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Reconstruction of historical riverine sediment production on the goldfields of Victoria, Australia

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ABSTRACT

A significant but previously unquantified factor in anthropogenic change in Australian rivers was the release of large volumes of sediment produced by gold mining in the 19th century. This material, known historically as 'sludge', rapidly entered waterways adjacent to mining areas and caused major environmental damage. We interrogate detailed historical records from the colony of Victoria spanning the period 1859 to 1891 to reconstruct the temporal and spatial distribution of sediment volumes released by mining activity. Based on these records, we estimate that at least 650 million m^3 of material was released into rivers in the 19th century, exceeding natural sediment yield to rivers by an average 140 times. Although the sediment yield per river is not high when compared with examples around the world, the widespread impacts of sludge distinguishes the case of Victoria. The sludge affected three-quarters of catchments in the state due to the large number of small mining operations spread over hundreds of creeks and gullies across the colony. The impacts of sludge to rivers and farmland filled newspapers for more than 50 years and generated numerous parliamentary inquiries. Today, the impacts are largely forgotten and unrecognised, as are the continuing impacts on aquatic systems. The estimates generated in this study provide a basis for understanding the continuing impact of historical mining on Victorian rivers.

1. Introduction

There has been a strong trend to move from general descriptions of human impacts on landscapes to interdisciplinary, quantitative reconstructions (Gillson and Willis, 2004). These detailed reconstructions can be regional (Butzer and Helgren, 2005) or thematic (Bradshaw, 2012). In Australia there are good examples of thematic quantitative reconstructions of vegetation and land use change since first European settlement (Bowman, 2001; Lunt, 2002). Indicators such as diatoms (Reid et al., 1995) have been used to extend the water quality record to the period before routine measurements and back to first European settlement. Detailed knowledge of changes wrought by humans is of great assistance, not only in understanding our landscapes but also in defining targets for management and restoration.

Forensic analysis of historical records is a major source of quantitative information about the period between first European colonisation and routine environmental monitoring. One spectacular period of human impact in Australia was gold mining in the 19th century. In this paper we interrogate the remarkably detailed historical records of this period to reconstruct the temporal and spatial distribution of sediment released by historical gold mining. We also consider how the sediment was dispersed by river systems in the then colony (now state) of Victoria. While there have been reconstructions of mining sediment in specific rivers (Knighton, 1989; Locher, 1996; Boggs et al., 2000) this is the first regional reconstruction of legacy sediments from mining in Australia. The same is true of the international literature. While there are numerous studies describing sediment sources and sinks for single mines, or single rivers (e.g. Hettler et al., 1997; Pickup et al., 1981), this

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study joins a small group of papers describing regional-scale mining effects (Clement et al., 2017; Hudson-Edwards et al., 1999; James, 1999; Knighton, 1989).

Gold mining mobilised large quantities of sediment and sludge in 19th-century Victoria, much of which flowed into and polluted local river systems (Lawrence and Davies, 2014). For more than half a century, miners diverted great volumes of water to separate gold from alluvial washdirt and produced huge amounts of mining waste in the process. In addition, smaller but significant volumes of tailings resulted from the crushing of auriferous ore in stamp batteries. The semi-liquid waste from these processes was known generally as ‘sludge’ and ranged in composition from fine silty-clays to coarse sands and gravels. Numerous contemporary accounts and government inquiries reported sediments that filled creeks and water holes and inundated farmland for tens of kilometres downstream (e.g. Royal Commission, 1859; Board, 1887; Committee, 1887). These historical sources indicate that disruption to river systems was significant and widespread. Mining activity was widely distributed across Victoria, extending from the north-eastern border with New South Wales to within 150 kilometres of the border with South Australia in the west. It was concentrated in the uplands along the continental divide that provide the primary source of Victoria's main rivers, so the rivers carried mining waste both north and south across Victoria.

In this paper we use historical research to estimate the volumes of mining sediment produced, based on the detailed analysis of 19th-century documentary records. This research is part of an on-going multi-disciplinary project to assess the scale and lasting impact of historical mining sediment across the state of Victoria. The goal is to determine the ongoing implications for stream health and land use today. In subsequent research these historical figures will be integrated with geomorphological analysis to derive the production of mining sediment that can be compared with other regions. In this paper we are not producing a full sediment budget, as we do not consider storage and end of valley delivery of sediment. Instead we estimate the volume of sediment delivered to streams by historical gold mining. Neither are we considering the chemical contaminants associated with the sediments. Future research will report full mining sediment budgets for Victorian catchments (including comparisons with other sources of anthropogenic sediment such as gullying and agriculture), as well as levels of contamination. While there is some knowledge of mercury use in Victoria based on historical records (Davies et al., 2015) and localised catchment studies (e.g. Bycroft et al., 1982; Churchill et al., 2004; McCredie, 1982) its relationship with sediment distribution and its impact regionally are yet to be determined. The scope of the present study is deliberately limited to 19th-century mining as this period experienced the greatest gold-mining activity, production and environmental impact. While there are many contemporary examples of uncontrolled sediment release in developing countries (e.g. Appleton et al., 2001; Day et al., 2009; Donkor et al., 2005), we are concerned here with a setting where we can observe more than a century of changes following a relatively short period of intense mining.

Our primary data in this paper relate to the years 1859–1891, which overlap all but the first eight years of the main gold rush period. We begin by reviewing the history and geology of Victoria's gold province and the development of mining techniques used to recover gold from primary (quartz ore) and secondary (placer or alluvial) deposits. Drawing on records published in the Mining Department's annual series *Mineral Statistics of Victoria* (MSV), we calculate sediment volumes for the main alluvial mining technologies, including puddlers, compound cradles, ground and box sluicing, and hydraulic sluicing. These data are arranged by the seven Mining Districts of Victoria: Ballarat, Beechworth, Sandhurst [Bendigo], Maryborough, Castlemaine, Ararat and (from 1867) Gippsland (Fig. 1). We also use MSV data to determine volumes of quartz ore processed in stamp batteries and track gold yields and mining populations against the volumes of alluvium processed. MSV data are mapped by Mining District and major river catchment to indicate the geographic distribution of sediment production across the colony. We then examine contemporary documentary sources to explore the effects of mining sludge on downstream communities and official responses to the problem. These figures will allow the quantity of alluvial mining sediments mobilised in Victoria to be compared with other anthropogenic sources of erosion in future work and for their management implications to be assessed.

2. Historical context

Payable quantities of gold were first discovered in Victoria in 1851, only three years after similar finds were made in California and 16 years after the first permanent European settlement of the colony. Hundreds of thousands of migrants arrived in Victoria from around the world, increasing the colony's population from 77,000 in 1851 to 540,000 just ten years later (Serle, 1968, p.382). By the time the gold rush had dwindled around the period of the First World War, the Victorian gold province had produced 80 million troy ounces of gold, approximately 2570 t or around 2% of all the gold ever mined globally. The 1500 t or more of alluvial gold from Victoria ranks the region as one of the world's most important shallow alluvial goldfields, along with Siberia, California, the Yukon/Klondike and Otago, New Zealand (Phillips et al., 2003, pp. 377–380, 414).

Gold mining also had a dramatic impact on the natural environment. Miners dug up and polluted hundreds of creeks and gullies in their relentless search for gold. They diverted huge volumes of water to sluice their claims and flushed the resulting sludge into the nearest waterway. Much of this material flowed downstream to inundate and damage productive farmland (Peterson, 1996). Significant volumes of mercury used in gold amalgamation were washed into creeks and rivers (Davies et al., 2015). Miners also had a voracious appetite for timber and firewood, decimating forests and woodlands in the vicinity of the goldfields (Howitt, 1972, p. 254; Ligar et al., 1865, p. 4; Smyth, 1980, p. 28). This was part of the wider pattern of broad-scale land clearance for agriculture during and after this period. The scale and impact of deforestation by mining on erosion and sediment yields, however, remains poorly understood (Dodson and Mooney, 2002; Lunt, 2002).

The geographic distribution of mining centres reflects the geological emplacement of gold-bearing strata. Primary or hard rock deposits of gold in quartz veins were formed in the Palaeozoic Era, ending with the Devonian Period around 350 million years ago. Existing basalts and the overlying sedimentary rocks were fractured during an intense period of volcanism and mountain building which allowed mineral-enriched water to flow into the cracks and precipitate-out to form gold-bearing quartz veins. Later, during the Cainozoic Era beginning some 65 million years ago, weathering and erosion liberated some of the gold and re-deposited it in valleys and stream beds (Phillips et al., 2003, pp. 381–383). Some of these alluvial deposits were themselves subsequently re-buried by later deposition and by volcanic activity that began around 3 million years ago, forming ‘deep lead’ gold deposits (Hughes and Phillips, 2001). Palaeozoic outcrops in Victoria form the southern end of the Lachlan Fold Belt, part of the Great Dividing Range that stretches from the high country in eastern Victoria near Omeo and Buchan through central Victoria to Stawell in the west. Gold has been found throughout these upland regions in both hard rock and alluvial deposits. Quartz reefs are oriented north-south as a result of the east-west orientation of the Palaeozoic compression. Shallow alluvial deposits are found across the uplands while the buried deep leads follow the Cainozoic rivers that flowed out of the highlands either south towards Bass Strait (the deep lead mines at Ballarat) or north towards the Murray Basin (the mines around Creswick, Maryborough and Rushworth (Phillips and Hughes, 1996; Phillips et al., 2003)).

Gold deposits in Victoria are frequently located in the interfluves between the larger north-flowing rivers. This meant that securing adequate water supplies for mining and domestic purposes was often difficult. Miners quickly adapted to the low and variable runoff