Nyalga PSC XVI, Mongolia:
Structure Development History Study and Evaluation of Basin

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SUMMARY

The geometry and deformation history of the Nyalga basin and its sub-basins in the China-Mongolia border region (CMBR) are investigated, with the emphasis on the Kherulen sub-basin. The findings are compared to the better understood, contemporaneous East Gobi basin (EGB) and both are put in the large tectono-sedimentary context that was established in a companion report (Kraus, 2010a). Nyalga records a protracted history from initial rifting and tectonic subsidence along a set of large conjugate shears in the Upper Jurassic to oblique compression, uplift, and erosion from the uppermost Lower Cretaceous on. In contrast, the East Gobi basin opened along tensile fractures but shares the later history of oblique compression. Despite their geometric differences based on different opening modes, the kinematics of both basins agree well with the published tectonic models for eastern Mongolia.

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1. Introduction

This report describes the geometry and structural evolution of the the Nyalga basin and its sub-basins in the context of the better explored East Gobi basin (EGB) and the China-Mongolia border region (CMBR) (Fig. 1). Nyalga Block XVI broadly coincides in extent with the relatively underexplored Nyalga basin (also referred to as 'Nilga' basin) (Fig. 2). Owing to the poor data, better exposed and explored nearby analog basins have been traditionally used in order to explain Nyalga's geometry and its structural and sedimentary development. These analog basins are aligned around the China-Mongolia border and share much of their geological evolution and therefore most likely have similar petroleum systems (Fig. 1; Kraus, 2010a and references therein). They are the Nyalga, Choibalsan, Tamtsag, South and East Gobi basins in southeastern Mongolia, and the Yingen, Erlian, Hailar basins in northeastern China, collectively referred to as the CMBR (Meng *et al.*, 2003). The best researched and thus most frequently used analogues are the heavy-oil producing EGB and, to some extent, the Tamtsag basin, with their numerous sub-basins. Recently, our knowledge of the Nyalga basin has increased through a new seismic survey and the interpretation of geological maps and Landsat images, and through reconnaissance field work. In the following, the latest knowledge of the development of Nyalga is reported and compared with published data on the EGB.

2. REGIONAL GEOLOGY

Nyalga Block XVI is located in east-central Mongolia, forming a structural corridor together with the Choibalsan basin, that is draped around the rigid Hangay-Hentey dome to the north along the Mongol-Okhotsk oceanic suture (Fig. 1). Two parallel corridors are located south and therefore more distal to this suture. The adjacent corridor consists of the South and East Gobi and Hailar-Tamtsag basins, and the most distal corridor hosts the Yingen and Erlian basins. All three corridors define the CMBR (Fig. 1).

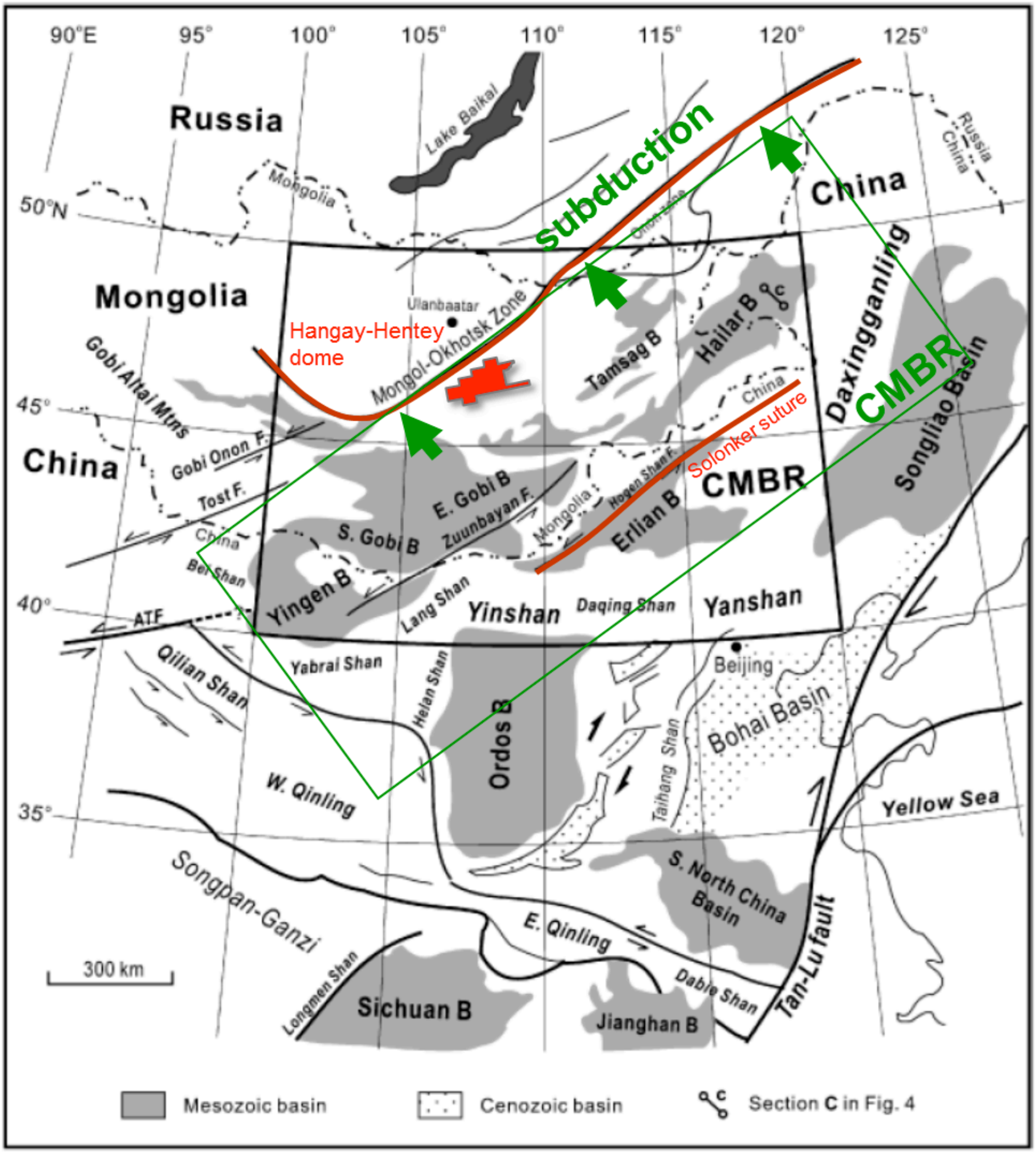

Fig. 1. Tectonic map showing the distribution of the Mesozoic sedimentary basins in North China and southern and eastern Mongolia. Green box delineates the China-Mongolia border region (CMBR) Nyalga Block XVI is red and the red lines track the oceanic sutures. Modified from Meng *et al.* (2003).

The CMBR has a joint tectono-sedimentary history since the end of the Permian, when the southern Mongolian terranes, likely island arcs, had been amalgamated into an accretionary collage, and docked onto the North China block (*e.g.* Webb and Johnson, 2006). Convergence between the Siberian continent and the CMBR collage/North China block led to northwestward subduction during terminal collision, until the Mongol-Okhotsk ocean closed in the Middle to early Late Jurassic (Fig. 1; Zorin, 1999; Kravinksy *et al.*, 2002; Meng *et al.*, 2003). These amalgamation processes were accompanied by bimodal volcanism and the intrusion of several granitoid suites that acted as rigid buttresses during later deformation – and their erosional debris constitutes 'clean' (*i.e.* low-feldspar and therefore clay-poor) reservoir rock. The CMBR experienced intermittent extensional deformation from the end of the Jurassic to the end of the olower Cretaceous. Slab breakoff from the subducting plate caused subsidence and magmatic underplating, which resulted in extensive oblique rifting ['transtension'] and rift-related volcanic rocks including flood basalts (J3-K1 Tsagantsaav Fm.), and 'tectonic' lakes (K1dz1&2 Zuunbayan Fm.) covering much if not all of the CMBR. Once the tectonic plates had readjusted, oblique compressional deformation ['transpression'] prevailed again, causing large-scale inversion along extensional faults during the Late Cretaceous and the Cenozoic. The geometry and deformation history of the Nyalga basin are established in the following, the latter in the context of the better known EGB.

3. NYALGA BASIN GEOMETRY

The Nyalga basin (Fig. 2) consists of eight first-order sub-basins which are orientated in 2 main directions: a set of east-northeast-trending sub-basins (Shiree, Kherulen, Bayanmunkh) is wider than the set of northeast-trending ones (Abdarbayan, Bayan Sum, Choyr, Delgerkhaan, and an unnamed one). The sub-basins of both directions intersect, for example the Kherulen and Delgerkhaan sub-basins. Each first-order sub-basin is subdivided into several second-order sub-basins separated by horsts/basement uplifts.

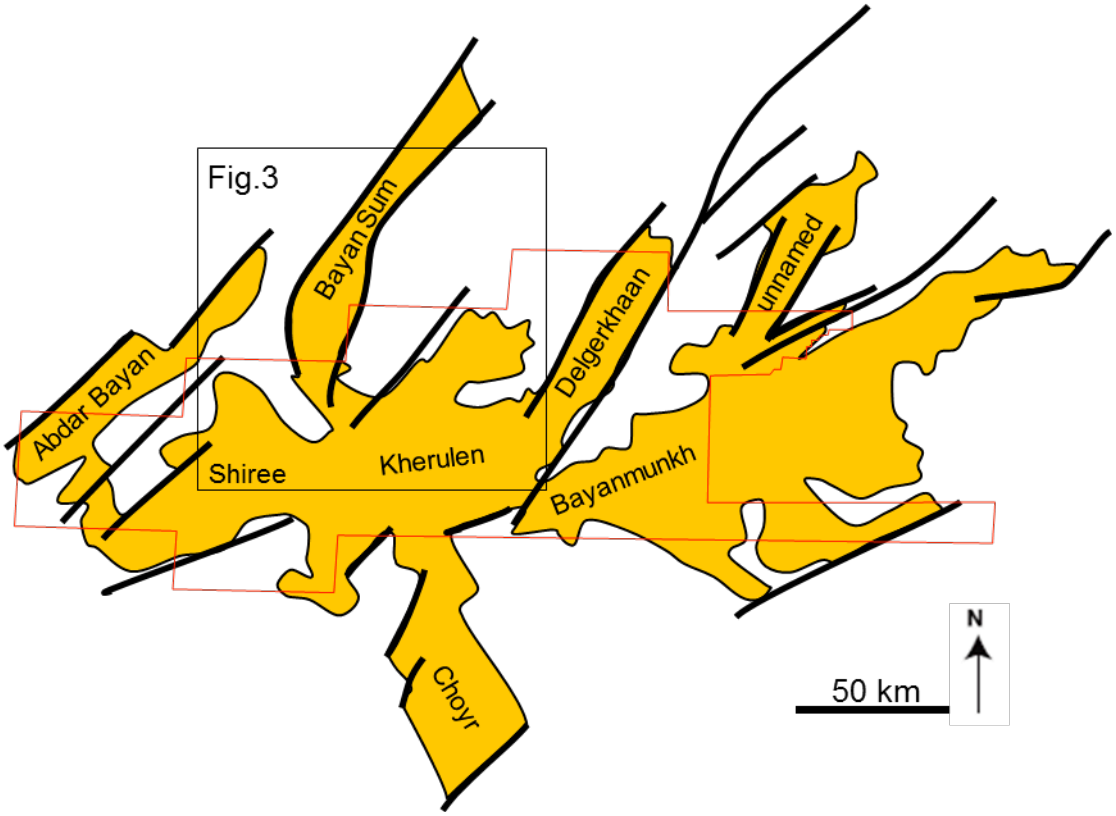

Fig. 2. Map of the Nyalga basin showing sub-basins, major faults, and block outline.

Zooming into the Kherulen and Bayan Sum sub-basins, they appear to contain the same basin fill, despite their different orientations (Fig. 3; BP Report, 1991). They are floored by >500 m of Upper Jurassic lacustrine and minor intraformational fluvial and volcaniclastic sediments (Sharilyn Fm.), and they host the complete Upper Jurassic to Lower Cretaceous syn-rift volcanic and lacustrine sequence (Tsgaantsaav Fm. > 630 m and Zuunbayan K1dz 1 > 570 m, K1dz2 > 625 m formations). The Upper Jurassic to Lower Cretaceous sequence is deformed and overlying undeformed Upper Cretaceous (K2) high-energy fluvial sediments are preserved locally, usually in the centres of the sub-basins. A summary of the Upper Jurassic and Cretacous section is given in Table 1.

The horsts that separate the *first- and second-order sub*-basins appear to be seismically isotropic. They are interpreted as being composed mainly of Paleozoic and older granitic and crystalline basement. Clastic J3 to K1dz2 wedges are typically thickest along the horst-bounding faults, but the overall thickness increases towards the basin centre.

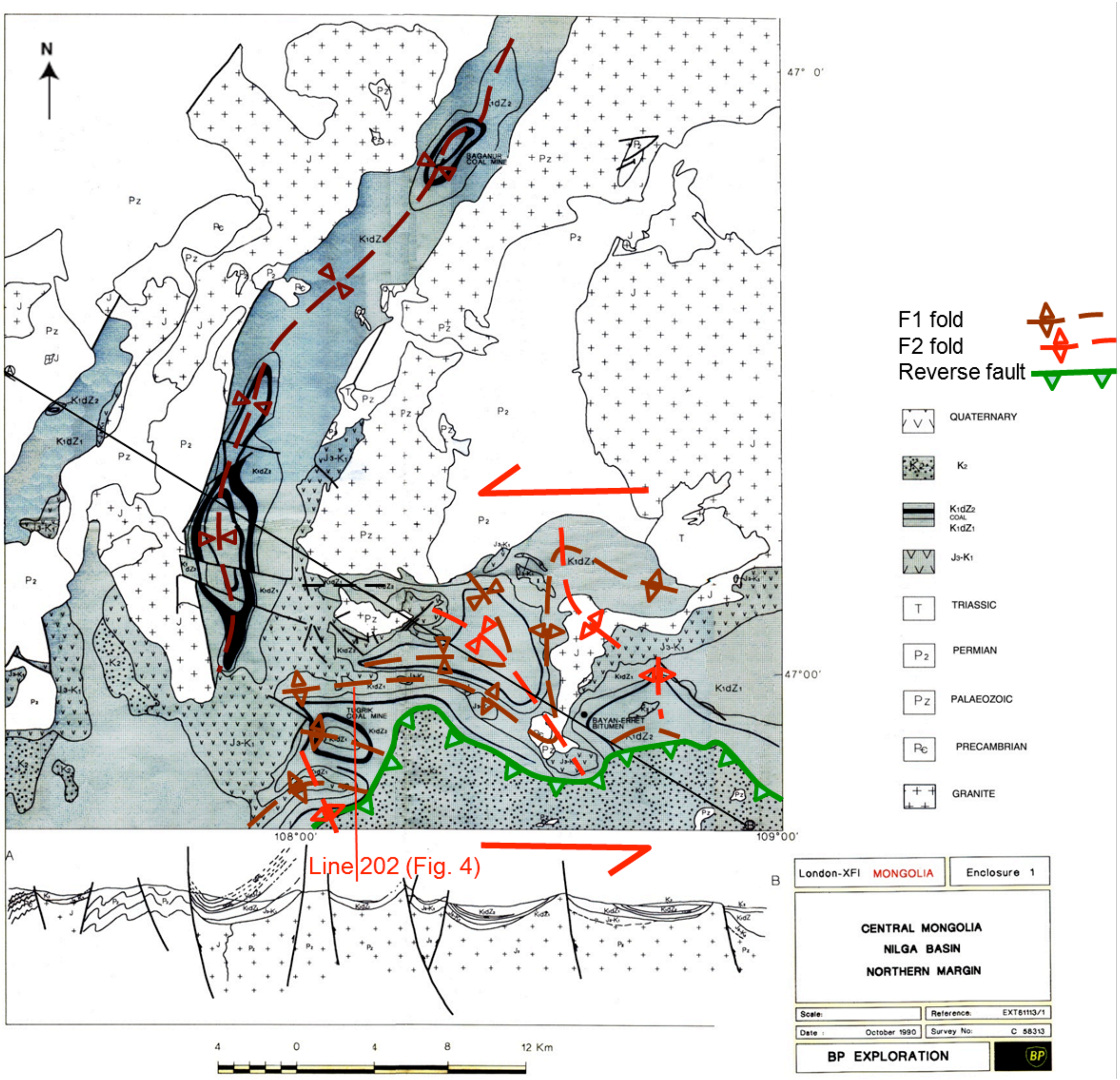

Fig. 3. Geological map of northern Shiree & Kherulen (and Bayan Sum) sub-basins with deformation sequence added. From BP report (1991).

These wedges show later compressional strain (shortening) owing to inversion postdating rifting. The northeast-trending Bayan Sum sub-basin is folded along its length into a syncline that appears gently refolded and the easterly trending Kherulen basement shows also two generations of folds (Fig. 3).

Age	Formation	Facies	Thickness
Tertiary	?	Fluvial sandstones, conglomerates, minor mudstones	<100 m
K2	Sainshand	inversion-related high-energy braidplain and fan sandstones and conglomerates; unconformity 2 at base	>80 m
K1dz2	Up. Zuunbayan	coal swamps; fluvial migrational channel sandstones, pebble conglomerates, and allochthonous coals, with thin mudstones and reddened overbank sand bodies due to inversion; erosive lower contact	>625 m
K1dz1	Low. Zuunbayan	syn-rift lacustrine, anoxic, saline shales & mudstones, interbedded with sandstones	>570 m
J3-K1	Tsagaantsav	continental & lacustrine mudstones, limestones, siltstones, sandstones, conglomerates. With >630 m of early syn-rift basalts and andesites and associated tuffs at the base.	>>630 m
J3	Sharilyn	lacustrine carbonates with minor intraformational fluvial and volcani-clastic rocks; unconformity 1 at base	>500 m
Mid Triass. – J3	?	Continental red-beds: conglomerates, sandstones, minor mudstones, and basalts	<1700 m

Table 1. Summary of Upper Jurassic and Cretaceous section in area of Fig. 3. Data taken from BP Report (1991).

A generation F1 with a wavelength of 2-4 km is refolded on a larger scale into a prominent s-shaped F2 fold pair near the Bayan Erhet bitumen deposit (Fig. 3). The outcropping F1 folds are well imaged in the northern part of seismic line 202 which transects the northern part of the Kherulen sub-basin, where they appear to constitute fault-propagation folds above blind thrusts (Fig. 4). Line 202 constitutes a cross section across two smaller, second-order grabens separated by a horst. The seismically isotropic central horst, viewed in context with the gravity data, may constitute granitoid (related to terminal continental collision, possibly of Permian age) or crystalline basement. The horst has listric, concave lateral terminations, which constitute faulted contacts with the country rocks. To the south of the horst, both the eroded granite top and a folded stratigraphic section from Upper Jurassic (Sharilyn Fm.?) through Lower Cretaceous (Tsagaantsav & Zuunbayan formations) is overlain by Upper Cretaceous rocks. The base of the Upper Jurassic is draping at a low angle along the faulted granite contact and the Upper Cretaceous appears unfolded in the 202 section plane (which is near-parallel to the F2 axial plane and thus the effects of F2 folding, if K2 was folded, would not be noticeable in this section). The CMBR-wide unconformity 1 (Table 1; Kraus, 2010a, and references therein) is inferred at the bottom of the Upper Jurassic and it is folded, too, whereas unconformity 2 appears undeformed in section 202. To the north of the horst, the folded Mesozoic section has been thrusted up so that the Upper Cretaceous is now eroded.

4. DEFORMATION HISTORY OF THE NYALGA BASIN

The deformational history and sequence of events can be well constrained from the orientations of the sub-basins, outcrop patterns on geological maps, and relationships on the lines of the 2010 seismic survey. The CMBR-wide unconformity 1 at the bottom of the J3 Sharylin Fm. indicates collision-related compressional deformation prior to extension and basin opening. Since the sub-basins of the two main orientations appear to be floored by the same stratigraphic unit (Upper Jurassic Sharilyn Fm.), they must have opened simultaneously. This can only have happened during initial Late Jurassic rifting following breakoff of the northerly subducting-slab after terminal collision of the CMBR (Mongolian amalgamated island arc tract) and the Siberian continent. North-south

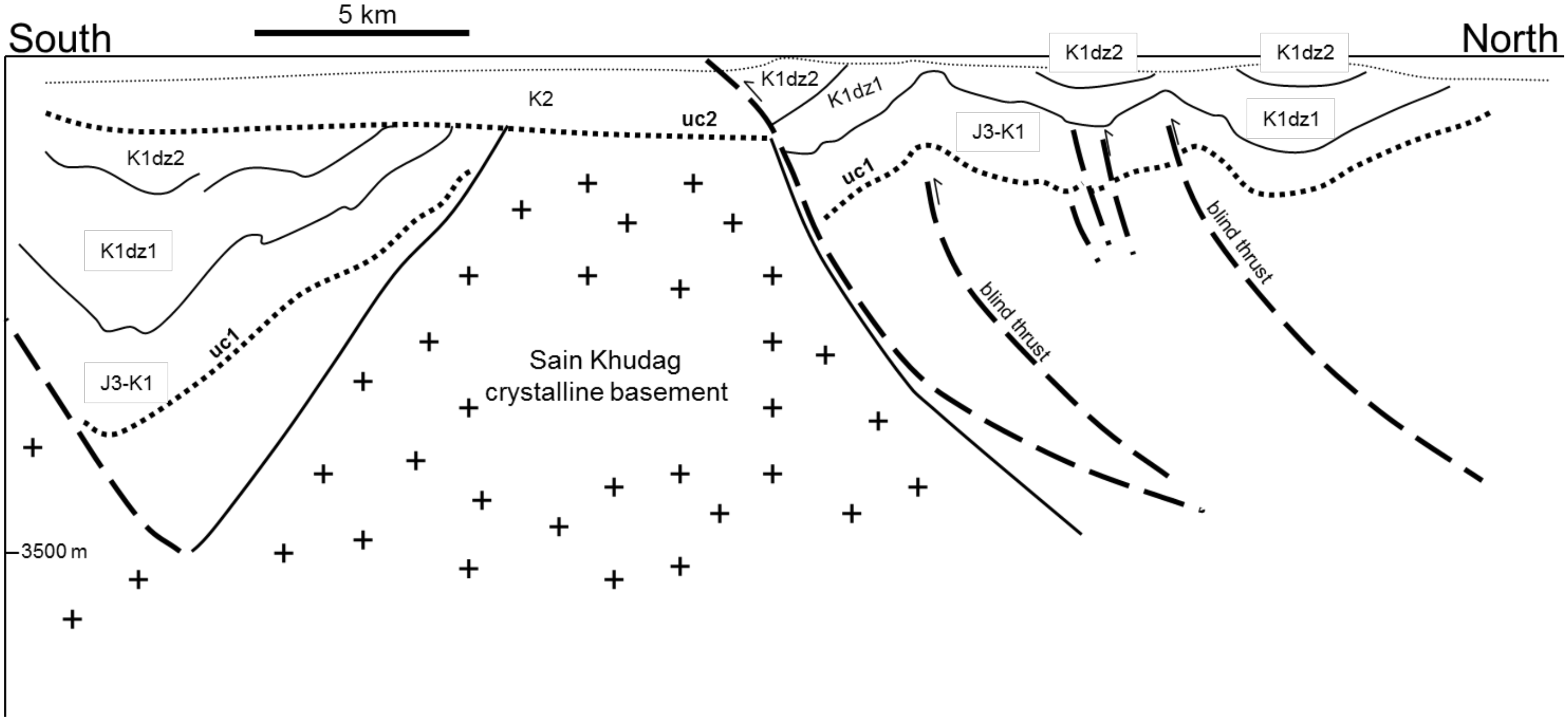

Fig . 4. Interpreted seismic line 202 through the Kherulen sub-basin (S. Farner, pers. comm. 2010). See Fig. 3 for location. See Table 1 for description of lithological units.

extension (gravity pull) generated conjugate faults pairs in easterly and northeasterly orientations so that the the obtuse bisectrix between the two constitutes the extension direction (Figs 5 & 6a). The faults grew into sub-basins in a transtensional setting (*i.e.* simultaneous strike-slip and extension). The strike-slip component is dextral on the east-northeast trending sub-basins and sinistral on the east to east-southeast-trending ones. The east to east-southeast-trending sub-basins opened wider, possibly through coalescence with the narrower east-northeast-trending ones and/or owing to slight relative rotation of extension direction and bounding faults during plate re-arrangement. Continued opening led from a volcanic environment through possibly a fluvial environment in the Upper Jurassic to tectonic lakes in which the Lower Cretaceous sequence was deposited. The extensional faults acted as growth faults so that the sedimentary wedge was always thicker near the bounding normal faults. Paleozoic, island-arc-related granites and other crystalline basement acted as local sediment sources for clean, porous, permeable reservoir sandstones (low feldspar content), but also as rigid buttresses along which the fluvial and lacustrine sediments were deposited.

Following the deposition of the uppermost Lower Cretaceous rocks (Upper Zuunbayan Fm.), large-scale basin inversion took place (in the CMBR), likely due to the re-adjustment of the tectonic plates following the slab breakoff and related tectonic subsidence – and possibly the beginning indentation of Asia by India. The rigid basement buttresses, like large nuts in a cake, moved closer together, which caused the re-activation of the normal faults as reverse faults, and related folding (Fig. 4). The compression direction was north-northeast. The main deformation was taken up by the east-trending faults in sinistral transpression (=sinistral strike-slip and shortening across the basins), leading to characteristic flower structure geometries with vertical extrusion of the rift sequence, smaller scale F1 folds and the large scale s-asymmetrical F2 fold observed in the Kherulen sub-basin (Fig. 3). Flower structures are observed on the 2010 seismic lines. The upthrusting of the folded Mesozoic section north of the granite on line 202 is ascribed to F1 shortening (Fig. 4). On the large scale, the Mongolian basins were wrapped around the rigid Hangay-Hentey passive indenter (Fig. 6b), which rotated the long-lived conjugate Nyalga sub-basins *ca.* 30 counterclockwise into their present orientations, the northeastern ‘Delgerkhaan’ trend and the eastern ‘Kherulen’ trend (Fig. 2).

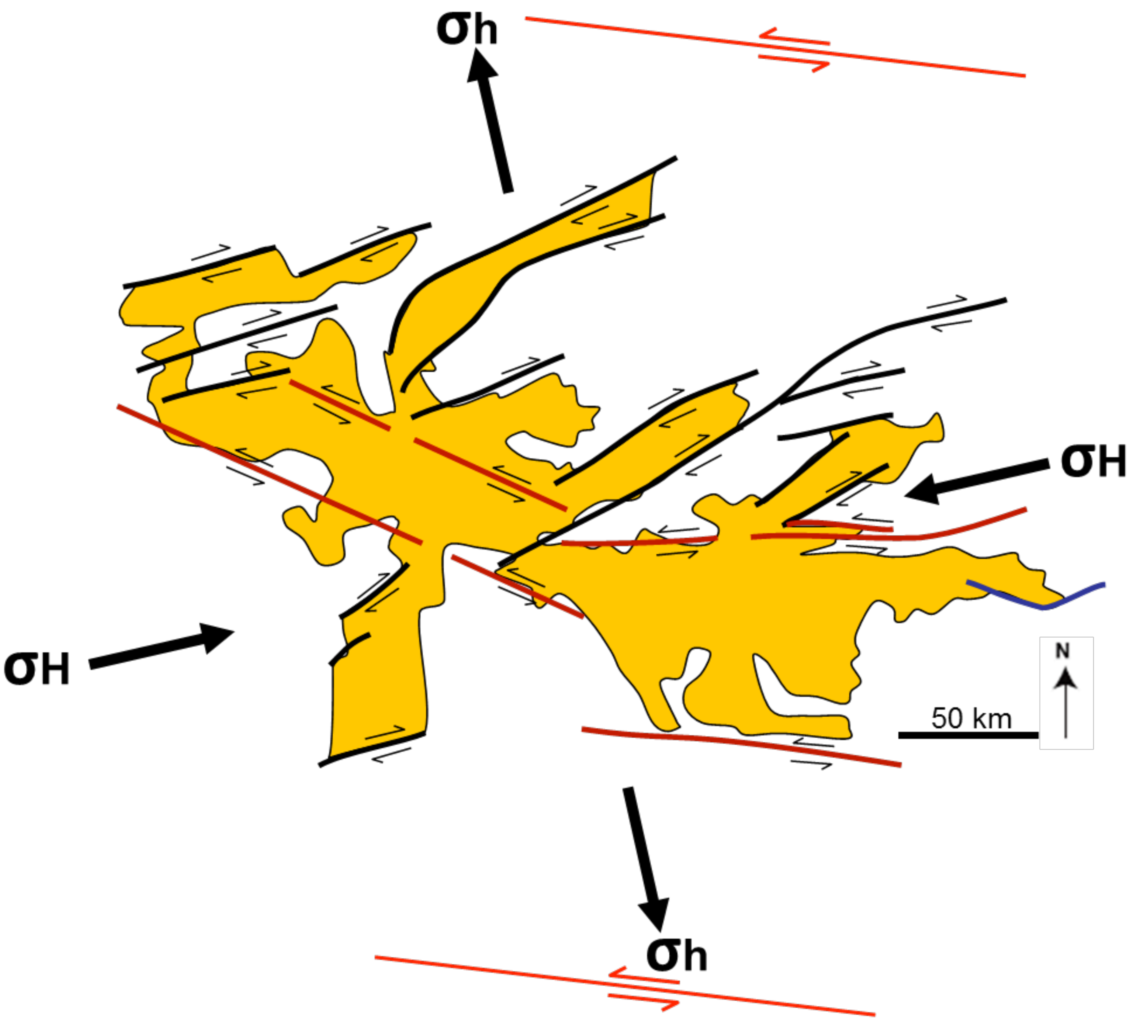

Fig. 5. Initiation of Nyalga rift basin at the Jurassic-Cretaceous boundary as sets of conjugate shear fractures. σH and σh constitute maximum and minimum horizontal stress, respectively.

5. DEFORMATION HISTORY OF THE EAST GOBI BASIN

The geometries and tectonometamorphic history of the EGB and its Unegt and Zuunbayan sub-basins and the kinematic history of the East Gobi fault zone (EGFZ) have been researched intensely since the late 1990s (Lamb *et al*., 1999; Graham *et al.*, 2001; Johnson, 2004; Prost, 2004; Webb & Johnson, 2006). The EGFZ is a > 300 km long, northeast-trending structural corridor that records protracted deformation following Late Paleozoic arc amalgamation and continental accretion – and is considered to show analogous developments to Nyalga and Tamtsag basins since that time (Fig. 7). Graham *et al.* (2001) observe three stages of Mesozoic deformation, including Late Triassic ductile sinistral shear, Early Cretaceous extension, and mid-Cretaceous basin inversion. Lamb *et al.* (1999) record left-lateral offset and extension (*i.e.* transtension) on the Zuunbayan fault and on the Gobi Onon and Tost faults north of the EGFZ, which they constrain between Triassic and early Late Cretaceous. Johnson (2004) investigates the tectono-sedimentary history of the Unegt and Zuunbayan sub-basin in detail as well as the kinematic history of the North Zuunbayan fault zone (part of the EGFZ) that separates them. The author interprets a Late Jurassic rift initiation starting with the deposition of the Sharilyn Fm., with the rift peaking in the mid- to late Early Cretaceous, and ending in inversion in the early Late Cretaceous. The offsets along the North Zuunbayan fault zone, during early synrift, were sinistral transtensional, and they were sinistral transpressional during inversion in the Late Cretaceous, continuing into the Tertiary. Webb & Johnson (2006) report Tertiary reactivation along the EGFZ: sinistral transpression in response to north-northwest compression (and east-northeast extension) caused inversion of the former extensional basins. Cunningham (2005) presents a simplified model of Tertiary active transpressional deformation in the Altai and Gobi Altai regions as a function of northeast-directed maximum horizontal compression impinging on the rigid curved boundary of the Hangay block which acts as a passive indentor focussing dextral transpressional deformation in the Altai and sinistral transpressional deformation in the Gobi Altai (and EGFZ) (Fig. 6b). Prost (2004), in stark contrast, reports Late Cretaceous to Tertiary dextral transtensional deformation

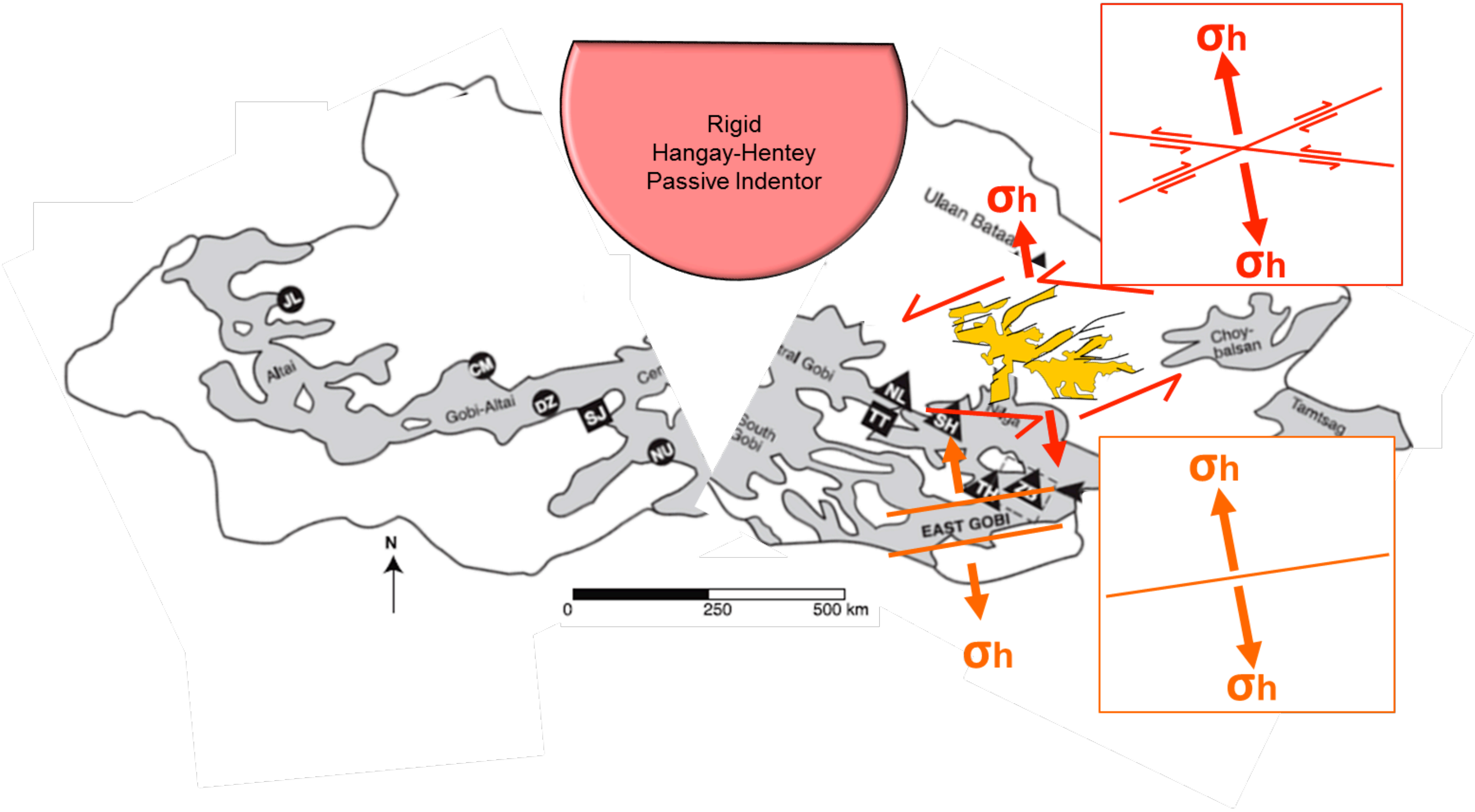

Fig 6a: Cartoon showing the possible different initiations of the Nyalga and East Gobi lacustrine rift basins in eastern Mongolia at the Jurassic-Cretaceous boundary, after removing the effects of Tertiary tectonics (*cf.* Fig. 6b). Map after Johnson *et al.* (2003).

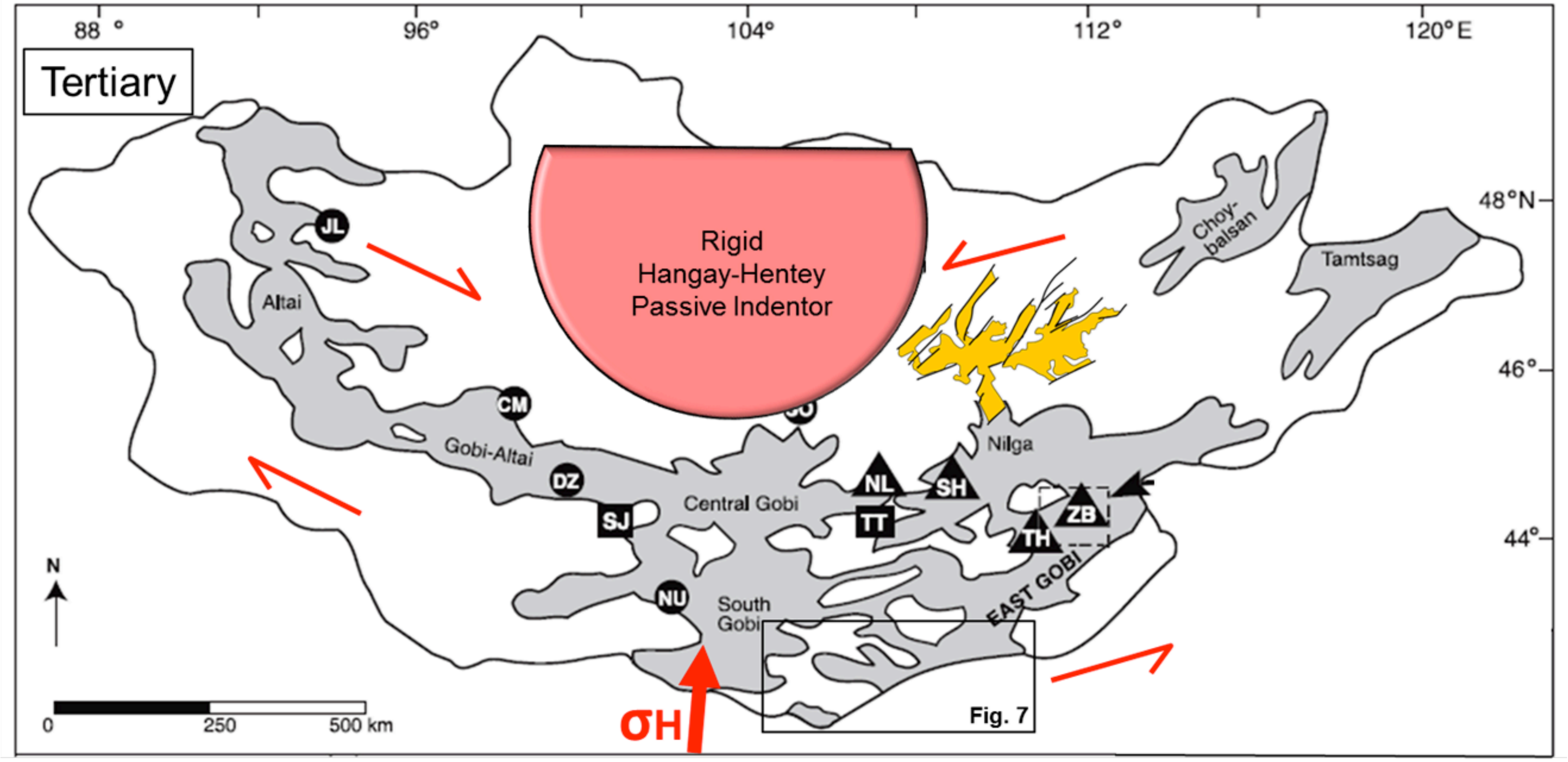

Fig 6b: Cartoon showing the Tertiary transpressive inversion, rotation, and draping of eastern Mongolia around the Hangay-Hentey passive indentor. Map modified from Johnson *et al.* (2003), with kinematic data from Cunningham (2005).

along northeast-trending SGFZ faults, following late Early Cretaceous sinistral transpression (inversion), and Middle Jurassic to Early Cretaceous dextral transtension (rifting). His interpretation is based on the evaluation of local structures out of the regional context. Therefore, the kinematics of Lamb *et al.* (1999), Cunningham (2005), and Webb & Johnson (2006) are favoured here.

6. DISCUSSION AND EVALUATION OF NYALGA BASIN

The Nyalga basin and the better researched EGB, despite apparently differing geometries, can be well correlated in terms of their tectonic and sedimentary developments (Fig. 6). From their basin fills it is evident that they started developing quasi-simultaneously. The EGB and its sub-basins, being farther away from the rift centre than Nyalga, developed along sinistral transtensional faults that correspond in orientation to the easterly trending conjugate set that delineate the Nyalga sub-basins. These EGB faults were also re-oriented into their current northeasterly orientation during the Tertiary draping of the lacustrine basins around the rigid Hangay-Hentey dome (Fig. 6b). The conjugate nature of the fault sets that delimit the Nyalga subbasins may be related to their proximity to the rift source, and it may be enhanced by orientations of rigid granite and other basement bodies inherent to this former subduction zone area. The Tamtsag basin (Fig. 1), which is aligned along strike with the EGB, is likely a good correlative of the former.

The Nyalga sub-basins are generally much deeper than their East Gobi and Tamtsag equivalents. One explanation could be Nyalga's proximity to the rift centre in the modified paleo-subduction zone. The deepening is enhanced in the intersection of its Nyalga subbasins: for example, the deepest depocentre of *ca.* 5 km exist at the intersection of the Kherulen and Delgerkhan subbasins, where conjugate faulting had produced maximum subsidence. Nyalga, from a geometrical standpoint, therefore appears to be the most promising oil basin in eastern Mongolia.

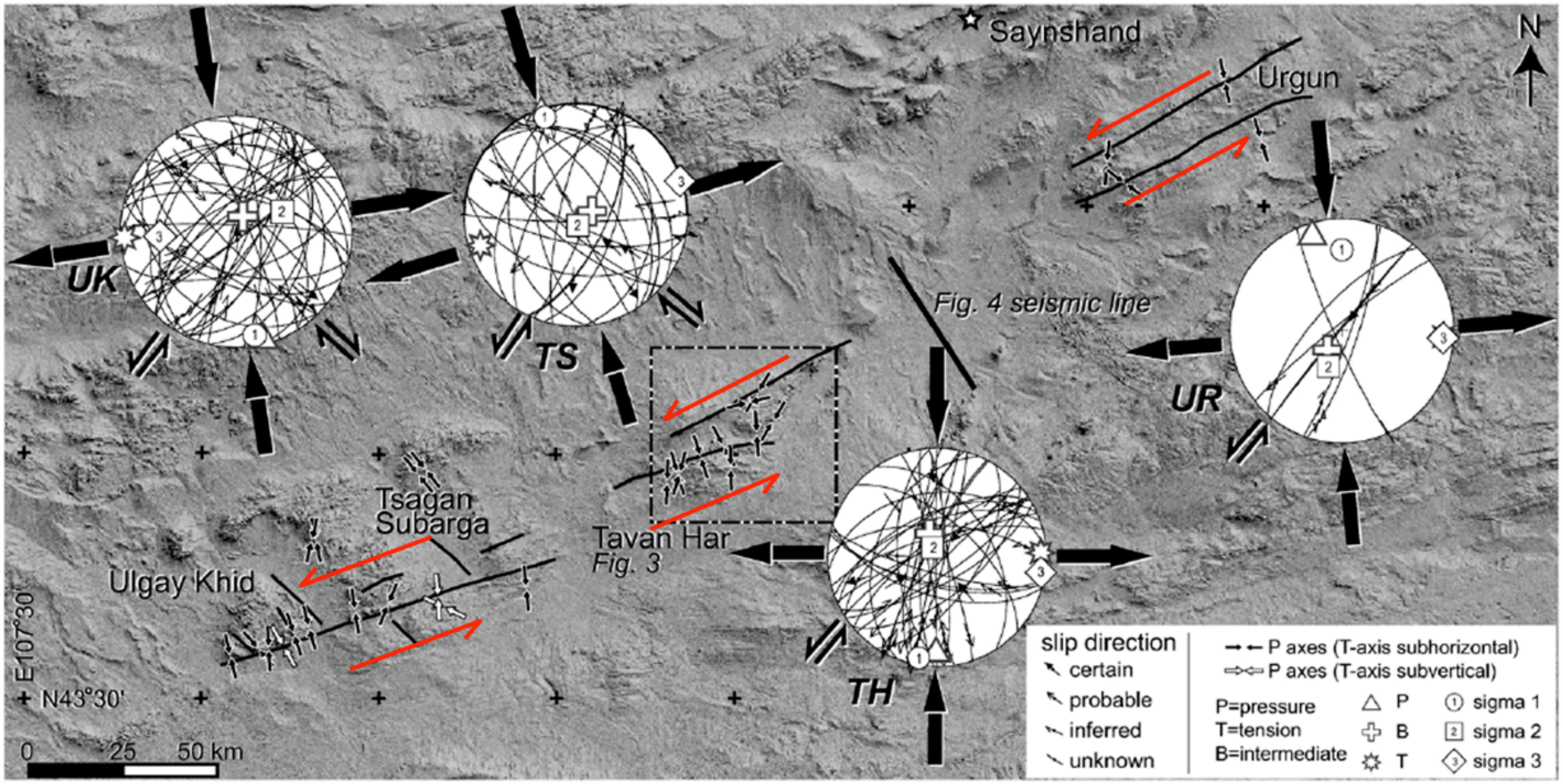

Fig 7: Digital elevation model of EGFZ with vertical exaggeration of 15. Traces of major Tertiary faults are shown as black lines From Webb and Johnson (2006). See Fig. 6b for location.

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