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Victorian gold deposits

G. Neil Phillips[1] & Martin J. Hughes[2]

[1]PO Box 3, Central Park, Victoria, 3145, Australia. [2]PO Box 148N, Ballarat North, Victoria, 3350, Australia.

EXPLORATION MODEL

Examples

Bendigo, Ballarat, Castlemaine, Stawell, Walhalla, Maldon, Woods Point (Victoria); Hodgkinson (Queensland); Murantau (Uzbek); Nome, Juneau (USA); Nova Scotia (Canada)

Target

- 1–10 Mt.
- Few large, many small.
- Grade: 10–40 g/t.
- Major metal is Au, minor Ag.
- Low Cu, Pb, Zn.
- Low Ag/Au, gold fineness >900.

Mining and treatment

- Multiple veins required for economic size.
- Coarse free Au in quartz is typical and facilitates recovery.
- High sulphides undesirable, especially if enclosing fine Au.
- High arsenopyrite or stibnite rare.

Geological criteria

- Greenschist facies.
- Metasedimentary (flysch) package, i.e. 'slate belt'.
- Subordinate mafic volcanics.
- Au broadly contemporaneous with acid volcanics, S-type granites, I-type granites, dioritic lamprophyres, and regional metamorphism.
- Au contemporaneous with close of deformation.
- Near major reverse faults (i.e. hangingwall).
- Black slate hosts and Fe-rich mafic hosts, e.g. mafic diorites, rare dolerites.
- Major placers and palaeoplacers near primary deposits.
- Palaeoplacers beneath Cainozoic basalt and sediments.
- Palaeoplacers are linear, few km to tens of km long.

Mineralisation features

- Quartz veins are mostly hosted by strike faults of moderate to steep dip.
- Goldfields and individual deposits parallel regional structural trends.
- Quartz veins cluster into highly elongate swarms that can be >100 km long.
- No spatial relationship to granites.
- Repetitive vein systems in larger deposits.
- Pyrite–arsenopyrite 1–3%, up to 10% locally.
- Pyrrhotite and loellingite in higher metamorphic grade domains (e.g. aureoles).
- Arsenopyrite widespread, stibnite less so.
- Sphalerite, galena and chalcopyrite only locally abundant, although slightly enriched in many ore shoots.

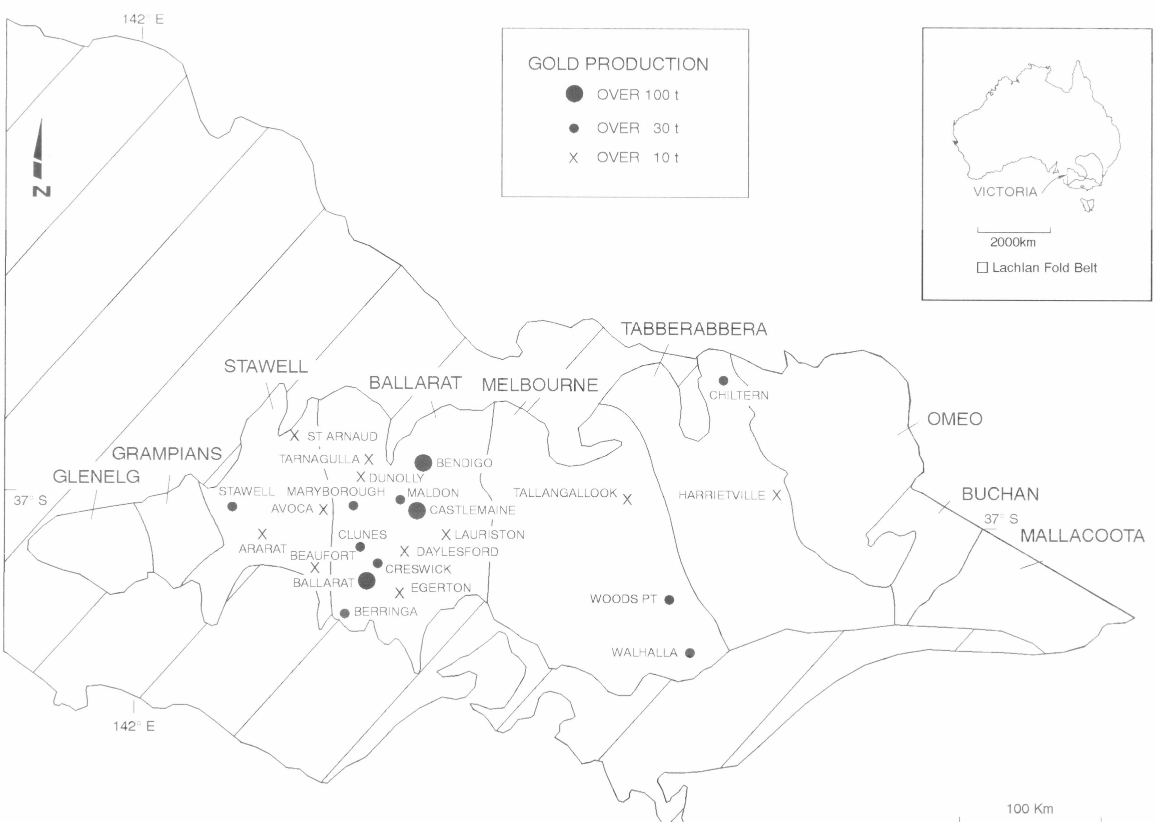

Figure 1. Victorian gold province, showing outcrop of the Palaeozoic succession and the separate geological zones. The zones are based primarily on age, lithology, metamorphism and deformational history. Goldfields over 10 t production are confined to west of the Omeo zone and east of the Grampians subzone of the Glenelg zone. The Palaeozoic succession is overlain by sediments of the Murray Basin to the north, and Cainozoic basalts and sediments to the south.

Alteration

- Alteration is a function of fluid *and* host rock (former shows limited variation).
- Mafics have distal carbonate–albite–clinozoisite–chlorite–pyrite, and proximal carbonate–muscovite–pyrite.
- Slates have carbonate–pyrite–muscovite, and some carbonate–sulphide halo.
- Felsics have muscovite–pyrite
- Carbonate type reflects host rock Fe/Mg/Ca.
- Ankerite common, calcite and siderite less common.

Geochemical criteria

- Enrichment of CO_2, K, S, As, ± Sb widespread.
- Minor anomalies of Cu, Pb, Zn, Ag.
- Bi, W, Mo and Te can occur in those deposits adjacent to granite.
- Cu, Pb, Zn abundant in some small Au deposits in east.
- B, F, P, Th, U and, probably, Hg negligible overall.
- S isotopes around 0, e.g. +2 ±5 per mil.
- C isotopes in carbonates slightly negative, e.g. from −3 to −10 per mil.
- Pb isotopes variable and not similar to host rocks in most instances, although a component of host rock Pb may be present (limited data).
- Various anomalous elements useful in exploration, for some deposits just As and Au, for other deposits just Au (commonly visible pyrite and/or carbonate halos).

Geophysical criteria

- Regional aeromagnetics and radiometrics for stratigraphy and structure.
- Low sulphides in most deposits hinder EM and electrical methods.
- Ground magnetics possibly useful where there is mineralisation-related magnetite destruction.

Fluid chemistry and source

- Limited data.
- Low salinity (<5 wt% NaCl eq.) mostly, no daughter products.
- 250°C homogenisation temperature (±50°).
- Reducing conditions overall (pyrite–chlorite, no magnetite, H_2S, CO_2, no barite).

Comments on genesis

- Syn-metamorphic, syn-deformational age suggested by most authors.
- Ramsay & VandenBerg (1986) have implied a significant role for seafloor exhalation and granites.
- All major deposits pre-date 365 Ma magmatism.
- Some major deposits post-date 395–410 Ma magmatism
- Au broadly synchronous with Devonian deformation and thermal anomaly.
- Fluids probably derived from metamorphic devolatilisation.
- Strong relationship to Fe and/or C in host rocks analogous to other Au-only deposit types (e.g. Archaean greenstone Au).

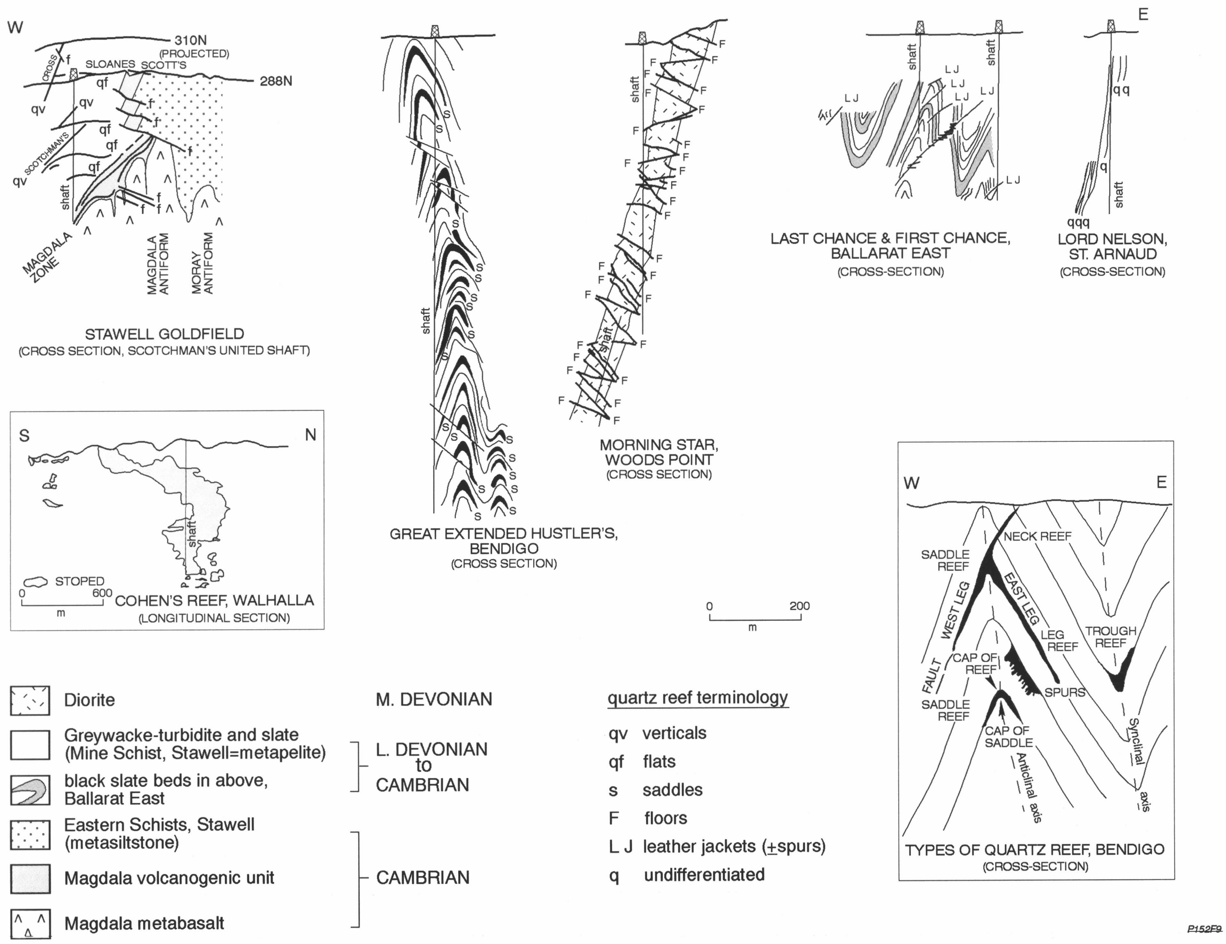

Figure 2. Cross-section through major goldfields, showing repetition of mineralised structures and variation between fields (vertical and horizontal scales are the same).

Victoria represents one of the world's major gold provinces, with a total production of 2500 t Au (i.e. 79 Moz). It is the prime example of a Palaeozoic 'slate belt' gold province (also known as 'turbidite-hosted', or 'shale-greywacke' gold province). Gold mining commenced in 1851, declined dramatically around 1914, and has not increased significantly since. Substantial production came from quartz veins (1000 t), modern placers (1200 t) and palaeoplacers (300 t). Up to 7000 'mines' produced gold from quartz veins; however, the 168 mines of this type which produced over 1 t Au contributed 68% of the total primary gold production. Twelve goldfields have exceeded 30 t Au (approximately 1 Moz) from all sources, with Bendigo (697 t), Ballarat (408 t) and Castlemaine (173 t) being the largest; these twelve largest goldfields have contributed 70% of the combined primary and secondary production (see Table 1, Fig. 1). Much of the following description is based upon the larger historic producers.

The Palaeozoic succession of Victoria is part of the Tasman orogenic belt. In Victoria, the succession is dominated by Cambrian to early Devonian clastic metasedimentary rocks that have undergone deformation and low-grade metamorphism, culminating in the Middle Devonian Tabberabberan orogeny. Elongate inliers of Cambrian metavolcanic and metasedimentary rocks are associated with thrust faults, which divide the province into several zones containing mostly metasedimentary rocks of Early Palaeozoic age. There are extensive acid volcanic complexes of Late Devonian age in central Victoria, and synchronous peraluminous granites, which represent high-temperature crustal melting. Tertiary to Quaternary basalts conceal some of the Palaeozoic gold deposits and several, rich palaeoplacer gold deposits of Cainozoic age.

Many larger goldfields, including Bendigo and Ballarat, occur in Ordovician slate and greywacke sequences. Primary deposits show structural control, although the controlling structural features vary between deposits; the most common mineralisation control is strike faults of moderate to steep dip which occur near major reverse faults (Fig. 2). Wallrock alteration is strongly influenced by host rock: in metasedimentary rocks it is restricted and subtle, but it is more pervasive in mafic and felsic igneous rocks. Carbonates, muscovite and pyrite are the most widespread alteration minerals in these rocks, representing addition of CO_2, K and S. Arsenic (and in some areas Sb) enrichment is common, whereas Cu, Pb and Zn are only abundant locally. Bi, W, Mo and Te show strong spatial association with granites and are rarely associated with gold deposits.

A single period of protracted and possibly diachronous gold mineralisation, culminating at the time of the Tabberabberan deformation (Middle Devonian), can explain geological relationships at many gold deposits. The possibility that this event was slightly older (i.e. Silurian) in the west of the state cannot be precluded on the available evidence. The mineralising event is temporally linked to granite intrusion, acidic and subordinate

Table 1. Production and features of major Victorian gold producers. Many figures are minima.

Goldfield	*Production (t Au)*				*Host rock*
	Total	*Primary*	*Placer*	*Palaeoplacer*	
Bendigo	697	540	157[1]	-	flysch[2]
Ballarat	408	65	273	70	flysch
Castlemaine	173	27	146*	-	flysch
Stawell	82	61		21*	basalt, hornfels
Creswick	81		27	54	flysch
Walhalla	68	68	-	-	diorite dyke
Maldon	65	56	9	-	hornfelsed flysch
Woods Point	52	40	12	-	diorite dyke
Clunes	47	37	10*	-	flysch
Chiltern	46	1	-	45	flysch
Maryborough	32	3	-	29	flysch, diorite dyke
Berringa	30	18		12*	flysch
Fosterville	27	27	-	-	flysch
Egerton	27	16	11	-	hornfelsed flysch
Harrietville	24	12	12*	-	flysch, diorite dyke
Avoca	23	-	18	5	
Ararat	20	1	-	19*	flysch
Daylesford	20	17	3*	-	flysch
Tarnagulla	13	13	-	some	flysch
St Arnaud	12	12	some	-	flysch
Dunolly-Moliagul	10	4	some	3	flysch
Beaufort	10	-	some	8	
Taradale-Lauriston	10	6	some	some	flysch

[1] includes both placer and palaeoplacer gold; [2] flysch includes turbidite, sandstone and slate

basaltic volcanism, dioritic lamprophyre intrusion, deformation and regional metamorphism.

Granites are an important volumetric component of the Palaeozoic succession in Victoria. No large gold deposits are within granites, but a few goldfields, including Maldon (65 t Au), are within contact aureoles of either S- or I-type granites of differing degrees of fractionation and silica content.

Sulphide-rich gold deposits in the east of Victoria, many of which contain significant arsenic and base metals, contrast with the rest of the province (gold deposits with lower sulphide content), and this eastern area should possibly be viewed as separate from the Victorian gold province, *per se*.

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