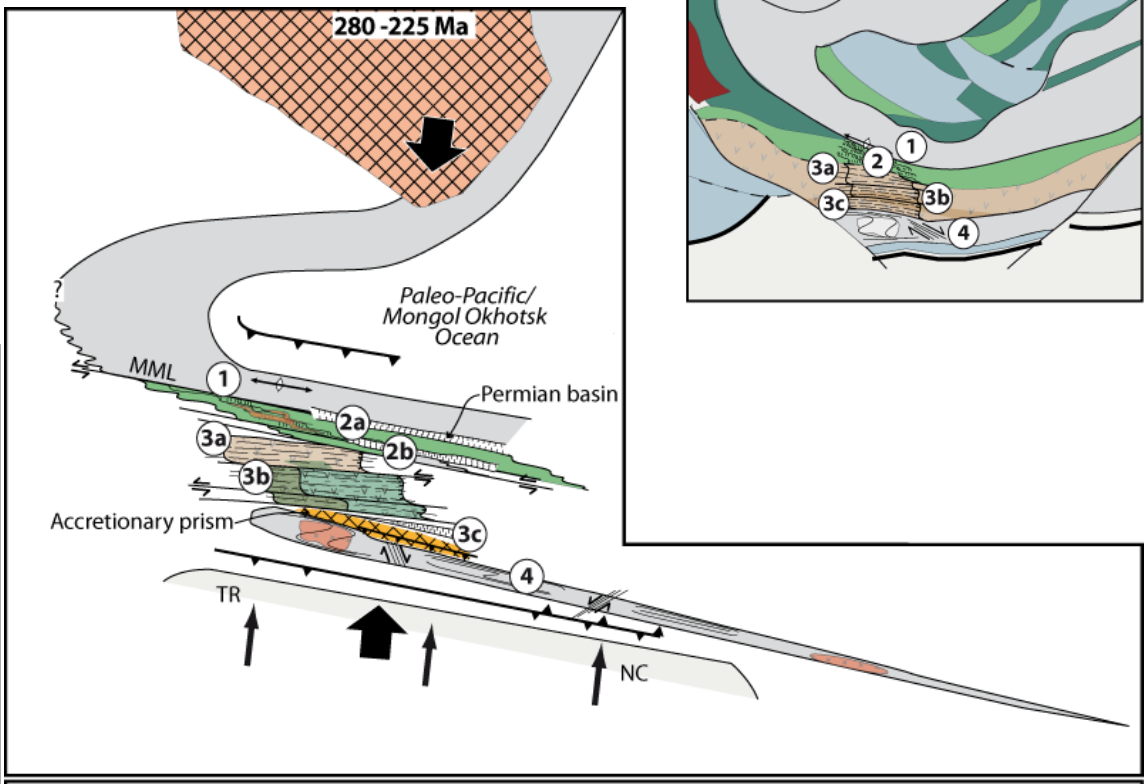


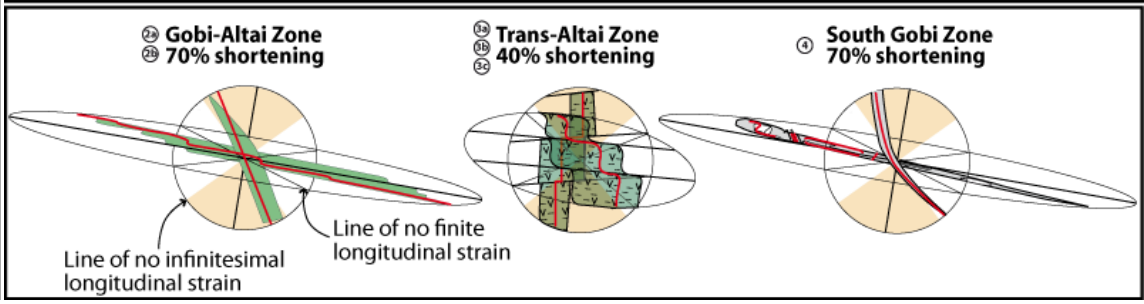




Locus of the arc magmatism in the South Gobi Zone







Major switch in the orientation of the compressional axis in early Permian

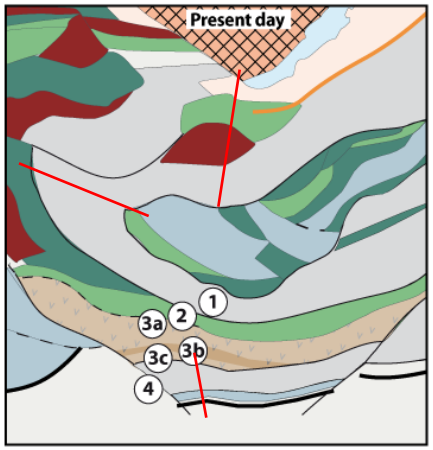
How and when the CAOB in SW Mongolia was accreted?

- **Late Silurian to Early Devonian opening of an Oceanic domain.**
- **Devonian-Carboniferous compressive Japan-type magmatic arcs emplacement during E-W shortening.**
- **Permo-Jurassic N-S oroclinal bending as the most possible mechanism to explain the newly defined :**
  - **lithotectonic zonation**
  - **geodynamic evolution of distincts zones**
  - **observed orthogonality of compressive structures**

The existing paleontological and paleomagnetic data

- **Different rheological behaviors imply different styles of deformation during the last N-S compressional event with special importance of the orientation of the Paleo-Transform faults and Permian magmatism.**

- Lithostructural profiles through the Tuva-Mongol fold in the hinge (location of the westward extension the Mongol-Okhostk Ocean) and the northern and southern limbs.
- Better understanding of the southern Solonker suture located south of the South Gobi Microcontinent.
- Analog modeling of the oroclinal bending phenomena of an elongated continental ribbon, particulary on the deformation of a subduction slab during folding.




Thank you for your attention!