Au-Ag-Te-Se deposits

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Tarina and Rodu: Gold mineralisation hosted in maar-diatreme contact environments in the Apuseni Mountains, Romania

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Abstract. The Tarina and Rodu epithermal gold and silver deposits are located at the peripheries of the Rosia Montana and Rodu-Frasin maar-diatreme complexes respectively, in areas distal to the mineralised dacite cores of these intrusive complexes. Structural geology has played a major part in the development of these deposits in the form of major fault structures that have acted as conduits for hydrothermal mineralising fluids. In the Tarina and Rodu prospects these fluids have been preferentially focused along the maar-diatreme contacts by a combination of fault structures and the rheological contrast between the vent breccia within the maar-diatremes, and the Cretaceous sediments. The Cretaceous sediments form the host into which the diatremes have been intruded. Gold mineralisation occurs in narrow faults and veins, in hydrothermal breccias in Cretaceous sediments, in pervasive alteration zones within the permeable vent breccia and also in altered intrusive polymictic breccias and dacite dykes.

Key words maar-diatreme, contact, faults, permeability, vent-breccia, Cretaceous sediments, hydrothermal fluids

Introduction

Significant deposits of gold and silver have been exploited in the past from the contact zones of intrusive maar-diatreme complexes at Rosia Montana and Rodu-Frasin, but these deposits are often overlooked due to their proximity to the larger and more conspicuous deposits hosted within the porphyritic dacite intrusives at the core of these maar-diatreme complexes. The Tarina prospect (including the Igre, Jig and North Orlea zones) is located on the northern periphery of the Rosia Montana intrusive maar-diatreme complex, close or coincident to the contact with the surrounding Cretaceous sedimentary sequence. Rosia Montana is a world class epithermal gold deposit with current resources of 16.1 M oz of

gold at 1.26 g/t (Gossage et al., 2003), and is located in the Apuseni Mountains, approx. 40 km NW of the town of Alba Iulia. The Rosia Montana deposit has been interpreted as an intermediate sulphidation epithermal deposit (Hedenquist, 2003). The Rodu deposit is located in a similar environment on the western edge of the Rodu Frasin maar-diatreme complex, a smaller intrusive complex located 5 km to the southeast of Rosia Montana. The current resource for the Rodu-Frasin deposits is 1.8 M oz of gold at a grade of 1.3 g/t (Verbeek, 2005).

In 1941, Ghitulescu and Socolescu observed that the deposit at Rodu is similar in nature to that of Tarina Rosia Montana, and recent work undertaken by the present authors confirms this hypothesis. However, it should be noted that although the two deposits are

broadly similar in their geological and metallogenic environment, there are a number of characteristics that differ between them.

Geological setting

Both the Tarina and Rodu deposits are located on the periphery of intrusive maar-diatreme complexes of Neogene age that have porphyritic dacite intrusives at their core (Leary et al., 2004a, b). At Rosia Montana the principal dacite bodies are the Cetate and Cirnic massives, whereas at Rodu Frasin it is Frasin Hill that it is composed of dacite. In both cases the greater proportion of the gold mineralisation is hosted within these dacite bodies. Both intrusive complexes are located on dilational sites associated with a regional scale fault system that has a northwesterly trend and hosts numerous phases of igneous activity. This structure been interpreted as a splay from the regional scale right-lateral strike-slip Zlatna fault, which passes to the south of area (Nash, 2004; O'Connor et al., 2004).

Geologically, the most obvious similarity between the Tarina and Rodu epithermal gold deposits is that they are both close or coincident to the contact between the tuffaceous vent breccia that fill large volumes of maar-diatreme complexes, and the surrounding Cretaceous sedimentary sequence, and are therefore distal to the core of these phreatomagmatic complexes.

Prospect geology

Both the Rosia Montana and Rodu-Frasin maar-diatreme complexes have been intruded into the same extensive package of Cretaceous sediments that is dominated by finely bedded shale with lesser fine to coarse-grained sandstone and occasional conglomerate beds and minor limestone. 40Ar/39Ar radiometric dates on neoformed, hydrothermal vein adularia from a quartz-adularia-pyrite vein in dacite from the Cetate pit at Rosia Montana yield ages of 12.78 ± 0.09 and 12.71 ± 0.13 Ma, which are regarded as a mineralisation age for the system (Manske et al., 2004).
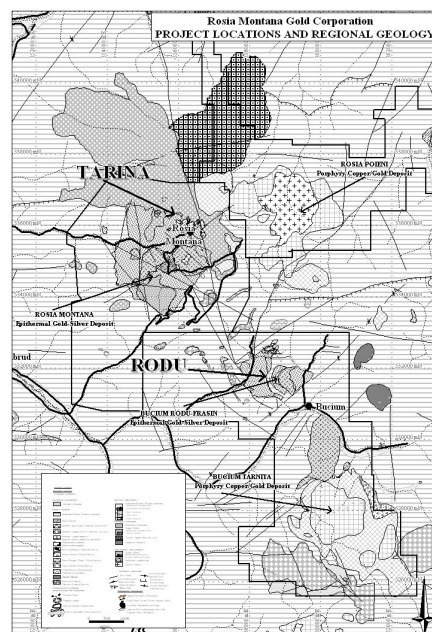

Fig. 1. Location map and district geology of the Rosia Montana-Bucium area

The principal geological unit at both Tarina and Rodu is a body of tuffaceous vent breccia that surrounds the intrusive porphyritic dacite bodies at the core of the maar-diatreme. The vent breccia is composed of eruptive and reworked phreato-magmatic material from the diatremes that has been intruded into and/or deposited on the Cretaceous sediments. In the Tarina area most of the vent breccia has been erupted into a water-filled maar and has been reworked in a sub-aqueous environment to a certain extent, resulting in gently dipping bedding. This reworked vent breccia is fine to coarsely bedded and varies from clay rich to more common sandy and gravely beds through to beds containing poorly sorted, cobble sized clasts (Leary et al., 2004a). The majority of the clasts within the vent breccia are composed of dacite or Cretaceous sediments of varying sizes, with a finer grained matrix that is generally composed of similar material. The contact between the vent breccia and the Cretaceous sediments dips moderately towards

the south at Tarina and towards the east at Rodu, but gradually becomes steeper towards the centre of the maar-diatreme complexes.

At Rodu there is much less evidence of reworking of the vent breccia, which has a more massive texture. However, at Rodu several varieties of vent breccia have been recognised depending on the dominant clast type, clast size and the nature of the matrix possibly representing different phases of eruption (Nadasan and Hewson, 2005).

A number of intrusive polymictic diatreme breccia bodies and dykes have been identified in the Tarina area and these are comprised of matrix-supported breccias with sub-rounded clasts of dacite, Cretaceous sediment and metamorphic basement schist. The presence of large clasts of metamorphic basement indicates a deeper source than the vent breccia. These polymictic diatreme breccias can be up to 150 m in width, are generally well mineralised, and have usually been intruded through the vent breccia at the intersections of major fault structures. Intrusive dacite bodies outcrop at Jig and Cos in the far eastern part of the diatreme-maar complex, and several dacite dykes have also been recognised in outcrop and in drill holes in the Tarina prospect. These dacite bodies have generally

been intruded along major fault zones and dilational fault intersections, and are often spatially associated with the polymictic diatreme breccia bodies. No bodies of intrusive polymictic diatreme breccia or dacite have yet been identified at Rodu.

The youngest geological unit in both the project areas is a series of andesitic lavas, and pyroclastic agglomerates known as the Rotunda andesites and pyroclstics, that have flown down the slopes from the higher ground and obscured much of the earlier geology. This material was derived from the Rotunda andesitic volcanic centre to the northeast of Rosia Montana (Wallier et al., 2005). Rosu et al. (1997) used whole rock K-Ar dating to estimate the age of the Rotunda Andesite as 9.3 ± 0.5 Ma, which therefore post dates the Rosia Montana and Rodu-Frasin diatremes and the mineralisation.

Structure

The dominant structural features at Tarina are a series of NW to NNW-trending faults associated with the maar-diatreme bounding structure and a number of major faults that cross-cut the intrusive complex with northerly and north-northeasterly trends (Hewson, 2003).
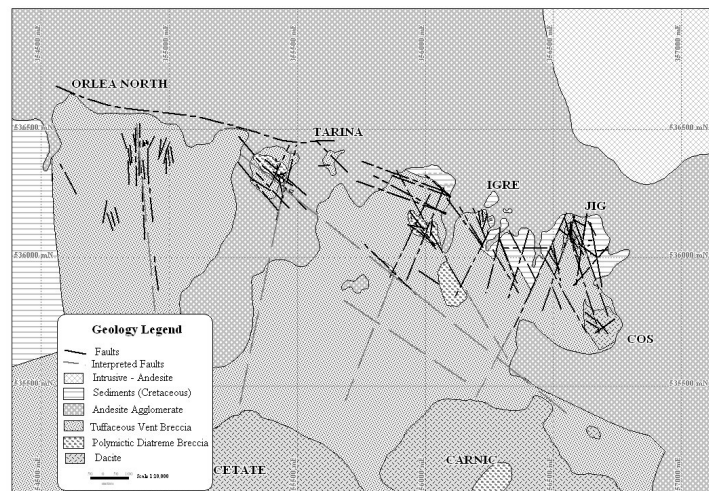

Fig. 2. Surface geology and structure of the Tarina Area

95

These faults appear to be the principal controls on the location and distribution of gold mineralisation, and this can clearly be seen by the fault and vein orientations exploited in previous eras at Tarina Jig, Igre and North Orlea. An important structure is the faulted contact between the vent breccia (hanging wall) and the Cretaceous sediments (footwall) that can be seen clearly in an old stope at Tarina/Igre. The contact in this exposure is oriented northwesterly and dips towards the southwest at 50º. Several splays and parallel subsidiary faults have also been identified in this area. Drilling results from Tarina have shown that a significant amount of gold mineralisation occurs within and close to these fault zones.

Some stopes oriented in a more north-south orientation have also been noted at Jig, and particularly at Orlea North, where this orientation predominates. It is interesting to note that in the far west and the far east of the maar-diatreme complex, the principal fault orientations are more north-northwesterly to northerly.

Stereographic analysis shows a distinct shear array consistent with a right-lateral strike-slip wrench fault system, and a secondary array consistent with normal dip-slip reactivation of some of these faults (Hewson, 2003). This secondary array corresponds with small-scale normal displacement of bedding in the vent breccia on steeply and moderately dipping northwesterly trending faults observed at Tarina. The sense of movement is generally southwest block down and is interpreted as being due to late stage relaxation and collapse on the margins of the maar-diatreme. It is interesting to note that the distribution of the polymictic diatreme breccias and the dacite dykes and bodies appears to be controlled by the major fault structures.

The principal structural feature at Rodu is a series of steeply dipping northerly trending faults (Hewson and Feier, 2004). Stereographic analysis indicates that these faults are part of the regional strike-slip array also identified at Tarina. It is likely that this fault system has played a significant role in the preparation of

dilational sites, which have become the focus for the introduction of hydrothermal mineralising fluids. Numerous faults and carbonate veins that dip at moderate angles (20 to 50º) towards the West have also been developed at Rodu, as well as a set of faults that dip moderately towards the East, parallel to the contact between the vent breccia and the Cretaceous sediments. It is interpreted that late stage dip-slip reactivation of the steep faults has created these low angle faults and poly-metallic carbonate tension veins. This dip-slip reactivation seems to be stronger at Rodu than at Tarina, although this may be due to the more extensive underground workings at Rodu that are accessible for mapping.

Close to the contact between the vent breccia and the underlying Cretaceous sediments a zone of intense deformation has been mapped. Both steeply and gently dipping north-south trending faults intersect and displace this contact. Some of the steeply dipping faults are sub-parallel to the Sperla Fault, approximately 400 m to the East. It is interpreted that late movement on some of these steep faults has displaced the contact and propagated a series of carbonate veins that dip gently towards the West. A number of these faults and veins have been exploited in the past by narrow underground mining methods.

A major north-south trending fault has been identified in the eastern part of the Rodu prospect, which is believed to be the Sperla fault as identified by Ghitulescu and Socolescu (1941). The Sperla Fault is considered to be a major district scale structure, and appears to be coincident with the major normal fault that marks the eastern boundary of the Rosia Montana maar-diatreme complex, approx. 4 km to the north (Nash, 2003). Normal movement (west block down) on the Sperla Fault in the north east of the prospect has produced a set of localised tension veins that dip moderately to the East. It is possible that dip-slip reactivation on the Sperla Fault and the western contact has created a normal conjugate array.

The dominant vein orientation at Rodu is northwesterly with a dip of 30º towards the southwest, and these veins are generally

narrow and carbonate dominated, with multiple sulphides including pyrite, chalcopyrite, sphalerite and galena (Hewson and Feier, 2004). Ghitulescu and Socolescu (1941) referred to these veins as the 'Crucile Bradului', and they have been exploited in the past where the vein thickness exceeds 10 cm. From stereographic analysis it is interpreted that these veins represent a set of en echelon tension veins related to late normal movement on steeply east dipping faults that can be seen close to the contact between the vent breccia and the Cretaceous sediments.

A number of northerly trending faults and veins that dip moderately towards the east have also been mined in a in the past. These faults are believed to be the 'Scaunele Bradalui' referred to by Ghitulescu and Socolescu (1941). From the geometry of the old stopes, it can be concluded that these faults are preferentially mineralised where they intersect westerly dipping faults or veins ('Crucile Bradului'). The intersection zones between these sets of faults and veins plunge at approximately 10º towards the south and were a favourite target for the old miners.
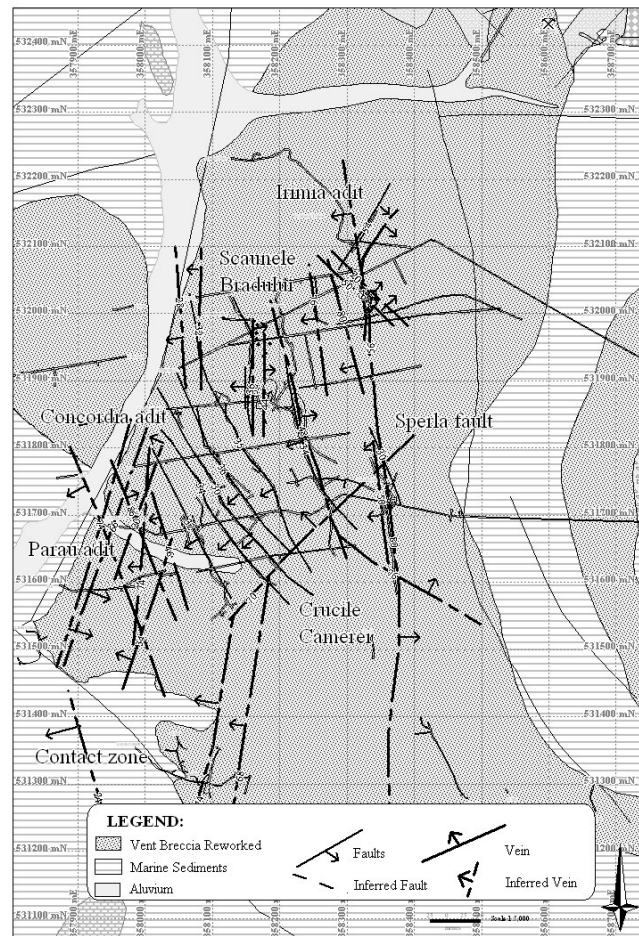

Fig. 3. Geology and structure of the Rodu prospect (projected on to the 700RL)

97

Mineralisation

The Tarina deposit is characterised by a zone of mineralisation that is coincident with the contact between the vent breccia and the surrounding Cetaceous sediments and has a general northwesterly orientation and a dip of approximately 50º towards the southwest, towards the core of the Rosia Montana maar-diatreme complex. Where this contact is exposed in underground workings it is faulted, silicified, mineralised and has been extensively mined (Hewson, 2003). The mineralised zone can be up to 80 m in width and contains gold within both the vent breccia and the underlying Cretaceous sediments.

Significant Au-Ag mineralisation is hosted within the vent breccia and is charac-terised by silicification, carbonate and adularia alteration and finely disseminated pyrite with infrequent veining. Some of the fine grained reworked vent breccia at Tarina is clay rich and less permeable than the coarser grained vent breccia, and is therefore a poor host for mineralisation in comparison to the coarse grained, clay poor horizons.

At Tarina a large proportion of the gold is hosted within a hydrothermal 'crackle' breccia formed in the Cretaceous sediments just below the contact (Leary, 2003). This mineralisation is characterised by both silicification and pervasive fine-grained disseminated pyrite and by hydrothermal crackle brecciation that varies from mm-width widely spaced spidery crackle breccia through to more intense mosaic (jigsaw) brecciation. The breccia matrix is typically vuggy and carbonate dominated (both calcite and rhodochrosite), with quartz, pyrite, galena, sphalerite and visible gold (Leary et al., 2004a).

Gold mineralisation is also associated with intrusions of polymictic diatreme breccia that have been intruded along fault structures and at major fault intersections. This minera-lisation is characterised by intense, pervasive
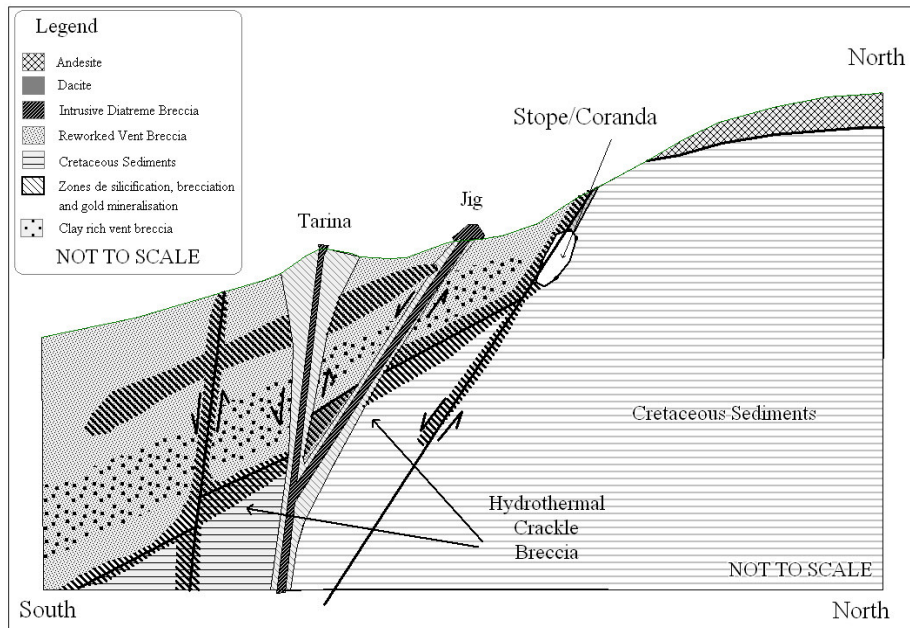

Fig. 4. Schematic cross-section of the Tarina prospect

98

silicification of both the breccia matrix and the diatreme breccia clasts, with pyrite replacement of clasts common. Rhodochrosite has also been identified, occurring within the matrix of the diatreme breccia.

A series of NW- to NNW-trending faults associated with the maar-diatreme bounding structure appear to be the principal controls on the location and distribution of gold mineralisation, and have been extensively mined in the past.

The Rodu deposit has been less thoroughly explored, but a significant amount of gold mineralisation has been identified in a zone of strongly altered vent breccia, usually located immediately above the contact with the Cretaceous sedimentary package. Most of the Rodu vent breccia is dominated by pervasive argillic alteration with the zones of better mineralisation characterised by silicic, carbonate, and adularia alteration with finely disseminated pyrite and occasional veining (Leary et al., 2004b). Two principal styles of gold mineralisation have been identified at Rodu; low to medium grade, large tonnage style mineralisation associated with pervasive alteration in the vent breccia above the Cretaceous contact, and high grade low tonnage mineralisation hosted within narrow fault zones and carbonate veins in various orientations (Hewson and Feier, 2004).

A number of the high grade structurally hosted zones have been mined in the past including low angle westerly dipping poly-metallic carbonate veins, moderately East dipping faults and steeply dipping faults. The intersections between these structures plunge at a low angle towards the south and represented a high grade target for historical mining operations. The mineralised fault zones themselves are generally silicified and often contain open spaces, indicating that they may have acted as conduits for hydrothermal fluids. Unlike at Tarina, only small amounts of gold mineralisation have been identified in the Cretaceous sediments to date, and no mineralised dacite dykes or intrusive polymict breccias have been intersected. However, one significant similarity between the Tarina and Rodu deposits is the coincidence of intense structural deformation associated with zones of major faulting intersecting the maar-diatreme contact.

The most probable reason why the gold mineralisation at Tarina is sometimes preferentially concentrated in the Cretaceous sediments is due to the impermeable nature of the overlying clay-rich reworked vent breccia in some areas, which leads to the pooling and boiling of hydrothermal fluids below this horizon (Leary, 2003). However, at Rodu, the vent breccia is clay poor, and is therefore more permeable than the underlying Cretaceous shales. This causes the hydrothermal mineralising fluids introduced along fault structures to be concentrated in the vent breccia above the contact (Hewson and Feier, 2004).

Resources

The latest resource calculation for Tarina has identified 41.5 Mt at 1.14 g/t Au and 3.9g/t Ag, using a 0.6 g/t Au cut off, for a total of 1.52 M oz of gold and 5.59 M oz of silver. This is relatively small compared to the total resource for Rosia Montana of 400 Mt at 1.26 g/t Au and 5.8 g/t Ag (for total amounts of contained Au and Ag of 16.1 and 73 M oz, respectively; Gossage et al., 2003). At Rodu a recent resource
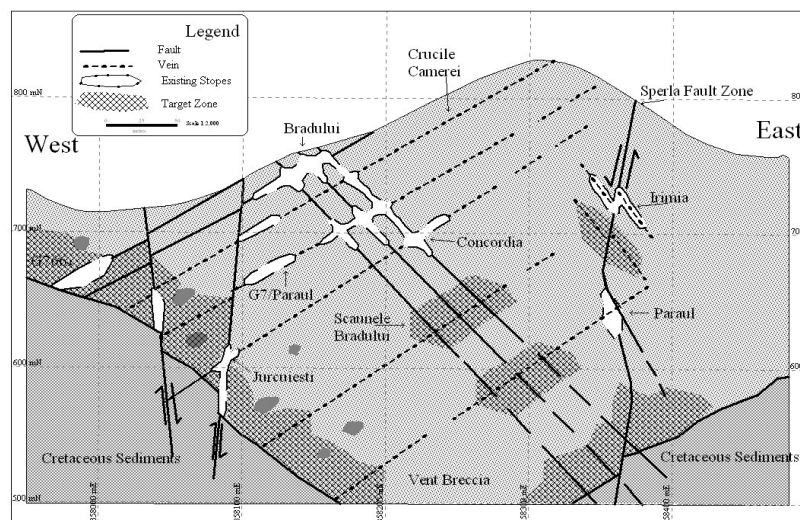
Fig. 5. Schematic cross-section of the Rodu prospect

update calculated a resource of 26 Mt at a grade of 0.97 g/t Au and 2.02 g/t Ag using a 0.6 g/t Au cut off, for a total of 812, 530 oz of contained gold and 1.7 M oz of silver. The total resource for the Rodu and Frasin deposits currently stands at 43.3 Mt at 1.3 g/t Au and 3 g/t Ag, which equals 1.8 M oz of contained gold and 4.7 M oz of contained silver (Verbeek, 2005). The potential exists to increase both these resources, as both deposits have been relatively under-explored in the past.

Conclusion

The Tarina and Rodu epithermal gold deposits have both been formed by the concentration of mineralising hydrothermal fluids close to the contact of maar-diatreme complexes due to the interaction between major fault structures and the presence of a permeability barrier caused by the differing nature of the various rock types across the contact. Although each deposit has slightly different characteristics due to local variability in geology and structure, in general terms they are very similar. The Tarina deposit is larger, higher grade and contains more geological variability than Rodu, but this is

probably due to its location on the periphery of a much larger maar-diatreme complex at Rosia Montana than the one at Rodu-Frasin.

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