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PETROLOGIC AND METALLOGENIC INVESTIGATIONS ON THE COLLIO FORMATION OF THE NOVAZZA URANIUM MINE, BERGAMASC ALPS (ITALY)

EVELINA ORIGONI GIOBBI

Centro per lo Studio della Stratigrafia e Petrografia delle Alpi Centrali del C.N.R., Milano, Istituto di Mineralogia, Petrografia e Geochimica, Via Botticelli 23, 20133 Milano

ANDREA BERNASCONI

AGIP S.p.A. - Servizio SGEL - San Donato Milanese, Milano

DANIELE RAVAGNANI

SIMUR S.p.A. - Gromo, Bergamo

RIASSUNTO. — Rocce vulcaniche di età permiana, intercalate a sedimenti piroclastici e clastici, costituiscono un membro importante della Formazione di Collio nelle Alpi Bergamasche. Le rocce vulcaniche comprendono ignimbriti, distinte in basali ed intercalate, e lave. Presso la miniera di Novazza le ignimbriti sembrano avere un'espansione maggiore che non i corpi subvulcanici e le lave, a differenza di quanto osservato in Val Trompia.

Il chimismo delle ignimbriti in cui non si rileva mineralizzzazione uranifera è molto simile a quello delle ignimbriti della Val Trompia e del Gruppo Superiore dell'Altopiano Atesino.

Le ignimbriti della miniera di Novazza, dove sono localizzati i livelli uraniferi, mostrano un particolare depauperamento in Na_2O e arricchimento in SiO_2, dovuti probabilmente a circolazione di acque in quella particolare zona del bacino.

L'età della mineralizzazione uranifera è probabilmente permiana, poco più recente dei fenomeni deuterici che hanno interessato tutta la serie vulcano-sedimentaria.

ABSTRACT. — Permian volcanic rocks interbedded within pyroclastic and clastic sediments constitute an important member of the Collio Formation in the Bergamasc Alps. The volcanic rocks comprise ignimbrites (basal and intercalated) and lavas.

At the Novazza uranium-mine the ignimbrites predominate over the lavas and the associated subvolcanic dykes that are very abundant in the Val Trompia section.

The bulk chemistry of the volcanics in the Novazza area is rhyolitic with weak dacitic characters in the lavas.

The chemistry of the rhyolites without uranium mineralization is very similar both to that of the Val Trompia ignimbrites and to that of the top layers of the Permian Athesian volcanic system.

At the Novazza mine, where uranium mineralization occurs, the ignimbrites show a marked leaching of Na_2O and enrichment in SiO_2.

The uranium mineralization is presumably Permian, though later than deuteric alteration.

Introduction

Uranium concentrations occur in the Collio Formation, which in the Novazza area consists of alternating more or less intensely reworked pyroclastic material, terrigenous sediments, rhyolitic ignimbrites with a porphyritic texture and minor amount of dacitic subvolcanic bodies. The Novazza mine is located in the southernmost part of the Bergamasc Permian Basin, in Val Seriana, near Gromo (BG) (fig. 1).

Information about the geology and petrography of the Val Seriana can be found in the studies published by PORRO (1903), DOZY (1935 a, b, c, d) and DE SITTER & DE SITTER KOOMANS (1949); these studies cover the entire Orobian Complex or the whole Permian of the Southern Alps and do not consider in detail the area dealt with in this paper.

Recent studies have been carried out on stratigraphy, petrography and tectonics of the Lombardian Permian Complex in the adjacent areas: ASSERETO & CASATI (1965, 1966); CASATI & GNACCOLINI (1967). BERNASCONI (1974) carried out the micro-

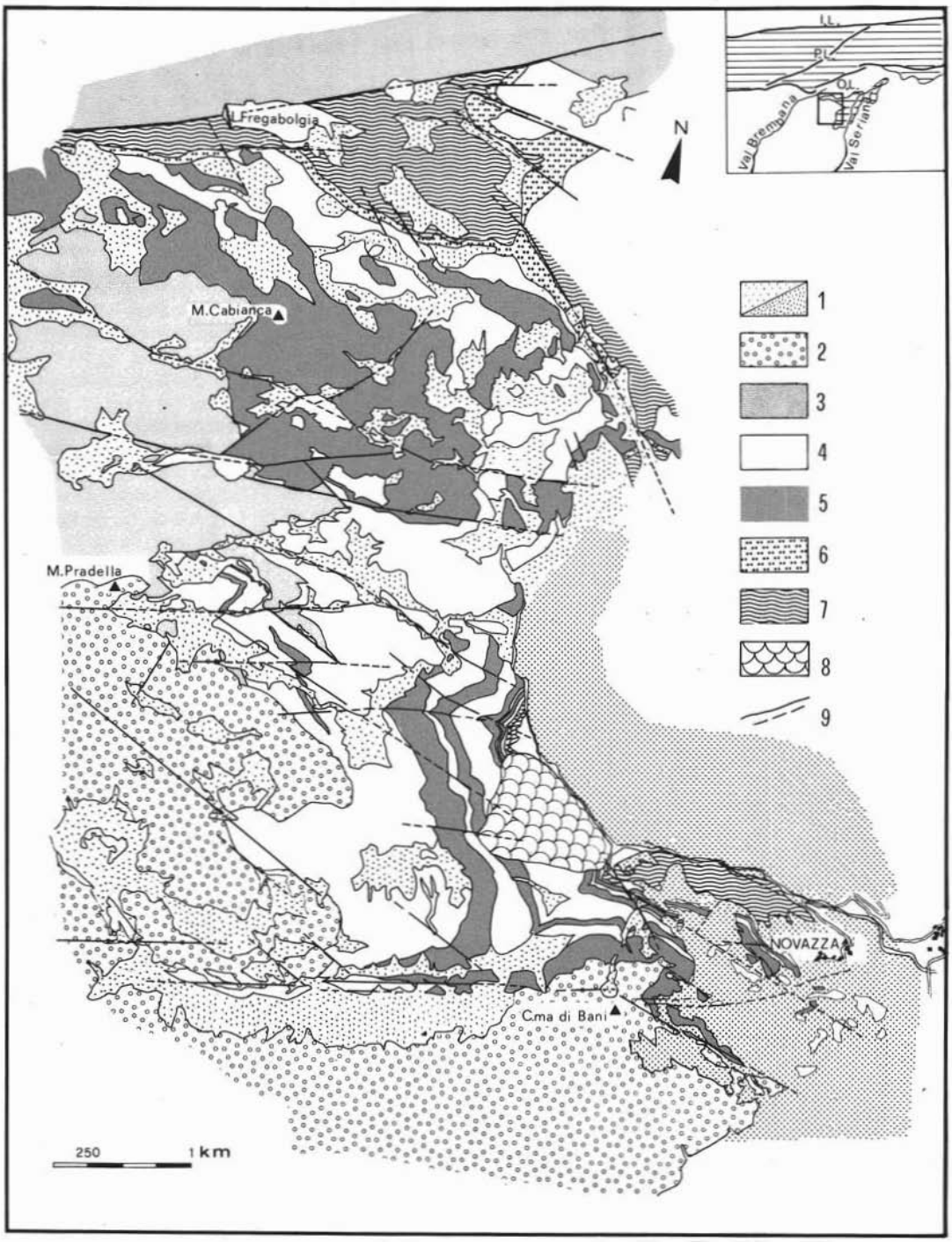

Fig. 1. — *Geological sketch of the Novazza U mine.* - 1) Alluvial and morainic deposits, 2) Verrucano Lombardo, 3) Carona schists, 4) Sedimentary deposits of the Collio Formation, 5) Volcanics interbedded in the Collio Formation, 6) Basal Conglomerate, 7) South Alpine Crystalline Basement, 8) Morainic debris, 9) Faults. *I.L.* = Insubric Line; *P.L.* = Porcile Line; *O.L.* = Orobic Line.

structural study of the Collio schists in the Rifugio Calvi area (Val Brembana) and RAVAGNANI (1974) studied the Novazza ore deposit, ORIGONI GIOBBI E. (1976) undertook the petrographycal study of the volcanics interbedded in the Collio Formation in the Rifugio Calvi and Novazza areas.

Geological outlines

The area under investigation is located in the Southern Alps, south of the Orobian Line and north of the Val Canale Line. In the Novazza area occurs a volcano-sedimentary cover of permian age (Collio Formation) which rests over crystalline rocks belonging to the Southern Alpine basement. The latter is affected by a series of gentle folds with a prevailing EW direction; one of the most important is the Trabucchello-Cabianca anticline, whose southern limb crops out in the area under investigation.

Volcano-sedimentary series of permian age are common all over the Southern Alps, but the best known is the sequence called Collio Formation in the Brescian area (CASSINIS, 1966 a, b).

The Bergamasc basin is separated from the Brescian basin by the Val Camonica uplift (ASSERETO & CASATI, 1965). The Novazza mine, in Val Seriana, is situated on the western slope of the Camuno ridge.

The basins are the results of the intense faulting that involved the region at the end of the variscan orogeny: a series of normal faults with considerable slip caused the formation of « horst » and « graben ». The volcanic activities that, in permian age, accompanied the faulting, favoured the subsidence of the basins. The uplift and erosion were different from place to place, so that a conglomerate of carboniferous age is occasionally found unconformably overlying the crystalline basement.

During middle and late variscan volcano-sedimentary deposits filled up the basins.

The saalian phase, responsible for late orogenic movements, caused the weak angular unconformity between the Collio Formation and the overlying Verrucano Lombardo (CASATI & GNACCOLINI, 1967).

On the basis of geological and paleobotanical evidences, the age of the sediments including the volcanic rocks in the South Alpine region is Permian (CASSINIS et alii, 1975). D'AMICO et alii (1980) recently performed a radiometric study on the coeval rhyolites: Rb/Sr ages on biotites range from 263 to 274 m.y. for the volcanic outflows.

Structural outlines of the Novazza U-mine

In the Novazza area the entire described sequence has a SW dip of about 25°.

Although tectonics (Alpine age) are particularly complex, the main faults of the system have been fairly accurately determined by both surface and subsurface surveys: they correspond quite closely to the structural features of the adjacent areas. Three main fault systems can be observed, with EW, NW-SE and NNE-SSW trends. We have gathered data of the NW-SE system in particular and, to a latter extent, of the E-W and NNE-SSW systems (fig. 1).

The NW-SE system consists of reverse faults strongly dipping NE. These faults produced an imbrication of the Permian sequence with the consequent uplifting of the northern elements with respect to the southern ones.

The different behaviour of ignimbrites and sandstones-siltstones under tectonic stress is well outlined: there is evidence that in some cases there have been movements between originally competent and incompetent layers.

Friction breccias or mylonites constitute the contact between the Collio Formation and the crystalline basement. This indicates the possibility that the whole Permian Complex has been overthrust.

Stratigraphical outlines of the Novazza U-mine area

Our mapping covers the area limited to the S by Val Canale, E by the Fiume Serio, N by the structural trend called the Lago Fregabolgia Line and W by the Val Brembana-Val Seriana watershed, as shown in fig. 1.

The field survey and particularly some

recent stratigraphic bore holes in the Novazza mine revealed the stratigraphical sequence in several localities in the Bergamasc valleys. In fig. 2 the stratigraphical sequences of four localities are reported, i.e.: 1) *Costa Magrera,* 2) *Novazza,* 3) *Val Pagherola,* 4) *M. Aga.*

Generally we can observe from bottom upwards the *South Alpine Crystalline Basement,* the *Basal Conglomerate,* the *Collio Formation s.s.* and the *Verrucano Lombardo.*

Detailed studies on the stratigraphy of the Upper Seriana Valley are found in the papers of WEEDA (1936), WENNEKERS (1930, 1932), RAASVELDT (1939).

In our paper we give a carefull description of the lithotypes present in the Novazza area.

South Alpine Crystalline Basement

It consists of very schistose rocks, tightly folded, with characteristic silvery surfaces, and is identified as a *garnet, staurolite-bearing micaschist.*

This rock shows a marked foliation.

Quartz grains in aggregates with polygonal texture are visible in thin section. Poikyloblasts of *plagioclase, garnet* and *staurolite* are also present. Flakes of primary *chlorite* are diffused.

A retrogressive metamorphism involved all the rock replacing garnet with chlorite, staurolite with chlorite and quartz and plagioclase with sericite. *Tourmaline, zircon* and more rarely *apatite* are common accessories.

Basal Conglomerate

This lithotype in the investigated area is very discontinuous and is represented by a coarse grained and poorly sorted quartz conglomerate, possibly proving its stream water or piedmont debris origin.

Occasionally we found conglomerates consisting uniquely of milky-white polycrystalline *quartz* pebbles, rarely containing large *biotite* fragments embedded in a micaceous-quartz matrix, ranging in colour from dark grey to greenish.

In the vicinity of Passo Portula, overlying a thin layer of the aforesaid rock, there are 30 m of conglomerate consisting of volcanic rock fragments in a reddish-violet sandy or silty matrix.

Near Lago dei Curiosi the Basal Conglomerate consists of 15 m of conglomerate with pebbles of milky-white *quartz* in a dark-red matrix, 1 m of fine grained sandstone-siltstone, 3 m of greenish micaceous siltstone and medium grained grey-coloured arkosic sandstone.

At Lago Cabianca this unit consists of conglomerate with pebbles of milky-white quartz in a dark-grey matrix in the lower part and of greenish schistose sandstone in the upper part.

Near Novazza this unit shows the characteristics of breccia consisting uniquely of basement fragments and the small amount of matrix is provided by a sericite-muscovite felt.

Collio Formation s.s.

The Collio Formation displays characters of continental environment and consists of alternated volcanic and sedimentary rocks.

It lies between the Basal Conglomerate or South Alpine Crystalline Basement and the overlying Verrucano Lombardo.

Detailed studies on the stratigraphy of Collio Formation in Val Trompia have been made by CASSINIS (1966 a, b), CASSINIS et alii (1975).

In the area dealt within this paper (Bergamasc Basin) the lower volcanic sequence is mainly represented by ignimbrites and minor amount of « *lavas* ».

We distinguished four (sometimes five) ignimbrite layers interbedded within pyroclastic or arenaceous or silty sediments.

The stratigraphy, except some discontinuous episodes is from bottom upwards:

a) volcano-sedimentary level with conglomerates (sometimes with volcanic fragments), sandstones and pyroclastites (20 m);

b) basal ignimbrite (0÷20 m);

c) volcano-sedimentary level represented by a thin tuffaceous horizon in the lower part followed by alluvial fan deposits with very evident sedimentary structures in the middle and upper parts (40 m);

d) first intercalated ignimbrite (40÷90 m);

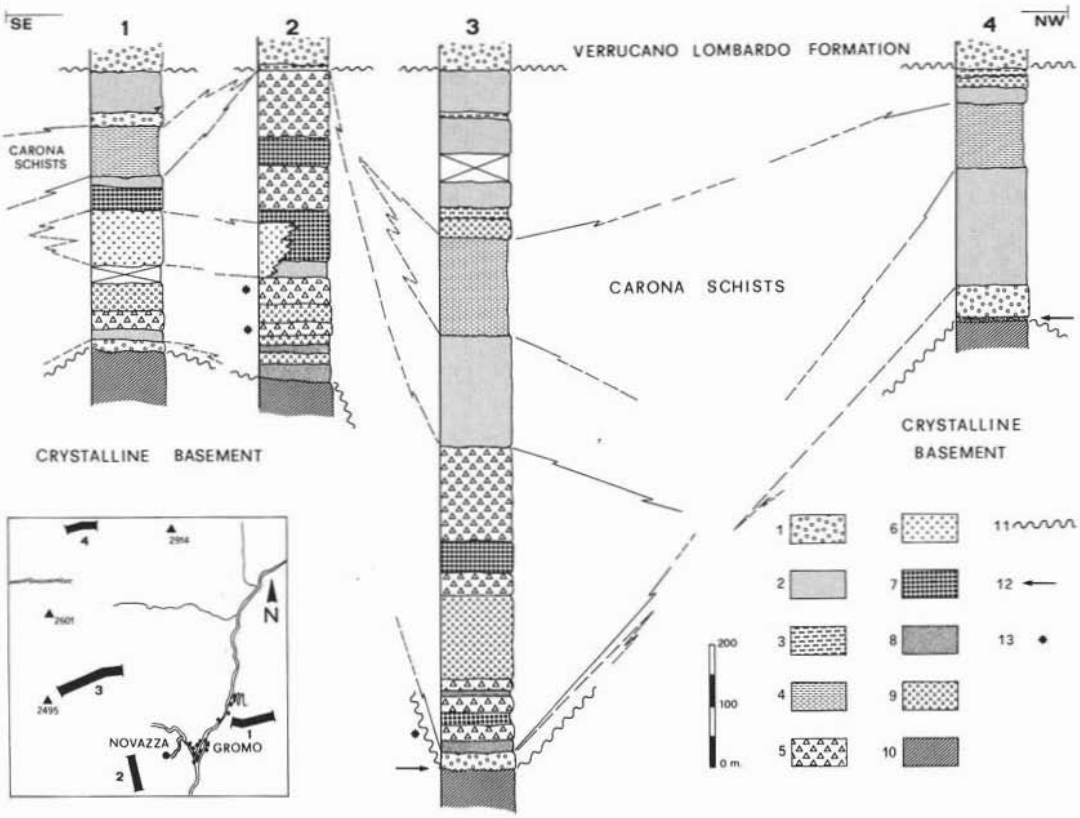

Fig. 2. — *Stratigraphic sequence, from bottom to top, of the Collio Formation s.s. in the Bergamasc basin.* - 1) Conglomerate, 2) Sandstone, 3) Siltstone, 4) Carona schists, 5) Ignimbrites, 6) Subvolcanic dacitic masses, 7) Volcanic agglomerates, 8) Fine pyroclastite, 9) Tuffaceous sandstone, 10) Crystalline basement, 11) Unconformity, 12) Mylonite, 13) Mineralization.

e) sedimentary layer with medium-grained sandstones grading to siltstones and shales, of lacustrine origin (140÷200 m);

f) second intercalated ignimbrite (50÷90 m);

g) sedimentary layers characterized by very fine grained clastic sediments, with no or very rare micaschist fragments. Sometimes in the proximal areas it is possible to observe quartz conglomerate intercalations indicating the transition between lacustrine and alluvial fan deposits (100÷120 m);

h) third intercalated ignimbrite (90÷100 meters);

i) upper lacustrine sediments (0÷350 meters).

The ignimbritic horizons, usually rhyolitic, are the most important facies of the Collio Formation in this area, both from the petrographical and metallogenic point of view, since they are the host rocks of the uranium mineralization.

In this paper we define the volcanics of the Collio Formation as ignimbrites because of their tabular structure, areal extent and other typical features, like:

— abundance of « fiamme » and pumices;
— vitroclastic texture of the groundmass;
— pseudo-layering and vertical sorting;
— fluidal banding and flowage, very evident at the bottom;
— columnar jointing.

On the field we have found up to five horizons of ignimbrites, but from the petrochemical and textural point of view we can distinguish only the *basal rhyolite ignimbrites* from the *other intercalated rhyolite ignimbrites*.

A third group of volcanics consists of *dacite shallow intrusives* (« *lavas* »).

Ignimbrites

They are generally greenish to light grey massive layers. In the groundmass small but evident rounded phenocrysts of quartz are present and stretched pumices, « fiamme » and xenoliths, mostly from the Crystalline Basement, are also frequent.

Generally these rocks are medium grained in the middle part of the layer, while they display a very fine grain size at the bottom.

Leaching and silification phenomena and degassing channels are frequently found at the top of each layer.

When sulphide or uranium impregnations are present the rocks become blackish and the sericitized feldspar phenocrysts are clearly visible.

The thickness of the ignimbritic layers is variable both laterally (due to the paleogeographical setting) and vertically, and ranges from 15 m in the lower layer to 100 m in the upper one.

Fragments of Crystalline Basement and quartz phenocrysts are numerous in the basal ignimbrite, spreading only in the southern part of the investigated area, where we noted a local collapse.

The intercalated ignimbrites are well developed over the whole area. Vitroclastic textures predominate: quartz phenocrysts are less abundant than plagioclase.

In the Cabianca and Lago Succotto area, where the ignimbrites were deposited together with lacustrine shales, perlitic and spherulitic textures appear.

« *Lavas* ». The mining works in Novazza showed the presence of a discordant volcanic body, about 100 meters thick, lying between the first and the second level of intercalated ignimbrites.

Its boundaries are not clearly defined, however its extent is very small and the bottom marked by an erosion surface.

On the basis of petrological studies we can define this volcanics as lava-flow or dome. It is very compact with a porphyritic texture and grey to greenish in colour.

The lavas are deeply altered with evident fractures filled by carbonates.

Upper lacustrine sediments. These rocks, best represented in the so called « Pagherola-Valle dei Frati » section, are very important for the chrono-stratigraphical classification and paleogeographical environment of the Collio Formation.

This facies groups all the transitional sediments between the marginal coastal deposits and the mid-basin areas. The deposits consist of fine-grained grey to greenish sandstones: sometimes they are microconglomeratic, micaceous, parallel-laminated, they show graded bedding and frequent burrows. Elsewere we find, W of Monte Cabianca, finer argillaceous blackish and platy sediments, similar to the Carona slates, which are typical mud-flat deposits. Fossil evidences such as « tetrapods » prints, remains of stromatolites, mud cracks, ripple marks etc. are frequently found in these sediments. Terrigenous-carbonaceous, varved and finely laminated sediments, often affected by microfractures are found NE of Monte Cabianca. NW of Monte Cabianca local evidences of restricted circulation environments (stromatolites, gypsum concretions) have been found.

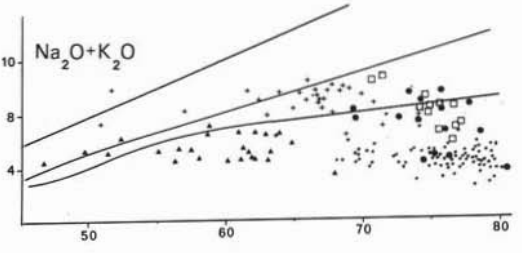

Fig. 3. — SiO_2 vs. ($Na_2O + K_2O$) diagram. - *The full circles* represent the ignimbrites outcropping between the Novazza mine and the Val Sanguigno, and on the northern slopes of M.te Cabianca. *The small dots* represent the ignimbrites drilled in the Novazza mine. *The full triangles* are representative of the lavas drilled in the Novazza mine. *The open squares* indicate the ignimbrites of the Val Trompia (from ORIGONI GIOBBI et alii, 1979) and the ignimbrites of the Upper Group of the Athesino Volcanic System (from MITTEMPERGHER, 1962; BRONDI et alii, 1970). *The horizontal crosses* indicate the lavas of the Val Trompia and of the Athesino Volcanic System of Val Giudicarie (from ORIGONI GIOBBI et alii, 1979).

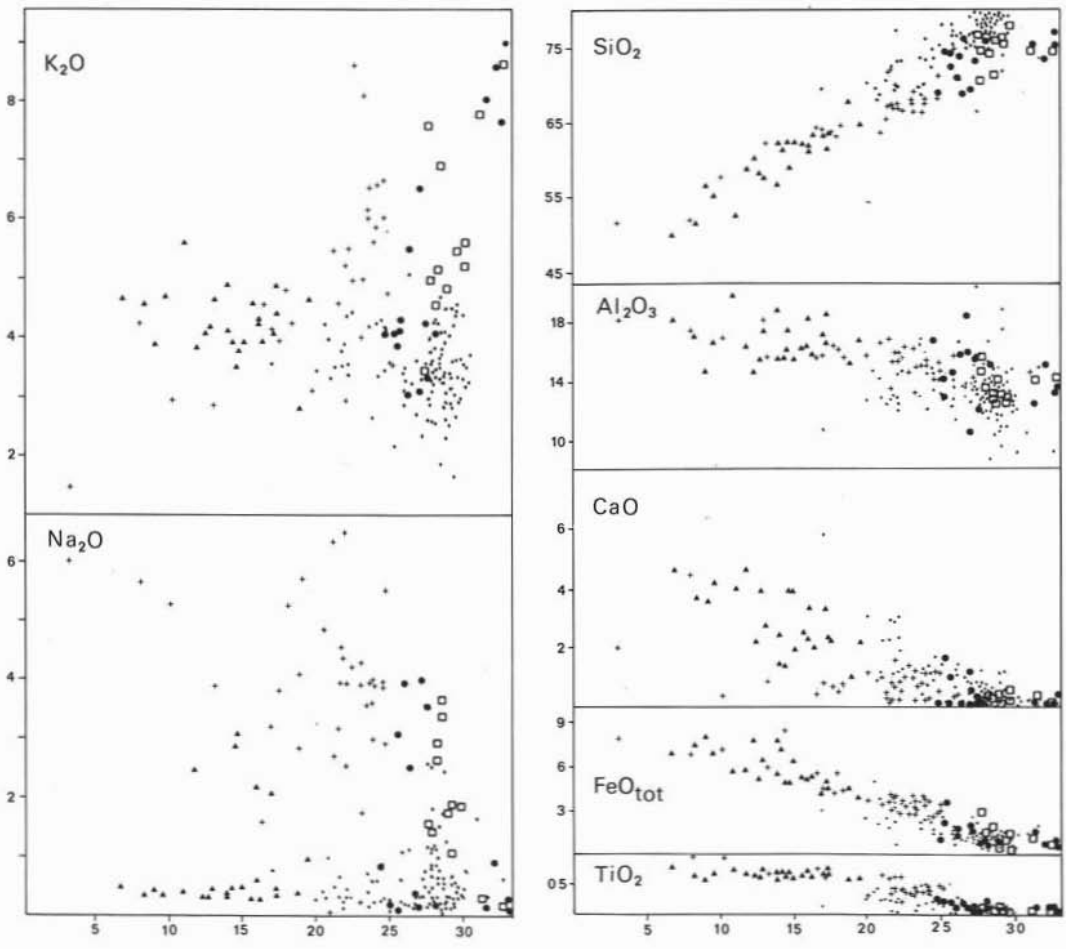

Fig. 4. — Index of Larsen vs. oxides diagram. For explanation see text.

Petrochemistry of the volcanic rocks in the Novazza mine area

The Permian volcanics are well known in the Trentino-Alto Adige region (D'Amico et alii, 1980) as well as in the Val Trompia-Giudicarie area (Origoni Giobbi et alii, 1979), but not in the Bergamasc area. Descriptions of the volcanic sequence can be found in the papers of Weeda J. (1936) and Raasveldt (1939), but no author gives a detailed description of the textural characters and chemistry of these volcanics.

Weeda distinguished a porphyritic sequence at the base of the Collio Formation overlain by more or less schistose arenaceous shales. Dozy (1935) noted that the whole sequence consists of alternating volcano-sedimentary and volcanic rocks. This Author describes near Monte Cabianca the gradual transition between Basal Conglomerate and tuffs. The tuffaceous sediments in the Monte Madonnino area grade upwards to medium grained tuffaceous shales with intercalations of arenaceous tuffs. The sequence is overlain by the porphiritic volcanics of Monte Cabianca.

The texture of the underlying tuffs are very different from those of the porphyritic volcanics.

The tuffs are distinguished into: *a*) conglomeratic tuffs with porphyritic pebbles in a tuffaceous matrix; *b*) tuffs s.s. with phenocrists of corroded quartz, feldspar, decolored biotite and abundant oxides. The groundmass show vitroclastic or spherulitic textures.

TABLE 1

Chemical analyses, CIPW norms of the ignimbrites from the Novazza U-mine area

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	69.53	75.47	73.45	74.07	73.63	77.54	69.37	70.85	72.67	75.54	77.19	75.20	80.32	76.15	74.97
TiO_2	.12	.10	.10	.16	.08	.10	.10	.24	.23	.07	.10	.19	.09	14	19
Al_2O_3	15.69	12.23	15.35	15.48	14.97	11.98	18.07	16.49	14.42	13.30	12.85	12.55	10.30	15.05	13.76
Fe_2O_3	1.49	.35	.49	.84	.47	1.19	1.12	1.45	1.11	.49	.45	1.74	1.71	.54	3.41
FeO	.49	1.31	.33	.59	.32	.30	.59	.23	.50	.26	.29	.45	.17	.26	.27
MnO	.58	.05	.02	.01	.01	.03	.01	.03	.03	.02	.02	.07	.11	.02	.06
MgO	.38	.22	.30	.38	.30	.03	.43	.44	.33	.06	.16	.50	.21	.18	.32
CaO	.56	.00	.27	.00	.00	.27	.00	1.36	1.00	.39	.00	1.60	1.16	.48	.00
Na_2O	.41	.11	4.00	3.93	.93	3.67	2.61	1.17	3.10	.20	.35	.14	.12	.23	.17
K_2O	6.47	7.94	4.13	3.16	8.51	3.42	5.37	4.19	4.24	8.92	7.78	4.18	3.15	4.11	3.91
P_2O_5	.00	.00	.00	.00	.00	.00	.00	.03	.00	.00	.00	.00	.00	.00	.05
H_2O+	3.50	1.72	1.50	1.69	.94	1.08	2.07	3.29	2.07	1.21	1.14	3.54	2.67	2.84	2.68
Somma	99.22	99.50	99.94	100.31	100.16	99.61	99.74	99.77	99.70	100.54	100.33	100.16	100.01	100.00	99.79
Q	40.36	43.18	33.31	38.48	35.16	42.47	32.98	44.52	35.77	39.31	45.12	54.21	64.76	57.78	58.68
C	6.99	3.45	3.80	5.59	4.22	1.75	7.96	7.62	2.91	2.68	3.85	4.88	4.58	9.35	9.36
Or	38.23	46.92	24.40	18.67	50.29	20.21	31.73	24.76	25.05	52.71	45.97	24.70	18.61	24.28	23.10
Ab	3.46	.93	33.84	33.25	7.86	31.05	22.08	9.90	26.23	1.69	2.96	1.18	1.01	1.94	1.43
An	2.77	.00	1.33	.00	.00	1.33	.00	6.55	4.96	1.93	.00	7.93	5.75	2.38	-.32
En/Hy	.94	.54	.74	.94	.74	.07	1.07	1.09	.82	.14	.39	1.24	.52	.44	.79
Fs/Hy	.54	2.04	.07	.14	.08	.00	.01	.00	.00	.00	.03	.00	.00	.00	.00
Mt	2.16	.50	.71	1.21	.68	.77	1.62	.14	1.04	.70	.65	1.12	.64	.49	.51
Hm	.00	.00	.00	.00	.00	.65	.00	1.35	.39	.00	.00	.96	1.26	.19	3.05
Il	.22	.18	.18	.30	.15	.18	.18	.45	.43	.13	.18	.36	.17	.26	.36
Ap	.00	.00	.00	.00	.00	.00	.00	.07	.00	.00	.00	.00	.00	.00	.11
Q	49.19	47.43	36.38	42.57	37.68	45.31	38.00	56.23	41.09	41.95	47.97	67.69	76.75	68.79	70.52
Qr	46.59	51.54	26.65	20.65	53.90	21.56	36.56	31.27	28.78	56.25	48.88	30.84	22.05	28.90	27.76
Ab	4.22	1.02	36.96	36.78	8.42	33.13	25.44	12.50	30.13	1.80	3.15	1.47	1.20	2.31	1.72

1) VB 29 - M.te Cabianca (67089636); 2) VB 33 - M.te Cabianca (67309610); 3) VB 60 - Lago Cabianca (66889670); 4) VB 61 - Lago Cabianca (66889672); - 5) VB 62 - Lago Cabianca (66929650); 6) VB 64 - M.te Cabianca (67309610); 9) VS 61 - Val Pagherola (72809276); 3) VB 93 - Lago dei Curiosi (67909580); 10) VB 94 - Lago dei Curiosi (67469600); 11) VB 95 - Lago Zelto (66389648); 12) VS 7 - Val Sanguigna (69129150); 13) VS 44 - Val Sanguigna (68459110); 14) VS 50 - Novazza (71209116); 15) VS 11 - Gromo (72209130).

The arenaceous tuffs are more similar to sedimentary rocks, with shale intercalations and evident bedding.

RAASVELDT (1939) divided the rocks of the Collio Formation into a « *volcanic series* » and a « *non volcanic series* ». The volcanic series is mostly made up of rocks with evident porphyritic texture and also of vitrophyric tuffs, tuffaceous sandstones and conglomerates with prevailing volcanic material. The non volcanic series or « *Collioschists* » consists of black shales, micaceous phyllites or arenaceous sediments. The black shales are named « *Carona schists* », because they crop out near the Carona village. In RAASVELDT's opinion the porphyritic volcanics of Monte Cabianca are younger than the underlying tuffaceous rocks, and they are closely related to the shales of the « *Carona schists* », because they represent the products of subaqueous or coastal volcanic activity. The amount of erupted material is very abundant, about km^3 3.6, i.e. km^2 2.7 and average thickness of 300 m. These are very fine grained rocks without phenocrysts; when the latter are present

TABLE 2

Chemical analyses, CIPW norms of the ignimbrites from the Val Caffaro, Val Trompia and Upper Group of the Athesian volcanic system (Trentino region)

	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	70.53	71.52	74.44	74.70	76.43	75.72	76.99	77.28	74.47	74.10	75.62	76.64
TiO_2	.15	.38	.05	.00	.16	.15	.11	.09	.17	.16	.15	.04
Al_2O_3	14.48	13.25	13.98	13.79	15.39	12.79	13.88	12.36	12.75	13.52	13.08	12.22
Fe_2O_3	1.07	2.04	.55	.73	.98	1.04	.88	.16	.95	1.66	1.19	1.14
FeO	1.89	.14	.23	.43	.26	.13	.31	.32	.49	.15	.13	.10
MnO	.02	.01	.00	.05	.04	.04	.03	.06	.03	.02	.02	.00
MgO	.61	.25	.12	.10	.16	.25	.07	.15	.14	.23	.14	.11
CaO	.05	.08	.12	.38	.45	.29	.49	.67	.50	.17	.13	.44
Na_2O	1.61	3.41	.20	.30	1.58	1.16	1.85	1.82	2.93	2.85	2.85	3.78
K_2O	7.56	6.86	8.60	7.75	4.10	5.55	4.81	5.26	5.25	5.16	5.44	4.58
P_2O_5	.15	.38	.00	.00	.03	.05	.03	.13	.06	.06	.06	.02
H_2O+	2.05	2.53	1.48	1.74	.57	1.57	.80	.84	1.69	1.11	1.15	1.01
H_2O-	.00	.00	.22	.08	.00	.53	.44	.00	.00	.49	.52	.00
Total	100.17	100.85	99.99	100.05	100.15	99.27	100.69	99.14	99.43	99.68	100.48	100.08
Q	30.55	25.95	39.92	42.20	50.42	46.87	46.74	45.07	36.22	37.23	37.90	36.07
C	3.91	.97	4.12	4.21	7.60	4.46	4.81	2.76	1.48	3.08	2.41	.29
Or	44.67	40.54	50.82	45.80	24.23	32.79	28.42	31.08	31.02	30.49	32.14	27.06
Ab	13.62	28.85	1.69	2.53	13.36	9.81	15.65	15.40	24.79	24.11	24.11	31.98
An	-.73	-2.08	.59	1.88	2.03	1.11	2.23	2.47	2.08	.45	.25	2.05
En/Hy	1.51	.62	.29	.24	.39	.62	.17	.37	.34	.57	.34	.27
Fs/Hy	2.37	.00	.00	.27	.00	.00	.00	.41	.00	.00	.00	.00
Mt	1.55	.00	.59	1.05	.50	.11	.77	.23	1.18	.08	.04	.20
Hm	.00	2.03	.13	.00	.63	.96	.34	.00	.13	1.60	1.15	.99
Il	.28	.31	.09	.00	.30	.28	.20	.17	.32	.30	.28	.07
Ap	.35	.90	.00	.00	.07	.11	.07	.30	.14	.14	.14	.04
Q	34.39	27.22	43.19	46.61	57.29	52.39	51.47	49.23	39.36	40.54	40.25	37.92
Qr	50.28	42.52	54.98	50.59	27.53	36.65	31.30	33.95	33.71	33.20	34.14	28.45
Ab	15.33	30.26	1.83	2.79	15.18	10.96	17.23	16.82	26.94	26.26	25.61	33.62

1) D 5 - Val Caffaro (from CASSINIS et alii, 1975); 2) Caps 21 - Val Caffaro (idem); 3) VT 2 - Val Trompia (from PEYRONEL PAGLIANI et alii, 1965); 4) VT 3 - Val Trompia (idem); 5) MI 128 - Ponte Gardena-Castelrotto (from MITTEMPERGHER, 1958); 6) MI 160 - (idem); 7) MI 143 - (idem); 8) MI 112 - (idem); 9) AA 279 - Val Sarentino (5152800) (from BRONDI et alii, 1970); 10) AA 393 - Val Sarentino (5157020) (idem); 11) AA 276 - Val Sarentino (5153130) (idem); 12) AA 115 - Val Sarentino (5164750) (idem).

they consist of quartz.

As previously noted (see stratigraphical outlines) we distinguish three groups of volcanics: the basal ignimbrite horizon, the intercalated ignimbrites and the « lavas ».

Basal ignimbrite. It is possible on the basis of petrographical investigations, to distinguish two levels:

a) A lower level basically consisting of microcrystalline volcanics with phenocrysts of rounded and corroded *quartz*. *Pumices* and altered *feldspar* are present.

b) An upper level consisting of a well crystallized groundmass, where abundant relics of *pumices, schistose basement,* deformed lamellae of *mica* are found. The vitroclastic textures are well evident, the *quartz* phenocrysts are more abundant than the sericitized *plagioclase*. *Biotite* is completely replaced by calcite, quartz, colourless chlorite and Fe-oxides.

Intercalated ignimbrites. In all these volcanics the corroded *quartz* phenocrysts (15 % modal content) are less abundant than the plagioclase phenocrysts (50 % modal content). *Plagioclase* (10 % An) is present as isolated unaltered crystals as well as aggregates with Albite or Albite-Carlsbad twinning. Rarely present is *biotite* (1.6 % modal content) in the form of completely altered lamellae. Idiomorphic crystals of *zircon* and sagenitic *rutile* are very diffused.

These ignimbrites exhibit compacted and welded glass shards in the groundmass.

Lavas. They show porphyritic texture with phenocrysts of *plagioclase* and, less frequently, of chloritized *biotite* and serpentinized *pyroxene*. Quartz is completely absent.

Generally the lavas are strongly altered with sericitized plagioclase; an An content of about 25 % was determined on unaltered phenocrysts.

The amount of phenocrysts is generally higher than that of the ignimbrites. The groundmass shows microcrystalline and micropegmatitic textures.

Chemical analyses were made both on ignimbrites and on lavas in order to compare their bulk chemical composition with that of the permian volcanics of the Trentino and Val Trompia regions.

Chemical analyses of the intercalated ignimbrites occurring in the Val Seriana between the Novazza mine and the Val Sanguigno, and in Val Brembana on the northern slope of Monte Cabianca were carried out in the Institute of Mineralogy, Petrography and Geochemistry of the University of Milan. The results are listed in table 1.

In the SIMUR laboratories chemical analyses were carried out on all the cores taken in these volcanics. The results of the analyses can be found at the AGIP Geological Laboratory or at the Novazza mine Offices.

Analyses from literature (MITTEMPERGHER, 1962; BRONDI et alii, 1970) are also reported in table 2.

The diagrams of SiO_2 vs. alkali, Index of Larsen vs. oxides and Q-Or-Ab are represented in figg. 3-4-5.

The most striking features that can be recognized in all the diagrams is the difference in silica content between the ignimbrites (about 75-80 %) and the « lavas » (about 60 %).

The basal ignimbrites of Novazza have an intermediate silica content (about 70 %).

The « lavas » of the Bergamasc Collio Formation seem to be more basic than the volcanics of the Brescian and Trentino-Alto Adige region (*horyzontal crosses*). The silica content of the Novazza U-mine ignimbrites (*small dots*) is higher than that of the other permian ignimbrites,

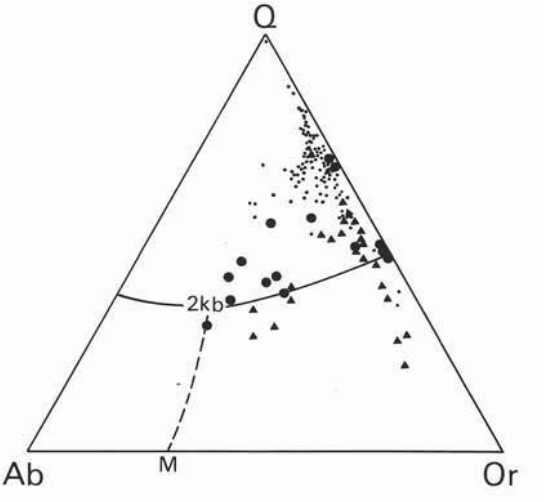

Fig. 5. — Q-Or-Ab diagram. For explanation see text.

but if we take into consideration the Larsen Index vs. Na_2O diagram we can see that the apparent enrichment in SiO_2 is due to the depletion of Na_2O (fig. 4). The values of K_2O are scattered as in the other volcanic rocks; the ignimbrites of Monte Cabianca show a K_2O content, higher than 6 %, similar to that of the Val Trompia ignimbrites, while the ignimbrites of Novazza have

a K_2O content lower than the ignimbrites of the Trentino-Alto Adige region. In the Larsen Index vs. Na_2O diagram two groups of ignimbrites can be individuated, in fact the full circles with Na_2O major than 2 % correspond to the ignimbrites of Monte Cabianca without mineralization; the full circles and the dots that lie below 1 % Na_2O, represent the ore-bearing ignimbrites of Novazza.

The U-mineralization free ignimbrites of Monte Cabianca show a sodium content similar to that of the Val Trompia ignimbrites (open squares), while the ignimbrites of the Trentino region show a soda content lower than 2.

In the Q-Or-Ab diagram (fig. 5) only the volcanics of the Bergamasc basin are represented. Also in this diagram it is possible to note that the ignimbrites and the « lavas » of the Novazza mine fall near the Q-Or side, while the mineralization free ignimbrites of Monte Cabianca fall as the usual rhyolitic volcanics, near the cotectic minimum.

Since it is likely that all the permian volcanics have a common origin by anatexis of crustal material, the presence of post-magmatic phenomena, responsible of the « shifting » of the samples out of the area of usual magmatic rocks, is again demonstrated.

Mineralization of the Novazza mine

The main uranium mineralization occurs within the first intercalated ignimbritic horizon. Some minor uranium occurrences have been found also in the underlying basal ignimbrite. No uranium occurrences are present in the other Collio levels.

The single ore bodies are generally lens shaped and elongated ENE-WSW, with a length width ranges from 50 to 20 metres.

The boundaries of these lenses are not clear cut (except at the bottom). As a whole, the uranium mineralization is roughly parallel to the edge of a paleoslope of the crystalline basement.

Pitchblende is the only uranium mineral occurring in the deposit. In the low grade zones it occurs either finely dispersed in the ground-mass of the rock or is pseudomorph of sericitized *feldspar* or *biotite* crystals; these impregnation structures are fairly typical and can be clearly observed at the edges of the ore bodies. Where the mineralization is high grade, *pitchblende* occurs as the infilling of microfractures or it replaces the ignimbritic groundmass. Sometimes it is possible to observe small lenses and patterns of veinlets consisting almost entirely of pitchblende, concentrated by remobilization process.

The mineralogical association is the following (in order of decreasing abundance): *blende, pitchblende, pyrite, arsenopyrite, marcasite, galena, « Pb-Mo sulphide », tetrahedrite, chalcophyrite.*

Whenever a fair amount of pitchblende is present, it displays colloidal deposition structures: framboids of minute spherulites or botroidal structures, with radial fissures often re-cemented by blende or (rarely) by pyrite, or reniform structures with transversal segmentation.

This pitchblende is always closely associated with blende, both in its original deposit and in the massive remobilization structures, where it is also accompanied by pyrite, marcasite, galena, arsenopyrite, tetrahedrite and an interesting mineral known as « Pb-Mo sulphide ».

The main sulphides, like blende, pyrite and arsenopyrite, show a larger independent diffusion from uranium: a yellow crystalline blende phase is dispersed in the groundmass of the ignimbritic rock, while a red colloidal blende (« *Schalen Blende* ») appears exclusively in the remobilized structures.

A multiple correlation study among uranium and 28 other elements has been made by step-wise approach, using the results of chemical analysis on 153 samples from drill hole cores. Further the same data have been processed by factorial analysis (R mode).

The most significant results obtained are:

a) very high direct correlation among U, Sb, Pb;

b) high inverse correlated between U and F;

c) factorial analysis has put into evidence two inverse correlations (silica-lithophiles;

silica-alkalis); direct relationship among U, Sb, Pb and B, Cu, As, Mo; a correlation between Zn and U or other sulphides does not seem to be possible.

The above results, supported by petrographical and minerographical observations, suggest a permian genesis of the uranium mineralization. Such genesis should be related on one side to the exalative volcanic activity (creation of phisical-chemical environment), on the other side to the leaching of the same volcanic rocks (uranium has been leached out in favourable host structure by percolating waters).

Conclusions

The volcanics of the Collio Formation in the Novazza U-mine are mostly ignimbrites and to a lesser extent, lavas chemically ranging from rhyolites to dacites.

The age of the volcanics is, on the basis of geological and paleobotanical data, permian. Most likely the parental magma as for the other permian rhyolites (ORIGONI GIOBBI et alii, 1979; D'AMICO et alii, 1980) was formed by anatexis of crustal material.

As a whole the volcanics of the Collio Formation are strongly deuterized: these rocks are supposed to have undergone post-consolidational phenomena that altered their original composition and texture. As far as the U-mineralization is concerned, we can suppose that leaching of Na and enrichment of U are cogenetic though not necessarly strictly contemporaneous.

The U enrichment is clearly younger than the ignimbrite deposition, and also a little younger than the phenomena that caused deuteresis and the formation of the widespread sulphide mineralization, but can be considered to be permian too.

In the Bergamasc area the rocks of the Collio Formation are slightly schistose: schistosity planes as well as fold axial planes show an EW direction and are almost vertical (BERNASCONI, 1970).

On the basis of the stratigraphical and petrographical data we can easily correlate the Collio Formation of the Brescian Valleys with the Collio Formation of the Val Seriana and the Val Brembana. The volcanics interbedded in the permian sedimentary sequence seem to be more similar to the volcanics of the Trentino region (Upper Group of the Athesian volcanic System) than to those of the Val Trompia.

The U-mineralization although fairly diffused in all the permian volcanics, is highly concentrated in the Novazza area because the structural setting favourable to the circulation of the mineralizing fluids.

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