Stratigraphic Controls on Structures and Mineralisation in Central Victoria 2: Ballarat East

R. K. Boucher, Linex Pty Ltd & La Trobe University
D. J. Osborne, LGL* Ballarat Goldfields
P. B. d'Auvergne, LGL* Ballarat Goldfields
* Lihir Gold Limited

Abstract

This is the second in a series of papers discussing the stratigraphic controls on structures and gold mineralisation in Victoria. Ballarat East does not have the thick shales and very coarse-grained sandstones that occur at Bendigo. Ballarat East has different structural styles as well. Although factors such as depth of burial and the number and magnitude of deformation events must be taken into account, stratigraphic contrasts between the two areas can help explain the differences in structural style.

Introduction

Central Victoria is a world class orogenic gold province. Faults and folds within Ordovician turbidites host gold and associated mineralisation. Turbidites occur across most of Victoria and in the field comprise monotonously interbedded sandstones and shales, although facies variations and lateral discontinuity of individual beds are characteristic at a local scale. At Ballarat nuggety gold is hosted by quartz veins within fault-related structures. Ballarat is one of the largest goldfields in Victoria, with a recorded production of 12 million ounces of gold, from Ballarat East, Ballarat West and Nerrina (Little Bendigo). LGL Ballarat Goldfields operation is continuing efforts to reopen the Ballarat East goldfield after merging with Ballarat Goldfields NL in 2007. This paper discusses the geology of the southern end of the Ballarat East goldfield. The Nerrina goldfield will be considered in a later publication in this series.

This study of the Ballarat East goldfield (Fig. 1) follows a review of the Bendigo goldfield by Boucher et al., (2008). Linex Pty Ltd was engaged by Ballarat Goldfields to review its logging and interpretation systems in 2004. The sedimentological core logging system established at Fosterville and Bendigo was adopted and correlation and interpretation roles were added as integral parts of the geologists' duties. In doing this, a career path was created for core logging geologists, enabling them to graduate from core logging to interpretation. The primary author assisted in setting up these roles and much of the data and concepts used in this paper are drawn from the ongoing work of LGL staff.

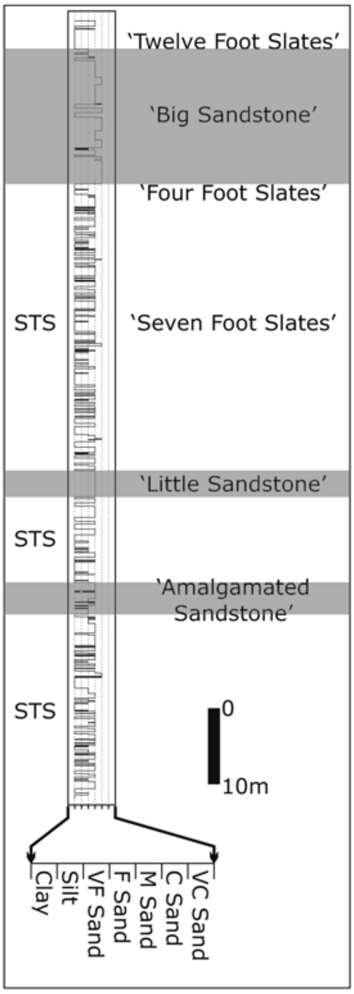

Figure 2. Composite stratigraphy from 200m north of the Woolshed Gully Decline portal. The rocks are mostly monotonous 'shale-topped sands' (STS) with the notable exception of the 'Big Sandstone' which hosts quartz veins, particularly where cut by west-dipping faults. Smaller sandstone units have been defined and mapped because they host quartz veining and gold mineralisation.

Ballarat East stratigraphy

The mine stratigraphy at Ballarat East (Fig. 2) is a monotonous succession of 'shale topped sands' (STS). Unlike Bendigo (Boucher et al., 2008) and elsewhere in Victoria, thick shales are rare and there are no very coarse grained sands.

The most notable unit within the stratigraphy is the 'Big Sandstone' which provides an important stratigraphic marker and as discussed later, is economically important also. The 'Big Sandstone' is interpreted to have been deposited in a channel environment and, like channel sands elsewhere in Victoria, is up to 10m thick. The 'Big Sandstone' thins towards the north and is not seen in the northerly drill sections. In contrast to channel sands elsewhere in central Victoria, there are no very coarse-grained sands in the 'Big Sandstone'. Instead, it is mostly medium-grained with occasional coarse-grained sandstone which distinguishes it from the fine- and very fine-grained sands elsewhere. The grain size of these channel sands is thought to be related to the provenance of the sediments.

As well as the 'Big Sandstone', two additional sand packages have been recognised (Figs 2 & 3). While the 'Little Sandstone' and the 'Amalgamated Sandstone' are not true channel sands, they are sufficiently thick and characteristic to be correlated. Additionally, they are good hosts for veining and associated gold mineralisation and as a result, effort is made to predict their location for drill targeting.

Thick shales are notably rare at Ballarat East. At Bendigo (Boucher et al., 2008) and elsewhere in Victoria it is common for shale successions to exceed 10 m. The thickest shale that occurs at Ballarat East is the 'Big Slate' which is up to 15 m thick in the northern section of the goldfield but is absent from the southern part (Fig. 2). Elsewhere in Victoria, including the adjacent Ballarat West goldfield, thick shales are good hosts to bedding parallel, laminated quartz veins. As there are no thick shales, Ballarat East does not have significant laminated quartz veins. Historically the 'Twelve Foot Slates', the 'Four Foot Slates' and the 'Seven Foot Slates' (Fig. 2) have been recognised

Figure 1. Location map showing the turbidite-hosted deposits discussed in this series of papers.

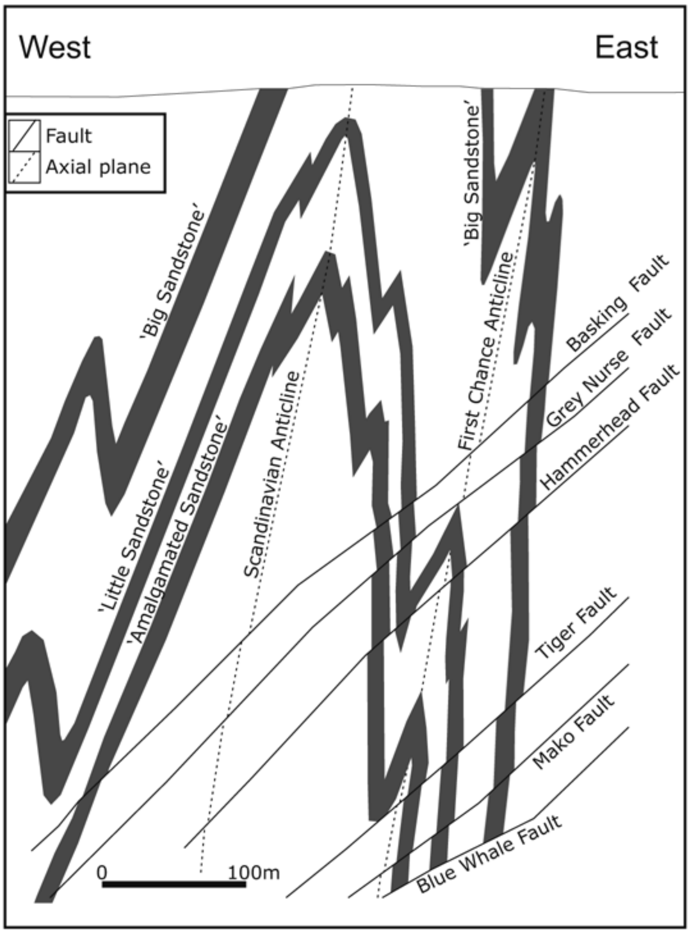

Figure 3. Cross-section showing correlatable sand packages that provide the best host for tension veins where cut by west-dipping faults. These faults commonly have displacements less than 5 m. The notable exception is the Blue Whale Fault which has more than 100 m displacement.

as mappable units to assist geological interpretations. However, these units are significantly thinner than shales elsewhere and commonly have thin sands within them.

'Indicators' are significant gold hosts at Ballarat East and were historically important. The general consensus is that they are thin (<1cm), bedding parallel faults. Reconstruction of the stratigraphic position of several indicators described by Lidgey (1894) shows that they occur within STS successions. The primary author suggests that indicators are thinner analogues of laminated quartz veins that occur in environments where there are no thick shales and where some bedding-parallel slip occurred during folding.

Stratigraphic controls on the development of veins, faults and folds

The vein types at Ballarat East are shown in Figure 4. Most quartz is related to west-dipping faults, often referred to as 'leatherjackets' in the historic literature. Quartz occurs on fault planes but more commonly as tension vein arrays. Tension veins also occur on faulted bedding contacts especially on the boundaries of thick sandstones. Cleavage is strongly developed and axial planar in shaly beds and fine sandstones, but only weakly developed in medium- to coarse-grained sandstones, where it is usually convergent (west-dipping).

At Bendigo, thick shales host laminated quartz veins that often culminate at anticlines to produce a variety of reefs (Boucher et al., 2008). Thick shales and prominent laminated quartz veins are absent from the southern portion of the Ballarat East goldfield and reef development within anticlines is rare (Fig. 3). However, the 'Big Slate' develops further north and more work is being done to establish the nature of the veins within this unit. Without multiple thick shales, the opportunity for numerous laminated/bedded veins like these at Bendigo (Boucher et al., 2008) is low at Ballarat East.

Thick, amalgamated channel sands are favourable sites for vein development. Brittle failure occurs in the thick sands and accompanying vein development is common, especially near faults. The 'Big Sandstone' was extensively stoped historically where intersected by west-dipping faults and along its margins. Similarly, the 'Little Sandstone' and 'Amalgamated Sandstone' are favourable sites for brittle deformation and vein formation that develops where high competency contrasts occur around thick sand beds. Interestingly, it was only the east limb of the folds that were worked and only where they remained dipping to the east and not overturned. Early stratigraphic/structural targeting success intersected a location where folded sandstones were intersected by a west-dipping fault and intersected 30 metres @ 24 g/t gold (Ballarat Goldfields, 2005).

Folding and fault styles at Ballarat East

Folds at Ballarat East are upright to overturned chevron folds with axial surfaces dipping steeply to the west. Folds are asymmetrical and possess parasitic folds that locally develop and separate into large individual folds. Hinge lines plunge gently to the north or south and adjacent anticlines sometimes plunge in opposite directions. Folds are generally tight with an interlimb angle of 20°. A notable feature of the Ballarat East goldfield is the presence of steeply dipping, conjugate, bedding oblique faults (crosscourse faults) that show strike-slip and dip-slip displacement of up to 100 m.

Bedding parallel fault styles at Ballarat East are different to Bendigo. Bendigo faults are linked systems of laminated quartz veins and thrusts that propagate from fold hinges and truncate fold limbs. They dip both to the west and east and have moderate displacement, likely exceeding 40 m (Boucher et al., 2008). Ballarat faults do not appear to track fold hinges, are dominantly west-dipping and have offsets that rarely exceed 20 m (Fig. 3). Brittle failure at Bendigo occurs incipiently from slip within thick shales and hinge dilations. However, without thick shales and coarse sands at Ballarat East, there is less opportunity for this type of strain accommodation and the folds are consequently tighter. Additional factors such as depth of burial and the number and magnitude of deformation events also probably exerted some influence.

Cont. Overleaf

Stratigraphic Controls on Structures and Mineralisation in Central Victoria 2: Ballarat East

Cont. from Page 7

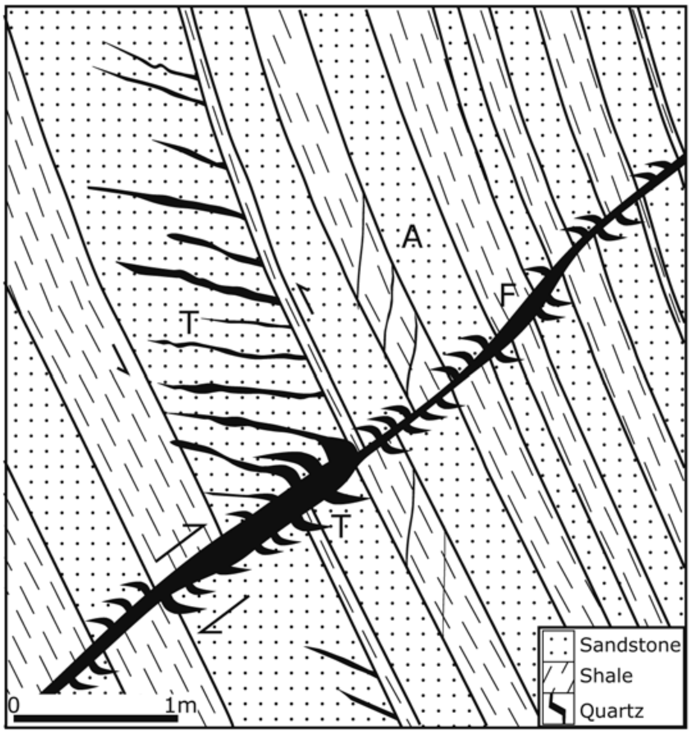

Figure 4. Lithological and structural controls on quartz veins at Ballarat. Veins occur on faults (F), as tension vein arrays (T) and aligned with axial planar (A) cleavage.

Conclusions

The southern portion of the Ballarat East goldfield is a thick succession of shale-topped sands containing a single channel sand (the 'Big Sandstone') and no thick shales. To the north, the 'Big Slate' thickens to 15m. The simplest conclusion is that with more uniform facies, the folds at Ballarat East continued to yield homogeneously and have tighter interlimb angles. Subsequent brittle failure was initiated by west-dipping faults, minor bedding parallel shearing and crosscourse faults. As a result, gold is concentrated in different structural positions at Ballarat; namely in west-dipping faults and vein arrays associated with bedding parallel shears. Whereas, at Bendigo, the gold is commonly found near fold hinges. ▲▲

Acknowledgments

Steve Olsen is gratefully acknowledged for establishing the logging and interpretation work at Ballarat Goldfields in 2003 and for providing the support and enthusiasm that allowed it to be developed. Numerous staff geologists diligently compiled detailed stratigraphic logs for analysis. Hamish Forgan, Tim Fogarty and Angela Steenhuis were instrumental in developing the interpretations. Rod McKenzie, Craig Stevens, Brad Cox and Charles Carnie provided fruitful discussions on geology, data collection and interpretation. Thanks to Allan Rossiter for assisting with the final editing.

References

Ballarat Goldfields N.L., 2005. Spectacular drilling result at Ballarat East. ASX & Media Release, 31/3/05

Boucher, R. K., Fraser, R. M. & Hill, R. L., 2008. Stratigraphic controls on structures and mineralisation in central Victoria 1: Bendigo. AIG News 74:21-23.

Lidgey, E., 1894. Report on the Ballarat East Gold-field. Geological Survey of Victoria. Special Report. 16pp.