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LAST CHANCE FOR DUES RENEWAL
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Giant Placers of the Victorian Gold Province

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ABSTRACT

The Victorian gold province has yielded 2500 tonnes (t) Au, nearly 2 percent of cumulative world gold production, mostly mined between 1851 and 1910. Fifty-five percent (1375 t) was placer gold from modern and paleostream systems, and from eluvial deposits, and the remainder came from primary quartz vein-related deposits. Most of the alluvial gold placers are in unconsolidated or weakly cemented quartz pebble conglomerate and gravel, dominated by hydrothermal quartz, although a few paleoplacers are within duricrusted conglomerate that required crushing. Large and abundant gold nuggets were common. Placer gold deposits formed in three intervals following uplift in the Late Cretaceous, Late Eocene, and Pliocene. An important factor in the preservation of the paleoplacers has been their burial by younger sediments and basalt flows, with consequent protection from erosion and dispersal.

Factors in the formation of the giant gold placers of Victoria include the following: (1) the existence of a major primary gold province with several multimillion-ounce gold deposits; (2) uplift and reactivation of older faults; and (3) high rainfall and deep Paleogene weathering.

INTRODUCTION

Placer gold deposits are generally easy to locate, relatively easy to mine, and commonly of high grade, and do not require expensive infrastructure to commence a viable mining operation. An understanding of the geology of placer gold deposits has rarely been critical to successful mining, and the geology is therefore poorly recorded and commonly not well integrated into a modern geoscientific framework. Given the antiquity of many gold-mining districts and their poor documentation, even the cumulative historic production of placer gold is poorly known. The Phanerozoic gold deposits recognized here as placers have contributed approximately 13,000 tonnes (t) of gold worldwide (Table 1), but the

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TABLE 1. Gold Production (tonnes) of Major Phanerozoic Placer Districts of the World with Greater Than 100 t of Recorded Placer Gold Production

District	This paper	Henley and Adams (1979)	Goldfarb et al. (1998)	Boyle (1979)	Bache (1987)
Southern California		1306	2131	1711	2000
Eastern Siberia		1244	>4043	>1244	
Victoria	1375		1500		
Columbia		995			1500
Northwest USA					576
- Montana					*270*
- Oregon					*110*
- N. California			*109*		
- Idaho					*87*
Yukon/British Columbia		467	>373	404	450
- Klondike		*280*		*311*	
- remainder		*187*		*93*	
South Island, N.Z.		404	>404		400
Bolivia		308			355
Chile		342			330
Fairbanks, Alaska		249	>342		289
Zaire					250
Borneo					200
Guyana/Surinam					200
Nome, Alaska			187		146
Madagascar					150
Guinea					150
Peru		124			
Mali					100
Spain					100

Note: Total placer production listed above is approx. 13,000 t Au

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data are poor in quality and the list is very incomplete. Only Phanerozoic placers are considered here, although older placers undoubtedly exist. However, some authors dispute a placer origin for the largest ancient example commonly cited, the Witwatersrand gold deposits of South Africa (e.g., Phillips and Law, 2000).

The Victorian gold province has yielded 2500 t Au, nearly 2 percent of cumulative world gold production, mostly between 1851 and 1910. The province provides a special opportunity to synthesize geologic data from one of the largest recorded placer provinces (1375 t Au production), and to integrate the placer gold deposits into the comprehensive existing framework of the Phanerozoic geology of southeast Australia. Although the record of placer production in Victoria is one of the weakest aspects of Victorian gold geology, the information is still superior to that of most other placer gold fields around the world (Table 2). Placer mining commenced in 1851 and, unlike many fields elsewhere, the remains of former placer mining districts have not been substantially modified, much less obliterated, by subsequent human activity. Much information can be gleaned from the recorded history, remaining infrastructure, existing old workings (Blainey, 1993; Hughes and Phillips, 2001), and diligent documentation by the Geological Survey of Victoria in the decades following discovery. All of these factors permit a detailed evaluation of the dispersion of gold, allowing several generations of placer development to be identified. This development is explained in terms of (1) proximity to major primary gold sources, (2) tectonic uplift within the province, and (3) weathering and climate change.

TABLE 2. Victorian Gold Fields with More Than 10 t of Either Primary or Placer Gold Production

Gold field	Total (t Au)	Primary	Placer	Deep paleoplacer[1]
Bendigo	697	540	157	*Unknown*
Ballarat	408	65	343	*70*
Castlemaine	173	27	146	-
Stawell	125	100[2]	25	-
Creswick	81	Minor	81	*54*
Walhalla	68	68	Unknown	-
Maldon	65	56	9	-
Woods Point	52	40	>12	-
Clunes	47	37	>10	*10*
Fosterville	>9	>9[3]	Minor	-
Chiltern	41	4	37	*30*
Maryborough	32	3	>29	*29*
Berringa	30	18	>12	*12*
Mount Egerton	27	16	11	-
Harrietville	24	12	>12	-
Avoca	23	Minor	23	*5*
Daylesford	20	17	>3	*3*
Ararat	20	<1	19	*5*
Tarnagulla	13	>13	Major	-
St Arnaud	12	12	Unknown	-
Pitfield Plains	11	1	10	*6*
Beaufort	10	Minor	>10 (major)	*8*
Gold fields <10 t	80	64	16	*33*[4]
Subtotal	2068	1103	965	*265*
Unassigned	432[5]			
Victorian total	2500			

Figures based on Phillips et al. (2003) but have been refined following recent compilations for some less well-recorded gold fields, and revision of an inaccurate source used in the past for the Chiltern area; other gold fields that possibly produced more than 10 t of gold, which lack records but were reportedly large producers, include Dunolly-Moliagul, Wedderburn, Inglewood, and Malmsbury-Lauriston-Taradale

[1] >30 m depth (included in placer totals)
[2] Also 52 t resource
[3] Also 37 t resource
[4] Bowen (1974)
[5] Dominantly placer

VICTORIAN PLACER MINING

The gold rushes to California in 1849 and Victoria in 1851 led to global population migration on a scale rarely seen. In Victoria, the non-indigenous population rose from 73,000 to 540,000 in the decade following 1851. The discovery of placer gold in 1851 led to a major rush, and by the end of the year, Bendigo, Ballarat, and Castlemaine had all been discovered (Fig. 1). For the next decade most of the 2 to 3 Moz of gold produced per year was from placer workings, and for a time nearly half the world's gold production came from Victoria.

Stories from individual mining centers told of fabulous riches during this period of placer mining (Hughes and Phillips, 2001). The 3 km stretch of Forest Creek and its tributaries at Castlemaine produced 80 t of gold in the first 10 years, peaking at 3 t of gold per week. Nearby at Donkey Gully, it is claimed a tonne of nuggets was picked from the surface. There are several reports from other locations of nuggets lying on the ground "like potatoes," or of prospectors using shovels to turn over the gravel and pick out the nuggets. At Ballarat, a 3 × 3 m placer claim yielded a total of 430 kg of gold. Even 55 years after the initial rush, at Poseidon near Tarnagulla, a single 25-m claim yielded five 10 to 30 kg nuggets, and an additional 100 kg of finer gold. Nuggets of many kilograms are still found (e.g., the 23 kg Hand of Faith found at Wedderburn in 1980).

Early alluvial and eluvial mining involved small claims worked by single miners or small groups. Alluvial production was from active stream systems (possibly a subordinate part of the total production), and on adjacent flats where buried river gravels were mined to depths of 30 m. Only in the 1860s and 1870s did syndicates and companies pursue the more deeply buried paleoplacer deposits ("deep leads") that lie beneath basalt flows, which were mined to 150 m depth in places (Hughes and Phillips, 2001). The Victorian placer gold production peaked in 1856 and then steadily declined, but large gold mines based on primary gold deposits became increasingly important producers and stabilized Victorian production from the 1880s until 1910. A third, minor phase of placer mining occurred

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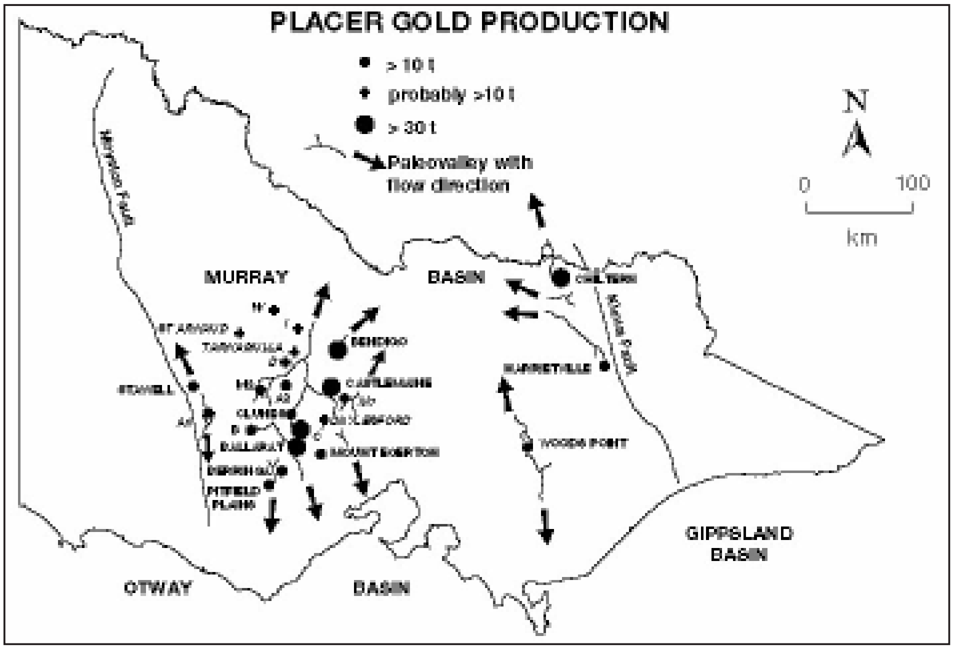

FIGURE 1. Map of Victoria with placer gold production from the Victorian gold province, showing gold fields with greater than 10 t placer gold production. These are all between the Moyston Fault in the west and the Kiewa Fault in the east. Most production was from the Ballarat zone (i.e., between the Avoca Fault and the Heathcote Fault of Fig. 2). Arrows indicate paleo-flow directions, north and south from an east-west topographic divide. A1 = Ararat, A2 = Avoca, B = Beaufort, C = Creswick, D = Dunolly, I = Inglewood, M1 = Malmsbury, M2 = Maryborough, W = Wedderburn.

between 1935 and the 1950s and involved dredging of some of the larger river flats, particularly in the Ovens and Loddon river valleys (Ralph, 1999).

GEOLOGICAL SETTING OF PRIMARY GOLD IN VICTORIA

The geologic history of Victorian primary gold deposits can be divided into two events: (1) eruption of Cambrian volcanic rocks, predominantly submarine and basaltic, followed by deposition of a Cambrian to Devonian graywacke turbidite and slate succession; (2) deformation, metamorphism, Siluro-Devonian intrusive and extrusive magmatic activity, and primary orogenic gold introduction.

The mostly subgreenschist to greenschist facies Paleozoic succession has been subdivided on structural and stratigraphic grounds into a series of geologic zones, separated by major faults (Gray et al., 1988). The Stawell, Ballarat, Melbourne, and Tabberabbera zones correspond to the Victorian gold province (Phillips et al., 2003; Fig. 2). Siluro-Devonian granites occur throughout the province, but do not host gold ore deposits. Felsic and mafic to ultramafic dike swarms are also widespread, and locally the more mafic types are major gold hosts (e.g., Woods Point).

Although there are more than 6000 quartz reef “gold mines” recorded in Victoria, probably 80 percent of Victoria’s past hard-rock production would be produced from a few tens of mining operations if mined today, using modern technology on larger mining leases. Most primary gold deposits are restricted geographically between the Moyston fault in the west and the Kiewa fault in the east (Fig. 2). Based on primary production alone, eight gold fields have produced close to 30 t of gold (i.e., 1 Moz) or more, the largest being Bendigo (697 t Au, or 23 Moz). A ninth (Fosterville) has a resource of this size (Table 2). The Ballarat zone has produced the most gold and contains the largest individual primary deposits.

All primary deposits show strong structural control on gold distribution. The surface expression of economic mineralization is up to 8 km along strike and 3 km wide in the case of Bendigo, and mines extended to depths of up to 1407 m. Auriferous quartz veins of orogenic (mesothermal) type were the most common deposit types mined.

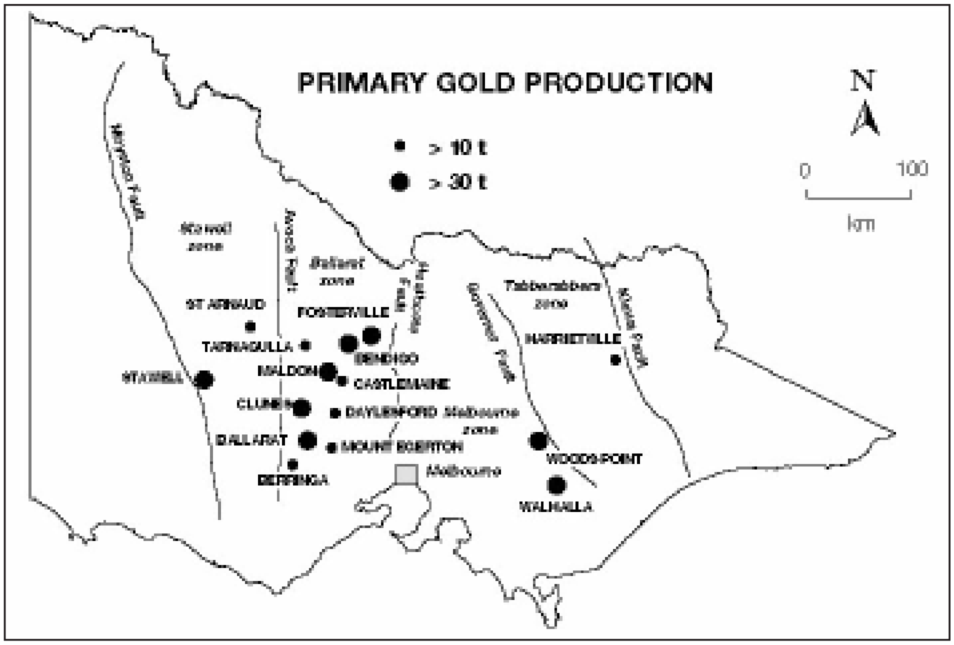

FIGURE 2. Primary gold production from the Victorian gold province. Gold fields with greater than 10 t and 30 t primary gold production are shown. These are confined between the same two faults as the placer gold fields of Figure 1, and mostly represent the same gold fields. The bulk of production was from the Ballarat zone. In the case of Fosterville, the estimated resource rather than production is shown.

POST-PALEOZOIC FRAMEWORK OF PLACER GOLD IN VICTORIA

The three generations of Victorian placer gold deposits are intimately linked to the post-Paleozoic geologic evolution of the region (Phillips et al., 2003). Late Mesozoic to Recent climate, tectonism, and subaerial volcanism determined the extent of erosion and the nature and depth of the regolith in Victoria. In particular, these factors controlled the development and distribution of fluvial gravels and their contained gold placers in highland areas.

White Hills Gravel placers

Small marine basins formed in rifts near the site of Mesozoic separation of Antarctica and New Zealand (the final rifting of Gondwanaland), with deposition of thick Cretaceous sedimentary sequences (Norvick and Smith, 2001). Mid-Cretaceous uplift formed the Victorian highland areas immediately to the north of these basins and created a drainage divide from which streams flowed north and south. The shallow Murray Basin formed north of the divide, and received just 600 m of marine and non-marine Cenozoic sediment (Fig. 1).

The first of three important generations of placer drainages, that of the White Hills Gravel, developed prior to the Late Eocene, and possibly as early as the Late Cretaceous. These drainages consisted of broad, high-volume rivers with low gradients that developed in shallow valleys on deeply weathered highlands of fairly low relief. These highland areas possibly developed from an uplifted paleoplain that formed during mid-Cretaceous uplift. The White Hills Gravel and exposed Paleozoic rocks were deeply weathered under humid conditions. Kaolinitic soil profiles up to 30 m thick, ferricretes, silcretes, and locally bauxites were formed at this time (Carey and Hughes, 2002), and duricrusts locally made the placer gravels uneconomic because of a need for crushing. Thick Cenozoic sedimentary sequences were deposited in the basins to the south. Subaerial basaltic volcanism increased for a time in the Paleocene, in association with reactivation of the rifts to the south.

Loddon River Group placers

The second generation of placer drainages, that of the Loddon River Group, was formed by incision of rivers into the highlands after base-level change in the Late Eocene. This was probably caused by uplift related to extension and wrench faulting in the rifts to the south, which were in turn related to transform faulting and microplate reorganization south and east of Victoria in the Southern Ocean and the Tasman Sea. The combined effect of uplift and sea-level fluctuations was to change the base-level of erosion, with incision of new and deeper valleys into the highland areas (Hughes and Carey, 2002). The White Hills Gravel was left as isolated remnants on hilltops in many areas (Phillips et al., 2003, fig.13.45) and this, together with the absence of ferricrete clasts (present in Loddon River Group gravels), assists in their identification.

The Loddon River Group drainages were initially of fairly high discharge volume, and had slightly higher gradients than the previous gravels, but flowed in valleys that were deeper and narrower than those of the White Hills Gravel. Many formed by deepening of the earlier White Hills Gravel valleys, and gravels of the latter were eroded and reworked. Some new drainages also formed, locally obliterating the White Hills Gravel valleys. Erosion probably exceeded chemical weathering, aided by change to a drier climate, and the earlier deep weathering mantle was extensively stripped. This climate change is indicated by a switch from forests of southern beech (*Nothofagus)* in the early Cenozoic to *Eucalyptus* in the Neogene.

Gold placers in the larger valleys were subsequently overlain by younger, fine-grained sediment of Eocene and Oligocene age as the sea invaded the Murray Basin and basins to the south, and the valleys were back-filled (e.g., Rutherglen), but placers would have continued to form and be reworked in the higher-gradient tributaries and headwaters of these valleys. *Nothofagus* forests reappeared at the Miocene-Pliocene boundary, in conjunction with deeper (or chemically distinctive) weathering, reflecting a brief reversion to a wetter climate.

Quaternary placers

There was a resurgence of basaltic volcanism in the latest Oligocene and again at the Miocene-Pliocene boundary, progressively affecting highland areas in the far south and east-central parts of the gold province. However, the most voluminous basaltic volcanism commenced in the Pliocene, and was active up until 5,000 years ago, affecting much of the gold province as far west as Ararat. Basalt lavas filled valleys from south of the highlands to north of the modern drainage divide, which had probably shifted little since the Paleogene. Many placers of the Loddon River Group were buried beneath the lavas (e.g., Ballarat, Creswick) or lake sediments that formed when the lavas dammed tributary valleys (e.g., Ballarat).

Collision of the Indo-Australian plate with the Sulawesi-New Guinea area to the north in the Late Miocene caused plate motion to slow, and a compressional stress regime developed throughout the Australian continent (Hillis et al., 1998). This compression resulted in uplift (e.g., up to 150 m south of Ballarat), and exposed even the earliest Loddon River Group paleoplacers to erosion in some areas. Drier conditions followed in the mid-Pliocene, with return of the *Eucalyptus* forests. The third and final, Quaternary, generation of placer drainages developed following this uplift. Many of the resultant alluvials were confined to fairly narrow channels in higher gradient, lava-free areas, or areas where lavas were dissected to expose Paleozoic bedrock. The modern rivers are small and low in discharge because of the current drier climate, some being ephemeral. Significant eluvial gold deposits also formed, and an unknown but important component of Victorian placer gold was mined from such deposits in thin cover on hillsides near primary gold deposits.

Supergene processes have played a major role in the development of Victorian gold since the early Paleogene. These include the weathering of the near-surface parts of primary gold systems, the physical modification of older alluvial deposits by erosion, fluvial redeposition, and in situ chemical (lateritic) weathering, and the chemical remobilization of gold in the regolith, probably including the formation of some gold nuggets.

NATURE OF PLACER GOLD DEPOSITS IN VICTORIA

Victorian placers are dominantly fluvial. Placers of the White Hills Gravel and Loddon River Group are strictly paleoplacers, in that they are deeply buried or uplifted and unrelated to

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modern drainage patterns, as is the case in parts of some other major placer fields (e.g., California; Henley and Adams, 1979). However, this paper mostly uses the less specific term “placer” when describing these deposits. Where rare paleocurrent indicators occur, they suggest no radical change in flow directions from the Paleogene to the present; that is, in northern areas paleoflow was generally to the north, and in the south paleoflow was to the south. Mining of paleoplacers was mostly confined to valleys of the highlands and only extended a few kilometers beneath cover of the basins to the north and south, although potential for gold remains in these areas.

Placer gravels

Placer gravels of the White Hills Gravel and Loddon River Group are thin fluvial units, generally not more than a few meters thick, which mostly consist of quartz pebbles and lesser cobbles (rather than bedrock clasts), and subordinate sands. The subangular to well-rounded gravels are very coarse in places, with quartz boulders in the range 0.5–1 m (and even larger) being fairly common. The quartz is mostly milky, and can be seen texturally to be of hydrothermal origin, with occasional visible gold. A lithic component is less commonly present and only locally exceeds the quartz in abundance. The proportion of hydrothermal vein quartz is so high that the placer pebble dumps have been evaluated as sources of low-grade gold ore for milling, and have been used to produce micronized silica.

Placers in the Quaternary drainages are mud-rich gravels and subordinate sands, and are therefore compositionally distinct from earlier gravels. Lithic clasts are abundant and less rounded. Eluvial placers are hosted by angular gravels of varying age, and volumetrically insignificant marine placers are confined to well-rounded quartz gravels and sands of Pliocene age (e.g., near Pitfield Plains).

Economic factors

There is a difference in the average economic length of placers of different ages. The distribution of old placer workings in the White Hills Gravel suggests that the placers extended only a very short distance from their source areas. However, the economic length of individual Loddon River Group placers was as great as that of Quaternary placers, or greater. In most cases, economically important placers formed considerably less than 10 km from their gold sources, as at Chiltern and Rutherglen (Fig. 3), and Ballarat (Finlay and Douglas, 1992, fig. 7), and commonly closer to 1 km. However, in other areas alluvial gold has formed economic deposits as much as 25 km from its source, for example, at Eldorado, near Chiltern, where placers occur over this distance on postore granite after leaving their source area in Paleozoic metasedimentary rocks at Beechworth (Fig. 3). The greater migration distances are accompanied by decreased gold abundance, increased rounding of gold grains, and finer grain size of the gold (Dunn, 1929).

Typical grades of the larger Victorian placers ranged from 5 to 40 g/m^3, averaging approximately 10 g/m^3 (Canavan, 1988). In the mountain section of streams, alluvial gold was mined over widths of 30–60 m, compared to widths of 100–400 m in mid-profile areas, and

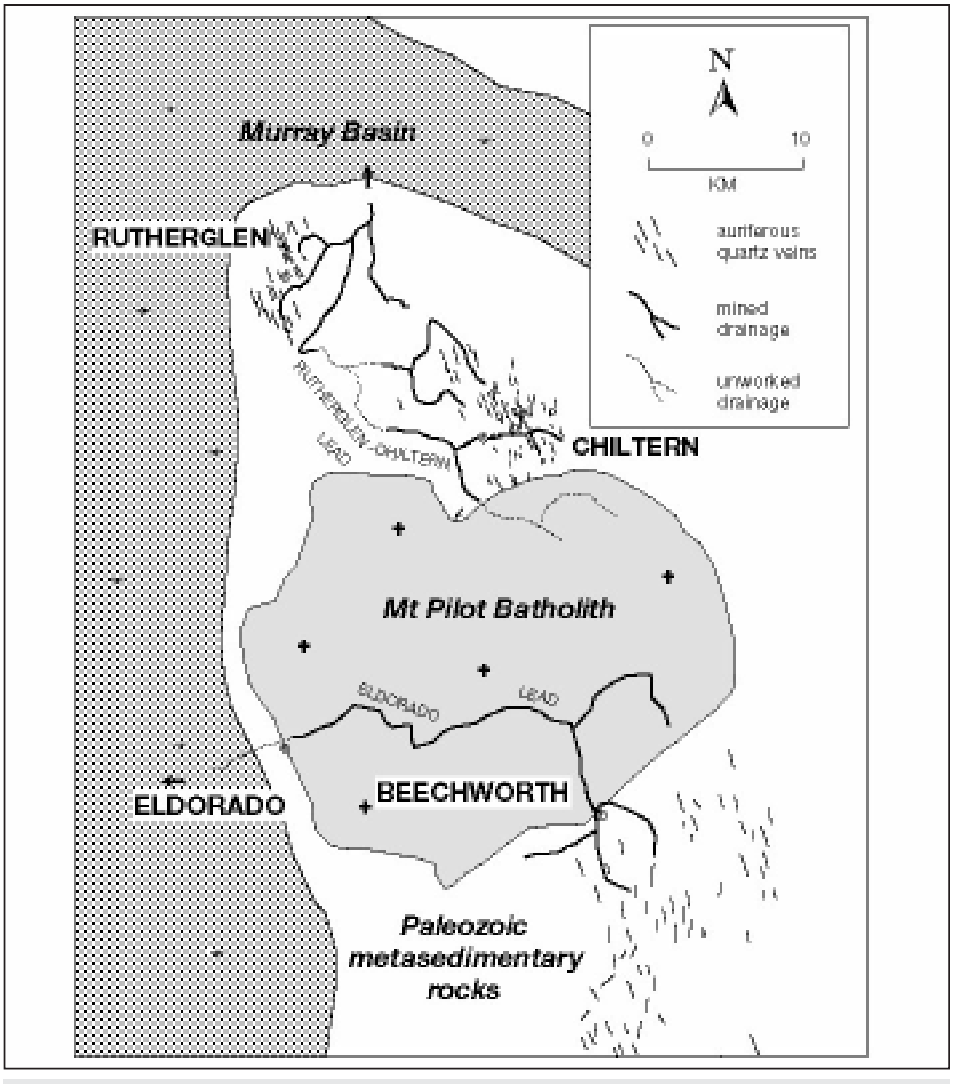

FIGURE 3. Placers of the Beechworth-Eldorado and Chiltern-Rutherglen gold fields (modified from Hunter, 1909, and Canavan, 1988). A major paleoplacer at Chiltern was stoped continuously for more than 10 km downstream in a single paleodrainage system after intersecting auriferous quartz veins of the Chiltern field. There was then negligible production from the paleodrainage for 8 km until it intersected primary gold veins of the Rutherglen field, beyond which it was stoped continuously for a further 10 km downstream. At Beechworth a drainage system (paleodrainage in part) was worked from its source area for 25 km across granite of the postore Mt. Pilot Batholith, which contributed no gold (but some cassiterite). The placer only became uneconomic downstream of Eldorado.

much greater channel widths in the unworked plains farther downstream (Hunter, 1909). Despite the different valley widths of the White Hills Gravel and Loddon River Group generations of placers, the stoped width of channels commonly appears to be comparable in both (e.g., a maximum of 350 m in the White Hills Gravel at Great Western, near Stawell, and in the Loddon River Group at Ballarat West).

Placer gold was mostly produced from within 2 m of the unconformity between the gravel and underlying Paleozoic rocks (Hunter, 1909). The basal gravels were typically 0.15 to 1 m thick, with thicknesses as great as 10 m being very rare. Tens of meters of mostly unconsolidated, permeable, water-saturated sands, then clays, occurred above the gravel (except for the White Hills Gravel deposits which were often dry because of their topographic elevation). Commonly, decimeters of the top of the Paleozoic bedrock were also mined because of the presence of gold in mechanical traps. The placer gravels were extracted over their entire width for valley lengths exceeding 10 km on some gold fields (e.g., Chiltern; Fig. 3).

The economic importance of the three generations of drainages varies, partly because of limited preservation of White Hills Gravel and the difficulty of mining deeply buried placers of the Loddon River Group. Most production was from the Quaternary placers, and from shallow placers of the Loddon River Group (e.g., Bendigo, Castlemaine, Maryborough; Phillips et al., 2003). Deep placers of the Loddon River Group (e.g., Ballarat, Creswick) were next most important, and then those of the White Hills Gravel (e.g., Ararat, Wedderburn, Bendigo). Other factors might also have influenced the economics, such as the different sizes of the rivers in which the gold formed, or a lack of earlier alluvial gold sources for the White Hills Gravel. There is also the possibility that coarse-grained, supergene gold was not so abundant prior to deposition of the White Hills Gravel as it was later.

Mineralogy and gold nuggets

The Victorian province yielded alluvial and eluvial gold nuggets in an abundance and size that together appear unmatched elsewhere in the world (Fig. 4). The largest gold nugget recorded was 71 kg, and a further 50 exceeded 15 kg.

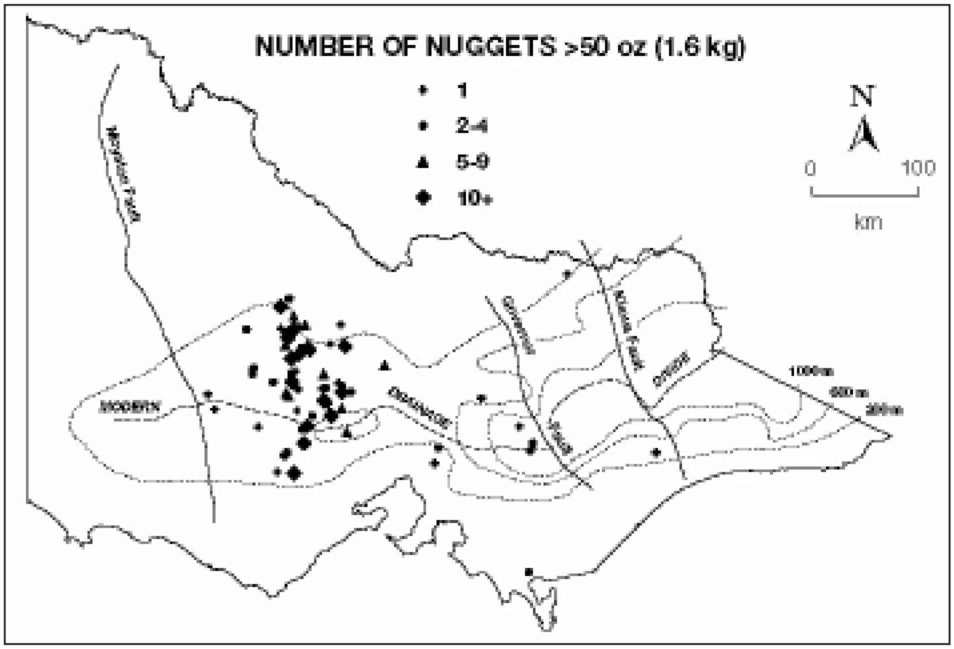

FIGURE 4. Distribution and number of recorded alluvial and eluvial gold nuggets exceeding 50 oz (1.6 kg) in mass (Dunn, 1912). The nuggets are most abundant in the lower-lying Ballarat zone (Fig. 2). The number of nuggets larger than 1.6 kg in the Ballarat zone relative to the area to the east of Melbourne (a ratio of 15:1) is greater than one might expect if it were simply a function of the relative abundances of gold in the two regions. This ratio increases to 165:1 for nuggets of more than 100 oz (3.1 kg). Topographic contours are 200, 600, 1000 m above sea level.

Cassiterite and rare diamonds are the only other economic minerals found in the alluvial placers of Victoria (e.g., Eldorado). Gold placers contain a complex diagenetic assemblage of minerals that includes iron sulfide layers up to 50 cm thick, arsenopyrite, and native copper (Phillips et al., 2003). However, most placer gold is rounded and its morphology is clearly detrital rather than diagenetic, although minor gold of probable secondary origin has been recorded (Hunter, 1909). For example, rounded gold crystals were common in paleoplacers at Ballarat West, where gold crystals were common in the primary gold deposits (Dunn, 1929). Placer gold is sometimes lower in silver content than primary gold from the same area, although it is mostly more silver rich in areas where the primary gold is high in silver (Phillips et al., 2003).

Slugs of coarse gold (i.e., non-alluvial lumps of gold) were found to be common in quartz veins of Paleozoic rocks in many nugget-rich fields to depths of 60 m (e.g., Wedderburn), but were rare below this depth. Other gold in quartz veins at these shallow depths shows textural and compositional evidence of a supergene origin (Phillips et al., 2003). This includes a lower silver content than gold at greater depth, and "paint" gold, "flour" gold, "spongy" gold, and gold with microcolloform, botryoidal, and arborescent forms. The slugs may therefore represent redistribution of orginal hypogene gold by supergene processes in the Cenozoic. Such slugs provide potential source material for the nuggets that were produced from alluvial and eluvial deposits, many of which had attached vein quartz. Nevertheless, the higher silver content of some gold nuggets suggests that those nuggets may represent detrital hypogene gold, and, therefore, that nuggets and slugs can be of either hypogene or supergene origin.

The number of large nuggets in the main gold-producing region northwest of Melbourne, relative to the area to the east, is greater than one might expect if it were simply a function of the relative abundance of gold in the two regions (Fig. 4). The reason may be that hypogene gold is coarser-grained in the west. Alternatively, lateritic weathering zones appear to be better developed in lower-relief areas in the west and lowland areas of the east, relative to the highlands in the east, and supergene growth of gold nuggets may have occurred in the upper parts of primary deposits in these areas.

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FACTORS IN THE FORMATION OF VICTORIAN PLACERS

Three major factors are thought to have influenced the formation of economic placer gold deposits in Victoria: proximity to primary gold sources; tectonic history; and climate, weathering, and regolith history.

Proximity to major primary gold sources

A direct spatial relationship between primary and placer gold deposits is evident at a regional scale throughout the Victorian gold fields (Figs. 1 and 2), and is also visible at an intermediate scale. For example, along the Rutherglen-Chiltern drainage system, placer deposits were worked immediately downstream of primary gold sources, but were uneconomic for several kilometers in between the primary gold fields (Fig. 3). The relationship also holds at a local scale: alluvial gold was a vector to primary gold for prospectors, and they followed auriferous creeks upstream to find major primary ore deposits at gold fields such as Bendigo, Ballarat, Castlemaine, and Stawell. Substantial concentrations of eluvial gold were sluiced directly from hillslopes below what subsequently became large primary gold mines (e.g., at Bendigo). In most Victorian gold fields, gold was readily traced up gullies and hillsides to the individual quartz vein system that was the placer source. At Ballarat, two of the three main primary mineralized zones, Ballarat East and Little Bendigo, are topographically elevated, and shed gold directly into highly auriferous placers at the ridge bases (Fig. 5; Baragwanath, 1923). The third mineralized zone, Ballarat West, was discovered in bedrock exposures in placer workings beneath basalt, again demonstrating an intimate relationship between primary and alluvial gold. The zones of primary gold mineralization at Ballarat, and elsewhere, typically strike north-south, so the buried north-south paleoplacer at Ballarat West remained close to its primary source area for a long distance. However, drainages that trend east-west (e.g., Bendigo) typically left their north-south source areas within a short distance.

The presence of different generations of placers at different elevations in single valleys indicates that earlier placers became sources for subsequent placers. Gold from primary deposits formed the oldest placers in the White Hill Gravel. These alluvial deposits, with further additions from primary sources, were reworked into the Loddon River Group and Quaternary placer systems. For example, the north-flowing Canadian Creek east of Ballarat East (Fig. 5) has older, elevated terraces immediately east of the creek, and parallel, higher-elevation White Hills Gravel outliers 3 km farther east. Elsewhere, former major White Hills Gravel valleys were crossed at a high angle by numerous small Loddon River Group valleys, and younger placer systems of importance failed to develop (e.g., between Avoca and Wedderburn, and west of Heathcote). These complex patterns could be one reason why it is impossible to relate some alluvial gold deposits to a significant primary source area.

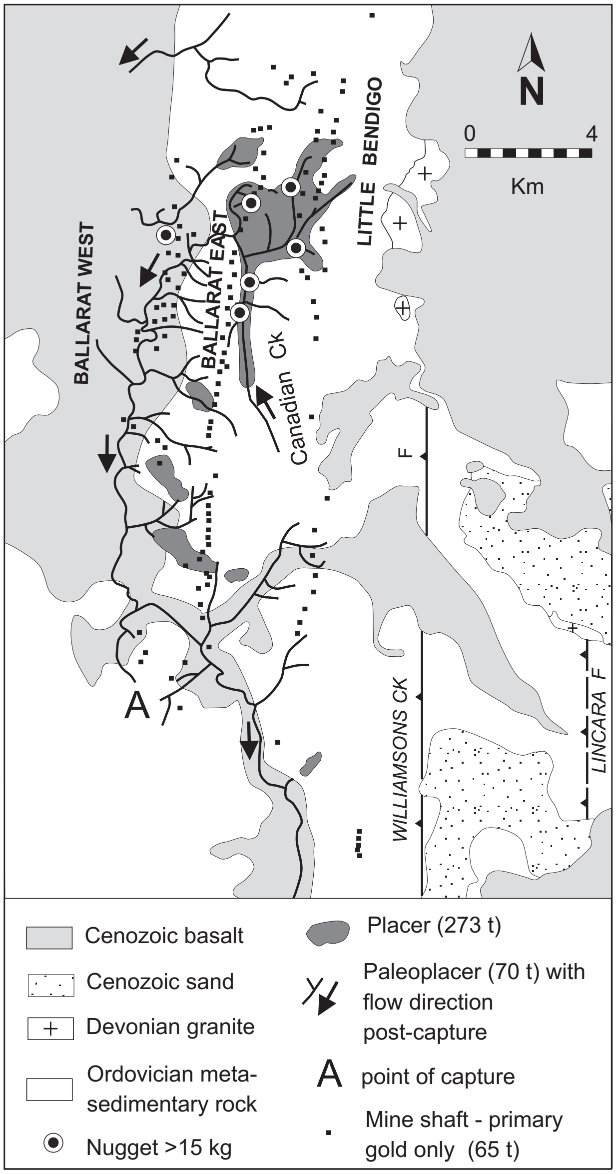

FIGURE 5. Placers of the Ballarat gold field, in the hanging wall of the Williamsons Creek Fault (modified from Baragwanath, 1923, and Canavan, 1988). The locations of the primary gold zones of Ballarat West, Ballarat East, and Little Bendigo are indicated by the linear zones of shafts from which they were mined. A paleoplacer system was also important, and this probably originally drained northwestward at Ballarat West (Taylor and Gentle, 2002) until captured by a south-flowing drainage at "A" (Phillips et al., 2003). It was then buried beneath Cenozoic basalt flows and lake sediments produced by the flows damming the outlet from the Ballarat East-Little Bendigo area. Gold production (tonnes) is shown for each type of mineralization. Gold nuggets shown have masses of 69 kg, 50 kg, 50 kg, 19 kg, 19 kg and 17 kg, and all were found in the immediate vicinity of the three primary source areas.

Tectonism

Late Cretaceous, Late Eocene, and Pliocene uplift, related at least in part to changes in plate motion, initiated intervals of accelerated erosion and placer formation by causing the stripping of regolith, modification of drainage styles, and recycling of gold from earlier placers. The influence of tectonism on drainage patterns is illustrated by the positions of some major valleys that were strongly controlled by reactivated Paleozoic and younger faults; these faults continued to influence drainage patterns throughout the Cenozoic. Examples include the north-south Coongee Fault at Ararat, and the east-west Bet Bet Fault near Maryborough. Tectonism may also have caused river capture, for example at Ballarat West, where the original drainage probably flowed northwest (Taylor and Gentle, 2002), but was subsequently captured by a south-flowing drainage at “A” in Figure 5 (Phillips et al., 2003).

Uplift influenced the efficient stripping of regolith east of the Williamsons Creek Fault (Fig. 5). Loddon River Group placers to the east of this fault have been uplifted and many have been mined from adits, rather than shafts. Preserved White Hills Gravel placers and deep placers of the Loddon River Group are mostly rare in the part of this area to the east and southeast of Daylesford and Castlemaine, despite the presence of primary gold fields. Uplift may also have resulted in efficient removal of important primary source areas. Lastly, volcanism that was broadly coeval with tectonism aided the preservation of some placer deposits (e.g., beneath basalt and lake sediments at Ballarat).

Climate, weathering, and regolith history

Climate, weathering, and the regolith history of the Victorian gold province are interrelated. The wetter climates of the past determined the volume of the rivers in which mechanical concentration of gold occurred, and influenced the volume and grade of auriferous gravel. Prolonged exposure, possibly aided by a wetter climate, resulted in deep and intense lateritic weathering that would have formed a regolith blanket of kaolinite, vein quartz, and gold (Ollier and Pain, 1994). This blanket would be the first material stripped and concentrated during subsequent uplift. The Ballarat East ridge still has a remnant kaolinite-rich weathering profile. This history is reflected throughout the province in the paucity of lithic clasts in the first two generations of placers, and an increase in lithic clasts with time. The alternative interpretation, that the vein quartz did not break down as readily as lithic clasts during fluvial transport, is not supported by the abundance and angularity of vein quartz clasts in the headwaters of placer drainages. The pre-concentration of quartz and gold relative to rock fragments in the regolith would have greatly decreased the concentration factor required to produce economic placers in the streams. Also, supergene processes in the weathering zone have coarsened the gold, and may have formed many nuggets, which were abundant in the area between Ballarat East and Little Bendigo (Fig. 5).

IMPLICATIONS FOR EXPLORATION AND GENESIS

Importance of prior deep weathering

The three factors discussed above that were critical controls on placer gold deposition in Victoria are common to most placer districts around the world. Features that Victoria has in common with other placer districts include reworking of successive generations of placers, regional-scale uplift and associated basaltic volcanism, subdued topography and incised plateaus, and deep chemical weathering (Henley and Adams, 1979). Chemical weathering profiles are preserved even in Arctic and subarctic areas like the Yukon (Boyle, 1979) and northeastern Siberia (Patyk-Kara, 1999), where they probably formed in the early Cenozoic when temperate, virtually ice-free climates extended to the poles (Victoria was then at high southern latitudes). Such weathering profiles are relics of important ground preparation for Victorian placers, and this may be the case elsewhere. Some of the other features that Victoria has in common with other placer districts reflect an environment in which deep chemical weathering is to be expected (e.g., low relief, prolonged tectonic stability).

Importance of gold-only source areas

An interesting observation is that major placers around the world source their gold almost completely from *gold-only* provinces (e.g., Archean greenstone, low-sulfidation epithermal, and especially, slate belt provinces). There is no substantive evidence that any giant placer districts have been sourced from areas dominated by *gold-plus* (i.e., polymetallic) deposits. Districts dominated by Cu-Au deposits, volcanogenic massive sulfides, and to a lesser extent, high-sulfidation epithermal deposits, do not appear to be important source regions. This relationship can be partly explained by the high grade, coarse grain-size, and regional extent of gold in primary gold-only provinces, and the lower grade, finer grain size, and more localized point sources typical of some of these other types of deposit.

Importance of major primary gold sources

There is clear evidence in Victoria that giant placers have derived their gold directly from the erosion of large, preexisting primary gold sources (i.e., areas of a

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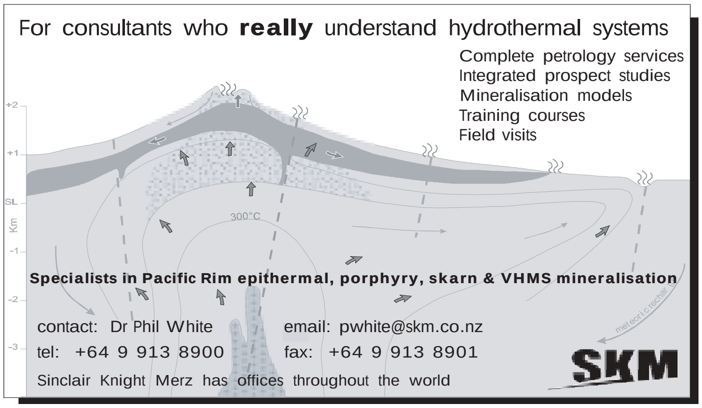

• • • from 17 Giant Placers of the Victorian Gold Province (Continued)

few tens of square kilometers at most, that contain significant primary ore deposits). The three giant placer fields of Victoria with greater than 100 t of placer gold production—Ballarat, Bendigo, and Castlemaine—all have significant primary gold sources (Table 2). Likewise, there are known primary gold sources for many of the smaller placer fields, and 45 percent of Victorian cumulative production has been from primary deposits. This spatial relationship applies on an even larger scale, in that the largest primary gold deposits of the Tasman fold system of eastern Australia are in exactly the same area as the largest placer gold deposits (Phillips and Hughes, 1998). A similar relationship appears to exist at many localities elsewhere in the world, where there is overall coincidence between giant placers and significant primary ore deposits (e.g., California, British Columbia, Democratic Republic of the Congo). Also, 43 percent of cumulative gold production and resources from central California and 31 percent of that from the South Island of New Zealand have been from primary deposits.

This relationship cannot be demonstrated in provinces such as the Yukon, parts of eastern Siberia, Fairbanks, and Nome, where the size of known primary gold sources is insignificant compared with that of the placers. Scenarios commonly invoked in such areas include derivation from dispersed low-grade gold sources, removal of the source area by uplift and erosion, separation from the source by lateral movement (strike-slip faulting), and removal of gold from its source by repeated re-cycling of fluvial sediments. There are also a few examples in Victoria where no major primary source is known, such as Ararat, Beaufort, and Creswick, but Ararat and Creswick have extensive regolith or basalt cover in the area where a source might be expected. All three fields have prospective bedrock geology and large alluvial gold nuggets, and large quartz veins have been intersected in deep placer workings at Creswick. A major concealed source area is suspected in all three areas, although an eroded source area is possible at Beaufort.

These Victorian examples demonstrate how difficult it is to show whether or not large primary gold sources, as defined, have been the source of individual placer gold fields, even in a well-understood province with reasonable bedrock exposure. However, given the similarity of the Victorian province to other gold-only provinces with giant placers, it is probable that major primary gold fields will still be found under younger cover in other regions which contain giant placer gold fields.

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