GEOLOGICAL AND MINEROCHEMICAL ANALYSIS OF HYDROTHERMAL MANIFESTATIONS ASSOCIATED TO THE AOSTA-RANZOLA FAULT (ITALIAN WESTERN ALPS)

ANNA VICIDOMINI

Dipartimento di Scienze della Terra, Università di Torino, Via Valperga Caluso 35, I-10125 Torino

INTRODUCTION

The aim of this work is the geological and minerochemical analysis of hydrothermal manifestations associated to the Aosta-Ranzola fault in the middle Aosta Valley (from Saint Vincent to Fenis) and between the Ayas and Gressoney Valleys.

The Aosta-Ranzola fault is known as an important post-metamophic E-W oriented half-graben type fault system consisting of a N dipping master fault and a number of conjugate and secondary faults (Ratto, 1998; Gianotti, 1999; Bistacchi *et al.*, 2000, 2001). Its eastern termination is debated: according to Gouffon (1993), the Aosta-Ranzola fault extends up to the Canavese line, through the entire Sesia-Lanzo Zone, while according to Bistacchi *et al.* (2000, 2001) its eastern end occurs at the Ranzola pass, where it branches into the NE-trending Ospizio-Sottile line. It runs as far as Aosta to W.

Evidences of hydrothermal circulation along the Aosta-Ranzola fault and related structures are represented by gold-bearing mesothermal veins in Ayas Valley (Diamond, 1986) and by fault rocks strongly affected by hydrothermal alteration, partially analysed by Ratto (1998) in the middle Aosta Valley. The latters are mainly composed of ultramafic rocks interested by carbonatation (listvenite) related to interaction with fluids characterized by high CO_2 activity.

In the studied area, the Aosta-Ranzola fault is E-W oriented with local NE-SW deflection. It occurs as an about tens to hundreds metres thick deformation zone with a kilometric persistence. Along the right side of the middle Aosta Valley the fault rocks crop out discontinuously for nine kilometres. Mesoscale studies has shown slices principally related to Piemonte Zone (with decimetric to metric thickness) that suggest Aosta-Ranzola fault setting along tectonic inheritance zone.

The Aosta-Ranzola fault is associated to a mainly E-W fracture cleavage dipping to the N (50-60°) that shows extensional reactivation suggested by hooked cleavage, S-C structure, antithetic Riedel shears and NNE-SSW minor faults along local NE-SW deflection. These minor faults are characterized by steps that also suggest extensional regime.

In the Gressoney Valley the Aosta-Ranzola fault continues E of the Ranzola pass in disagreement with the remote sensing approach adopted by Bistacchi *et al.* (2000). In this area, aplitic and pegmatitic dikes, not reported previously, have been found within and parallel to the main shear zone. These dikes mainly consist of K-feldspar and quartz; their mineral assemblages, the crosscutting relationships with the greenschist facies schistosity of the "gneiss minuti" and the petrographic features suggest that they represent acidic differentiates related to the periadriatic magmatism. In this sector the carbonatation associated to fault zone is absent, the alteration being only represented by some seriticization along fractures within dikes and host rocks (both showing a cataclastic texture). Prehnite veins, coeval gouge fault nearly parallel to main shear zone and pseudotachylite set along anthitetic Riedel shear probably testify the seismic activity of this fault system.

HYDROTHERMAL ASSOCIATIONS (MIDDLE AOSTA VALLEY)

In the middle Aosta Valley along the main shear zone there is evidence of:

1) an earlier fluid circulation characterized by talc-bearing alteration affecting the ultramafic rocks. Talc is in equilibrium with serpentine replacing diopside or olivine;

2) a subsequent, strongly developed fluid circulation responsible of intense rock carbonatation along the Aosta-Ranzola fault. A complex shear fault evolution is recorded, accompanied by fluids circulation. The rock fault analysis stresses the occurrence of a multistage hydrothermal evolution, with the recognition of 5 to 6 hydrothermal stages named E_n sometimes spaced out by cataclasis and/or brecciation. The hydrothermal stages and relative chronology have been distinguished based on:

- cross-cutting relations between different vein systems and alterations;
- microstructural features and composition of different veins and alterations.

Moreover wallrock nature (and its possible reaction with hydrothermal vein fluids) has been distinguished to evaluate its potential effect on fluid chemistry and possible ore mineralization.

A first stage (E_1) is generally given by carbonatation of some minerals (diopside, tremolite, serpentine in ultramafic rock and actinolite in mafic rock); the rock texture is still partially preserved, and alteration often follows the rock schistosity. During a second stage (E_2) granular carbonate veins form; these veins are crosscut by low angle carbonate + quartz + hematite (E_3) veins which are, in turn, fractured and cemented by E_4 veins, principally composed of carbonate and showing deformational viscous regime. The latest stages are represented by E_5, undeformed carbonate granular veins or quartz + kaolinite + anatase; a final filling stage (E_6), represented by zeolite and opale, is locally observed.

Such hydrothermal evolution is particularly well recorded in the ultramafic rocks, which may still contain relics of antigorite, tremolite, diopside, spinel and magnetite and display all the six hydrothermal associations. E_1 is characterized by fine-grained aggregates of Fe-magnesite and quartz. Relative bulk abundances (qualitative estimation) of carbonate and quartz related to this stage are broadly in agreement with a dominant reaction like serpentine + magnetite + CO_2 = Fe-magnesite + quartz. This association is often characterized by mylonitic fabric with ribbon of quartz or Fe-magnesite and S-C structures. Sometimes relicts magnetite partially substituted by hematite have wrapped by milonitic fabric. E_2 is represented by vein systems (Fe-magnesite and minor Fe-dolomite) that cut (at low angle) milonitic fabric previously described. E_3 is characterized by vein systems of Fe-magnesite + quartz + hematite fine-grained aggregates. These veins are cataclased and cemented by E_4 veins of Fe-magnesite rim and quartz core. E_5, undeformed vein systems is characterized by granular Fe-magnesite rim and Fe-dolomite core. In these rocks the hydrothermal carbonate of all stages is always a (sligtly zoned) Fe-magnesite, apart from carbonate related to E_2 and E_5 stage, which is instead Fe-dolomite. A final filling stage E_6, not always present, is characterized by zeolites and opale. Compared with the typical listvenite, the carbonatized serpentine schists are characterized by the absence of phyllosilicates, which are instead a common wallrock alteration product (as fuchsite) in ultramafite crosscut by the mesothermal veins in the Ayas Valley (Diamond, 1986). Metallic phases are rare, being mostly represented by corroded chalcopyrite, vaesite (NiS_2) and millerite (NiS). These metallic phases have been observed in the early stages E_1 and E_2. No gold has been observed in this "listvenitic" rocks in spite of Böhlke (1989) study. In his paper he shows that starting from fluids that give auriferous mesothermal veins, ultramafic and granitic rocks better destabilize Au in solution and as a consequence make it precipitate during fluid-host rock interaction reactions. In fact in other alpine orogenic zones (Lavagnina Lakes, Voltri Group) there

are serpentinites that interact with auriferous fluids, resulting in rich auriferous listvenite. A possible hypothesis of this discrepancy is discussed after.

Carbonatized metabasite also occur along the Aosta Ranzola fault. They typically contain relics of amphibole and Fe-Ti oxide, replaced by ankerite and rutile + Fe-dolomite respectively. Mafic rocks are also characterized by mineral association that suggests a detrital origin (Ratto, 1998). In these rocks five hydrothermal associations have been observed.

Carbonates range in composition from ankerite to Fe-dolomite. Fuchsite also occurs. In these rocks there are phyllosilicates that could hypothetically be related to the host rocks inheritance (pre-hydrothermalism relics) but there aren't clear petrographic relations. E_1 is generally characterized by fine-grained aggregates of ankerite and minor quartz that replace amphiboles. E_2 is constituted by granular Fe-dolomite veins in equilibrium with rutile and quartz veins. E_3 is characterized by fine-grained aggregates of ankerite + quartz + hematite. E_4 is a network of ankerite veins. The last stage of evolution E_5 is characterized by the ubiquitous presence of kaolinite + quartz + anatase. Rare, corroded metallic phases occur, namely pyrite, bravoite $(Ni,Fe)S_2$, vaesite NiS_2, and gersdorffite $(Ni,Fe,Co)AsS$. These crystals fabric varies from sub-idiomorphic to xenomorphic and is attributed to the early stages (E_1 and E_2) of the hydrothermal evolution.

FLUIDS INCLUSIONS (MIDDLE AOSTA VALLEY)

Quartz veins related to E_2 contain numerous small inclusions classified according to petrography in four inclusions generations: type I) early vapour-rich inclusions, as clusters in less deformed crystal portions. Raman analysis did not detect CO_2 in appreciable amount; type II, III, IV) secondary inclusions. Microthermometry analysis was possible only on II (intracrystalline) and IV (intercrystalline) secondary inclusions. For type II) biphase (L+V) inclusions microthermometry data ($T_f = -38°C$; $T_m = -6.7°C$; $T_h = 222°C$) suggest entrapment of a moderate salinity aqueous fluid containg besides NaCl also a minor amount of other dissolved salts (KCl, $MgCl_2$ and/or $FeCl_2$ and $CaCl_2$. Type IV biphase (L+V) inclusions show a similar salinity but lower homogenization temperature (Th = 188°C). In both generations chlatrate formation has not been observed, suggesting a CO_2 content ≤ 1.5 moles %.

These data suggest the analyzed fluid inclusions population represent the circulation of moderate salinity fluids (Type II: 10.1 %, Type IV: 9.7% $NaCl_{eq}$), with fluid density ranging from 0.92 (Type II) to 0.95 g/cc (Bakker, 2003).

DISCUSSION

There are important differences among sectors related to Aosta-Ranzola fault.

In the middle Aosta Valley (Western sector) fault rocks testify to a complex multiphase evolution, characterized by several stages of brittle deformation accompanied by fluid circulation; strong carbonatation occurs, with formation of carbonatized serpentinite devoid of potassic mica; sulphides appear to be only stable during early hydrothermal stages; gold is notably absent.

A different picture is observed in the Ayas Valley, which has been studied in detail by different Authors (Diamond, 1986; Diamond & Wiedenbeck, 1986; Diamond, 1990; Diamond & Marshall, 1990; Pettke & Diamond, 1997; Pettke & Frey, 1996; Pettke *et al.*, 1999, 2000; Yardley *et al.*, 1993).

The hydrothermal system in the Ayas Valley consists of gold-bearing quartz-carbonate mesothermal veins which occur within the Arcesa-Brusson Unit, mostly consisting of orthogneiss (Mori,

1991; Diamond, 1990), and in the geometrically overlying Piemonte Zone. The veins are located along minor order structures related to the Aosta Ranzola fault more than along the main fault zone. When they crosscut serpentinite the formation of a typical listvenite, composed of Fe-magnesite, Fe-dolomite, quartz and fuchsite is observed. It is mineralized to pyrite, galena, copper and gold (Richard, 1981). In his landmark paper, Diamond (1990) described in detail the nature and evolution of the gold-bearing quartz vein fluids (Ayas Valley), which are characterized by a main stage composed of principally H_2O-CO_2 three-phase inclusions (containing liquid CO_2, vapour CO_2 and liquid H_2O) and Cl, Na, K, S, Ca, Mg, CH_4 fluids. Author's estimate temperatures range from 300°C at 1300 bar to 240°C at 600 bar; although the density of the ore bearing solution progressively increases throughout this interval, its major element composition remains almost constant.

In Gressoney Valley there is not carbonatation but only seriticization. The link between the two kinds of alteration is not clear.

Apparent differences between previously mentioned inclusions and Diamond's data are linked to different environment in which observations fall. The Diamond (1990) inclusions come from gold-bearing quartz veins located along minor order structures associated to Aosta-Ranzola fault where there is not the complex structural evolution recorded along main shear zone. However the widespread carbonatation suggests that circulation of H_2O-CO_2 fluids occurred both in the middle Aosta Valley and in Ayas Valley. This hydrothermal stage is not preserved anymore in fluid inclusions in the Aosta Valley because structural reworking involved reopening of the system. In this context, aqueous fluids characterized by relatively low homogenization temperature are likely linked to late aqueous fluids circulating at decreasing temperature. Homogenization temperatures measured suggest, for the studied inclusions generations, minimum temperatures of 220 to 190°C; in absence of baric constraints, P conditions should surely be lower than the minimum conditions (600 bars) determined by Diamond (1990) for the mesothermal veins in the Ayas Valley.

Although the study of fluids source has not been the main aim of this work, the occurrence of aplitic and pegmatitic dikes probably related to the periadriatic magmatism in Gressoney Valley underlines a spatial link between Aosta-Ranzola fault and the magmatism itself; further studies are needed in order to clarify a possible genetic connection between magmatic cycle and hydrothermal circulation.

REFERENCES

Bakker, R.J. (2003): Package FLUIDS 1. Computer programs for analysis of fluid inclusion data and for modelling bulk fluid properties. *Chem. Geol.*, **194**, 3-23.

Bistacchi, A., Dal Piaz, G.V., Massironi, M., Zattin, M., Balestrieri, M.L. (2001): The A-R extensional fault system and Oligocene-Present evolution of the Austroalpine-Penninic wedge in the northwestern Alps. *Int. J. Earth Sci.*, **90**, 654-667.

Bistacchi, A., Eva, E., Massironi, M., Solarino, S. (2000): Miocene to Present kinematics of the NW-Alps: evidences from remote sensing, structural analysis, seismotectonics and thermochronology. *J. Geodynam.*, **30**, 205-228.

Böhlke, J.K. (1989): Comparison of metasomatic reactions between a common CO_2-rich vein fluid and diverse wall rocks: intensive variables, mass transfers, and Au mineralization at Alleghany, California. *Econ. Geol.*, **84**, 291-327.

Diamond, L.W. (1986): Hydrothermal geochemistry of late-metamorphic gold-quarz veins at Brusson, Val d'Ayas, Pennine Alps, NW Italy. PhD Thesis, ETH Zürich, 256 p.

Diamond, L.W. (1990): Fluid inclusion evidence for P-V-T-X evolution of hydrothermal solutions in late-Alpine gold-quartz veins at Brusson, Val d'Ayas, northwest Italian Alps. *Am. J. Sci.*, **290**, 912-958.

Diamond, L.W & Marshall, D.D. (1990): Evaluation of the fluid-inclusion crushing-stage as an aid in exploration for mesothermal gold-quartz deposits. *J. Geochem. Explor.*, **38**, 285-297.

Diamond, L.W. & Wiedenbeck, M. (1986): K-Ar radiometric ages of the gold-quartz veins at Brusson, Val d'Ayas, NW Italy: evidence of mid-Oligocene hydrothermal activity in the Northwestern Alps. *Schweiz. Mineral. Petrog. Mitt.*, **66**, 385-393.

Gianotti, F. (1999): Geological and geomorphological evidence for the Aosta-Ranzola fault along the Aosta-Valley. *Mem. Sci. Geol.*, **51**, 498-501.

Gouffon, Y. (1993): Géologie de la nappe du Grand St-Bernard entre la Doire Baltée et la frontière suisse (Vallée d'Aoste-Italie). *Mém. Géol. Lausanne*, **12**, 147 p.

Mori, D. (1991): Geologia e struttura dell'area Arcesaz-Brusson. Tesi di laurea, Univ. di Torino, 191 p.

Pettke, T. & Diamond, L.W. (1997): Oligocene gold-quartz veins at Brusson, NW Alps: Sr isotopes trace the source of ore-bearing fluid to over a 10 km depth. *Econ. Geol.*, **92**, 4, 389-406.

Pettke, T. & Frey, R. (1996): Isotope systematics in vein gold from Brusson, Val d'Ayas (NW Italy). 1. Pb/Pb evidence for a Piemonte metaophiolite Au source. *Chem. Geol*, **127**, 111-124.

Pettke, T., Diamond, L.W., Villa, I.M. (1999): Mesothermal gold veins and metamorphic devolatilization in the northwestern Alps: The temporal link. *Geology*, **27**, 7, 641-644.

Pettke, T., Diamond, L.W., Kramers, J.D. (2000): Mesothermal gold lodes in the north-western Alps: A review of genetic constraints from radiogenic isotopes. *Eur. J. Mineral.*, **12**, 213-230.

Ratto, S. (1998): Il versante destro della Valle d'Aosta tra Pollein e Saint Vincent: cartografia geologica di dettaglio e studio delle mineralizzazioni. Tesi di laurea, Univ. di Torino, 213 p.

Richard, A. (1981): Le district aurifère de Challand (Val d'Aoste, Italie): githologie, géochimie et metallogénie de l'or. These de doctorat de specialité, Univ. de Grenoble, 223 p.

Yardley, B.W.D., Banks D.A., Bottrel, S.A. (1993): Post-metamorphic gold-quartz veins from NW Italy: the composition and origin of the ore fluid. *Mineral. Mag.*, **57**, 407-422.