2007

Gold bearing veining linked to transcrustal fault zones in the Transantarctic Mountains (northern Victoria Land, Antarctica)

L. Crispini
University of Genova

G. Capponi
University of Genova

L. Federico
University of Genova

F. Talarico
Università Degli Studi di Siena, talarico@unisi.it

Gold bearing veining linked to transcrustal fault zones in the Transantarctic Mountains (northern Victoria Land, Antarctica)

L. Crispini,[1] G. Capponi,[1] L. Federico,[1] and F. Talarico[2]

[1]Dip.Te.Ris, University of Genova, C.so Europa 26, Genova, Italy
[2]Dipartimento di Scienze della Terra, University of Siena, V. Laterina 8, Siena, Italy

Summary Gold mineralization is associated with the paleo-Pacific margin of Gondwana and is related to processes of subduction/accretion and magmatism. Northern Victoria Land (Antarctica) was part of this margin during the Paleozoic, however no occurrence of gold has been reported up to now in the Transantarctic Mountains. Here we describe for the first time gold-bearing quartz veins in northern Victoria Land. The veins are hosted primarily by metabasalts and occur in a brittle-ductile high strain zone with curved geometry and reverse kinematic. Veins are extensional and shear veins; they often have ribbon/banded texture typical of crack and seal processes. Preliminary petrographic investigations point to strong hydrothermal alteration with growth of chlorite + quartz and then of sericite + carbonates + sulphides approaching the vein. Available data are discussed with the aim to understand the origin of the gold deposit and to frame it in the regional tectonic evolution.

Citation: Crispini, L., G. Capponi, L. Federico, and F. Talarico (2007), Gold bearing veining linked to transcrustal fault zones in the Transantarctic Mountains, in Antarctica: A Keystone in a Changing World - Online Proceedings of the 10th ISAES, edited by A.K. Cooper and C.R. Raymond et al., USGS Open-file Report 2007-1047, Extended Abstract 212, 4 p.

Introduction

Paleozoic gold formation occurred along all the active paleo-Pacific margin of Gondwana (Goldfarb et al., 2001), for instance in what is now eastern Australia, the South Island of New Zealand and southern South America. The Antarctic continent was part of this long margin, but up to now gold has been reported only from the Antartic Peninsula (Rowley et al., 1991) in the equivalent of the Meso/Cenozoic andean orogen.

Northern Victoria Land (NVL, Antarctica) was adjacent to south-eastern Australia and New Zealand during the Paleozoic and the Early Paleozoic Delamerian and Lachlan orogenies of Australia are supposed to continue in NVL (e.g. Flöttmann et al., 1993; Bradshaw et al., 1997).

Here we report for the first time the occurrence of gold-bearing quartz mineralization in NVL. The vein architecture and the structural control on the mineralized veins, carefully investigated in the field during the XXI Italian Antarctic Expedition, are presented together with data on the petrographic and microstructural features. The origin of the gold deposit, its linkage to the Early Paleozoic orogeny and the emplacement of the Devonian Admiralty Intrusives is discussed.

Geological setting

NVL can be subdivided into three NW-trending domains (e.g. Gair et al., 1969, Kleinschmidt & Tessensohn, 1987), known as the Wilson, Bowers and Robertson Bay terranes.

This configuration results from an Early Paleozoic convergent regime at the paleo-Pacific margin of Gondwana that produced the Ross-Delamerian Orogeny. The Wilson terrane (WT) is made up of low- to high-grade metasedimentary rocks, intruded by Cambrian-Ordovician granitoids (Granite Harbour Intrusives). The Bowers terrane (BT) consists of low-grade metasedimentary and metaigneous rocks of Middle Cambrian-Early Ordovician age. The Robertson Bay terrane (RBT) is made up of a very low grade to low grade turbiditic sequence; its uppermost portion ranges in age from Late Cambrian to Early Ordovician (Wright and Brodie, 1987).

The terrane arrangement in NVL is increasingly interpreted as a fossil arc-trench system resulting from a westward-directed subduction at the paleo-Pacific margin of Gondwana during the Ross orogeny (Finn et al., 1999; Ferraccioli et al., 2002; Federico et al., 2006). In this framework, a correspondance between the WT, BT and RBT with the continental magmatic arc, the forearc/back-arc and the trench sedimentary sequence, respectively, can be envisaged.

The contact between the BT and the WT is the Lanterman Fault Zone (Bradshaw et al., 1982). This structure experienced a multiphase tectonic evolution (Capponi et al., 1999; Crispini et al., 2006) and is decorated by metasomatic rocks such as listvenites, albitites and carbonatised albitite which contain native gold grains included in albite, chlorite and amphibole crystals (Crispini & Capponi, 2002). The contact between the BT and the RBT is known as the Leap Year Fault. In the Millen Range between the two terranes there is a low-greenschist metamorphic belt (the Millen Schists) made up of two units separated by a thrust surface (Capponi et al., 2003 and references therein). After the Paleozoic Ross orogeny, all the three terranes were intruded by the Admiralty Intrusives, a calc-alkaline association of Devonian-Carboniferous age (Borg, 1984).

Geology and structures of the study area

The gold-bearing quartz-carbonate mineralization is hosted in the BT, in the eastern sector of the Bowers Mountains (Ob'Bay: Transantarctic Mountains, northern Victoria Land).

The structural setting of this area is characterized by a NNW-SSE trending belt where folded rocks of the BT are bounded to the W by the tectonic contact with the WT and to the E by the high strained zone of the Millen Schists.

Here the BT is characterized by outcrops of the Sledgers Group (Wodzicki and Robert, 1986) that consists of low-grade metavolcanic rocks (Glasgow Formation) and metasediments with volcaniclastic components (Molar Formation) of Middle Cambrian age (Laird and Bradshaw, 1983). The Glasgow Formation is composed mainly of massive and banded flows, pillow lavas, volcanic breccias and tuffs of basic to intermediate composition (Jordan et al., 1984). The Molar formation consists of sandstone, conglomerate, mudstone and subordinate limestone. The Glasgow Formation overlies the Molar Formation and locally conformably underlie and interfinger with it (Wodzicki and Robert, 1986).

The rocks of the Sledgers Group show a Ross-related metamorphic overprint in greenschist to low greenschist facies. They are deformed by NW-SE-trending folds, with subvertical axial plane and axes plunging to both the NW and the SE. The Admiralty Intrusives crop out at a distance of 250-300 Km from the studied outcrop, which show no evidence of contact metamorphism.

The gold-bearing quartz-carbonate mineralization is hosted in metabasalts with thin layer (a few m thick) of metasedimentary rocks. Quartz-carbonate veins occurs in a brittle-ductile high strain zone superimposed on the earlier regional metamorphic foliation and folds. The high strain zone is characterized by foliated fault rocks with S-C structures, widespread veining, and hydrothermal alteration of the host rocks. It can be interpreted as the result of repeated events of hydraulic fracturing and mineral crystallization in a transpressional regime of deformation.

The main gold-quartz vein is up to 2 m wide; it has a curved geometry, strikes N-S and dips to the E. The veins architecture, typical of a composite Riedel shear structure, and the kinematic indicators suggest a reverse kinematic during the development of the veining events. Veins are extensional and shear veins; they often have ribbon/banded appearance and texture typical of crack and seal processes (Ramsay, 1980). The main vein is a composite-textured vein: close to the wallrock quartz is in elongate crystals with syntaxial geometry, in the middle part it is buck and has cataclastic texture, whereas in the inner portion we find comb quartz in euhedral crystals.

Veins are surrounded by zones of wall-rock alteration, which was generally not texturally destructive; the host rocks are partially to completely transformed into Fe-Mg carbonate-rich rocks, greenish to brownish in colour. The alteration zone is approximately up to 500 m wide and is bounded by two steeply dipping faults.

Petrographic and microstructural features

Metasedimetary wall-rocks are fine-grained meta-sandstones, with abundant detrital grains of quartz, plagioclase, white mica, opaque minerals, tourmaline and rare lithic fragments of cherts and meta-quarzarenites. Neoformed, fine-grained white micas and recrystallized very fine-grained quartz are aligned along a pressure-solution cleavage. Plagioclase is usually replaced by carbonate+sericite microaggregates. Veins of quartz and minor carbonate are common, aligned sub-parallel to the cleavage and at places weakly folded.

Far (c.a. 10 m) from the gold-bearing quartz veins, wall-rock metabasalts show relics of plagioclase (in subhedral laths partially sericitized), augite and ilmenite, sometimes skeletal, within a fine-grained aggregrate of pale green Ca-amphibole, Fe/Mg- chlorite and sericite. The variolitic texture is locally still recognizable. Evidence exhists of at least three cross-cutting generations of veins, filled by: I) carbonate +/- green chlorite; II) green chorite; III) Mg-rich chlorite +/- ores.

Closer to the vein, metabasalts shows a marked increase in sericite and opaque minerals (mainly rusty/reddish grains of probable hematite/limonite, and subhedral sulphides), but with the original subophytic texture still recognizable. Augite relics are rare and often replaced by sub-microscopic rusty aggregates. The pristine feldspar is usually completely replaced by sericite and carbonate, or the rocks shows a marked recrystallization with abundant secondary plagioclase (albite), carbonate, sericite and clinozoisite-epidote. In these rocks veins consist of 1) quartz, 2) chlorite + sericite + carbonate + opaque minerals, or 3) albite +/-chlorite +/- pale green Ca-amphibole. Vein type 3) is apparently restricted to the albite-rich recrystallized metabasalts.

Approaching the core of the alteration zone, phenocrysts of plagioclase and pyroxene are completely replaced by Fe-chlorite + quartz and ores by sphene; veinlets of chlorite and of quartz + carbonate dissect the altered rock and are in turn overgrown by patches of calcite. The basalts are therefore completely silicified and chloritized.

Progressive hydrothermal alteration induces coalescence of the carbonate crystals (belonging to the magnesite-siderite solution series) and sericitization (micas have muscovitic composition). Pyrite and arsenopyrite growth, often with pressure fringes of chlorite and quartz.

The altered rock is cross-cut by quartz-carbonate veins; in some case evidence exhists of repeated cracks with earlier chlorite veins re-opened and filled with quartz and carbonate (mainly ankerite), some muscovite and minor apatite. In most cases the growth is syntaxial with early carbonate crystals near the wall-rock and quartz towards the core.

Some veins are laminated veins and contain inclusion bands of wall-rock; the mineral growth is "displacement-controlled" and result from cyclic microcrack opening at different sites followed by sealing (Ramsay, 1980). According to Vearncombe (1993) these textures are diagnostic of mid-crustal levels. Other veins are massive, without oriented mineral textures. Quartz vein crystals often show clear evidence of intracrystalline deformation (undulose extinction, deformation bands, subgrains) and dynamic recrystallisation which eventually leads to complete replacement of the original crystals by a microcrystalline aggregate. Some veins are characterized by tourmaline growth.

Most altered samples, which display a complex anastomosing vein network, have a reddish colour resulting from widespread alteration of Fe-Mg carbonates into Fe-Mg oxides. Preliminary EMP and SEM data point to different generation of white mica alteration, with K-rich micas replaced by Na-rich micas both in the wallrock and in the veins.

Preliminary chlorite thermometry, based on the content of Al^{IV} (Cathelineau & Nieva, 1985), provided temperature estimates ranging from 270 to 280 °C in the chl-altered metabasalts and from 290 to 310°C in the more altered samples. Gold occurs as coarse-grained (up to some millimeters) native gold, associated with silver, arsenopyrite and an iron-arsenic compound.

Discussion

Gold mineralizations can be classified in different ways: hystorically they were subdivided into epithermal, mesothermal and hypothermal on the basis of temperature of formation (Lindgren, 1907). Modern workers introduced a subdivision based on the tectonic setting and proposed the term "orogenic gold deposits" for ores formed during deformation processes (compressional to transpressional) at convergent plate margins (e.g. Kerrich & Wyman, 1990; Groves et al., 1998). An overall consensus on the genesis of these deposits is still lacking, but most authors agree on some type of metamorphic model, with fluids originating from the accreted host terranes and/or from subducted oceanic material (Groves et al., 1998; Groves & Bierlein, 2007). Typically orogenic gold provinces develop in the fore-arc region of an active margin and often during the late stage of orogeny (Goldfarb et al., 2005), and are characteristically associated with regional contacts between terranes (Kerrich & Wyman, 1990).

Alternatively, the studied gold mineralization could be more directly linked to magmatism (intrusion-related gold deposits, e.g. Sillitoe, 1991; Lang & Baker, 2001). A full understanding of the origin of this veins clearly needs further data: first of all, fluid inclusion and/or isotopic studies to characterize the type of fluids, secondly, a geochronological study to define the age of the mineralization. However, preliminary investigations highlight some points which fit the description made by Groves et al., (1998) and therefore we favour the hypothesis of orogenic gold; in particular:

- the association with deformed metamorphic (greenschist-facies) rocks; - the mineralogy of the vein system (quartz-dominated) and the type and zonation of hydrothermal alteration (though common to intrusion-related deposits);

- the strong control of structure on mineralization, because veins occur in brittle-ductile shear zones that do not affect the Admiralty Intrusives. The internal deformations of many quartz crystals actually imply crystallization pre- to syn-deformation events;

- the absence of plutonic bodies (Admiralty Intrusives) in a range of 250-300 Km from the gold locality and the lack of evidences of contact metamorphism. Moreover, preliminary inspection of geomagnetic maps revealed no buried plutonic body in the surroundings (Armadillo E., pers. comm.). With present knowledge, however, a contribution of far and/or deep-seated (possibly with low magnetic susceptibility) plutons as heat source and/or fluid source cannot still be excluded.

Both orogenic and intrusion-related gold mineralization occur in the once adjacent fragments of South-East Australia and New Zealand, therefore the potential of the Antarctic gold-bearing veins for correlation is extremely high.

The Lachlan Fold Belt of South-East Australia developed by stepwise accretion to the paleo-Pacific margin of Gondwana of deformed oceanic sequences and of deep sea turbidites. Deformation produced folding and high-angle reverse faulting. Orogenic gold deposits of the western Lachlan Orogen (Bierlein et al., 2002) are spatially related with the hanging walls of 2nd- and 3rd-order splays of these faults and are often located at the contacts between greenstones and sedimentary rocks. Mineralization occurred in response to episodic, eastward progressing deformation and metamorphism, in the interval 455-440 Ma, between 420 and 400 Ma and again in the interval 380-370 Ma (Bierlein et al., 2004). The older and main phase of gold mineralization has no genetic link with magmatism but is related to metamorphism . This was followed by remobilisation of gold into new structures/or new pulses of mineralisation linked to Devonian magmatism (Bierlein et al., 2001).

In the Western Province of the South Island of New Zealand, the Buller terrane is made up of Late Cambrian- Early Ordovician turbidites. Paleozoic gold deposits are hosted in greywacke and argillite that are folded and metamorphosed to lower greenschist facies (Goldfarb et al., 2005 and references therein). Mineralization occurs along NNE-striking shear zones and reverse faults that follow axial planes of regional folds (Bierlein et al., 2004 and references therein). The age of the ores is not yet constrained. Most authors interpret these deposits as orogenic (e.g. Bierlein et al., 2004; Goldfarb et al., 2005), but some suggest a possible magmatic source (Leach et al., 1997).

Different types of of quartz-veins (barren) have been described in the Roberson Bay terrane, in an area c.a 180-200 km to the southeast relative to the gold locality (Rossetti et al., 2006). The authors favour vein formation as a consequence of deformation in an accretionary complex setting in the Early Paleozoic, even if a late contribution to the hydrothermal circulation by the Devonian-Carboniferous Admiralty Intrusives is not excluded.

This finding of gold-bearing quartz veins is therefore relevant for better understanding of the structural regime and fluid circulation in NVL and for tectonic correlations at the scale of the whole paleo-pacific margin. Further investigations are underway to define the origin of the fluids and circumstances of ore formation.

Acknowledgements. This work benefitted from financial support of the National Antarctic Research Program of Italy (P.N.R.A.).

References

Bierlein, F.P., Christie, A.B., and P.K. Smith (2004), A comparison of orogenic gold mineralisation in central Victoria (AUS), western South Island (NZ) and Nova Scotia (CAN): implications for variations in the endowment of Paleozoic metamorphic terrains, Ore Geology Reviews, 25, 125-168.

Bierlein, F.P., Dennis, C.A., Foster, D.A., and P. Reynolds (2001), A geochronological framework for orogenic gold mineralisation in central Victoria, Australia Mineralium Deposita, 36, 741-767.

Bierlein, F.P., Gray, D.R., and D.A. Foster (2002), Metallogenic relationships to tectonic evolution the Lachlan orogen, Austr. Earth and Plan. Sci. Lett., 202, 1-13.

Borg, S.G. (1984), Granitoids of Northern Victoria Land, Antarctica. PhD. Thesis, Arizona State University, Tempe, 355 pp.

Bradshaw, J.D., Laird, M.G., and A. Wodzicki (1982), Structural style and tectonic history in northern Victoria Land. In: C. Craddock ed., Antarctic geoscience. Madison: University of Wisconsin Press. pp. 809-816.

Bradshaw, J.D., Pankhurst, R.J., Weaver, S.D., Storey, B.C., Muir, R.J., and T.R. Ireland (1997), New Zealand superterranes recognized in Marie Bird Land and Thurston Island. Ricci C.A. (ed) The Antarctic Region: Geological Evolution and Processes, Terra Antarctica Publication, Siena, 429-436.

Capponi, G., Carosi, R., Meccheri, M:, and G. Oggiano (2003), Strain Analisys in the Millen Range of Northern Victoria Land, Antarctica Geol. Jahr. B85, 225-251.

Capponi G., Crispini, L., and M. Meccheri (1999), Structural history and tectonic evolution of the boundary between the Wilson and Bowers terranes, Lanterman Range, northern Victoria Land, Antarctica, Tectonophysics, 312, 249-266.

Cathelineau, M., and D. Nieva (1985), A chlorite solid solution geothermometer The Los Azufres (Mexico) geothermal system, Contrib. to Mineral. and Petrol., 91, 235-244.

Crispini, L., and G. Capponi (2002) Albitite and listvenite in the Lanterman Fault Zone (northern Victoria Land, Antarctica) In: Gamble J., Skinner D.N.B. & Henrys S. (eds) Antarctica at the close of a millennium. Royal Soc. New Zealand Bull., Wellington, 35, 113-119.

Crispini, L., Di Vincenzo, G., and R. Palmeri (2006), Petrology and 40Ar-39Ar dating of shear zones in the Lanterman Range (northern Victoria Land, Antarctica): implications for metamorphic and temporal evolution at terrane boundaries, Mineralogy and Petrology, DOI 10.1007/s00710-006-0164-2

Federico, L., Capponi, G., and L. Crispini (2006), The Ross orogeny of the transantarctic mountains: a northern Victoria Land perspective. Int. J. of Earth Sci., 95 (5), 759-770, DOI 10.1007/s00531-005-0063-5.

Ferraccioli, F., Bozzo, E., and G. Capponi (2002) Aeromagnetic and gravity anomaly constraints for an early Paleozoic subduction system of Victoria Land, Antarctica, Geoph. Res. Lett., 29 (10), 10.1029/2001GLO14138. 2002.

Finn, C., Moore, D., Damaske, D., and T. Mackey (1999), Aeromagnetic legacy of early Paleozoic subduction along the Pacific margin of Gondwana Geology, 27 (12), 1087-1090.

Gair, D.R., Sturm, A., Carryer, S.J., and G.W. Grindley (1969), The Geology of Northern Victoria Land. Antarctic Map Folio Series, American Geographical Society, New York. Folio 12, Pl. XII,

Goldfarb, R.J., Christie, A.B., and F.P. Bierlein (2005), The orogenic gold deposit model and New Zealand: consistencies and anomalies, Proceedings of the 2005 New Zealand Minerals and Mining Conference, pp. 105-114, Publicity Unit, Crown Minerals, Ministry of Commerce.

Goldfarb, R.J., Groves, D.I., and S. Gardoll (2001), Orogenic gold and geologic time: a global synthesis Ore Geology Reviews 18, 1-75.

Groves, D. I., and F. Bierlein (2007), Geodynamic settings of mineral deposit systems, J. of the Geol. Soc., London, 164, 19-30.

Groves, D.I., Goldfarb, R.J., Gebre-Mariam, M., Hagemann, S.G., and F. Robert (1998), Orogenic gold deposits: a proposed classification in the context of their crustal distribution and relationship to other gold deposit, Ore Geology Reviews, 13, 7-27.

Jordan, H., Findlay, R., Mortimer, G., Schmidt-Thomé, M., Crawford, A., and P. Muller (1984), Geology of the northern Bowers Mountains, North Victoria Land, Antarctica. Geol. Jahr., B60, 57-81.

Kerrich, R., and D. Wyman (1990), Geodynamic setting of mesothermal gold deposits: An association with accretionary tectonic regimes, Geology, 18, 882-885.

Kleinschmidt, G., and F. Tessensohn (1987), Early palaeozoic westward directed subduction at the Pacific Margin of Antarctica, In: "Gondwana Six: Structure, Tectonics, and Geophysics. McKenzie G.D. (Ed.), pp. 89-105.

Laird, M.G., and J.D. Bradshaw (1983), New data on the lower Paleozoic Bowers Supergroup, Northern Victoria Land. In: Oliver, R.L., James, P.R., Jago, J.B. (Eds.), Antarctic Earth Sciences. Australian Academy of Science, Canberra, pp. 123-126.

Lang, J.R., and T. Baker (2001), Intrusion-related gold systems: the present level of understanding, Mineralium Deposita, 36: 477-489.

Leach, T., Corbett, G.J., Magner, P., and M. McKenzie (1997), A geological model for gold mineralization at Reefton, New Zealand. Proceedings of the 1997 New Zealand Minerals and Mining Conference, pp. 159-166, Publicity Unit, Crown Minerals, Ministry of Commerce.

Ramsay, J.G. (1980), The crack–seal mechanism of rock deformation, Nature 284, 135 - 139.

Rossetti, F., Tecce, F., Aldega, L., Brilli, M., and C. Faccenna (2006), Deformation and fluid flow during orogeny at the paleo-Pacific active margin of Gondwana: the Early Palaeozoic Robertson Bay accretionary complex (north Victoria Land, Antarctica). J. metam. Geology, 24, 33-53.

Rowley, P.D., Williams, P.L., and D.E Pride (1991), Metallic and non-metallic mineral resources of Antarctica, In: Tingey, R.J. (Ed.), The Geology of Antarctica. Clarendon Press, Oxford, pp. 617-651.

Sillitoe, R.H. (1991), Intrusion-related gold deposits. In: Foster R.P. (Ed) Gold metallogeny and exploration. Blackie, Glasgow, pp. 165-209.

Vearncombe, J.R. (1993), Quartz vein morphology and implications for formation depth and classification of Archean gold-vein deposits, Ore Geology Reviews, 8, 407-424.

Wodzicki, A., and R. Robert (1986), Geology of the Bowers Supergroup, central Bowers Mountains, northern Victoria Land. In: Stump, E. (Ed.), Geological Investigation in Northern Victoria Land. Am. Geophys. Union, Antarct. Res. Ser. 46, 39-68.

Wright, T.O., and C. Brodie (1987), The Handler Formation, a new unit of the Robertson Bay Group, northern Victoria Land, Antarctica. In G.D. McKenzie, ed., Gondwana Six: Structure tectonics, and geophysics. Geophysical Monograph 40. Washington DC: American Geophysical Union, pp. 25-29.