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Original Article

Sedimentary basins, hydrocarbons, graphite, coal, and Cu-Au deposits -from Mongolia to the Pacific margin: Interplay between the ubiquitous orthogonal fracture network and Global Wrench Tectonics

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ABSTRACT

Mongolia is exceptionally rich in coal and copper-gold resources-with world-class deposits like Tavan Tolgoi, Oyu Tolgoi and Erdenet. Thus, the mining industry has a crucial importance for the national economy, yet most of the country remain very underexplored. Within today's global tectonics, an acceptable understanding of metal enrichments -including leaching, the internal hydrostatic-hydraulic pumping system, and surface emplacement mechanisms -has remained unresolved. However, a broader view of the structural situation in the Mongolia-China region shows a close link between orientation of elongate sedimentary basins, important mineral belts, and the fundamental orthogonal fracture/fault system. In the east the tectonic trend is dominantly northeast, while it is nortwest in western areas. The main east Mongolian graphite deposits have northeast structural trends like numerous regional Cu and Au belts. A new theory of the earth, Global Wrench Tectonics, offers an exciting approach to better understanding the various facets of Earth's geological history and its surface resources. Earth's degassing, dynamo-tectonic consequences, inertia-driven crustal wrench tectonics, as well as surface products such as water, hydrocarbons and ore deposits are given a coherent system explanation. Many hydrocarbons are products from the interior of our slowly degassing Earth, with massive hydrocarbon fields such as Songliao and the Yamal megaproject producing from the basement. Crustal thinning in the Songliao region is about the same as in southeast Mongolia, suggesting that they may have had similar degassing and crustal evolution histories. As such, it is not unlikely that the underexplored Mesozoic basins of southeast Mongolia -particularly at the deepest levels and/or in the adjacent crystalline basement -may have important hydrocarbon potential.

Keywords: Mongolia, NE China, wrench tectonics, elongate sedimentary basins, and ore resources

BACKGROUND

It is generally accepted that the Earth's liquid outer core has a density deficit of 10-15%; that is, it probably consists of alloys of iron and light elements such as hydrogen, silicon, carbon, oxygen, and sulphur (Poirier, 1994 for a review). For example, Allègre et al. (1995) proposed an admixture of 7.3% Silicon, 2.3% Sulphur, and 4% Oxygen (in wt. %), while authors like Wood (1993) and Fischer et al. (2020) regarded carbon as the most significant contributor. The latter authors claimed that the core probably contains most of the Earth's carbon content, while Okuchi (1997), based on high pressure laboratory experiments, inferred that hydrogen might be the core's major "additive". The core-mantle boundary (CMB) is thought to be extremely heterogeneous (Weber et al., 1990; Kendall and

Shearer, 1995; Williams and Garnero, 1996) -a physico-chemical complex likely to be the product of outgassing of lighter constituents from the core. If so, the core probably contains a mix of gravitationally unstable hydrides, carbides (Hunt et al., 1992) and hydrocarbon compounds (Gold, 1987), but the apparent slow development of the present iron-rich core, the non-uniform silica-rich mantle, the Moho transition, and the disparate crustal history-with its seawater, deep-sea and continental basins, hydrocarbon reservoirs and ore deposits, have remained matters of speculation. Thus, Turekian (1977) argued that, if the average carbonaceous chondrites resemble the original material of the mantle-as is commonly believed, most of the Earth's water content must still be present in the interior. Therefore, degassing of the mantle's large water content would have produced a significantly larger volume than is now present on the Earth's surface. Furthermore, the bewildered state having emerged from seismic mantle tomography, has led to a series of shifting ad hoc hypotheses (Kellogg et al. 1999; Van der Hilst and Karason, 1999; Albarede and Van der Hilst, 1999). Therefore, the rooted notion of an initially molten planetary mass, which then underwent cooling and chemical differentiation, seems ready for replacement.

Instead of the ingrained planetesimal growth from a nebular disk eddy, Cameron (1962, 1978, 1985) put forward that isolated source clouds may have been expelled as relatively concentrated, but compositionally diverse proto planets, inserted into orbit close to the Sun's plane of rotation. He proposed that the Earth began as an isolated sphere of fast rotating gas (predominantly hydrogen) and an assortment of rock dust-at temperatures close to that of outer space (ie. c. 2.725K/-270ºC). Alfvén and Arrhenius (1976) suggested that the Earth's primordial daily spin rate may have been as fast as 5-6 hours. Thus, centrifugal radial segregation, with respect to density, size, shape, and other particle properties (Cooke et al., 1976; Donald and Roseman, 1962; Fan et al., 1990; Hill et al., 1997) is likely to have occurred in such a fast-rotating gas-particle cloud. In this process, elements like potassium, uranium and thorium would be concentrated at the outer region which would have experienced significant rise in temperature caused by radioactive decay, while the deep interior remained in the initially cold state. Several authors (Ramberg, 1951; Glickson and Lambert, 1973; Richter, 1985; Fowler, 1990; Thompson et al., 1995) have demonstrated that heat production in the crust, from break-down of long-lived radioactive isotopes, must have been greater in the Archaean than today. However, due to the originally low temperatures of the deep interior, degassing has been a very slow process and apparently still in progress. Thus, redistribution of inner mass has led to the documented changes in planetary dynamics (spin rate and spatial reorientation of the Earth's body/true polar wander), which in turn have given rise to inertia-driven surface tectonic events. Therefore, Earth's geological history, the extraordinarily late (post-Precambrian) expulsions of surface water (the first instalment was concurrent with the explosion of higher marine life in the Lower Palaeozoic), and injection of crustal ore deposits have all been episodic, with Shen et al. (2018) documenting six pulses in central Asia during the Palaeozoic and Mesozoic eras with ~32-68 Ma intervals between the metallogenic pulses (Table 1). The CMB seems to be bumpy, and Morelli and Dziewonski (1987) found that its "topographic" heights may be thousands of kilometres, while the boundary is flat in other regions. When the elevated features are projected onto the Earth's surface, CMB regions correspond to the present world's oceanic depressions. This hint to the possibility that processes in the core release energy as well as buoyant masses that on the surface of the Earth lead to formation of the thin deep-sea crust. The apparent relationship between the gross surface topography and the CMB 'morphology' gives a 'first order' indication of an overall continental stationarity. In this connection, seismic studies of the upper mantle are consistent with the, by now, well-accepted concept of continental roots (Dziewonski and Woodhouse, 1987; Forte et al. 1995; Ekstrom and Dziewonski, 1998); they show relatively fast seismic velocities for the upper continental mantle, and correspondingly reduced velocities for oceanic mantle. That is, the continental-oceanic surface configuration is anchored to corresponding deep upper mantle relationships, a connection that seemingly also can be extended inward to the undulating core-mantle boundary layer.

As the, by now, well-established continental root aspect is a serious impediment to plate tectonics, it is ignored. Therefore, paleomagnetic data in terms of crustal mobility must be related to an alternative mobilistic theory. Such an alternative dynamic system is readily at hand, brought about by crustal inertia effects triggered by Earth's unrelenting variable rotation-the geophysical prerequisite of Global Wrench Tectonics (Storetvedt, 1990, 1997, 2003/2023, 2011). According to the new tectonic fundamentals, the granitized upper continental crust has an old Precambrian substrate-petrologically altered and structurally modified by a long history of penetrating degassing fluids. This *in situ* geological progression has for example gradually built up the fault-bounded tectono-magmatic "terrane" complexity in Mongolia (Michaelsen and Storetvedt, 2023).

In evolving oceanic regions, the presence of reactive hydrous fluids has given rise to subcrustal eclogitization; the large density increase resulting from these metamorphic transformations has destabilized the lower granulitic crust and caused it to detach from the crust above (Leech, 2001). This metasomatic-gravitative process has gradually given rise to the variably thin oceanic crust and associated isostatic surface subsidence. The model proposed by Leech requires hydrous fluids rather than temperature to drive eclogitization and subcrustal delamination. Elongated continental sedimentary basins, such as those in Mongolia and eastern China, have a similar origin -the basic requirement is the availability of water. The only difference is that subcrustal eclogitization, gravity-driven upper crustal thinning and basin subsidence, has occurred along prominent crust-cutting fault zones. Resulting crust-mantle undulations are unlikely to be observed in conventional seismic Moho mapping. Global dynamic changes (reorientation of the body of the Earth and its speed of rotation) have also acted as a kind of hydraulic pumping mechanism which has driven water, hydrocarbons and metal-containing liquids to the surface. Therefore, it is important to assess the importance of the fundamental fracture systems in upper mantle and crust-in that they represent pathways for ejection of fluids and ores to the surface.

At the end of the Archaean, with the origin of

Table 1. Schematic overview of the six main mineralization pulses of major Cu-bearing porphyry and Au deposits in central Asia. Modified from Shen et al. (2018). Note the significant intervals between the major metallogenic pulses of 32-68 Ma as well as the lack of mineralization pulses during the Permian.

Mineralization pulse #	**Pulse 1**		**Pulse 2**		**Pulse 3**		**Pulse 4**		**Pulse 5**		**Pulse 6**
Timespan of pulse (Ma)	490-475		443-435		374-370		335-310		242-240		180-179
Geological period	Cambrian–Ordovician		Silurian		Devonian		Carboniferous		Triassic		Jurassic
Interval between pulses (My)		32		61		35		68		60	
Wunugetushan (China)											
Boroo (Mongolia)											
Erdenet (Mongolia)											
Bayan Khundii (Mongolia)											
Almalyk (Uzbekistan)											
Kharmagtai (Mongolia)											
Tuwu-Yandong China)											
Aktogay (Kazakhstan)											
Kounrad (Kazakhstan)											
Yubileinoe (Kazakhstan)											
Tsagaan Suvarga (Mongolia)											
Oyu Tolgoi (Mongolia)											
Koksay (Kazakhstan)											
Nurkazgan (Kazakhstan)											
Duobaoshan (China)											
Bozshakol (Kazakhstan)											

the first greenstone belts around 2.5 billion years ago, it is likely that the Earth still had an inverse temperature profile-warm in the exterior (crust and part of the upper mantle) and relatively cold in the deep interior. But the often elongate (probably fault-bounded) shape of the greenstone belts suggests that the crust had become more brittle. Further cooling led to shrinkage, which caused deep contraction dislocations -so-called Benioff zones (Benioff, 1949, 1954). Although the Circum-Pacific Benioff Zone appeared highly distorted, and a large section of it was hidden beneath western North America, Wilson (1954) believed that these deep contraction structures had fundamental global tectonic significance. He attributed the tectonic structures around the Pacific Ocean as fragments of an originally great-circle contraction belt formed during the cooling of Archaean crust and upper mantle. The arcuate Indonesian Benioff Zone was thought to be part of another deep great-circle fault zone (subsequently deformed), allegedly continuing along the narrow epicontinental Tethys on the southern flank of Eurasia, and which during the Phanerozoic had undergone slow subsidence and sedimentation. In the Jurassic, the continental crust along the narrow Tethys had broken up into a horst-and-graben topography, resulting in varying water depths (Trümpy, 1965, 1971; Falcon, 1967; Stöcklin, 1968). At that time, the epicontinental Tethys seems to have continued across the present Central Atlantic to the Caribbean (Aubouin et al., 1977; Hallam, 1977).

As plate tectonics became the dominant model in global tectonics, the traditional view of the Tethys as an elongate and narrow epicontinental sea (Sonnenfeld, 1981 and references therein) was replaced by a large-scale fan-shaped indentation of the Pacific. This was Wegener's idea that geoscientists for decades almost unanimously rejected. But with the embrace of plate tectonics some 50 years ago, both Wegener, the fan-shaped oceanic Tethys, and his Gondwana assembly have been almost unanimously accepted-albeit on doubtful scientific grounds. In addition, re-evaluation of paleomagnetic data (Storetvedt, 1990, 1997) has unveiled those interpretations in favour of wandering continents, as well as questionable paleomagnetic attempts to confirm Wegener's Gondwana, have led global tectonics astray. However, by correcting the present continents and continental blocks for their individual Alpine-age wrench rotations in situ, the two Benioff belts take on great-circle shapes-in support of the Wilson proposal. As we shall see below, the two Benioff zones proposed by Wilson (1954) have utmost importance for understanding the global distribution of porphyry metal deposits.

Accepting the combined Benioff/Wilson proposals, the deep upper mantle fracture zones would have served as effective conduits for leaching and upward transport of metal-bearing fluids, after which narrow surface belts of metal concentrations, deposited in transtensive segments of fracture zones, would have occurred. When the proposed Benioff zones are corrected for Alpine age wrench tectonic deformation, the exposed surface sectors are indeed characterized by narrow and relatively concentrated copper and gold deposits-for which tectonic details and ore aspects will be addressed in a later paper. On the other hand, the broad metalliferous belts of Central Asia-included in the present paper, lacks a deep Benioff zone. The degassed ore deposits must therefore have found alternative routes to the surface. This leads to another fundamental aspect: the ubiquitous steeply inclined and near-perpendicular sets of rock discontinuities (Scheidegger, 1963). Small-scale concordant and conjugate fault systems form a worldwide orthogonal joint-fault system, often genetically linked to major fault zones and cratonic dyke swarms (Lyatsky et al., 1999). The orthogonal fracture network not only characterizes the Earth's surface, but is also recognized on the Moon, Mars, and Venus (Hast, 1973; Fielder et al., 1974; Phillips and Hansen, 1994; Cattermole and Moore, 1997). This suggests that the orthogonal tectonic system is a general phenomenon dating back to surface consolidation of terrestrial planets. On Earth, the original fracture pattern, probably of late Archaean age, has obviously been transferred to increasingly younger surface rocks, in concert with degassing-related dynamic pulses. Fig. 1 shows representative examples from the North

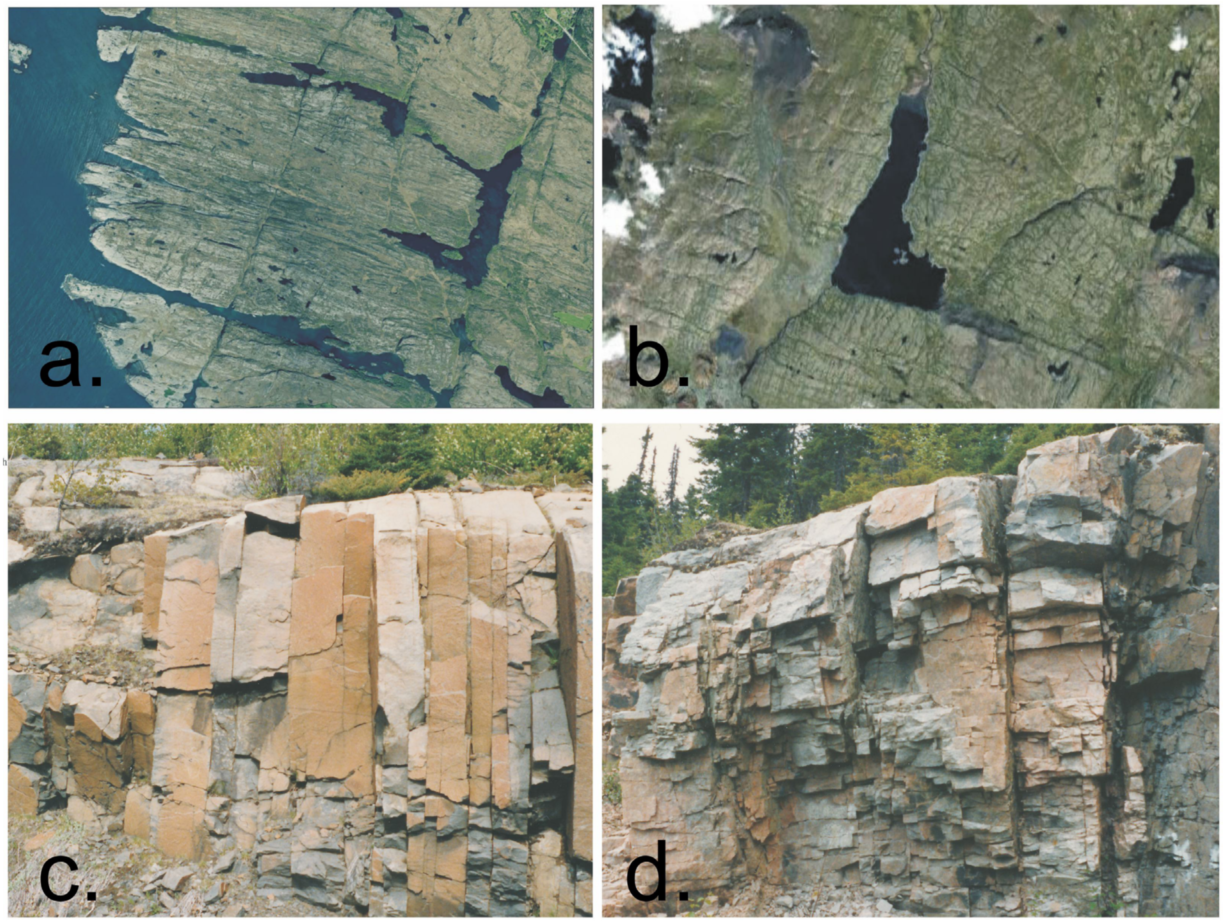

Fig. 1. Examples of the steeply inclined orthogonal fracture/fault network. a) and b) are satellite images from the metamorphic basement of coastal southwest Norway and the Tertiary lava complex in Iceland (Langavatn) respectively. c) and d) are photos (by KMS) from road cuts in the Appalachians of Newfoundland.

Atlantic region. Note that the fracture network in Precambrian-Caledonian gneisses of Western Norway is the same as in late Tertiary lavas in Iceland -both satellite images having the same geographic orientation.

With the deep oceans having formed during the Upper Cretaceous (as confirmed by Deep Sea Drilling), the resulting continents were by then surrounded by thin and mechanically weak oceanic crust -and Eurasia and Africa were split by the faulted Tethyan Benioff belt. Hence, the stage was set for palaeolatitude-dependant inertial wrench rotations of individual continents, along with tectonic deformation of the thin deep-sea crust. The upper Eurasian crust (Michaelsen and Storetvedt, 2023 and references therein), being located north of the Upper Cretaceous-Lower Tertiary palaeoequator, has since then been subjected to a clockwise rotation of c. 25° (Storetvedt, 1990). However, tectonic torsion of large extensively fractured landmasses would be expected to have undergone internal deformations especially in the upper crust, which we (Michaelsen and Storetvedt, 2023) conclude has occurred in Mongolia. This is probably the reason for the overall moderate eastward torsion of the Eurasian orthogonal fracture network. Along the North Atlantic margins, the tectonic sets have NNE and WNW orientations, while in Central Asia they are dominantly oriented NE and NW respectively. Moreover, GPS velocity vectors (Fig. 2) show that there is an ongoing clockwise rotation of Eurasia (Zemtsov, 2007) - demonstrating the tectonic system of the inertia-driven Global Wrench Tectonics.

According to the biogeographic evaluation of Spjeldnæs (1961), the late Ordovician (Caledonian) equator ran along eastern North America, continuing via the Arctic, further across Central Asia in a NW-SE direction. Within this palaeoequatorial belt, Mongol Altai -traditionally referred to as Caledonian, and following along one of the primordial orthogonal fracture sets, became an overall transpressive

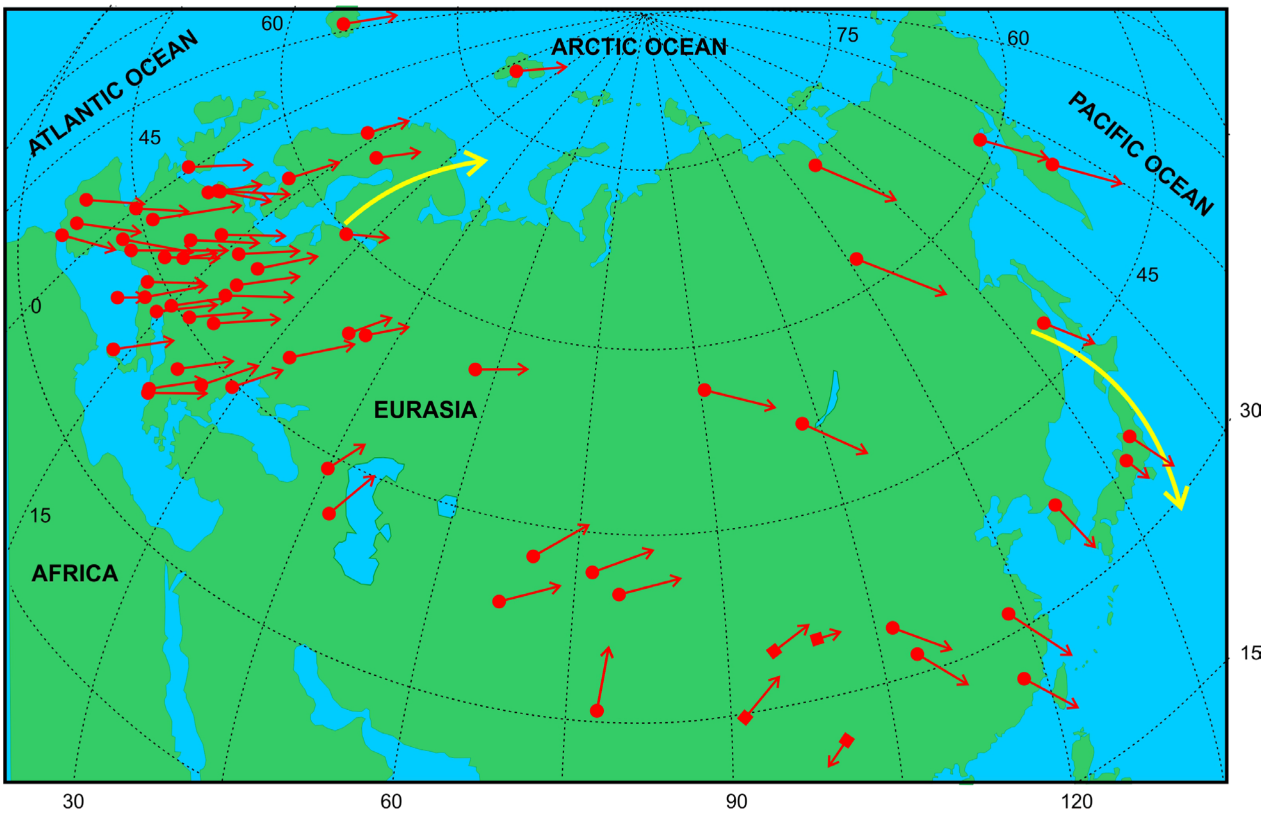

Fig. 2. Simplified version of GPS compilation map for Asia (Zemtsov, 2007)

belt. The passage of the Caledonian equator along the southwestern tip of Mongolia led to strong reactivation of the orthogonal fault network of Central Asia -which again laid the foundation of the complex wrench tectonic development of regions such as Mongolia and eastern China. Many transtensive sectors developed narrow and deep channels that paved the way for outgassing products, such as hydrocarbons and ore deposits. In eastern China, the NE -directed transtensive zones gave rise to eastward crustal thinning- a development that, in combination with the impact of the marked oceanization process in the Pacific, laid the foundation of the elongated coastal basins along East Asia

Sedimentary basins, coal, and hydrocarbon prospectivity

The process by which thick continental crust transforms into an increasingly oceanic structure, has many similarities to the evolutionary crustal model of Belousov (1962, 1984, 1990) who introduced the concept of *endogenous regimes*. This term includes the important role of progressive physical and chemical interaction between the crust and mantle, a process that accelerated in the Upper Cretaceous and gave rise to the uneven thinning of the deep-sea crust. This means that there are no fundamental differences in the formation of continental and oceanic basins, only in the degree and extent of their development. Many studies have shown that there is a clear correlation between deep surface basins and pinching out (delamination) of the lower crust (Pinet et al. 1987; Pavlenkova, 1996, 1998).

Pavlenkova (1996) who gave a comprehensive seismic evaluation of crust and upper mantle of Northern Eurasia, including also results from a cross-section of the circular Vilyui Basin in East Siberia (Pavlenkova, 1996). This is a crustal depression that has resulted in a sedate accumulation of unconsolidated Mesozoic sediments characterized by a pronounced negative gravity anomaly (Pavlenkova and Romanyuk, 1991). The circular shape of the basin suggests a sub-crustal fractured zone in which crustal loss to the upper mantle has proceeded at about an equal rate along the two orthogonal directions. The characteristic crustal thickness of the Vilyui region is 40-45 km (Egorkin et al., 1987), but beneath the basin the Moho depth is less than 35 km. Considering the additional thickness of overlying sediments, it follows that the thickness of the crystalline crust has been reduced by 40-50%. If only one of the conjugate sets of orthogonal crustal fractures had enabled effective crustal thinning and fluid penetration-in apparent contrast to the "chimney-like" crustal structure beneath the Vilyui Basin, crustal subsidence and formation of sedimentary basins would have taken on an elongate shape.

After the first major outflow of water in the early Palaeozoic, the pan-global continental crust was largely covered by relatively shallow seas. However, throughout the rest of the Palaeozoic, the marine flooding was punctuated by several marked regressive and related global dynamo-tectonic events (Hallam, 1992) -corresponding to sub-crustal delamination and subsidence in regions that would later become world oceans (Storetvedt, 2003/2023). The longstanding but episodic withdrawal of the widespread shallow continental seas culminated in a marked sea-level low-stand at around the Permian-Triassic (PT) boundary; by then continental masses had become drier overall than they had ever been during the earlier Palaeozoic. In Central Asia the once widespread epicontinental seas (Boucot and Johnson, 1973) had been replaced by a combination of narrow seaways, lakes, rivers and low land topography with growing vegetation. In Mongolia, inertia-driven transtensive reactivation of primordial fracture zones gave rise to the development of a sequence of related but disconnected fault-bounded sub-basins; some of which developed significant peat accumulation that subsequently led to economically important coal deposits (Michaelsen and Storetvedt, 2023). While the coal-bearing sub-basins in Mongolia are related in time, they formed as isolated entities often sandwiched in-between fault-bounded basement blocks and as such very different from the laterally continues Permian coal basins in Australia - like the Bowen Basin with over 40 active coal mines (Michaelsen and Henderson, 2000a, 2000b, Michaelsen et al., 2000, Michaelsen et al., 2001, Michaelsen, 2002).

A starting point for better understanding of the tectonic circumstances in the Mongolia-China region is the Caledonian (late Ordovician) palaeoequator, which in NW-SE direction passed along southwestern Mongolia (Michaelsen and Storetvedt, 2023 and references herein). Triggered by the palaeolatitude-dependent and westward-rotating inertia effect, the primordial orthogonal fracture system -with NW and NE orientations respectively, were reactivated (Michaelsen and Storetvedt, 2023). In this process, coal-bearing break-off basins in the Mongolia-China region developed-regionally characterized by "many in the east-fewer in the west". The eastern structurally strained basins are predominantly oriented NE whereas western ones are generally trending NW. Similarity in trends suggest they were deposited under somewhat uniform tectonic conditions -which in our case means transtensive reactivation of the basic orthogonal fracture/fault network. Due to extensive post-Permian cover sequences, however, most late Permian coal-bearing deposits are poorly defined and understood. The South Gobi Basin -a concentration of related but disconnected fault-bounded sub-basins (Michaelsen and Storetvedt, 2023, 2024), is by far the most important given its vast economically important metallic and thermal coal resources, including the world class deposit at Tavan Tolgoi with potential total coal resources of c. 10 Gt (ie. to a depth of 1,000 m). Contrary to the regionally relatively restricted late Palaeozoic coal-bearing sub-basins, Mongolian Mesozoic-Tertiary sedimentary depressions are widely distributed-notably in southern parts of the country (Fig. 3) where the tectonic wrench interplay, between the basic NE and NW conjugate fracture/fault systems, has generated a broader southward bending and disrupted links chain system. The Mesozoic-Tertiary sedimentary series are generally thicker than the late Palaeozoic basins, and in eastern Mongolia the post-Palaeozoic sequence can reach a thickness of 5 km, in an accelerating Mesozoic development. In a crustal structure study across central-south Mongolia, He et al. (2016) found that the crust thins southward -from 46 km in the Khentii region to 38 km in the southern area of the Zuunbayan Basin. Considering a maximum subsidence of 5 km, it means that the crystalline crust in southern Mongolia has been thinned by up to 10-12 km. Furthermore, by using a new approach - integrating the Bouguer anomaly gradient and the receiver function-derived crustal thickness, He et al. arrived at a relatively dense lower crust beneath the Middle Gobi region. These results are consistent with an important premise of the wrench tectonic theory: outgassing of hydrous fluids has triggered upward migrating eclogitization (ie., density increase) of the lower crust-with subsequent sub-crustal loss to the upper mantle, crustal subsidence, and basin formation. The main difference between the development of deep ocean and intracontinental basins can be attributed to the much lower content of water in the gas and liquid flows that affect and seep through the continental crust.

The geology of the South Gobi Basin is characterized by deep-seated Permian strata in places, generated by transtensive processes caused by late Jurassic to early Cretaceous wrench tectonic reactivation. Therefore, extensive tracts of Permian coal-bearing strata are overlain by significant thicknesses of Mesozoic-Cenozoic fill (>2 km in places). Norvick and Handke (2005) pointed out that between the ranges in southern Mongolia, the sedimentary basins have thick upper Middle Jurassic to late Cretaceous mega-sequences. These observations are consistent with the fact that crustal thinning and related isostatic subsidence accelerate towards the late Cretaceous- in harmony with the progressive sea-level rise and prediction of the wrench tectonic theory (Storetvedt, 2003/2023). Hence, much of the covered areas have apparently been formed as Cretaceous transtensive basins. To this end, Norvick and Handke (2005) concluded that, in places, they effectively push the Permian coal-prospective section beneath minable depths.

According to the wrench tectonic theory Storetvedt (2003/2023), the deep regression at around the Permian-Triassic boundary was directly linked to a marked subcrustal delamination-triggered by, and associated with, exhaustion of a major hydrostatic pressure build-up in the upper mantle. The marked sea-level regression must have been replaced by transgression -a sequence of relatively rapid eustatic fluctuations that gave rise to the episodic exhalation of carbon dioxide, methane, and other toxic gases that led to the largest marine mass extinction in Earth history. Thus, Hallam and Wignall (1999) concluded that "Rapid high-amplitude regressive-transgressive couplets are the most frequently observed eustatic changes during times of mass extinction".

Following the major gas exhalation around the Permian-Triassic boundary, accumulation of hydrostatic gas pressure in the upper mantle continued through the Mesozoic-

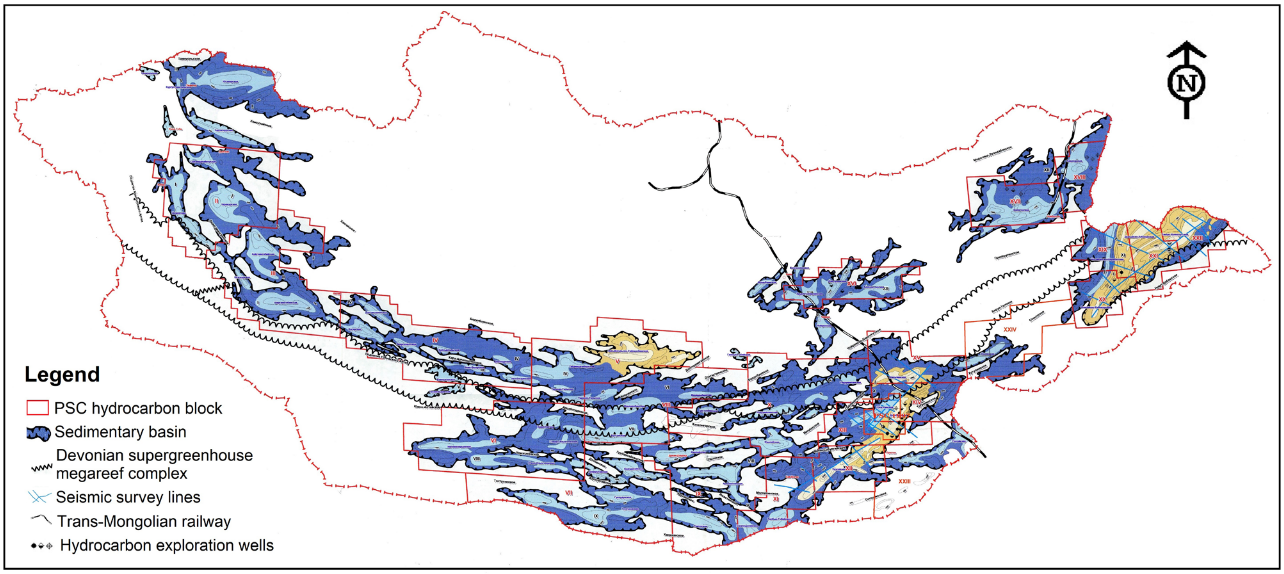

Fig. 3. Mesozoic sedimentary basins of Mongolia. The wider sedimentary belt in the south corresponds to Palaeozoic tectonic interaction between the fundamental NW and NE fault systems. The Mesozoic-Tertiary sedimentary series are generally thicker than the late Palaeozoic basins in an accelerating Mesozoic development. Map showing hydrocarbon blocks and exploration wells (a: oil, b: oil show, c: dry), seismic lines, isopaches and extensive Devonian reef zone (coiled outlines). Modified from Tatnefti (2001).

reaching its maximum during the Cenomanian transgression. The new build-up of interior gas/fluid pressure lifted the developing, and progressively thinner, oceanic crust whereby a major water pulse flooded significant tracts of low standing surfaces of the continents. After this substantial transgression, a major phase of delaminated lower crust led to sinking of the present deep-sea basins. Consequently, the late Cretaceous transgression was followed by a distinct regression at the Cretaceous-Tertiary boundary, giving rise to another major biotic crisis. However, the increasing hydrostatic pressure in the upper mantle was not only critical for formation of the relatively thin oceanic crust and its deep-sea basins. Also in the continental crust, prominent representatives of the orthogonal fracture system were intruded by high-pressure gases and fluids. The gas and liquid penetration into the continental crust expectedly led to a variety of chemical reactions, heat production, magma production and magmatic processes (Hunt et al., 1992). At surface level, transtensive segments of the primordial fracture network became pathways for rising hydrocarbons and ore-bearing fluids.

According to Hunt et al. (1992), pressure reduction will cause degassed carbides and hydrides to undergo a series of chemical reactions where H_2O and SiO_2, plus heat, may be important end products. This results in the formation of granite melts, and probably also silicon oil (a silicon-hydrocarbon structure, Gold, 1999), which causes granitization of the (upper) continental crust including injection of veins and sometimes thick veins of pure quartz (see below). Furthermore, the presence of supercritical hydrous fluids in the middle crust, which due to their low viscosity, high diffusivities, high degree of solubility, and effective metasomatizing effect (Liebscher, 2010; Schienbein and Marx, 2020), apparently can break down solid rock into rock mud, is expectedly the primary cause of the Meso-Cenozoic rift basins in Mongolia and eastern China, including the Erlian and Songliao depressions (Fig. 4). The action of supercritical fluids has most likely given rise to many silty horizons observed in hydrocarbon provinces, forming cap rocks. Once physical pathways between the upper mantle and the Earth's surface have been established, we have also ready transport routes for abiotic hydrocarbons and ore-carrying fluids. All in all, degassing eventually ends up with a diversity of surface products-water (fresh or salty), crude oil, natural gas, ore deposits, magma from chemical reactions, and gases under high

Fig. 4. Map of Mesozoic sedimentary basins of Mongolia and adjacent China, with schematized Chinese hydrocarbon fields and the Zuunbayan and Tsagaan Els oil field, South Mongolia. Simplified after Manas Petroleum (www.manaspetroleum.com).

pressure are likely to be the dominant cause of both earthquakes and craters As depicted in Fig. 4, the structural patterns of the regional Chinese oil fields are consistent with the basic orthogonal NW- and NE-oriented fracture/fault systems. The late Ordovician structural pattern has therefore formed the basis of the geological development in Central Asia (Michaelsen and Storetvedt, 2023).

Despite the overwhelming support for the biotic view of hydrocarbons, the scientific literature appears to be completely devoid of experiments in which biological material is converted into crude oil, and putative oil-producing source rocks have also remained an open question (Mahfoud and Beck 1995; Mahfoud, 2000). Major oil fields in fractured basement rocks are frequently discovered (see chapter on "Major salt basins and hydrocarbon provinces …" in Storetvedt and Longhinos, 2012), Sephton and Hazen (2013). Today there is no shortage of petroleum; several producing fields might not cease producing in the foreseeable future as they are probably being recharged from reservoirs in basement rocks (Glasby, 2006; Guo et al., 1997). Many large oil fields probably have hydrostatic connection to hydrocarbon accumulations in crystalline crust or deeper, so with increasing production and reduced liquid/gas pressure in sedimentary reservoirs, an upward replenishing stream comes in action.

In Mongolia, there are so far 33 petroleum blocks, but only four of them have advanced to production with oil discoveries or oil shows reported in a further seven other blocks; exploration is being conducted in 10 blocks and c. 1,500 oil wells have been drilled. The (proved) ultimate recovery for the four producing blocks has been estimated at 320 million barrels of oil, but between 1996 and 2021 only a mere 73 million barrels has been produced. As per today, the Mongolian oil production is therefore immaterial. Until recently, London listed Petromatad had two large petroleum blocks along the prospective Valey of the Lakes basins which had never previously been seriously explored for oil and gas. However, drilling in 2018 terminated in granitic basement at 1,490 m, and later drilling campaigns have shown only uneconomic oil and gas shows. Therefore, oil drilling within Valley of the Lakes basins has so far not been promising. On the other hand, the elongate NE-trending Toson Tolgoi sub-basin in southeastern Mongolia is the country's largest sub-basin with an area of over 3,500 km^2 and a sedimentary fill up to 5,000 m. In 2014, Wolf Petroleum carried out a 450-line km seismic survey, and from a total of 723 test hole samples, 150 of them were characterized by light oil seeps.

If hydrocarbons are degassing products from the Earth's interior, it requires that vertical migration paths are available, and that reservoir rocks and lithofacies-tectonic cap structures are present. An important question is under which conditions degassing-related wrench tectonics satisfies these conditions and thus becomes a favourable production basis in oil exploration. In a recent paper (Michaelsen and Storetvedt, 2023) we interpreted the prominent convexity of the Mongolian tectono-topographic grain as a stepwise structural transition between the two basic fault sets-with NW and NE orientation respectively. Thus, the Mongolian South Gobi region plays a decisive position for understanding the country's south-directed structural convexity -a gradual transition that must have occurred as detached tectonic elements. The crustal distortion (a link chain structure) has consequently resulted in gradual localized openings-expansion of gas and liquid pathways, thus laying the foundation for up flowing hydrocarbons and mineral combinations probably in the form of organometallics.

Some 380 km east of the Mongolian border zone and Mesozoic basins, the Songliao Basin (Fig. 4) is the largest, and high-producing, oil basin in China. It is an interesting observation that the Songliao Basin has the same inertia-based southwest curvature (Lee, 1986) and therefore presumably the same inertia-based crustal splitting up as the southeast Mongolian border basin. Moreover, crustal thinning is about the same in the two regions, suggesting that they may have had similar degassing and crustal development histories. It is not unlikely therefore that also the Mesozoic basins of SE Mongolia-notably in the deepest basins, may have substantial hydrocarbon potential. Lee (1986) wrote: "The Daqing oil field of the

Central Depression supergiant field, oil and gas in the (Songliao) reservoirs are trapped by anticlinal and nose-shaped folds, fault barriers, and lithofacies changes, which are then sealed by overlying shale and mudstone". Some cap rocks of shale and mudstone might represent the physical disintegration effect of rising supercritical fluids (Hovland et al., 2006).

The Daqing oil field has produced over 10 billion barrels of oil since production started in 1960. Oil in place was estimated at 16 billion barrels and current daily production is 800,000 barrels. Because of the apparent abundance of hydrogen and carbon in Earth's interior, there are good reasons for believing that the Daqing field, like many Middle East fields probably will continue to produce into an unforeseeable future. Moreover, there is every reason to seriously consider the oil and gas potential of the southeast Gobi basins. In case a promising sedimentary entrapment are not encountered, profitable reservoirs may be found in fractured basement rocks.

In Mongolia, inertia-based wrench deformation was in action in the late Ordovician (Michaelsen and Storetvedt, 2023), and subsequent disturbances have repeatedly swept the region-including folding phases in the Meso-Cenozoic sedimentary basins of southeast Mongolia (Graham et al., 2001). Hydrous fluids seem to play a crucial role in global tectonics, which, in their supercritical state, has apparently the ability to break down solid rocks into mud (see above). After being deposited on the surface, the mud fraction upon burial becomes shale and mudstone layers. In hydrocarbon exploration work, such sedimentary layers may be mistakenly referred to as source rocks.

From Mongolia eastwards, the typical Moho depth becomes progressively shallower- from 45 km beneath the craton to 38-33 km of crystalline crust below the Meso-Cenozoic basins (Guo et al., 2014; Sebastian et al., 2023) -before a more marked crustal thinning occurs near and below the Sea of Japan (Zheng et al., 2011) where the crustal thickness is anti-correlated with water depth, and the NE-oriented bathymetry conform to the ridge-basin structure in Meso-Cenozoic rift basins in the Mongolia-NE China. Karig (1971) made the first attempt to incorporate the marginal basins of NW Pacific into the plate tectonic model-suggesting that they had been formed by some form of seafloor spreading. However, plate tectonic explanations have not reached sensible conclusions, and ad-hoc suggestions have continued to this day.

On the other hand, Choi (1984) inferred that the tectono-topographic trends of Japan and adjacent continental tracts were traceable in the bottom topography of the Sea of Japan -suggesting that the Sea originated as a fault-controlled continental collapse structure during which the present-day NE-oriented basin-and-ridge topography developed. Moreover, Meissner (1986) proposed that all marginal basins along the northwest Pacific margin are thinned and modified continental crust formed under transtensive conditions. The proposals of Choi and Meissner fit well with the inertia-driven wrench tectonic theory. After late Cretaceous to early Tertiary oceanization of the northern North Atlantic crust, Eurasia has undergone slow clockwise wrench rotation (Storetvedt, 1990). According to GPS velocity data (Zemtsov, 2007), the torsional rotation is still in action (Fig. 2). Along the steeply inclined Benioff zone of the northwest Pacific margin, Eurasia's inertial rotation has led to moderate clockwise deformations -demonstrated by the seaward convexity of the outer boundary of marginal basins -eg., Sea of Okhotsk, Sea of Japan and East China Sea. Furthermore, there is no accretion of marine sediments along the NW Pacific trenches-simply because seafloor spreading, and subduction do not exist (see Fig. 5). On the other hand, wrench rotation of Eurasia has produced left-lateral shear along the bordering trench/Benioff Zone. Fig. 5 exemplifies the left-lateral shearing and shear partitioning in the Nankai Trough off southern Japan (Le Pichon et al., 1994).

Graphite deposits

Graphite is a soft, low-density mineral of pure carbon that is stable under surface conditions -consisting of stacked layers in a hexagonal nanostructure lattice. It is commonly assumed that graphite has somehow converted from the cubic diamond structure-the hardest of all natural materials and formed under high

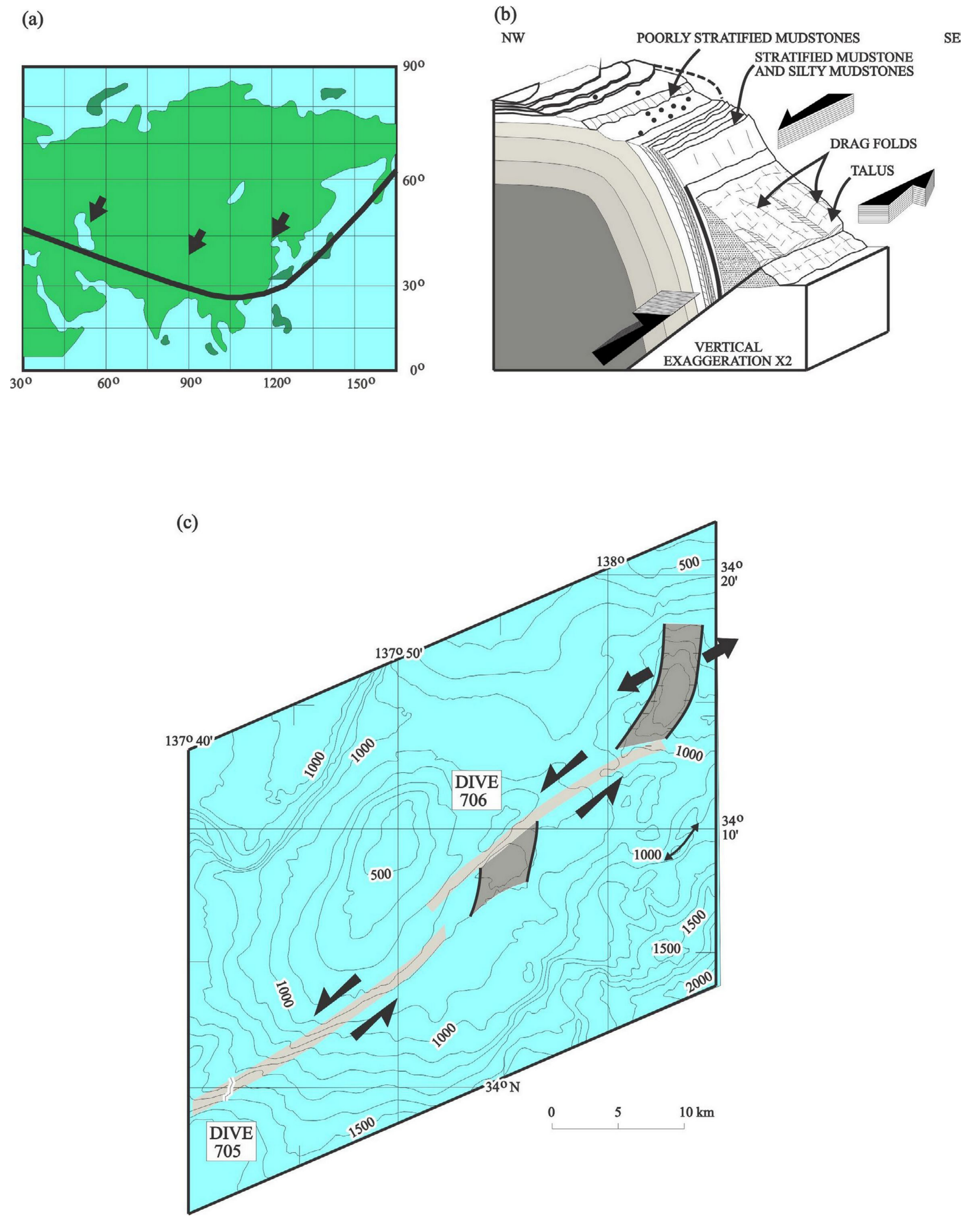

Fig. 5. a) Fault plane solutions (Scheidegger, 1982) indicating strike-slip along NW Pacific Benioff Zone. b) and c) are from marine geological studies along the sheared scarp off Japan (Le Pichon et al., 1994).

pressures at mantle depths of a few hundred kilometres. Natural diamonds, partially replaced by graphite, have frequently been reported from occurrences in ultra-high pressure metamorphics and from peridotites emplaced into continental crust. For example, Pearson et al. (1998) described graphitized diamonds from a peridotite massif in Morocco, in which the graphite had octahedral and other cubic forms interpreted as pseudomorphs after diamond. Thus, the graphite inclusions must have originated as diamond, but during slow ascent, gradual cooling and other affecting factors, the carbon atoms had reassembled into the low-pressure graphite form. Although there is a diversity of opinions about how the various types of graphite have formed-varying from precipitation from mantle liquids to metamorphic reactions in coal seams (Simandl et al., 2015), the uncertainty of formation is no less for diamonds (Smit and Shirey, 2018). Regrettably, in experimental work on mantle processes (Hayes and Waldbauer, 2006; Tumiati et al., 2020), it is usually taken for granted that the high pressures necessary for diamond formation are achieved by deep subduction, and Tappert et al. (2005) concluded that diamond was formed by direct transformation of graphite with increasing pressure through subduction. No one seems to care that none of the basic plate tectonic mechanisms and principles have been verified.

Regardless the multitude of uncertainties, one thing is indisputable: diamonds usually contain a variety of fluid inclusions-including water, carbon dioxide, methane, nitrogen, and silicates (Schrauder and Navon, 1994). Moreover, in a recent study by Matjuschkin et al. (2020) demonstrated spontaneous crystallization of diamond from methane-rich fluids, at pressure, temperature and redox conditions approximating those of deeper continental lithosphere. From deep continental drilling (Kola and KTB, Germany) it has been observed that the fracture spaces increase with depth and that the expanding fractures have a flow of hydrous fluids with dissolved natural gases (hydrogen, carbon dioxide, methane, ^{3}helium etc). Furthermore, ore fluids leached from the mantle are typically associated with significant concentrations of methane, nitrogen, salts etc. (Goldfarb and Groves, 2015). These lighter components must originate from the deep interior, and they often occur as inclusions in magmatic rocks (Harris, 1986; Webster, 2006). Melton and Giardini (1974) and many others have found that natural diamonds frequently contain inclusions of carbon-bearing fluids, mostly methane and carbon dioxide-regarded by Hunt et al. (1992) to be reaction products of silicon carbides from the deep mantle or outer core.

Simandl et al. (2015) grouped economic deposits of natural graphite into three main categories: microcrystalline graphite, vein graphite and flake graphite. The first group is believed to have developed from sedimentary coal seams and followed by sub-greenschist to greenschist metamorphism. The second variant was deposited in open fracture systems where the host rocks show granulite facies metamorphism, and flaky graphite were again regarded as formed by precipitation of carbon particles from (hydrocarbon) fluids-in amphibolite to granulite facies environment.

There is every reason to believe that the Earth's present constitution is the product of internal reorganization of its original disorganized mass distribution. The slow process towards internal physico-chemical equilibrium has resulted in an episodic dynamo-tectonic development. Thence, the related hydrostatic-hydraulic system has given rise to several geological processes-including granitization and general compositional and structural reworking of the original continental crust. The degassing process produces an outward hydrostatic force that counteracts the inward gravitational effect -resulting in an internal pressure bath situation consistent with the exponential opening of fractures with depth, as demonstrated in deep continental drillings. Furthermore, with temperature and pressure conditions in the lower crust and mantle, fluids will be in their reactive supercritical state. Therefore, aqueous fluids apparently can break down crystalline rocks -as demonstrated by the wide distribution of mud volcanoes (Milkov, 2000). In this process, reactive (hydrocarbon) fluids are likely to have released graphite from graphitized diamonds -dragging graphite particles with them in the upward flow.

It is reasonable to believe that the rarity of gem-quality diamonds at the Earth's surface is not due to their shortage at depth of origin (150 km and more). It is more likely that the necessary high gas pressure, required for the explosive delivery system, has been a rarity. The bulk of diamonds have thus had a much slower rise to the surface, where several factors may have played a role in the solid-to-solid transition from diamond to graphite (Kononenko et al., 2016; Tavella et al., 2017; O'Bannon et al., 2020). Considering that graphite seemingly formed under high-grade metamorphic conditions, the combination of high hydrostatic pressure and the physical decomposition effect of supercritical fluids may have had crucial importance in the diamond-to-graphite structural transition. It seems likely therefore, that the great majority of graphite deposits have their origin from converted diamonds, and that graphite fragments precipitated from hydrocarbon streams under variable tectonophysical circumstances. Deposits of vein and flake graphite fit particularly well with the assumption that they were deposited from fluids along primordial fractures under transtensive conditions.

Regarding microcrystalline graphite deposits, Simandl et al. (2015) believe they have formed “by maturation of organic material in sedimentary rocks (coal seams) followed by regional or contact metamorphism attaining sub-greenschist to greenschist facies.” However, unless one assumes that coal formation is partly abiotic-which is not supported by evidence, the Proterozoic surface conditions were fundamentally different from those of main coal producing times. Thus, tree vegetation-regarded to be the main material for coal formation, did not appear until late Devonian -associated with a sea-level regression. Furthermore, the Proterozoic was characterized by limited amounts of shallow water, the cause of smaller-scale limestone formation, but life was only in form of bacteria, microscopic plankton etc. The first major outflow of surface water took place at the onset of the Palaeozoic, associated with the Cambrian explosion of higher marine life. In addition, during the Proterozoic hydrous gas pressures in the outer mantle had apparently not yet reached a level to instigate effective sub-crustal delamination and basin formation.

As the predicted volatile hydrides and carbides rise buoyantly through the mantle, reactions with hydrogen/oxygen can produce other volatiles, such as monosilane (SiH_4) and methane (CH_4) -both being combustible and endowed with latent heat. During further ascent, Hunt et al. (1992) conjectured that water, monosilane, quartz, molecular hydrogen and heat would be produced. In Upper Archaean and Proterozoic times, the original anorthosite kindred crustal rocks-including gabbroic varieties (Storetvedt 2003/2023), led to generation of silicon melts and extensive granitization. However, in the uppermost Archean the crust was apparently sufficiently brittle to enable implantation of the pan-global, steeply dipping and near-perpendicular fracture system (Scheidegger 1963 and our Fig. 1). The increasing granitization vs. depth in the cratonic crust, has been strongly demonstrated in the Kola superdeep borehole (Russ. Acad. Sci., 1998). Another striking example is the Paleoproterozoic-deformed Bundelkand Craton of north-central India showing extreme quartz enrichment (Absar et al., 2009) -the region has tens of metres thick orthogonal quartz dykes (Das et al., 2019; Singh et al., 2021) most likely injected in the form of silicon oil (Gold, 1999, p. 136-137) and under strong transtensive conditions.

In the same way as for today’s irregular distribution of continents and deep-sea basins, there is every reason to assume that crustal granitization was also unevenly distributed, by mineral transformation and replacement in situ, including heat (Hunt et al., 1992). Thus, variably granitized cratonic crust with associated melt production must have led to a variably thick upper crust being moderately detached from its lower part (Michaelsen and Storetvedt, 2023, and references therein). The degree of crustal wrench deformation will depend both on planetary spin rate and palaeolatitude, factors that are largely unknown for the Precambrian Earth, but Alfvén and Arrhenius (1976) argued that the early Earth may have rotated 4 times faster than at present. Furthermore, for regions having undergone extreme granitization and associated magma production-such as the Bundelkhand Craton, the resulting tectonic ductility and deformability would make the palaeolatitude factor less critical. Thus, the extremely granitized and thereby relatively ductile Bundelkhand cratonic crust was tectonically sheared and strained during the Proterozoic, for which Sikdar et al. (2023) provide an appropriate description. In their study of the mid-upper greenschist facies rocks, they write that “The weak CPOs [crystallographic preferred orientation] and ... a high shear strain suggests a significant contribution of grain boundary sliding in strain locations inside the ductile shear bands", and in the same vein they also reported superplastic deformation inside shear bands in granites.

According to Simandl et al. (2015), India is the second largest graphite producer in the world. As graphite occurrences are regionally associated with concentrated metamorphic gold and other Proterozoic metal deposits, it is reasonable to assume a close physical link between the emplacement of ore deposits in India and Proterozoic crustal deformation and metamorphism. This means that changes in Earth's rotation accelerated ore leaching processes, after which accumulated metals and graphite particles were transported with pressurized hydrous and hydrocarbon fluids. The ore cargo was unloaded step by step-in concert with Earth's dynamic pulsation and within the simultaneously deforming and metamorphosing crust when temperature and pressure conditions made it possible.

Graphite occurrences and deposits are widely distributed in Mongolia and eastern China, with host rocks restricted to Neoproterozoic and Proterozoic metasediments. Two of the graphite-bearing areas in Mongolia were inspected and are being briefly described below.

Area 1 is in central Mongolia c. 110 km S-SE of Ulaanbaatar. The elongate fault-bounded graphite-bearing sub-basin extends for c. 600 m in length and c. 200 m in width. The 25-30 m thick ore body occurs within a lower Proterozoic (c. 1.2-1.6 Ga) schist and limestone unit, it is preserved in a NE-SW trending syncline which might extend beneath Jurassic basalt cover to the southwest. The graphite exposures are sporadically exposed in 10 open trenches and in two shallow historical test pits. For the present survey, one of us (PM) visited and sampled five trenches and a minor test pit along the western limb of the syncline and five trenches and a small test pit along the eastern flank. In the surrounding landscape, no graphite exposures were observed. The trench exposures show that the graphite units are characterized by abundant fractures and a structural complexity. A few faults were observed within the trenches as well as tight parasitic folding along the flanks of the syncline. The NE trend of the ore body corresponds to one of the primordial orthogonal fracture/fault sets which Scheidegger (1963) assigned to the Upper Archean. The sedimentary host rocks probably formed in a relatively shallow marine depositional setting characterized by base-level changes and subsequently subjected the wrench reactivation. Within the steeply dipping wrench faults, acting as conduits for graphite-carrying fluids from the interior, the deposited graphite ores were subsequently compressed and deformed. Given the lack of graphite deposits in Phanerozoic host rocks, timing of the graphite mineralization and its deformation is considered here to be Precambrian. It is noted that the relatively minor orebody (Area 1) is hosted in a c. 2 km wide and c. 10 km long NW-SE trending low relief in a lower Proterozoic metamorphic unit which might contain further graphite-bearing deposits along strike. However, the tectonic situation means that area 1 graphite occurs at a junction between orthogonal faults which sometimes, in a wrench tectonic setting, forms an effective outgassing pipe.

Area 2 is situated in far southern Mongolia proximal to the Chinese border. The ore appears in Neoproterozoic schist outcropping over a c. 7 km long NE-SW trending zone. Subsurface data indicate a maximum thickness of 84 m of graphite-bearing ore. This is a relatively advanced project with a 36 Mt open space graphite resource base containing c. 5% TGC for 1.8 Mt contained graphite carbon. The Neoproterozoic host rock is schist. The basement rock is often exposed as slabs (up to c. 50 cm in length) in c. 20 largely covered trenches. The structural complexity is uncertain; however, a few faults were observed, with bedding dips changing rapidly over short distances, almost vertical in places -suggestive of strong shear deformation. The northeast trending orebody is in concordance with that of Area 1 (as well as for numerous other economical deposits in Mongolia). It is envisaged that steep orthogonal fault lines acted as conduits for upward rising carbon-rich fluids which unloaded the graphite ore within relatively thin confined packages.

The TGC% of both deposits compares well with global graphite deposits developed by other graphite explorers such as Volt Resources (Bunyu, Tanzania), Lomiko Metals (La Loutre, Canada), International Graphite (Springdale, Australia) and Tirupati Graphite (Sahamamy, Madagascar).

The renowned Botogol vein graphite is located c. 90 km north of the Mongolian border around 52°20'43"N /100°14'56"E. The Botogol graphite deposit used to be the largest graphite mine in the world with the cleanest and highest quality. This deposit was used by the French since the XIX century. Within the 10 km² large complex, about 30 graphite bodies have been discovered with mining only confined to the northern area. The graphite occurs as irregular lenses, stocks, and veins (Lobzova, 1975). Mineral ages from associated intrusive rocks have given Devonian-Carboniferous K-Ar ages (Lobzova, 1975), but undated graphite xenoliths are probably Precambrian.

In China, the graphite occurrences appear predominantly in crystalline flake format with subordinate aphanitic deposits with "many in east and few in west" (Sun et al., 2018). As depicted in Fig. 6, the bulk of the East China ore deposits is distributed in a broad NE-SW oriented belt -just like the individual deposits in Mongolia. In addition, the dominating structural trends, metallogenic belts, and graphite deposits in China (Sun et al., 2018) comply with the fundamental orthogonal rupture/fault pattern for Asia-directed NW-SE and NE-SW respectively. The host rocks unveil high grade late Archean-late Proterozoic metamorphic ages, but the graphite ores may have been deposited during transtensive conditions at later wrench tectonic events-Proterozoic or younger. For example, a closer look at the northwestern segment of the NW China graphite distribution has the same south-facing shape as the inertia-

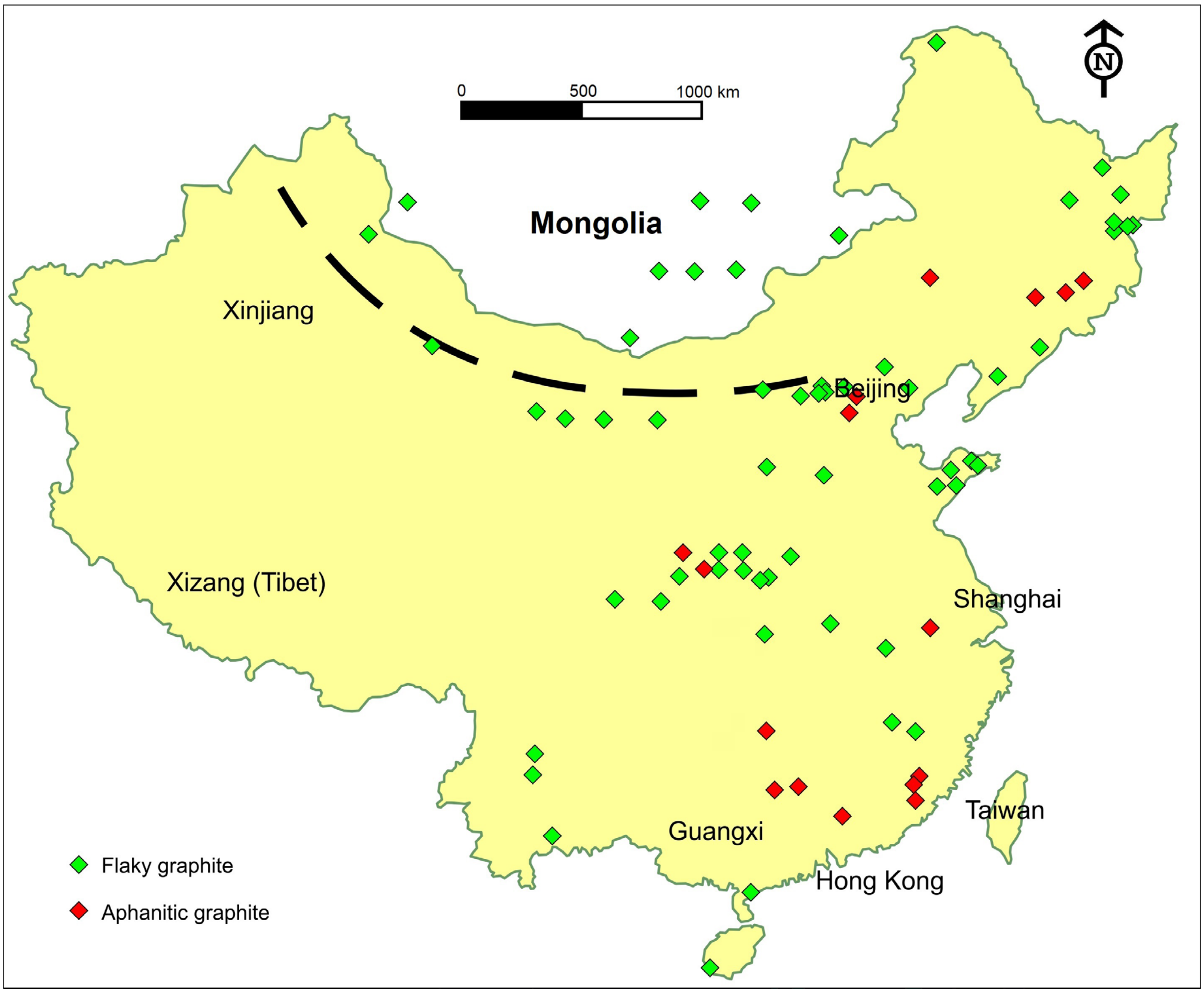

Fig. 6. Distribution of main graphite deposits in China and Mongolia, simplified after Sun et al. (2018). The northwestern Chinese deposits define the same southward curvature as the tectono-topographic southern border of Mongolia. See text for explanations.

based tectono-physiographic shape as South Mongolia (Michaelsen and Storetvedt, 2023). This may imply that the Chinese graphite deposits located proximal to southern Mongolia were emplaced in the Lower Palaeozoic. The reason is that the late Ordovician palaeoequator passed the southwestern tip of Mongolia along which Caledonian wrench tectonics was at its maximum. The triggering dynamic mechanism for this and all other global-tectonic upheavals has been degassing-related changes of the globe's moments of inertia. This dynamic transition led to changes in rotation, which in turn gave rise to inertia-driven crustal tectonic wrenching as well as accelerating the interior upward carbon-rich fluid flows. On this background, it is inferred that the metamorphic-magmatic history of host rocks is unlikely to have direct connection with origin and emplacement of ore deposits. Therefore, with the assumption that the curved linear spread of graphite deposits in northern China is of Caledonian age, it seems likely that also Area 2 graphite in southernmost Mongolia (discussed above) was emplaced during Caledonian events.

During the Proterozoic eon, spanning the time from 2500 to c. 540 Ma, both the Pre-Archean basement and the fault-oriented graphite deposits must have been subjected to Proterozoic and younger wrench tectonic events. Flaky graphite may fit into this sequence. Furthermore, as inertia-based crustal wrenching is latitude-dependent, the question arises whether the palaeolatitude effect is the primary cause of the concentration of graphite deposits in eastern China. Thus, a common tectonic and palaeomagnetic consideration of the Upper Proterozoic suggest that the actual palaeoequator passed along the Atlantic, across Arctic Canada, continuing along north-western Pacific etc. (chapter 7 in Storetvedt, 2003/2023). This palaeogeographic setting gives eastern China low intermediate latitudes, and as expected, at a time of significant crustal granitization, it would give rise to prolific tectonic inertia effects. Thus, being in the northern palaeo-hemisphere, the clockwise torsion of the upper crust would readily provide transtensive conditions of the NE-SW oriented fracture set, thereby providing opening space for progressive unloading of graphite particles from carbon-rich fluids.

Both granitization and graphitization of the crust are apparently mainly of Proterozoic age. In contrast, the main supply of surface water is dominantly a post-Precambrian phenomenon -an assumption which is supported by the explosion of higher marine life in the Lower Palaeozoic. This suggests that outgassing of lighter elements and their chemical combinations -such as fluid carbides and hydrides, has not had a homogeneous temporal escape rate. Thus, it is proposed here that, at an early stage, carbon compounds led the outgassing from the core. In this process, phases like silicon carbide (SiC), in reaction with hydrogen/oxygen *en route*, may have given rise to free carbon with formation of diamonds, heat production and silicon melts (Hunt et al., 1992; Gold, 1999). As rising fluids will have been in their reactive and disintegrating supercritical state, carbon-rich streams have transported graphite particles (detached from graphitized diamonds) -depositing them in transtensive fault zones.

Concentrated Cu-Au deposits

How thinly distributed metal particles in the mantle ended up as concentrated deposits in near surface locations have remained an unsettled problem. Firstly, there must be a fluid that can flow through the fracture spacing, leaching the metal particles from the rock and carry them along with the stream. Water has generally been considered the responsible agent, although conventional theory has predicted that even at relatively moderate crustal depth, gravity pressure would close all fractures making fluid flow an impossibility. However, deep continental drilling (Kola and TKB, Germany) has refuted this assumption-demonstrating that fractures open with depth and thereby paving the way for rising fluids. Hoyle (1955) and later Gold (1999) pointed out that if a buoyant fluid, occupying an existing fracture network, exerts an outward pressure as great as the opposing gravity pressure of the surrounding rocks, fluid flows will be maintained. Hence, it is the pressure differential, not the absolute pressure level, that decides the fate of fractures at depth. It follows those fractures within a rock can be sustained under very high pressures, but, at least in the outer layers of the Earth, rocks (being without noteworthy tensile strength) cannot withstand a fluid that comes up with a pressure greater than that exerted by the weight of the overburden. The result is a wide range of outgassing rates -varying from very slow ascent to explosive outbursts. The first category includes the bulk of surface water, natural gas, and ore deposits, while the second (high-pressure) group accounts for the great majority of earthquakes, cratering, and the required rapid upward transfer of high-quality diamonds from their origin in the mantle to the surface.

After developing from a relatively rapidly rotating cloud of cold gas and mineral dust, the proto-Earth must have acquired an inverse temperature distribution (Storetvedt, 2003/2023 and references therein). It is the unstable temperature-chemical starting point that is the basis for the Earth's perpetual degassing and its slow and staccato dynamic history. Thus, the vertical reorganization of the Earth's mass has led to changes in its moment of inertia and thus of its rotation properties -ie. relatively distinct spatial reorientations and changes in velocity of rotation. These pulse-like dynamic changes, which correspond to geological time boundaries, are the principal drivers of Earth's modus operandi; they represent the main pumping system for ascending fluids, trigger crustal inertia-driven wrench tectonics, and are the causation of all pulse-like geological events -including injection/precipitation of ores from hydrocarbon fluids (see below).

In the longstanding process of gaining internal physical equilibrium, major parts of the interior would gradually have been subject to a kind of pressure bath situation characterized by an open fracture system. Deep continental drilling has shown that fractures open exponentially with depth which must mean that the inward gravity pressure is increasingly counteracted by outward hydrostatic pressure. That is, at mantle depths fractures are being kept open, they don't feel being subjected pressure. In addition to the episodic supply of surface metal deposits, outgassing fluids must not only be able to gather up thinly disseminated metals from mantle rocks but must also provide the source of physical energy that can push the fluid through the rock. Thus, at mantle depths fluids will apparently be in their reactive supercritical state (Liebscher, 2010; Hirschman and Kohlstedt, 2012; Galli and Pan, 2013) -characterized by strong buoyancy and high diffusivity, thereby overcoming most critical mass transfer limitations. Therefore, the traditional inadequacy of the hydrothermal hypothesis-regarding leaching, transport, and unloading of metal deposits-may perhaps take a completely new direction if the supercritical state of fluids is considered. Nonetheless, Gold (1999) considered the matter differently.

Gold

At mantle depths hydrocarbons may enter molecular arrangements with metals to form carbon-metal bounds -so-called *organometallics*. Gold (1999) believed that a whole range of organometallics are produced by hydrocarbons leaching through mantle rocks, arguing that several of the metals in these chemical compounds could not have a biological origin. In support of his hypothesis, he noted that "Most organometallics are soluble in [abiotic] hydrocarbon oils and thus will be carried along with the flow. When temperature, pressure, or other solubility conditions reach a threshold at which a particular kind of organometallics can no longer be carried by the stream, a concentrated metal deposit would be generated in that spot" (Gold, 1999, p. 135). Consistent with this assumption, methane is a commonly occurring gas in many metal mines. For example, in the Witwatersrand Basin in South Africa, which hosts some of the largest and deepest gold mines in the world, faults act as conduits for the upward migration of methane gas-often accompanied by explosions, and seismic detection of potential methane pathways is therefore of significant safety and economic importance (Manzi et al, 2012, Mkhabela and Manzi, 2017). An abrupt physical change leading to the unloading of fluid-transported metals can occur when the rock overburden weight suddenly gives way to a supercritical fluid front causing abrupt pressure release (Weis et al., 2012). The fluid penetration gives rise to reactivation of the local fracture/fault system with structural collapse, often resulting in a series of low to moderate intensity earthquakes referred to as earthquake spots (Sibson, 1987). However, another important factor behind the tectono-hydrostatic breakthrough of high pressurized liquids may well be Earth's dynamic pulsation.

Throughout the long history of ore mining there are many accounts of the apparently close connection between concentrated metal deposits and hydrocarbon liquids and gases (Gold, 1999), but in modern times the possibility that these volatile substances can be relevant transport media has gained little attention (Henley et al., 2022, Henley and Berger, 2013). The reason for this lack of understanding probably lies in the ingrained belief that hydrocarbons are predominantly fossil-based products and hence have a sedimentary (surface) origin. Since the leaching of metals must have mainly taken place in the mantle, hydrocarbons as a means of transport were therefore seen as an impossibility. However, the presence of major oil and gas reservoirs in fractured basement rocks (metamorphic and igneous) on a global scale have become a commonly recognized fact (Gutmanis et al., 2012; Koning, 2019; Morariu, D. 2012) for which the biotic theory has no acceptable explanation. Another pressing problem is this: Why are there so much water and salts (in the form of salt stocks) in major hydrocarbon fields? This question was asked to the principal author (KS) during a seminar at Equinor (formerly Statoil) in 2004. The degassing theory has a ready account: Hydrocarbon fluids and gasses, water, and salts can be understood as reaction products from outgassing of hydrides and carbides from the deep Earth. Unfortunately, the extreme subject specialization in our time, the economic geological research community has obviously not realized that hydrocarbons-both as gasses, liquids and solids (ice) -are dominant chemical compounds in the planetary system (Kaufmann, 1988).

Nevertheless, evidence for the spatial coexistence between hydrocarbons and diverse mineral deposits is growing, and so has the interest of hydrocarbon fluids as a means of metal carrier (Hulen and Collister, 1999; Williams-Jones et al. 2009; Ge et al. 2022; Saintilan et al. 2019). Thus, Hulen and Hollister, studying the oil-bearing Carlin-type gold deposits of Yankee Basin, Nevada, concluded that timing of the fluid-inclusion oils was clearly involved in the gold-mineralizing system, and associated free oil could have arrived at any time prior to, during, or after mineralization. Furthermore, based on solubility experiments, Ge et al. (2022) suggested that liquid oil could have acted as a transport system for gold particles before they were deposited.

In view of the degassing model, it is likely that mantle hydrocarbons with varying chemical composition have infiltrated the orthogonal fracture network of the Earth's crust and precipitated the metal content when physical conditions required it (Gold, 1999). Furthermore, Hunt et al. (1992) argued that degassing of the core's stock of hydrides and carbides has, during their upward flow, led to a series of chemical reactions *en route*. In this process, the crust was subjected to progressive granitization - through production of siliceous melts and/or silicon oil, the latter giving rise to dykes or veins of pure quartz. So, when metal-bearing hydrocarbon fluids and silicic magma were competing for space in the same transtensive segments of the orthogonal fracture network, the solidified rock would acquire a porphyry character. Furthermore, due to the Earth's dynamo-tectonic pulsation, it follows that also the deposition of concentrated metal deposits will be time-related to principal tectono-magmatic events (Table 1).

Gold in quartz veins-where small gold particles either occur scattered between the quartz grains or compose more concentrated deposits along fractures in the veins, is a common combination. Illuminating results have recently been reported from the strongly granitized crust of the Kola Superdeep Borehole (Prokofiev et al., 2020). In veins at depths between 9.500 and 11.000 m, all quartz grains contained inclusions of chloride brines and CO_2 -rich fluids with exceptional concentrations of gold nanoparticles. The study indicates that in the deeper upper crust fluid inclusions may be abnormally rich in gold, but the question remains under what conditions the gold nanoparticles were formed. It is conceivable that the reactive, but poorly understood supercritical state of fluids has played a decisive role; during the leaching process they presumably have broken down larger particles to nano-size. Prokofiev et al. suggest that the fluids could be a precursor of "orogenic gold fluids" -reducing the "large volume of metamorphic fluids [required] to form orogenic ore deposits". However, the concept of orogenic gold, which within the framework of plate tectonics is associated with metamorphic and magmatic processes, is a very speculative notion. So, when Goldfarb and Pitcairn (2023) discussed the origin of gold deposits, along with the incorporated concept of orogenic gold, they may have hit the nail on the head when including the following passage in the article headline: "is a genetic association with magmatism realistic?" Perhaps time has come to replace the plate tectonic paradigm with an entirely new thought construction-based on a slowly degassing Earth?

Fig. 7 gives a generalized global distribution of gold and copper porphyry deposits. The dominant linear ore belts correspond to surface exposures of established or predicted deep and relatively steeply inclined fault zones. These several hundred km deep crustal discontinuities were originally discovered by seismology in peri-Pacific regions (Wadati, 1929; Benioff, 1949, 1954), but Wilson (1954) extended the Wadati-Benioff concept with another corresponding fault zone, nearly orthogonal to the original one - including the Indonesian island arc and its predicted continuation along the classical narrow epicontinental Tethys basin (Sonnenfeld, 1981) for which the associated eastern tectonic belt is now being referred to as the Tethysides. During India's major tectonic rotation (in situ) at around c. 60 Ma. ago, during which also the Deccan lava complex was formed (Storetvedt, 2003/2023, p. 69-73), the Himalaya Tethysides was strongly deformed.

Fig. 7. Generalized overview of the global distribution of porphyry copper (modified after Dicken et al., 2016). The linear bands can be associated with unloading from deep fault zones, but the broad ore belt across the thick crust of Central Asia requires a different approach.

However, what we are concerned with here is the broad first-rate porphyry belt across Central Asia -the only one of its kind in the world. These trans-Asian metallogenic belts have apparently no direct link to deep upper mantle tectonic discontinuities or larger-scale Moho variations. For example, the regional Mongolian crust has an estimated thickness of c. 45 km (Mordvinova et al., 2007; Feng, 2021; Guy et al., 2024) -and Eshagh et al. (2016), employing satellite gravity gradients, a similar Moho depth for all Central Asia is estimated. On the other hand, He et al. (2016) found a slightly thinner crust (38 km) beneath the South Gobi Basin. However, the overall flat and normally thick Central Asian crust would imply that the sub-crustal metamorphic granulite-to-eclogite transition, with attendant gravity-driven crustal delamination to the upper mantle, have largely been hindered. In this context, several authors (Austrheim, 1987; Walther, 1994; Leech, 2001) have stressed the importance of hydrous fluids for the metamorphism-regulated density transition to take place. Without sufficient H_2O-rich fluids in the mantle beneath the thick Central Asian crust, this may explain why large-scale sub-crustal thinning has not occurred. This may also weaken the traditional hypothesis of hydrothermal mineralization, as well as strengthening the possibility that carbonaceous solutions are the important fluids as carriers of ore particles extracted from mantle rocks.

According to Hunt et al. (1992) and Gold (1999), silicon-rich and hydrocarbon fluids have probably intruded the crust and given rise to heat producing chemical reactions with quartz melts, methane gas, water and siliceous/granitic magmas as likely products. The apparent lack of earthquake focal depths less than c. 20 km in Central Asia (Chu et al., 2009) indicate that the lower crust is relatively fluid-infiltrated and ductile. This supports the possibility that quartz melts and hydrocarbon fluids may have played a prominent role in the transport of metals to the Central Asian metalliferous belt; unloading of concentrated ore deposits have occurred

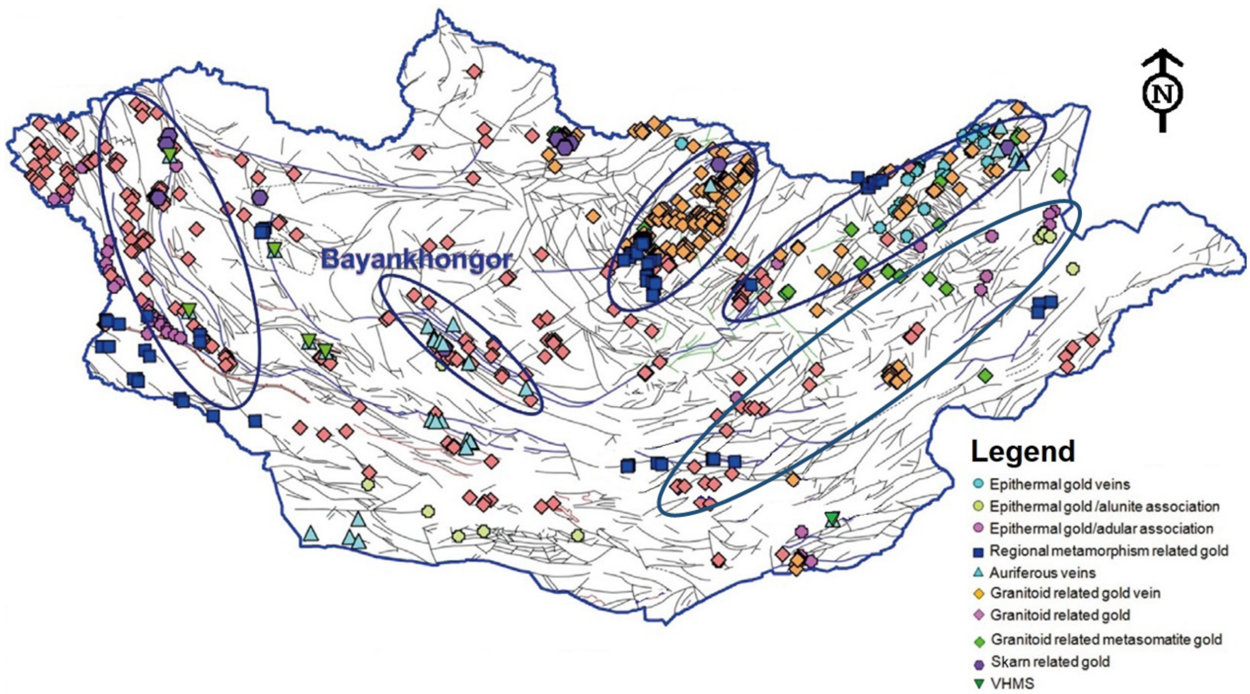

Fig. 8. Gold is widespread in Mongolia but shows concentrations along certain segments of the orthogonal NE/NW fault system.

along wrench tectonic produced transtensive segments of the ubiquitous orthogonal fracture/fault system. Mongolia is rich in gold with widespread occurrences and number of important deposits. However, the fact that Mongolia is hugely under-explored means that the reserves can increase significantly with a more systematic targeted search.

Fig. 8 shows the distribution of various types of gold mineralization in Mongolia, with enclosures outlining principal metallogenic sectors. As with practically all regional geological conditions in the country, the distribution of its gold deposits is associated with the steeply dipping fundamental orthogonal fracture network, with NW and NE orientation respectively. In a wrench tectonic setting, however, it is not only the subvertical orthogonal faults that are reactivated and in places make room for the intrusion of metal-transporting fluids. Upper crustal wrenching processes may also produce sub-horizontal detachment surfaces, notably at lithological transitions, into which ore-loaded fluids may be intruded. The northern Mongolian Boroo gold (10.7 Mt at 3.3 g/t) is an appropriate example. This NE -oriented gold deposit (Fig. 9), which not unexpectedly also shows signs of orthogonal (NW) offsets, occurs within Palaeozoic granitoids hosting platy quartz veins. According to Cluer et al. (2005), almost all economic gold in the Boroo deposit is found in sub-horizontal tectonic detachment structures generally occurring at lithological transitions.

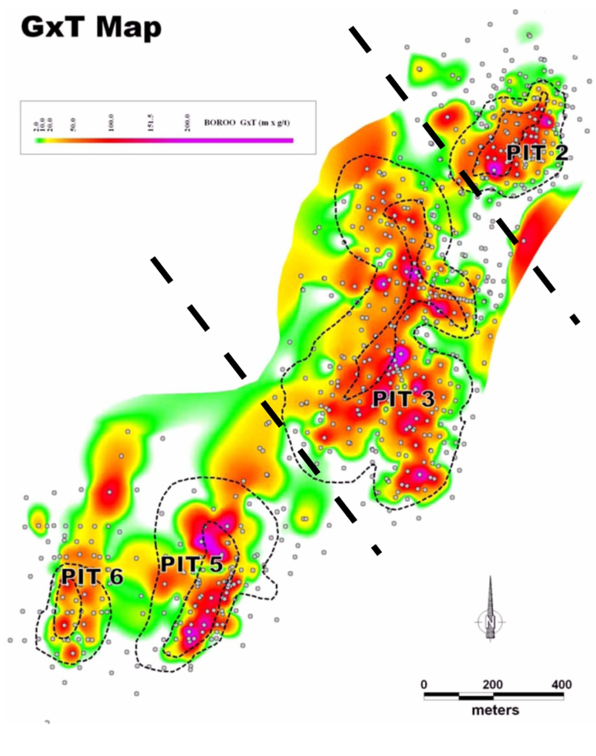

Fig. 9. Grade and thickness map of the dominant NE trending Boroo gold deposit, northern Mongolia. Grey dots are drill holes. Modified from Cluer et al. (2005). Two slightly offsetting orthogonal structures are marked.

Such sub-horizontal detachments are predicted wrench tectonic consequences.

Copper

The broad E-W oriented metallogenic belts in Central Asia (Fig. 7) are characterized by many world-class porphyry copper deposits, and for the great majority of them the host rocks are Palaeozoic (Shen et al., 2018). The most prolific interval of ore fluid precipitation, including the largest deposits, was during the late Devonian and early Carboniferous (Yakubchuk et al., 2002; Porter, 2015). In Mongolia, copper deposits are widely scattered -as porphyries, skarns and massive sulphide deposits, and copper mining is a major industry. On a global scale, Mongolia is currently ranked nr. 12 in terms of Cu reserves which are estimated to more than 1 billion tons. However, the fact that Mongolia is hugely under-explored means that Cu reserves can increase significantly with a more systematic targeted approach Fig. 10 shows the distribution of the most prolific copper mines in Mongolia: Oyu Tolgoi and Erdenet with Tsagaan Suvarga currently under development, and large lower grade exploration projects such as Zuunmod (218Mt measured and indicated resource at 0.069% Cu and 0.057% Mo) and Kharmagtai (1.3 Bt at 0.3% Cu and 0.2 g/t Au).

The Erdenet deposit (c. 1.7Bt at 0.58% Cu and 0.018% Mo) occurs within a Permian-Triassic volcanic-plutonic belt. The region is characterized by well-developed orthogonal drainage systems formed along NW and NE trending fault zones, and though the copper site has been known since prehistoric times (Singer et al., 2008), with exploration in the early 1940s, late 1950s and the 1960s, production finally began in 1978. Mineralization at depth between the Erdenet Central and SE orebodies, supported by drilling results, suggests a nearly continuous mineralization extending more than 10 km in NW-SE direction (Singer et al., 2008). On a larger scale, the Erdenet complex belongs to an elongated NE -trending copper-infiltrated belt, implying that the Cu concentration was deposited at a transtensive junction between NE- and NW -trending fault zones. However, the Erdenet transtensive junction constitutes only an infinitesimal part of the additive inertia driven south-facing tectonic convexity of Mongolia -including the large-scale Middle-Upper Palaeozoic magmatic belts and the southern arcuate tectono-topographic boundary (Michaelsen and Storetvedt, 2023).

Kavalieris et al. (2017) conveyed that whole-rock $^{40}Ar/^{39}Ar$ age analyses of granodiorite porphyry and of the silica-rich wall rocks cannot be discriminated. The results show early Triassic ages of 239.7±1.6 and 240±2 Ma for muscovite

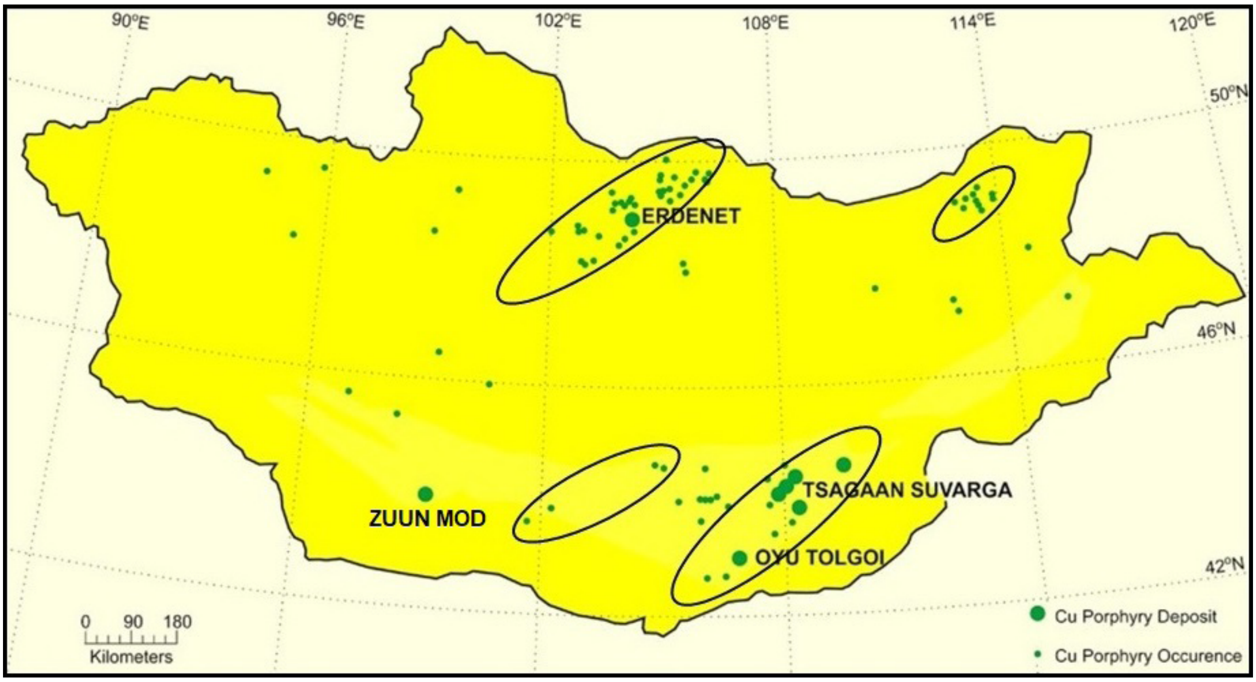

Fig. 10. Distribution of copper porphyry deposits and occurrences in Mongolia. Deposits discussed in the text are specified.

that envelopes the authors' Cu-bearing D veins-age figures that are in accordance with previous Re-Os ages for molybdenite in quartz veins (Watanabe and Stein, 2000). Thus, the Erdenet mineralization corridor and injection of the host rocks followed in the wake of the major environmental and biotic mass extinction characterizing the Permian-Triassic boundary. During this most revolutionary event in the history of life, the upper mantle of the embryotic ocean basins had gained a sufficiently high hydrous fluid pressure to instigate the first major crustal eclogitization/delamination event. Thus, the remaining continental masses were drained, and a rudimentary outline of the continental blocks was beginning to take shape. But the chemical composition of outgassing fluids from the Earth's core may have varied spatially (Storetvedt, 2003/2023). Ascending fluids which on the surface led to the development of the eclogitization of the lower crust and gravitational delamination must have been particularly water rich. In contrast, outward flows towards embryonic continental regions probably had a predominance of silicon carbides (SiC) which during their slow ascent, reacting with hydrogen and oxygen *en route*, would tend to produce methane gas (CH_4) and silicon melts (SiO_2) -reactions that were both heat-producing and explosive (Hunt et al., 1992).

According to Michaelsen and Storetvedt (2023, and references therein), these chemical reactions may have taken place even at mid-upper crustal levels suggesting that the pressure-temperature condition made fluids to be in their supercritical state. According to Agroli et al. (2020), these physical situations apparently existed during the multiple generations of veins within the Erdenet Cu-Mo deposit (Fig. 11). With reference to the latter authors, the host rock was emplaced at temperatures of 700-750°C, and the first quartz vein was derived from supercritical fluids at 650-700°C, and ore-carrying veins deposited at c. 600°C. In these relatively high-pressure conditions, first [fluid injection] stage is syn-mineralization activity, followed by explosive events and brecciation. Field observations by Agroli et al. (2020) have documented two large explosion pipes of up to 250 m in diameter that are connected to the surface. The second stage porphyries are represented by granodiorite and granite porphyries." Agroli et al. (2020).

The dynamo-tectono-magmatic and metallogenic Erdenet event seemingly was an integral part of the major environmental and biological upheaval that affected the Earth around the Permian-Triassic boundary. A marked retreat of epicontinental seas culminated

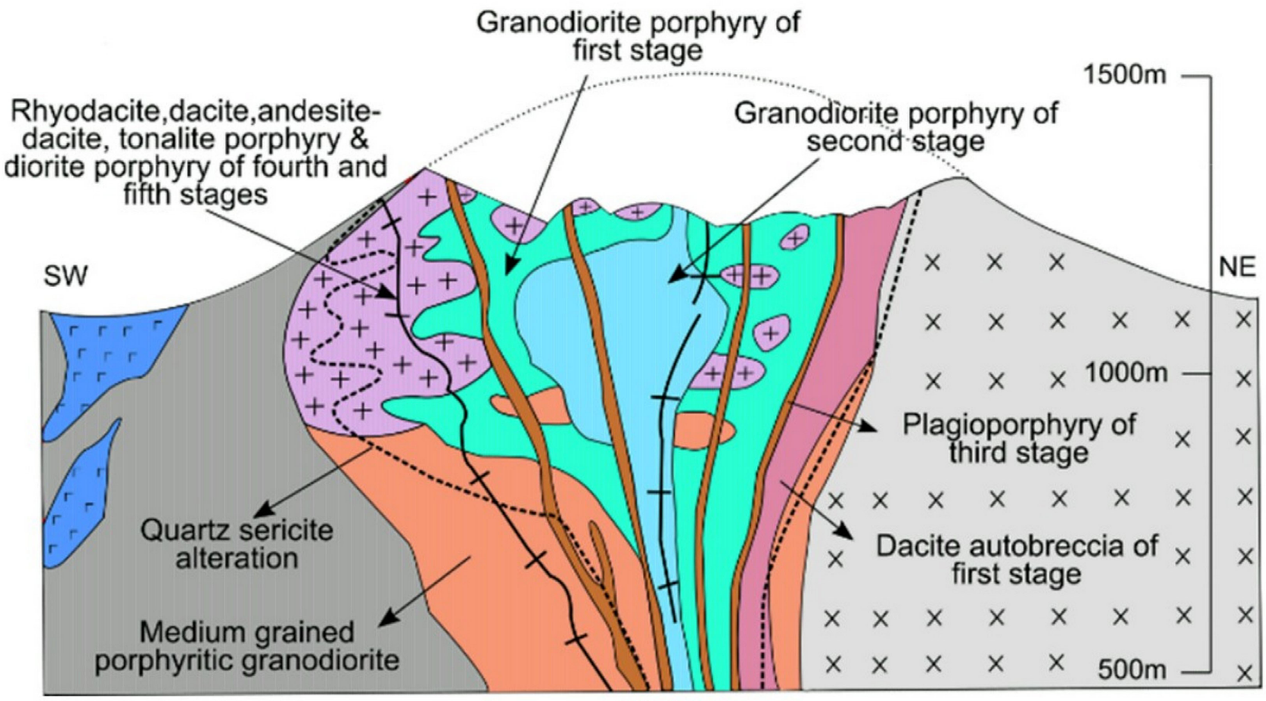

Fig. 11. Structural and geological overview map of the Erdenet Cu-Mo deposit. Modified from Agroli et al. (2020).

in an exceptionally low level, after which low-lying continental areas, in the beginning of the Triassic, were intruded by a relatively rapid sea-level rise. As shown by Holser and Magaritz (1987) and Ross and Ross (1987), the first-order sea-level variation across the Permian-Triassic boundary represent the smoothing effect of a higher frequency sea-level oscillation. Furthermore, Hallam and Wignall (1999) concluded that rapid high-amplitude regressive-transgressive pulsation is a characteristic feature during times of mass extinction -which in a wider perspective correspond to principal geological time boundaries. To reiterate, this eustatic effect is mainly related to changes in Earth's moment(s) of inertia caused by outgassing and related reorganization of its inner mass. The dynamic effect of these changes is that the Earth works like a pump machine on the upward fluid flow (Storetvedt, 2003/2023) -reviving the old phrase "the pulse of the Earth" (Umbgrove, 1942; Rampino et al., 2021).

As has been confirmed by deep continental drilling, the crustal fracture volume increases with depth-even exponentially at depths greater than 10 km, as shown in the Kola super-deep borehole. This implies that even the thick continental crust will be relatively permeable to the accumulating pressure of gases and reactive supercritical fluids-surging into the crustal fracture system in accordance with the global dynamo-hydraulic pulsation. On their journey upwards, both ore-carrying carbides and hydrides will be prone to undergo explosive chemical reactions with heat generation (Hunt et al., 1992), and there are good reasons to believe that these processes have been in operation even in middle-upper crust -suggesting that magma may have formed nearer the surface than hitherto envisaged. An apparent lack of earthquake focal depths below c. 20 km for Central Asia (Chu et al., 2009) makes it likely that even in regions of the upper crust there might be hot and ductile detachment zones with magma pockets.

Michaelsen and Storetvedt (2023) suggested that, in Central Asia, melt production and crustal granitization are primarily middle-upper crustal phenomena -a conclusion which is consistent with rock data from the Kola superdeep borehole (Russ. Acad. Sci., 1998). It follows that over-pressured ore-bearing fluids approaching the surface will be in their supercritical state. This interpretation is consistent with geological and geophysical data from the Erdenet complex, representing a multi-phase intrusion of granitic and related rocks. The explosive origin of the vent is demonstrated by the two large volcanic pipes mentioned above, which are associated with brecciation, having most likely also resulted in surface cratering. The ore-bearing fluid stream was then "filtered" through the blasted zones during which the metal content was deposited (Agroli et al., 2020). In harmony with this conclusion, Crieve (1982) -discussing global dispersion, shock effects and other features associated with cratering, found that for events in recent geological time, with ejected rock material being relatively intact, was littered with metal particles. Thus, in a degassing scenario also cratering is apparently an integral part of the planet's modus operandi, with potential to use such geomorphological features in the landscape for gold deposit as well as hydrogen gas exploration (Malvoisin and Brunet, 2023)

Tsagaan Suvarga and Oyu Tolgoi

In southern Mongolia, the Tsagaan Suvarga Complex (TSC - c. 255 Mt at 0.55% Cu and 0.02% Mo) and Oyu Tolgoi (OT - c. 6.382 Bt at 0.67% Cu and 0.29 g/t Au) porphyry deposits occur within a NNE trending mineralized zone (Fig. 10). Both ore bodies are elongate, and fault bounded.

The quartz monzonitic TSC deposit trends ENE and extends for c. 1.8 km with a width of c. 300 m; it is dipping at about 45° to the NNW, with widespread Cu occurrences away from the main NNE trending ore terrane (Tungalag et al., 2018). Re-Os analysis of molybdenite has given late Devonian ages, 370.6±1.2 Ma (Watanabe and Stein, 2000). The TSC is followed by a volcanic and sedimentary sequence which, based on fossil evidence from its southwestern and northwestern margins, indicate early Carboniferous ages. In other words, the major Tsagaan Suvarga deposit might date from the Devonian-Carboniferous boundary. Like the younger Erdenet metal discharge, the TSC deposit also occurs relatively near a prominent geologic time boundary -representing an important dynamo-tectonic event in Earth history.

According to Tungalag et al. (2018), the early Carboniferous volcano-sedimentary succession is strongly deformed, and on the SW margin it "appears to wrap around the granitoid contact"- indicating enhanced upper crustal deformability/ ductility caused by persistent regional magmatic activity. The tectonic complexity is further supported by a c. 25° of the delimited clockwise tectonic shearing, turning of the fault controlled orthogonal mineralization zones -from NE to ENE and NW to NNW respectively. Based on the descriptions of Tungalag et al., we conclude that the tectonic deformation of TSC was primarily the consequence of the accelerating inertia-based clockwise rotation of the northern palaeo-hemispherical crustal cap (Storetvedt, 2003/2023). This tectonic event reactivated the orthogonal fracture system for which the tectonic effect in the TSC region apparently was a combination of transtension followed by transpression. In this process, the deeper segment of the mineralization zone and its late Devonian host complex, were forced towards the NW beneath early Carboniferous strata -at an intermediately steep angle. In this process, the current mine (ie. under development) was apparently disconnected from its deeper tectonic connection (Tungalag et al., 2018).

Based on palaeoclimatic evidence, Wegener (1929/66) defined a stepwise spatial reorganization of the Earth (true polar wander) in approximately the Greenwich meridian plane -a polar wander path later confirmed by palaeomagnetic data (Storetvedt, 1990). Within this palaeogeographical framework, the Devonian of southern Mongolia had sub-tropical latitudes, with relatively strong inertia-based wrenching. Aided by the long-term magmatic activity of this region, the upper crust acquired a deformable wrench tectonic state. The increasingly ductile and laminated deeper crust probably acted like a moderately twisted deck of cards. During the Middle-Upper Palaeozoic, southern Mongolia was a nodal region in the tectono-topographic curvature of the country -representing a kind of wrench tectonic link chain between the prevailing NW-SE and NE-SW fracture sets of Central Asia. In this bending process, the east-west running structural split-ups in the Gobi region form an expected constructional transition (Michaelsen and Storetvedt, 2023). It can therefore be expected that, in the late Devonian to early Carboniferous, Oyu Tolgoi deposit underwent even stronger deformation than Tsagaan Suvarga. A separate 25° of regional clockwise torsion was already noted for the Tsagaan Suvarga Complex. So, with the extensive Devonian to Permian magmatic activity further south, the structural situation in the Oyu Tolgoi region would be expected to be even more complex and strong -including both syn -and post-tectonic clockwise wrench tectonic rotations. It appears that we also have a reasonable explanation for the weak arc shape of the Oyu Tolgoi corridor -an additive displacement to the west along transverse faults (see also below). The regional structural maps, compiled by Porter (2015), supports these predictions. Furthermore, the OT mineral belt is apparently not developed between fault zones but is interpreted here as consisting of additive wrench tectonic mineralization fragments (see below).

Fig. 12 shows the tectonic setting of the Oyu Tolgoi mineralized corridor, representing one of the largest high-grade group of Palaeozoic Cu-Au porphyry deposits currently known in the world. All ore deposits are connected to phenocryst-crowded monzodiorite intrusions and a deformed irregular network of quartz veins (Porter, 2015 and references therein), indicating that the veins are syn-tectonic. Several NE-ENE trending faults cut across and disrupt the slightly bended NNE oriented and 12 km long porphyry corridor. According to the structural maps of Mike Porter, the major and gently curved regional faults form an approximately orthogonal bundle binding them together west of the Javkhlant porphyry deposit -an orebody that is markedly offset to the west relative to the moderate westward bend of the main mineralized corridor (Fig. 12). To the west of the NNE trending mineralization zone, Mike Porter's compilation map shows another tectonic bundle (his Fig. 4) -with fault zones varying from the north-trending

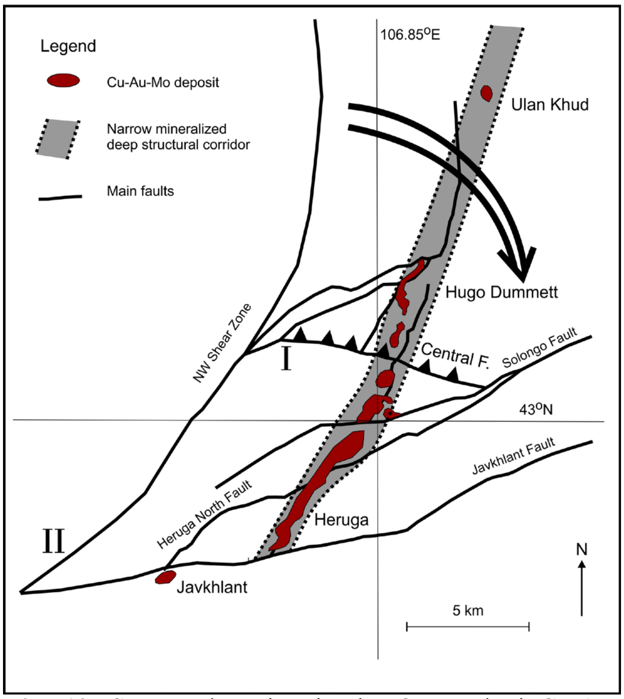

Fig. 12. Structural setting in the Oyu Tolgoi Cu-Au province, southern Mongolia - simplified from compiled maps in Porter (2015). Due to additive clockwise wrench rotation, the upper crust underwent significant deformation in the middle Palaeozoic. The orthogonal NE/NW fault system was distorted into two tectonic bundles - I and II.

Southwest Shear Zone (to the west) to the E-W oriented Central Fault (cutting across the mineralization axis) which has a compressive-transpressive character. This may indicate that during the Oyu Tolgoi mineralization, the northern sector underwent significant additive clockwise wrench rotation, in addition to causing shear-tectonic stresses along the entire ore corridor. That is, the mineralization trend of the porphyry deposits represents separate additive transtensive sectors within the regional wrench tectonic system. This again means that the mineralized belt probably had its tectonic and mineralizing beginning in the NW-oriented conjugate fault structure, before the region was deformed during significant clockwise torsion.

The south-directed compressive shear stress noted along the Central Fault is most likely the main reason why both the northern (Hugo Dummett) and the southern (Heruga) mineralization block underwent NNE-directed post-mineral tectonic dip. Age dating of the mineralization (Re-Os on molybdenite) have given late Devonian ages c. 372 to 370 Ma (Khashgerel et al., 2009; Crane and Kavalieris, 2012). The ores were deposited within syn-mineral quartz-monzodiorites after which an allochthonous sequence of older Devonian (or pre-Devonian) rock sequence was overthrust and a post-ore granodiorite intruded at c. 365 Ma (Porter, 2015, and references therein). Hence, the age information for Tsagaan Suvarga and Oyu Tolgoi deposits correspond to the Frasnian-Famennian mass extinction (ie. the Kellwasser event) -a degassing related forerunner to the tectonic upheaval that occurred around the Devonian-Carboniferous boundary. Fig. 13 shows that the Hugo Dummett sector is currently the most profitable mineral deposit. The reason is apparently that the northern province has undergone the strongest wrench-tectonic rotation and thus has established the readiest syn-tectonic supply channels for metal-bearing silicic fluids. It follows therefore that also the Ulaan Khud prospects are likely to have significant mineral resources.

Pathway to new discoveries

"The error in geology has been neglect of mantle plumes which rework the surface. In geophysics the error has been neglect of the control of faulting in the lithosphere. […] Two separate revolutions to correct these errors seems likely to lead to a common fresh paradigm uniting structural geology, geophysics, and classical" wrote John Tuzo Wilson -in the abstract for a guest lecture at Memorial University of Newfoundland in fall 1992.

To understand the content of Earth's physical manifestations and its pulsating geological history, a stock of unorganized scientific facts is of extremely limited value. True scientific knowledge is always dependent on a functional overarching theory that ties together different types of observations and phenomena -and repudiate the classical flow of ad hoc repairs. Such a theory must have predictive capacity which in turn must lead to confirmatory observations and then to realistic conclusions. Within the context of the new Earth degassing-based theory -Global Wrench Tectonics (Storetvedt, 1997, 2003/2023), the authors recently reevaluated several geological and geophysical facts from Mongolia (Michaelsen and Storetvedt, 2023, and references therein). A fundamentally new geological interconnection

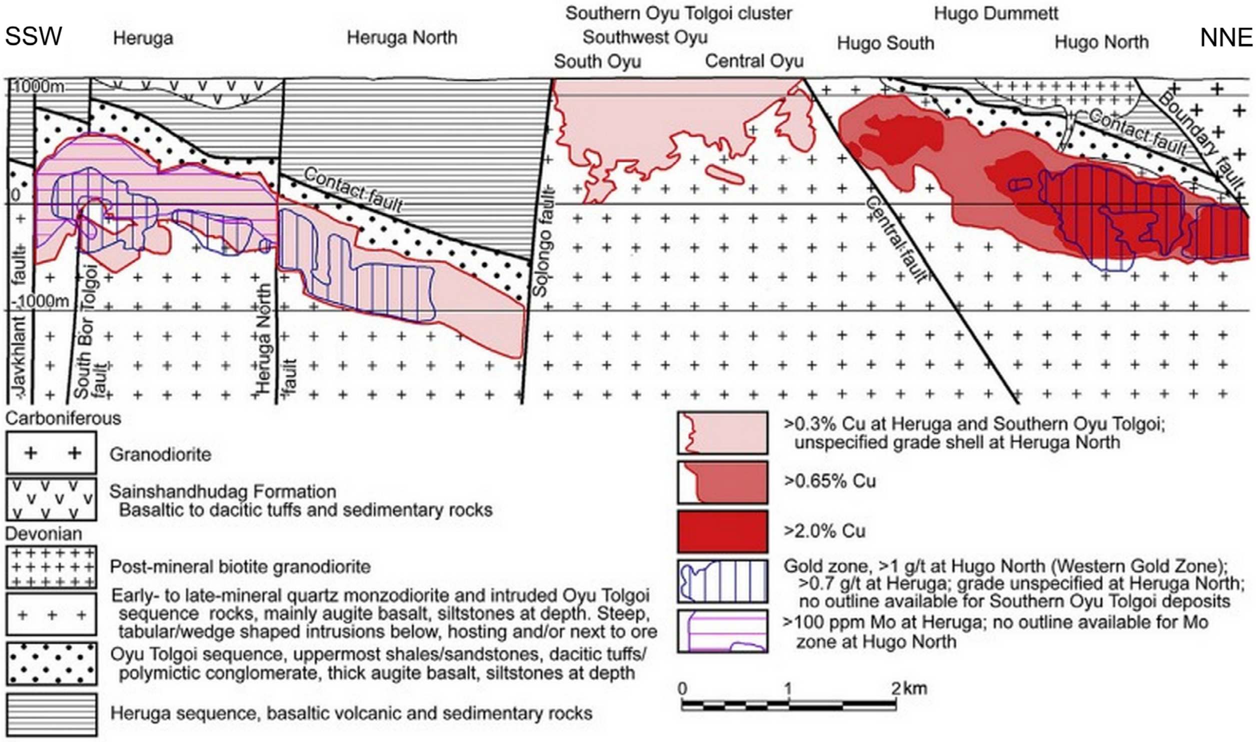

Fig. 13. Longitudinal cross section along Oyu Tolgoi mineral belt, Mongolia, based on Porter (2015). The northward tilting of the ore zones is explained by cumulative transpressive clockwise rotation in the northern sector which in turn has made the Hugo Dummett deposit(s) particularly rich in mineral resources.

has been established -within which the pulsating tectono-magmatic history is driven by changes in Earth's moment(s) of inertia, in combination with inertial effects of the mechanically detached upper crust.

In the present paper, we have extended the new theoretical platform to assess other surface aspects in Central Asia -such as development of elongate sedimentary basins, origin of (abiotic) hydrocarbon fields, and graphite and metal deposits, including leaching, transport and unloading. The interpretations and surface emplacement are closely linked to the Earth's dynamo-hydrostatic-hydraulic pumping system, which also provides the internal machinery for Earth's pulsating geological history. The new starting point is the more than a hundred-year-old recognition that the core has a density deficit. Modern assessments have pointed out that the core must still contain up to 15 wt.% of light elements -including hydrogen, oxygen, carbon, silicon and sulphur. This means that the Earth has not yet reached thermochemical equilibrium -indicating an extremely slow degassing-related planetary evolution, and the very reason why it still is a tectonically active planet. Thus, it is presumed that liquid carbides and hydrides, in their supercritical states and at pressure bath situations (ie. with a relatively open fracture network), have slowly left the core, moving through the mantle to the crust. The associated mass transfer has progressively reworked the crust both petrologically and tectonically, beside supplying the surface with water, hydrocarbons, and ore resources. The rate of Earth's geological and tectonic development has apparently been exponential.

Owing to its high abundance ratio, silicon may be one of the potentially more important elements of the core's metal hydrates -its low density giving it a differential buoyancy that during chemical reactions may produce SiO_2. Eventually, the rise of silicon fluids has been responsible for the intense granitization of the upper continental crust, as for example demonstrated in the Kola Superdeep Borehole. Also, the widespread granitic-silicic magmatism in Mongolia can be explained the same way. Furthermore, it is probable that the enigmatic veins, and sometimes very thick dykes, of pure quartz, especially characteristic in the ancient metamorphic basement, have been formed by the injection of silicon oil driven by high hydrostatic pressure. As outlined in our previous paper, the topography of the core-mantle boundary (CMB) seems to be closely associated with the gross crustal structure. Thus, when projected to the surface, upstanding CBM regions correspond to deep oceanic depressions with their thin and metasomatized crust. In addition, the vertical outer core-crust correlation contradicts the idea of lateral crustal movements, and provides a reasonable answer to the fundamental, but presently ignored, problem of the several hundreds of kilometres deep continental roots. Regarding the fluid flow instigating the development of thin oceanic crust, it has been suggested that water may be the most critical factor for the eclogitization process and its attendant gravity-driven subcrustal delamination. It follows that the potential water content of the fluid flows beneath the emerging oceans, have been much greater than for those that percolated through the fracture network of the thick continental crust of Central Asia. However, the water content was apparently sufficient for eclogitization and limited crustal thinning along transtensive fault zones -thereby initiating the development of elongate sedimentary basins. Furthermore, ongoing degassing of metal hydrides through the seabed is demonstrated by the widespread occurrence of multi-metal nodules on the deep-sea floor. We cannot emphasize strongly enough the fundamental role the orthogonal fracture system, in combination with inertia-driven deformation of the upper crust, has for assessing surface-geological structure and resources.

We began this short fragmentary discussion with excerpts from an abstract by John Tuzo Wilson, one of the leading proponents of the plate tectonic revolution in the late 60s. However, in his older (and presumably wiser) days, he called for a necessary paradigm shift in global tectonics, pointing to some critical facts that had been ignored. First, he apparently had become aware of the connection between fluid flows from the core (his plumes) and their role in physical and geological restructuring of crust and mantle. Second, he drew attention to the ingrained neglect (or ignorance) of the importance of faults in the lithosphere -where the steeply dipping orthogonal fracture/fault network is of paramount importance. Wilson saw the need for a new paradigm to correct these errors -one that could unite structural geology, geophysics, and classical physics. This is precisely what the new degassing-based theory aims at.

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