were found (up to 145 ounces). Even today, small nuggets are found regularly and keep some prospectors in employment. For example, in the two decades following 1975, six nuggets greater than 100 ounces (the largest 730 ounces) have been reported, and many have not—popular reports indicate that others this size were found in 1996 and 2001. Despite these bonanzas, many nineteenth century diggers must have made a mediocre living. For example, there were 66 000 diggers in 1853 and gold worth £12 million was produced. This is an average of £3. 10s. per digger per week, when the average wage was £4 to £5 per week, so many probably earned less, even if some gold was transported overseas for sale.[12] However wages appear to have been lower than this nearly half a century later, and it is difficult to balance probable inflationary effects of the early 1850s against those of a country coming out of depression in the 1890s.

The fossil stream valleys were followed by prospectors beneath increasingly deeper alluvium, then commonly beneath basalt lava flows—the deep leads. Because mining of deep leads was more difficult and expensive, there was commonly a delay on any goldfield before they became the next phase of mining, resulting in a resurgence of mining in some goldfields (e.g. Ballarat, Creswick). In later years, drilling was used to locate the buried valleys prior to shaft sinking (geophysics could be used now). This phase of production became an important employer, although the work was dangerous. The buried valleys were mined rapidly for remarkable distances, for example, the Chiltern–Rutherglen lead system was continuously economic over 15 kilometres (within the extensively worked 48 kilometres of the Chiltern Valley-Prentice lead system).

By working alluvial gold upstream, the diggers found that the gold in many streams had its source in gold-bearing quartz veins (reefs) within hard (Palaeozoic) rock. Some of the veins stuck metres out of the ground as low, white walls (Figure 5). Initially these could not be mined except by smashing the quartz to separate any lumps of gold. In some cases this was warranted because of the extremely high gold grades common at shallow depths on Victorian goldfields. Once crushing and separation techniques such as the Chilean mill, a stone wheel running in a shallow ditch, and the much more effective stamp battery were developed, the auriferous veins were extensively prospected. These were located by panning upstream, then panning the soil on the hill-slope (loaming) and, once discovered, chipping the quartz and looking for gold (possibly crushing in a mortar

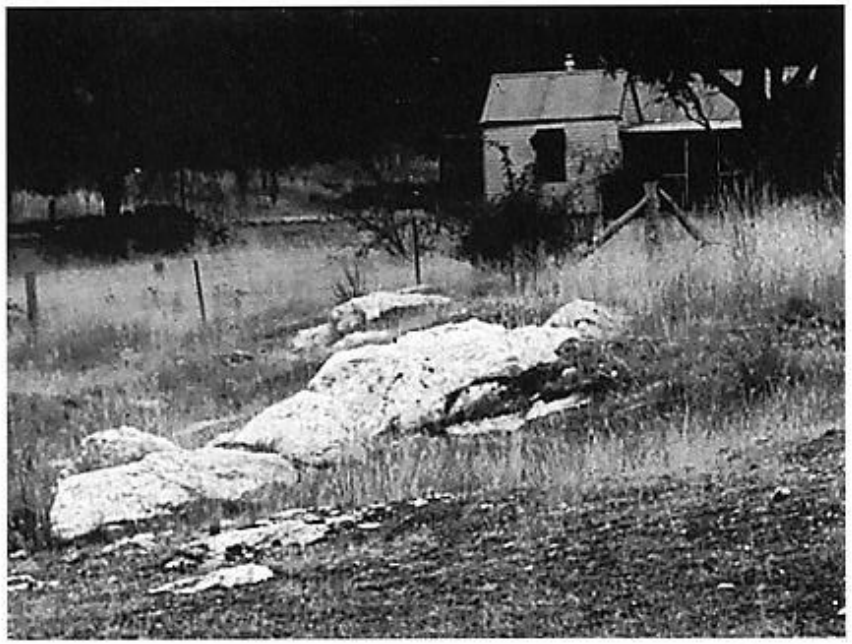

Figure 5. Outcrop of gold-bearing quartz vein (reef), Maldon.

and pestle—dollying—followed by panning). Any promising shows were then followed up with shallow, and if justified, deep shafts (or horizontal adits in steeper areas such as Walhalla–Woods Point). Drilling was used in exploration in later years, and today we mostly use a combination of geochemical analysis (in place of visual detection of gold) and drilling. Quartz mining using crude but simple techniques, such as Chilean mills, had commenced on a modest scale by late 1855 (e.g. Mount Egerton).[13] However there were still only two important quartz mines in the colony by 1863, at Clunes and Bendigo, although their number then increased steadily.[14]

Although some reefs were extraordinarily rich or profitable (e.g. Cohens reef at Walhalla, and some of the Deborah, Hustlers and Garden Gully mines at Bendigo), quartz mining was more notable for its continuity than its profitability, and for its importance during the 1890s depression. The mines that made large profits often paid spectacular dividends by today's standards, but failed to retain sufficient working capital for long-term de-

velopment.[15] Fraud was common, and brokers were often major investors. Quartz mines in some goldfields, e.g. Ballarat from 1870–1900[16] and many mines on the Bendigo field, were probably only marginally economic despite significant production. Some quartz mining was grossly inefficient, as emphasized by the nearly 300 shafts greater than 100 metres deep on the 8 kilometre long Bendigo field, with a further 3000 shafts of shallower depth. A single shaft system would serve kilometres of length if such a goldfield were found today. Bendigo was the most important quartz field, and Victoria's quartz mines were the deepest mines in the world at the time (e.g. the 1407 metre Victoria Quartz mine in the early 1900s, or Stawell in the 1880s). British investment was important in Victorian mining in some areas, such as the Port Phillip Company, Clunes, but it usually favoured pastoralism, so local investment was also important. For example, when Victorian mining revived in 1880, half the capital invested in the Ballarat and Creswick mines probably came from central Ballarat, where most of the companies had their offices and where their shares were traded.[17] The cities of Bendigo and Ballarat are directly underlain today by continuous warrens of interconnected quartz mine tunnels, over distances of 4 to 8 kilometres.

Population changes and mobility during shallow alluvial mining

With the goldrushes from 1851 onwards Victoria became an important colony. Its population increased more than sevenfold in less than a decade, from 73,000 on 1 July 1851 to 540,000 in 1861. Gold was the catalyst required for a colony that was already attracting increased immigration (the Victorian population had been 11,600 in 1842). The discovery of gold in California in 1849, then in Victoria in 1851, precipitated global migration at a rate and scale rarely seen. This was mostly from Great Britain and Ireland (more than 80 per cent of the Victorian population in 1857), and to a lesser extent from China (13 per cent in 1857) where political events had caused an economic downturn in a coastal region. The remainder were mostly Germans, with smaller numbers of Americans and French.[18] The mix on the goldfields was probably slightly different from the overall State mix, mostly because of the Chinese diggers who made up 22 per cent of all those involved in mining in Victoria in 1858. Much of the gold production, and the labour-intensive phase of shallow alluvial gold mining, came

while the population was small and so had a profound effect on Victorian life. Ships lay idle as sailors left for the goldfields. By 1852 nearly 8000 people lived in tents in Melbourne (Canvas Town), cartage from Melbourne rose to £120 per ton (with gold at £3 per ounce), and Governor La Trobe reportedly had to feed and groom his own horse because of a shortage of labour.[19] Nevertheless, except at the beginning of the goldrushes, the majority of the new immigrants did not become directly involved in mining—only 100,000 were directly involved in 1861, and this decreased to 52,000 by 1871 and 21,000 by 1891.[20] This probably partly reflected an initial need to service the diggers, but more importantly reflected a steady decline in gold production after the early years (concomitant with the growth of agriculture and industry) and a change to deeper, capitalist-funded mining. The phase of individualism in gold digging was brief, the diggers soon becoming miners, working deeper, mechanized, company-owned alluvial and quartz mines for wages.

The mining population was highly mobile, and the populations of the goldfields changed rapidly. For example, the Ballarat goldfield was discovered on 24 August 1851, and 567 diggers had arrived by the end of September. The shallow diggings were very rich, as on many other goldfields. However by 5 November the field was nearly deserted because diggers moved to Castlemaine to exploit its easily mined shallow alluvial gold discoveries.[21] The population of Castlemaine reaching 20,000 by the end of the year. The population of Ballarat rose again in 1852 because of rich yields and abundant gold nuggets, but its population of 8000 dropped to 300 later in the year with the Bendigo goldrush. Bendigo had been discovered in October 1851, but was disappointing until May 1852; it produced 66 per cent of Victoria's gold that year.[22] In Ballarat, there were 30,000 to 40,000 diggers in 1854, despite there being only 66,000 in the whole of Victoria the previous year. Nevertheless, Ballarat was nearly deserted again in 1855, which was its highest year of production until then. This was because the Fiery Creek (Beaufort) field was discovered.[23] The population there soon rose to 60,000 before the field was deserted in 1857, only to be rushed again in 1858. Ballarat had 45,000 diggers again in 1856, when its gold production peaked, and there was a similar number in 1862.[24] The mining industry was now firmly established. Shallow alluvial gold was exhausted by 1859, and some diggers left for the New Zealand goldrushes in 1861 and 1863. Changes in the nature of employment and a

downturn in the mining industry resulted in the mining population dropping to around 7500, including miners on wages, by 1870 (in a population of 50,000). Ballarat did not have the amount of very shallow alluvial gold present at Castlemaine or Bendigo, but attracted a population in the long term because of the presence of a major alluvial gold resource at greater depth. Nevertheless, the high mobility of the mining population continued to some degree for many years because, unlike British coal-miners, no Victorian miner was likely to spend most of his life working on a single mine. An example of this is the move of many Ballarat miners, complete with families and houses, to the new deep lead discoveries at nearby Creswick in the 1870s. The Creswick goldfield had been discovered in 1854, but went rapidly into decline until the discoveries beneath its basalt plain.

The evolution of mining and the nature of employment

The nature, as well as the size, of the mining population changed as the nature of gold mining changed. There were four main types of gold mining, each reflecting the geological characteristics of the gold deposits. The first was shallow alluvial gold, which was well suited to the individual digger. Deeper mining of alluvial gold through clay and rock, that is to a depth of less than 30 metres, could be done by groups of diggers. Mining of alluvial gold at greater depth, especially beneath lava flows (the deep leads), required expensive machinery and prolonged de-watering with large pumps, and was suited to mining companies (especially public companies) that employed miners. Mining of gold-bearing quartz on any large scale required similar equipment to deep lead mining, plus large treatment plants (batteries) to crush the ore and separate the gold. Although some batteries would do this on a fee basis, it was largely a company undertaking.

This is illustrated by the Ballarat goldfield, which geologically coincides with a 5 kilometre by 20 kilometre north-south range of hills of older (Palaeozoic) gold-bearing rocks, surrounded on all sides by younger (Cainozoic) rocks that lack gold, at least at the surface (Figure 6). The younger rocks are mostly basalt flows that are up to tens of metres in

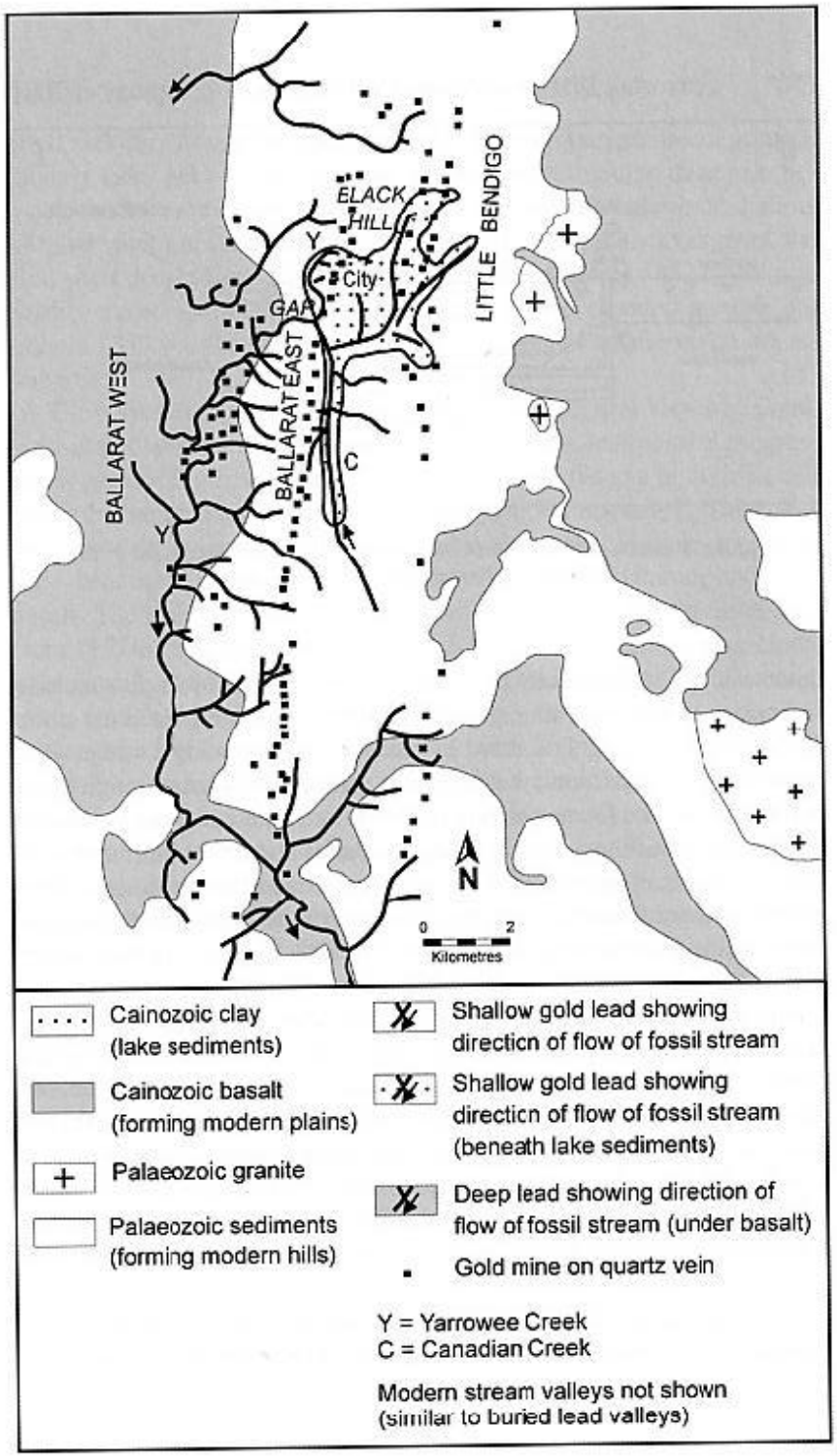

Figure 6 (opposite). Geology of Ballarat goldfield showing alluvial gold leads of varying depth, and shafts on auriferous quartz veins. The north-south range of Palaeozoic hills discussed in the text occupies the central third of the figure.

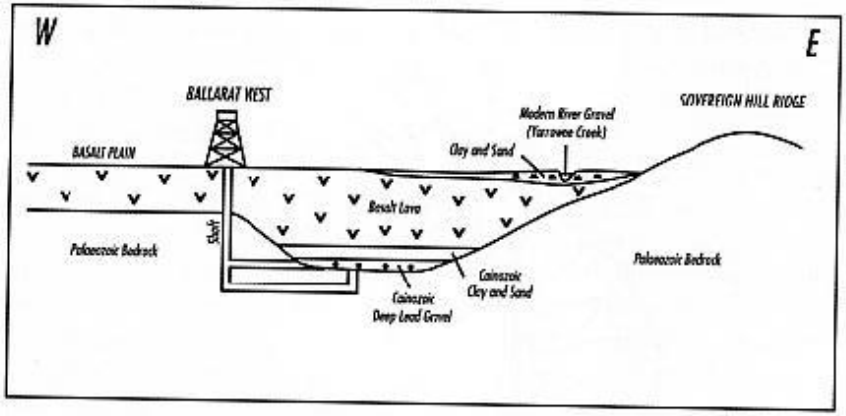

Figure 7. Idealised deep lead cross-section, Ballarat West, west of the Ballarat East area depicted in Figure 6.

thickness, and which totally lack gold, but the younger rocks also include sediments of the basin-like area of Ballarat City within the older hills. These sediments largely formed by basalt flows damming a stream (the ancestral Yarrowee Creek) that originally flowed westwards through a gap in the hills. A lake formed behind this dam, and gold occurs in concealed valley gravels of the ancestral creek, buried at depth beneath the barren lake sediments. Together the Cainozoic basalt and lake sediments form plains that constitute a barren blanket obscuring underlying older Palaeozoic rocks of the type exposed in the hills. The hills contain exposed quartz veins of the Ballarat East mining area that strike north-south for several kilometres and form a slightly elevated ridge, which includes Sovereign Hill. These veins continue north of the gap in the hills, at Black Hill, and a parallel belt of auriferous quartz veins occurs east of that in Palaeozoic hills of the Little Bendigo (Nerrina) mining area. Erosion broke down the rocks on these ridges and hills, and water washed the vein quartz and its now largely separated gold grains down-slope into the surrounding creek system to form rich, shallow alluvial deposits. Examples occurred in the Canadian Creek to the east of the Sovereign Hill ridge, and the Yarrowee Creek to the west and north.

This alluvial gold was identified by prospectors and initiated the first and short-lived phase of mining. This phase was immediately followed by

shaft sinking through the lake sediments to reach buried stream gravels, slightly older but still of Cainozoic age, that were found to disappear beneath the lake sediments where they left the hills. The phase of shallow alluvial mining at Ballarat, from 1851 to 1854, involved many diggers; the first shaft deeper than 30 metres was sunk at the end of 1852. Gold was readily traced upstream to the quartz veins on the elevated ground, but only in 1853 was the first, unsuccessful, crushing of auriferous quartz attempted.[25]

The buried tributaries and main channel of the ancestral Yarrowee Creek were mined westwards across the basin beneath lake sediments at progressively greater depth, until they passed out through the gap in the hills and under the basalt as a deep lead at Ballarat West (Figures 6 & 7). There was then some delay in mining the deep lead system—the third phase of mining—because of the technical difficulties of locating and mining under the basalt. The main phase of deep lead mining beneath the lava flows was from 1855 to 1872, mostly involving miners working for companies. However, not only had the government been slow in abandoning the gold licence, but it similarly restricted deep lead mining with its frontage system of tenure, which it finally abandoned only after lengthy opposition. Deep lead mining was initially not very successful, and mining was in recession in early 1866. However, it recovered later in that year, resulting in a spate of company formations that made Ballarat a more significant investment centre than Melbourne for a few years.[26] The nature of employment had now changed, with less than a quarter of the Ballarat mines owned by working miners in 1870, and the company mines generally had larger individual gold production.

The fourth phase of mining at Ballarat, that of auriferous quartz veins, was slow to start. After its false start in 1853 it became slightly more important from 1859, though subordinate to alluvial mining. This contrasts with developments at Bendigo, which because of geological differences became the outstanding quartz-mining field. Quartz reefs at Bendigo had received minor attention from prospectors as early as 1859 but, with alluvial mining in decline after 1859 (15 years prior to Ballarat), there was significant quartz mining developed in that year. Bendigo was producing more than 190,000 ounces of reef production per annum by 1860. Despite the lesser importance of quartz mining at Ballarat at this time, Ballarat was the pioneer in the treatment of low-grade quartz ore, with 2.5 to 5 grams of

gold per ton being economic.[27] Deep lead mining at Ballarat declined, quite abruptly, in 1873. Fortunately, although partly as a consequence, quartz mining increased by 1874 and received a needed boost in 1879 with the discovery of the Consols lode at Ballarat West. It boomed from 1886 with development of the adjacent Star of the East mine on the Guiding Star and other lodes, and with commencement of large-scale quartz mining on the Ballarat East field in 1887. The Ballarat West quartz field had been completely unknown until this time because it was blanketed by the lava flows—it was discovered in the deep lead alluvial mines beneath the lava. Alluvial mining essentially ceased in 1882. Quartz mining gave Ballarat a comparatively smooth passage through the 1890s depression, and the city even showed a slight increase in population. In 1891, six-hundred stampers still pounded through the night crushing the quartz ore.

The interaction between mining and permanent settlement

Unlike most of the world's mineral fields, the Victorian goldfields were in arable, in part highly fertile land, suitable for permanent settlement on a large scale. From 1854 to 1857, agriculture was the fastest growing sector in the Victorian economy, and because of a shortage of labour, mechanisation was being rapidly introduced.[28] Rural towns were soon established on all the larger goldfields, transport infrastructure was developed, agricultural capacity rose rapidly and heavy-engineering industries developed. This development can be illustrated for Ballarat, where pastoral settlement commenced in 1836. The Eureka rebellion of 1854 resulted not only in a change from an expensive gold licence to an inexpensive miners right, but the latter also permitted miners to take up areas for residence and to cultivate these areas (changes in 1857 added the right of many to own and sell this land). In 1856, land sales began and the first flourmill commenced. By 1859, 50,000 acres were under cultivation in the district. The Land Acts of the 1860s permitted selection of land that was previously the preserve of the squatters.

The great depth of alluvial (deep lead) mining at Ballarat and the low-grade, large tonnage characteristics of its quartz mines required much heavy machinery and treatment plant. Eight foundries supplied the mines by 1861, nearly all mining machinery (including engines) being made in Ballarat. Even some stamp pads of the crushing batteries were made from iron smelted in the district (at Lal Lal). The Melbourne to Ballarat railway line

was completed in 1862, and by 1869 there was a ratio of one industrial worker for every four miners. The School of Mines (now part of the University of Ballarat) was founded in 1870, at which time Ballarat was proclaimed a city. Apart from the national capital, which was established in the 1920s, Ballarat and Bendigo still remain Australia's largest inland cities.

Contributions to science

The Victorian goldfields were important to the growth of the science of geology, and the gold deposits of Ballarat, Bendigo and Woods Point were cited as classic examples in economic geology text books throughout the twentieth century.[29] The goldfields resulted in the founding of the Geological Survey of Victoria, the government scientists of which made important contributions to our understanding of the geology of gold, as well as assisting in the development of other types of mineral deposit. The role of government geologists in the Geological Survey was greater than this, given the multi-disciplinary interests of scientists of the day. An example was Alfred Howitt, whose name is preserved in features as varied as a mountain (Mount Howitt), ghost-town site (Howittville), cattleman's hut (Howitt Hut), and various brachiopod (*Howittia howitti*), fish (*Howittacanthus kentoni*) and plant (*Archaeopteris howitti*) fossils, some of which were collected during his alpine explorations. His geological studies of the highlands of 'North Gippsland', immediately in the footsteps of the first gold prospectors, resulted in the first systematic and documented exploration of much of the Victorian Alps (Eastern Highlands). For example, Howitt undertook a nine-month trip into the highlands in 1860, partly in the company of the colonial artist Eugen von Guerard, with specific instructions to find a new goldfield. He was directly responsible for the discovery of the Crooked River goldfield during this expedition—some of his party immediately resigned to mine gold—and this led to the establishment of Grant and other mining towns.[30] His activities on various expeditions included the recording of geological, topographic, botanical and anthropological data. Especially important were his observations relating to the soon-to-disappear aboriginal culture of the region.[31] He documented features as varied as Snowy Bluff, Lake Tarli Karng, the Wonnangatta River valley, the Den of the Nargun on the Mitchell River (and its mythological associations), and the aboriginal mining of

greenstone axe blanks at Mount William, closer to Melbourne.[32] The reports of such geologists are also invaluable records of the birth, life and ultimate decline of many short-lived mountain gold-towns, such as Grant, where the population exceeded 700 (briefly 2300), but which was already largely abandoned by 1874, the last resident leaving in 1916.[33]

The future

The goldrushes of the nineteenth century were brief and unique, and their style will not be repeated. However, gold still has the potential to be an important part of the Victorian economy. A feature of Victoria, which makes it stand out from virtually every other major gold province in the world, is the way it was completely passed over during the 1980s global gold boom (Figure 1). Since 1920, the scale of gold exploration in Victoria has been minuscule considering the earlier international pre-eminence of the province, and the potential size of remaining targets. The lack of large-scale modern exploration leads many to believe that much more gold still lies under cover where early prospectors had no techniques to find it.[34] The exploration of old goldfields such as Bendigo and Stawell will provide ore for the future. However the one geological environment that the diggers could not explore effectively was gold in hard rock (e.g in quartz veins) that was covered by metres of gold-poor rock or alluvium. Although a significant part of the Victorian gold province is under shallow cover of this type, nearly all of this ground was inaccessible to the nineteenth century prospectors. Such areas are more accessible now using a combination of modern geological knowledge, drilling and geochemical methods, including sophisticated techniques such as groundwater geochemistry. These regions have the most potential for the discovery of completely new goldfields, and include areas such as Ararat, Creswick and Chiltern–Rutherglen, for which the major alluvial gold production suggests that important, undiscovered, primary sources exist.

Notes

1 R.M. Younger, *Australia! Australia! The Pioneer Years*, Rigby, 1975

2 G.B. Weber, 'History of events leading to the discovery of gold in Victoria, and the early mining years', *Australian Institute of Geoscientists Bulletin*, vol. 20, 1996, pp. 5–9.

3 G.N. Phillips and M.J. Hughes, 'The geology and gold deposits of the Victorian gold province', *Ore Geology Reviews*, vol.11, 1996, pp. 255–302.

4 G.N. Phillips and M.J. Hughes, Gold, Geology of Victoria, in preparation, Geological Society of Australia (Victorian Division).

5 J.W. Gregory, 'The Ballarat East Goldfield 1914', *Memoirs of the Geological Survey of Victoria*, No. 4, 1907.

6 *ibid.*

7 M.J. Hughes, A. Kotsonis and S.P. Carey, 'Cainozoic weathering and its economic significance in Victoria,' *Australian Institute of Geoscientists Bulletin*, vol. 24, 1998, pp. 135–48.

8 Gregory, *op. cit.*

9 L. Peterson, 'A forgotten legacy of gold mining: archival research leads to the location and identification of gold-bearing mining residue', *Australasian Institute Mining Metallurgy, Annual Conference*, 1997. pp. 237–8.

10 W. Baragwanath, 'The Ballarat Goldfield', *Memoirs of the Geological Survey of Victoria*, No. 14, 1923.

11 T.F. Potter, 'The Welcome Stranger nugget', *Australian Institute of Geoscientists Bulletin*, vol. 24, 1998, pp. 127–33.

12 H Anderson, *Victoria: From Discovery to Federation*, Rigby, 1974.

13 W Bate, *Lucky City: The First Generation at Ballarat 1851–1901*, Melbourne University Press, 1978.

14 Anderson, *op. cit.*

15 Weber, *op. cit.*

16 Bate, *op. cit.*

17 *ibid.*

18 Weber, *op. cit.*

19 Younger, *op. cit.*

20 Anderson, *op. cit.*

21 Gregory, *op. cit.*

22 Weber, *op. cit.*

23 Bate, *op. cit.*

24 Baragwanath, *op. cit.*

25 *ibid.*

26 Bate, *op. cit.*

27 *ibid.*

28 *ibid.*

29 W. Lindgren, *Mineral Deposits*, 4th Edition, McGraw-Hill, 1933; M. Solomon and D.I. Groves, *The geology and origin of Australia's mineral deposits*. Monographs on Geology and Geophysics 24, Oxford University Press, Oxford, 1994.

30 R W Christie, *Ghosts and Gold in the Victorian High Country*, Dargo, High Company Publishing, 1993.

31 A.W. Howitt, *The Native Tribes of South-East Australia*, MacMillan, 1904.

32 J. Flood, *Archaeology of the Dreamtime*, Angus and Robertson, 1995.

33 R B Smyth (ed.), *Report of Progress*, vol. 3, Geological Survey of Victoria, 1876; R.W. Christie, *Dargo Crooked River; A Pictorial History*, Dargo, High Country Publishing, 1997.

34 G.N. Phillips and M.J. Hughes, 'Victorian gold: a sleeping giant', *Society Economic Geologists Newsletter*, vol. 21, 1995, pp. 1, 9–13.