Per. Mineral. (2007), 76, 5-24
SPECIAL ISSUE: From Petrogenesis to Orogenesis

doi:10.2451/2007PM0006
http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment*, *Archaeometry* and *Cultural Heritage*

Tracing metamorphism, magmatism and tectonics in the southern Alps (Italy): constraints from Rb-Sr and Pb-Pb geochronology, and isotope geochemistry

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Accepted, April 2007

Abstract. — The Variscan metamorphic basement of the westernmost part of the Southern Alps consists of the Ivrea-Verbano Zone and Serie dei Laghi separated by the Cossato-Mergozzo-Brissago Line, a subvertical, late-Variscan ductile shear zone. The paper deals with the complex history of magmatism, deformation, and metamorphism during pre-Alpine and Alpine evolution of the Serie dei Laghi, a metasedimentary sequence hosting older and younger granites.

Rb-Sr whole-rock (WR) isochron (466±5 Ma) and Pb-Pb single zircon evaporation ages (458±6 Ma and 463±4 Ma) on metagranites date the emplacement of the older intrusive series, whereas Rb-Sr muscovite ages (311-325 Ma) approach the Carboniferous metamorphism (331-340 Ma). Rb-Sr WR isochrons (277±8 Ma) and biotite ages (276-281 Ma) on granitic plutons date the emplacement of the younger intrusive series. However, both intrusive series have some rejuvenated biotite ages (up to 170 Ma). Such ages suggest opening of the Sr isotope system, though the timing of this event cannot be determined precisely via Rb-Sr systematics.

The metasediments reached incomplete whole-rock Sr isotopic homogenisation at 288±99 Ma, very close to the age of the Permian event recorded by the granites. Ordovician U-Pb zircon ages have been ascribed to infiltration of residual granitic melts. Moreover, zircons of 1003±2 Ma reflect the presence of old detrital components.

Finally, most of the intrusive, metaintrusive, and metasedimentary rocks plot on well-defined linear correlations in both the initial Pb-Pb and the $^{206}Pb/^{204}Pb(i)$ vs. $^{238}U/^{204}Pb$ diagrams. These correlations, as well as $^{238}U/^{204}Pb$ ratios far higher than those reported for crustal rocks, are interpreted as due to recent opening of the Pb isotope system, which caused either an increase in the U/Pb ratios and/or a rough homogenisation of the Pb isotopes. However, this process affected the Sr isotope system only at the mineral scale (post-Variscan biotite ages), while whole-rock isochrons are still preserved in both metaintrusive and intrusive rocks. An estimated age of 26±10 Ma is obtained by applying an "inverse" approach to the Pb data. Such a widespread process, which involved most of the igneous, metaigneous, and metasedimentary rocks of the Variscan belt, implies a large-scale mobilisation of fluids that could be attained only through the reactivation of the many pre-Alpine faults dissecting the Serie dei Laghi.

Riassunto. — Il basamento metamorfico Varisico della parte occidentale delle Alpi Meridionali è costituito dalla Zona Ivrea-Verbano e dalla Serie dei Laghi, separate dalla Linea Cossato-Mergozzo-

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Brissago, una zona di *shear* duttile subverticale tardo-Varisica. Il presente lavoro si occupa della complessa storia di magmatismo, deformazione e metamorfismo durante l'evoluzione pre-Alpina ed Alpina della Serie dei Laghi, una sequenza metasedimentaria che ospita due serie granitiche di età diversa.

L'età di messa in posto della serie granitica più vecchia è definita da un'isocrona Rb-Sr su roccia totale (RT) (466±5 Ma) e da due età Pb-Pb su zircone (458±6 Ma e 463±4 Ma). Le muscoviti della medesima serie hanno età (311-325 Ma) che si avvicinano a quella del metamorfismo Carbonifero (331-340 Ma). Due isocrone Rb-Sr RT (277±8 Ma) e le età su biotite dei plutoni granitici (276-281 Ma) datano invece la messa in posto della serie intrusiva più giovane. Entrambe le serie, tuttavia, presentano il ringiovanimento di alcune età su biotite (fino a 170 Ma). Tali età suggeriscono la riapertura del sistema isotopico dello Sr, anche se l'età di tale evento non può essere determinata tramite la sistematica isotopica Rb-Sr.

I metasedimenti hanno raggiunto una parziale omogeneizzazione isotopica dello Sr alla scala di roccia totale a 288±99 Ma, un'età che si avvicina a quella dell'evento Permiano registrato dai graniti. Zirconi con età U-Pb Ordoviciane sono stati attribuiti all'infiltrazione, nei metasedimenti, di fusi residuali granitici. Inoltre, zirconi di 1003±2 Ma riflettono la presenza, in tali rocce, di una componente detritica più vecchia.

La maggior parte delle rocce intrusive, metaintrusive e metasedimentarie definiscono delle correlazioni lineari sia nei diagrammi Pb-Pb che in quello $^{206}Pb/^{204}Pb_{(i)}$ vs. $^{238}U/^{204}Pb$. Tali correlazioni, insieme a rapporti $^{238}U/^{204}Pb$ più elevati di quelli comunemente riportati per rocce crostali, sono attribuite alla riapertura dei sistemi isotopici del Pb in tempi recenti, che ha causato un aumento dei rapporti U/Pb e/o una riomogeneizzazione degli isotopi del Pb. Tale processo ha disturbato il sistema isotopico dello Sr solo alla scala dei minerali (età post-Varisiche di alcune biotiti), in quanto le isocrone RT si sono mantenute sia nelle rocce intrusive che in quelle metaintrusive. Applicando un approccio "inverso" ai dati isotopici del Pb si ottiene un'età di 26±10 Ma per l'episodio di riapertura. Un processo così ampiamente diffuso, che ha interessato la maggior parte delle rocce ignee, metaignee e metasedimentarie dello scudo Varisico, implica una mobilizzazione di fluidi su ampia scala che può essere stata raggiunta solo attraverso la riattivazione delle numerose faglie pre-Alpine che attraversano la Serie dei Laghi.

KEY WORDS: *Rb-Sr geochronology, Pb-Pb evaporation geochronology, metamorphism, magmatism, Southern Alps.*

INTRODUCTION

The Southern Alpine domain is located to the south of the Insubric Line, which is part of the Periadriatic Lineament – a major fault system that separates the Europe verging belt, that is, the Alpine Belt proper, from the Africa verging belt, which is the Southern Alpine basement. Pre-Mesozoic basement rocks that have a complex history of magmatism, deformation, and metamorphism dominate both areas. Old structures in the pre-Mesozoic basement were reactivated during the pre-Alpine and Alpine evolution of the Southern Alps (Laubscher, 1990).

The western part of the Southern Alps is subdivided into the Ivrea-Verbano Zone and the Serie dei Laghi. A Variscan ductile shear zone delineates the contact between Ivrea-Verbano Zone and Serie dei Laghi: the Cossato-Mergozzo-Brissago Line (CMBL). The Serie dei Laghi is a metasedimentary sequence intruded by older (Ordovician; Boriani *et al.*, 1982-83) and younger (Permian; Pinarelli *et al.*, 1988) granites. The main metamorphism occurred under amphibolite facies conditions about 331-340 Ma (Boriani and Villa, 1997, Zurbriggen, 1996). In the adjacent Ivrea-Verbano Zone, peak regional metamorphism was reached between 273 and 296 Ma (Pin, 1986; Bürgi and Klötzli, 1990; Vavra *et al.*, 1996; Henk *et al.*, 1997; Boriani and Villa, 1997).

In contrast with other sectors of the Alpine chain (i.e. the Austroalpine), the Southern Alps seem to have been affected only slightly or not at all by the Alpine metamorphism, though brittle fault zones of supposed Alpine age have been described throughout the Serie dei Laghi (Schumacher, 1990). A very low-grade Alpine metamorphism has also been described in the Orobic Alps (stilpnomelane: Crespi *et al.*, 1981).

Sr and Pb geochronometers are based on different minerals (mainly micas and zircon/monazite, respectively), whose thermal stabilities and fluid-induced recrystallisation conditions are both quite different. As a result, the Sr and Pb isotopic systems may yield different responses to metamorphism and deformation, thereby enabling different geological events to be traced in the same crustal section.

The Rb-Sr system is relatively insensitive to rehomogenisation at the scale of whole rock, provided that samples are sufficiently large and well spaced.

Under favourable circumstances igneous protolith ages can still be deduced by means of Rb-Sr whole-rock isochrons, despite severe metamorphic overprints that affected the isotopic systems at the mineral scale. Thus, the Rb-Sr method offers the possibility to determine both the igneous and metamorphism ages for the same samples.

By contrast, Pb isotopic systematics are very sensitive to even low-temperature fluid circulation, which may induce Pb loss and partial or complete resetting of the U-Pb system. The resetting of the U-Pb system, caused by the consequent fluid circulation, may indirectly date the fault zone activity.

In the present paper, new and published isotope data are evaluated to reach a better understanding of the complex magmatic, metamorphic, and tectonic events that took place in the Serie dei Laghi.

Geological setting and previous studies

The Variscan metamorphic basement of the westernmost part of the Southern Alps (Fig. 1) consists of the Ivrea-Verbano Zone and the Serie dei Laghi, which are separated by the Cossato-Mergozzo-Brissago Line (CMBL), a subvertical, late-Variscan ductile shear zone.

The Serie dei Laghi consists of a metapelitic unit, the Scisti dei Laghi, and a mostly meta-arenaceous unit, the Strona-Ceneri Zone (SCZ), exhibiting lower amphibolite facies metamorphism. The two units are separated by a horizon of metasedimentary rocks that includes banded amphibolites with lenses of (retrogressed) peridotite-eclogite: the Strona-Ceneri Border Zone (SCBZ).

Ordovician plutonic rocks, absent in the Ivrea-Verbano Zone, are abundant in the Serie dei Laghi, where they occur in all units as metagranites, though they are particularly abundant within and close to the SCBZ. The metapelitic assemblages include staurolite and kyanite (rarely sillimanite). The main metamorphism under amphibolite facies conditions occurred at a temperature between 540-610 °C and a pressure of 0.6-0.9 GPa (Franz *et al.*, 1996; Giobbi Origoni *et al.*, 1997; Zurbriggen at al., 1997; Henk *et al.*, 1997). $^{39}Ar/^{40}Ar$ geochronologic data on the hornblende indicates ages of 331-340 Ma (Boriani and Villa, 1997). The prograde Variscan metamorphism is locally affected by a weak greenschist facies overprint. Near the CMBL such retrograde mineral assemblages have been overprinted by a static lower pressure event (T=615-580 °C; P=0.23-0.43 GPa; Henk *et al.*, 1997) that generated new andalusite and sillimanite in the metapelites and brought about partial melting in the quartz-feldspatic rocks. The heat for such an event was provided either by contact with the "hot" Ivrea-Verbano Zone juxtaposed along the CMBL, and/or by the intrusive rocks along the fault plane.

A row of late-Variscan granitoid plutons ("Graniti dei Laghi") occurs in the Serie dei Laghi south of the CMBL. A swarm of mafic to acidic dykes and small mafic stocks – consisting mostly of hornblende-diorites (Appinites) occurring in a 1 km-wide belt along the CMBL – accompanies them. The connection of the Appinites to the CMBL is clear. Since the mafic rocks are slightly foliated, they have been interpreted by Zurbriggen (1996), Mulch (1999) and Mulch *et al.* (2002) as due to a syn-mylonitic intrusion. However, the dikes are mostly concordant with the mylonitic foliation, and it is not rare to find crosscutting dikes. Their pattern actually suggests that most of them were intruded after the mylonitisation along the CMBL, in a trans-tensional tectonic environment (Boriani and Giobbi Mancini, 2004).

Near the CMBL shear zone the magmatic rocks often show a more or less pronounced alteration, suggesting a later reactivation of the tectonic line.

Evidence for still younger brittle deformation is found as reactivation of many, mostly subvertical, faults dissecting the Serie dei Laghi. These faults can be roughly attributed to two main systems: (a) an N-S system, especially well-developed in the area N of Verbania, responsible for the sinistral slip of the SCBZ amphibolites; (b) an E-W system roughly parallel to the Cremosina Line (the southern tectonic boundary of Serie dei Laghi), a fault still exhibiting geomorphologic effects in aerial and satellite images (Boriani and Sacchi, 1974). The main lineament belonging to this second system runs South of Cannobio and its Eastern continuation towards "Passo di M.Ceneri", where it becomes a S-verging thrust. S-verging

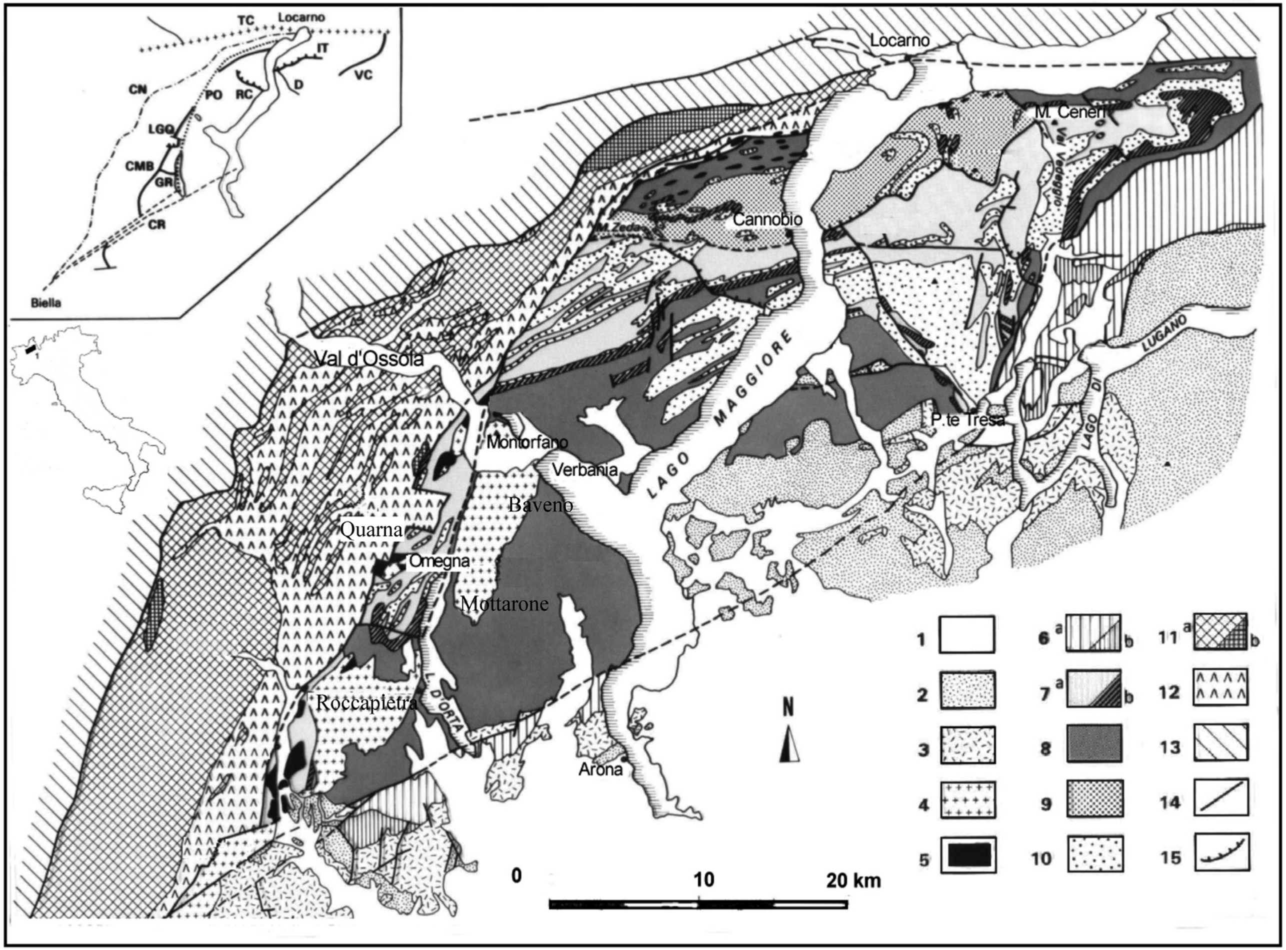

Fig. 1 – Geological sketch-map of Massiccio dei Laghi (modified after Boriani *et al.*, 1990). 1 - Quaternary. 2 - Sedimentary Mesozoic-Cainozoic cover. 3 - Permian volcanic rocks. 4 - Permian granites (“Graniti dei Laghi”). 5 - Permian mafic and acidic stocks and dykes (“Appinites”). 6 – Val Colla Zone: a) Schists, phyllonites, epidote- amphibolites; b) “Gneiss Chiari“. SERIE DEI LAGHI: 7a - Strona Ceneri Zone (SCZ)-meta-arenites, including Cenerigneisses and Gneiss minuti. 7b - Strona Ceneri Border Zone (SCBZ) – amphibolites. 8 - Scisti dei Laghi (micaschists, paragneisses). 9 - Serie dei Laghi rocks with low-P, high-T Permian overprint along the CMBL in Val Cannobina. 10 - Ordovician metagranitoids (MGs). IVREA-VERBANO: 11 - a) Mafic rocks in both granulite and amphibolite facies; b) Ultramafites. 12 - Kinzigites and stronalites (pelitic and semipelitic, high-grade metasedimentary rocks, with minor marble and metabasite intercalations). 13 – Alpine domain. 14 - Faults. 15 – Overthrusts. In the inset: CN = Canavese line; CMBL = Cossato - Mergozzo - Brissago Line; CR = Cremosina line.

backthrusts are also present as minor, but quite widespread, subhorizontal brittle faults, like those N of Verbania and N of Omegna and in many other areas.

The rocks studied here have been described in detail in previous papers from both the geological (Boriani *et al.*, 1990 and references therein; Zurbriggen, 1996) and geochemical (Boriani *et al.*, 1988, 1995; Pezzotta and Pinarelli, 1994; Pinarelli *et al.*, submitted) point of view. They are the following:

1) coarse and fine-grained meta-arenites of the Strona Ceneri Zone (*SCZ-meta-arenites*).

2) amphibolites of the Strona Ceneri Border Zone (*SCBZ-amphibolites*), locally grading into K-feldspar-rich augengneisses (*SCBZ-augengneisses*).

3) kilometre-sized lenses of metagranites-metagranodiorites with minor mafic terms (*MG*).

4) Late-Variscan intrusive rocks (*LVIRs*): granites ("Graniti dei Laghi") and mafic-to-acidic stocks and dykes, consisting mostly of hornblende-diorites (referred to in the regional literature as "Appinites").

Analytical methods

Isotopic measurements were carried out on a Finnigan MAT262 mass spectrometer at the CNR - Istituto di Geoscienze e Georisorse in Pisa.

Sr and Pb were analysed after separation from acid solutions by standard ion-exchange chromatographic techniques. Measured $^{87}Sr/^{86}Sr$ were corrected for mass fractionation by normalisation to $^{87}Sr/^{88}Sr = 0.1194$, and adjusted to a value of $^{87}Sr/^{86}Sr = 0.71025$ for the NBS987 standard. Replicate measurements of NBS987 gave $^{87}Sr/^{86}Sr = 0.710206±11$. Rb and Sr concentrations were determined via Isotope Dilution. The uncertainty is less than 1% for the $^{87}Rb/^{86}Sr$ values. The Pb isotope ratios were corrected for thermal fractionation by a factor of 0.10% per mass unit. The uncertainties at the 95% confidence level were estimated to be less than ±0.08% for $^{206}Pb/^{204}Pb$, ±0.07% for the $^{207}Pb/^{204}Pb$, and ±0.10% for $^{208}Pb/^{204}Pb$. Pb concentrations were determined via Atomic Absorption Spectrometry (uncertainty ±10%), while U and Th contents via Inductively Coupled Plasma Spectrometry (uncertainty ±7%).

Stepwise single-grain zircon evaporation measurements were performed following the technique described in Kröner *et al.* (1992) and Pinarelli and Quercioli (1995). No correction was made for mass fractionation, which is significantly less than the relative standard deviation of the measured $^{207}Pb/^{204}Pb$ ratios, and insignificant at the age range considered in this study. The evaporation temperatures were gradually increased by 20-50 °C steps during repeated evaporation-deposit cycles until no further changes in the $^{207}Pb/^{204}Pb$ ratios were observed. Only data from the high temperature runs or those with no changes in the $^{207}Pb/^{204}Pb$ ratios were considered for geochronological evaluation.

Geochronology

Rb-Sr

Table 1 shows the new Rb-Sr isotope data on whole rocks, together with already published Figures, while Table 2 shows the corresponding mineral data.

Late-Variscan intrusive rocks (LVIRs) and metagranites (MGs)

The "Graniti dei Laghi" is an array of metaluminous granodioritic-granitic plutons occurring from the area of Biella up to the western shore of Lago Maggiore. The studied plutons are the Mottarone-Baveno and the Montorfano, which are not in contact with the CMBL. These plutons are mostly granitic and show little variation in composition. The other two studied plutons (the Alzo-Roccapietra and the small Quarna pluton) are in contact with the CMBL shear zone. They show major mineralogical and chemical variations when approaching the CMBL (Boriani *et al.*, 1988, Burlini and Caironi, 1988), where they become definitely more mafic. The Baveno-Mottarone and Montorfano plutons give rise to two Rb-Sr WR isochrons of 277±7 Ma (Fig. 2a-b), and have biotite ages of 276-281 Ma (Fig. 2d) (Pinarelli *et al.*, 1988). Quarna and Alzo-Roccapietra data points also plot on the 277 Ma isochron (except for one sample from Roccapietra), but have rejuvenated biotite dates of 233-219 Ma (Fig: 2c-d).

TABLE 1 — *Rb-Sr and U-Th-Pb isotope data from Serie dei Laghi rocks*

SAMPLE	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	±2σ	$^{87}Sr/^{86}Sr$ (466 Ma)	Pb ppm	U ppm	Th ppm	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$ (466 Ma)	$^{207}Pb/^{204}Pb$ (466 Ma)	$^{208}Pb/^{204}Pb$ (466 Ma)	Ref.
LVIR (Late-Variscan Intrusive Rocks)																
Granites																
GL1	195	98	5.771	0.73319	4	0.71020	27	4.7	18.3	18.793	15.678	38.705	18.298	15.652	38.079	2,3
GL5	163	20	23.806	0.80545	31	0.71061	38	3.3	18.2	18.593	15.641	38.728	18.347	15.628	38.264	2,3
GL7	44	57	2.237	0.72196	4	0.71305										2
BB1	212	69	8.923	0.74599	11	0.71044	34	3.2	18.0	18.801	15.688	39.010	18.532	15.674	38.519	2,3
BB2	255	25	29.850	0.82468	27	0.70576	41	4.7	21.4	18.803	15.673	38.836	18.476	15.656	38.353	2,3
BB3	234	19	36.128	0.84945	29	0.70552	37	5.3	18.1	18.882	15.674	38.881	18.473	15.653	38.427	2,3
BB5	120	194	1.791	0.71671	9	0.70957	25	2.1	14.0	18.484	15.666	38.895	18.245	15.654	38.378	2,3
GL24	157	155	2.935	0.72117	10	0.70948	27	2.2	15.2	18.680	15.700	39.010	18.447	15.688	38.488	2,3
GL22	185	175	3.062	0.71927	7	0.70707	21	1.5	7.1	18.620	15.690	38.710	18.417	15.679	38.398	2,3
BB9	120	201	1.729	0.71681	5	0.70992	26	4.0	24.6	18.700	15.650	39.460	18.258	15.627	38.578	2,3
Appinites																
BB11	116	259	1.297	0.71477	5	0.70960	16	1.5	11.0	18.609	15.700	39.349	18.340	15.686	38.710	2,3
BB13	133	273	1.410	0.71264	7	0.70702	30	3.0	11.6	18.529	15.683	38.802	18.529	15.683	38.802	2,3
BB14	31	388	0.231	0.70914	5	0.70822	6	0.6	0.7	18.590	15.690	38.750	18.306	15.675	38.642	2,3
GL10	126	314	1.161	0.71095	16	0.70632	9	0.9	2.6	18.815	15.715	38.835	18.530	15.700	38.567	2,3
GL11	180	293	1.779	0.71739	12	0.71030	29	2.1	22.2	18.600	15.672	38.948	18.600	15.672	38.948	2,3
GL12	48	327	0.425	0.70676	17	0.70507	8	0.6	1.3	18.491	15.652	38.631	18.279	15.641	38.482	2,3
AP16	55	287	0.555	0.70926	9	0.70705	5	6.4	3.2	18.539	15.619	38.641	14.915	15.431	38.053	3,4
GL16	20	478	0.121	0.71034	7	0.70984	22	1.3	11.7	18.524	15.721	38.949	18.356	15.712	38.457	2,3
GL18	58	350	0.480	0.71249	5	0.71058	21	1.2	4.2	18.473	15.684	38.574	18.311	15.676	38.390	2,3
GL20	50	390	0.445	0.71149	5	0.70972	6	2.0	8.5	18.540	15.677	38.759	17.594	15.628	37.454	2,3
AP6	67	305	0.636	0.70810	3	0.70557	4	5.4	2.6	18.687	15.677	38.713	14.851	15.478	38.113	3,4
AP11B	38	373	0.295	0.70777	4	0.70660	8	2.0	2.3	18.591	15.634	38.547	17.883	15.597	38.283	3,4
AP24	72	401	0.519	0.70640	2	0.70433	15	2.3	5.9	18.734	15.734	38.893	18.297	15.711	38.529	3,4
AP36	11	140	0.227	0.70811	4	0.70720										4
AP37	22	398	0.160	0.70523	2	0.70459	9	1.1	4.1	18.467	15.659	38.803	18.120	15.641	38.383	3,4

pp = present paper. * = Sr isotope data from Boriani *et al.*, 1982-83. 2 = Pinarelli *et al.*, 1988. 3 = Pinarelli *et al.*, 1993. 4 = Pinarelli *et al.*, 2002

TABLE 1 — *continued...*

SAMPLE	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	±2σ	$^{87}Sr/^{86}Sr$ (280 Ma)	Pb ppm	U ppm	Th ppm	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{206}Pb/^{204}Pb$ (280 Ma)	$^{207}Pb/^{204}Pb$ (280 Ma)	$^{208}Pb/^{204}Pb$ (280 Ma)	Ref.
MG (metagranites)																
LM 80-2	61	378	0.467	0.7071*	3	0.7040	7	9.4	6.1	18.878	15.627	39.594	12.345	15.259	38.231	pp
LM 80-5	154	118	3.785	0.7325*	2	0.7074	22	6.1	14.2	18.784	15.622	38.762	17.452	15.545	37.765	pp
LM 80-6	143	142	2.920	0.7285*	2	0.7091	25	6.0	14.2	18.647	15.633	38.594	17.498	15.568	37.720	pp
LM 80-13	87	192	1.312	0.7175*	2	0.7088	18	2.6	7.5	18.686	15.666	38.636	17.994	15.627	37.994	pp
LM 80-15	59	343	0.498	0.7077*	2	0.7044	11	7.6	8.0	19.127	15.650	39.045	15.778	15.461	37.912	pp
LM 80-21	182	88	6.008	0.7490*	2	0.7091	24	5.1	10.5	18.711	15.640	38.330	17.697	15.583	37.659	pp
SCOG 1	66	208	0.919	0.71560	3	0.70950	17	2.2	6.9	18.570	15.622	38.504	17.952	15.587	37.881	pp
SCOG 2	93	270	0.997	0.71466	4	0.70804	27	8.0	3.9	18.451	15.654	38.391	17.040	15.575	38.170	pp
SCOG 3	226	61	10.796	0.78082	3	0.70914	27	6.9	8.5	18.991	15.667	38.330	17.766	15.598	37.845	pp
SCOG 4	55	252	0.632	0.71285	3	0.70866	20	21.5	26.1	18.909	15.650	38.398	13.759	15.360	36.388	pp
PF71	91	289	0.912	0.71328	2	0.70723	6	1.2	1.5	18.454	15.623	38.501	17.501	15.569	38.118	pp
EL35	200	47	12.412	0.79108	11	0.70867	24	3.4	9.1	18.908	15.720	38.957	18.223	15.681	38.368	pp
Metasediments																
SCBZ-amphibolites																
RB 13A	41	207	0.573	0.70693	82	0.70313		0.42	0.54	18.695	15.609	38.220				5
RB 15	14	212	0.191	0.70606	19	0.70479	6	0.11	0.26	17.956	15.528	37.807	17.870	15.523	37.742	5
VA 25	16	211	0.219	0.70604	35	0.70458	6	0.57	2.27	18.696	15.671	38.419	18.242	15.645	37.838	5
VA 26	10	165	0.175	0.70527	82	0.70410	5	0.27	0.67	18.424	15.707	38.442	18.167	15.692	38.237	5
RB10	36	225	0.463	0.70649	18	0.70342										5
RB11a	14	209	0.194	0.70657	15	0.70528										5
RB21	20	138	0.420	0.71431	11	0.71152										5
SCBZ-augengneisses																
RB 1 RT	225	728	0.895	0.71466	20	0.70872	26	7.2	44.6	18.574	15.630	38.789	17.247	15.555	36.145	5
RB 16	163	427	1.105	0.71319	35	0.70586	68	8.9	33.3	19.573	15.685	38.817	18.936	15.649	38.051	5
GL6	70	370	0.547	0.70877	4	0.70659	36	2.1	6.6	18.330	15.629	38.770	18.165	15.620	38.602	2,3
SCZ-meta-arenites																
EL 8	149	177	2.440	0.72558	33	0.70938	42	3.3	13.0	18.716	15.714	39.264	18.336	15.693	38.782	5
EL 17	130	349	1.079	0.71902	61	0.71186	48	3.2	11.3	18.572	15.688	38.642	18.253	15.670	38.280	5
EL 19	88	238	1.071	0.71755	37	0.71044	31	3.3	19.6	18.985	15.711	39.933	18.463	15.682	38.937	5
EL 21A	130	225	1.674	0.72006	74	0.70895	29	2.9	11.4	18.919	15.686	39.454	18.433	15.659	38.839	5
EL 30	163	150	3.150	0.72584	11	0.70493	25	3.5	10.5	18.790	15.679	38.682	18.117	15.641	38.033	5
EGC 2	121	225	1.558	0.71996	28	0.70962	55	2.8	12.7	18.654	15.703	38.994	18.409	15.689	38.636	5
EGC 9	133	187	2.061	0.72327	12	0.70959	22	4.0	10.6	18.695	15.661	38.744	17.822	15.612	38.000	5
EL 13	124	221	1.626	0.72148	11	0.71068	35	3.8	11.5	18.876	15.692	38.887	18.352	15.662	38.377	5

2 = Pinarelli et al., 1988. 3 = Pinarelli et al., 1993. 4 = Pinarelli et al., 2002. 5 = Pinarelli et al.,submitted

The associated gabbro-noritic to granodioritic dykes (Appinites) plot mostly under the 277 Ma isochron, and have biotite ages of 259-170 Ma (Fig: 2c-d).

The *MG* forms a calc-alkaline intermediate to acidic association. Boriani *et al.* (1982-83) obtained an Rb-Sr WR isochron of 466±5 Ma with thirteen metagranite samples of granodioritic to granitic composition (Fig. 3a). Further Rb-Sr isotope data from Pezzotta and Pinarelli (1994) and the present paper (Table 1) have supplemented the data set to include gabbrodioritic composition. As a whole, most of the data plot on the 466 Ma isochron (Fig. 3a). This value agrees with the U-Pb zircon ages (450 Ma; Köppel, 1974; Köppel and Grünenfelder, 1971). However 5 samples, the most mafic ones (gabbrodiorite to tonalite), plot below the isochron. Muscovite ages of *MG*

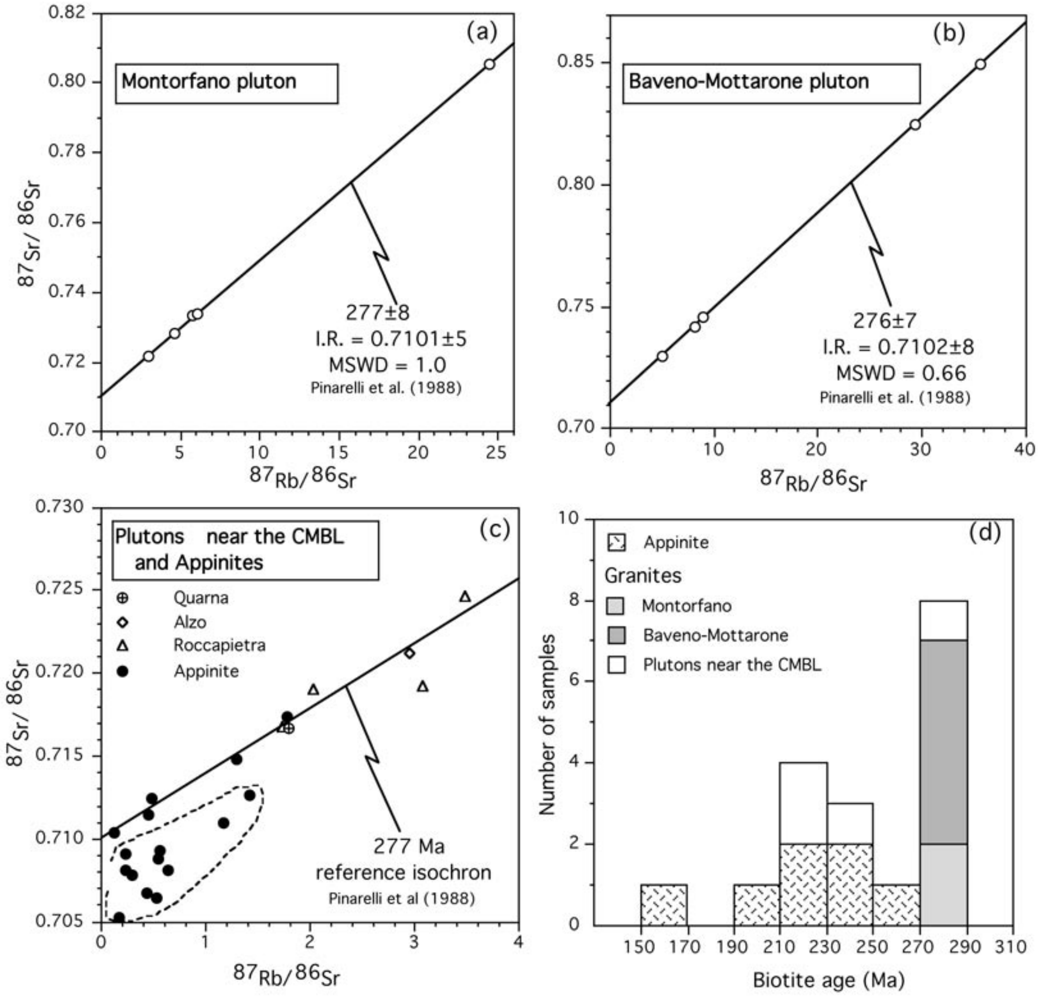

Fig. 2 – $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ isochron diagrams for the *LVIRs* (Pinarelli *et al.*, 1988). a) Rb-Sr whole rock (WR) isochron of the Montorfano pluton. b) Rb-Sr WR isochron of the Baveno-Mottarone pluton. c) Quarna and Alzo-Roccapietra granites, and Appinites. d) Histogram of the biotite dates.

TABLE 2
Rb-Sr mineral ages of MG and LVIR from Serie dei Laghi

Unpublished data						
Sample	Mineral	Rb	Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$	Age±2σ *
MG						
SCOG1	biotite	413	8	162	1.4136±3	305±5
SCOG2	biotite	320	5	185	1.5260±6	310±5
SCOG3	muscovite	637	8	245	1.8520±1	323±3
Data from the literature						
Rock group	Mineral	Ref		Age range	Average±2σ (n)	
MG	muscovites	1		311-325	318±4 (2)	
MG	biotites	1		234-310	266±2 (4)	
LVIR						
Baveno-Mottarone pluton	biotites	2		276-281	279±4 (5)	
Montorfano pluton	biotites	2		274-278	276±6 (2)	
Plutons near the CMBL	biotites	2		219-276	232±38 (4)	
Appinites	biotites	2		170-259	215±27 (8)	

* Age value of the two-point isochron (mica+whole-rock)
1 = Boriani *et al.*, 1982-83; 2 = Pinarelli *et al.*, 1988

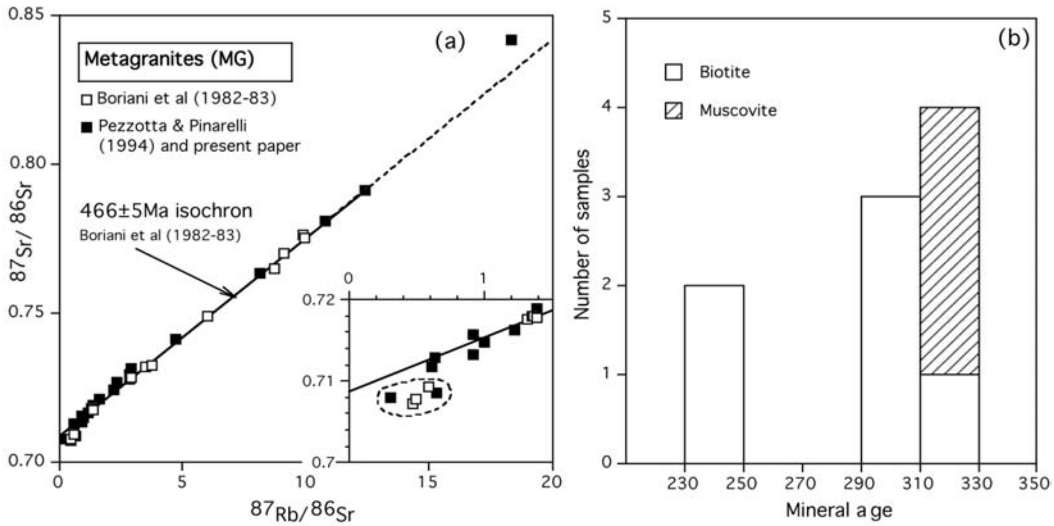

Fig. 3 – $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ isochron diagram for the *MGs*. a) Rb-Sr WR isochron from Boriani *et al.* (1982-83). Most data from Pezzotta and Pinarelli (1994) and the present paper plot on the isochron, except for the mafic samples, which plot below the isochron. b) Histogram of the mineral dates including both new and literature data from Table 2.

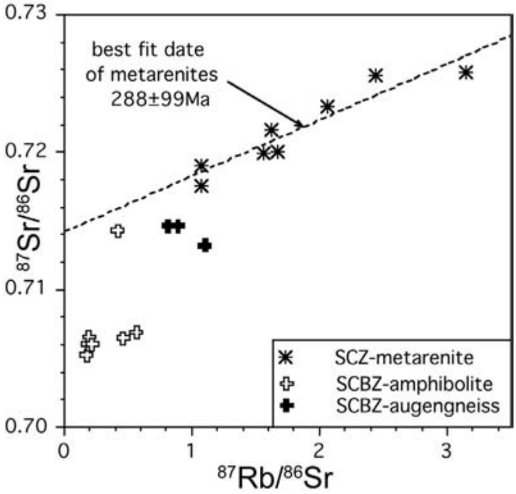

Fig. 4 – $^{87}Sr/^{86}Sr$ vs. $^{87}Rb/^{86}Sr$ isochron diagram for the Serie dei Laghi metasediments. Only the *SCZ-meta-arenites* plot on a roughly linear array, which yields a date of 288±99 Ma, while the other metasediments are scattered.

are in the range of 325-311 Ma (Fig. 3b), a value that approaches the age of the Variscan regional metamorphism (331-340 Ma , §2). Biotite dates, instead, vary between 316 and 234 Ma (Fig. 3b), indicating that their Rb-Sr system has not remained closed.

METASEDIMENTS

In the Rb-Sr isotopic diagram (Fig. 4), the *SCBZ-amphibolites* and *SCBZ-augengneisses* are scattered, and the heterogeneity in Sr isotopes does not allow for estimating an age value. The *SCZ-meta-arenites,* instead, define a linear array. From a statistical standpoint, this line cannot be considered an isochron, owing to the excessive scatter of data points around the best-fit line (MSWD=59). Nevertheless, the obtained best-fit date, 288±99 Ma , is very close to the 280 Ma age of the Permian event recorded by the *LVIRs*.

TABLE 3
Pb isotope data from single-grain zircon evaporation

Sample	Rock type	Morphology	Grain	Evaporation temp. in °C	Mean $^{207}Pb/^{206}Pb$ and 2σ error (a)	$^{207}Pb/^{206}Pb$ age and 2σ error
LM80-2	*MG*	Short prismatic, clear euhedral, brown-yellowish	1	1571	0.05547±52	431±21
			2	1596	0.05554±21	438±14
			3	1622	0.05629±18	465±7
Average of the 3 grains						**458±6**
SCOG4	*MG*	Long euhedral, brown-olive, sharp ends	1	1544	0.05622±32	461±13
			2	1604	0.05631±7	464±3
Average of the 2 grains						**463±4**
N14II	metadiorite fragment in a SCZ-meta-arenite	Short prismatic clear, euhedral dark-brownish	1	1553	0.05600±6	451±2
			2	1595	0.05610±2	456±2
			3	1604	0.05681±8	483±6
Average of the 3 grains						**462±6**
CH1	SCZ-meta-arenite	Euedral, clear	1	1598	0.05545±80	430±31
			2	1625	0.05693±61	491±23
Average of the 2 grains						**460±23**
SFCH4	SCBZ-augengneiss	Short euedral sharp ends yellowish	1	1597	0.07263±7	**1003±2**

(a) Mean ratio corrected for commom Pb where necessary

Pb-Pb single-zircon evaporation

Table 3 and Fig. 5 report the results of stepwise, single-grain zircon evaporation dating. The ages obtained for two *MGs* (458±6 Ma and 463±4 Ma) agree with the Rb-Sr whole-rock isochron age for the same samples. Regarding the metasediments, the low Pb content of zircons from the *SCZ-meta-arenites*, with a large fraction of common lead, caused wide measurement errors. However, the mean value of 460±23 Ma obtained for an *SCZ-meta-arenite* sample, as well as the value of 462±6 Ma for a metadiorite xenolith, agrees with the $^{206}Pb/^{238}U$ concordant age of 465±14 Ma reported by Pinarelli *et al.* (submitted) for the same rocks. Lastly, a sample of the *SCBZ-augengneisses* yielded an age of 1003±2 Ma, which agrees with two U-Pb SHRIMP ages (1026±19 Ma and 1003±18 Ma) reported by Pinarelli *et al.* (submitted) for the Serie dei Laghi metasediments and ascribed by the authors to the Kibaran orogeny in Africa.

Pb isotopes

The Pb isotope data are reported in Table 1. Overall, the present-day Pb isotope ratios of the studied rocks cluster in a roughly circular area, as shown in the lead-lead diagrams of Fig. 6, although the $^{208}Pb/^{204}Pb$ varies more than the other two ratios. The fields of the *LVIRs, MGs* and metasediments overlap each other and plot near the transition between the Upper and Lower Crust, with the exception of two samples: one *SCBZ-amphibolite* (RB15), which projects towards mantle compositions, and one *SCBZ-augengneiss* (RB16), which has distinctly higher $^{206}Pb/^{204}Pb$ than the other rocks. These two "outliers" seem to suggest a larger mantle- and crustal-signature, respectively, than the bulk of the samples.

In the $^{206}Pb/^{204}Pb$ vs. $^{238}U/^{204}Pb$ and $^{208}Pb/^{204}Pb$ vs. $^{232}Th/^{204}Pb$ diagrams in Fig. 7, each rock type has been plotted separately. As a whole, the samples are scattered and do not define any isochrons. Most samples have $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$

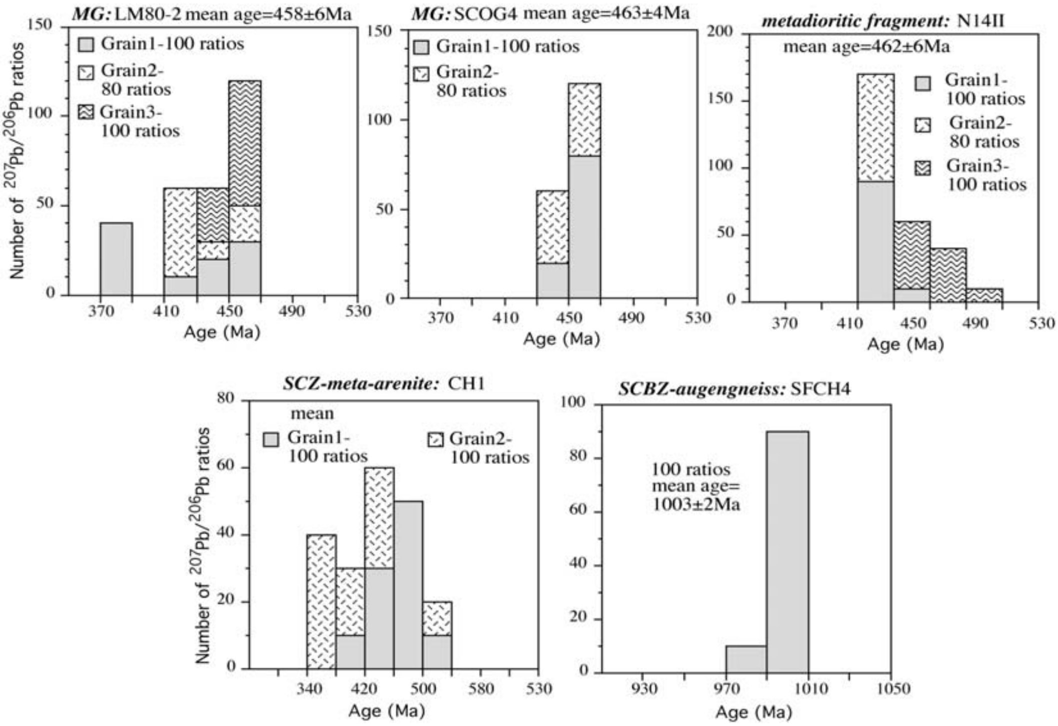

Fig. 5 – Histograms showing the distribution of lead isotope data derived from evaporation of zircon grains from the Serie dei Laghi metagranites and metasediments. Mean ages are given with 2σ errors.

ratios in the range of crustal rocks and show positive correlations with $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$, respectively. By contrast, some samples with very high $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$, far outside the range of crustal rocks, are present in each rock type. These values are associated to Pb isotope ratios in the range of the other samples. This correspondence suggests a secondary increase in the U/Pb and, in part, Th/Pb values in such samples.

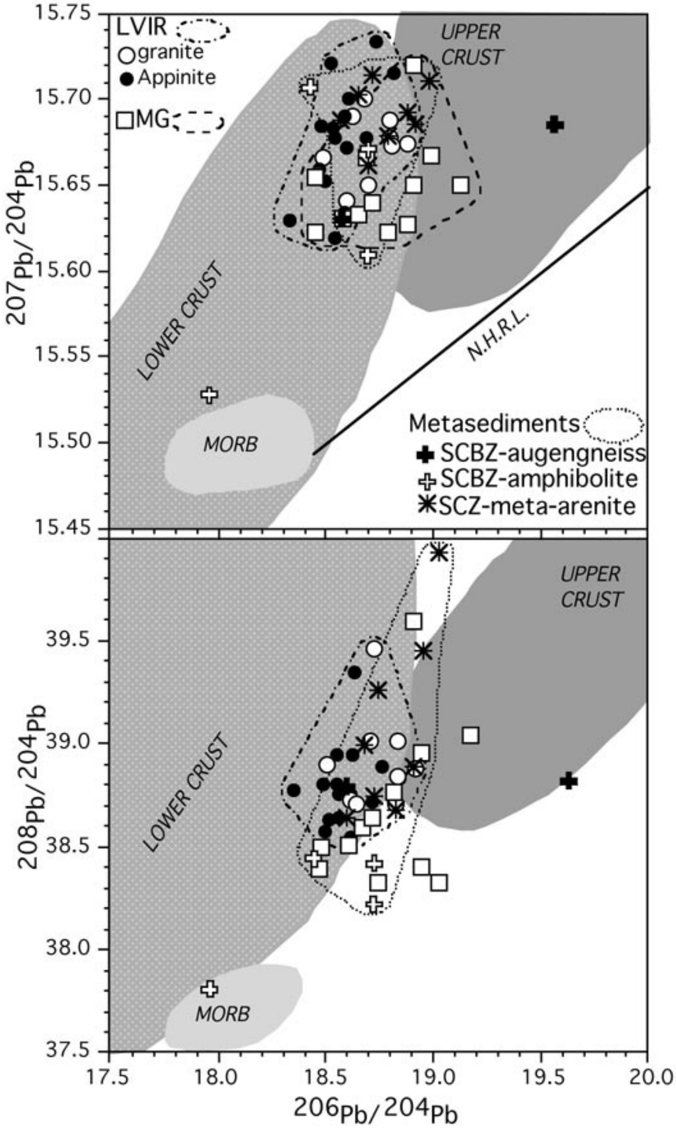

Fig. 6 – $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagrams plotting the studied rocks from Serie dei Laghi. Upper crust, Lower crust and MORB fields are from Zartman and Doe (1981); N.H.R.L. from Hart (1984).

Discussion and interpretation of the age data

In the previous sections we have seen that the *SCZ-meta-arenites* define a linear array at 288±99 Ma in an $^{87}Rb/^{86}Sr$ vs. $^{87}Sr/^{86}Sr$ plot. Even though it cannot be considered an isochron due to the excess scatter of the data points, such a date is however very close to the age of 280 Ma obtained for the granitic intrusions with both whole-rock isochrons and biotites. Therefore, the array at 288 Ma can be considered an indication that the *SCZ-meta-arenites* reached a rough Sr isotopic homogenisation at the whole-rock scale during the thermal Permian event. These same rocks contain zircons of 460±23 Ma. Ordovician zircon ages in these rocks, have already been inferred by Köppel and Grünenfelder (1971) as metamorphism ages, while Boriani and Villa (1997) alternatively interpreted them as dating an Ordovician diagenesis. In addition, the coarse-grained *SCZ-meta-arenites* (Cenerigneiss) often grade into Kfs-bearing augengneisses. Pinarelli *et al.* (submitted) interpreted the augens as the result of infiltration of residual hydrous magmas into the sedimentary protolith of the Cenerigneiss at the time of the emplacement of Ordovician granites. Such an origin may account for the presence in the *SCZ-meta-arenites* of zircons of 460 Ma, which coincides with the emplacement age of the Ordovician granites. Zircons of 1003 Ma from the *SCBZ-augengneisses* instead suggest the presence of old detrital components.

With regard to the *LVIRs*, two different granite plutons yielded the same Rb-Sr whole-rock isochron age. It follows that they behaved mainly as closed systems. The Appinites, which plot below the isochron, were interpreted by Pinarelli *et al.* (2002) as the result of crustal assimilation by a subcrustal magma, with following evolution via

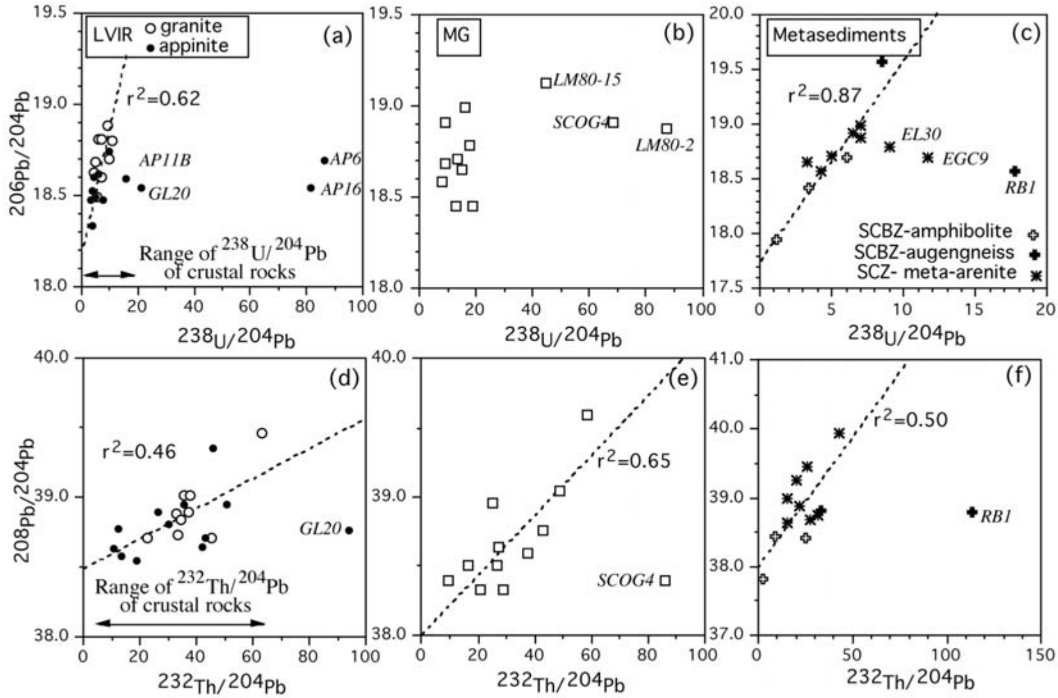

Fig. 7 – $^{207}Pb/^{204}Pb$ vs. $^{238}U/^{204}Pb$ (a, b, c) and $^{208}Pb/^{204}Pb$ vs. $^{232}Th/^{204}Pb$ (d, e, f) diagrams plotting the studied rocks. r^2 = linear correlation coefficient. The ranges of $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ of crustal rocks are from Zartman and Doe, 1981, Taylor and McLennan, 1985, Faure, 1986. Most samples exhibit $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$ values in the range of normal crustal rocks and have positive correlations, while some samples show higher values of both $^{238}U/^{204}Pb$ and $^{232}Th/^{204}Pb$, particularly in the *LVIRs* and *MGs*, where they reach values far outside the range of normal crustal rocks.

assimilation and crystal fractionation to produce more acidic magmas. This process may have caused isotopic heterogeneity of the mafic vs. acidic magmas, which explain why the Appinites fail to plot on the granite isochron. Biotite ages from both the granites occurring near the CMBL and the Appinites (259 to 170 Ma) tend to become younger towards this lineament.

Most of the *MGs* also yielded a well-defined Rb-Sr WR isochron of 466±5 Ma, a value confirmed by ^{207}Pb/^{204}Pb ages from single zircons. Hence, the *MGs* also behaved as closed systems for the whole-rock Sr isotopes, with the exception of a few mafic samples, which plot below the isochron. This heterogeneity may be explained through a process like that envisaged for the *LVIRs*, as they share a similar genesis, from a mantle-derived magma that evolved through crystal fractionation and crustal contamination (Boriani *et al.*, 1995).

The muscovite ages of the *MGs* (325-311 Ma) approach the age of Carboniferous metamorphism, while their biotites are rejuvenated up to 234 Ma.

Actually, in both the intrusive suites of the Serie dei Laghi (*LVIR* and *MG*) part of the biotite ages are rejuvenated, and recorded a re-opening of the Rb-Sr isotopic system following both their emplacement and the Carboniferous metamorphism. This suggests a post-Variscan tectonic history of the basement, although the timing of this event cannot be pinpointed with Rb-Sr systematics.

In this regard, the distribution of the lead isotopes allows taking a step forward. We have seen that the present-day Pb isotope ratios of the rocks studied exhibit a round distribution. By contrast, the initial Pb isotope ratios define for the most part linear correlations in the initial ^{207}Pb/^{204}Pb and ^{208}Pb/^{204}Pb vs. ^{206}Pb/^{204}Pb plots (Fig. 8). Two groups of samples can be distinguished in the diagrams (Fig. 8a to f): one group exhibits a restricted range of initial Pb isotope ratios, comparable to those reported for other Italian pre-Variscan crustal sections (Ivrea-Verbano and Le Serre). The ^{238}U/^{204}Pb and ^{232}Th/^{204}Pb of this first group of samples lie in the value ranges commonly found in crustal rocks (Fig. 7). These samples will be collectively referred to as "Group A" in the following.

A second group of samples show a wider range of initial ^{207}Pb/^{204}Pb and ^{206}Pb/^{204}Pb ratios, with well-defined linear correlations in the diagrams (Fig. 8a, b, c). It is evident from Fig. 8b that the whole MGs belong to this second group. LVIRs and MGs define trends with the same slope (0.006), while the metasediments are more scattered. The ^{208}Pb/^{204}Pb ratios of this second group are, on the whole, less variable than the uranogenic Pb isotope ratios (except RB1, Fig. 8f). They also exhibit ^{238}U/^{204}Pb and, in part, ^{232}Th/^{204}Pb values far higher than those reported for crustal rocks (Fig. 7). The above samples will be collectively referred to as "Group B" in the following.

Linear correlations in the initial Pb-Pb diagrams, like those exhibited by the "Group B" rocks, are unexpected in homogeneous undisturbed rock series. In principle, they could be the result of a two end-member mixing. But in the case of the Serie dei Laghi rocks, the less radiogenic end member of the mixing would have unrealistically low Pb isotope composition (Fig. 9). Indeed, such a hypothetical end-member cannot be traced back to any of the known crustal or mantle reservoirs. Nor can it be modelled by any of the two-stage evolution curves, even assuming unrealistically high μ values (time-integrated ^{238}U/^{204}Pb ratio of the source reservoir).

Also, a linear array in the Pb-Pb diagrams could represent a secondary isochron. However, it is evident from Fig. 9 that the data presented do not fit such a hypothesis. Indeed, the line defined by the Serie dei Laghi rocks does not converge towards either the origin of the secondary isochrons, or the Pb evolution curves.

In an attempt to clarify the significance of the above array, let us take into consideration the equation for the radioactive decay in the form used for the age-recalculation. Here, the initial (calculated) Pb isotope ratio is a function of: 1) the present-day (measured) Pb isotope ratio, 2) the U/Pb ratio, and 3) t. For fixed t and measured Pb isotope ratio, higher U/Pb ratios would result in lower calculated initial Pb isotope ratios. In a homogeneous rock series with restricted ranges of Pb isotope ratios and U/Pb, a progressive increase in the U/Pb, due, for instance, to secondary fluid circulation, would produce progressively decreasing calculated initial Pb isotope ratios. The corresponding rock samples would define straight lines in the Pb-Pb diagrams (as in Fig. 8). A similar conclusion can be reached for the Th-Pb system as well.

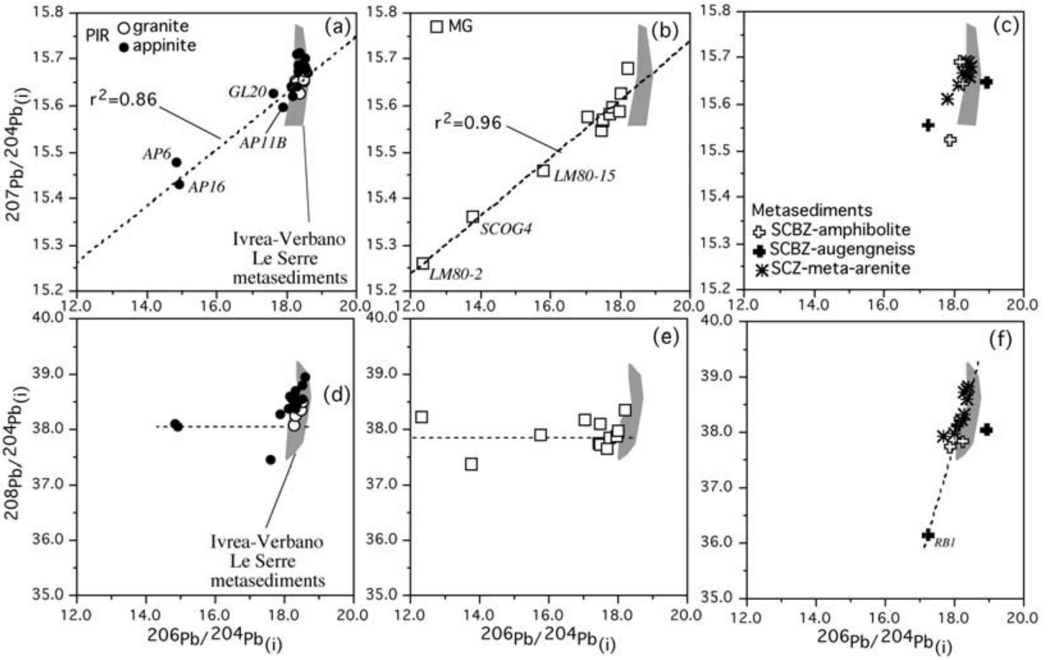

Fig. 8 – $^{207}Pb/^{204}Pb_{(i)}$ and $^{208}Pb/^{204}Pb_{(i)}$ vs. $^{206}Pb/^{204}Pb_{(i)}$ diagrams plotting the studied Serie dei Laghi rocks. r^2 = linear correlation coefficient. The initial Pb isotope ratios of *LVIRs* and *MGs* were recalculated at their emplacement age (280 Ma and 466 Ma, respectively); the metasediments were also recalculated at the age of 466 Ma. Most samples mainly overlap the field of other pre-Variscan crustal sections (shaded area: Ivrea-Verbano and Le Serre: Caggianelli *et al.*, 1991; Cumming *et al.*, 1987). Some samples show a wider range of initial $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ ratios, with well-defined linear correlations.

Accordingly, the low, well-correlated initial Pb isotope ratios of the “Group B” rocks could be the result of an increase in either the U/Pb and/or Th/Pb ratios. It remains to be clarified whether this process is primary or secondary. U-Th enrichment by magmatic crystal fractionation could produce a primary increase in the U/Pb and Th/Pb ratios. Also, mafic rocks with low Pb content could show variable high U/Pb ratios. But the “Group B” rocks do not show any correlations between initial U/Pb ratios and other chemical parameters indicative of the degree of differentiation (note, for instance, the $^{238}U/^{204}Pb$ vs. SiO_2 plot in Fig. 10). In addition, if the increase in the U/Pb ratios was primary, even if extreme, without any secondary opening of the isotope systems, the calculated initial Pb isotope values should still be significant.

To investigate the hypothesis of secondary modifications of U/Pb, the following data were plotted into the initial $^{206}Pb/^{204}Pb$ vs. $^{238}U/^{204}Pb$ plot

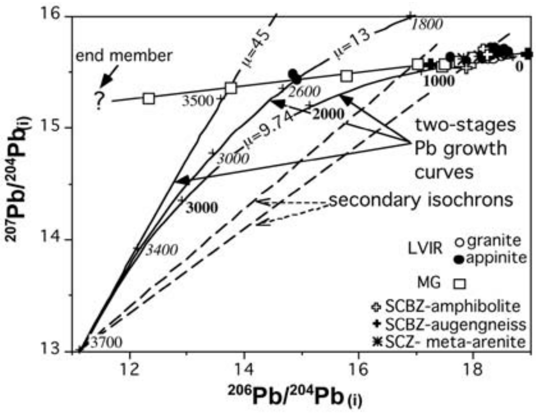

Fig. 9 – $^{207}Pb/^{204}Pb_{(i)}$ vs. $^{206}Pb/^{204}Pb_{(i)}$ diagram plotting, besides the studied Serie dei Laghi rocks, three examples of two-stages Pb growth curves (Stacey and Kramers, 1975) based on different μ values (time-integrated $^{238}U/^{204}Pb$ ratios of the source reservoir), and two examples of secondary isochrons. The numbers along the curves are the model ages in Ma.

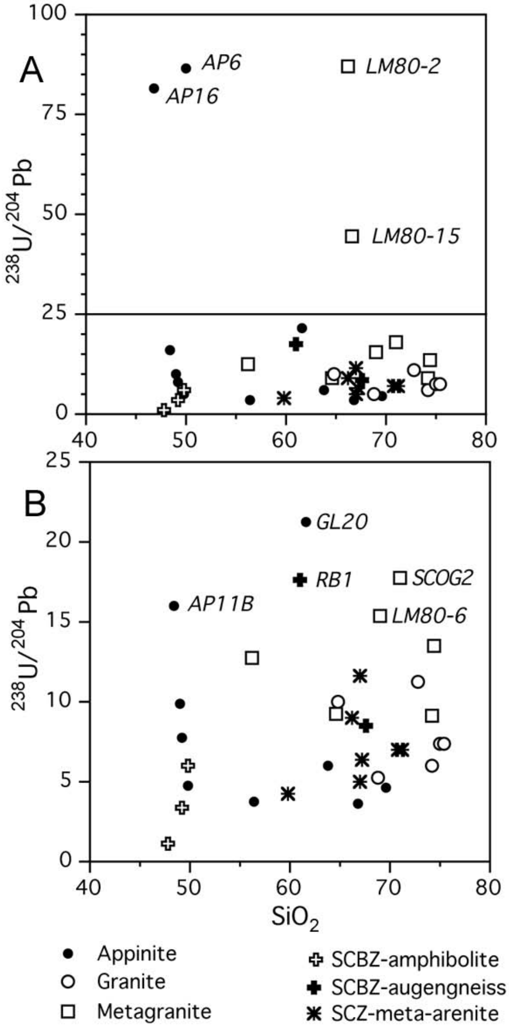

Fig. 10 – (a) $^{238}U/^{204}Pb$ vs. SiO_2 diagram plotting the studied Serie dei Laghi rocks. (b) The same diagram with enlarged scale of the ordinates.

in Fig. 11: i) the mean values of the *SCZ-meta-arenites* and *LVIRs* belonging to "Group A". Their restricted ranges of initial Pb isotope, $^{238}U/^{204}Pb$, and $^{232}Th/^{204}Pb$ ratios, similar to those reported for other Italian pre-Variscan crustal sections, suggest that they may represent, as closely as possible, the corresponding rocks before the system's opening. ii) The rocks hypothetically affected by a secondary increase in the U/Pb ratios: *SCZ-meta-arenite*, *SCBZ-augengneiss*, and *LVIR* samples belonging to "Group B", and all the *MG* samples.

In Fig. 11a, the $^{206}Pb/^{204}Pb_{(i)}$ of *LVIRs* were calculated at 280 Ma, while those of *MGs* and metasediments at 466 Ma. Two separate linear arrays with different slopes are evident: the line with the lesser slope is defined by the *LVIRs*, while the line with the greater slope is defined by the *MG + SCZ-meta-arenites + SCBZ-augengneisses*. It is obvious that the slope of the line is proportional to the age to which the $^{206}Pb/^{204}Pb$ were recalculated. Accordingly, if the Pb isotope ratios of *MG + SCZ-meta-arenites + SCBZ-augengneisses* are computed for 280 Ma, instead of 466 Ma , the obtained initial values plot on the same line as the *LVIRs* (Fig. 11b).

There should therefore be a value of t, between 466 Ma and the present, for which the initial Pb isotope ratios of the samples plot on a horizontal line in the diagram in Fig. 11b: such t represents the age at which the samples acquired a homogeneous Pb isotope composition and variable U/Pb ratios, without any correlation between the two parameters. This is the age at which the rocks underwent a secondary modification. Undoubtedly this episode was very recent, because the U-Pb chronometer did not have time to accumulate, given the newly acquired U/Pb ratios, enough radiogenic Pb to yield an isochron in the diagrams of Fig. 7.

To estimate this age, we have applied an "inverse" approach to equation for the decay of ^{238}U in ^{206}Pb, by means of an iterative, non-linear, least-square minimisation. The data set used is that plotted in Fig. 11. We have progressively varied t, for each pair of present-day $^{206}Pb/^{204}Pb$ and $^{238}U/^{204}Pb$ ratios, until the calculated initial Pb isotope ratios of the data set lined up as closely as possible on the horizontal in the diagram (Fig. 11c). In this way we obtained an age of 26±10 Ma (2σ) with initial $^{206}Pb/^{204}Pb$ of 18.63±0.33. However, the isotope heterogeneity still present both within and among the different rock groups (inset in Fig. 11c), suggests that the isotope reset has not been completed and that the age of 26 Ma should only be considered an approximate estimate of the true age of the process.

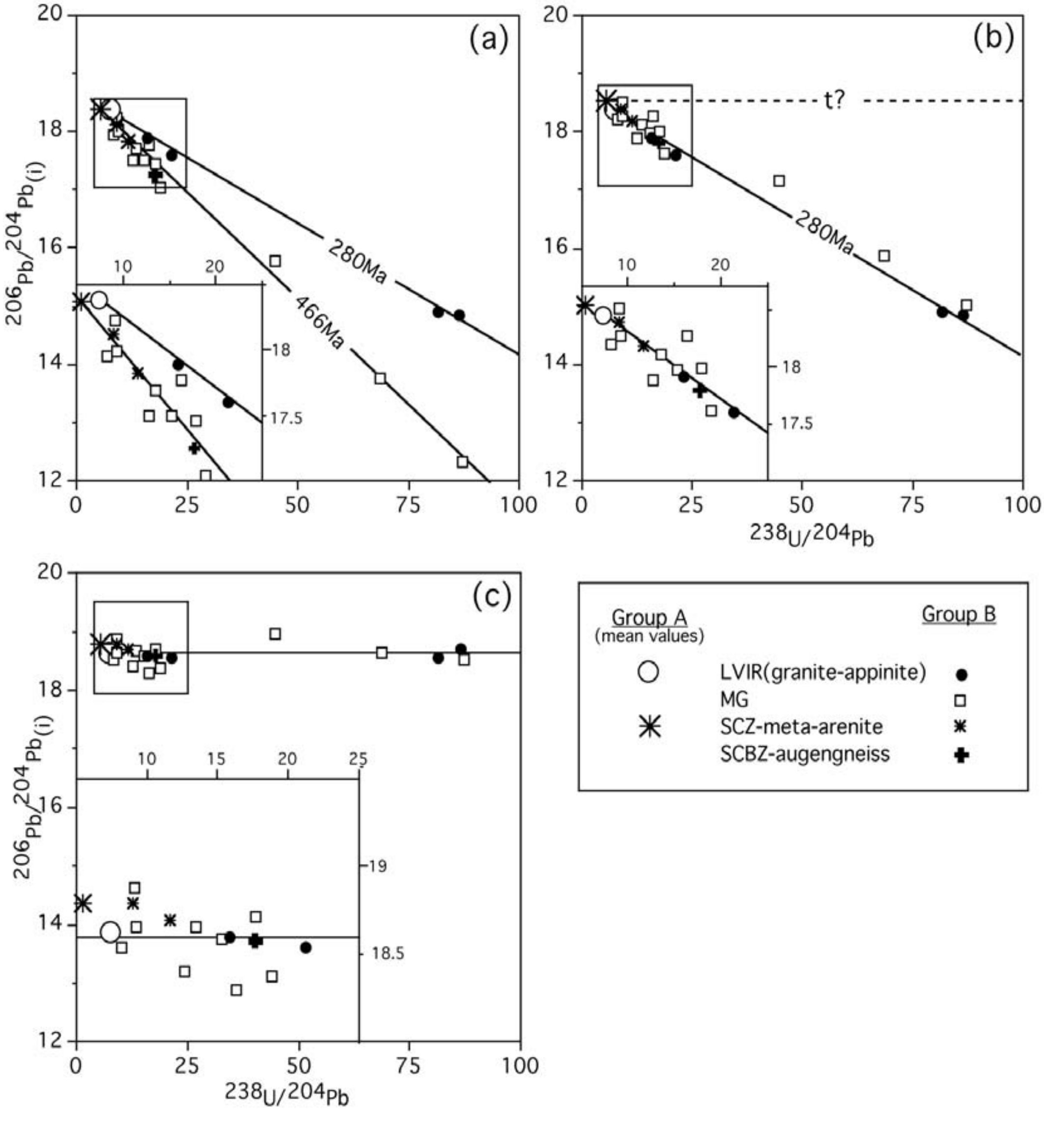

Fig. 11 – $^{206}Pb/^{204}Pb$ vs. $^{238}U/^{204}Pb$ diagrams in which the following data were plotted: i) The mean values of the "Group A" *SCZ-meta-arenites* and *LVIRs*. Such mean values may represent the original values of the respective rocks before the opening of the isotope system. ii) The rocks hypothetically affected by a secondary increase in the U/Pb ratios: *SCZ-meta-arenite, SCBZ-augengneiss*, and *LVIR* samples belonging to "Group B", and all the *MG* samples.
a) The initial isotope ratios of *LVIRs* were recalculated at 280 Ma, those of *MGs* and metasediments at 466 Ma. The *LVIR* and *MG* + metasediments plot on two separate lines with different slopes.
b) The initial isotope ratios were recalculated at 280 Ma for all samples, which now plot along the same line.
c) The initial isotope ratios were recalculated at the age of re-opening of the U-Pb isotope systematics, 26 Ma. The Pb isotope composition acquired at that age by each sample is independent of its U/Pb ratio; therefore the samples plot near the horizontal.

Summary and conclusions

The Serie dei Laghi is a metasedimentary sequence hosting older and younger granites. The main metamorphism occurred under amphibolite facies conditions about 340 Ma ago.

The WR Rb-Sr emplacement age of the older intrusive series, *MG,* is 466±5 Ma, in agreement with their Pb-Pb single zircon evaporation ages (458±6 Ma and 463±4 Ma). Muscovite ages (325 Ma) approached the Carboniferous metamorphism.

The WR Rb-Sr emplacement age of the younger intrusive series, *LVIR*, is 277±8 Ma, in agreement with biotite ages (276-281 Ma).

However, part of biotite ages from the *LVIRs* tends to become younger towards the CMBL (259 to 170 Ma), as do the biotite ages throughout the *MGs* (300-234 Ma). Such ages are intermediate between the emplacement (or metamorphism in the case of *MGs*) age and a more recent age of opening of the Sr isotope system, although the timing of this event cannot be pinpointed via Rb-Sr systematics.

As regards the metasediments, they attained approximate Sr isotopic homogenisation during the thermal Permian event, with an Rb-Sr WR date of 288±99 Ma. Ordovician Pb-Pb zircon ages may be ascribed to both the diagenesis and the infiltration of residual granitic melts. Moreover, zircons of 1003±2 Ma reflect the presence of old detrital components.

When the Pb isotopes are taken into account, a group of samples from all the rocks of the Serie dei Laghi (except the *SCBZ-amphibolites)* exhibit well-defined linear correlations in both the initial Pb-Pb and the $^{206}Pb/^{204}Pb_{(i)}$ vs. $^{238}U/^{204}Pb$ diagrams, with large variations in the parameters. In addition, they show $^{238}U/^{204}Pb$ and, in part, $^{232}Th/^{204}Pb$ values far higher than those reported for crustal rocks. These Pb isotope patterns were interpreted as due to the opening of the isotope system in recent times, which caused a rough homogenisation of the Pb isotopes and modified the U/Pb and Th/Pb ratios. An "inverse" approach applied to the $^{206}Pb/^{204}Pb_{(i)}$-$^{238}U/^{204}Pb$ linear correlations allowed for estimating an approximate age of 26±10 Ma for this process.

This secondary event has affected not only the rocks occurring near the CMBL (Appinites), but also the other metaintrusive and metasedimentary rocks of the Variscan belt. Such a widespread process presupposes a large-scale mobilisation of fluids that could be attained only through reactivation of the many faults dissecting the Serie dei Laghi, such as for instance the Cremosina line, which shows a geomorphologic effect in the aerial and satellite images.

Acknowledgements

The authors wish to thank A. Kröner for his kind help in applying the single-grain zircon evaporation method at IGG in Pisa. They are also indebted to R. Petrini and C. Villaseca for their helpful comments on the manuscript.

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