Rend. Fis. Acc. Lincei
s. 9, v. 14:79-99 (2003)

Petrologia. — *Pre-Alpine ophiolites in the basement of Southern Alps: the presence of a bimodal association (LAG- Leptyno-Amphibolitic Group) in the Serie dei Laghi (N-Italy, Ticino-CH).* Nota di EVELINA GIOBBI MANCINI, ATTILIO BORIANI e IGOR VILLA, presentata (*) dal Socio A. Boriani.

ABSTRACT. — In several portions of the Hercynian belt, a peculiar bimodal lithological association is found. Its name, Leptyno-Amphibolitic Group, reflects its being made of alternating cm-thick, fine-grained leucocratic and melanocratic layers of amphibolite facies metamorphic rocks. In the «Strona Ceneri Border Zone» (SCBZ), a part of the Southalpine basement, the banded amphibolites, contain lenses of metagabbro, retrogressed eclogites and ultramafites. To discriminate among the hypotheses on their origin proposed in the literature, we obtained major and trace elements concentrations and Sr-Nd (Pb) isotopic data. All data concordantly indicate that the SCBZ banded amphibolites derive from arc/back arc bimodal volcanics whose emplacement occurred in an Early Paleozoic convergent zone. The leptynites show geochemical characters, *i.e.* high HREE and $(Tb/Lu)_N = 1.11$ (average), and isotopic composition (εNd from +2.66 to +3.49; $^{87}Sr/^{86}Sr_{466} = 0.7034$ - 0.7053) that are clearly different from those of the Strona Ceneri metasiliciclastic rocks like the Gneiss Minuti which show an average $(Tb/Lu)_N = 1.52$ and $\varepsilon Nd_{466} = -6.69$. Their isotopic composition is also completely different from that of the Ordovician intrusives of Serie dei Laghi ($\varepsilon Nd_{466} < -4.64$ and $^{87}Sr/^{86}Sr_{466} > 0.7078$). The fine-grained amphibolitic layers are clearly derived from basaltic tuffites and have εNd_{466} from +3.21 to +7.73. Their geochemistry is compatible with a derivation from back-arc tholeiites. The SCBZ, including the banded amphibolites, may well represent the reworked products of an early Hercynian suture, in which ophiolitic remnants that underwent HP metamorphism in a subduction zone, have been incorporated in turbiditic sediments derived from back-arc bimodal volcanites prior to the intrusion of the Ordovician granites that cut across all the rocks belonging to the Serie dei Laghi

KEY WORDS: Hercynian belt; LAG (Leptyno-Amphibolitic Group); Pre-Alpine Ophiolites; Southalpine basement.

RIASSUNTO. — *Ofioliti pre-alpine nel Basamento delle Alpi Meridionali*: *la presenza di una associazione bimodale (LAG- Gruppo Leptino-Anfibolitico) nella Serie dei Laghi (N-Italia, Ticino-CH).* In alcune porzioni della catena Ercinica si trova una peculiare associazione litologica bimodale. Il suo nome, Gruppo Leptino-Anfibolitico, riflette il fatto di essere costituito da straterelli alternati, di qualche centimetro di spessore, di rocce metamorfiche leucocratiche e melanocratiche in facies delle anfiboliti. Nella «Strona Ceneri Border Zone» (SCBZ), che fa parte del basamento sudalpino, le anfiboliti a bande contengono lenti di metagabbro, eclogiti retrocesse e ultramafiti. Per discriminare tra le ipotesi sulla loro origine che sono state proposte in letteratura, noi abbiamo determinato le concentrazioni degli elementi maggiori, minori e in traccia e i dati isotopici Sr-Nd (Pb). Tutti i dati indicano concordemente che le anfiboliti a bande della SCBZ derivano da vulcaniti bimodali di arco/retro-arco, messe in posto in una situazione di zona convergente nel Paleozoico inferiore. Le leptiniti mostrano caratteri geochimici, alte HREE e $(Tb/Lu)_N = 1.11$ (media), e composizione isotopica (εNd da +2.66 a +3.49; $^{87}Sr/^{86}Sr_{466} = 0.7034$ - 0.7053) che sono chiaramente differenti da quelli delle rocce metasilicoclastiche della Zona Strona Ceneri quali gli Gneiss Minuti, che mostrano in media $(Tb/Lu)_N = 1.52$ e $\varepsilon Nd_{466} = -6.69$. La loro composizione isotopica è anche completamente diversa da

(*) Nella seduta del 10 gennaio 2003.

quella degli intrusivi Ordoviciani della Serie dei Laghi ($\varepsilon Nd_{466} < -4.64$ and $^{87}Sr/^{86}Sr_{466} > 0.7078$). Gli straterelli anfibolitici a grana fine risultano chiaramente derivati da tufiti basaltiche e hanno un εNd_{466} da +3.21 a +7.73. La loro geochimica è compatibile con una derivazione da tholeiiti di retro-arco. La SCBZ, e le sue anfiboliti a bande può ben rappresentare i prodotti rimaneggiati di una sutura eo-Ercinica, in cui i relitti ofiolitici, che subirono un metamorfismo di HP in una zona di subduzione, sono stati incorporati in sedimenti torbiditici derivati da vulcaniti bimodali prima dell'intrusione dei graniti Ordoviciani che tagliano tutte le rocce che appartengono alla Serie dei Laghi.

Introduction

Associations of banded mafic/felsic metamorphic rocks are rather widespread in the European Hercynian basement. In the French Massif Central, Forestier (1963) described interlayered acidic and basic rocks associated with biotite-sillimanite gneisses as «Complexes Leptyno-Amphiboliques» (LAC), defining «*leptynite*» as a leucocratic, fine-grained metamorphic rock. The French Massif Central is part of the European Hercynian Belt, resulting from the collision between Laurussia and Gondwana. It consists of two main nappes whose emplacement occurred during the Devonian (Matte, 1991; Ledru *et al.*, 2001). The Lower Gneiss Unit, composed of ortho- and para-derived rocks represents the north Gondwana continental margin. The relics of Early Paleozoic oceanic or marginal basins are represented by the Upper Gneissic Unit. The Leptyno-Amphibolitic Complex or Group (LAC or LAG), is a sequence which occurs at the base of this unit (Burg and Matte, 1978).

In his reconstruction of the evolution of Hercynian belt in Western Europe, Matte (1991) reported the presence of the Leptyno-Amphibolitic Group in the Montagne Noire, in the Albigeois-Levezou-Cevennes (Levezou dome) and Haut-Allier-Margeride units of Massif Central (France), in the Moldanubian units of the Bohemian Massif (Austria) and in the Western Galicia and Coimbra-Cordoba shear zone (Spain). The sequence of basic-acidic layers frequently contains lenses of mostly mafic and ultramafic rock showing relics of a HP event, like garnet peridotites, retrogressed eclogites and/or HP-granulites. The complex has been interpreted as a relict of a volcanic/volcanoclastic deposit whose emplacement occurred either in the early stages of oceanization (Pin and Vielzeuf, 1988) or in a marginal, or back arc, basin above a subduction zone (Bodinier *et al.*, 1988). The age of the HP metamorpism is estimated between 500 and 380 Ma (pre-collisional stages). For this reason the LAG are interpreted as sutures predating the Hercynian intracontinental collision (380-300 Ma). The mafic and ultramafic rocks represent remnants of oceanic lithosphere trapped during the closure of two oceanic basins, the Rheic in the north and the Galicia-Massif Central in the south. The closure of the two oceanic basins, by respectively southward and northward subduction-obduction, was responsible for the HP event. It was followed by intracontinental lithospheric (collisional stage) subduction which caused intermediate pressure metamorphism at about 380-300 Ma. According to Matte, the Austroalpine nappes, and consequently the Southalpine basement, mostly correspond to the internal part of the Hercynian belt (see also von Raumer, 1984).

Many authors proposed different models for the origin of the basic-acidic complexes, on the basis of their lithological association or geochemical characters. The basic rocks commonly show geochemical features similar to those of oceanic, or back-arc tholeiites, whilst the acidic ones seem to derive from original rhyolites. The most common associated rocks are siliciclastics, rarely carbonates.

An acidic-basic bimodal suite of Late Devonian age, with which to compare the relative geochemical and isotopic patterns, is present in the Brévenne Unit of the eastern Massif Central (Pin and Paquette, 1997). The isotopic composition and trace element data point to a derivation from a common mantle source for both mafic and felsic rocks. The metarhyolites could represent the residual liquids of a crystal fractionation process. The Brévenne metavolcanics on the whole, present many affinities with bimodal suites whose emplacement occurred in the early stages of rifting of volcanic arcs.

The banded amphibolites of the Serie dei Laghi, SdL (Western Southern Alps) show strong structural and compositional similarities with most of the LAG of the French Massif Central. They also contain lenses of mafic and ultramafic rocks with relics of HP metamorphism and occur at the base of the upper gneissic unit of SdL, the Strona Ceneri Zone. They may as well represent interlayered bimodal volcanics. Other interpretations are possible, such interlayered basaltic tuffites and fine-grained siliciclastic sediments (Giobbi Origoni *et al.*, 1997) or original lit-par-lit injections of granitic residual melts into a metabasite sequence (metaplite and metapegmatite veins are present in the banded amphibolites), as proposed by Spicher (1940) for Serie dei Laghi or by Spaenhauer (1932) for similar rocks of the Silvretta Nappe.

In order to shed light on the origin of the SCBZ banded amphibolites we have conducted a petrochemical and isotopic study. *Leptynite* indicates a felsic, fine-grained metamorphic rock. Although not accepted in modern petrographic classifications, it is adopted here because of the wide use in the international literature of the term *Leptyno-Amphibolitic Group*.

Geological setting

The Serie dei Laghi (Northern Italy and Ticino Switzerland) consists of an upper gneissic unit (Strona Ceneri Zone), including coarse (Cenerigneiss) and fine-grained (Gneiss Minuti) meta-siliciclastic sediments and a lower metapelitic unit (Scisti dei Laghi) (fig. 1).

The basal part of the Strona Ceneri Zone, called Strona Ceneri Border Zone (SCBZ), forms a continuous horizon that varies from less than one hundred to several hundred meters in thickness. It mainly consists of banded amphibolites, associated with equally banded paragneisses, quartzschists and garnet-staurolite

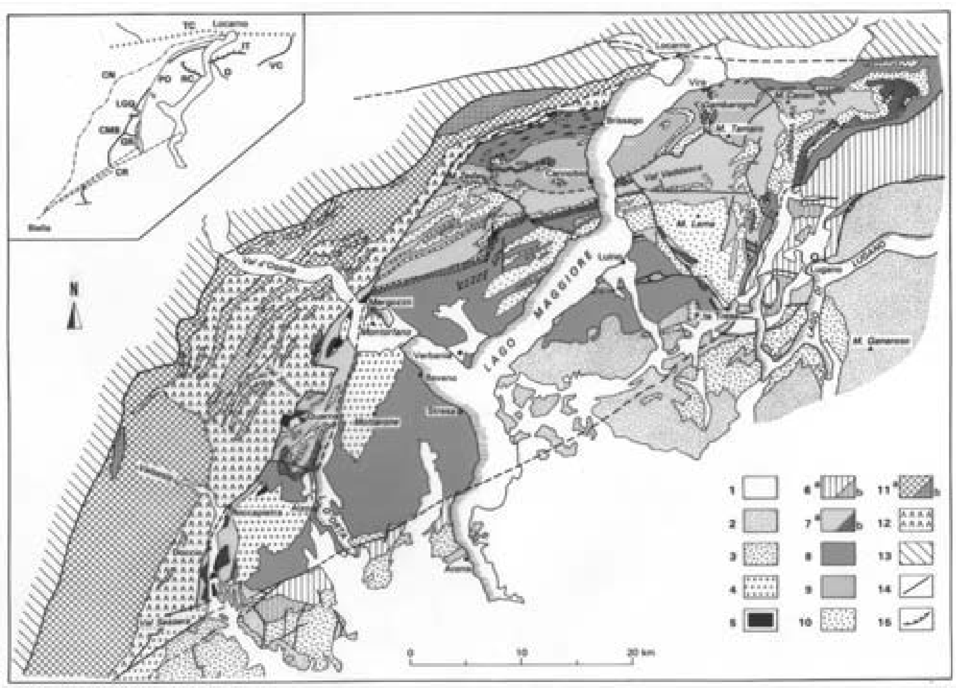

Fig. 1. – Geological sketch-map of Massiccio dei Laghi (modified after Boriani *et al.*, 1990). 1. Quaternary. 2. Sedimentary Mesozoic-Cainozoic cover. 3. Permian volcanic rocks. 4. Permian granites («Graniti dei Laghi»). 5. Permian mafic and acidic stocks and dykes («Appinites»). VAL COLLA ZONE: 6. *a*) Schists, phyllonites, epidote- amphibolites; *b*) «Gneiss Chiari». SERIE DEI LAGHI: 7*a*. Strona Ceneri Zone (paragneisses, including Cenerigneisses and Gneiss Minuti); 7*b*. Strona Ceneri Border Zone (mostly banded amphibolites with retrogressed eclogites and minor ultramafites - LAG). 8. Scisti dei Laghi (mica schists, paragneisses): 9. M. Riga and Gambarogno Zone: Strona ceneri and Scisti dei Laghi rocks with complex deformation. 10. Ordovician metagranitoids. IVREA VERBANO ZONE. 11. *a*) Basic rocks, in both granulite and amphibolite facies; *b*) ultramafites. 12. Kinzigites (pelitic and semipelitic, high-grade metasedimentary rocks, with minor marble and amphibolite intercalations). 13. ALPINE DOMAIN. 14. FAULTS. In the inset: CN = Canavese; TC = Tonale-Centovalli; CMB = Cossato-Mergozzo-Brissago; GR = Grottaccio; PO = Pogallo-Lago d'Orta; LGQ = Val Lessa, Germagno, and Quarna faults; CR = Cremosina; D = Val Dumentina; VC = Val Colla; IT = Indemini-Monte Tamaro overthrust. 15. OVERTHRUSTS.

bearing micascists, with minor lenses of ultramafites, metagabbros and garnet-bearing amphibolites (retrogressed eclogites).

Large lenses of metagranitoids, metapegmatite and meta-aplite dykes (Boriani *et al.*, 1995; Pezzotta e Pinarelli, 1994) are mainly localized within or close to the SCBZ. The metagranitoids are metamorphic products of Ordovician (Boriani *et al.*, 1982-83) granites and granodiorites, that were intruded across the SCBZ. Xenoliths of partially retrogressed eclogites are enclosed in the metagranites.

These relationships constrain both the age of the emplacement of the two units of Serie dei Laghi and the age of the HP metamorphism.

According to Giobbi Origoni *et al.*, 1997 the SCBZ rocks are remnants of an ophiolite belt; the rocks with relics of the HP event (the garnet-bearing amphibolites) could have been incorporated as clasts in turbiditic metasediments within an accretionary prism in the early stages of the Hercynian cycle and undergone partial re-equilibration in the amphibolite facies during the main Hercynian metamorphism. Another possibility is that these rocks may represent the only relics of an eo-Hercynian HP-LT metamorphic phase.

Geo-thermobarometric data for the main amphibolite facies event suggest temperatures in the range of 590-690 °C and P of about 6-8 kb (Giobbi Origoni *et al.*, 1997). $^{39}Ar/^{40}Ar$ geochronologic data give an age of 340 Ma (Boriani and Villa, 1997).

PETROLOGY

The SCBZ banded amphibolites consist of alternating dark (fine-grained amphibolites) and leucocratic (leptynites) layers varying from less than 1 cm to almost 2 cm in thickness.

The contacts between the dark and leucocratic beds are generally very sharp; sometimes it is possible to observe grain-size variations even at the scale of millimeters.

The fine-grained amphibolites contain hornblende and plagioclase and minor biotite. Sphene, apatite and opaque minerals are widespread. Accessory minerals are sphene, apatite, ores and very rare zircon. Metagabbros, garnet-bearing amphibolites and ultramafites form lenses of variable size embedded in the banded amphibolites of the SCBZ. The ultramafite lenses can reach a size of several hundred meters (Muricce, in the Sottoceneri area (CH), Alpe Morello and Oira near Lago d'Orta).

The leptynites contain quartz and plagioclase (An 12%), in polygonal aggregates, as dominant minerals. Plagioclase is also present as relict crystals with Albite-Carlsbad twinning. Rare and small lamellae of brown-green biotite are aligned in the foliation plane. Hornblende, when present, is almost completely replaced by chlorite and epidote. The accessory minerals are the same of the fine-grained amphibolites, but with more zircon.

Garnet-bearing amphibolite lenses show sharp contacts with the banded amphibolites; they are fine-grained, dark rocks, which show symplectitic intergrowths of Mg-hornblende and plagioclase (An 10-29%) and kelyphytic rims of plagioclase (An 33-49%) with Mg-hornblende around garnet relics ($Alm_{46-59}\,Grs_{23-31}\,Prp_{9-14}\,Sps_{2-7}$).

In places the associated paragneisses and micaschists of the SCBZ are more abundant than the amphibolites. They are locally very rich in garnet and staurolite. They are also banded, especially in the Sottoceneri area. These metasediments grade into the paragneisses of the Strona Ceneri, making the mapping of the geological boundary somewhat arbitrary.

Analytical techniques

Major and trace elements of the fine-grained amphibolites, leptynites, metapegmatites, the VA26 garnet-bearing amphibolite and the metasiliciclastic rocks of Serie dei Laghi were determined by fusion-ICP/MS at Activation Laboratories Ltd, Ontario (Canada) in 1998 and 1999. The FeO content was determined by potentiometric titration with $K_2Cr_2O_7$.

The Rb, Sr, Sm and Nd and concentrations of RB13A-15 and VA25 fine-grained amphibolites, VA26 garnet-bearing amphibolite, RB10-11A-21 leptynites and metasiliciclastic rocks were determined by isotope dilution.

Sr and Nd isotope ratios were determined on a Nu Instruments inductively coupled plasma source multicollector mass spectrometer (Schoenberg *et al.*, 2000). The external reproducibility of NBS 987 and the La Jolla Nd standard were ±20 and ±35 ppm (95%c.l.), respectively, over a period of several months including the analysis period (Kleinhanns *et al.*, 2002).

Chemistry

Chemical analyses of fine-grained amphibolites and leptynites are shown in tables I-IV. Chemical data of selected garnet-bearing amphibolites, metapegmatites and micrograrites, and of Gneiss Minuti (average) are also presented for comparison.

The composition of the fine-grained amphibolites is moderately inhomogeneous. Their SiO_2 content varies from 48% to 56%. Also Na_2O, TiO_2, P_2O_5, Sr, Ba, K_2O vary significantly. The garnet-bearing amphibolites are chemically more homogeneous with SiO_2 from 49.25 to 50.66 (table III).

The LILE pattern of the fine-grained amphibolites is quite irregular, while the HFSE define a relatively flat pattern as shown in the diagram of incompatible elements normalized to E-MORB (Sun and McDonough, 1989) (fig. 2). This pattern of

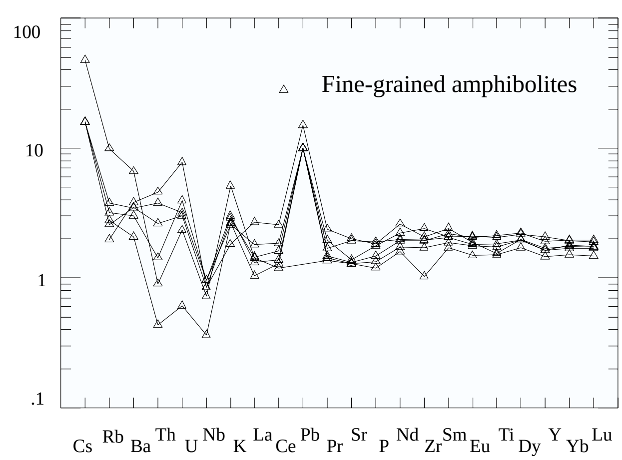

Fig. 2. – E-MORB normalized incompatible elements of fine-grained amphibolites. Normalization after Sun and McDonough (1989).

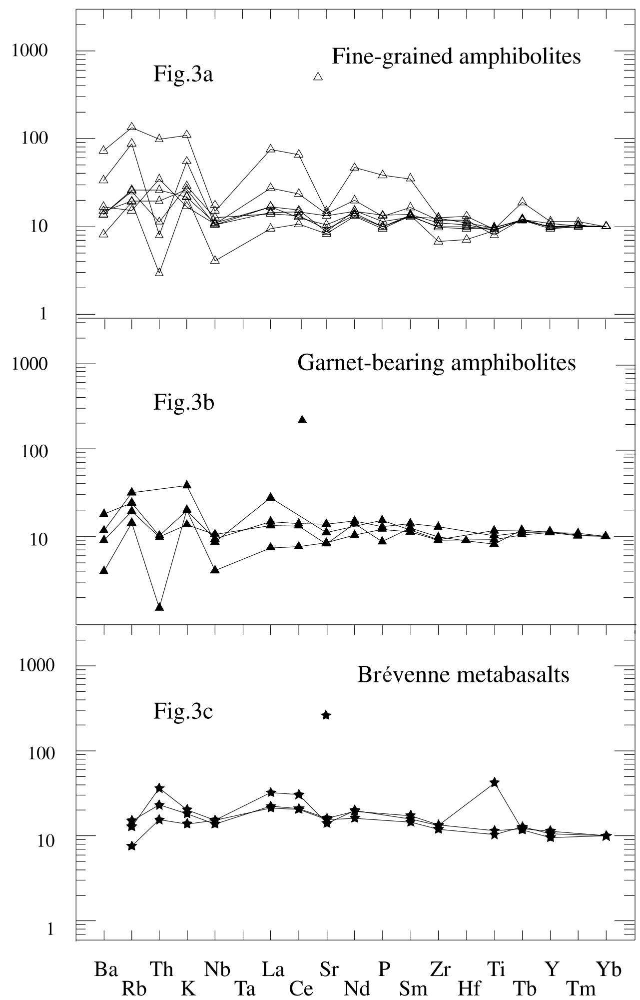

Fig. 3. – Spider diagrams after Thompson (1982) for selected incompatible elements of fine-grained amphibolites. Garnet-bearing amphibolites and Brévenne metabasalts are shown for comparison.

incompatible elements is characteristic of many oceanic island-arc tholeitic basalts and of some back-arc basin basalts (Saunders and Tarney, 1991).

The peculiar variability in the abundance of incompatible elements of the fine-grained amphibolites is also shown in the chondrite-normalized diagrams (Thompson, 1982) (fig. 3*a*). The REE element patterns of the fine-grained and of the garnet-bearing amphibolites, on the contrary, are flat, about 10 times the chondrite values, (fig. 3*b*), and quite similar to those of the Brévenne metabasalts (fig. 3*c*).

The chemical composition of leptynites is rather homogeneous, with SiO_2 varying from 72.07 to 76.07% and Al_2O_3 from 12.98 to 14.43%. FeO, MgO, K_2O and CaO

TABLE I. – *Whole rock chemistry of selected samples of amphibolites from Strona Ceneri Border Zone.*

Rock type	Fine-grained amphibolites									Garnet-bearing amphibolites					
Sample	MCMA 32	RB 12	MCMA 20	MCMA 16	RB 2	VA 25	RB 4	RB 15	RB 13A	MCMA 48	EGCA 2	MCMA 53	MCMA 55	MCMA 26	VA 26
SiO2	56.10	54.71	54.34	50.20	50.09	49.77	48.58	47.81	47.25	51.33	50.66	49.86	49.35	49.27	49.25
Al_2O_3	16.27	15.62	15.60	13.08	14.52	14.35	14.98	14.88	16.06	10.92	19.11	15.34	15.19	14.35	14.25
Fe_2O_3	1.67	1.90	2.40	2.08	2.02	3.50	1.54	1.71	0.88	6.37	1.20	1.27	1.28	1.91	2.46
FeO	6.41	8.00	4.65	6.85	9.55	8.85	9.64	10.18	10.25	6.76	6.90	9.40	9.30	10.01	6.93
MnO	0.14	0.19	0.12	0.15	0.20	0.23	0.19	0.21	0.21	0.23	0.13	0.18	0.16	0.18	0.22
MgO	5.16	4.57	7.18	11.48	5.69	5.57	6.31	7.31	8.31	8.41	5.17	6.76	6.09	6.25	7.43
CaO	8.19	7.88	8.12	8.97	8.87	9.30	9.90	10.35	6.57	10.08	9.13	11.82	12.49	10.31	11.13
Na_2O	3.35	3.73	3.60	2.41	3.74	3.77	2.94	2.73	2.91	0.74	4.32	2.33	2.55	3.07	2.75
K_2O	0.54	0.46	0.42	0.77	0.73	0.65	0.76	0.67	1.29	1.30	0.17	0.55	0.41	0.44	0.32
TiO_2	0.36	1.55	0.53	0.65	1.82	2.06	1.73	2.13	1.51	0.97	1.02	1.20	1.33	1.63	1.36
P_2O_5	0.06	0.26	0.14	0.15	0.27	0.25	0.19	0.21	0.17	0.11	0.16	0.16	0.18	0.21	0.15
LOI	1.56	0.84	2.03	2.61	0.67	0.42	1.17	0.91	2.69	1.93	1.56	1.63	0.46	1.07	1.17
Rb	14	10	12	30	13	16	16	14	41	89	1	11	7	13	10
Sr	182	312	438	292	299	211	199	207	207	169	908	131	140	249	165
Ba	119	218	82	208	198	197	171	118	377	64	161	81	39	192	101
Y	17	37	18	18	36	45.4	36	42	32	23	21	23	31.3	34.9	35.7
Nb	16	7.4	1	1	7.3	7.9	8.3	3.2	6	2	0	3	2.2	5.1	5.6
Zr	39	152	58	64	143	176	125	141	75	47	67	63	87	136	109
Sc	—	31	—	—	42	46	43	51	44	0	23	0	27	28	56

continued

TABLE I. – *Continued.*

Rock type	Fine-grained amphibolites									Garnet-bearing amphibolites					
Sample	MCMA 32	RB 12	MCMA 20	MCMA 16	RB 2	VA 25	RB 4	RB 15	RB 13A	MCMA 48	EGCA 2	MCMA 53	MCMA 55	MCMA 26	VA 26
V	216	273	156	203	278	338	291	353	285	302	203	286	288	316	286
Cr	104	40	242	459	98	76	165	181	281	189	77	262	301	157	186
Co	26	30	25	35	32	93	43	45	42	40	31	41	38	38	79
Ni	33	16	82	170	30	0	43	67	95	58	33	82	83	22	0
Cu	94	46	11	24	26	69	43	56	22	16	22	57	61	27	64
Zn	64	83	75	88	87	137	81	87	100	111	82	81	86	99	105
Ga	—	21	—	—	21	22	21	20	21	—	—	—	—	—	18
Ge	—	1.1	—	—	1.4	—	1.5	1.8	2	—	—	—	—	—	—
Mo	—	1	—	—	1	4	1	0	0	—	—	—	—	—	3
Sn	—	2	—	—	1	2	2	2	2	—	—	—	—	—	1
Sb	—	0	—	—	0	1	1	0	0	—	—	—	—	—	1
Cs	—	0	—	—	1	1	1	0	3	—	—	—	—	—	0
Hf	—	4.4	—	—	4	4.6	3.6	4	2.3	—	—	—	—	—	2.9
Ta	—	0.5	—	—	0.4	3.8	0.5	0.2	0.3	—	—	—	—	—	3
W	—	0.3	—	—	0	627	0	0	0	—	—	—	—	—	526
Tl	—	0.09	—	—	0.12	0.34	0.11	0.1	0.52	—	—	—	—	—	0.14
Pb	1	9	1	5	6	6	6	6	0	2	—	1	2	5	5
Bi	—	0.07	—	—	0.08	0	0.11	0.09	0.15	—	—	—	—	—	0
Th	—	2.8	—	—	1.6	2.3	0.9	0.3	0.5	—	1	—	0.1	0.7	0.7
U	—	1.4	—	—	0.54	0.57	0.71	0.11	0.42	—	—	—	0.01	0.56	0.27

TABLE II. – *Rare earth element content of selected samples of amphibolites from Strona Ceneri Border Zone.*

Rock type	Fine-grained amphibolites									Garnet-bearing amphibolites					
Sample	MCMA 32	RB 12	MCMA 20	MCMA 16	RB 2	VA 25	RB 4	RB 15	RB 13A	MCMA 48	EGCA 2	MCMA 53	MCMA 55	MCMA 26	VA 26
La	9.00	16.90	10.00	—	9.14	11.40	8.30	6.55	8.98	2.00	—	9.00	3.43	7.41	7.07
Ce	—	38.30	6.00	—	24.20	27.60	20.70	19.30	17.80	—	—	—	9.36	18.59	18.50
Pr	—	4.88	—	—	3.47	4.01	2.92	3.03	2.79	—	—	—	1.63	2.92	2.84
Nd	—	17.90	—	—	17.90	19.90	17.90	16.6	16.1	—	—	—	9.14	14.47	14.8
Sm	—	6.28	—	—	5.35	5.39	4.84	4.8	4.7	—	—	—	3.20	4.36	4.5
Eu	—	1.70	—	—	1.65	1.91	1.61	1.87	1.35	—	—	—	1.22	1.62	1.44
Gd	—	6.10	—	—	5.86	7.00	5.53	6.27	5.00	—	—	—	3.47	4.50	5.36
Tb	—	1.19	—	—	1.17	1.30	1.12	1.28	1.02	—	—	—	0.76	0.89	1.00
Dy	—	7.00	—	—	6.97	7.72	6.98	7.90	6.07	—	—	—	4.81	5.52	6.25
Ho	—	1.43	—	—	1.45	1.54	1.41	1.64	1.26	—	—	—	1.27	1.38	1.26
Er	—	4.24	—	—	4.22	4.97	4.17	4.82	3.70	—	—	—	3.34	3.66	3.94
Tm	—	0.64	—	—	0.65	0.72	0.64	0.74	0.57	—	—	—	0.52	0.54	0.56
Yb	—	4.15	—	—	4.22	4.59	4.01	4.64	3.58	—	—	—	3.09	3.38	3.56
Lu	—	0.61	—	—	0.62	0.67	0.60	0.69	0.52	—	—	—	0.50	0.53	0.53

TABLE III. – *Whole rock chemistry of selected samples of leptynites, metapegmatites and microgranites of Serie dei Laghi.*

Rock type	Leptynites					Metapegmatites and microgranites								Gneiss Minuti
Sample	RB 11A	RB 10	RB 11B	RB 21	RB 13B	RB 5	RB 23A	RB 23C	RB 3	RB 23B	FP 121	FP 134	FP 113	average
SiO_2	76.07	74.54	72.57	72.55	72.07	75.42	74.67	74.24	74.09	73.93	73.78	72.73	71.07	68.15
Al_2O_3	12.78	13.66	14.00	14.26	14.43	14.41	15.64	15.01	15.51	15.56	13.41	14.14	14.75	14.25
Fe_2O_3	0.93	0.83	0.70	0.09	0.77	0.14	0.21	0.30	0.08	0.24	0.80	0.41	0.53	0.78
FeO	2.09	1.93	0.97	2.53	2.13	0.15	0.24	0.65	0.25	0.49	1.28	1.12	1.48	4.12
MnO	0.03	0.06	0.07	0.05	0.05	0.01	0.00	0.01	0.00	0.01	0.03	0.03	0.04	0.08
MgO	0.22	0.51	0.62	0.89	0.62	0.13	0.16	0.50	0.15	0.41	0.53	0.48	0.71	2.25
CaO	1.77	1.99	2.54	1.97	3.20	0.64	1.88	0.64	2.32	1.96	1.47	1.92	1.29	1.61
Na_2O	5.47	5.35	5.52	4.71	4.92	3.10	5.36	5.46	6.10	4.99	2.54	3.44	3.76	3.04
K_2O	0.68	0.63	0.76	2.05	0.86	5.95	2.03	1.76	0.75	2.31	5.02	3.70	3.75	2.95
TiO_2	0.17	0.28	0.37	0.32	0.42	0.02	0.06	0.14	0.03	0.13	0.37	0.18	0.25	0.76
P_2O_5	0.02	0.06	0.08	0.08	0.08	0.25	0.05	0.09	0.04	0.09	0.12	0.08	0.15	0.22
LOI	0.67	0.85	1.16	0.77	0.99	0.66	0.52	1.03	0.79	0.57	0.58	0.55	0.68	1.09
Rb	14	36	20	20	27	98	50	63	24	60	98	126	151	116
Sr	209	224	173	138	329	116	687	285	563	772	128	220	148	226
Ba	669	450	396	643	455	495	1039	706	714	1036	1090	592	575	659
Y	49	53	33	35	42	2	3	4	5	4	23.7	28.9	27.9	33
Nb	13	14	10	12	9.6	0.7	2.7	2	1.1	2.1	6.3	8.7	9.2	13
Zr	241	274	255	247	232	16	56	76	38	78	134	114	85	261
Sc	6	9	7	6	12	0	0	2	2	2	7	7	6	12

continued

TABLE III. – *Continued.*

Rock type	Leptynites					Metapegmatites and microgranites								Gneiss Minuti
Sample	RB 11A	RB 10	RB 11B	RB 21	RB 13B	RB 5	RB 23A	RB 23C	RB 3	RB 23B	FP 121	FP 134	FP 113	average
V	7	15	20	25	11	0	6	16	0	15	29	25	33	88
Cr	0	0	0	18	0	10	12	13	0	12	25	24	30	71
Co	3	3	3	5	4	0	0	1	1	1	4	3	3	26
Ni	0	25	19	43	0	22	24	27	14	23	0	0	16	41
Cu	37	14	31	0	32	0	0	0	0	0	0	0	0	108
Zn	22	33	50	34	31	0	17	16	11	35	0	0	0	21
Ga	19	20	18	20	18	11	17	18	15	19	12.9	15.3	19.2	1.5
Ge	1.1	1.2	1.2	1.1	1.1	1.8	0.8	0.5	0.9	0.9	2.3	1.3	1.4	1.26
Mo	1	0	—	0	0	1	—	—	—	0	0	0	0	0.91
Sn	2	2	4	3	1	3	1	3	—	1	1	1	3	3
Sb	1	0	0	0	0	—	—	—	0	—	0	0	0	—
Cs	1	1	1	2	1	1	1	1	1	2	2	4	5	9
Hf	7.8	8.5	7.3	7.4	6.2	0.7	1.8	2.3	1.3	2.5	3.5	3.5	2.3	6.7
Ta	1	0.9	0.7	0.9	0.7	0.1	0.2	0.1	0	0.1	0.4	1.3	0.8	0.00
W	0.5	0	0.4	0	0.5	0	0	0	0	0	2	2.1	3.1	1.5
Tl	0.16	0.12	0.15	0.26	0.18	0.51	0.29	0.25	0.14	0.34	0.09	0.22	0.57	0.76
Pb	7	0	0	8	12	71	70	10	31	38	6	0	15	33
Bi	0.23	0	0.3	0.11	0.14	0.09	0	0	0	0	0	0	0.11	0.4
Th	8.5	7	6.6	7.6	4	1.9	3.1	4.9	9	5.2	8.1	17.2	6	13.2
U	4.82	3.54	3.53	2.94	2.95	1.63	1.11	1.3	1.38	1.46	1.05	5.32	2.2	3.04

TABLE IV. – *Rare earth element content of selected samples of Leptynites, metapegmatites and microgranites of Serie dei Laghi.*

Rock type	Leptynites					Metapegmatites and microgranites								Gneiss Minuti
Sample	RB 11A	RB 10	RB 11B	RB 21	RB 13B	RB 5	RB 23A	RB 23C	RB 3	RB 23B	FP 121	FP 134	FP 113	average
La	32.50	27.30	23.00	31.80	22.60	8.83	9.28	16.00	18.20	14.80	17.97	32.54	14.79	39.53
Ce	67.50	62.60	50.10	68.80	48.50	16.40	18.10	31.20	35.70	31.40	45.05	58.56	29.94	79.10
Pr	8.07	7.20	5.46	7.42	5.93	1.73	1.96	3.33	3.98	3.10	4.17	6.30	3.26	9.11
Nd	32.90	30.80	22.40	30.30	28.20	6.48	7.90	13.80	16.50	12.70	17.00	24.43	13.02	35.77
Sm	7.50	7.60	5.14	6.5	7.01	1.28	1.34	2.33	3.87	2.36	3.80	4.95	3.06	7.15
Eu	1.01	1.44	1.10	1.03	1.54	0.56	0.53	0.72	0.66	0.70	0.92	0.75	0.73	1.38
Gd	7.90	7.47	4.77	5.74	6.72	0.97	0.90	1.50	2.70	1.46	3.44	4.68	3.16	5.72
Tb	1.55	1.51	0.91	1.04	1.26	0.14	0.12	0.18	0.34	0.19	0.65	0.81	0.71	0.98
Dy	9.10	9.17	5.45	6.21	7.53	0.69	0.56	0.84	1.36	0.81	3.98	4.60	4.41	5.48
Ho	1.83	1.90	1.13	1.25	1.51	0.11	0.10	0.14	0.19	0.13	0.86	0.89	0.90	1.04
Er	5.75	6.00	3.66	3.93	4.55	0.34	0.30	0.41	0.47	0.36	2.95	2.86	2.82	3.12
Tm	0.94	0.98	0.60	0.65	0.72	0.05	0.04	0.06	0.05	0.05	0.47	0.44	0.43	0.47
Yb	6.14	6.44	4.00	4.17	5.07	0.34	0.25	0.36	0.28	0.31	3.27	2.90	2.81	2.95
Lu	0.89	0.99	0.63	0.63	0.71	0.05	0.04	0.05	0.04	0.05	0.49	0.43	0.39	0.44

The analyses of the MCMA32-20-16 fine-grained amphibolites, MCMA48-53-55-26, EGCA2 garnet-bearing amphibolites are from Giobbi Origoni *et al.* (1997) and those of the FP121-134-113 Ordovician granitoids are from Pezzotta and Pinarelli (1994).

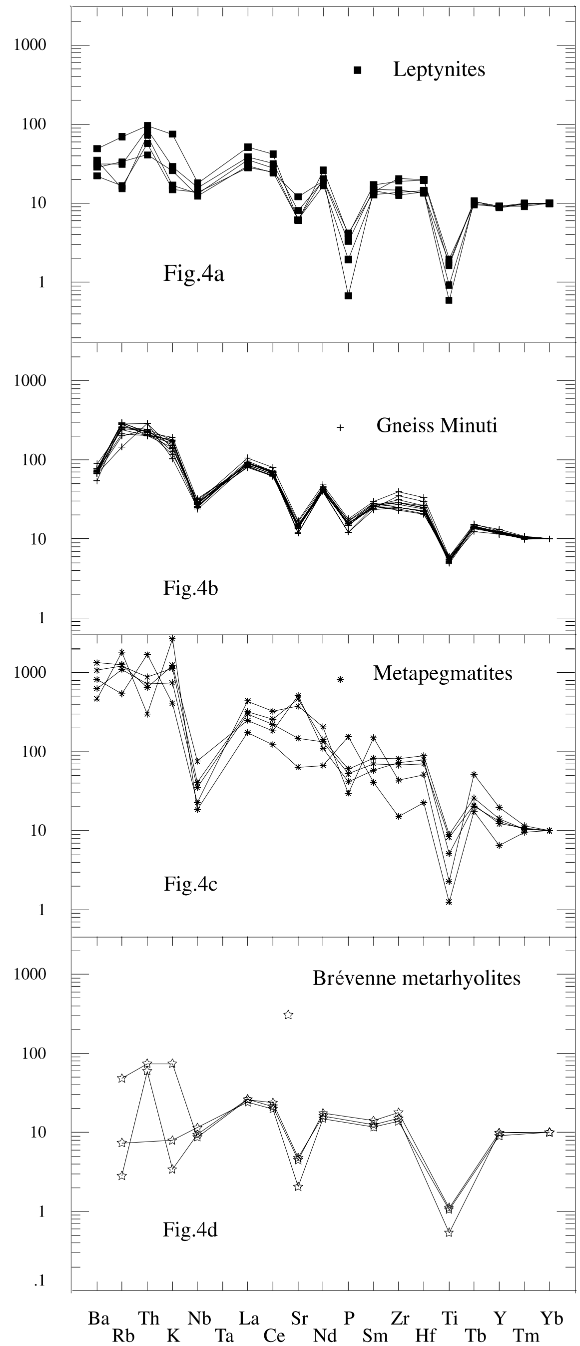

Fig. 4. – Chondrite normalized diagrams after Thompson (1982) for selected incompatible elements of leptynites. Gneiss Minuti, metapegmatites and Brévenne metarhyolites are shown for comparison.

vary by factors of 2 to 4 (table I). The major element composition of leptynites is quite different from that of Gneiss Minuti, metapegmatites and micrograanites.

The Gneiss Minuti have lower SiO_2 content (average=68.15%) and higher FeO (average=4.12%), MgO (average=2.25%) and K_2O (average=2.95%). Compared to metapegmatites and microgranites, the leptynites show the same compositional range in SiO_2, but higher FeO and MgO and, on the whole, lower K_2O (except for RB3) (tabs. I, II).

The SdL leptynites do not show analogies with other rocks of the same unit, but look very similar to the Brévenne metarhyolites (Pin and Paquette, 1997), both for major and trace elements.

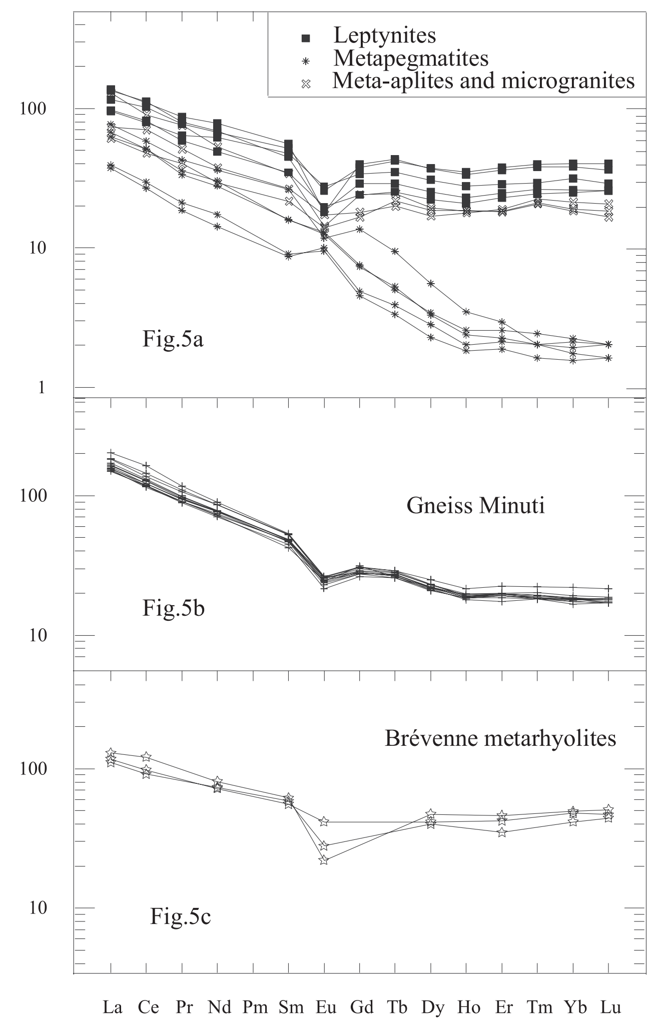

Fig 5. – Chondrite-normalized REE patterns of *a)* leptynites, meta-microgranites and metapegmatites of Serie dei Laghi; *b)* Gneiss Minuti; *c)* Brévenne metarhyolites. Normalization after McDonough and Sun (1995).

It is interesting to note that the patterns of incompatible elements (Thompson, 1982) of leptynites are characterized by a moderate fractionation with a positive Th anomaly and negative anomalies of P, Sr, Nb and Ti (fig. 4*a*). The Gneiss Minuti pattern is different because of the higher LILE content and the less pronounced P and Ti negative anomalies. The scattered incompatible element pattern of metapegmatites appears completely discordant from those of leptynites, because the very high LILE content.

If we examine in detail the REE content we can better distinguish the leptynites from the other leucocrathic rocks of Serie dei Laghi.

In the chondrite-normalized REE diagrams (McDonough and Sun, 1995) the leptynites display a moderate enrichment in LREE $(La/Sm)_N$=2.0-3.0, a slight negative Eu anomaly and a flat HREE pattern $(Tb/Lu)_N$=1.0-1.2 at ca. 20-40 times the chondrite level (fig. 5*a*).

The REE patterns of Gneiss Minuti (fig. 5*b*) appear more fractionated, with $(Tb/Lu)_N$=1.5 (average), and with a less pronounced Eu negative anomaly. The REE patterns of metapegmatites (fig. 5*a*) are extremely different from those of leptynites, because they show much lower HREE and are highly fractionated with $(Tb/Lu)_N$=1.2-2.1. The microgranites show patterns similar to the leptynites, though with lower REE content.

The Brévenne metarhyolites are characterized by moderate enrichment in LILE and a flat HREE pattern, at ca. 40 times the chondrite level (fig. 5*c*).

Sr and Nd isotopes (table V)

The Sr and εNd geochemistry and isotope ratios have been calculated to 466Ma, (the estimated intrusion age of Serie dei Laghi metagranitoids which cut across the banded amphibolites).

In fig. 6 (εNd_{466} vs. $^{87}Sr/^{86}Sr_{466}$) the representative points of the fine-grained amphibolites and leptynites are plotted together with selected samples of garnet-bearing amphibolite, metasiliciclastic rocks (Gneiss Minuti and Cenerigneisses) and the more differentiated Ordovician metagranites of Serie dei Laghi (EL35 and FP134-111-121-125-126-144, from Pezzotta and Pinarelli, 1994).

The two fine-grained amphibolites VA25 ($\varepsilon Nd_{466} = +3.21$; $^{87}Sr/^{86}Sr_{466} = 0.7045$) and RB13A ($\varepsilon Nd_{466} = +5.49$; $^{87}Sr/^{86}Sr_{466} = 0.7031$) plot in the field of the depleted mantle, as well as the garnet-bearing amphibolite VA26 (εNd_{466} from +2.48 and $^{87}Sr/^{86}Sr_{466} = 0.7041$).

RB15 ($\varepsilon Nd_{466} = +7.73$), which has slightly higher Sr isotopic ratio ($^{87}Sr/^{86}Sr_{466} = 0.7048$) than the other amphibolites, could have suffered an interaction with marine water.

The leptynites RB10 (εNd_{466} from +3.49; $^{87}Sr/^{86}Sr_{466} = 0.7034$) and RB11A ($\varepsilon Nd_{466} = +2.66$; $^{87}Sr/^{86}Sr_{466} = 0.7053$) are isotopically similar to the fine-grained am-

TABLE V. – *Isotopic data of selected samples of amphibolites and leptynites from Strona Ceneri Border Zone.*

Rock type	Fine-grained amphibolites			Garnet-bearing amphibolite	Leptynites		
Sample	RB 13A	RB 15	VA 25	VA 26	RB 10	RB 11A	RB 21
Sm_{ppm}	4.7	4.8	5.4	4.5	7.6	7.5	6.5
Nd_{ppm}	16.1	16.6	18.9	14.8	31.8	32.9	30.3
$^{147}Sm/^{144}Nd$	0.176	0.176	0.173	0.185	0.144	0.138	0.129
$^{143}Nd/^{144}Nd$	0.512857	0.512970	0.512729	0.512730	0.512655	0.512596	0.512567
2SE abs.	0.000033	0.000032	0.000017	0.000024	0.000009	0.000006	0.000004
εNd_0	4.28	6.48	1.77	1.79	0.33	− 0.82	− 1.38
εNd_{466}	5.49	7.73	3.21	2.48	3.49	2.66	2.67
tDM	1.19	0.72	1.55	2.21	1.08	1.12	1.04
tDM (2st)	0.77	0.58	0.95	1.02	0.92	0.99	0.99
Rb ppm	41	14	16	10	36	14	20
Sr ppm	207	212	211	165	225	209	138
$^{87}Rb/^{86}Sr$	0.571	0.192	0.221	0.179	0.461	0.190	0.422
$^{87}Sr/^{86}Sr$	0.706930	0.706061	0.706040	0.705265	0.706490	0.706570	0.714312
2SE abs.	0.000082	0.000019	0.000035	0.000082	0.000018	0.000015	0.000011

phibolites, whereas they are clearly different from the Strona Ceneri metasiliciclastic rocks and from the Ordovician metagranitoids, as both have slightly negative εSr_{466} and positive εNd_{466} (Giobbi *et al.*, unpublished).

The Brévenne metavolcanics also have negative to slightly positive εSr_{500} (Pin and Paquette, 1997).

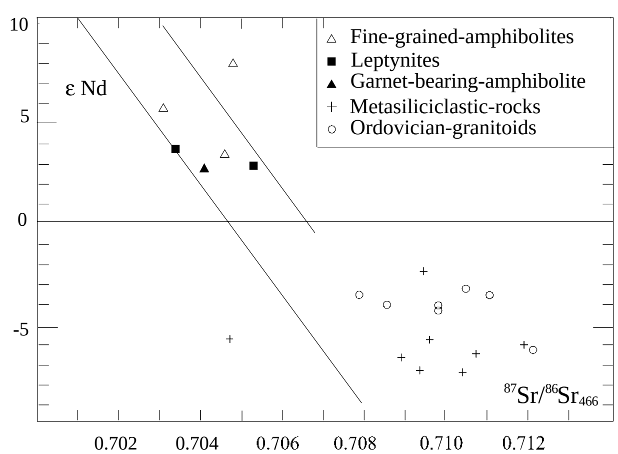

Fig. 6. – εNd vs. $(^{87}Sr/^{86}Sr)_{466}$ of selected samples of fine-grained amphibolites and leptynites. A garnet-bearing amphibolite (VA26), metasiliciclastic rocks and Ordovician granitoids of SdL are plotted for comparison.

The $(^{87}Sr/^{86}Sr)_{466}$ of the SdL amphibolites (0.7032-0.7047) is compatible with that of some arc and back-arc basin basalts as, for example, the South Sandwich arc (0.7038-0.7042) and East Scotia Sea back-arc basin (0.7028-0.7033) (Luff, 1982).

Similar isotopic data have been obtained by Biino (1995) on the fine-grained amphibolites of the Gothard and Tavetsch units, with slightly negative to slightly positive εSr_{500}.

Conclusions

The nature of the banded structure of the amphibolites has been variously addressed in the literature:

a) Interlayered basaltic tuffites and fine-grained siliciclastic sediments (*e.g.*: the protolith of Gneiss Minuti) with some mixing; fine-grained amphibolites and Gneiss Minuti are indeed strictly connected in the field and sometimes they grade one into the other so that it is very difficult to define the boundary (Giobbi Origoni *et al.*, 1997).

b) Metabasites with lit-par-lit injections of leucocratic residual melts derived from the Ordovician granitoids (Spicher, 1940).

c) Interlayered basaltic and rhyolitic tuffites.

The chemical and isotopic characters show that interpretation *a*) can be definitely ruled out. The chemical composition of the leptynites, as can be seen from their incompatible elements and REE patterns, is very different from that of Gneiss Minuti (fig. 2 *b*, *e*). The Gneiss Minuti show REE patterns very similar to those of many shales, with quite flat HREE, enrichment in LREE, and strong enrichment in incompatible elements. The Nd-Sr isotopic compositions demonstrate that the fine-grained siliciclastic sediments are unrelated to the light coloured layers of the banded amphibolites.

The second possibility *b*) conflicts with the chemical features. Even if the REE patterns of the leptynite layers show some similarities with the fine-grained dykes connected with the Ordovician metagranites, it can be noted that their HREE content is generally higher. But the main difference is that their positive εNd_{466} and low εSr_{466} point to a mantle origin, whilst the Ordovician granitoids have a clear crustal signature (negative εNd_{466}).

Our results indicate that fine-grained amphibolites and their leucocratic inlayers (the leptynites) have a common origin. They also indicate that the SCBZ banded amphibolites are indeed very similar to some occurrences of the Leptyno-Amphibolitic Group (LAG) and to the Brévenne metavolcanics, geochemically and isotopically identified as a bimodal suite erupted in a suprasubduction environment.

This is the first time that the presence of LAG is fully recognized in the basement of Southern Alps. The presence of an early Hercynian suture had been already reported by Giobbi Origoni *et al.* (1997).

The age of this subduction is constrained by the circumstance that fragments of amphibolites with HP relics are enclosed in the Ordovician granitoids (466 Ma, Boriani *et al*., 1982-83). This upper age boundary is compatible with age determinations in other parts of the Hercynian belt. An age of 499 ± 5 Ma has been obtained on zircons (method of mono-zircon evaporation $^{207}Pb/^{206}Pb$) of the leptyno-amphibolitic complex of Vergonzac (Limousin, Massif Central - Ledru and Calvez, 1988). Alexandrov *et al*. published in 2001 an ion probe age of 525 ± 6 Ma of zircons from leptynites of the same unit. Similar ages have been obtained in the LAG of Marvejols (478 ± 6 Ma e 484 ± 7 Ma) and Levezou (485 ± 30 Ma, Pin and Piboule, 1988).

Although metamorphosed in the amphibolite facies conditions these rocks preserve many sedimentary features like graded bedding and fining upward. They should be therefore considered re-sedimented volcanoclastic rocks (tuffites). The preservation of delicate sedimentary structures is not compatible with an interpretation of the sequence as a tectonic mélange.

In conclusion our field, chemical and isotopic data confirm the similarity of the banded amphibolites of Serie dei Laghi with the Leptyno-Amphibolitic Group, as defined by Burg and Matte (1978). The presence of this metavolcanic bimodal sequence (LAG), of back arc basin siliciclastic rocks and fragments of mafic rocks with relics of an HP metamorphic event, enables us to correlate this sequence occurring in the Serie dei Laghi with similar pre-Alpine associations that are found in the Hercynian belt.

If we apply the interpretation which had been proposed for the French Massif Central, the LAG of Serie dei Laghi may represent a remnant of the suture of the collision between Gondwana and Laurussia in the South Alpine basement. The Scisti dei Laghi may therefore belong to the north Gondwana continental margin.

References

Alexandrov P., Floc'h J.P., Cuney M., Cheilletz A., 2001. *Datation à la microsonde ionique des zircons de l'unité supérieure des gneiss dans le Sud Limousin, Massif Central.* C.R. Acad. Sci. Paris, Earth and Planetary Sciences, 332: 625-632.

Biino G.G., 1995. *Pre-Variscan evolution of the eclogitised mafic rocks from the Helvetic basement of the central Alps.* Eur. J. Mineral., 7: 57-70.

Bodinier J.L., Burg J.P., Leyreloup A., Vidal H., 1988. *Reliques d'un bassin d'arrière-arc subducté, puis obducté dans la région de Marvejols (Massif Central).* Bull. Soc. Geol. Fr., s. 8, (4) 1: 21-33.

Boriani A., Villa I., 1997. *Geochronology of regional metamorphism in the Ivrea-Verbano Zone and Serie dei Laghi, Italian Alps.* Schweiz. Mineral. Petrol. Mitt., 77: 381-401.

Boriani A., Origoni Giobbi E., Del Moro A., 1982-83. *Composition, level of intrusion and age of the «Serie dei Laghi» orthogneisses (Northern Italy - Ticino, Switzerland).* Rend. Soc. Ital. Mineral. Petrol., 38 (1): 191-205.

Boriani A., Giobbi Origoni E., Borghi A., Caironi V., 1990. *The evolution of the «Serie dei Laghi» (Strona-Ceneri and Scisti dei Laghi): the upper component of the Ivrea-Verbano crustal section; Southern Alps, North Italy and Ticino, Switzerland.* Tectonophysics, 82: 103-118.

BORIANI A., GIOBBI ORIGONI E., PINARELLI L., 1995. *Paleozoic evolution of southern Alpine crust (northern Italy) as indicated by contrasting granitoid suites.* Lithos, 35: 47-63.

BURG J.P., MATTE P., 1978. *A cross-section through the French Massif Central and the scope of its Variscan geodynamic evolution.* Z. dt. Geol. Ges., 129: 429-460.

FORESTIER F.H., 1963. *Métamorphisme hercynien dans les bassins du Haut Allier.* Bull. Serv. Carte Géol. Fr., 271: 294 pp.

GIOBBI ORIGONI E., ZAPPONE A., BORIANI A., BOCCHIO R., MORTEN L., 1997. *Relics of pre-alpine ophiolites in the Serie dei Laghi (Western Southern Alps).* Schweiz. Mineral. Petrol. Mitt., 77: 187-207.

KLEINHANNS I.C., KREISSIG K., KAMBER B.S., MEISEL TH., NAEGLER TH.F., KRAMERS J.D., 2002. *Combined chemical separation of Lu, Hf, Sm, Nd, and REEs from a single rock digest: precise and accurate isotope determinations of Lu-Hf and Sm-Nd using multicollector ICPMS.* Analytical Chemistry, 74: 67-73.

LEDRU P., CALVEZ J.L., 1988. *Implications géodynamiques de la datation du complexe leptyno-amphibolique de Vergonzac (Limousin, Massif central français) par la méthode d'evaporation des mono-zircons* ($^{207}Pb/^{206}Pb$). Cartographie geol. de France Princ. résultats scient. de BRGM.

LEDRU P., COURRIOUX G., DALLAIN C., LARDEAUX J.M., MONTEL J.M., VANDERHAEGHE O., VITEL G., 2001. *The Velay dome (French Massif Central): melt generation and granite emplacement during orogenic evolution.* Tectonophysics, 342: 207-237.

LUFF I.W., 1982. *Petrogenesis of the island arc tholeiite series of the South Sandwich Islands.* Unpubl. PhD thesis, Univ. Leeds, UK.

MATTE P., 1991. *Accretionary history and crustal evolution of the Variscan belt.* Tectonophysics, 196: 309-337.

MCDONOUGH W.F., SUN S.S., 1995. *The composition of the Earth.* In: W.F. MCDONOUGH, N.T. ARNDT, S. SHIREY (eds.), *Chemical evolution of the mantle.* Chemical Geology, 120, 3-4: 223-253. Elsevier, Amsterdam, Netherlands.

PEZZOTTA F., PINARELLI L., 1994. *The magmatic evolution of Ordovician Metagranitoids of Serie dei Laghi (Southern Alps): inferences from petrological, geochemical, and Sr Nd isotope data.* Per. Mineral., 63: 127-147.

PIN C., PAQUETTE J.L., 1997. *A mantle derived bimodal suite in the Hercynian Belt: Nd isotope and trace element evidence for a subduction-related rift origin of the Late Devonian Brévenne metavolcanics, Massif Central (France).* Contrib. Mineral. Petrol., 129: 222-238.

PIN C., PIBOULE M., 1988. *Age devonien supérieur de la série calco-alcaline de la ceinture basique du Levezou (Rouergue); un exemple de complexe leptyno-amphibolique composite.* Bull. Soc. Geol. Fr., s. 8, 4: 261-265.

PIN C., VIELZEUF D., 1988. *Les granulites de haute-pression d'Europe moyenne temoins d'une subduction èo-hercynienne; implications sur l'origine des groupes leptyno-amphiboliques.* Bull. Soc. Geol. Fr., s. 8, 4: 13-20.

RAUMER J.F. VON, 1984. *The Hercynian basement in the Helvetic realm, western and central Alps.* Mem. Soc. Geol. It., 29: 57-69.

SAUNDERS A.D., TARNEY J., 1991. *Back-ark basin.* In: P.A. FLOYD (ed.), *Oceanic Basalts.* Blackie, Glasgow-London: 219-263.

SCHOENBERG R., NAEGLER TH.F., KRAMERS J.D., 2000. *Precise Os isotope ratio and Re-Os isotope dilution measurements down to the picogram level using multicollector inductively coupled plasma mass spectrometry*. International Journal of Mass Spectrometry, 197: 85-94.

SPAENHAUER F., 1932. *Petrographie und Geologie der Grialetsch-Vadret-Sarsura-Gruppe, GR.* Schweiz. Mineral. Petrol. Mitt., 12: 27-146.

SPICHER A., 1940. *Geologie und Petrographie des oberen Val d'Isone (suedliches Tessin).* Schweiz. Mineral. Petrol. Mitt., 20: 17-100.

SUN S.S., McDONOUGH W.F., 1989. *Chemical and isotopic systemathic of ocean basalts: implications for mantle composition and processes.* In: A.D. SAUNDERS, M.J. NORRY (eds.), *Magmatism in the Ocean Basins.* Geol. Soc. Spec. Publ., 42: 313-345.

THOMPSON R.N., 1982. *Magmatism of the British Tertiary volcanic Province.* Scott. Jour. Geol. Edinburg, 18: 49-107.

Pervenuta il 12 dicembre 2002,
in forma definitiva il 30 dicembre 2002.

A. Boriani:
Dipartimento di Scienze della Terra
Università degli Studi di Milano
Via Botticelli, 23 - 20133 MILANO
boriani@r10.terra.unimi.it

E. Giobbi Mancini:
Dipartimento di Scienze Geologiche e Geotecnologie
Università degli Studi di Milano-Bicocca
Piazza della Scienza, 4 - 20126 MILANO
evlina.giobbi@unimib.it

I. Villa:
Dipartimento di Scienze Geologiche e Geotecnologie
Università degli Studi di Milano-Bicocca
Piazza della Scienza, 4 - 20126 MILANO
Geologisches Institut, Isotopengeologie
Universität Bern, Erlachstr. 9a - 3012 BERN (Svizzera)
igor.villa@unimib.it

Table I. – *Whole rock chemistry of selected samples of amphibolites from Strona Ceneri Border Zone.*

Rock type	Fine-grained amphibolites									Garnet-bearing amphibolites					
Sample	MCMA 32	RB 12	MCMA 20	MCMA 16	RB 2	VA 25	RB 4	RB 15	RB 13A	MCMA 48	EGCA 2	MCMA 53	MCMA 55	MCMA 26	VA 26
SiO2	56.10	54.71	54.34	50.20	50.09	49.77	48.58	47.81	47.25	51.33	50.66	49.86	49.35	49.27	49.25
Al_2O_3	16.27	15.62	15.60	13.08	14.52	14.35	14.98	14.88	16.06	10.92	19.11	15.34	15.19	14.35	14.25
Fe_2O_3	1.67	1.90	2.40	2.08	2.02	3.50	1.54	1.71	0.88	6.37	1.20	1.27	1.28	1.91	2.46
FeO	6.41	8.00	4.65	6.85	9.55	8.85	9.64	10.18	10.25	6.76	6.90	9.40	9.30	10.01	6.93
MnO	0.14	0.19	0.12	0.15	0.20	0.23	0.19	0.21	0.21	0.23	0.13	0.18	0.16	0.18	0.22
MgO	5.16	4.57	7.18	11.48	5.69	5.57	6.31	7.31	8.31	8.41	5.17	6.76	6.09	6.25	7.43
CaO	8.19	7.88	8.12	8.97	8.87	9.30	9.90	10.35	6.57	10.08	9.13	11.82	12.49	10.31	11.13
Na_2O	3.35	3.73	3.60	2.41	3.74	3.77	2.94	2.73	2.91	0.74	4.32	2.33	2.55	3.07	2.75
K_2O	0.54	0.46	0.42	0.77	0.73	0.65	0.76	0.67	1.29	1.30	0.17	0.55	0.41	0.44	0.32
TiO_2	0.36	1.55	0.53	0.65	1.82	2.06	1.73	2.13	1.51	0.97	1.02	1.20	1.33	1.63	1.36
P_2O_5	0.06	0.26	0.14	0.15	0.27	0.25	0.19	0.21	0.17	0.11	0.16	0.16	0.18	0.21	0.15
LOI	1.56	0.84	2.03	2.61	0.67	0.42	1.17	0.91	2.69	1.93	1.56	1.63	0.46	1.07	1.17
Rb	14	10	12	30	13	16	16	14	41	89	1	11	7	13	10
Sr	182	312	438	292	299	211	199	207	207	169	908	131	140	249	165
Ba	119	218	82	208	198	197	171	118	377	64	161	81	39	192	101
Y	17	37	18	18	36	45.4	36	42	32	23	21	23	31.3	34.9	35.7
Nb	16	7.4	1	1	7.3	7.9	8.3	3.2	6	2	0	3	2.2	5.1	5.6
Zr	39	152	58	64	143	176	125	141	75	47	67	63	87	136	109
Sc	—	31	—	—	42	46	43	51	44	0	23	0	27	28	56

continued

TABLE I. – *Continued.*

Rock type	Fine-grained amphibolites									Garnet-bearing amphibolites					
Sample	MCMA 32	RB 12	MCMA 20	MCMA 16	RB 2	VA 25	RB 4	RB 15	RB 13A	MCMA 48	EGCA 2	MCMA 53	MCMA 55	MCMA 26	VA 26
V	216	273	156	203	278	338	291	353	285	302	203	286	288	316	286
Cr	104	40	242	459	98	76	165	181	281	189	77	262	301	157	186
Co	26	30	25	35	32	93	43	45	42	40	31	41	38	38	79
Ni	33	16	82	170	30	0	43	67	95	58	33	82	83	22	0
Cu	94	46	11	24	26	69	43	56	22	16	22	57	61	27	64
Zn	64	83	75	88	87	137	81	87	100	111	82	81	86	99	105
Ga	—	21	—	—	21	22	21	20	21	—	—	—	—	—	18
Ge	—	1.1	—	—	1.4	—	1.5	1.8	2	—	—	—	—	—	—
Mo	—	1	—	—	1	4	1	0	0	—	—	—	—	—	3
Sn	—	2	—	—	1	2	2	2	2	—	—	—	—	—	1
Sb	—	0	—	—	0	1	1	0	0	—	—	—	—	—	1
Cs	—	0	—	—	1	1	1	0	3	—	—	—	—	—	0
Hf	—	4.4	—	—	4	4.6	3.6	4	2.3	—	—	—	—	—	2.9
Ta	—	0.5	—	—	0.4	3.8	0.5	0.2	0.3	—	—	—	—	—	3
W	—	0.3	—	—	0	627	0	0	0	—	—	—	—	—	526
Tl	—	0.09	—	—	0.12	0.34	0.11	0.1	0.52	—	—	—	—	—	0.14
Pb	1	9	1	5	6	6	6	6	0	2	—	1	2	5	5
Bi	—	0.07	—	—	0.08	0	0.11	0.09	0.15	—	—	—	—	—	0
Th	—	2.8	—	—	1.6	2.3	0.9	0.3	0.5	—	1	—	0.1	0.7	0.7
U	—	1.4	—	—	0.54	0.57	0.71	0.11	0.42	—	—	—	0.01	0.56	0.27

TABLE II. – *Rare earth element content of selected samples of amphibolites from Strona Ceneri Border Zone.*

Rock type	Fine-grained amphibolites									Garnet-bearing amphibolites					
Sample	MCMA 32	RB 12	MCMA 20	MCMA 16	RB 2	VA 25	RB 4	RB 15	RB 13A	MCMA 48	EGCA 2	MCMA 53	MCMA 55	MCMA 26	VA 26
La	9.00	16.90	10.00	—	9.14	11.40	8.30	6.55	8.98	2.00	—	9.00	3.43	7.41	7.07
Ce	—	38.30	6.00	—	24.20	27.60	20.70	19.30	17.80	—	—	—	9.36	18.59	18.50
Pr	—	4.88	—	—	3.47	4.01	2.92	3.03	2.79	—	—	—	1.63	2.92	2.84
Nd	—	17.90	—	—	17.90	19.90	17.90	16.6	16.1	—	—	—	9.14	14.47	14.8
Sm	—	6.28	—	—	5.35	5.39	4.84	4.8	4.7	—	—	—	3.20	4.36	4.5
Eu	—	1.70	—	—	1.65	1.91	1.61	1.87	1.35	—	—	—	1.22	1.62	1.44
Gd	—	6.10	—	—	5.86	7.00	5.53	6.27	5.00	—	—	—	3.47	4.50	5.36
Tb	—	1.19	—	—	1.17	1.30	1.12	1.28	1.02	—	—	—	0.76	0.89	1.00
Dy	—	7.00	—	—	6.97	7.72	6.98	7.90	6.07	—	—	—	4.81	5.52	6.25
Ho	—	1.43	—	—	1.45	1.54	1.41	1.64	1.26	—	—	—	1.27	1.38	1.26
Er	—	4.24	—	—	4.22	4.97	4.17	4.82	3.70	—	—	—	3.34	3.66	3.94
Tm	—	0.64	—	—	0.65	0.72	0.64	0.74	0.57	—	—	—	0.52	0.54	0.56
Yb	—	4.15	—	—	4.22	4.59	4.01	4.64	3.58	—	—	—	3.09	3.38	3.56
Lu	—	0.61	—	—	0.62	0.67	0.60	0.69	0.52	—	—	—	0.50	0.53	0.53

TABLE III. – *Whole rock chemistry of selected samples of leptynites, metapegmatites and micrograNites of Serie dei Laghi.*

Rock type	Leptynites					Metapegmatites and micrograNites								Gneiss Minuti
Sample	RB 11A	RB 10	RB 11B	RB 21	RB 13B	RB 5	RB 23A	RB 23C	RB 3	RB 23B	FP 121	FP 134	FP 113	average
SiO_2	76.07	74.54	72.57	72.55	72.07	75.42	74.67	74.24	74.09	73.93	73.78	72.73	71.07	68.15
Al_2O_3	12.78	13.66	14.00	14.26	14.43	14.41	15.64	15.01	15.51	15.56	13.41	14.14	14.75	14.25
Fe_2O_3	0.93	0.83	0.70	0.09	0.77	0.14	0.21	0.30	0.08	0.24	0.80	0.41	0.53	0.78
FeO	2.09	1.93	0.97	2.53	2.13	0.15	0.24	0.65	0.25	0.49	1.28	1.12	1.48	4.12
MnO	0.03	0.06	0.07	0.05	0.05	0.01	0.00	0.01	0.00	0.01	0.03	0.03	0.04	0.08
MgO	0.22	0.51	0.62	0.89	0.62	0.13	0.16	0.50	0.15	0.41	0.53	0.48	0.71	2.25
CaO	1.77	1.99	2.54	1.97	3.20	0.64	1.88	0.64	2.32	1.96	1.47	1.92	1.29	1.61
Na_2O	5.47	5.35	5.52	4.71	4.92	3.10	5.36	5.46	6.10	4.99	2.54	3.44	3.76	3.04
K_2O	0.68	0.63	0.76	2.05	0.86	5.95	2.03	1.76	0.75	2.31	5.02	3.70	3.75	2.95
TiO_2	0.17	0.28	0.37	0.32	0.42	0.02	0.06	0.14	0.03	0.13	0.37	0.18	0.25	0.76
P_2O_5	0.02	0.06	0.08	0.08	0.08	0.25	0.05	0.09	0.04	0.09	0.12	0.08	0.15	0.22
LOI	0.67	0.85	1.16	0.77	0.99	0.66	0.52	1.03	0.79	0.57	0.58	0.55	0.68	1.09
Rb	14	36	20	20	27	98	50	63	24	60	98	126	151	116
Sr	209	224	173	138	329	116	687	285	563	772	128	220	148	226
Ba	669	450	396	643	455	495	1039	706	714	1036	1090	592	575	659
Y	49	53	33	35	42	2	3	4	5	4	23.7	28.9	27.9	33
Nb	13	14	10	12	9.6	0.7	2.7	2	1.1	2.1	6.3	8.7	9.2	13
Zr	241	274	255	247	232	16	56	76	38	78	134	114	85	261
Sc	6	9	7	6	12	0	0	2	2	2	7	7	6	12

continued

TABLE III. – *Continued.*

Rock type	Leptynites					Metapegmatites and micrograntes								Gneiss Minuti
Sample	RB 11A	RB 10	RB 11B	RB 21	RB 13B	RB 5	RB 23A	RB 23C	RB 3	RB 23B	FP 121	FP 134	FP 113	average
V	7	15	20	25	11	0	6	16	0	15	29	25	33	88
Cr	0	0	0	18	0	10	12	13	0	12	25	24	30	71
Co	3	3	3	5	4	0	0	1	1	1	4	3	3	26
Ni	0	25	19	43	0	22	24	27	14	23	0	0	16	41
Cu	37	14	31	0	32	0	0	0	0	0	0	0	0	108
Zn	22	33	50	34	31	0	17	16	11	35	0	0	0	21
Ga	19	20	18	20	18	11	17	18	15	19	12.9	15.3	19.2	1.5
Ge	1.1	1.2	1.2	1.1	1.1	1.8	0.8	0.5	0.9	0.9	2.3	1.3	1.4	1.26
Mo	1	0	—	0	0	1	—	—	—	0	0	0	0	0.91
Sn	2	2	4	3	1	3	1	3	—	1	1	1	3	3
Sb	1	0	0	0	0	—	—	—	0	—	0	0	0	—
Cs	1	1	1	2	1	1	1	1	1	2	2	4	5	9
Hf	7.8	8.5	7.3	7.4	6.2	0.7	1.8	2.3	1.3	2.5	3.5	3.5	2.3	6.7
Ta	1	0.9	0.7	0.9	0.7	0.1	0.2	0.1	0	0.1	0.4	1.3	0.8	0.00
W	0.5	0	0.4	0	0.5	0	0	0	0	0	2	2.1	3.1	1.5
Tl	0.16	0.12	0.15	0.26	0.18	0.51	0.29	0.25	0.14	0.34	0.09	0.22	0.57	0.76
Pb	7	0	0	8	12	71	70	10	31	38	6	0	15	33
Bi	0.23	0	0.3	0.11	0.14	0.09	0	0	0	0	0	0	0.11	0.4
Th	8.5	7	6.6	7.6	4	1.9	3.1	4.9	9	5.2	8.1	17.2	6	13.2
U	4.82	3.54	3.53	2.94	2.95	1.63	1.11	1.3	1.38	1.46	1.05	5.32	2.2	3.04

TABLE IV. – *Rare earth element content of selected samples of Leptynites, metapegmatites and microgranites of Serie dei Laghi.*

Rock type	Leptynites					Metapegmatites and micrograntes								Gneiss Minuti
Sample	RB 11A	RB 10	RB 11B	RB 21	RB 13B	RB 5	RB 23A	RB 23C	RB 3	RB 23B	FP 121	FP 134	FP 113	average
La	32.50	27.30	23.00	31.80	22.60	8.83	9.28	16.00	18.20	14.80	17.97	32.54	14.79	39.53
Ce	67.50	62.60	50.10	68.80	48.50	16.40	18.10	31.20	35.70	31.40	45.05	58.56	29.94	79.10
Pr	8.07	7.20	5.46	7.42	5.93	1.73	1.96	3.33	3.98	3.10	4.17	6.30	3.26	9.11
Nd	32.90	30.80	22.40	30.30	28.20	6.48	7.90	13.80	16.50	12.70	17.00	24.43	13.02	35.77
Sm	7.50	7.60	5.14	6.5	7.01	1.28	1.34	2.33	3.87	2.36	3.80	4.95	3.06	7.15
Eu	1.01	1.44	1.10	1.03	1.54	0.56	0.53	0.72	0.66	0.70	0.92	0.75	0.73	1.38
Gd	7.90	7.47	4.77	5.74	6.72	0.97	0.90	1.50	2.70	1.46	3.44	4.68	3.16	5.72
Tb	1.55	1.51	0.91	1.04	1.26	0.14	0.12	0.18	0.34	0.19	0.65	0.81	0.71	0.98
Dy	9.10	9.17	5.45	6.21	7.53	0.69	0.56	0.84	1.36	0.81	3.98	4.60	4.41	5.48
Ho	1.83	1.90	1.13	1.25	1.51	0.11	0.10	0.14	0.19	0.13	0.86	0.89	0.90	1.04
Er	5.75	6.00	3.66	3.93	4.55	0.34	0.30	0.41	0.47	0.36	2.95	2.86	2.82	3.12
Tm	0.94	0.98	0.60	0.65	0.72	0.05	0.04	0.06	0.05	0.05	0.47	0.44	0.43	0.47
Yb	6.14	6.44	4.00	4.17	5.07	0.34	0.25	0.36	0.28	0.31	3.27	2.90	2.81	2.95
Lu	0.89	0.99	0.63	0.63	0.71	0.05	0.04	0.05	0.04	0.05	0.49	0.43	0.39	0.44

The analyses of the MCMA32-20-16 fine-grained amphibolites, MCMA48-53-55-26, EGCA2 garnet-bearing amphibolites are from Giobbi Origoni *et al.* (1997) and those of the FP121-134-113 Ordovician granitoids are from Pezzotta and Pinarelli (1994).