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Mineralogy and petrology of rodingites from the Nain ophiolite (Central Iran)

Mineralogía y petrología de rodingitas en la ofiolita de Naín (centro de Irán)

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ABSTRACT

Rodingites, composed predominantly of hydrogrossular, prehnite, pectolite, xonotlite, diopside and chlorite, have been recognized in the Nain Ophiolitic Complex (Iran). On the basis of petrographic and field data, two different stages of rodingitization from gabbroic protoliths are inferred. The first rodingitization stage, characterized by an increase in log a (Ca^{2+}/Mg^{2+}) and a decrease in the log a (SiO_2) of the reactant aqueous fluids, is recorded by the crystallization of diopside and grossular-hydrogrossular leading to pervasive rodingitization. The second stage, corresponding to veined rodingite along brittle fractures led to the crystallization of pectolite, prehnite and xonotlite and is characterized by a decrease in log a (Ca^{2+}/Mg^{2+}) and an increase in log a (SiO_2).

Key-words: *Nain Ophiolite Complex, rodingite, hydrogrossular, xonotlite, pectolite.*

RESUMEN

En este trabajo se describe la presencia de rodingitas, ricas en hidrogrosularia, prehnita, pectolita, xonotlita, diópsido y clorita, en el Complejo Ofiolítico de Naín (Irán). En base a datos petrográficos y de campo se han identificado dos etapas principales de rodingitización de protolitos gabroicos. La primera etapa de rodingitización, ligada a un incremento generalizado en el valor del log a (Ca^{2+}/Mg^{2+}) y disminución del log a (SiO_2) de los fluidos reactantes con sus protolitos, se caracteriza por la cristalización generalizada de diópsido y grosularia-hidrogrosularia. La segunda se asocia a una rodingitización localizada en venas donde se produce la cristalización de pectolita, prehnita y xonotlita. Esta última etapa se caracteriza por disminución e incremento de los valores del log a (Ca^{2+}/Mg^{2+}) y del log a (SiO_2), respectivamente.

Palabras clave: *Complejo Ofiolítico de Nain, rodingita, hidrogrosularia, xonotlita, pectolita.*

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Introduction

Rodingites are calc-silicate rocks characterized mainly by grossular- hydrogrossular, diopside and prehnite, and many other minor minerals like vesuvianite, titanite, chlorite, amphibole, epidote, xonotlite, wollastonite, pectolite and zeolites formed by metasomatic processes between felsic and mafic rocks by the fluid which composition is buffered by the serpentinization of ultramafic host-rocks (Thayer, 1966; Coleman, 1977; O'Hanley *et al*., 1992). During this metasomatic process, the Ca^{2+} released mainly from the clinopyroxene cannot be accommodated into the serpentine crystal structure and is transported within the serpentinizing aqueous fluid (Coleman, 1977) leading to the neoformation of calc-silicate minerals. It is worth noting that rodingites, which act as Ca^{2+} traps, are originated at temperatures between 250 to 450 °C (Schandl and Mittwede, 2001) coetaneously with the serpentinization. For this reason, rodingitization processes provide useful information on the evolution of their host rocks (e.g. Tsikouras *et al*., 2009).

The fluids originated during the serpentinization, usually referred as "*serpentinization-buffered fluids*", are Si undersaturated and Ca-rich (Capedri *et al*., 1978; Muraoka, 1985; Frost and Beard, 2007; Bach and Klein, 2009). The interaction of such serpentinization-buffered fluids with rodingite protoliths is responsible for the precipitation of fine-grained aggregates composed of grossular-rich garnet and/or diopside.

Rodingites have been recognized in different tectonic settings, including seafloor spreading centres, rifted continental margins, ophiolites, greenstone belts, alpine settings and supra-subduction zones (Bach and Klein, 2009).

In this work, we present a preliminary petrographical and mineralogical characterization of rodingites from the Nain Ophiolite Complex, Central Iran.

Geological setting

The Nain ophiolite is a highly dismembered ophiolitic complex located at the north-western margin of the central Iranian micro-continental block (CIM), in the *Eastern Mediterranean* Tethyan region. This complex covers ~ 600 km^2 and spreads in a NNW-SSE direction. According to Davoudzadeh (1972) the area to the north of Nain (Fig. 1) can be divided into three main geological units: 1) the Coloured Mélange zone (CMZ) characterized by a variety of ophiolitic rocks, limestones and radiolarites formed from late Cretaceous to Early Eocene times, 2) the Tertiary sedimentary zone (TSZ) and 3) the Tertiary volcanic zone (TVZ), including volcanic and plutonic rocks (Fig. 1).

The Nain Ophiolite Complex consists, from top to bottom, of radiolarian cherts and pelagic limestones underlain by pillow and massive lavas, sheeted dykes, layered, isotropic and pegmatitic gabbros, small plagiogranite bodies and variable proportions of harzburgite, lherzolite and dunite. Albian ages (~ 100 Ma) and Upper Cretaceous ages (93-67 Ma) have been reported (Hassanipak and Ghazi, 2000; Shafaii Moghadam *et al.*, 2007) for the genesis and obduction, of the Nain Ophiolite, respectively. In most cases, the ophiolitic unit has undergone a sub-sea metamorphism and spilitization leading to a wide variety of metamorphic rocks such as amphibolites, skarns, metacherts, schists and marbles, serpentinites and serpentinized ultramafics, listwaenite, spilites and rodingites (e.g. Torabi *et al.*, 2007).

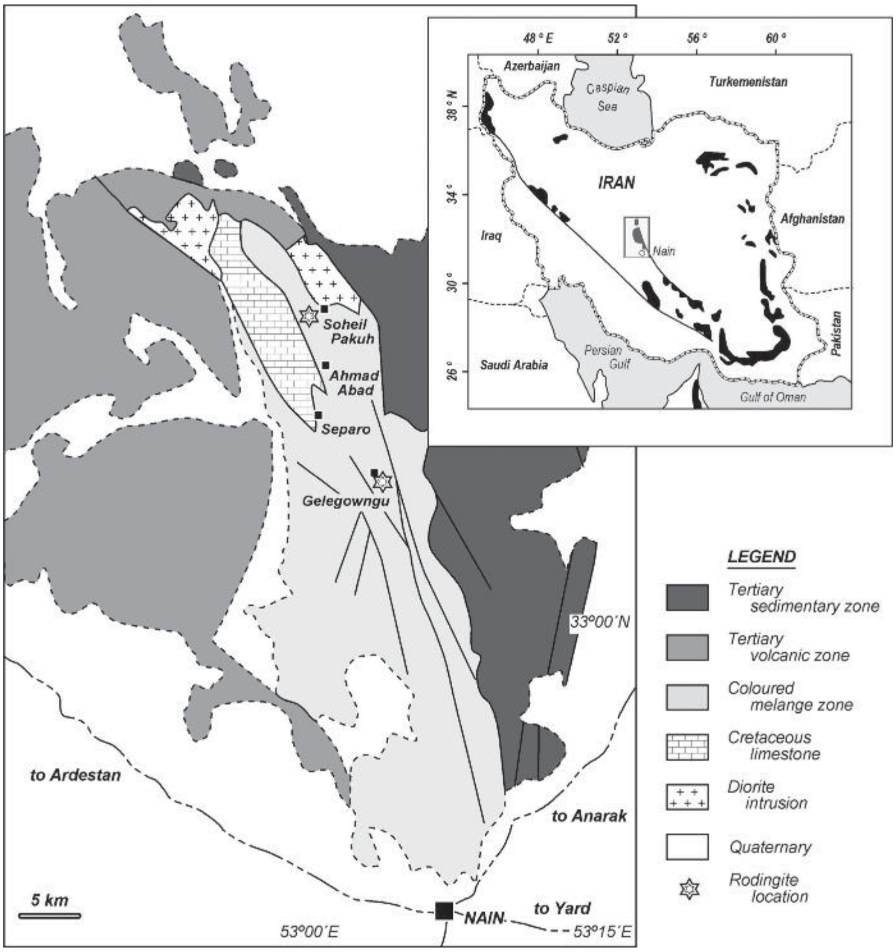

Fig. 1.-Distribution of ophiolites in Iran and simplified geological map of the northern area of Nain city (modified after Davoudzadeh, 1972).

Fig. 1.-Distribución de las ofiolitas en Irán y mapa geológico simplificado del área norte de Naín (modificado de Davoudzadeh, 1972).

Samples description

Rodingites in the Nain ophiolite are formed from several protoliths that include: pegmatitic gabbro dykes, doleritic dykes and minor basaltic pillow lavas. Field observations indicate that the rodingites occur as altered dykes (Fig. 2A), dismembered or isolated bodies (Fig. 2B), and also as alteration zones along the contacts between serpentinites and country rock. Veined rodingites are observed as white veinlets of prehnite-pectolite cutting rodingites and rodingitized micro-gabbros (Fig. 2C).

The studied rodingitized dykes (Fig. 1) are observed in two outcrops of the Nain ophiolite: a) one in the north of Ahmad Abad village (53º1′ E, 33º8′ N) and the other in Gelegowngu village (53º8′ E, 33º3′ N). These rodingitized dykes are generally white-coloured rocks with a rather homogeneous appearance in the field. The dykes have variable thickness, from a few centimeters to some meters, in sharp contact with the host- serpentinized harzburgite.

Fig. 2.- Field outcrop photos. A) Rodingitized dyke. B) Block of rodingitized pegmatitic gabbro. C) Veins of prehnite-pectolite cutting rodingites and microgabbro.

Fig. 2.- Fotografías de campo. A) Dique rodingitizado. B) Bloque de un gabro pegmatítico rodingitizado. C) Venas de prehnita-pectolita cortando a una rodingita y a un microgabro.

Textural features

Studied rodingites consist predominantly of hydrogrossular, prehnite, pectolite, xonotlite, diopside and chlorite. Rodingite minerals have been analyzed with a Cameca SX 100 instrument at the Institute of Mineralogy, Hannover University.

Rodingites show granoblastic pseudomorph textures from their precursors and cataclastic ones. Two different types of rodingites based on crosscutting relationships have been identified: (a) an early, pervasive rodingite assemblage, with granoblastic pseudomorph textures of diopside and grossular-hydrogrossular (Fig. 3A), and (b) a late, veining rodingite assemblage with pectolite, prenhite and xonotlite that shows cataclastic and radial textures. Cataclastic textures are also found within bands across the pervasive rodingite matrix (Fig. 3B)

Clinopyroxene occurs usually in association with chlorite forming granoblastic and local cataclastic patches. Petrography studies and EMPA analyses (Table I) reveal three types of clinopyroxene: augite and diopside of magmatic origin and metasomatic diopside. Single pyroxene geothermometry (Nimis and Taylor, 2000) provides average equilibrium temperatures of ~ 1000 °C and ~ 700 °C for the augite and diopside, respectively, which support the primary, magmatic origin of these minerals. It is crucial to note that magmatic diopside is often recrystallized into pure diopside plus grossular.

Augite is replaced by tremolite-actinolite aggregates that retain the habit of the former mineral (Fig. 3C). Plagioclase crystals are completely replaced by garnet, occurring as fine-grained clusters dispersed within the rodingite or forming quasi-monomineralic veins. These veins suggest channelling of a fluid phase in discontinuities of the rock mass. Garnet occurs between pyroxene and usually it pseudomorphs magmatic plagioclase (Fig. 3D). Pectolite is characterized by fine radial growths with silky luster with prismatic habits, which is mainly concentrated in monomineralic veins and veinlets but it also appears dispersed throughout the rodingitized dykes. The monomineralic veins are composed of needle-shaped crystals, up to 0.5 cm long, forming radial aggregates (Fig. 3E). Xonotlite forms radial aggregates in veined rodingites (Fig. 3F) and it is likely to replace former hydrogrossular and plagioclase. Finally, prehnite is observed in some thin sections as a minor, interstitial phase between the main rodingite-forming minerals.

	Di_1	Aug	Di_2	Hgr
SiO_2	53.4	50.9	53.4	30.7
TiO_2	0.01	0.47	0.02	0.11
Al_2O_3	1.7	2.8	1.4	21.9
FeO	3.2	10.8	4.0	1.1
Na_2O	0.02	0.20	0.00	0.02
MnO	0.35	0.28	0.31	0.03
MgO	17.1	14.6	16.0	0.3
CaO	24.4	19.9	24.8	38.6
K_2O	–	–	–	–
Total	100.2	99.96	99.85	92.80
Si	1.95	1.91	1.96	5.15
Al	0.07	0.12	0.06	4.33
Ti	–	0.01	–	0.01
Fe	0.1	0.34	0.12	0.15
Mn	0.01	0.01	0.01	–
Mg	0.93	0.81	0.88	0.08
Ca	0.95	0.80	0.98	6.94
Na	–	0.02	–	0.01
K	–	–	–	–
T (°C)	~694	~1013	–	–

Table I.- Mineral average composition of Nain rodingites and calculated magmatic temperatures for clinopyroxene (Di_1: magmatic diopside / Aug: magmatic augite / Di_2: metasomatic diopside / Hgr: hydrogrossular).

Tabla I.- Quimismo mineral de las rodingitas de Naín y temperaturas medias de formación de clinopiroxenos magmáticos (Di_1: diópsido magmático / Aug: augita magmática / Di_2: diópsido metasomático / Hgr: Hidrogrosularia).

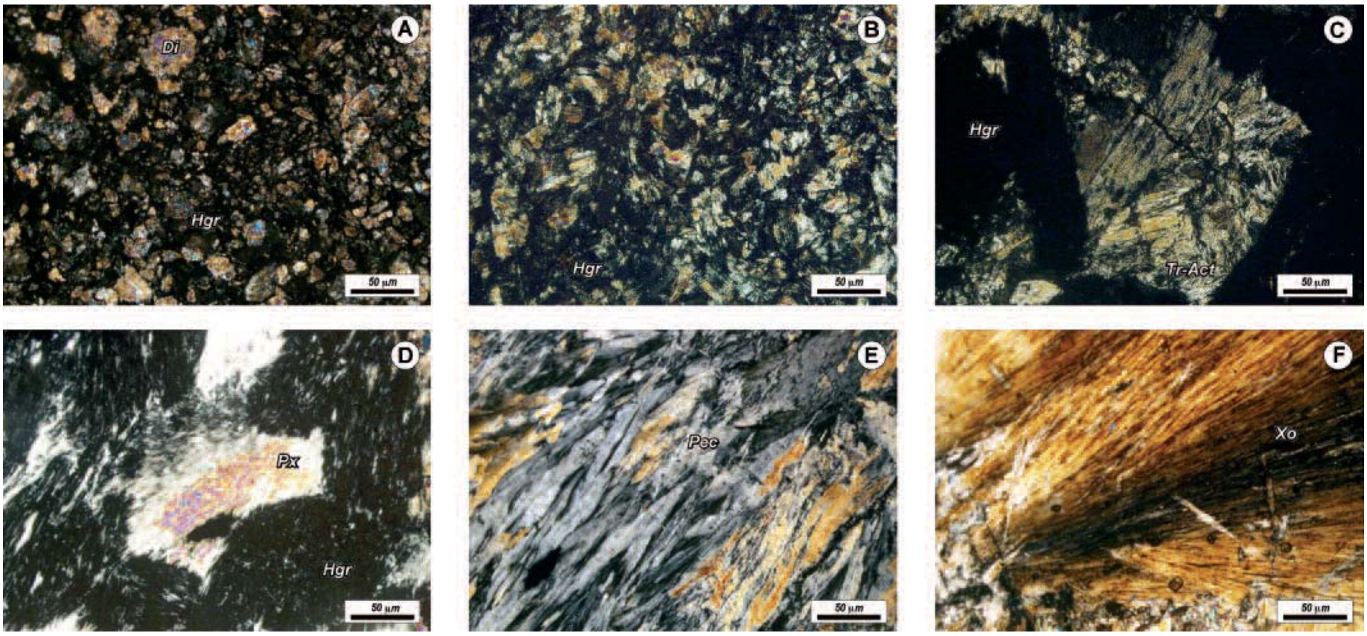

Fig. 3.- A) Rodingitized dyke showing pseudomorphization of a gabbroic texture. Note inherited diopside (Di) and neoformed hydrogrossular (Hgr) crystals. B) Cataclastic bands with fragmented garnet (Hgr) and diopside (Di). C) Pseudomorphized crystal of augite by tremolite-actinolite. D) Metasomatic hydrogarnet replacing magmatic plagioclase. (E) Pectolite blades within a monomineralic veined rodingite. F) Radial aggregates of xonotlite in veined rodingite.

Fig. 3.- A) Dique rodingitizado donde se observa la pseudomorfización de texturas granoblásticas de un protolito gabroico. Nótese los piroxenos heredados (Di) y las hidrogrosularias neoformadas (Hgr). B) Bandas cataclásticas con fragmentos de hidrogranates (Hgr) y diópsido (Di). C) Pseudomorfización de augita por anfíboles de la serie tremolita-actinolita. D) Reemplazamiento de plagioclasa magmática por hidrogranate metasomático. E) Cristales tabulares de pectolita de una vena rodingítica. F) Agregados fibroso radiales de xonotlita en una vena rodingítica.

Discussion and conclusions

In the study area, the rodingites are spatially and temporally associated to oceanic serpentinization of ultrabasic rocks, supporting their formation by metasomatic reactions triggered by Ca^{2+}-fluids. The source of Ca has been a controversial issue, attributed to: a) the breakdown of pyroxenes during serpentinization, which may release Ca^{+2} into serpentinizing aqueous fluids (Coleman, 1967; Sabzehei, 2002), b) the Ca^{2+} can be likely added from serpentinizing peridotite into rodingite-protoliths by diffusive mass transfer (Bach and Klein, 2009) in the form of hydroxo species (CaOH+), c) it can be derived form external hydrothermal solutions or even d) from gabbroic lithologies by Ca-leaching. Clinopyroxene is a common phase in many of the Nain peridotitic rocks (Ghazi *et al*., 2010) and it suggests that the source of Ca^{2+} for the Nain rodingites is likely related to the clinopyroxene breakdown during serpentinization.

According to the identified mineral chemistry, different activities of Ca, Mg, Ti and Na in the related fluid during formation of the rodingites are evidenced. The proposed evolution model of Nain rodingites is quite consistent with the model proposed by Schandl and Mittwede (2001). These authors described three groups of rodingites identified by different index minerals (diopside, grossular-hydrogrossular and epidote) representing successive stages of the advance of the rodingitization of the protoliths. Presence of epidote in the Nain rodingites (Falahaty *et al*., 2009) agrees that studied rodingites represent a quite advanced alteration process. The first stage of rodingitization (pervasive one) is characterized by an increase in log a (Ca^{2+}/Mg^{2+}) and a decrease in the log a SiO_2, as recorded by the crystallization of mainly grossular-hydrogrossular. Then, Mg-chlorite, tremolite and talc formed at the expense of augite. Finally, secondary diopside will form with a subsequent decrease in log a (Ca^{2+}/Mg^{2+}) during later stages. The second stage, temporally associated with secondary diopside formation (veined rodingitization), recorded also an increase in log a SiO_2, by the crystallization of pectolite, prehnite and xonotlite. The xonotlite formed at the expense of garnet and plagioclase. Xonotlite is abundant rather than other vein minerals suggest that fluid responsible for the formation of veining rodingite (dynamic rodingitization) should had high CaO/SiO_2 ratios equal to 1 (Falahaty *et al*., 2009) but this ratio decreases through the time and prehnite and pectolite are respectively formed at small amount.

All these features suggest that rodingitization was heterogeneous and strongly favoured by structural pathways that promoted circulation of the fluid phase. In most of the analysed rodingites, primary igneous textures have been obliterated, but some of them are still preserved in the form of magmatic augite and plagioclase, association that agrees with a gabbroic protolith for the studied rodingites.

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