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Busting at the seams?

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Permo-Triassic flood basalts, felsic flares, large/scattered igneous provinces, and metal deposits

- The Siberian, Emeishan and Tarim Flood Basalt Provinces were formed in the course of the Permian and Early Triassic.
- The West Siberian basalts were emitted around 250 Ma, within about one million years. Recent isotope geochronological results indicate similar volcanics were formed at the same time in the far northeast of Siberia [1, 2].
- Other recent isotope geochronological results indicate the bulk of the Tarim volcanics formed between 290±4.1 and 286±3.3 Ma [3].
- In the latter time frame, largely felsic volcanics erupted across western Europe and northwestern Africa in a Scattered Igneous Province [4, 5]. These volcanics are generally inferred to represent lower crustal melts formed after ponding of HT mantle melts [6, 7, 8].
- In addition, diverse and prominent ore deposits were formed between western Europe and central Asia, including world class gold-dominated deposits.

In Permo-Triassic Eurasia two transcontinental mantle events can be recognized (Fig.1):

- the *c.* 295-280 Ma Tarim event, between western Europe and eastern Kazakhstan (*c.* 8,500 km apart) and
- the *c.* 250-245 Ma Siberia event, between western Europe and northeastern Asia (*c.* 10,000 km apart).

Were these events driven by deep mantle plumes, shallow mantle processes, or both, or something else?

Distribution in space and time

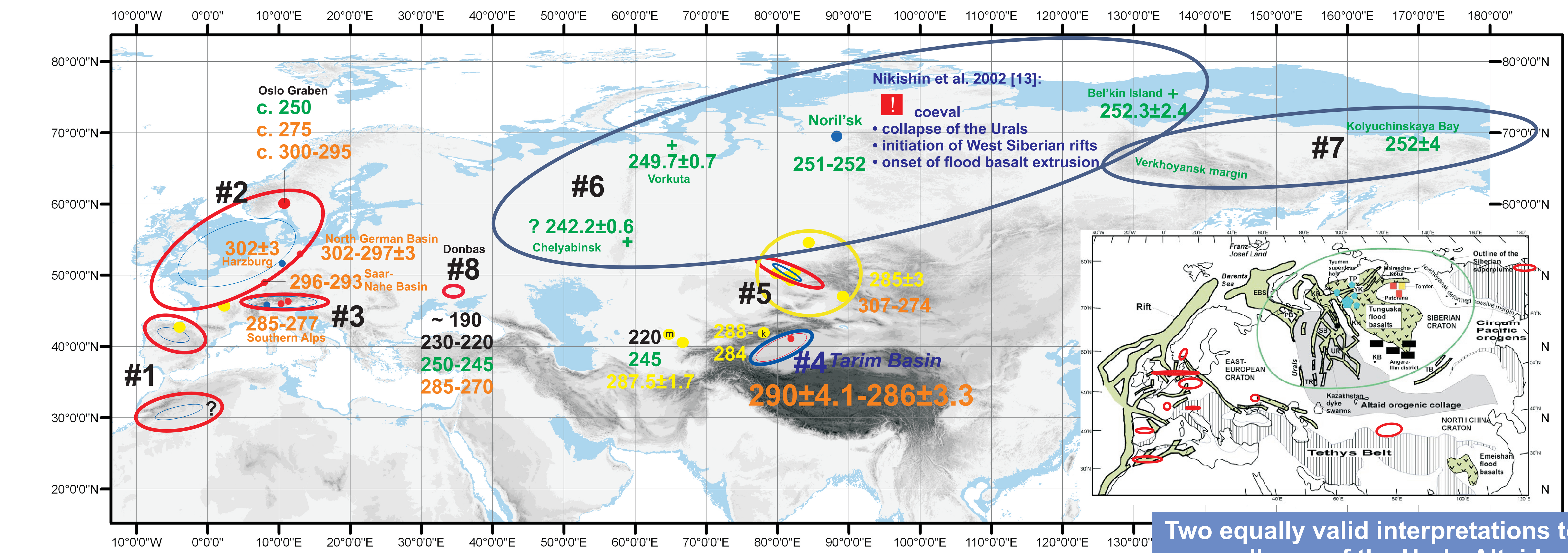

Fig. 1 Schematic space-time distribution of principal Eurasian Late Palaeozoic - Early Mesozoic volcano-plutonic complexes (#1-8) variably attributed to mantle plumes. Blue ellipses indicate mafic melts, red ellipses indicate felsic melts. Outer ellipse defines dominant lava type. Ages in green define the 'Siberia event'. Ages in orange define the 'Tarim event'. Yellow dots and ages in yellow represent prominent gold districts; m - Muruntau, k - Kumtor. Inset - Late Permian to Middle Triassic continental rifts and flood basalt basins, in green, after Yakubhuk & Nikishin [52], with provinces and districts #1-8 in red.

Lithologies

\# 1 Southwestern Europe and Northern Africa association of calc-alkaline, shoshonitic, and subalkaline basaltic melts [5].

\# 2 Northern Central Europe association of rhyolite-ignimbrite (flare) - andesite - basalt - gabbro - granite; T_{source} 850-1000°C [6, 7, 9].

\# 3 South Alpine association of gabbro - granite - rhyolite [10, 8].

\# 4 Tarim flood basalt association of picrite - basalt - rhyolite T_{source} >1300°C [3].

\# 5 East Kazakhstan association of subalkaline gabbro - picrite - olivine gabbronorite - plagiogranite [11,12].

\# 6 The West Siberia flood basalt association of ferropicrite, silica-saturated basalt, basaltic andesite, tholeiitic basalts, dolerite sills, Cu-Ni-PGE and porphyry Cu deposits; comprising of seven individual provinces/districts [13-17].

\# 7 Kolyuchinskaya Bay association of tholeiitic flood basalts and dolerite sills [2].

\# 8 Donbas association of Late Devonian (380-355 Ma) alkaline basalts, dacite and rhyolite, ~285-270 Ma shonkinite and monzonite, 250-245 Ma and 230-220 Ma trachyandesite and dacite [18, 19].

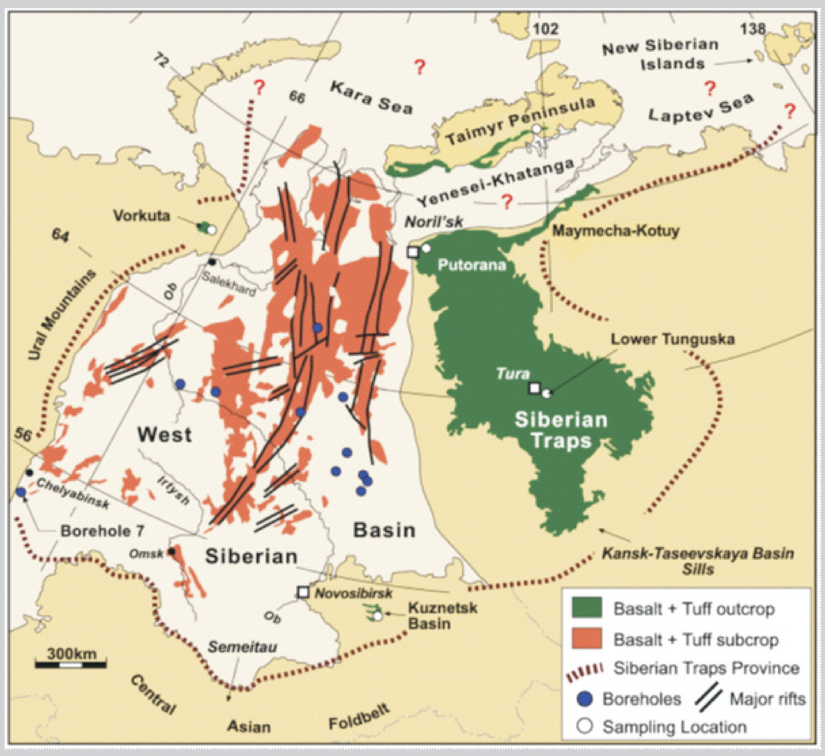

Fig. 2 Extent of flood basalts in Western Siberia [16].

Two equally valid interpretations together suggesting collapse of the Urals-Altaid orogenic edifice?

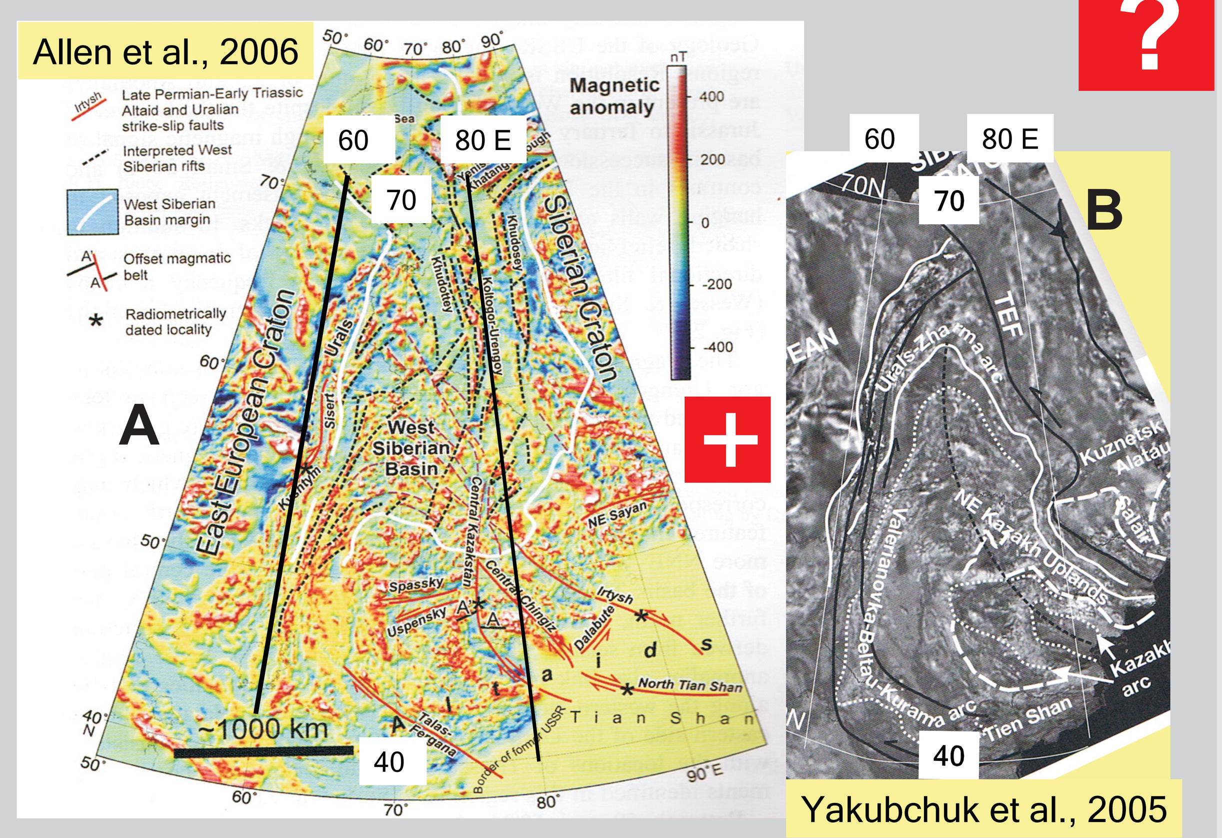

Fig. 3 Two interpretations of the same magnetic database [15, 34]. Together they suggest the superimposition of a strike-slip system with localized extension domains and an extensive West Siberian sag (A) upon a complex orogen (B).

Metallogeny

- The flood basalt provinces of the Siberia event are primarily known for their Cu-Ni-PGE deposits, especially the Noril'sk districts.
- Importantly, porphyry Cu, Hg-Sb, and Ag-Au deposits can form part of the association [17, 20].
- The ore deposits associated with the earlier Tarim event seem more diverse, with Sn-W(-Cu), Au-Sb(-Hg), Cu-Ni-PGE and Mo-W-Cu porphyry deposits [11, 12, 35-51].
- Notably, the Au-dominated deposits of the Tarim event in the Tianshan and the Cu-Ni-PGE deposits of Western Siberia stand out as worldclass deposits that, volumetrically, have no counterparts in Western Europe.
- On the other hand, the Middle Triassic Idria Hg deposits [44] and the Donbas Hg-Sb deposits of uncertain post-Carboniferous age [45] constitute unique worldclass occurrences in southern Europe.
- The porphyry deposits appear out of place and time [17]. However, in line with earlier observations these could have formed from lithospheric mantle that was metasomatized during earlier subduction [21].

Destruction of the orogens

•• **Are the Siberian flood basalts a function of the destruction of the Urals and the Western Altaids?**

- The West Siberian strike-slip system (Fig. 3A [15]) probably reached into the asthenosphere as suggested by the length of the fault system and the chemistry of the magmas.
- The coeval association of (I) collapse of the Urals, (ii) West Siberian rift formation and (iii) the initiation of flood basalt volcanism [13] implies that the collapse processes extended from the Urals towards the western periphery of the Siberian Craton, that is - they affected the western Altaids as well.
- The West Siberian Basin may, therefore, have to be viewed as a collapse basin. This appears supported by the sedimentary-volcanic complex near Noril'sk reflecting pre-volcanic uplift, erosion and subsidence with initially submarine volcanism [55].
- In Western Siberia, 'the main region of magma production was ... beneath the relatively thin (50-100 km) lithosphere of the basin, and *not the craton* on which the present day exposure of the Traps occur ... ' [14].
- The flood basalts are therefore closely related to the destruction of the orogen(s). Consequently, the distribution of Cu-Ni-PGE deposits along the circumference of the Siberian Craton is not a function of the craton margin [54] alone.

•• **The Tarim flood basalts formed in a similar destructive framework in the Late Palaeozoic to Early Mesozoic Variscides of Western Europe and the Tianshan of Central Asia, comprising:**

- a translithospheric strike-slip belt between Gondwana to the south and Eurasia to the north (Fig. 4),
- pull-apart basins [8],
- detachment of subducted lithosphere [22,23, 24].
- regional uplift [22, 25, 26],
- orogenic collapse [26],
- localized uplift of the asthenosphere,
- mantle-derived decompression melts [22],
- consequent melting of the lower crust and flares of ignimbrite [7, 8].
- A-type granites [27, 28].
- Alaskan-type mafic-ultramafic intrusions [29].

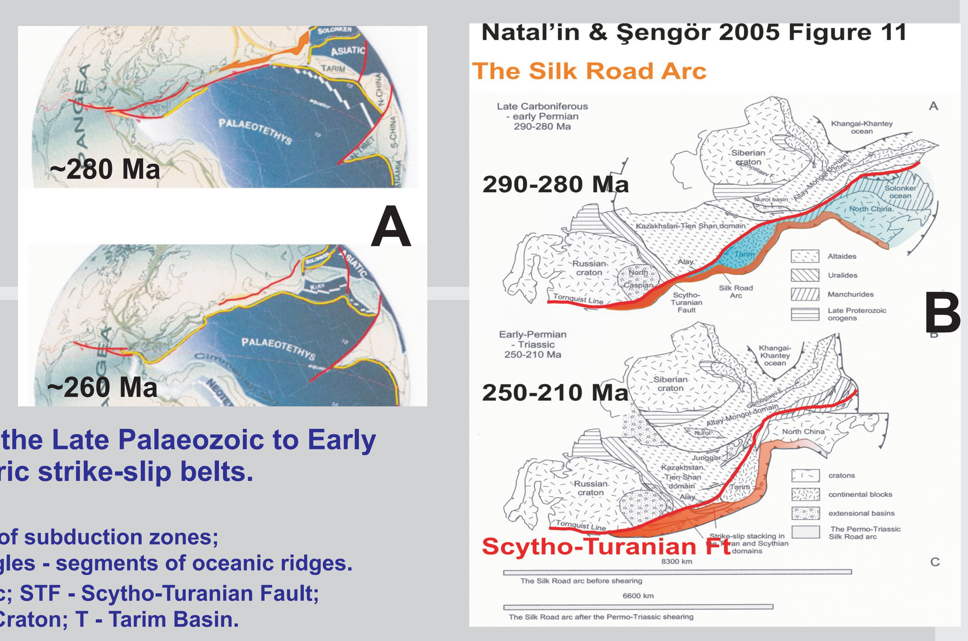

Fig 4 Two views of southern Eurasia during the Permo-Triassic.

The northern coasts of the Palaeo-Tethys Ocean during the Late Palaeozoic to Early Mesozoic - destruction of orogens along translithospheric strike-slip belts.

A - modified after Stampfli & Borel [30]. Yellow lines - traces of subduction zones; red lines - transform fault zones; orange areas - rift zones; white rectangles - segments of oceanic ridges.
B - modified after Natal'in & Şengör [31]. SRA - Silk Road Arc; STF - Scytho-Turanian Fault; NCC - North China Craton; SC - Siberian Craton; EEC - East European Craton; T - Tarim Basin.

Conclusions

- The Tarim and Siberia flood basalts erupted in extensional domains along translithospheric transcurrent shears that destroyed their orogenic hosts, that is - principal seams in the lithosphere fabric.
- In Asia, the visible volume of lavas is much greater than in Europe where the mantle melts generally stalled at the Moho and caused formation of felsic melts in the lower crust represented by rhyolite and ignimbrite flares.
- The patchy outcrop patterns suggest they constitute Scattered Igneous Provinces rather than Large Igneous Provinces.
- The dimensions of their surface distributions, with diameters up to 6,000 - 10,000 km, and their practically synchronous emplacements across these vast regions militate against underlying classical plumes and migrating plume heads.
- The flood basalts, in Europe in combination with the overlying Late Permian Zechstein evaporites, are an independent diagnostic of the collapse of the orogenic edifices [32].
- The ore deposits associated with these lithosphere-asthenosphere events are not fundamentally different though differences do occur in magnitude and grade. The ore deposits turning up in the disintegrating/disintegrated orogens include orogenic Au, Sb, Hg, Cu-Ni-PGE and porphyry deposits.

The continent-wide distribution and the coeval emplacement of the volcanics and intrusions suggest a primary relation with the continental lithosphere, albeit in mutual exchange with the asthenosphere where the basalts had their origin. Their emplacement was controlled by localized lithospheric extension, in a framework of orogenic collapse and translithospheric strike-slip deformation.

Distribution and timing are also compatible with earlier suggestions involving lithosphere swells following buildup of heat [33], due to either insulation by the lithosphere itself [4, 5] or by debris of subducted slabs accumulated at the core-mantle boundary [53].

- Can these hypotheses be integrated?

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