称号及び氏名　　　　博士（理学）　Yousif Osman Mohammad

学位授与の日付　　　平成２０年６月３０日

論　文　名　「Petrology of ultramafic and related rocks along Iraqi Zagros Thrust Zone（イラク・ザグロス衝上断層帯に分布する超苦鉄質岩類よび付随する岩石類の岩石学的研究）」

論文審査委員　　　　主査　　前川　寛和
副査　　田中　智
副査　　小川　英夫
副査　　石井　和彦

論文要旨

Four main ultramafic rock bodies are distributed along the Iraqi Zagros Thrust Zone (IZTZ). They are Penjwin, Mawat, Pauza, and Qalander ultramafic bodies in the order from southeast to northeast (Fig. 1). They are typical lithological markers of the suture zone between Arabian and Iranian plates. Mineralogical and petrological investigations of the IZTZ peridotites indicate that they are mantle tectonite, rather than cumulate or replacive rock. They are mainly depleted harzburgite and dunite along with restricted occurrence of spinel lherzolite to the Pauza ultramafic body, and consist of olivine, diopside, enstatite, spinel, serpentine polymorphs, amphibole, and chromian chlorite. In dunite and harzburgite, chromian spinel occurs as a coarse subhedral to euhedral grain. Chromian spinel in dunite and harzburgite commonly has Cr-rich core and Cr-poor rim. Rarely Chromian spinel in harzburgite shows peculiar zoning of Cr-rich core and Al-rich rim. The lherzolite contains aluminous spinel which occurs as fine subhedral to anhedral grains with lobate boundaries.

The core compositions of chromian spinels in both Mawat and Penjwin peridotites [Cr#(=Cr/(Cr+Al)) > 0.6] correlate with those of type III alpine peridotite. The chromian spinel core composition in Pauza comprises both type I alpine peridotite for lherzolite (Cr# = 0.36 - 0.40) and type III alpine peridotite for dunite (Cr# = 0.78 - 0.82) and harzburgite (Cr# = 0.58 - 0.6). Gradual increasing of TiO_2 and gradual decreasing of Al_2O_3 in chromian spinels with increasing the degree of partial melting in peridotite, suggesting that these ultramafic bodies are fragments of suprasubduction zone residual mantle peridotites.

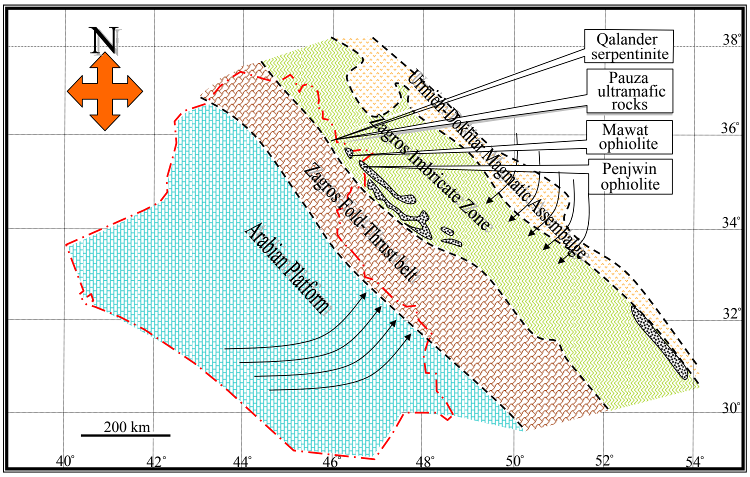

Fig. 1. Main tectonic units of Iraq and adjacent territories, showing the location of the main ultramafic bodies.

The peridotites of the IZTZ show many petrologic and geochemical signatures of partial melting. On the scale of the entire complex, the mantle rocks range from lherzolite throughout harzburgite to dunite. These petrological variations are associated with systematic changes in mineral compositions especially spinel and olivine. The Cr# of spinel vs. Fo diagram of the Pauza peridotites show that a fertile lherzolite 10-15 % of partial melting becomes harzburgite at about 30 % melting and dunite at about 40 % melting (Fig. 2). Harzburgite in both the Mawat and Penjwin peridotites with 30 % of partial melting becomes dunite at about 40 % melting.

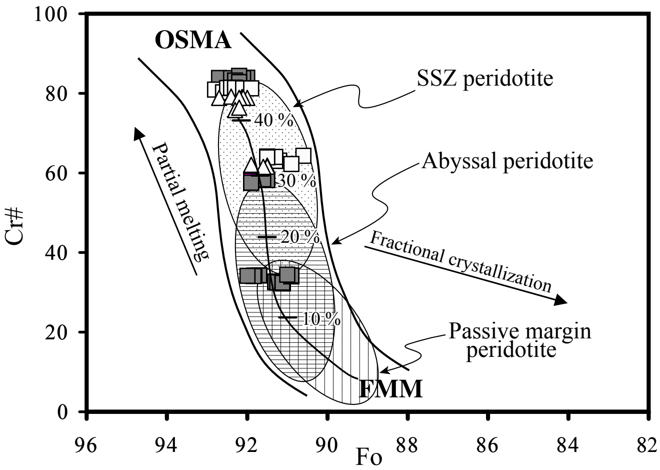

Fig. 2. Cr-number of spinel vs. Fo content of olivine in ultramafic rocks from the IZTZ. Fields for spinels occurring in abyssal (and ocean ridge), oceanic SSZ and passive margin peridotites are after Dick and Bullen (1984) and Pearce et al. (2000). OSMA field is after Arai (1994). Gray boxes, colorless boxes, and colorless triangles are from the Pauza, Mawat, and Penjwin peridotites, respectively.

The degree of serpentinization of peridotites along the IZTZ ranges from incipient to extensive. The transition from partly to extensively serpentinized rock is best observed in the Penjwin peridotites where the color of peridotites change from chocolate-brown of partly serpentinized samples to the yellowish-green of extensively serpentinized samples. This color variation between partly and extensively serpentinized samples cannot be noticed in the isolated serpentinite bodies in Mawat and Qalander areas. For these occurrences, the best evidence of this transition is the development of “kernel” texture, which is more common for the Mawat serpentinized peridotite. The kernel texture consists of extensively serpentinized green colored zone forming a rind around rectangular to trapezoidal block of dun-colored partly serpentinized rock.

The serpentinization process of peridotite along the IZTZ having both criteria of isochemical and allochemical processes. The formation of metasomatic rocks, rodingite and albitite in the Penjwin peridotite body involves loss and gain of CaO, SiO_2, and Na_2O between serpentinized peridotite and country rock, indicating that the serpentinization of the Penjwin peridotites is constant-volume process. However, the intensive fracturing in the massive serpentinite as well as the occurrence of kernel pattern requires an increase of the volume of ultramafic body, suggesting that serpentinizations of Mawat and Qalander peridotites are of constant-chemical process.

For the first time, albitite was found in the IZTZ near the village of Mlakawa, 60 km northeast of Sulaimani City, Kurdistan region, northeastern Iraq. It occurs as a white pod within the massive tectonized and serpentinized part of Penjwin ophiolite sequence. The preserved texture and mineralogical, petrological, and geochemical data from the core of the albitite pod suggest that protolith of Mlakawa albitite is plagiogranite. It has undergone rodingitization and blackwall formation along its rim.

The occurrence of barium aluminoslicate (celsian), cymrite, barium muscovite, and a high Na_2O concentration (11 wt. %) of albitite suggests that barium-sodium-rich fluid was involved during the albitization process of plagiogranite. Evidence of the progressive albitization includes the metasomatic replacement of Ca-plagioclase to albite and grossular, celsian to cymrite, replacement of tremolite by edenite, and new formation of sheaf-like barium muscovite. The presence of analcime and multiple generations of chlorite suggest that the albitite protolith was accompanied by chloritization and retrograde metamorphism before and after the albitization process.

Ca-amphibole thermobarometry (Fig. 3) and modes of occurrence of polygenetic metamorphic titanite, along with the occurrence of strontium apatite and cymrite, suggest that the albitization of plagiogranite occurred at < 650 °C and 1.5 GPa.

Three types of metamorphic titanite have been noted in albitite. Type I metamorphic titanite occurs as subhedral to anhedral fine-grained disseminated crystals within chlorite that was formed during chloritization of biotite as a result of low-temperature (T = 330 – 340 °C) ocean-floor metamorphism or rodingitization of plagiogranite under a reducing environment. It is characterized by intermediate Al_2O_3 (Av: 3.61 wt .%), high FeO_{total} (Av: 0.89 wt. %), and intermediate TiO_2 (Av: 34.7 wt. %). Type II metamorphic titanite occurs as a thin rim around ilmenite and has high Al_2O_3 (Av: 4.8 wt. %), intermediate FeOtotal (Av: 0.6 wt. %), and low TiO_2 (Av: 33.7 wt. %); it represents a reaction product between grossular and ilmenite, which resulted from an oxidizing high pressure–high temperature (P = 1.4 – 1.6 GPa and T > 750°C) metamorphic event involving plagiogranite. Type III metamorphic titanite occurs as very coarse, highly fractured grains up to 0.5 mm, with inclusions of ilmenite, and surrounded by albitic plagioclase, analcime, and chlorite. The titanite is characterized by low Al_2O_3 (Av: 1.23 wt. %), low FeO_{total} (Av: 0.30 wt. %), and high TiO_2 (Av: 36.98 wt. %). It formed during extensive titanitization of ilmenite by a reaction with Ca- plagioclase during moderate pressure and temperature (P < 1.6 GPa and T< 750°C) conditions, as a result of albitization of Ca-plagioclase in plagiogranite.

Many researchers working on titanite conclude that the iron is trivalent and occupies the Ti site. This study suggests that the state of Fe in the titanite structure is directly controlled by oxygen fugacity during metamorphic titanite formation. In conditions below QMF, the Fe in the titanite structure is divalent and

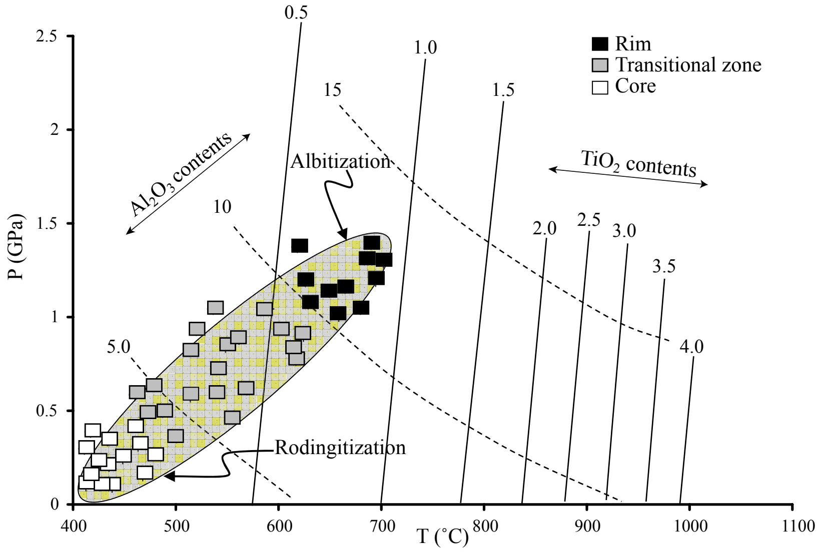

Fig. 3. Chemical compositions of amphiboles in Mlakawa albitite plotted on a diagram with isoplethes of Al_2O_3 and TiO_2 of clacic amphibole (after Ernst and Liu, 1998).

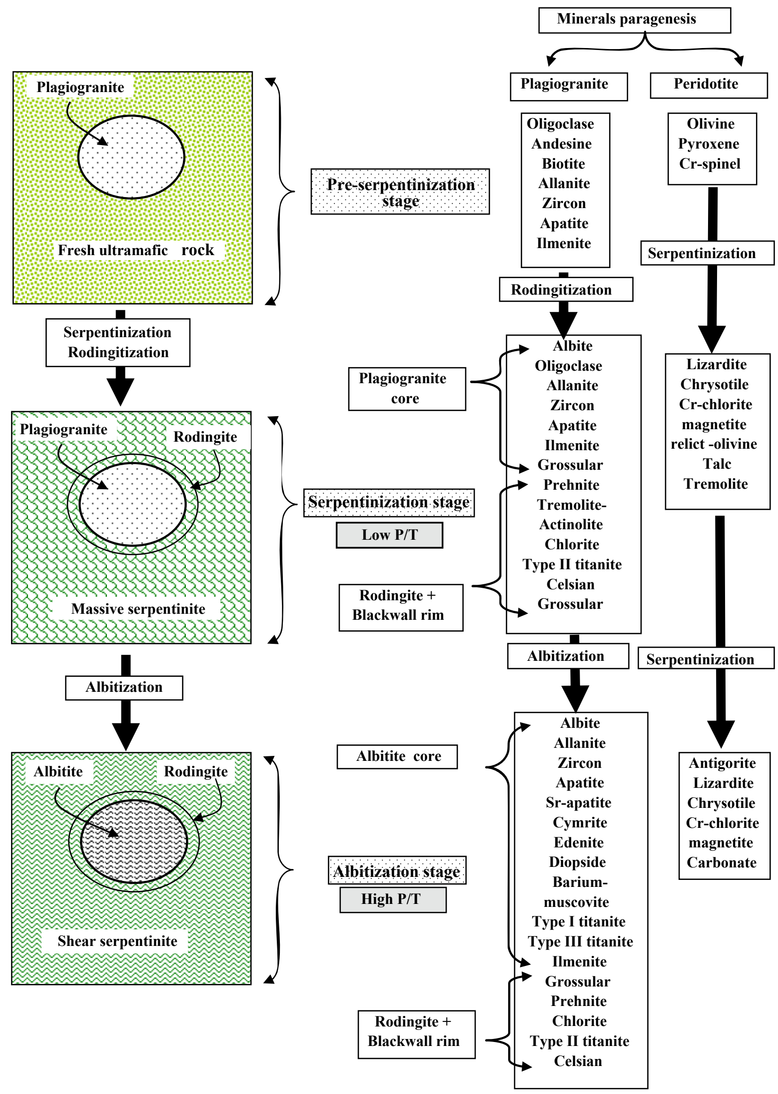

Fig. 4. Time-paragenesis diagram showing the relation between albitization, serpentinization, and rodingitization.

occupies the Ca site. In conditions above QMF, the Fe is trivalent and occupies the Ti site

Serpentinization, rodingitization, and albitization processes observed in the Mlakawa albitite are complementary processes (Fig. 4). Each process has a specific effect during a particular time in the evolution of the ultramafic-plagiogranite part of the Penjwin ophiolite sequence, leading to the formation of the Mlakawa albitite. Both serpentinization of peridotite and rodingitization of plagiogranite represent low-temperature and low-pressure conditions during the oceanic and the subduction stages before collision of the Arabian plate with the Iranian plate. In contrast, the albitization of plagiogranite represents high-pressure and high-temperature conditions at the collisional stage of the Arabian plate with the Iranian plate during the Late Cretaceous period.

審査結果の要旨

本研究は、イラク・ザグロス衝上断層帯に分布する超苦鉄質岩類およびそれに付随する岩石類を対象とし、その岩石学的・鉱物学的特徴を解析し、それらの成因を解明した。

イラク・ザグロス衝上断層帯は、アラブプレートとイランプレートの境界部に位置し、大陸衝突の現場として第一級の研究価値をもつ。本研究が対象とする超苦鉄質岩類は、元来、衝突帯深部に位置していたマントル物質が地殻変動により地表まで上昇してきたもので、その研究を通じて、衝突帯深部の温度圧力条件をはじめとする、さまざまな地球科学的現象を理解することが可能となる。

本研究では、衝上断層帯に分布する 4 つの超苦鉄質岩体について、その鉱物共生、形成条件を解析した。主要構成鉱物であるスピネルとカンラン石について系統的な組成変化があることをみいだし、超苦鉄質岩類がマントルの部分溶融（メルトの抜き去り）を経て形成されたことを示した。その上で、全体の 10-15％部分溶融したレルゾライトと 30-40％部分溶融したダナイト～ハルツバージャイトを区別し、それぞれが海嶺起源、島弧起源である可能性を指摘した。単純な鉱物組合せをもつ超苦鉄質岩から得られる情報量には限りがあるため、本研究では、調査地域の超苦鉄質岩体に含まれる優白質の曹長岩、ロジン岩にも注目し、その詳細な解析を行った。その結果、それらが Sr-アパタイト、Ba- 白雲母など高圧変成作用に特徴的な鉱物を含む斜長石花こう岩起源の変成岩であることを明らかにした。さらに、曹長岩に含まれるチタナイトに注目し、その産状、化学組成を詳細に検討を行い、蛇紋岩化作用、ロジンジャイト化作用、アルバイト化作用の相互関係を明らかにした。

イラク国内におけるイラク・ザグロス衝上断層帯は、第一級の衝突体としてその研究価値が非常に高いにもかかわらず、治安上の問題から岩石学的研究はほとんど行われてこなかった。衝突体深部における高圧変成作用の発見をはじめとする本研究の一連の成果により、アラブプレートとイランプレートの衝突前後の地殻～マントル深部の地学現象の理解が大きく進展したことに疑いの余地はない。岩石試料の観察から具体的な研究のターゲットを選定・研究テーマを設定し、短期間で問題を解決、成果を論文としてまとめる能力には非凡なものがあり、博士論文からも、今後のさらなる発展が期待できることが読み取れる。

本委員会は、本論文の審査ならびに最終試験の結果に基づき、博士（理学）の学位を授与する事を適当と認める。