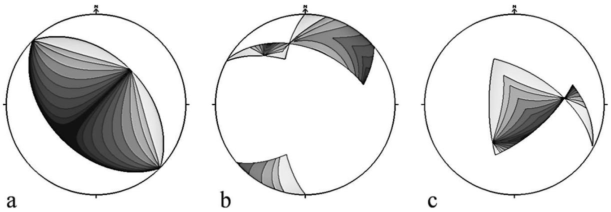
hand orthogonal system *lmn*, it is easy to derive equation for Lode parameter $\mu = (2\sigma_2 - \sigma_1 - \sigma_3)/(\sigma_1 - \sigma_3)$ in dependence on direction of σ_1 and σ_3 respectively. This function limits field of possible σ_1-directions with decreasing of μ_{max} (Fig. 2a) and σ_3-field with increasing of μ_{min}. The field of σ_1 is equivalent to right dihedra quadrant for $\mu \leq 1$ as one extreme and is reduced to part of M-plane for $\mu = -1$ as the second extreme (Fig. 1). Base on this idea we can make equal-area plot for fields of σ_1 and σ_3 with isolines of μ (Fig. 2b, c). With these plots we can determine upper and lower limits of μ (μ_{max}, μ_{min}), and corresponding fields of σ_1 and σ_3 respectively.



a b c

Fig. 2. Equal-area plots of distribution σ_1 and σ_3 showing field reduction in dependence on μ_{min} and μ_{max}: a – one fault, σ_1-plot with μ_{min} isolines; b – σ_1-plot of μ_{min} for two faults from Fig. 1; c – σ_3-plot of μ_{max} for the same faults. Isolines of μ: −1.0, –0.9, –0.8, –0.6, –0.3, 0, 0.3, 0.6, 0.8, 0.9, 1.0.

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A Record of Oceanic and Continental Stages in Evolution of the Sudetic Ophiolites – New Evidence from Stable Isotope Composition of Silicate Minerals.

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Hydrogen and oxygen isotope ratios in mafic and ultramafic rocks of Ślęża (Sl) and Nowa Ruda (NR) ophiolites complexes (N margin of Bohemian Massif, Sudetes Mts., SW Poland), have been analysed. This was done to assess the role of ocean floor metamorphism and continental processes in the evolution these two ophiolites.

These ophiolites belong to the mafic-ultramafic massifs surrounding the significantly older Precambrian Sowie Mts. gneissic block (SM). The NR ophiolite is situated at the SW margin of the SM. Its northern part is composed of variable petrologic types of altered gabbro (metagabbro) and the southern, subvolcanic part, consist of metadiabases and altered pillow lava. The northern and southern parts are divided by the Słupiec cataclastic zone. The Ślęża ophiolite represents almost complete ophiolite sequence composed of: Gogołów-Jordanów (G-J) serpentinite massif (ultramafic member), Ślęża Mt. gabbro (mafic, plutonic member) and Wieżyca Hill (WH) metadiabases and amphibolites (volcanic member). The ophiolite is in overturned position and the pillow lava and sedimentary members have not been found. The Sl ultramafics contact on S to the N border of SM, and all the Sl members contact on N and NW to the SE border of slightly younger Variscan Strzegom-Sobótka (S-S) granite massif. Comparison of mesostructural features of the ophiolite to such features of other Sudetic units of known age, suggests that the emplacement of these ophiolites took place during Variscan orogenesis (continental collision with NE-SW suture zone). Sm-Nd age determination of the mafic member confirmed that thesis. The Sm-Nd age of the mafic member of Sl is 353 ± 21 Ma and that of NR is 351 ± 16 Ma.

Structural evolution of rocks is not necessary accompanied by formation of new minerals however, apparently may result in a redistribution of isotope ratios in the deformed primary minerals. Thus, isotope analysis may be a good tool to reconstruct geological condition of structural evolution of rocks. Mesostructural observations in Sl revealed presence of the primary magmatic lamination S_0 and metamorphic and/or tectonic foliations S_1, S_2, S_3 and S_4. Moreover, 6 systems of slickensides have been observed. In case of the sheeted dykes member (amphibolites) the S_0 may be considered as sequence of rhythmic variations of the structure, parallel to the margins of the dykes. In lower members of the ophiolite the S_0 is a dark and light lamination. In the metagabbro the leucocratic laminae are composed predominantly of feldspars and products of their hydrothermal decomposition. The melanocratic laminae are composed mostly of diallage and uralitic hornblende. In the ultramafic cumulates the light laminae consist mostly of chlorites, tremolite and primary calcite, and the dark ones are relics of pyroxenes and amphiboles. In the tectonites (serpentinites) the S_0 exists in presence of flat sectors composed predominantly of pyroxene relics, and the overlying spaces are filled mostly with olivine and products of its decomposition.

The S_1, in general, is parallel to S_0, but sometimes one can observe centimetre-scale intrafoliation folds F_1 formed during the D_1 deformation. Despite that in the outcrop-scale the F_2

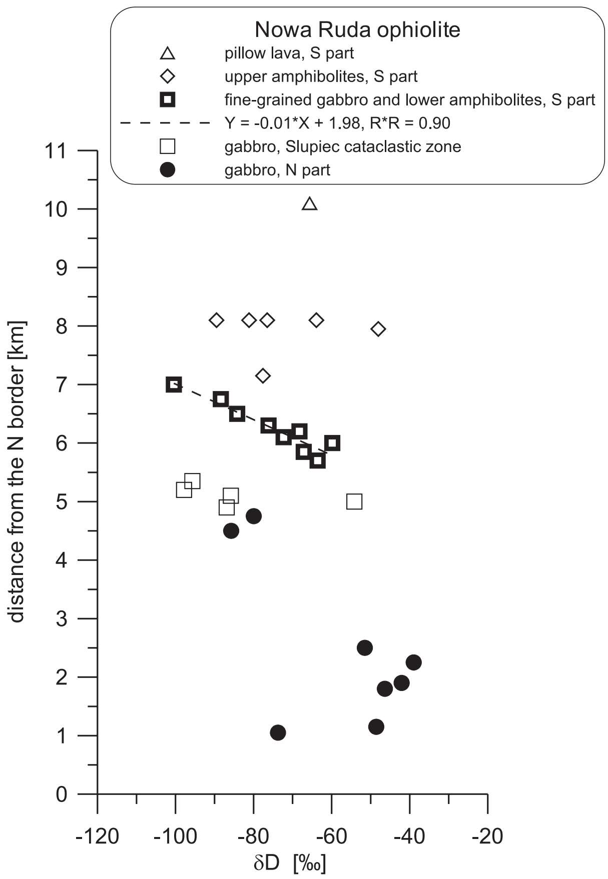

Fig. 1. δD *versus* distance to the N border (the potential Moho) of the Nowa Ruda massif

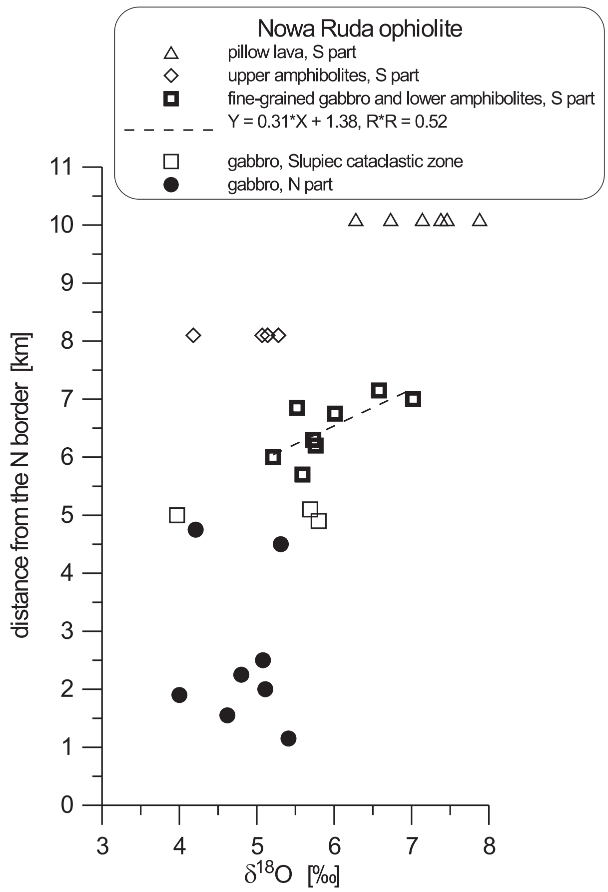

Fig. 2. $\delta^{18}O$ *versus* distance to the N border (the potential Moho) of the Nowa Ruda massif

folds have not been noticed, the S_2 foliation is very clear, especially in ultramafic rocks. It is developed as typical schistosity possibly formed during deformation D_2. Generally, the S_2 is perpendicular to S_0 and S_1. The D_3 deformation of S_2 yielded meter-scale open folds F_3. The S_3 surfaces are not penetrative and occur only in ultramafic rocks as the axial cleavage in F_3 folds. The F_4 folds have been noticed in schistose serpentinites and amphibolites as small knick folds with cataclasis developed along axial planes (S_4). The S_4 in ultramafic cumulates occur only in a few zone of cataclasis.

In non-mineralised (ore minerals are accessory or not observed) rocks, the $\delta^{18}O$ whole rock (wr) value varies from 3.97 ‰ (Słupiec tectonised gabbro) to 8.35 ‰ (G-J serpentinites). These values are typical for ophiolitic sequences. It was suggested earlier that ocean water was an important factor controlling hydrogen isotope ratios in chlorite from rodingites in GJ and sulphur isotope ratios amphibolites in SM. Therefore, it could be expected that advances in oceanic floor metamorphism (higher w/r ratio and lower temperature) would leave hydrogen and oxygen isotope offprint in whole rocks too. Therefore, vertical profiles in Sl () and NR (δD and) ophiolites have been constructed, and isotope values versus the distance from petrologic Moho have been plotted (Figs 1, 2, 3). In general, overall vertical distributions of δD and values do not show regular pattern. Nonetheless, the upper horizons of gabbro (dominantly fine-grained) close to the contact to subvolcanic rocks (amphibolites), show clear upward decrease in δD value in NR (Fig. 1), increase in value in NR (Fig. 2) and decrease in value in Sl (Fig. 3).

Temperature and mineralogical composition are the dominant factors governing D and O isotope fractionation in water – rock system. Metagabbro is composed of minerals showing slightly negative O and D fractionation factors in mineral-water system, and the α factor decreases with temperature decrease. However, amphibolites show significant content of albite, quartz, carbonates and zeolites which, in turn, show strongly positive O isotope fractionation in the mineral-water system. Therefore, it is expected, that an increase in seawater alteration during potential ocean floor metamorphism, in temperatures between 100 to 500 °C, and decrease in temperature of this alteration, should result in decrease in in metagabbro, and higher values in the amphibolites. This is the case in the Sl profile (Fig. 3) but not the in the NR one (Fig. 2). This suggest that the Sl ophiolite rocks were strongly altered due to an ocean floor metamorphism, but the NR rocks much less or oceanic traces were overwhelmed by later continental processes. The NR δD profile, support this thesis, as the D/H ratios in the NR are very low and the NR δD value decreases upward suggesting decrease in temperature of the rock alterations and increasing role of meteoric origin fluids. Likewise, and δD values and profiles in GJ serpentinites do not show any relation to oceanic alteration (Fig. 3 and 4) or potential influence of S-S granite.

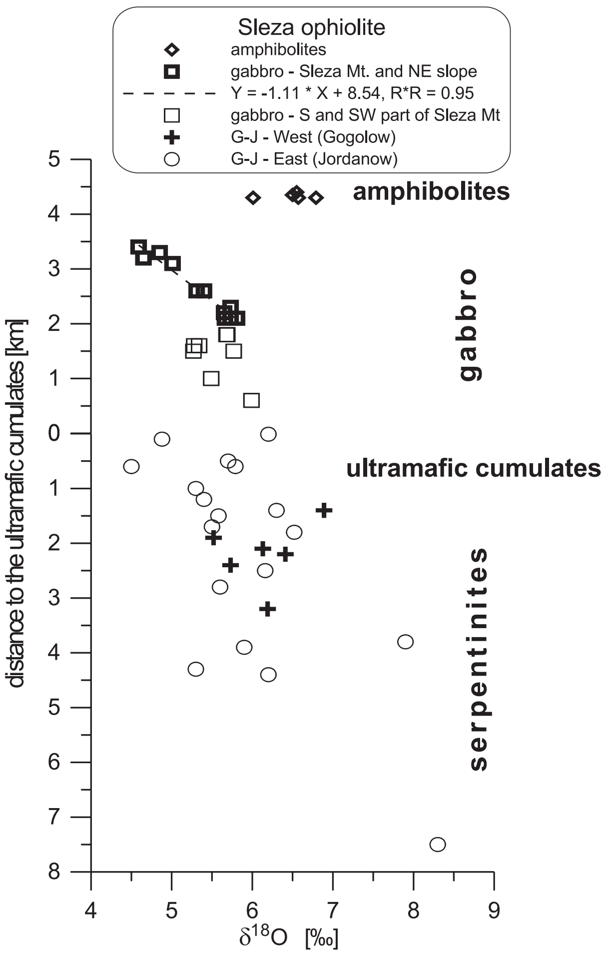

Fig. 3. versus distance to the ultramafic cumulates (the potential Moho zone) of the Ślęża massif

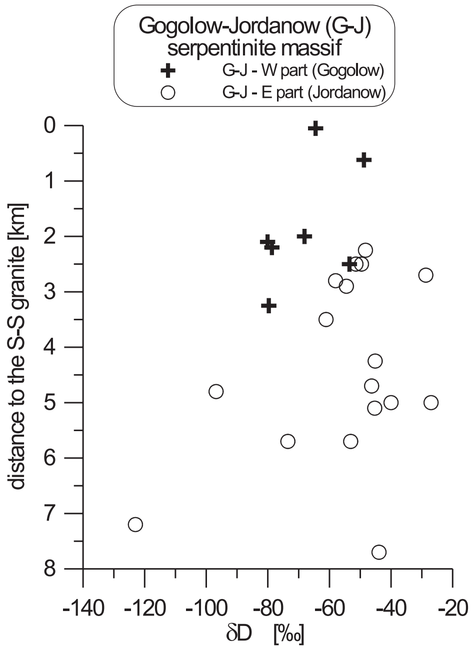

Fig. 4. δD *versus* distance to the contact with S-S granite massif

Therefore, we suggest that the S_1 formed in the oceanic stage of the evolution of these ophiolites.

The δD values show gradual increase and $\delta^{18}O$ values show gradual decrease, from margin into the centre of the GJ serpentinite body. It suggests that during serpentinization(s), w/r ratio was (were) much higher in the marginal parts than in the centre of the serpentinite body. This suggestion may be supported by D/H isotope analysis in whole rocks and carbon and oxygen isotope analysis in scattered ophimagnesites. On the other hand, tectonic deformations in GJ, which are considered as a result of D_2, are extensive and seem more "plastic" at the marginal parts of the serpentinite body. We suggest that possibly this is caused by gradient of water flow penetrating the massif during deformations and the main antigoritic serpentinization. Low hydrogen and oxygen isotope ratios evidence signifficant influence of meteoric origin fluids during serpentinization and formation of the S_2.

It is expected that hydrothermal alteration due to S-S intrusion should result signifficant variations in isotope ratios, especially in δD in the western part of the GJ. However, this is not very clear pattern. Thus, apparently, the S-S intrusion could be regarded to D3 deformation, however, likewise to the potential D4 deformation, no clear isotope evidence has been found in the scale of the massif. Nonetheless, earlier isotope study evidence that vein chrisotile from the S-S contact zone has been formed due to the granite intrusion, and lizardite formed at surficial temperatures under isotope equilibrium with water of meteoric origin.