Stratigraphic Controls on Structures and Mineralisation in Central Victoria 3: Fosterville

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Abstract

This is the third in a series of papers discussing the stratigraphic controls on structures and gold mineralisation in Victoria. Fosterville shows a similar stratigraphic succession to Bendigo, including thick shales and coarse amalgamated channel-sands. Both areas have linked systems of shale-hosted laminated quartz veins and thrusts that propagate from fold hinges and truncate fold limbs. However, the significant faults at Fosterville are all west-dipping, unlike Bendigo where faults dip both east and west.

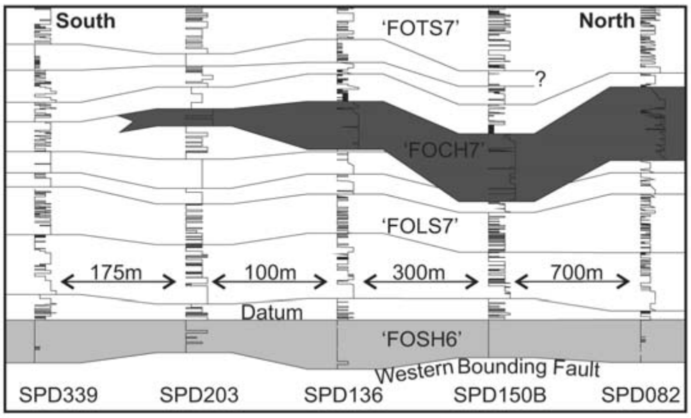
Introduction

Central Victoria is a world-class orogenic gold province. Faults and folds within Ordovician turbidites host gold and associated mineralisation. Such 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. This study of the Fosterville goldfield (Fig. 1) follows a review of the Bendigo and Ballarat East goldfields by Boucher et al., 2008a, 2008b. The majority of the research and development of the stratigraphic logging and correlation methods, now used widely in Victoria, were conducted at Fosterville.

Mining commenced in Fosterville at 1894 and was reinvigorated between 1986 and 2001 when a series of shallow oxide pits was excavated along several parallel fault systems. Fosterville Gold Mine are currently exploring and mining the down-plunge, sulphide mineralisation beneath the oxide pits.

While nuggety gold characterises most Victorian deposits, the gold at Fosterville occurs mainly within fine-grained, disseminated arsenopyrite. The Fosterville mineralisation is structurally (fault) controlled, occurring as selvages to quartz-carbonate vein stockworks beside late brittle faults (Roberts et al., 2003). Related, mineralised faults have been identified over a strike length of 14 km on the mining lease. This study concentrates on the longest of these fault systems which includes the Phoenix, Fosterville and Western Bounding Faults.

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



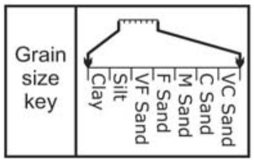


Figure 2: True thickness correlation diagram of sedimentary rocks in the hanging wall of the Western Bounding Fault.

Detailed logging of sediments in the hanging-wall above the Western Bounding Fault (Fig. 2) enabled correlation between drillholes, but it took several years to link the stratigraphy of the hanging-wall succession with that of the sedimentary rocks to the east. Eventually, stratigraphic correlation enabled detailed cross-sections to be constructed, fold geometries to be constrained and fault paths and offsets to be determined even when the drilling was widely spaced (typically 50 m spaced holes on sections 100 m apart). A total of 163.3 km of oriented diamond-tailed drilling from 506 drillholes has provided a large dataset. Many holes were stratigraphically logged so that a detailed correlation and interpretation process could take place.

Unlike elsewhere in Victoria, there is no formal mine stratigraphy at Fosterville. Instead a coded numbering system has been used to identify units (Fig. 3). Until the footwall and hanging-wall successions were correlated, they were given the prefixes 'FO' and 'HA' respectively. Thick shales are denoted as 'SH' and amalgamated channel-sands as 'CH'. The 'shale-topped sands' (STS) above and below the channel-sands are designated 'TS' and 'LS' respectively. Packages from the top of a shale to the top of the next shale above are considered analogous to a formation and are assigned a number for the combined LS/CH/TS/SH facies (Fig. 2).

Fosterville stratigraphy

A stratigraphic succession of almost 1,000 m has been identified at Fosterville, including the portion shown in figure 3. Sedimentary units have been correlated over a total distance of 10 km within the mine lease and in exploration drilling to the south. The stratigraphy is dominated by a monotonous succession of STS punctuated by thick shales and channel-sands, as is the case elsewhere in Victoria.

The most notable shale is 'FOSH13' (Fig. 3) which exceeds 75 m in thickness. This is three times the thickness of any shale seen elsewhere in central Victoria, which rarely exceed 10 m. Each of the thick shales at Fosterville host laminated quartz veins that are usually less that 10 cm thick but can reach 80 cm. The thick shales at Bendigo similarly host laminated quartz veins (Boucher et al., 2008a), however, the latter are virtually absent at Ballarat East (Boucher et al., 2008b).

Some of the shales at Fosterville are carbonaceous black shales. The most notable is 'FOSH6', colloquially referred to as the 'Black Shale', which

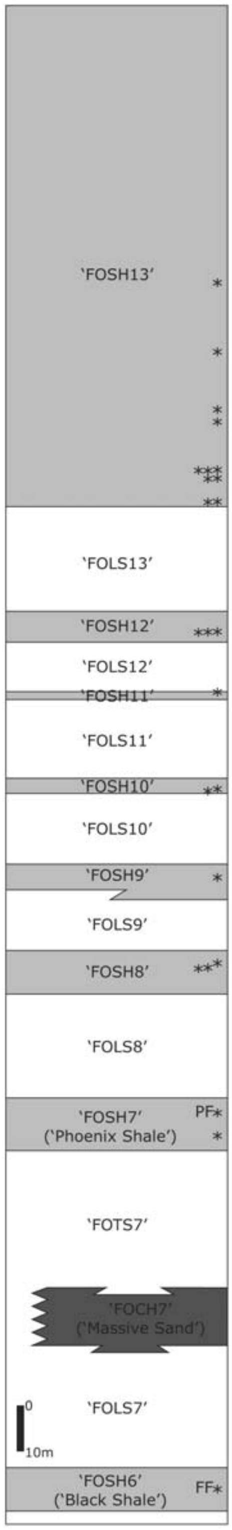


Figure 3. Stratigraphic column highlighting thick shale units and major bedding-parallel, laminated quartz veins (*). The stratigraphic positions of the Phoenix (PF) and Fosterville (FF) Faults are shown.

averages 10 m thick and is commonly faulted by the bedding-parallel Western Bounding and Fosterville Faults (Figs 4 & 5). Laminated, ripple-bedded, massive and black siltstones/claystones provide characteristics that makes each of the shale units uniquely identifiable.

The shale units at Fosterville can be correlated over significant distances without significant changes in thickness or internal character. This differs from Bendigo where the shales have a more restricted and varied distribution. As a result of the extensive shale development at Fosterville, the laminated quartz veins that are hosted within the shales are well represented. At Bendigo where shale thickness can be variable, the accompanying laminated quartz veins have a more restricted distribution.

A notable hanging-wall marker unit is 'FOCH7', the 'Massive Sand'. This comprises coarse and very coarse amalgamated channel-sands. Like the channel-sand units at Bendigo and Ballarat, 'FOCH7' is typically just over 10 m thick. A second channel-sand unit, not shown in figure 3, occurs about the same distance above 'FOSH13' as 'FOCH7' does below it. Channel-sands comprise a small percentage of the overall stratigraphy at Fosterville and it is interesting that the mine successions at Bendigo, Ballarat and Fosterville all occur close to or within this rare facies.

The extent of channel-sands at Fosterville are constrained by drilling (Fig. 2). In the hanging-wall in the northern part of the study area, 'FOCH7' is about 10 m thick (Fig. 4). However, the facies dies out dramatically (Fig. 5) and are not observed in the south (Fig. 6). Channel-sands have not been seen to the east of the Phoenix Fault (Fig. 4) and so the channel margin must lie somewhere between the two west-dipping limbs. The distribution of 'FOCH7' shows that the overall direction of the flow in the channel was to the northeast. While the lower boundary of the channel facies is conformable overall, there are local facies changes that suggest the channel is erosional (Fig. 2).

Stratigraphic controls on the development of veins, faults and folds

Laminated quartz veins are common at Fosterville within thick shale hosts. Stockwork quartz occurs close to major faults and is especially well developed in sand units. Away from the faults, veins exploit axial-planar cleavage in shales and radial cleavage in sandstones. This is more similar to the vein styles seen at Bendigo (Boucher et al., 2008a) than those at Ballarat (Boucher et al., 2008b).

The fault system at Fosterville is a series of faults that breach a parasitic fold on a large west limb. West-dipping beds persist for at least 600 m to the west of the Western Bounding Fault. It is uncertain how far west-dipping beds extend to the east. Figure 5 best demonstrates how faults are linked to laminated quartz veins hosted by thick shales above the syncline. Unlike Bendigo where the folds are more symmetrical and linked fault systems dip both to the east and west, the west-verging fold system at Fosterville hosts mostly west-dipping faults. Without significant east-dipping faults, there is little opportunity for neck or saddle reef development as occurs in the fold hinges at Bendigo (Boucher et al., 2008a).

As a general rule, the thicker the shale the greater is the associated fault offset. Multiple and thicker laminated quartz veins are seen in the thicker shales. The Phoenix and Fosterville Faults both have approximately 150 m of displacement (Figs 4 & 5). Fault offset diminishes where the associated shales are thinner and there is only about 5 m of displacement below the thin 'FOSH11' (Fig. 5). In contrast, a large fault system with significant offset is associated with 'FOSH13' (Fig. 6).

At Ballarat and Bendigo, there is good vein development in the channel-sand units. This is not apparent in the hanging-wall units at Fosterville. However, sandstones contain good stockwork vein development when east-dipping beds are truncated by west-dipping faults.

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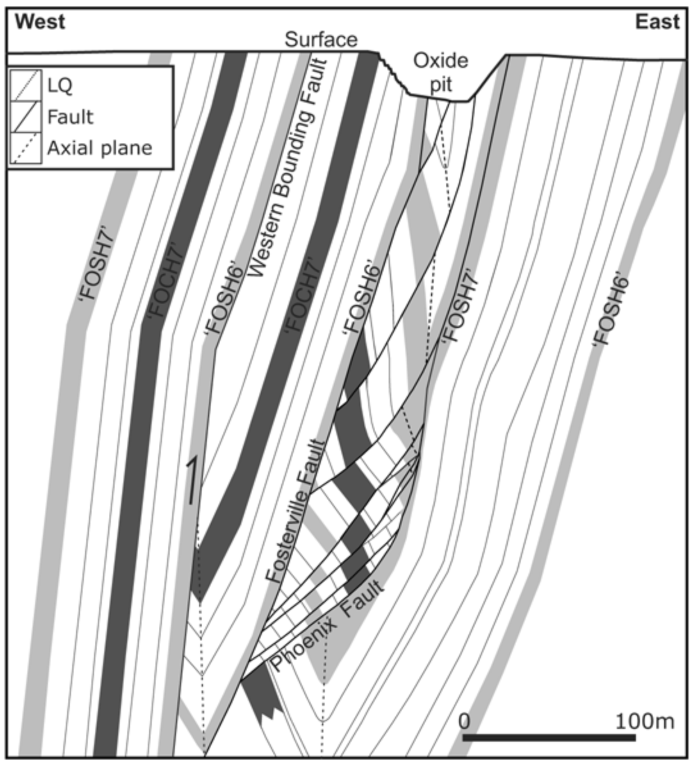

Figure 4. Section 8150mN showing major shale and channel-sand units, major faults and laminated quartz veins (LQ's).

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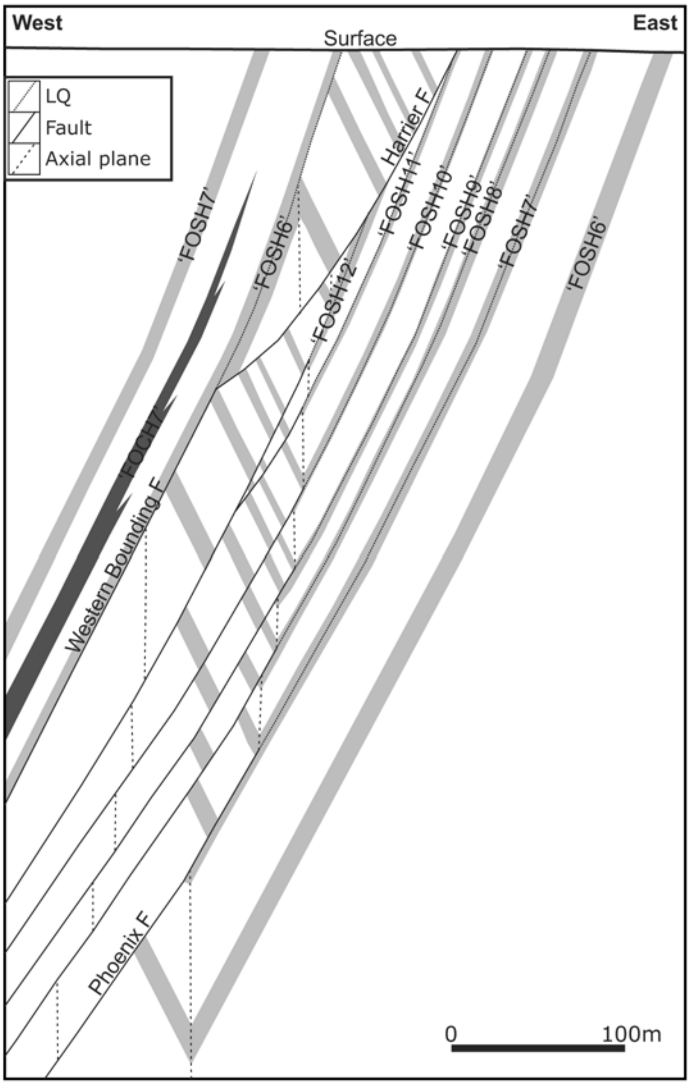

Figure 5. Section 7100mN showing major shale and channel-sand units, major faults and laminated quartz veins (LQ's).

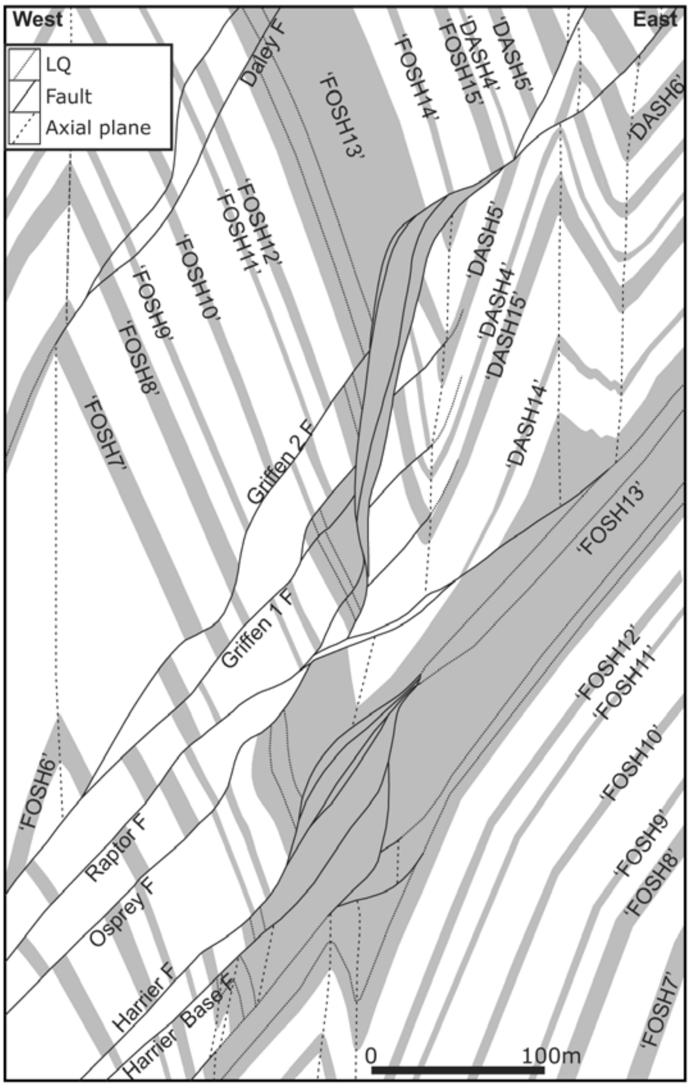

Figure 6. Section 5400mN showing major shale and channel-sand units, major faults and laminated quartz veins (LQ's).

Folding and fault styles at Fosterville

Folds at Fosterville are of upright chevron and occasional open style with vertical axial surfaces. Overall, the folds in the mine area are parasitic on a larger west limb. A domal structure culminates at about 8800mN and hinge lines plunge gently north and south of this point. The dip of the faults and associated mineralisation is controlled by the plunge of the folds. Folds have interlimb angles of between 40° and 60°, similar to those at Bendigo but greater than those at Ballarat.

The overall fault style is dominantly west-dipping and east-dipping faults are rare and small. As at Bendigo, faults typically are linked systems of laminated quartz veins and thrusts that propagate from fold hinges and truncate fold limbs. This is best seen in figures 4 & 5. The structural geometry becomes significantly more complex when the thick 'FOSH13' is faulted (Fig. 6).

At Fosterville, laminated quartz veins are not mineralised, in contrast to Bendigo where they commonly contain good nuggety gold. The best mineralised fault positions occur when east-dipping hanging-wall beds overlie west-dipping footwall beds, such as along the Phoenix Fault (Fig. 4). Significant fault displacement was imperative in providing a good down-dip window for mineralisation to occur. Where east-dipping beds occur in both the footwall and the hanging-wall, mineralisation is typically patchy and low grade. Without bedding control, faults that transect the east limb have a more erratic path. This is best seen in figure 6. Such faults change dip along their path. In section 5400 mN (Fig. 6), the two Griffin Faults split from a single fault further north. The anastomosing Harrier Fault is a single discrete fault elsewhere. The Osprey Fault ramps to become vertical in one of the axial surfaces.

The hanging-wall stratigraphy is repeated by the Western Bounding Fault on section 8150 mN (Fig. 4). This fault is mostly parallel with the stratigraphy, but lower down in the system it cuts across bedding and merges with the faults below. A drag syncline occurs beneath the fault where beds are truncated (Fig. 4). The Western Bounding Fault must have considerable displacement in order to repeat the stratigraphy. It is likely that this faulting occurred during early deformation of the succession. There is no mineralisation associated with the fault and this supports the notion that it formed and locked up earlier than the later mineralised faults.

Conclusions

Fosterville has similar sedimentary facies to other mines in central Victoria, but a thicker mapped stratigraphic succession reveals numerous thick shales and comparatively few channel-sand units. The stratigraphy can be correlated over many kilometres along strike and has been important in reconstructing the geology. Fosterville is dominated by west-dipping, linked faults that propagate from shale-hosted bedding-parallel laminated quartz veins across fold hinges and truncate opposing limbs. This is also seen at Bendigo, but not at Ballarat where thick shales are rare. However, Bendigo has east-dipping as well as west-dipping fault systems. Unique to Fosterville is a complete thrust-repeated succession and a shale that is three times thicker than any other yet seen in central Victoria. ▲▲

Acknowledgments

The management at Fosterville showed great initiative in developing and supporting the stratigraphic studies that have enabled a greater understanding of the structural complexity of the area and proved the benefit of detailed geological investigations. In particular, Chris Roberts, Trevor Jackson and Neil Norris provided enormous support. Steve King (Solid Geology) contributed valuable discussions during concurrent structural studies. The senior author is particularly grateful to the numerous staff geologists and research students who diligently collected data, assisted with field mapping and contributed to geological understanding of Fosterville. Thanks to Allan Rossiter for assisting with the final editing.

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Complaints, Complaints, Complaints

Complaints Committee targets some Competent Persons!

The Complaints Committee has noted in announcements an increase in the use of the term *target* with an associated lack of transparency. In some examples, it would have been possible to substitute the words "inferred resource", or another resource or reserve category, for "target" in the announcement without the reader being confused by the syntax.

Clause 18 of the JORC Code is quite clear about the use of the term *target* within the context of exploration results. A target is a conceptual body of mineralization of a desired type, size, metallurgy etc that a company is hoping to discover. Once you have found your target, it's no longer a target!

The JORC Code states (Clause 18): "information relating to exploration targets must be expressed so that it cannot be misrepresented or misconstrued as an estimate of Mineral Resources or Ore Reserves. The terms Resource(s) or Reserve(s) must not be used in this context. Any statement referring to **potential quantity** and grade of the target must be expressed **as ranges** and must include (1) a detailed explanation of the basis for the statement, and (2) a proximate statement that the potential quantity and grade is conceptual in nature, that there has been insufficient exploration to define a Mineral Resource and that it is uncertain if further exploration will result in the determination of a Mineral Resource."

To be on the safe side, Competent Persons should follow Clause 18 and if in any doubt, substitute the words "inferred resource" for "target". If it still makes sense (remember targets must be expressed as ranges), you may have overstepped the transparency mark.

Current complaints

Two complaints are currently being investigated by the Complaints Committee. The complaint mentioned in the May AIG News was closed with a warning issued to the member who signed the announcement as Competent Person. ▲▲