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COMPOSITION, LEVEL OF INTRUSION AND AGE OF THE « SERIE DEI LAGHI » ORTHOGNEISSES (NORTHERN ITALY - TICINO, SWITZERLAND)

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RIASSUNTO. — La « Serie dei Laghi » è un'unità a medio grado metamorfico del basamento Sudalpino, che può essere divisa in due parti: « Strona-Ceneri » (per lo più metapsammiti) e « Scisti dei Laghi » (per lo più metapeliti) separate in genere da metabasiti. Entrambe contengono intercalazioni di ortogneiss; questi derivano da intrusivi da tonalitici a granitici. Tredici campioni di ortogneiss definiscono un'isocrona di 466 ± 5 m.a. (rapporto iniziale dello Sr = 0,7087). L'età del metamorfismo è intorno a 325 m.a. (età Rb/Sr delle miche) e l'età del raffreddamento decresce verso l'« Ivrea-Verbano ». I caratteri chimici indicano una differenziazione magmatica con miscuglio variabile di cumulus e intercumulus nei diversi stadi di frazionamento. Al momento dell'intrusione gli « Scisti dei Laghi » (sicuramente già metamorfici) giacevano sotto la debolmente metamorfica « Strona-Ceneri ». Quest'ultima contiene gneiss occhiadini, che derivano dai prodotti dell'estremo frazionamento del magma, nonchè pegmatiti laminate, che ancora conservano, nelle rocce incassanti, relitti di un metamorfismo di contatto.

ABSTRACT. — The « Serie dei Laghi » is a medium grade metamorphic unit of the Southern Alps that can be split in two parts: « Strona-Ceneri » (mostly metapsammites) and « Scisti dei Laghi » (mostly metapelites) generally separated by metabasites. Both contain orthogneiss intercalations. These derive from tonalite-to-granite intrusives. Thirteen samples define an isochron of 466 ± 5 m.y. (initial Sr ratio = 0.7087). The age of metamorphism is around 325 m.y. (Rb/Sr muscovite ages), with cooling ages decreasing towards the « Ivrea-Verbano ». The chemical characters indicate a differentiation with variable mixing of cumulus and intercumulus in the various fractionation stages. At the moment of their intrusion the « Scisti dei Laghi », which were already metamorphosed, underlay a weakly metamorphosed « Strona-Ceneri ». The latter contains augen-gneisses, that derive from the extreme fractionation products of the intrusions, and strongly laminated pegmatite dykes with relics of contact metamorphism in their country rocks.

Introduction

The « Serie dei Laghi » is a metamorphic unit of the South-Alpine basement of the Central and Western Alps; the series consists of probably late Precambrian or early Palaeozoic sediments that were subjected to repeated deformational and metamorphic actions and were the seat of igneous activity at different times during the Paleozoic era. Basically the series was not involved in the Alpine orogeny, whose very marginal effects can be ignored for the purpose of this paper; the authors intend this paper to be a contribution to the understanding of the palaeozoic history of this part of the continental crust.

The area under consideration is that extending E and W of Lago Maggiore where the « Serie dei Laghi » is known also as « Ceneri Zone » (REINHARD, 1953) or « Strona-Ceneri » (SCHMID, 1967).

The « Serie dei Laghi » was divided by BORIANI (1970) in two subunits: « Scisti dei Laghi » mostly composed by pelitic and semipelitic metasediments, « Strona-Ceneri » mostly composed by metapsammites. The two subunits, W of Lago Maggiore are separated by a continuous layer of metabasites.

The relationships between the various rock types of the « Serie dei Laghi » were long a matter of uncertainty so that, in his paper of 1964 (a conclusive work of a period of field and petrographic studies that lasted from 1925) REINHARD wrote « ... offenbar keine scharfen Grenzen zwischen den verschiedenen Gneisarten bestehen »; then,

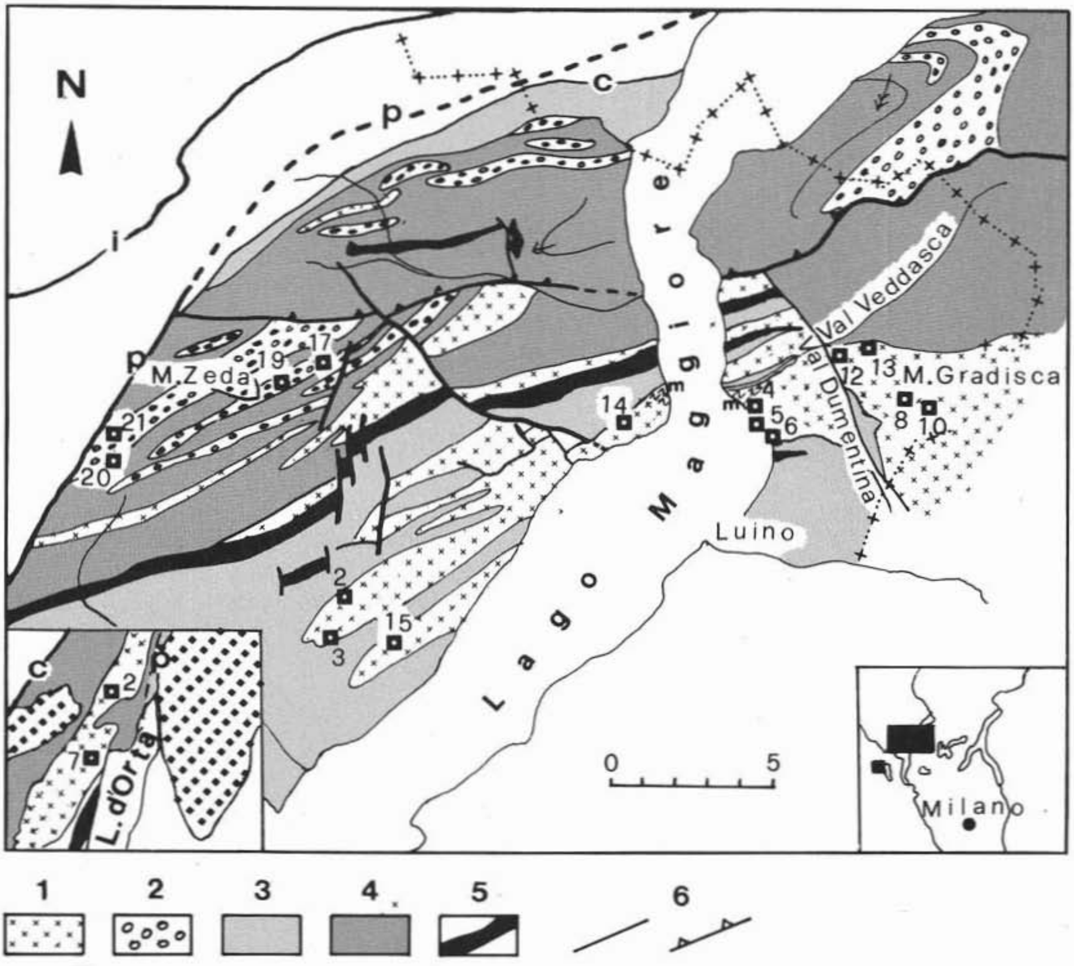

Fig. 1. — Sketch map of the « Serie dei Laghi » (Southern Alps) west and east of Lago Maggiore and location of the samples used for age determinations. - 1) Hornblende-bearing and hornblende-free orthogneisses; 2) Augengneisses; 3) « Scisti dei Laghi »; 4) « Strona-Ceneri »; 5) Metabasites; *m*) Migmatites; 6) Faults and overthrusts. *i* = Insubric line; *p* = Pogallo line; *c* = Cossato-Mergozzo-Brissago line.

introducing the «Orthogneistypus»: «...keine genetische Deutung verbunden sein ».

The Swiss Authors of that period looked at the variety of metamorphic rock types as at a metasedimentary series that suffered a metamorphism with variably deep textural transformation and various degrees of soakage by feldspathizing palingenetic solutions. In REINHARD'S (1964) opinion, no large scale melting nor mobilization took place. In BACHLIN'S (1937) opinion the importance of mobilization was greater: for example he saw the explanation of the different tectonic style of the « Nördliche Injectionszone » from that of the « Südliche Injectionszone » in an invasion of the former by a true melt that increased its bulk mobility, whilst the latter was only permeated by granitizing solutions. BORIANI (1970) and BORIANI et al. (1977) used the term *orthogneiss* in the original Rosenbusch's meaning, i.e. an igneous rock that was later subjected to a regional metamorphism; they recognized intrusive bodies of granite-to-tonalite composition with an inferred Ordovician age of intrusion, that later underwent regional metamorphism and became gneisses. The old intrusive bodies, now transformed into elongated intercalations within the metasedimentary rocks, were described only in the « Scisti dei Laghi » of the area W of Lago Maggiore.

Field and petrological work has been carried out by E. ORIGONI GIOBBI since 1978 on the zone E of the Lake in the area between Luino and Val Veddasca. Scopes of her investigation were:

a) to check the possibility of extending E of Lago Maggiore the distinction, recognized on the western shore, of the «Serie dei Laghi» into two subunites separated by an amphibolite horizon;

b) to investigate the relationships between orthogneisses and country rocks, however, some 2 Km E of the coast, the amphibolites are abruptly cut off by the Val Dumentina Fault and E of that point, they no longer constitute the divider between the two subunites.

The orthogneiss body of M. Gradisca seems to pass gradually into the fine grained paragneisses of Val Veddasca (the *Hornfelsgneisse* or *Biotithornfelsgneisse* of the Swiss Authors) through an undefinable band of biotite-plagioclase gneiss.

The orthogneiss retains its sharp contacts towards the micaschists and paragneisses occurring in Val Dumentina and belonging,

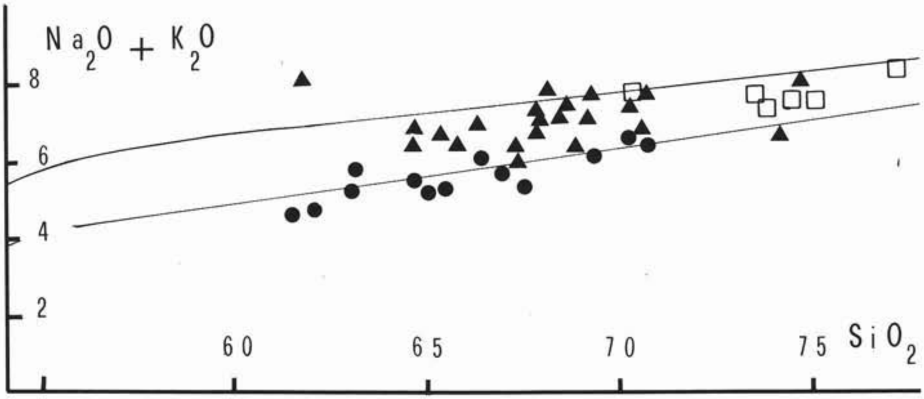

Fig. 2. — Alkali/silica diagram for the « Serie dei Laghi » orthogneisses. *Circles* = hornblende-bearing; *triangles* = hornblende-free; *open squares* = augen-gneisses.

since they were described as mostly transitional by the Swiss Authors;

c) to improve the knowledge of the structural setting of the zone in comparison with the already studied one;

d) to acquire systematic petrochemical and petrographic data on the orthogneisses.

Having achieved all these targets, the new data compelled us to undertake a new survey on the previously investigated western area and to request the collaboration of A. DEL MORO (Istituto di Geocronologia e Geochimica Isotopica del C.N.R. di Pisa).

As one can see from the map of fig. 1, on the eastern shore of the Lake the amphibolites are not present as an individual horizon but are tectonically repeated twice in the sequence near S. Rocco di Campagnano. Nevertheless they retain their role of divider between the rocks belonging to the «Scisti dei Laghi» and «Strona-Ceneri»; beyond any doubt, to the «Scisti dei Laghi».

Our idea that « Scisti dei Laghi » and « Strona-Ceneri » were separated all along their contact by metabasites was disproved. We had to concede that the Ordovician intrusives also penetrated the fine-grained gneisses of « Strona-Ceneri ».

The « Strona-Ceneri », described by BORIANI (1970), BIGIOGGERO and BORIANI (1975), BORIANI et al. (1977), consists of unquestionable metasediments (*fine-grained gneisses* and « *Cenerigneisses* »), and *augengneisses* of migmatitic appearance and ill-definable biotite-plagioclase gneisses that could not be attributed with care to an igneous or sedimentary domain on account of their variable characters. The only rock type of the « Strona-Ceneri » that clearly displays an igneous origin is represented by the laminated pegmatite dykes within the fine-grained gneisses. We interpreted these

TABLE 1

Chemical analyses and mesonorms (MIELKE & WINKLER, 1979) *of the hornblende-bearing orthogneisses of the « Serie dei Laghi »*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SiO_2	66.31	69.10	64.47	67.38	65.24	64.70	66.65	65.19	63.07	62.02	61.22	63.06	70.35	70.68
TiO_2	.41	.28	.58	.45	.52	.54	.37	.51	.50	.63	.67	.46	.30	.20
Al_2O_3	16.29	14.84	16.12	16.18	15.97	16.30	16.14	15.85	16.57	16.37	17.00	16.26	15.35	13.43
Fe_2O_3	.81	.57	.97	1.54	1.25	2.04	.84	1.41	1.61	3.51	2.26	1.64	.70	.67
FeO	2.99	2.00	4.17	2.94	3.52	3.06	2.58	3.14	2.83	2.14	3.75	2.68	1.89	2.10
MnO	.07	.06	.10	.08	.08	.09	.06	.05	.07	.09	.08	.00	.00	.00
MgO	2.47	1.75	2.16	1.46	2.09	2.15	2.34	2.16	2.15	2.38	2.71	3.02	.92	1.87
CaO	4.18	3.22	4.35	3.96	4.34	4.56	3.80	3.71	4.05	4.18	4.72	4.45	2.77	3.31
Na_2O	4.25	3.88	2.72	2.72	2.63	2.65	3.69	2.84	3.90	2.79	2.71	3.83	3.82	3.88
K_2O	1.68	2.18	2.57	2.55	2.57	2.43	1.85	2.97	1.89	2.07	1.90	2.38	2.75	2.43
P_2O_5	.04	.01	.02	.02	.03	.02	.03	.11	.15	.13	.13	.09	.38	.14
H_2O	.92	1.53	1.16	.89	1.05	1.26	1.15	1.87	2.23	2.71	2.34	2.02	1.21	1.04
TOTAL	100.42	99.42	99.39	100.17	99.29	99.80	99.50	99.81	99.02	99.02	99.49	99.89	100.44	99.75
Ap	.09	.02	.05	.05	.07	.05	.07	.26	.36	.31	.31	.21	.89	.33
Mt	1.17	.83	1.42	.00	1.83	.00	1.22	2.05	.00	.00	.00	.00	1.01	.97
Hm	.00	.00	.00	1.54	.00	2.04	.00	.00	1.63	3.54	2.27	1.64	.00	.00
Il	.39	.27	.55	.43	.50	.51	.35	.49	.48	.60	.64	.44	.28	.19
Ab	35.85	33.06	23.18	23.00	22.44	22.49	31.41	24.10	33.36	23.87	23.07	32.48	32.21	32.95
Or	.68	6.41	4.97	7.54	6.21	5.05	2.43	9.01	2.22	3.55	.00	5.24	11.88	12.30
An	20.18	16.00	21.58	19.48	21.48	22.53	18.75	17.72	19.30	20.08	22.16	18.76	11.20	8.56
Bi	14.87	10.56	17.03	12.47	14.86	15.27	13.75	13.88	14.77	14.05	18.99	14.08	7.08	3.16
Hb	.35	.35	.35	.35	.35	.35	.35	.35	.35	.00	.24	4.54	4.54	11.20
Qz	26.10	31.49	29.73	33.31	31.11	30.33	30.19	29.71	25.14	29.57	28.41	21.49	32.59	29.90
C	.00	.25	.99	1.78	1.04	1.05	1.22	1.47	1.09	2.26	2.31	.00	1.94	.00
REST.	.32	1.12	.51	.41	.48	.66	.61	1.32	1.67	2.17	1.65	1.36	.92	.68

1) LM 80-2: Pian Nava-Esio (67709230); 2) LM 80-3: Pian Nava-Manegra (67709110); 3) LM 80-8: Pradecolo-M. Gradisca, q. 910 (83709912); 4) LM 80-10: Pradecolo-M. Gradisca, q. 1000 (84309900); 5) LM 80-12: Runo-Curiglia road (83009890); 6) LM 80-13: Runo-Curiglia road (83209978); 7) LM 80-15: M. Segletta road (70609506); 8) VLU 45: M. Gradisca (82889924); 9) PC 43: M. Morissolo (71709650); 10) VLU 51: M. Colmegnino (84819740); 11) VLU 46: Runo-Curiglia road (82909962); 12) ELPC 82: Pian Nava (from BORIANI, 1968) (67749100); 13) ELPC 3: M. Morissolo (from BORIANI, 1968) (71249604); 14) PR 1: Luera (from BORIANI, 1968) (71709650) [IGM coordinates].

dykes as the outermost limbs of the Ordovician plutons that intruded the « Scisti dei Laghi » underlying the « Strona-Ceneri » rocks.

Having shown that the Ordovician intrusive reached directly the «Strona-Ceneri» we had to explain the apparently transitional contact between orthogneisses and fine-grained gneisses.

BÄCHLIN (1937) and REINHARD (1964) ascribed this circumstance to a metasomatic origin of the orthogneissic looking rocks; their formation occurred through a modification of their texture and composition that also involved, to some extent, the adjoining rocks. We now believe that their interpretation was essentially correct, but with the difference that we envisage real intrusive bodies that changed the texture of the adjoining fine-grained gneisses in their contact aureoles; we cannot disregard the possibility that metasomatical exchanges also occurred between the intrusive and the very low grade country rocks.

The reexamination of the zone W of Lago Maggiore proved that it was possible to recognize the orthogneisses in the « Strona-Ceneri » too. For example along the Cadorna Road S of M. Bavarione one can see repeated contacts between orthogneisses and paragneisses. The repetition is due to the strong deformation of the original

TABLE 2

Chemical analyses and mesonorms (MIELKE & WINKLER, 1979) *of the hornblende-free orthogneisses of the « Serie dei Laghi »*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	74.62	74.00	70.37	69.09	68.75	68.51	68.28	67.97	67.81	67.77	70.39	71.01	68.95	74.64	67.73
TiO_2	.60	.19	.26	.70	.27	.53	.56	.63	.63	.59	.48	.52	.62	.10	.63
Al_2O_3	12.19	12.18	15.21	14.44	15.42	15.20	14.97	15.17	15.41	15.27	14.62	14.82	15.10	13.65	15.38
Fe_2O_3	.74	.80	1.12	2.52	.69	1.36	2.04	3.53	1.68	1.02	.76	.12	1.26	.01	1.56
FeO	2.33	2.18	1.64	1.10	2.12	2.44	1.95	.92	2.57	2.89	2.63	3.39	2.89	.79	2.66
MnO	.03	.04	.03	.04	.03	.04	.02	.04	.05	.04	.07	.07	.06	.04	.05
MgO	.42	.42	1.15	.85	1.66	1.35	1.12	1.73	1.11	1.47	.81	.81	1.10	.22	1.47
CaO	.74	.72	2.03	1.67	1.20	1.38	1.78	1.77	1.77	.78	1.56	1.63	2.19	.60	1.72
Na_2O	3.50	3.26	3.28	1.75	3.84	3.67	3.03	3.32	3.34	3.25	3.32	3.14	3.35	2.96	3.48
K_2O	3.79	3.29	3.44	5.93	2.59	3.75	3.92	4.51	3.72	3.41	4.21	4.18	3.65	5.05	3.80
P_2O_5	.17	.12	.09	.20	.11	.16	.14	.20	.16	.18	.03	.05	.07	.08	.17
H_2O	1.62	2.51	1.28	1.42	2.96	2.00	1.47	.94	1.67	2.38	.92	.69	.81	1.04	1.70
TOTAL	100.75	99.71	99.90	99.71	99.64	100.39	99.28	100.73	99.92	99.05	99.80	100.43	100.05	99.18	100.35
Ap	.40	.28	.21	.47	.26	.38	.33	.47	.38	.43	.07	.12	.17	.19	.40
Mt	1.07	1.16	.00	.00	1.00	.00	.00	.00	.00	1.49	1.10	.17	1.83	.01	.00
Hm	.00	.00	1.12	2.53	.00	1.35	2.05	3.50	1.68	.00	.00	.00	.00	.00	1.55
Il	.57	.18	.25	.67	.26	.50	.54	.59	.60	.57	.46	.49	.59	.10	.60
Ab	29.42	27.69	27.81	14.87	32.78	30.96	25.85	27.92	28.31	27.79	28.18	26.48	28.36	25.28	29.37
Or	18.33	16.01	15.40	31.31	8.99	15.49	17.85	20.92	15.70	13.37	19.74	18.07	15.60	28.45	15.36
An	2.54	2.79	9.49	6.99	5.25	5.77	7.97	7.42	7.74	2.72	7.56	7.72	10.40	2.47	7.39
Bi	6.60	6.00	8.11	6.12	10.30	10.85	8.97	8.60	10.47	11.43	8.72	11.17	9.85	2.81	11.87
Hb	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.35	.00
Qz	38.34	41.34	34.05	33.28	34.35	30.17	32.45	27.95	30.81	34.97	31.75	33.24	30.97	37.32	29.62
C	1.37	2.23	2.61	2.60	4.38	2.96	2.85	2.07	3.05	5.29	1.83	2.27	1.81	2.43	2.80
REST.	1.35	2.29	.96	1.17	2.56	1.57	1.13	.57	1.26	1.95	.59	.27	.43	.94	1.23

	16	17	18	19	20	21	22	23
SiO_2	67.23	67.14	66.01	65.57	65.28	64.52	64.46	61.64
TiO_2	.37	.64	.65	.89	.74	.80	.69	.77
Al_2O_3	16.07	15.00	15.94	15.82	15.68	16.00	16.16	17.53
Fe_2O_3	1.36	1.82	1.80	1.84	1.77	2.42	1.97	1.57
FeO	2.55	2.59	2.46	2.60	3.09	2.74	2.60	3.32
MnO	.04	.04	.05	.05	.06	.69	.03	.05
MgO	.77	2.28	2.10	2.10	1.93	1.77	2.54	1.79
CaO	3.55	1.54	1.99	2.20	1.96	3.26	2.07	3.30
Na_2O	3.43	2.65	3.30	3.32	3.28	3.73	2.97	4.32
K_2O	2.59	3.67	3.61	3.09	3.32	2.75	3.75	3.83
P_2O_5	.12	.20	.19	.19	.22	.22	.19	.20
H_2O	1.25	2.03	2.29	1.91	1.90	1.80	2.49	1.90
TOTAL	99.33	99.60	100.39	99.58	99.20	100.70	99.92	99.22
Ap	.29	.47	.45	.45	.52	.52	.45	.48
Hm	1.37	1.83	1.79	1.85	1.78	2.40	1.97	1.58
Il	.35	.61	.62	.85	.71	.75	.66	.74
Ab	29.25	22.54	27.84	28.24	28.01	31.37	25.18	36.88
Or	10.05	12.73	12.84	9.54	10.85	7.24	12.54	13.83
An	16.94	6.35	8.59	9.71	8.35	14.63	9.03	10.18
Bi	9.10	14.59	13.58	14.18	14.63	14.67	15.47	14.79
Qz	30.29	35.07	29.14	30.37	30.14	25.74	28.94	17.61
C	1.45	4.36	3.42	3.47	3.67	1.46	3.90	2.58
REST.	.91	1.45	1.73	1.35	1.34	1.21	1.87	1.33

1) VLU 32: Colmegna-Luino road, Km 30 (80679778); 2) VLU 6: Colmegna-Torretta (80609750); 3) VLU 33: Pradecolo-M. Gradisca (83359872); 4) VLU 2: S. Rocco-Campagnano (80150022); 5) VLU 32: Colmegna (81109705); 6) GLU 2: Colmegna (80849685); 7) VLU 17: Due Cossani (82839770); 8) VLU 34: Pradecolo-M. Gradisca (83409875); 9) VLU 39: Runo (83499672); 10) VLU 29: M. Gradisca (83109900); 11) LM 80-4: Colmegna-Maccagno road (80809720); 12) LM 80-5: N of Colmegna (80759370); 13) LM 80-6: N of Colmegna (80759730); 14) LM 80-14 Ronchi, near Trarego (75009830); 15) VLU 30: «Casa Venere» W of Maccagno, q. 359 (80409885); 16) VLU 44: Alpone-M. Gradisca (84109930); 17) GLU 5: S. Rocco, near Campagnano (80220042); 18) VLU 41: Campagnano (80660022); 19) VLU 3: S. Rocco, near Campagnano (80200038); 20) VLU 20: Val Casmera (81920046); 21) GLU 4: Colmegna (80849685); 22) VLU 19: Garabiolo (81100000); 23) VLU 21: Val Casmera (81900056).

TABLE 3

Chemical analyses and mesonorms (MIELKE & WINKLER, 1979) *of the augen-gneisses of the « Serie dei Laghi »*

	1	2	3	4	5	6
SiO_2	73.56	77.26	74.94	74.49	70.30	73.54
TiO_2	.19	.06	.17	.17	.36	.24
Al_2O_3	14.07	12.97	13.96	13.73	14.80	13.93
Fe_2O_3	.47	.01	.18	.02	.34	.08
FeO	1.16	.85	1.14	1.40	2.12	1.87
MnO	.03	.01	.03	.03	.06	.03
MgO	.35	.04	.30	.30	.54	.39
CaO	.87	.29	.64	.66	1.35	.90
Na_2O	2.85	2.58	2.49	2.90	3.10	3.01
K_2O	5.00	5.43	4.85	4.59	4.53	4.65
P_2O_5	.02	.10	.08	.03	.08	.08
H_2O	.99	.80	1.02	.80	1.47	.86
TOTAL	99.56	100.40	99.80	99.12	99.05	99.58
Ap	.05	.24	.19	.07	.19	.19
Mt	.68	.01	.26	.03	.50	.12
Il	.18	.06	.16	.16	.35	.23
Ab	24.25	21.77	21.13	24.78	26.51	25.60
Or	27.49	30.74	26.52	24.72	22.92	24.14
An	4.20	.78	2.66	3.10	6.23	3.96
Bi	3.67	2.20	3.74	4.56	6.97	5.95
Qz	36.18	40.95	40.81	39.05	32.55	36.67
C	2.44	2.55	3.65	2.88	2.55	2.51
REST.	.85	.72	.88	.64	1.22	.64

1) LM 80-17: M. Vadà-Cadorna road (67309920); 2) LM 80-19: M. Vadà-Cadorna road (67209922); 3) LM 80-20: Val Pogallo (61009660); 4) LM-80-21: Val Pogallo (60959662); 5) LO 81-2: Germagno - Valle Strona di Omegna (52608220); 6) LO 87-7: Cireggio - Valle Strona di Omegna (52668040).

igneous contact. The grain size, especially of the micas, increases in the fine-grained gneisses near the contact, in addition the fine-grained gneisses with white feldspatic bands proved to be a contact zone with highly laminated concordant pegmatite dykes.

The biotite-plagioclase gneiss of the Ospedaletto locality (Cadorna Road) is a biotite-hornblende orthogneiss very similar in composition to that of Piancompra and Premeno; it is in direct contact with the amphibolites of M. Spalavera; the feldspathization of the metabasite horizon seems to be due to metasomatic phenomena related to the intrusion of the Ordovician «granites». (Originally we attributed the feldspathization to a migmatic episode that involved the « Cenerigneisses » (BORIANI & GIOBBI MANCINI, 1972)).

One of the most important evidences that were at the base of the hypothesis (BIGIOGGERO & BORIANI, 1975; BORIANI et al., 1977) of the nature of Caledonian suprastructure of the « Strona-Ceneri », was the recognition of the contact metamorphic effect of the pegmatite dykes on the fine-grained gneisses in the zone of Cannobio. The contact metamorphism that produced chiastolite porphyroblasts, now transformed by successive regional metamorphism into Al-silicates nodules, confirmed the very low metamorphic grade of the fine-grained gneisses at the moment of the intrusion of the Ordovician granites or, at least, of their pegmatitic extensions.

The reexamination of the contacts between the orthogneiss bodies and the paragneisses of « Scisti dei Laghi » did not reveal the presence of inequivocable mineral or textural relics of contact metamorphism, but if we consider the distribution of the Al-silicates polymorphs in the whole area, we notice that sillimanite seems to be present only near the orthogneisses or in the thin intercalations of paragneisses within the orthogneiss bodies (Rio Colmegnino, N of Dumenza). The sillimanite is present as fibrolite inclusions in the muscovite; kyanite and andalusite are also sometimes present in these rocks that probably coincide with the « Giumello-Gneis » of REINHARD (1964).

In the bed of the Torrente Giona near the outlet of Val Veddasca (E of Maccagno) the orthogneiss body of Agra is interrupted by an intercalation of country rocks showing a very peculiar aspect. It can be defined as gneissic migmatites that consist of strongly heterogeneous material with tightly folded alternating leococratic and melanocratic bands and veins. Similar rocks can be observed near Carmine di Cannobio, i.e. exactly on the opposite shore of the Lake in front of Maccagno (sample KAW 564 HUNZIKER & ZINGG, 1980).

Only very seldom is it possible to observe good exposures of unquestionable xenoliths within the orthogneisses. Probably the best one is that of M. Piancompra where, in a road cut (Aurano-Piancavallo road), one can see many lense-shaped inclusions of paragneiss a few dm to few m long; one of these xenoliths shows a crenulation cleavage, which proves that the fragment of metasediment included by the « Ordovician »

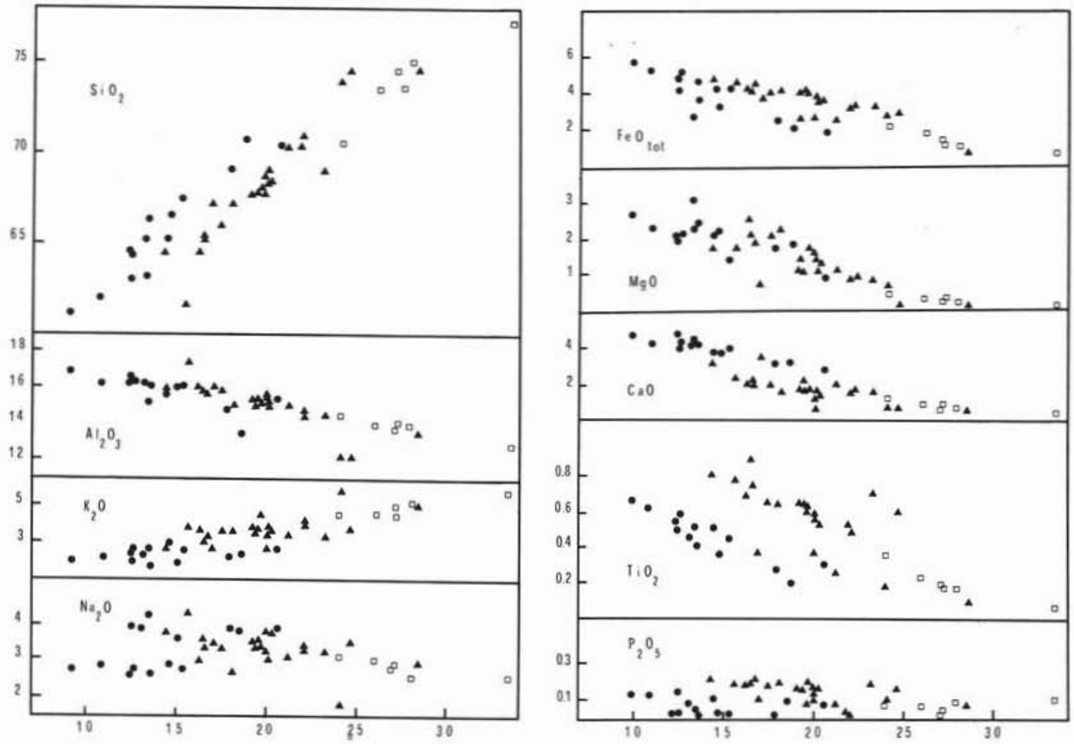

Fig. 3. — Larsen/oxides diagrams for the « Serie dei Laghi » orthogneisses. For legend see fig. 2.

intrusive was already schistose.

Amphibolite xenoliths occur E of Lago Maggiore along the Runo-Pradecolo road (M. Gradisca). Biotite or quartz concentrations with ill-defined margins are very common all over the area of occurrence of these orthogneisses.

The characters of the xenoliths are similar, if one does not consider the deformation and recrystallization due to the successive metamorphism, to those displayed by the xenoliths of common unmetamorphosed granites. These is another evidence for the real igneous origin of these rocks.

In our preceding papers (Boriani, 1970; Boriani et alii, 1977) we divided the orthogneisses in two types:

a) hornblende-bearing gneisses (Premeno and M. Morissolo);

b) granitic (biotite-) gneisses (Piancompra).

This division was motivated by the essentially uniform composition of the individual horizons, in the investigated area.

E of the Lake, where the orthogneisses reach their maximum abundance, the composition appears more heterogeneous within the individual bodies. A biotite-gneiss, only locally with augen texture (Runo, Colmegna) prevails between the Lake and the Val Dumentina fault. E of Val Dumentina the orthogneisses seem to be mostly biotitic with patches of more mafic, hornblende-bearing types.

The mineral assemblage, described in detail in the preceding papers, is: quartz, plagioclase (15-25 % An), K-feldspar, biotite, muscovite, epidote, allanite, apatite, zircon, opaques in the biotite gneisses. In the more mafic types the hornblende can be very abundant and the plagioclase becomes more An-rich (35-40 %).

With the exception of the already mentioned orthogneisses with augen texture, that can be considered varieties of the main type, no true augen-gneisses, in the sense of Boriani (1970), Boriani et al. (1977), were found on the eastern shore of Lago Maggiore S of Val Veddasca.

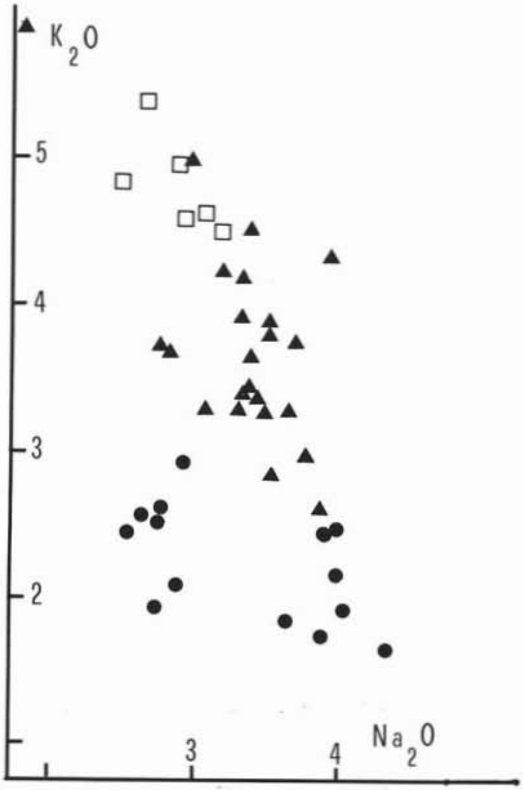

Fig. 4. — The Na_2O/K_2O relationships in the hornblende-bearing (circles), hornblende-free (triangles) and augen-gneisses (open squares) of the « Serie dei Laghi ».

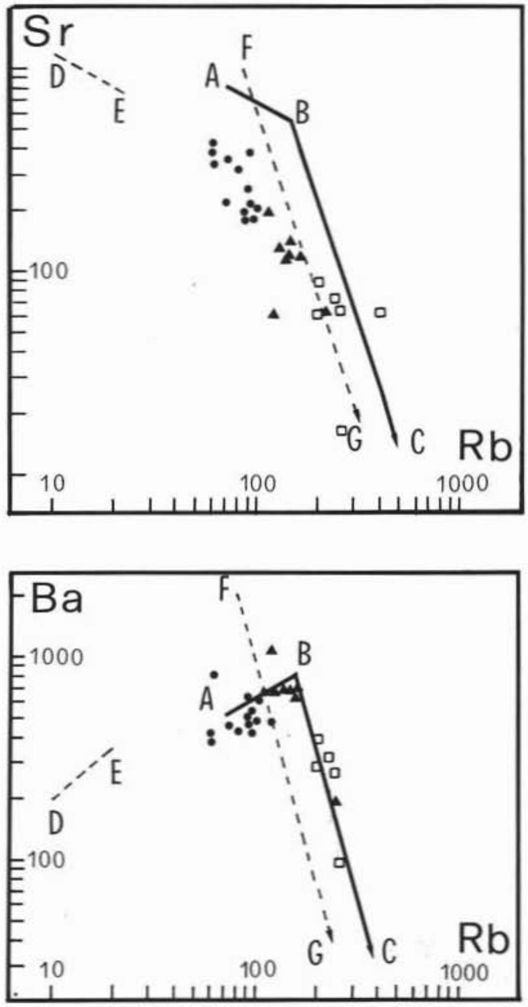

Fig. 5. — The Ba, Sr and Rb relationships in the three types of the « Serie dei Laghi » orthogneisses. The curves (McCarthy & Robb, 1978) represent the composition of the solid phase (dashed lines) and of the melt (solid lines) during the crystallization of a liquid of composition A lying on the plagioclase-quartz cotectic surface of the Q-Or-Ab-An tetrahedron.

In the light of the new evidences on the presence of true metaplutonites in the « Strona-Ceneri », we also reconsidered the nature and origin of the augengneisses. For this purpose we carried out Rb-Sr isotopic determinations as well as chemical analyses on a few samples of augengneisses from M. Vadà, Val Pogallo and Valle Strona di Omegna.

Petrochemistry

43 major element analyses, 27 of which included Rb, Sr, Ba, were performed on samples collected on both sides of Lago Maggiore (Tables 1, 2, 3).

In the alkali-silica diagram (fig. 2) the samples plot almost entirely between the two curves of Kuno that bound the fractionation products of the high-alumina basalts (the use of this diagram is only for reference purpose and does not imply a genetic interpretation).

On the diagram the amphibole-bearing and the amphibole-free suites trace two fairly well distinguishable trends with higher and lower alkali content respectively.

The two trends can be individualized in most of the oxide/Larsen index diagrams (very clearly in the TiO_2, CaO and SiO_2 diagrams, fig. 3).

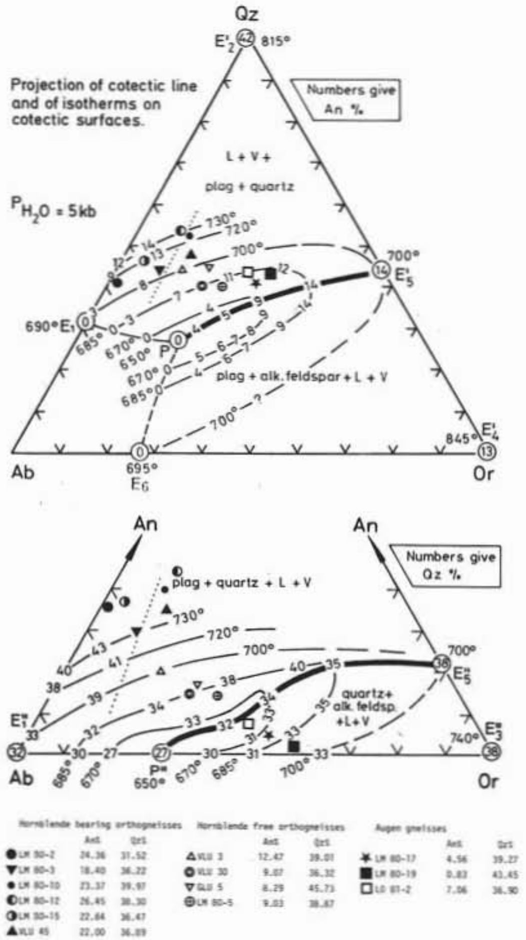

Fig. 6. — Winkler's diagrams for 13 representative samples of the « Serie dei Laghi ». For interpretation see text.

In the K_2O/Na_2O diagram (fig. 4) the three groups (hornblende-bearing, hornblende-free and augen-gneisses) are well defined by their different alkali ratio; the hornblende-bearing gneisses can be split in two groups at lower and higher Na_2O content. One can see a major rectilinear trend from high Na low K to high K low Na members that corresponds to a magmatic differentiation with different degrees of mixing of cumulate and melt (McCarthy & Robb, 1978); the minor trend, resulting from the alignement of the points representing the low Na group of the hornblende-bearing gneisses, can be interpreted as due to concentrations of cumulate hornblende.

TABLE 4

Ba determined by A.A., Rb and Sr determined by isotope dilution (apostrophe) and by XRF

Sample	Rb ppm	Ba ppm	Sr ppm
Hornblende bearing orthogneisses			
LM 80-2	61'	804	378'
LM 80-3	70'	537	343'
LM 80-8	95'	491	202'
LM 80-10	95'	638	197'
LM 80-12	90'	524	193'
LM 80-13	87'	499	192'
LM 80-15	59'	430	343'
PR 1	88	485	255
PC 3	78	442	304
PC 82	90	426	381
VLU 45	90	616	205
VLU 46	72	452	215
PC 43	61	392	407
Hornblende free orthogneisses			
LM 80-4	146'	682	119'
LM 80-5	154'	677	118'
LM 80-6	143'	651	142'
VLU 17	120	1011	147
VLU 31	130	686	132
VLU 33	106	657	207
VLU 34	121	652	63
LM 80-14	209'	206	62'
Augen gneisses			
LM 80-17	215'	330	72'
LM 80-19	252'	91	16'
LM 80-20	221'	283	65'
LM 80-21	182'	292	88'
LO 81-2	128'	1307	129'
LO 81-7	193'	382	62'

For sample location see legend of tables 1 - 2 - 3.

This is probably the explanation for the presence of the two apparently different trends in the above illustrated diagrams.

The Rb/Sr and the Rb/Ba diagrams (fig. 5) give the same indications. For comparison purposes we have traced the lines, calculated by McCarthy & Robb (1978), representing the effect of fractional crystallization of a granitic melt on Ba, Sr and Rb concentrations in solid and liquid. One can see that most of the points lie near the line AB, i.e. in the fractionation interval corresponding to the crystallization on the plagioclase-quartz cotectic surface. One of the hornblende-free and all the augen gneisses lie in the line representing the liquid during the cotectic crystallization of plagioclase, quartz, K-feldspar.

TABLE 5
Whole rock isotopic ratios for the « Serie dei Laghi »

Sample	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 1\sigma$
LM 80-2	0.47	0.7071±3
LM 80-3	0.59	0.7093±2
LM 80-4	3.54	0.7320±2
LM 80-5	3.79	0.7325±2
LM 80-6	2.92	0.7285±2
LM 80-8	1.36	0.7180±4
LM 80-10	1.39	0.7177±2
LM 80-12	1.35	0.7180±2
LM 80-13	1.32	0.7175±2
LM 80-14	9.91	0.7762±2
LM 80-15	0.49	0.7077±2
LM 80-17	8.73	0.7652±2
LM 80-19	47.94	1.0371±2
LM 80-20	9.94	0.7745±2
LM 80-21	6.02	0.7490±2
LO 81-2	2.88	0.7275±3
LO 81-7	9.11	0.7702±2

For sample location see legend of tables 1 - 2 - 3.

TABLE 6
Data for mineral separates from the « Serie dei Laghi » orthogneisses

Sample	Mineral	Rb ppm	Sr ppm	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 1\sigma$	AGE* m.y. ($\pm 1\sigma$)
LM 80-2	biotite	416	4.7	290	1.9578±30	298±5
LM 80-4	biotite	700	3.0	977	5.1082±90	316±5
LM 80-14	muscovite	757	6.9	373	2.4561±34	325±5
LM 80-19	muscovite	753	2.5	1458	7.2692±49	311±5
LM 80-19	biotite	1528	1.9	10638	36.267±167	234±4
LO 81-2	biotite	563	5.6	321	1.8315±31	244±4

For sample location see legend of tables 1 - 2 - 3.

* Age value of the two-points isochron (mica + whole-rock).

In fig. 6 a few representative analyses (mesonorms according to MIELKE & WINKLER, 1979) are plotted in Winkler's diagrams; it can be seen that only the plotted hornblende-free orthogneisses fall near the plagioclase-quartz cotectic surfaces, whilst the hornblende-bearing gneisses fall well within the plagioclase volume and the augengneisses in the quartz volume.

But, for the preceding considerations, it is very difficult to attribute a real liquidus composition to our rocks.

Geochronology: methods and results

The radiometric study was carried out on « total rocks » as well as on separated minerals by means of the Rb/Sr method.

Rb and Sr concentrations were measured by isotope dilution with ^{87}Rb (98 %) and ^{84}Sr (99,9 %) « spikes ». Sr isotope compositions were determinated on fractions of the solutions containing the Sr « spike ». All the analyses were performed with a Varian Mat TH5 mass spectrometer. The least square method was used to calculate ages and relative errors according to YORK (1966) with a ^{87}Rb decay constant of $1.42 \cdot 10^{-11}/y$.

Age of intrusion

The analytical results on total rocks are listed in Tab. 5.

We must notice that the hornblende-bearing and the hornblende-free orthogneisses generally show a Rb/Sr ratio lower than that of the augengneisses, on account of their minor concentration of Rb and a higher content of Sr. However this difference is not reflected in the distinction of two rock groups with different isotopic characters. All of them define an isochron (fig. 7) of 466 ± 5 m.y. and a value of initial isotopic Sr composition of 0.7087 ± 0.0002. These data were obtained on 13 samples (full circles) of hornblende-bearing, hornblende-free and augen gneisses with the exclusion of the samples (open circles) with clearly different chemical and isotopic characters. Samples LM80-2, LM80-3 and LM80-15 fall well below the isochron (hornblende-bearing gneisses) and show low Rb/Sr ratio. If they behaved like closed system since their origin, their isotopic Sr ratios were 0.7040, 0.7044 and 0.7054 respectively at the moment of their solidification. These values, definitely not typical of crustal magmas, indicate that the origin of the « granites » of « Serie dei Laghi » cannot be confined to the highest levels of the lithosphere. Also the augen gneiss LM80-19 was excluded from the calculation of the isochron, since its Sr isotopic composition is quite different from that of the other samples; its use would yield an age value of 469 m.y.

However it is possible that even other samples used for the isochron calculation were originally characterized by a value of Sr isotopic composition slightly different from 0.7087. This possibility is suggested by the small dispersion of some points around the isochron line. Slight modifications to our calculated age could result from the analyses of other surely comagmatic rocks. This would presumably lead us to the individuation of a system of parallel isochrons with slightly different initial isotopic Sr ratios, but for the moment our data indicate unquestionably that the orthogneisses of « Serie dei Laghi » belong to the late-Ordovician magmatic cycle.

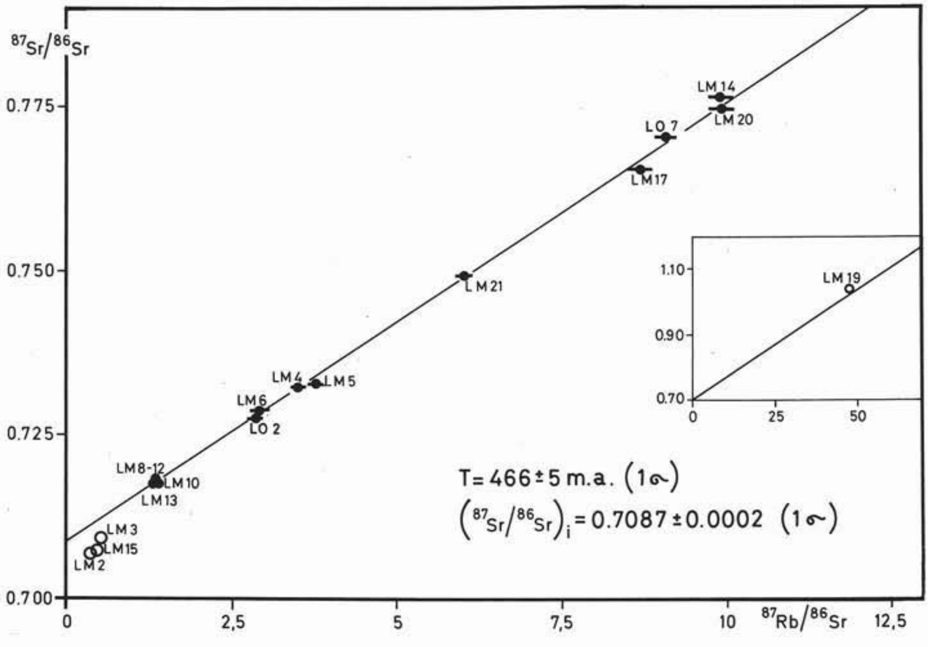

Fig. 7. — Rb/Sr whole-rock isochron for the « Serie dei Laghi » orthogneisses. Sample location in the legend of table 1-2-3.

Our results are similar, within the limits of analytical uncertainity, to those obtained with the same method on other plutonic bodies of the alpine region connected to the «Caledonian» magmatism, i.e. on the Anterselva and Casies orthogneisses (Borsi et al., 1973) and on those of the Oetztal region (Satir, 1975; Borsi et al., 1980).

Similar ages were obtained also by means of the U-Pb method by Pidgeon et al. (1969) on zircons from a « Strona-Ceneri » orthogneisses (400-450 m.y.). Köppel & Grünenfelder (1971) determined an age of 430-500 m.y. on zircons from the «Strona-Ceneri» rocks and placed at this time the « anatectic granitization » of this zone.

It is important to emphasize the difference between the age obtained for the « Strona-Ceneri » orthogneisses and that recently determined by Hunziker & Zingg (1980) for the peak of the regional metamorphism (478 ± 20 m.y.) in the adjoining « Ivrea-Verbano » Zone. If metamorphism was coeval to the magma formation and if we admit that « Serie dei Laghi » and « Ivrea-Verbano » belonged to the same part of the basement (as also suggested by the incomplete data of Hamet & Albarede (1973) recalculated by Hunziker & Zingg (op. cit.)) the difference of 10-15 m.y. could be real and correspond to the time employed by the magmas to rise from the source zone up to the level of their emplacement as plutonic bodies.

It is interesting to compare the analytical data obtained on the « Serie dei Laghi »

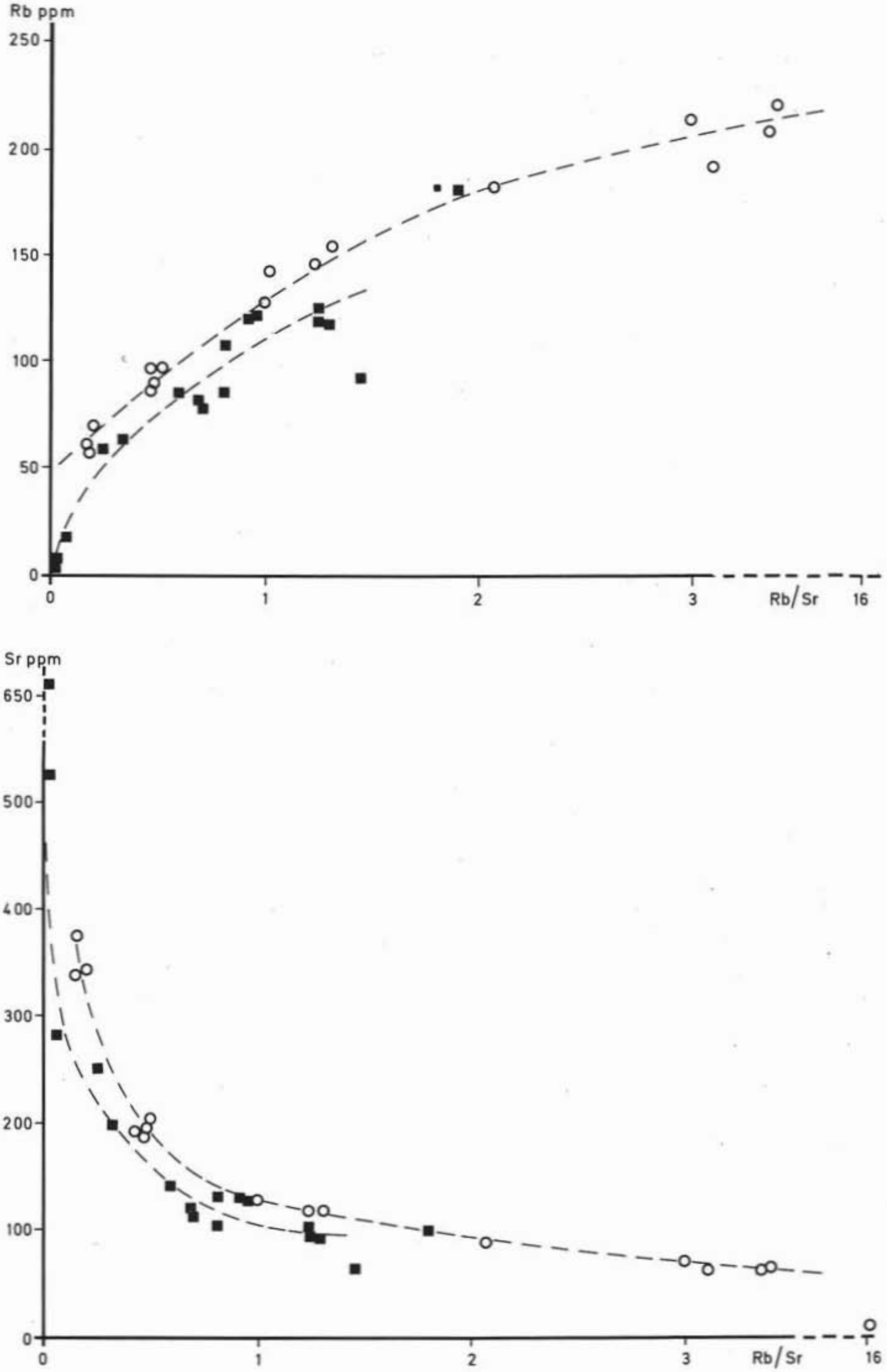

Fig. 8. — Rb and Sr concentrations versus Rb/Sr ratio of the « Serie dei Laghi » orthogneisses (open circles) and of the paragneisses of the « Ivrea-Verbano » zone (full squares).

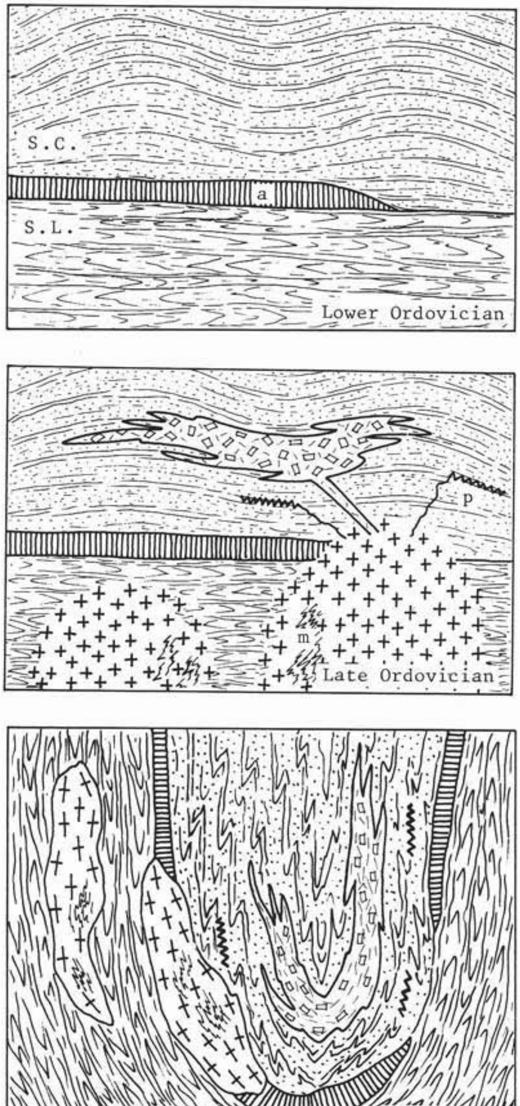

Fig. 9. — Evolutionary scheme of the « Serie dei Laghi ».
1) *Lower Ordovician.* From the bottom upwards the sequence is: *S.L.* = metapelites of the « Scisti dei Laghi » (probably low grade); *a* = basic extrusives; *S.C.* = psammitic rocks of the « Strona-Ceneri » (probably very low metamorphic grade). 2) *Late Ordovician.* Diapiric intrusion of semi-molten magma of granodioritic composition entraining migmatite blocks (*m*). Filter-press mechanisms during emplacement generate differentiation. The intrusive bodies reach also the S.C., but this unit is mostly affected by extremely fractionated liquids that generate pegmatites (*p*), porphyritic granites and, to some extent, feldspathization of the country rocks. Contact aureoles are developped around plutonic bodies and pegmatite dykes.
3) *Westphalian.* Hercynian folding of both supra- and infrastructure; staurolite grade metamorphism and generation of the present schistosity in the orthogneisses. Contact aureoles are strongly deformed and overprinted by regional metamorphism.

orthogneisses with those obtained by HUNZIKER & ZINGG (1981) on the metapelites (« kinzigites » and « stronalites ») of the « Ivrea-Verbano » zone: the two rock suites, though genetically different, show essentially the same initial Sr isotopic composition, but different corresponding amounts of Rb and Sr. The orthogneisses of « Serie dei Laghi » (open circles) show, at the same Rb/Sr ratio, a higher concentration of both Rb and Sr than the paragneisses of the « Ivrea-Verbano » zone (full squares), fig. 8. These differences could be due to an originally different chemical composition between different crustal levels or could represent the consequence of a « degranitization » process (SCHMID, 1978-79; HUNZIKER & ZINGG, 1980) that caused a depletion of Rb and Sr.

Metamorphic evolution

The « Caledonian granites » of « Serie dei Laghi » were metamorphosed during the hercynian cycle; the stratigraphical relations indicate that in the area under investigation, it occurred before Westfalian B, because this is the age of the base of the post-metamorphic sedimentary sequence. Many radiometric data on the hercynian metamorphism are available for this sector of the Southern Alps. GRAESER & HUNZIKER (1968) determined an age of 329 ± 19 m.y. (recalculated with $\lambda = 1.42 \cdot 10^{-11}$ y^{-1}), for the peak of the hercynian metamorphism with the Rb/Sr method applied to separated slabs of a single « stronalite » sample. MC DOWELL (1970), on the basis of K-Ar determinations on micas and hornblende concentrates, concluded that in the « Strona-Ceneri » the metamorphism occurred around 325 m.y. ago. KÖPPEL (1974), determined the minimum age of the metamorphism of « Ivrea-Verbano » and « Strona-Ceneri » zones around 295 m.y. with the U-Pb method on monazites and zircons. Furthermore, on the basis of other K-Ar and Rb-Sr data on mineral concentrates from the « Massiccio dei Laghi » region (JAEGER et al., 1967; MAC DOWELL & SCHMID, 1968; GRAESER

& HUNZIKER, 1968; MC DOWELL, 1970; HUNZIKER, 1974), it was ascertained a systematic variation of the cooling age values that decrease gradually in NW direction towards the « Ivrea-Verbano » zone. From values around 325 m.y. E of Lago Maggiore, the K-Ar and Rb-Sr mineral ages concentrate towards 170 m.y. in the NW part of « Serie dei Laghi » and in the adjoining « Ivrea-Verbano ».

This cooling age pattern was attributed to a post-hercynian thermal evolution that involved this part of South-Alpine basement in a different way from place to place: the NW part of the « Serie dei Laghi » towards the « Ivrea-Verbano », underwent a more prolonged cooling period in consequence of a slower combined process of post-orogenic uplift and erosion. Alternatively all the data could be interpreted as due strictly to magmatic cooling of the basic-ultrabasic Ivrea complex.

Our results fit well in the already described geochronological frame. The age of the muscovite concentrate of sample LM80-14 is very close to the inferred age of the hercynian metamorphic peak. The biotites become younger, going from the eastern shore of Lago Maggiore towards the « Ivrea-Verbano » in an even more marked way since they range from 315 m.y. of sample LM80-2 to 234-244 m.y. of two samples collected near the « Strona-Ceneri »-« Ivrea-Verbano » boundary (Table 6).

If we assume the values suggested by PURDY & JAEGER (1976) for the temperature of the Rb-Sr system closure, we obtain from the age differences of the micas coexisting in sample LM80-19, a local cooling rate of only 4° C/m.y.

Conclusions

Orthogneisses with a Rb/Sr age of intrusion of 466 m.y. are one of the characteristic rock types of both « Scisti dei Laghi » and « Strona-Ceneri ». $^{87}Sr/^{86}Sr$ initial ratio (0.7087) favours a crustal origin of the intrusives that can be considered cogenetic though not strictly comagmatic; individual lower initial ratios reflect a deeper origin of part of the magma.

The chemical characteristics are compatible with magmatic fractionation mostly without a real separation of cumulate and melt, such that each rock type results from mixing of different amounts of both materials, giving a bulk composition ranging from tonalite to granite. Only the augengneisses show a marked character of residual melt.

In spite of the presence of superimposed regional metamorphism and deformation, one can recognize the igneous nature of the original contacts with the country rocks.

The already proposed structural setting of the « Serie dei Laghi » at the end of Ordovician (a weakly metamorphic « Strona-Ceneri » overlying a more deeply metamorphosed « Scisti dei Laghi ») is confirmed: the level of intrusion seems to be more shallow in the « Strona-Ceneri » than in « Scisti dei Laghi ».

The proposed evolutionary scheme is sketched in fig. 9.

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