PETROLOGICAL STUDY OF PLAGIOGRANITES IN THE NAIN OPHIOLITE (CENTRAL IRAN)

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ABSTRACT

The plagiogranites from the Nain ophiolite consist of plagioclase (albite to andesine), quartz, amphibole (mostly magnesio-hornblende), apatite, titanite and oxide phases. These rocks have low K_2O, Sr and high Y contents, with low Sr/Y ratios; they are geochemically similar to volcanic arc granites. The chondrite normalized REE patterns of the selected samples are characterized by negative Eu anomalies. We propose that the Nain plagiogranites formed by fractional crystallization of a low-K tholeiitic magma in a supra-subduction setting.

INTRODUCTION

Ophiolites have a major role in our understanding of earth's processes ranging from seafloor spreading, melt evolution and magma transport in oceanic spreading centers, hydrothermal alteration and mineralization of oceanic crust and to collision tectonics, mountain building processes and orogeny. Ophiolites are assembled during a primary accretion stage at an oceanic spreading center and later tectonically emplaced on a continental margin or island arc (Dilek and Newcomb, 2003). Plagiogranites are acidic rocks that play a major role in distinguishing the tectonic setting of ophiolites. Plagiogranites have been found generally in oceanic settings such as mid-oceanic ridges (Engel and Fisher, 1975; Moores and Vine, 1971), island arcs (Alabaster et al., 1982; Gerlach et al., 1981; Miyashiro, 1973), marginal or back arc basin ridge (Malpas, 1979; Saunders et al., 1979) and supra- subduction zone (fore arc basin) ridges (Alabaster et al., 1982; Pearce et al., 1984). Considerable amounts of leucocratic rocks have been reported in ophiolitic sequences such as Troodos, Antalya, Vourinos, and Oman. Plagiogranites in association with tonalite, quartzdiorite and diorite are often called oceanic plagiogranite (Coleman and Peterman, 1975) and occur within the gabbroic section of the oceanic crust. This paper deals with the chemistry, petrogenesis, tectonic setting and formation of plagiogranites located north of Nain, Central Iran. These issues are critical to constrain the features of felsic (plagiogranite) magmatism in the fore-arcs of post volcanic arcs.

GEOLOGICAL SETTING

The Nain ophiolite melange has an area of ~ 480 km^2 and is part of an ophiolite belt (e.g., Allahyari et al., 2010) around the Central Iranian microcontinent lying north of Nain, along the Nain- Baft fault (Fig. 1). Geologically, the Nain area is divided into four parts: 1 - Tertiary sediments in the eastern part; 2 - Tertiary volcanics in the western part; 3 - intrusive rocks of Cenozoic age in the northern and north-western parts; 4 - Mesozoic ophiolitic mélange in the central part (Rahmani et al., 2007; Shirdashtzadeh et al., 2011; Ghazi et al., 2011). The dismembered ophiolitic rocks consist of tectonitic peridotites, cumulus peridotites, basaltic dikes, layered gabbros, isotropic gabbros, plagiogranites, basaltic to andesitic pillow lavas, pelagic sediments, silicic shales, radiolarites, rodingites and listvenites. The best exposures of the plagiogranites in the Nain ophiolitic mélange are situated between Kohezard and the Separab village (Davoudzadeh, 1972) (Fig. 2).

PETROGRAPHY

The plagiogranites occur as thin (mm to several cm wide) leucocratic dykes or vein networks intruding basalt dykes

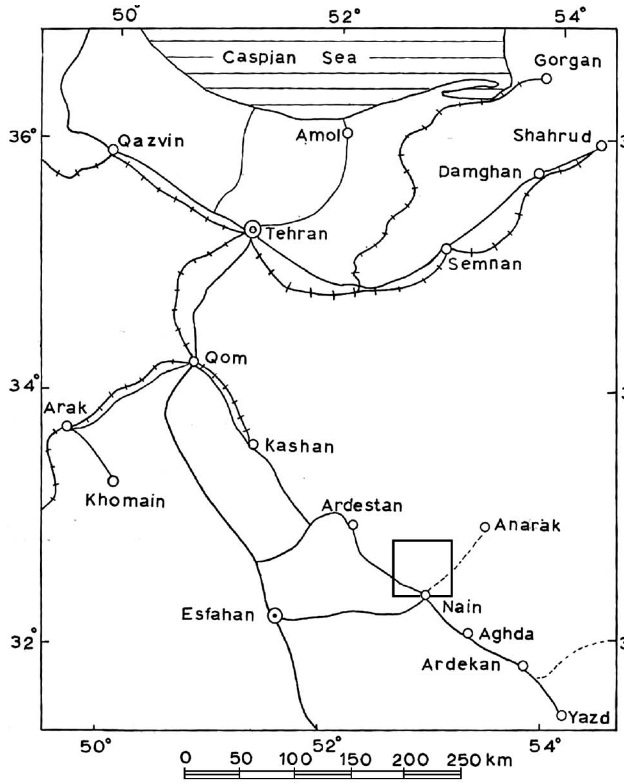

Fig. 1 - Location of the studied area (Davoudzadeh, 1972).

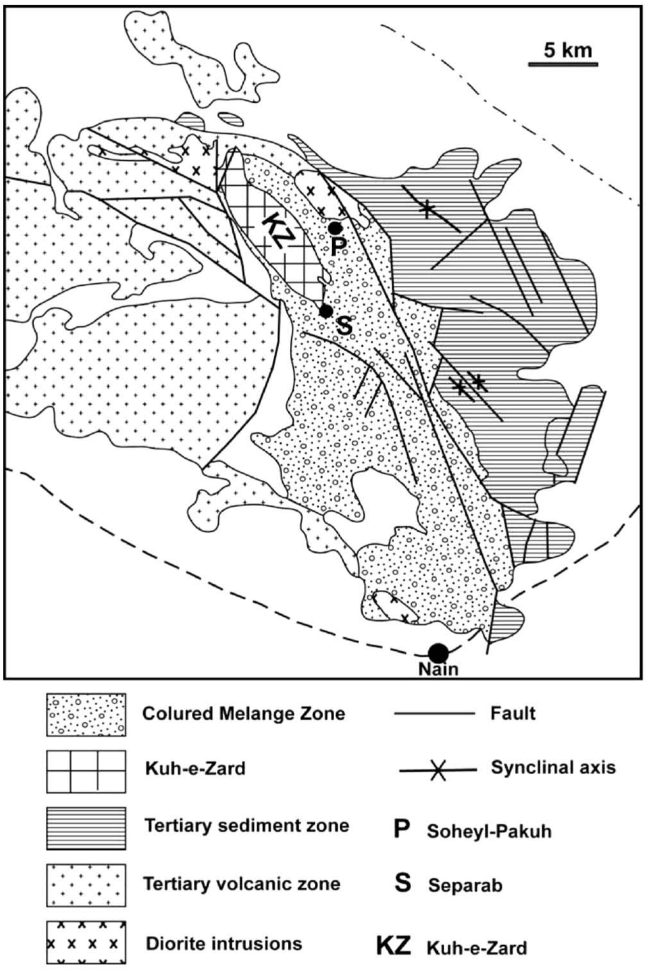

Fig. 2 - Simplified geological map of the northern part of Nain area (Davoudzadeh, 1972).

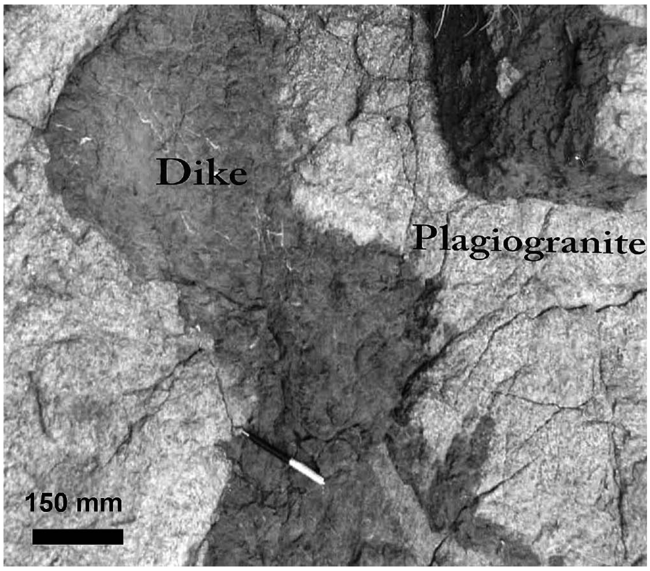

Fig. 3 - Mutual cross-cutting relationship between plagiogranite and rhyolitic dikes.

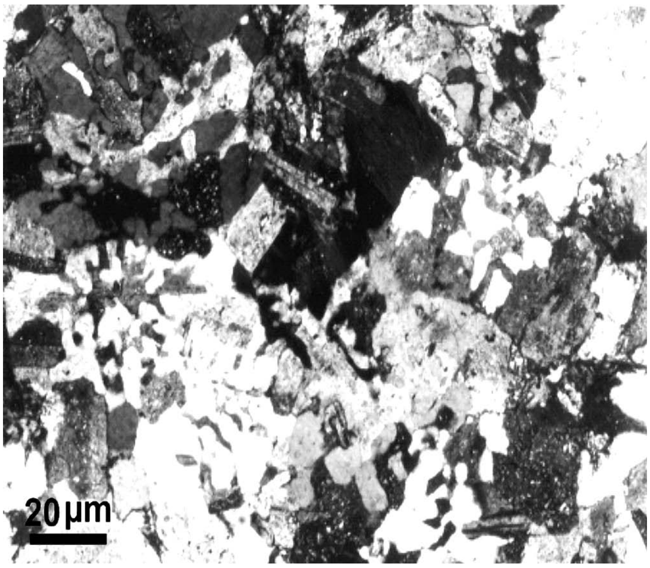

Fig. 4 - Micrographic texture in the Nain plagiogranites.

Table 1 - Representative chemical analyses of plagioclases from the Nain ophiolite plagiogranites (R-200, host rock).

	Core		Intermediate			Rim				
Sample	Pl1	Pl2	Pl3	Pl4	Pl5	Pl6	Pl7	Pl8	Pl9	Pl10
SiO_2	56.97	56.16	57.59	57.7	57.63	65	68.13	66.6	65.3	66.11
TiO_2	0	0.01	0.02	0.01	0.04	0.02	0	0.03	0	0.01
Al_2O_3	27.42	27.78	26.9	26.76	26.9	22	21.06	21.88	22.04	22.17
FeO*	0.32	0.35	0.35	0.31	0.32	0.18	0.11	0.25	0.17	0.15
MnO	0	0	0	0	0.01	0.02	0	0	0	0
MgO	0.02	0.01	0.02	0.01	0.02	0	0	0	0	0
CaO	9.29	9.83	8.49	8.68	8.79	2.83	1.21	2.32	2.63	2.54
SrO	0	0.05	0.02	0.05	0	0.01	0	0	0	0
BaO	0	0	0.07	0	0	0.08	0.04	0.09	0	0.06
Na_2O	6.45	6.16	6.81	6.69	6.7	9.58	10.8	9.7	9.63	9.71
K_2O	0.08	0.08	0.1	0.11	0.09	0.81	0.29	0.61	0.55	0.39
Total	100.57	100.46	100.37	100.34	100.51	100.53	101.72	101.5	100.42	101.18

Table 2 - Representative chemical analyses of amphiboles from the Nain ophiolite plagiogranites (R-200, host rock).

	Core	Intermediate		Rim	
Sample	Am1	Am2	Am3	Am4	Am5
SiO_2	40.46	45.27	49.66	48.43	47.93
TiO_2	1.33	1.56	0.59	0.78	0.82
Al_2O_3	10.08	6.76	3.16	3.52	4
FeO*	23.01	19.1	19.65	22.17	22.08
MnO	0.44	0.48	0.54	0.72	0.7
MgO	7.32	11.32	11.87	10.88	10.99
CaO	11.21	10.57	9.4	8.68	9.04
SrO	0.03	0.01	0.02	0	0.03
BaO	0	0.02	0.04	0	0
Na_2O	2.02	2.4	1.16	1.97	1.99
K_2O	1.22	0.67	0.36	0.42	0.45
Total	97.87	99.29	96.72	98.5	99.03

(Fig. 3). The contacts between the plagiogranites and the basalt dykes are diffuse to sharp; no chilled margins were observed. The plagiogranites are grayish-white to grey with a medium to fine grained massive structure (Fig. 4). These leucocratic rocks consist predominantly of quartz, plagioclase and accessory amphibole. Quartz displays undulatory extinction, thereby indicating that the rocks have been subjected to deformation. Plagioclase is locally altered to sericite, and amphibole is altered to chlorite and epidote. Accessory minerals include Fe-Ti oxide phases, zircon, titanite, apatite and allanite. The plagiogranites are characterized by the occurrence of micrographic intergrowths of quartz and plagioclase feldspar (Fig. 4). They also contain accessory amounts of calcite of likely secondary origin.

SAMPLES SELECTED FOR THE CHEMICAL ANALYSES AND ANALYTICAL TECHNIQUES

Three of the least altered plagiogranites were selected for mineral and whole-rock chemical analyses. We also considered the compositions of plagiogranites SP-11 and SP-16 (Jabari, 1996), and of plagiogranite RSP1 and gabbro RS22 (Rahmani, 2002).

Plagioclase and amphibole in sample R-200 were analysed by using an Electron Microprobe (Tables 1 and 2) at the laboratory for Mineral Deposits for Research at the Oklahama City University (U.S.A.). The conditions of analysis were 20 kV accelerating voltage, 20 nA sample current (measured at the Faraday cup), and a 2 micrometer spot size. Counting times were 30s on peak for all elements, yielding minimum detection limits in the range of 0.01-0.03 wt% of the oxides for all components except Sr (0.03 wt% SrO). Whole-rock major and trace element compositions were obtained (Table 3) by ICP-MS at the Activation Laboratories (Ancaster, Ontario). Precision and accuracy are generally within 10%. Samples SP-11 and SP-16 were analysed by NAA (Neutron activation analysis) at the University of Isfahan.

RESULTS

1. Mineral chemistry

The plagiogranites contain plagioclases with andesine cores and oligoclase rims (Fig. 5). According to the classification of Leake et al. (1997), the studied amphiboles are essentially magnesio-hornblendes (Fig. 6).

2. Whole-rock geochemistry

The Nain plagiogranites display high SiO_2, Na_2O and CaO (70.8-78.6 wt%, 4.2-6.8 wt% and 1.5-2.4 wt%, respectively) and low K_2O (0.35-1.18 wt%).

In the Nb vs. Y and Rb vs. (Y+ Nb) diagrams, the selected samples lie within the field of volcanic arc granites, near the field of ocean ridge granites (Figs. 7 and 8). The chondrite normalized REE patterns of the plagiogranites are slightly enriched in LREE (La_N/Sm_N= 0.88-2.45) and with nearly flat HREE (Gd_N/Yb_N= 0.72-1.34). The REE patterns are also characterized by negative Eu anomalies (Fig. 9). On the An-Ab-Or diagram, the samples fall in the trondhjemite field (Fig. 10).

The chondrite normalized REE patterns fractional crystallization of plagioclase, which has a high partition coefficient for Eu, is commonly considered as a cause of negative Eu anomalies in igneous rocks (Möller and Muecke, 1984). The Nain plagiogranites are also characterized by relatively low concentrations of high field strength elements and variable concentrations of large ion lithophile elements.

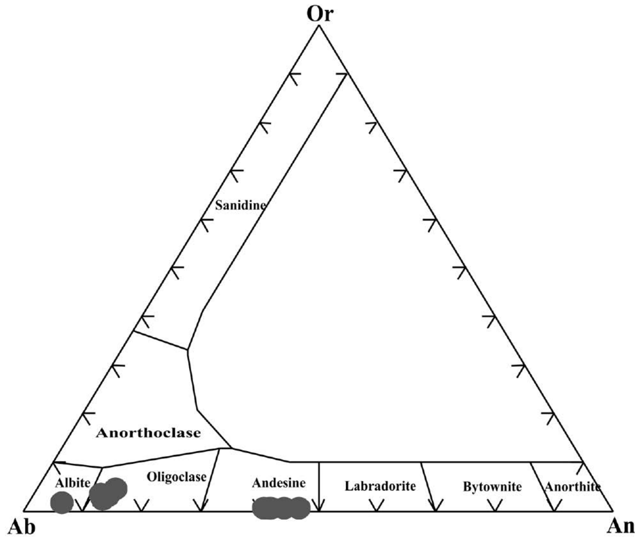

Fig. 5 - The studied plagiogranites in the Or-Ab-An diagram (Deer et al. 1963).

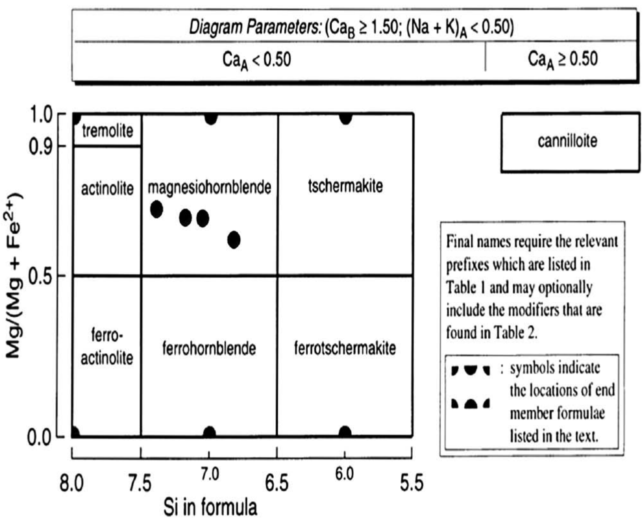

Fig. 6 - Mg/ Mg+ Fe^{+2} - Si diagram (Leak et al.,1997) for the amphiboles of the Nain plagioranites.

Table 3 - Major (wt%) and trace element (ppm) compositions of representative plagiogranites and gabbro from the Nain ophiolite.

Samples / Oxides	✕ RS22	✱ R-200	▽ R-212	○ R-281	△ RSP1	◇ SP-11	□ SP-16
SiO_2 (wt%)	54.28	71.27	76.2	70.83	78.6	75	73.11
TiO_2	0.47	0.43	0.26	0.39	0.16	0.3	0.28
Al_2O_3	14.17	13.05	11.16	14.35	10.84	12.5	12.07
$Fe_2O_3{}^T$	9.23	5	3.89	2.66	1.75	2.69	2.69
MnO	0.17	0.08	0.04	0.04	0.02	0.03	0.01
MgO	6.99	1.2	0.94	0.56	0.92	1.04	1.4
CaO	8.37	2.35	2.32	2.08	1.47	1.7	2.42
Na_2O	4.34	4.54	4.46	6.79	4.22	4.75	5.14
K_2O	0.14	0.63	0.35	0.43	0.35	0.84	1.18
P_2O_5	0.01	0.09	0.1	0.15	0.03	-	-
LOI	1.7	1.4	0.3	1.6	1.2	0.98	2.27
Total	99.89	100.01	100	99.86	99.56	99.08	113.17
Ba (ppm)	19.1	172.4	91.2	75.8	54.2	198	150
Rb	1.4	8.2	7.4	15.9	5.4	15	16
Sr	108.5	215.6	140.9	280.2	103.7	-	-
Cs	0.1	0.3	0.2	0.6	0.1	0.82	0.51
Ga	9.7	12.3	10.6	11.8	-	-	-
Tl	0.1	0.1	0.1	0.1	-	-	-
Ta	0.1	0.2	0.2	0.4	0.1	0.17	0.11
Nb	0.5	1.4	2.3	4.5	1.4	1.3	1.1
Hf	0.5	2.7	2.6	4.4	2.4	2.69	3.81
Zr	5.2	88.2	78.8	141.8	67.5	35.7	2.9
Y	12.1	33.6	44.4	19.3	29.7	33	26
Th	0.1	1.3	1.5	4	0.5	1.2	2.8
U	0.1	0.4	0.5	0.9	0.4	0.26	2.63
Cr		6.84	13.68	13.68	20.53	-	-
Ni	10.6	5.5	16.3	11.5	4.2	92	56
Co	34.9	6.3	3.8	3	1.6	3	2
Sc	48	15	16	6	9	14	6
V	260	48	36	40	12	12	11
Cu	7.3	11.4	30.8	21.9	9.2	854	816
Pb	0.4	40.1	52	40.1	0.6	-	-
Zn	21	63	227	156	11	33	13
La	0.6	4	5.9	4.9	2.9	3.07	2.69
Ce	1.3	10.9	13.1	10.8	6.9	6.4	12.2
Pr	0.3	1.81	2	1.58	1.03	-	-
Nd	1.6	8.6	10.2	6.8	5	4.2	9.2
Sm	0.7	3	3.9	2	1.7	-	-
Eu	0.31	0.86	0.61	0.26	0.39	0.58	0.65
Gd	1.44	3.8	5.76	2.38	2.63	-	-
Tb	0.24	0.74	1.07	0.46	0.61	0.87	0.8
Dy	1.58	4.81	6.74	2.77	4	5.24	5.9
Ho	0.42	1.04	1.5	0.59	0.96	-	-
Er	1.31	3.24	4.57	1.93	3.26	3.24	2.99
Tm	0.2	0.52	0.73	0.31	0.47	0.7	0.6
Yb	1.3	3.13	4.31	2.05	3.54	4.4	2.75
Lu	0.18	0.53	0.68	0.36	0.52	0.63	0.4

SP-11, SP-16 data from Jabari, 1996; RSP1, RS22 data from Rahmani, 2002.

PETROGENESIS

The Nain plagiogranites have trondhjemitic compositions. The occurrence of micrographic intergrowths provide textural and chemical evidence for the simultaneous late stage growth of quartz and feldspar in an extremely differentiated liquid derived from a low-K magma (Coleman and Donato, 1979).

Three main models are proposed for the plagiogranite genesis in the ophiolites:

1 - Extreme crystal fractionation (Coleman and Peterman, 1975).

2 - Liquid immiscibility in silicate melts (Dixon and Rutherford, 1979).

3 - Partial melting of mafic rocks like amphibolites under hydrous conditions (Gerlach et al., 1981; Pedersen and Malpas, 1984).

The first model of fractional crystallization is preferable for the genesis of plagiogranite in the Nain ophiolite. Plagiogranites also have a negative Eu anomaly (Fig. 9), there-

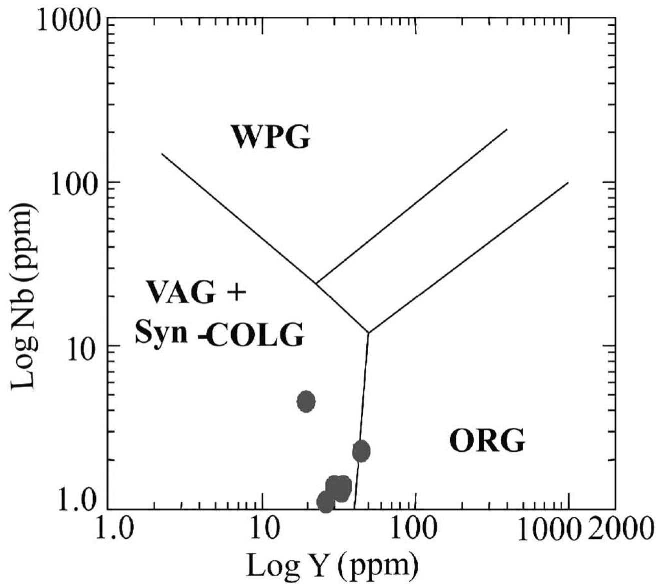

Fig. 7 - Log Nb-Log Y diagram for plagiogranites of the Nain ophiolite (Pearce et al., 1984).

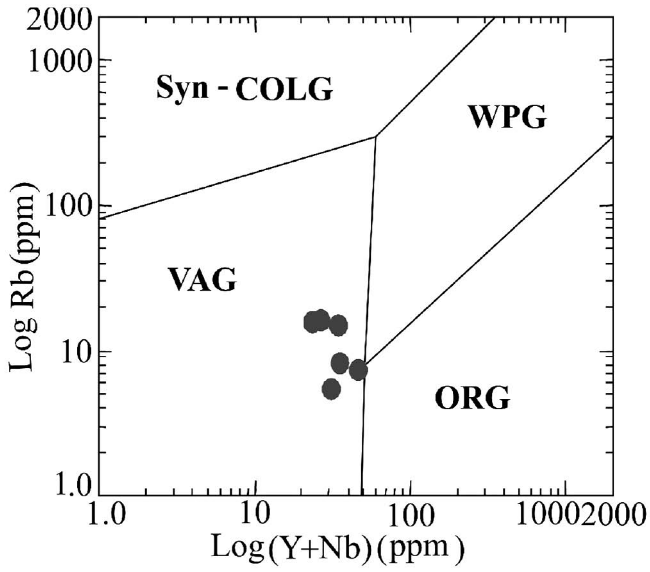

Fig. 8 - Plot of the Nain plagiogranites on petrotectonic discrimination diagram (Pearce et al., 1984).

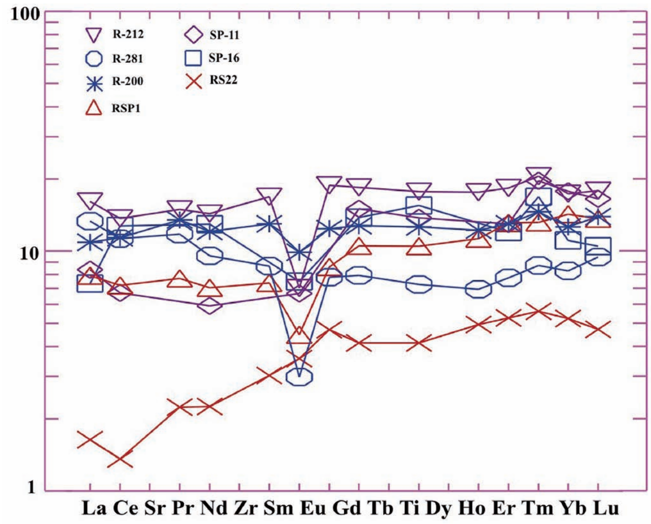

Fig. 9 - Chondrite-normalized REE diagrams for the Nain plagiogranites and gabbro (×) (normalizing values after Sun and McDonough, 1989).

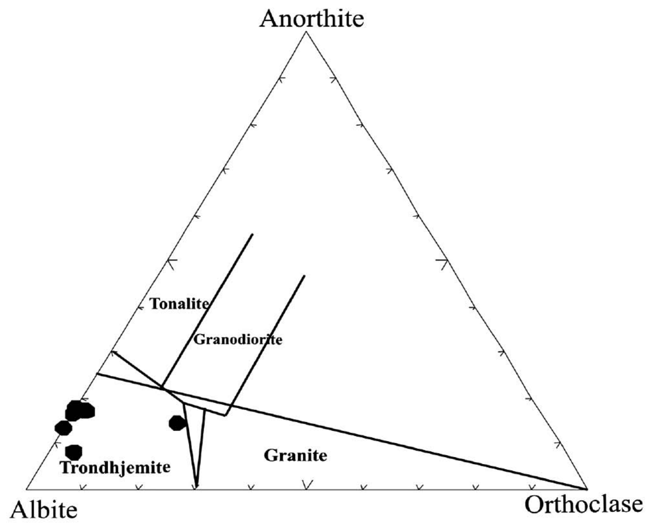

Fig. 10 - Triangular diagram for normative An-Ab and Or of the Nain plagiogranites (Barker, 1979).

by supporting the fractional crystallization model (Luchitskaya, 1996).

According to Dixon and Rutherford (1979), identification of Fe-rich conjugate magma is also essential in any rock suite if a completely convincing case for silicate liquid immiscibility is to be made, which is not observed in the present study. Brophy (2009) showed that for liquids in the felsic range (SiO_2 > 63 wt%) basalt fractionation led to constant or steadily increasing REE abundances. Conversely, either dehydration melting of amphibolites or hydration melting of mid-ocean ridge gabbros led to steadily decreasing REE abundances with increasing liquid SiO_2. Fig. 11a shows that worldwide anatectic oceanic plagiogranites display La and Yb abundances that are essentially constant in the high-SiO_2 range (though with a lot of scatter) and are similar to those of the mafic rocks. In contrast, Fig. 11b documents that the fractionation-generated oceanic plagiogranites display either steadily increasing La and Yb abundances or rather constant La and Yb abundances but higher than in the associated mafic rocks. The plagiogranites (and associated mafic rocks) from the Nain ophiolite (Fig. 11c) display an increase in La and Yb with increasing SiO_2, thereby suggesting a fractional crystallization rather than a crustal melting origin.

CONCLUSIONS

The petrochemical and geochemical characteristics of the Nain plagiogranites indicate a similarity with volcanic arc granites. Although post-crystallization metasomatism has locally affected the chemical compositions of the plagiogranites, geochemical, textural and mineralogical evidences indicate that they are primarily products of igneous processes such as fractional crystallization of a basic magma.

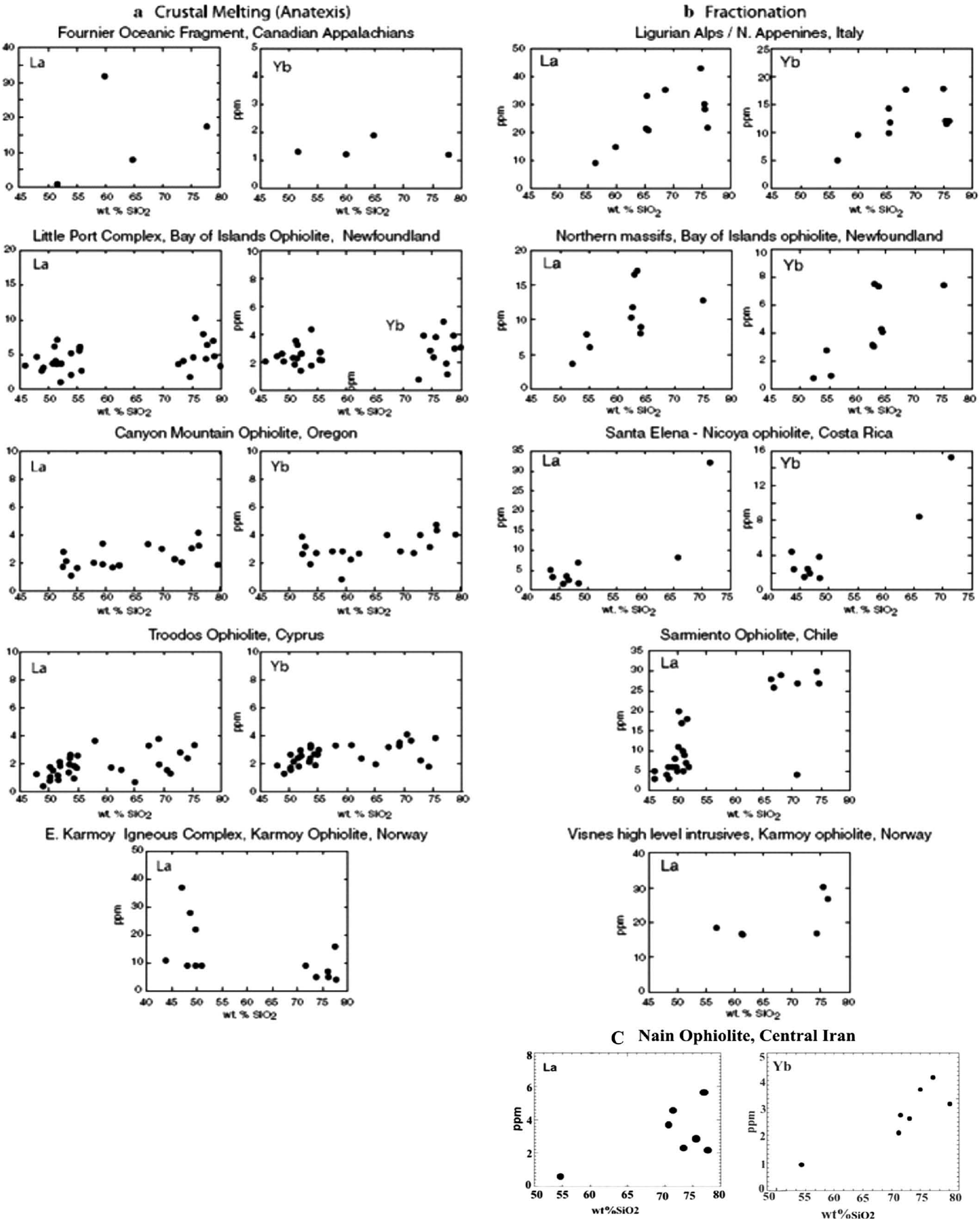

Fig. 11 - (a) La and Yb versus whole rock SiO_2 for mafic and felsic (oceanic plagiogranite) rocks believed to be related to one another through (a) melting of MOR cumulate gabbro (anatexis) and (b, c) fractional crystallization of MORB. Data sources include: Fournier oceanic fragment (Flagler and Spray, 1991), Little Port Complex, Bay of Islands ophiolite (Malpas, 1979; Jenner et al., 1991), Canyon Mountain ophiolite (Gerlach et al., 1981), Troodos Ophiolite (Gillis and Coogan, 2002), East Karmoy igneous complex (Pederson and Malpas, 1984; Furnes et al., 1980), Ligurian alps/northern Appenines (Borsi et al., 1996), northern massifs, Bay of Islands ophiolite (Malpas, 1979; Casey et al., 1985; Siroky et al., 1985), Santa Elena-Nicoya ophiolite (Beccaluva et al., 1999), Sarmiento ophiolite (Saunders et al., 1979), Visnes high-level intrusive, Karmoy ophiolite (Pederson and Malpas, 1984; Furnes et al., 1980), Nain ophiolite (Rezaei, 2007).

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