Importance of an Expanded Definition of Ocean Plate Stratigraphy For Evaluating Tectonic versus Sedimentary Mélanges

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The transfer of materials from a subducting oceanic plate to a subduction-accretionary complex has resulted in rock assemblages that record the history of the subducted oceanic plate from creation to arrival at the trench. These rock assemblages, which comprise the uppermost igneous part of the oceanic crust (commonly basalt) overlain by pelagic sedimentary rocks (chert and/or limestone) overlain by clastic sedimentary rocks (mostly sandstone, shale/mudstone), have been called Ocean Plate Stratigraphy (OPS). The original definition of OPS as a basalt-chert (with or without limestone)-clastic triad, was based on early recognized examples in ancient subduction complexes and the prevailing model for oceanic crust. Growing recognition of the variability of oceanic crust, including examples of serpentinite exposed on the sea floor, as well as observations of lithologic variability of oceanic imbricates in subduction complexes, suggests the need to expand the OPS definition. For example, at a structurally intermediate level in the Sierra City mélange of the Shoo Fly Complex of California, oceanic lithologies include zones of serpentinite, gabbro, diabase, basalt and chert up to 200 m thick, with internal structural style ranging from imbricate slabs to block-in-matrix with serpentinite, gabbro, and basalt locally forming matrix. Serpentinite-dominated OPS may also include slices of continental crust affinity where the subducted crust was apparently a hyper-extended continental margin. Examples of this type of OPS have been recently identified in high-pressure metamorphic rocks of the Western European Alps. The definition of OPS is important in interpreting “native” blocks, derived by progressive deformation from OPS, versus “exotic” blocks (may be introduced by sedimentary means) in mélanges. Prior to the defining of OPS, chert and basalt blocks in a clastic matrix were commonly considered exotic; a wider range of native lithologies needs to be considered and this requires corresponding care in evaluation of tectonic versus sedimentary origin of blocks-in-mélanges.

Keywords: Subduction Complexes, Ocean Plate Stratigraphy, Sedimentary and Tectonic Mélanges

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Phase relation of lawsonite-blueschists and their role as a water budget: A case study from the Hakoishi sub-unit of the Kurosegawa belt, SW Japan

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This study investigated progressive changes in the mineral assemblage of a Palaeozoic lawsonite-blueschist (BS) unit of the Kurosegawa belt, Kyushu, Japan. The BS unit is mainly composed of intercalated metachert and metabasaltic rocks surrounded by serpentinite. Based on the spatial distribution of mineral assemblages in metabasaltic rocks, three mineral zones can be identified in a ca. 10 km-long east¬-west oriented unit: (1) a pumpellyite (Pmp) + Na-amphibole (Namp) assemblage dominated area (Zone 1); (2) an intermixture area of lawsonite (Lws) + Na-pyroxene (Napx) + Pmp and Lws + Namp + Pmp assemblages (transition zone); and (3) an area dominated by Lws + Namp + Napx assemblages (Zone 2), with excess chlorite (Chl), albite (Ab), quartz (Qz), titanite, and Fe oxides. Na-pyroxene varies its composition from jadeite(Jd)20-diopside(Di)25 of Zone 1 to Jd35Di15 in Zone 2 with a similar composition range of aegirine(Ac) content (from 40 to 55). Glaucophane component {XGln =Al/(Al+Fe3+)} of Na-amphibole associated with Lws and Pmp increases from XGln =0.2 in Zone 1 to XGln =0.8 in Zone 2. Jd contents and a lack of epidote and zeolite group minerals suggest that the pressure (P) conditions of the BS increase from Zone 1 (0.50 GPa) to Zone 2 (0.75 GPa) between 200-300 °C, suggesting that a low geothermal gradient (ca. 5-10 oC/km). Schreinemakers' analyses in a NaCaMgFe3+AlSiH (NCMF3ASH) system using mean mineral compositions of representative samples with excess of Chl, Ab, Qz and H2O suggest that 1) observed variations in mineral assemblages can be formed by a hydration reaction of Pmp + Napx + Chl + H2O = Lws + Namp, which was driven by a P increase from Zone 1 to Zone 2 and they represent the transition from the Pmp-BS to Lws-BS sub-facies; 2) the total H2O content stored in hydrous minerals increases from 3.6 wt % in the Pmp-Namp assemblage of Zone1 to 5.0-6.4 wt % in the Lws + Namp + Napx assemblages in Zone 2; and 3) along with the Lws-Namp and Pmp-Namp assemblages, the Napx + Chl assemblage can retain a significant volume of H2O and its stability field can expand to higher P conditions by decreasing the Di and increasing the Jd and Ac contents of Napx.

Keywords: lawsonite blueschist, phase relation, H2O budget in subduction zone, Kurosegawa belt.

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The promise and pitfalls of microsampling Lu-Hf garnet geochronology

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The technique of microsampling, such as micro-drills and micro-saws, is an intriguing approach for unraveling the growth pace of garnet as well as the dynamics of tectonic and petrologic processes. Microsampling method so far has been successfully used for Sm-Nd and Rb-Sr garnet geochronology, yet, the difficulties of this method for Lu-Hf garnet system remain unresolved. The micro-zircon inclusion in garnet and the relatively large amount of materials needed for Hf analysis, are the two barriers to applying microsampling for Lu-Hf garnet geochronology. Here, we present several Lu-Hf dates from distinct zones of a single large garnet by conventional microsampling method. Two large garnet porphyroblasts of several centimeters in diameter, comprised of dark cores and pale rims, were studied. Elemental compositions and mineral inclusions in the garnet indicate two garnet generations. Lu-Hf dates of ~400 to 264 Ma were obtained from twelve micro-sawed sections from the porphyroblasts. These Lu-Hf dates were interpreted to bracket the period of garnet growth. The spread from 400 to 264 Ma is interpreted by a protracted and episodic garnet growth, which suggests two subduction cycles for the host rocks. Microsampling Lu-Hf geochronology of consecutive garnet shells is a promising approach to deciphering the growth rates of individual porphyroblasts.

Keywords: Lu-Hf, Microsampling, Garnet

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Ophiolite in the Western Ethiopia: A fossil mantle wedge of the East African Orogenic Belt

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East African Orogenic Belt (EAO) along eastern Africa and western Arabia is the world's largest Neoproterozoic to Cambrian orogenic belt (Fritz et al. 2013). This amalgamated belt with a ~6000 km length reflects collision of arcs or microcontinents against the Archean craton margins. Although ophiolites and their subducted equivalents are minor components, those rocks provide a clue to understand the petrotectonic evolution, particularly geodynamic process of Neoproterozoic arc-trench systems. In this contribution, we will present petrological features of the Arabian-Nubian Shield ophiolite of the western Ethiopia, and will introduce significance of metasomatism to form "listvenite" (Cr-muscovite-bearing silica-carbonate rock) by CO_2-rich hydrothermal fluids.
We have studied metamorphosed mafic-ultramafic bodies in Tulu Dimtu area (western Ethiopia) of the Arabian-Nubian Shield. The ophiolitic bodies exposed within a NNE-SSW trending metavolcanics and quartzite complex; they consist mainly of serpentinite (antigorite schist), serpentinized harzburgite with minor metagabbro/metadolerite. The ultramafic bodies bear abundant Cr-muscovite-bearing silica-carbonate rocks, so called "listvenite". The serpentinized harzburgite contains high-magnesian metamorphic olivine (forsterite [fo]93-96) with magnetite and rare relict primary mantle olivine (fo90-91). Both serpentinite schists and serpentinized harzburgite contain zoned chromite; the cores with the ferritchromite rims preserve a pristine Cr/(Cr+Al) atomic ratio (Cr#= 0.79-0.87), suggesting a highly-depleted residual peridotite likely formed a supra-subduction zone wedge mantle. Metagabbros have a MORB/OIB-like affinity; they contain epidote-amphibolite facies mineral assemblages but rich in carbonate minerals. Listvenites in Tulu Dimtu contain relict chromites that overlap with Cr# of those in serpentinite and serpentinized harzburgite, excepting one sample (Cr#=0.57). Noteworthy chromites in listvenite has a significantly higher Mg/(Mg+Fe) ratio. This indicates that a complete metasomatic replacement of serpentinized peridotite to form listvenite took place prior to re-equilibration between chromite and surrounding mafic minerals; in other words, listvenite-forming metasomatism have occurred before the serpentinization of harzburgite. The CO_2-rich hydrothermal fluids infiltration into wedge mantle might have occurred prior to regional metamorphism/deformation of the EAO.

Keywords: listvenite, metasomatism, serpentinization, East African orogeny, Ethiopia

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Geological significance of unusually Fe-rich ultramafic cumulate of the Furudono ophiolite in Abukuma Mountains (NE Japan)

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Since Miyashiro (1961)'s concept of "paired metamorphic belts", the Abukuma LP-HT metamorphic belt of NE Japan has been thought as an eastern extension of the Ryoke belt that was paired with the Sambagawa HP-LT metamorphic belt. However as our recent study of the "Furudono ophiolite (FDO)" (Sato and Ishiwatari, 2015) showed the ophiolitic rocks provide new insights into a framework of pre-Jurassic geotectonic units of Japan. In this talk, we will introduce petrological characteristics of the FDO and will propose a few new ideas of correlation between the FDO and ophiolitic rocks not only in NE Japan but also in SW Japan.
Sato and Ishiwatari (2015) studied on small mafic-ultramafic bodies in the central part of the Abukuma Maintains; they proposed to distinguish the ophiolitic bodies from the Gosaisho-Takanuki metamorphic rocks as the "Furudono ophiolite". Key petrological features of the ophiolite includes: (1) highly-depleted residual peridotite, (2) unusually Fe-rich ultramafic, and (3) gabbroic rocks with arc-affinity. It is noteworthy that Fe-rich ultramafic cumulate is a rare rock-type in common ophiolites; it might have been produced by a partial melting at relatively great depths.
The recognition of a unique ophiolite in the Abukuma belt is significant in terms of the regional tectonic framework of Japan. What is the significance of the FDO? Sato and Ishiwatari (2015) agreed some similarities in highly-depleted residual peridotites between the FDO and the Hayachine-Miyamori ophiolite (HMO) of Kitakami Mountains (NE Japan). However here we also address a similarity between ultramafic rocks of FDO and these from the Higo belt in central Kyushu, in particular mineral assemblage and compositional similarity. Recently, Ichiyama (2015) reported unusually Fe-rich ultramafic cumulate (Mikame ultramafic body) from the Oshima metamorphic rocks of the westernmost Shikoku; he also pointed out the geological and petrological similarities between the Fe-rich ultramafic cumulate and ultramafic rocks from the Higo belt. Considering our study of the FDO together with recent finding of unusually Fe-rich ultramafic cumulates in the westernmost Shikoku, the FDO may correlate to ultramafic rocks of the Higo belt rather than HMO. It had been postulated a geological correlation between the Higo and Abukuma metamorphic rocks on the basis of protolith etc (e.g., Isozaki et al. 2010). Unusually Fe-rich ultramafic cumulates would be a new geological tracer to link between the Higo and Abukuma belts.

Keywords: Furudono ophiolite, Ultramafic cumulate, Supra-subduction zone, Abukuma belt

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Deciphering a diverse garnet zoning pattern observed in a single eclogite lens in Nové Dvory, Moldanubian Zone of the Bohemian Massif

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There is an argument on the origins of the Nové Dvory eclogite which experienced over 4GPa and 1000 ^{o}C (Nakamura et al., 2004). It occurs as intercalated lenses in an ultrahigh-pressure (*UHP*) peridotite block surrounded by the country gneiss. Medaris et al. (1998) invoked the high-pressure melt origin of the eclogite based on a geochemical study. Nakamura et al. (2004), however, proposed the subduction origin of the eclogite inferred from a garnet which increases XGrs and decreases XMg toward the rim in a kyanite-SiO2 phase-bearing eclogite. Changes in XMg and XGrs of garnet are commonly utilized as indicators of temperature (*T*) and pressure (*P*), respectively. These assumptions are applicable to eclogites with low-variant and appropriate mineral assemblages. However, it is unlikely to be applied to eclogites with high variant systems. Recently, Faryad et al. (2013) and Nakamura et al. (2013) identified more variety of garnet zoning patterns in bi-mineralic eclogites in Nové Dvory. It made a new argument on the *P-T* history of the eclogite. This study reports further diverse zoning patterns of garnet identified in the Nové Dvory eclogite, and deciphers their formation process by taking into account of the above mentioned factors.
The study eclogites (ND120 and ND0207) are bi-mineralic type collected at one outcrop in Nové Dvory. They are dominated and modally layered by garnet and omphacite. Accessory rutile and apatite are observed. Garnet and omphacite are partially decomposed to amphibole, diopside, spinel, and plagioclase at the margin in various degrees. X-ray mappings show that garnets have individual core compositions and identical rim compositions among each modal layer. Omphacite inclusions are observed only in the inner rim of garnet. In ND120, three kinds of layers are identified, and they contain garnet with Fe-rich core (XMg = 0.30, XGrs = 0.22), Mg-rich-core (XMg = 0.65, XGrs = 0.22), and Ca-rich core (XMg = 0.55, XGrs = 0.25), respectively. The compositions of garnet rims are similar as XMg = 0.50 and XGrs = 0.22. In ND0207, two kinds of layers were identified, and they contain garnet with Mg-rich core (XMg = 0.69 XGrs = 0.21), and Ca-rich core (XMg = 0.52 XGrs = 0.37), respectively. The compositions of garnet rims are similar as XMg = ca. 0.60 and XGrs = ca. 0.30. In both samples, omphacites tend to be Mg-richer and Na-poorer when it appears near or in garnet with Mg-richer core. Because both increase and decrease in XMg (ND120) and XGrs (ND0207) of garnet are observed in hand specimen samples, these parameters cannot be utilized as *P-T* indicators.
The garnet rim contains omphacite, and is indicated to be developed under eclogite-facies. Yasumoto & Hirajima (2015) identified F-bearing pargasites in garnet from a Nové Dvory eclogite, which is stable up to ca. 3GPa at 800^{o}C. It also suggests the eclogite was formed through subduction. In the study samples, omphacite inclusions are not observed in the garnet core. This infers some cores formed under amphibolite-facies conditions. The chemical variation of garnet cores (i.e., Fe-rich, Mg-rich, and Ca-rich cores in ND120) and omphacites in the study samples are considered to be strongly controlled by local effective bulk compositions of their located layers. In contrast, similarity of the garnet rim compositions can be explained by the coincidence of effective bulk compositions of each layer. Drive force of changes in effective bulk compositions can be *T* increase along subduction or water liberated from decomposition of amphibole. Note garnet with Ca-rich core in ND120 has a Fe^{3+}-enriched omphacite-free mantle (XMg = 0.52, XGrs = 0.22, XAdr = 0.03) while the core and the rim are free from Fe^{3+}. This Fe^{3+} in the garnet mantle can be inherited from decomposed amphibole.

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Keywords: ultrahigh-pressure, garnet, fluid

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Discovery of H_2O inclusions in Kokchetav metamorphic diamond; diamond crystallization during metasomatism in UHP conditions

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Metamorphic diamond was first reported from the Kumdy-Kol area of the Kokchetav Massif (Sobolev & Shatsky, 1990). Kokchetav diamond occurs in dolomite marbles, gneisses, and garnet-clinopyroxene rock with various features of morphology and occurrence. The coarsest crystal (> 100 μm across) of metamorphic diamond occurs in garnet-clinopyroxene rock, compared to diamond in dolomite marble and gneisses (average size: 10 μm across after Schertl & Sobolev, 2013). We report H2O inclusions and carbonate inclusions in coarse-grained cubic diamond in this rock.
The garnet-clinopyroxene rock collected at the Kumdy-Kol area is composed of garnet layers and clinopyroxene layers with minor amounts of rutile. Due to the simple main constituents, this rock looks like low-P skarn. Diamond occurs as inclusions in garnet and clinopyroxene, and interstitial phases in their boundary. Recently, the same rock type but diamond-free one was described; this diamond-free garnet-clinopyroxene rock contains supersilicic titanite as evidence of UHP conditions (Sakamaki & Ogasawara, 2014).
Cubic diamond grains (approximately 100 μm across) chemically separated from the rock was examined by micro-Fourier transform Infrared spectroscopy (micro-FTIR) spectroscopy in transmission mode. IR spectra of diamond were obtained by using a KBr pellet as an IR transparent window in N2 gas atmosphere. Obtained transmission IR spectra show CO32- bands at 1455 cm-1 (weak), clear CH bands at 3107 cm-1 (strong), broad H2O bands at 3428 cm-1 (strong), and sharp OH bands at 3555 cm-1 (strong) were identified. These bands are caused by carbonate inclusions, H2O fluid inclusions, hydrogen in diamond matrices, and a hydrous silicate mineral, respectively. These IR absorption bands are similar to those from garnet-clinopyroxenite from the same area in De Corte et al. (1998). Strong IR absorption bands by C-N bonds at 1282 cm-1 (A center, very strong), 1180 cm-1 (B center, very weak), and 1133 cm-1 (C center, weak) are also detected.
High concentrations of water as structural OH and submicron-sized H2O fluid inclusions in garnet and clinopyroxene coexisting with diamond were detected; 0 (dry) to OH: 1727 ppm and H2O: 1592 ppm in garnet and total water (OH+H2O): 721 to 4515 ppm in clinopyroxene. Water (OH and H2O) distribution in the host rock is very heterogeneous grain by grain.
The skarn-like constituents, H2O fluid inclusions in diamond, host garnet and clinopyroxene, and high OH contents in host garnet and clinopyroxene indicate that the diamond and its host rock formed under H2O-rich fluid environments such as metasomatism at UHP conditions. The heterogeneous water distribution in the host rock results from a spatial and temporal heterogeneities of H2O fluid conditions during UHP metasomatism.

Keywords: Kokchetav Massif, Diamond, H2O fluid inclusion, micro-FTIR

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Crystallographic preferred orientation analysis of Sanbagawa eclogites using a Scanning Electron Microscope EBSD method

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Sanbagawa metamorphic belt in Japan is characterized by the high-pressure and low-temperature (HP/LT) intermediate type belt which extends from northeast Kanto through the Kii peninsula, passing through central Shikoku until Kyushu in the southwest. The belt is mainly composed of basic, quartzose, pelitic-psammitic schists with several eclogite and ultramafic bodies.
In this paper, we present our study conducted on three three eclogite samples collected from the Iratsu eclogite body. Samples Sb-1 and Sb-3 represent hornblende eclogite whereas Sb-2 represents the quartz-bearing eclogite. From each eclogite samples thin sections in 3D were prepared (i.e. XY-direction, XZ-direction, and YZ-direction). The samples were then studied(1) petrographical under the optical microscope for textural and mineralogical features, (2) chemical features (elemental maps), and (3) Physical features (crystallographic preferred orientations). (1) Petrographically, Sb-1 and Sb-3 are mainly composed of light green omphacite (Omp), pinkish red garnet (Grt), dark green secondary hornblende (Hbl), and actinolite (Act) with pale yellow or colorless epidote (Ep). The samples exhibited granoblastic texture in which Grt was embedded in clustered imp and hHbl. Most of the Omp grains have been retrogressed to Hbl and Act. Garnet porphyroblasts have numerous cracks. Sample Sb-2 was composed of Grt, Omp, secondary Hbl, Ep with abundant quartz. Garnet porphyroblasts have identical features to those observed in Sb-1 and Sb-3, however in this sample they are heavily fractured. In this sample too, Omp grains have secondary Hbl along their rims.(2) Based on chemical elemental mapping (using XGT), all the three samples exhibited Fe-rich Grt with some amount of Mn-component, Ca-rich Omp and Hbl. (3) For physical features, we measured selected areas in each samples for crystallographic preferred orientations (CPO) using Backscattered electron backscattered diffraction (EBSD) method. EBSD maps were collected and from representative phases (Grt, Omp, Hbl, Act) CPOs were presented in pole figures which were constructed along a-axis [100], b-axis [010], and c-axis [001], respectively. The data obtained show that Grt did not show any specific pattern of orientation, hence behaved like rigid body whereas Omp and Hbl/Act display the strongest CPO along [001]-axes, typical for the L-type fabric, representing subduction-related deformation rheology at mantle depth. Hornblende and Act, are secondary after Omp, hence did not modify the CPO during the retrogression stages.

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Seismicity and Tectonics of the Black Sea

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The Black Sea, a complex basin between the Arabian, Anatolian and Eurasian plates is a feature of special interest for understanding the geologic history of the region. It was formed as a “back-arc” basin over the subduction zone during the closing of the Tethys Ocean. In the past few decades, the Black Sea has been the subject of intense geological and geophysical studies, including deep seismic sounding and reflection profiling for scientific and petroleum exploration purposes. The Black Sea consists of two basins, Eastern and Western Black Sea, seperated by NW-SE tending topographic ridges. The deepest part of the basins have oceanic crust below a thick cover of sediments at a depth of about 10 km. The margins and the ridges have continental crusts.
In this paper, we present the seismic and fault mechanisms of earthquakes in and around the margins of the Black Sea. Although seismic activity is spare in the basin relative to the surrounding region of the Caucauses and Turkey, the broad-band seismic networks established in surrounding countries, especially in Turkey since 2005, have provided the capability for the detection, location and source mechanism studies of earthquakes in the Black Sea basins. The data shows that; There are a significant number of earthquakes in the Black Sea, mostly of magnitude Mw=4.0 or smaller.
The seismicity increases toward the margins, with the largest events at the margins. The focal mechanisms indicate primarily N-S compression with some E-W component. The mechanism are consistent with the GPS observations, where Westward motion of the Anatolian Plate and N-S deformation of the Caucuses take up most of the motion of the Arabian Plate and only small motions (about 1 mm per year) are transmitted through the Pontides and the Black Sea is being compressed in N-S direction.
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Keywords: Black Sea, oceanic crust, seismicity, fault mechanisms, GPS deformation

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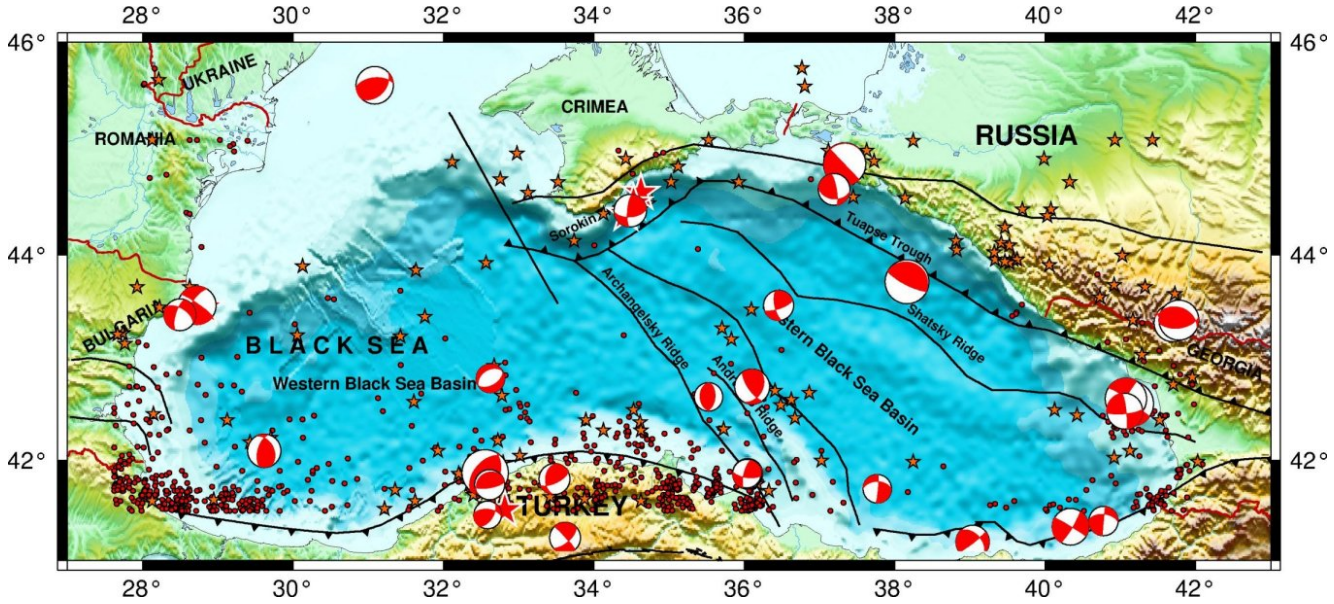

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