Government of **Western Australia**
Department of **Mines and Petroleum**

RECORD 2010/9

THE APPLICATION OF ABANDONED MINE SITE DATA TO THE INTERPRETATION OF REGIONAL GEOLOGY AND GOLD MINERALIZATION IN THE KALGOORLIE TERRANE, WESTERN AUSTRALIA

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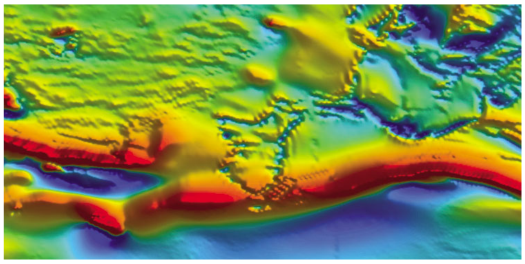

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The University of
Western Australia

MINISTER FOR MINES AND PETROLEUM
Hon. Norman Moore MLC

DIRECTOR GENERAL, DEPARTMENT OF MINES AND PETROLEUM
Richard Sellers

ACTING EXECUTIVE DIRECTOR, GEOLOGICAL SURVEY OF WESTERN AUSTRALIA
Rick Rogerson

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The application of abandoned mine site data to the interpretation of regional geology and gold mineralization in the Kalgoorlie Terrane, Western Australia

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WR Ormsby

Abstract

A database of abandoned gold mine sites in the Kalgoorlie Terrane, Western Australia, is combined with data for historic gold production to test whether there is a strong correlation between the locations and sizes of the abandoned mine sites and gold workings, and 1) gold production, and 2) geological structures related to gold deposits.

Regional databases, compiled by the Department of Mines and Petroleum, comprising historical gold production (MINEDEX database) and expired Gold Mining Leases (Dead Tenement database) are integrated to produce a single GIS database layer showing total gold production along the Menzies Shear, near the town of Menzies. Bedrock-gold excavations are selected from the Inventory of Abandoned Mine Sites (WABMINES database) and gold production statistics are produced for the following measures of mine size: excavation depth, volume, bund (surrounding waste material) height, and number of excavations per 100 m^2 and per 10 000 m^2. Scatter plots of these measures against total gold production find the best positive correlation with gold production is for excavation volume ($R^2 = 0.8108$), followed by excavation depth ($R^2 = 0.7358$). However, excavation depth is more widely available than excavation volume, and has less inherent error, hence is found to be the best semi-quantitative measure of past gold production.

A method is developed for estimating the original depth of a collapsed shaft by comparing its mean bund height to those for shafts of known depth in the same area. Smoothed images in which maximum excavation depth is represented using a spectrum colour scheme, and density of excavations is used to create a hill-shaded topographic or ‘elevation’ layer, are found to be an effective display and interpretive tool when viewed at scales of less than 1:5000.

Case studies in the Menzies, Coolgardie, Widgiemooltha, and Norseman mining districts examine detailed spatial relationships between abandoned mine site data, regional geology, and gold mineralization. Abandoned mine workings are shown to have a close correlation with known gold mineralization and mapped regional-scale geological structures, and are used to identify mineralized structures that are not apparent in other regional datasets.

Four gold exploration targets are identified in Norseman where anomalous variations in host-rock foliation and weathering intensity coincide with intersections between interpreted faults and shear zones.

This study has shown a number of new ways in which data on abandoned mine sites can be applied to GIS-based prospectivity studies and to generate targets for gold exploration.

KEYWORDS: Western Australia, Yilgarn Craton, Eastern Goldfields Superterrane, Kalgoorlie Terrane, Menzies, Coolgardie, Norseman, Widgiemooltha, abandoned mines, gold, mineralization, gold exploration, GIS, spatial data, underground mining, mine geology

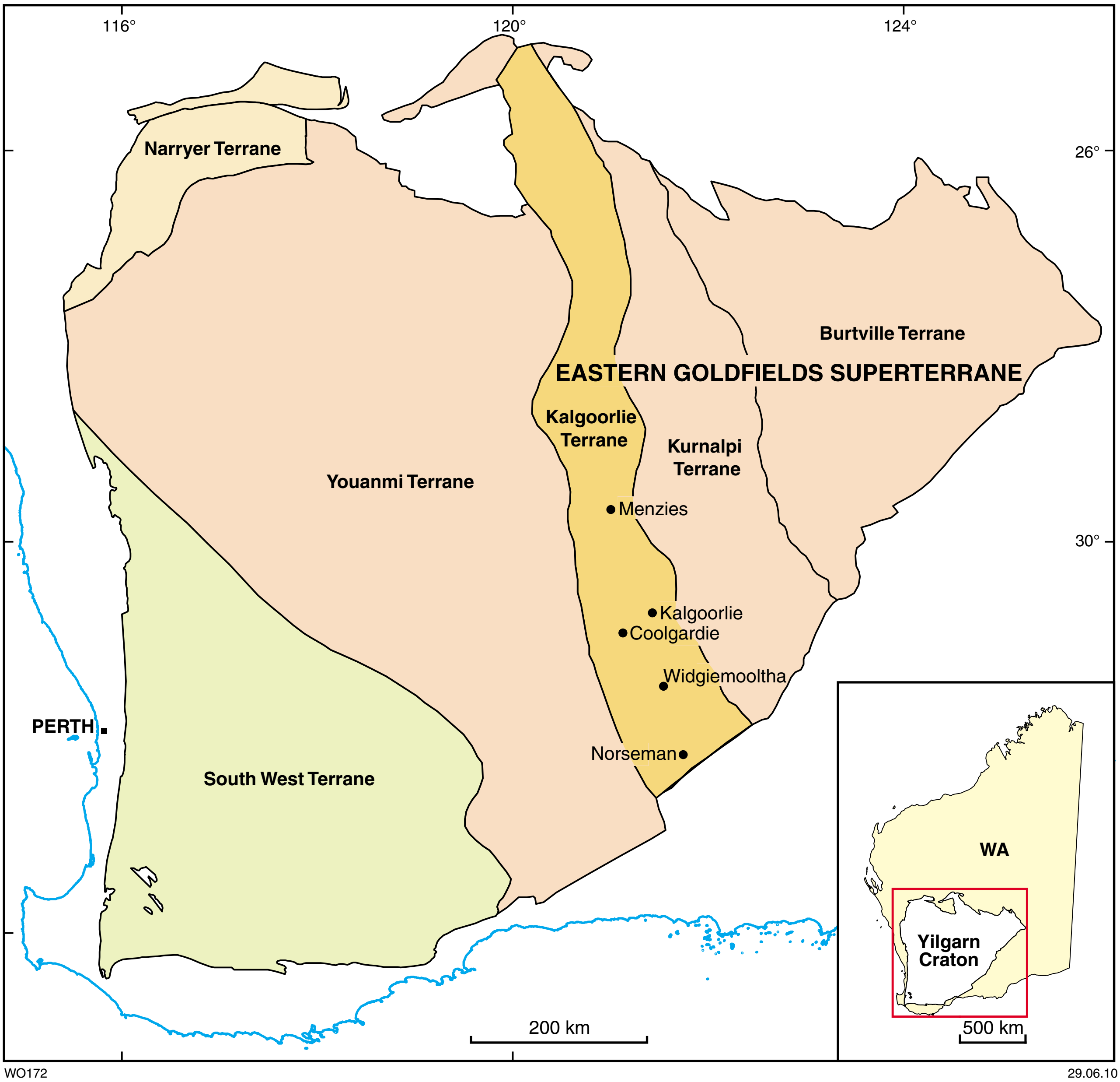

Figure 1.1 Tectonic divisions of the Yilgarn Craton, showing the location of the Kalgoorlie Terrane and mining centres discussed in the text (after Cassidy et al., 2006).

Chapter 1

Introduction

By far the largest proportion of recent exploration activity in the Eastern Goldfields is related to brownfields or near-mine discoveries as opposed to greenfields discoveries. Therefore, any approach that helps identify prospective structures is an important contribution to exploration targeting. Currently, explorers in both brownfields and greenfields areas have had success with follow-up investigations of historic workings. For example, St Ives Gold Mine employs prospectors to locate old mine workings and prospects. This study shows that a systematic study of abandoned mine workings is a useful guide to original gold resources and to their controlling geological structures. Consequently, a database of abandoned mine workings is a valuable adjunct to the inventory of exploration datasets.

The focus for this study is on abandoned mine sites in the Kalgoorlie Terrane of the Yilgarn Craton in Western Australia.

1.1 Abandoned mine sites in the Kalgoorlie Terrane

Since the discovery of gold in 1892 at Coolgardie and Norseman in the Archean Kalgoorlie Terrane of the Yilgarn Craton, Western Australia (Fig. 1.1), many thousands of gold exploration and mine workings have been excavated and later abandoned. For the next 80 years, Western Australia's gold production was principally from the Kalgoorlie Terrane, dominated by the 'Golden Mile' in Kalgoorlie–Boulder.

Gold output peaked in 1903 with two later minor recoveries in the late 1930s and 1950s (Fig. 1.2). Most of this gold production was the result of selective mining of narrow, high-grade orebodies (Witt, 1993a). Large-scale opencut mining, which commenced in the 1980s, eclipsed all previous production rates, albeit at much lower head grades. Many of the former exploration and mine workings

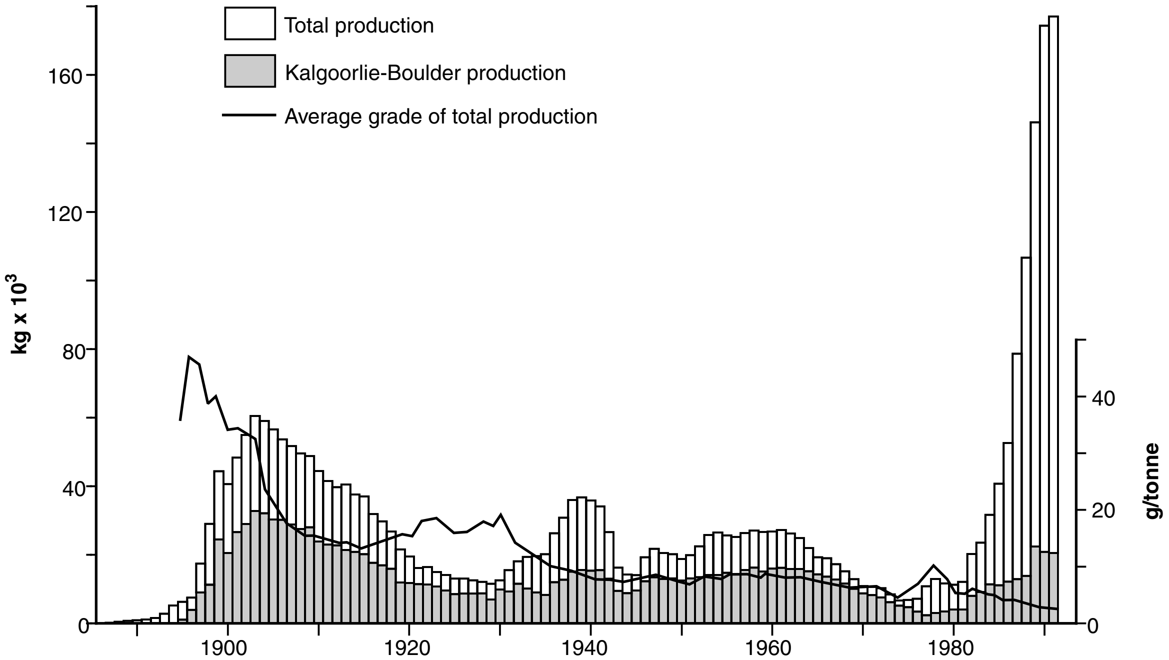

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Figure 1.2 Historical (pre-1990) gold production in Western Australia (Witt, 1993b).

that were not engulfed by opencut mining operations remain open in varying states of disrepair.

The Western Australian inventory of abandoned mine sites was initiated in 1999 by the Geological Survey of Western Australia (GSWA) in response to community concerns for public safety and the environment. The inventory, which is now commonly referred to as the Western Australian abandoned mine site database (WABMINES) is a comprehensive digital database that records all mining-related features including underground and surface excavations, dumps, associated infrastructure and rehabilitation (Ormsby et al., 2003).

WABMINES focuses on sites that were closed before 1990 and, in particular, upon mining activity that took place before the commencement of the Mining Act 1978 and associated regulations. Mines that closed since 1990 are already well located and have had environmental matters addressed by the Department of Mines and Petroleum's (DMP) mining proposal and environmental management requirements.

All pre-1985 historic mine (MH) production sites in Western Australia are recorded in DMP's mines and mineral deposits information database (MINEDEX). These were predominantly sites of gold production under the pre-Mining Act 1978 Gold Mining Lease (GML) tenure system and effectively represent all abandoned mine sites in the State. Former gold mines in the Kalgoorlie Terrane comprise 33% of the 11 450 known abandoned mine sites in Western Australia (Fig. 1.3).

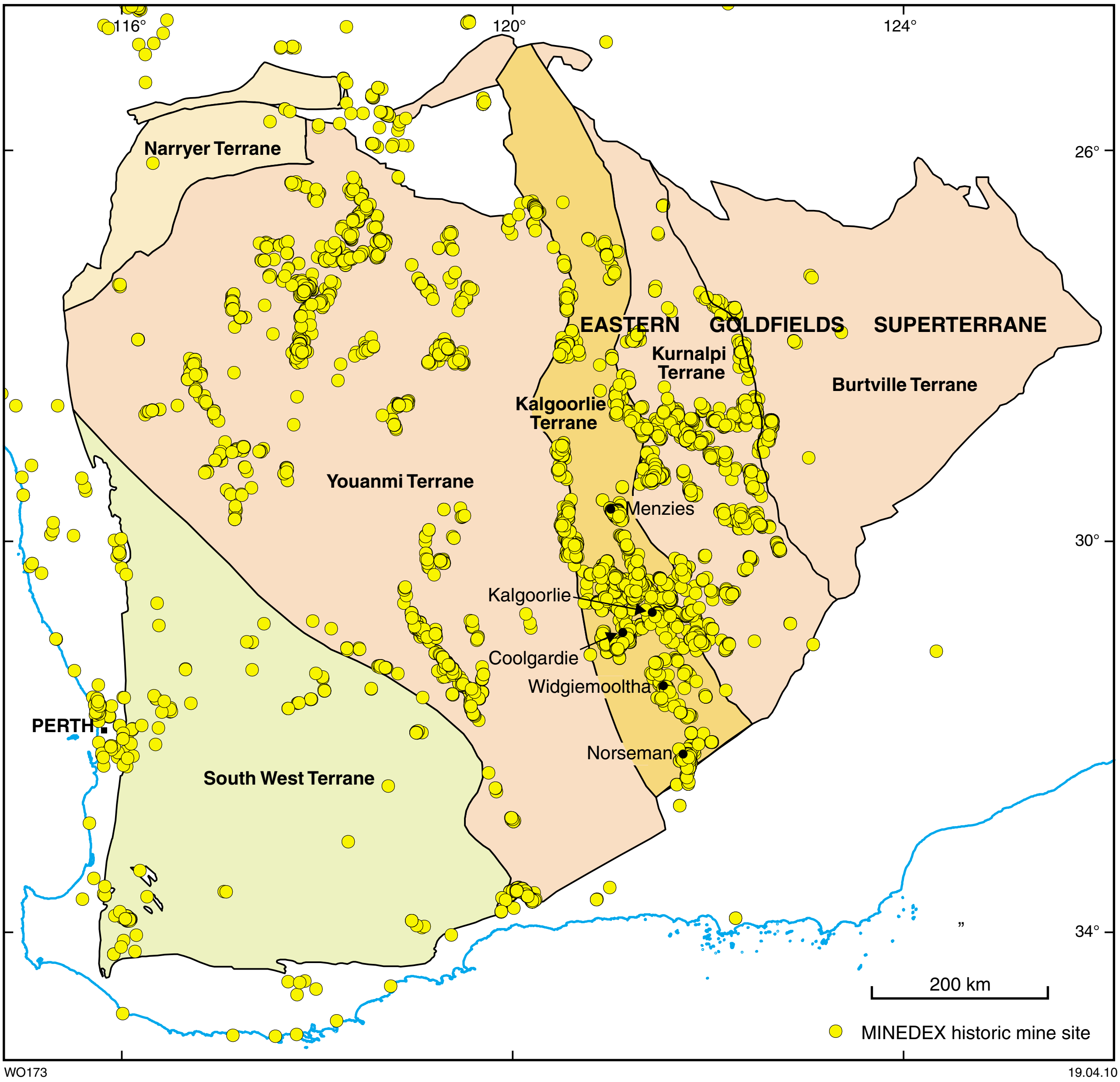

Figure 1.3 **Location of abandoned mine sites (MINEDEX historical mine sites) for all commodities in southwestern Western Australia, showing the high concentration of abandoned mine sites in the Kalgoorlie Terrane. More than 91% of the 10 184 sites shown were gold mines.**

By 31 December 2006, 71% of all 3875 abandoned mine sites in the Kalgoorlie Terrane had been inspected by GSWA. Each of these sites typically consists of many tens of mining-related features, all of which are individually recorded in WABMINES using Global Positioning System (GPS) and integrated hand-held personal computers. A total of 129 722 features are recorded within the Kalgoorlie Terrane in the 2007 digital WABMINES database release (Geological Survey of Western Australia, 2008).

Patterns in the location of abandoned mine shafts have previously been reported by Hunter (1993), who noted a correlation between the location of abandoned mines and the intersection of structures with specific stratigraphic horizons in the Kalgoorlie region. Sofoulis (1965) also noted that gold workings are commonly aligned in particular directions, and suggested ore is localized along parallel fault or shear lineaments. These patterns arise because shallow gold workings and shafts commonly follow outcropping mineralized features such as quartz veins.

Early prospecting methods involved the dollying (crushing) of outcrop samples and panning to examine for traces of gold after following a lead of panned gold in soil or sediment, or both, downslope from a source. Further excavation resulted in a prospecting pit and, if sufficient encouragement was obtained, a shaft would be sunk on the auriferous outcrop. Prospecting also resulted in workings on secondary, surficial concentrations of gold that more closely reflect paleodrainage patterns.

Early in the abandoned mine sites program, GSWA recognized the potential to use information from the WABMINES database to assist in studies of gold mineralization. Consequently, all types of former mine workings, including small prospecting pits, were recorded and progressively additional geological data were recorded for each excavation, particularly after 2002 when upgraded software and hardware were introduced.

1.2 Study area selection

Given the strong safety emphasis of the abandoned mine sites program, the highest priority was assigned to recording mining-related features within 10 km of major towns, 5 km of smaller towns, and one kilometre of main roads and tourist routes. Thus, detailed data were generated for many of the historical mining centres in the Kalgoorlie Terrane (Fig. 1.4).

There is a high density of preserved abandoned gold workings around the townships of Menzies, Coolgardie, Norseman, and Widgiemooltha, which makes them particularly suitable for study using Geographic Information System (GIS) software. Although the Kalgoorlie–Boulder region has by far the highest historical gold production in Western Australia, the vast majority of the historical workings have now been either removed by later opencut mining, or backfilled for other land use or safety.

Before 1991, the second highest producing gold area in Western Australia was Norseman (Fig. 1.5). Menzies and the greater Coolgardie region, including Burbanks, were also significant historical producers of gold (Fig. 1.5), and represent a good geographical spread throughout the Kalgoorlie Terrane (Fig. 1.4). Widgiemooltha was a comparatively small gold producing area, with total historical (pre-1985) production of about 256 kg, which is several orders of magnitude lower than Menzies and Coolgardie. Nevertheless, Widgiemooltha represents a remarkably well-preserved area of abandoned workings, and WABMINES records a substantial amount of additional geological information here. Widgiemooltha is also strategically located between Norseman and Coolgardie, and southwest of the productive Kambalda – St Ives area.

Since the increased mining activity of the 1980s, gold mineralization in the Kalgoorlie Terrane has been well documented (Groves and Barley, 1988; Groves, 1993; Hagemann and Cassidy, 2000), particularly for the Menzies to Kambalda region (Witt, 1993a–c), and for individual mining camps such as Coolgardie (Swager, 1990; Keele and Shelton, 1990; McCormick and Hanna, 1990; Middleton, 1990; Knight et al., 1993) and Norseman (Thomas et al., 1990; Archer and Turner, 1998). In addition, GSWA published a number of bulletins and detailed geological maps that were produced during or shortly after the main periods of early mining activity in Coolgardie (Blatchford, 1899, 1913; McMath et al., 1953), Menzies (Woodward, 1906), and Norseman (Campbell, 1906).

Modern mapping of the regional geology of the study area by GSWA commenced in the 1960s, resulting in 1:250 000-scale maps and accompanying explanatory notes (Sofoulis, 1966; Kriewaldt, 1969, 1970; Doepel, 1973). In the 1980s and 1990s more-detailed investigations led to the publication of 1:100 000-scale maps and explanatory notes (e.g. Griffin, 1990; Hunter, 1993; Swager, 1994). This work culminated in a 1:250 000-scale interpretive geological map and accompanying explanatory note for the entire Kalgoorlie Terrane (Swager et al., 1995), and the release of second edition 1:250 000-scale maps and explanatory notes (e.g. Griffin, 1989a; Hunter, 1991; Wyche, 1998, 2003).

Since the early 2000s, GSWA has also released a regularly updated GIS dataset (East Yilgarn Geological Information Series) that covers the Kalgoorlie Terrane, including all of the mining areas that make up this study (Geological Survey of Western Australia, 2009). This dataset includes seamless 1:100 000-scale mapping and a range of publications and georeferenced maps and images.

1.3 WABMINES and gold distribution

Although primarily intended as a tool for assessing abandoned mine safety, the WABMINES database has potential to assist in GIS-based studies on gold mineralization and regional geology.

The two main aims of this study were to:

1) test the relationship between abandoned mine workings and total gold production;

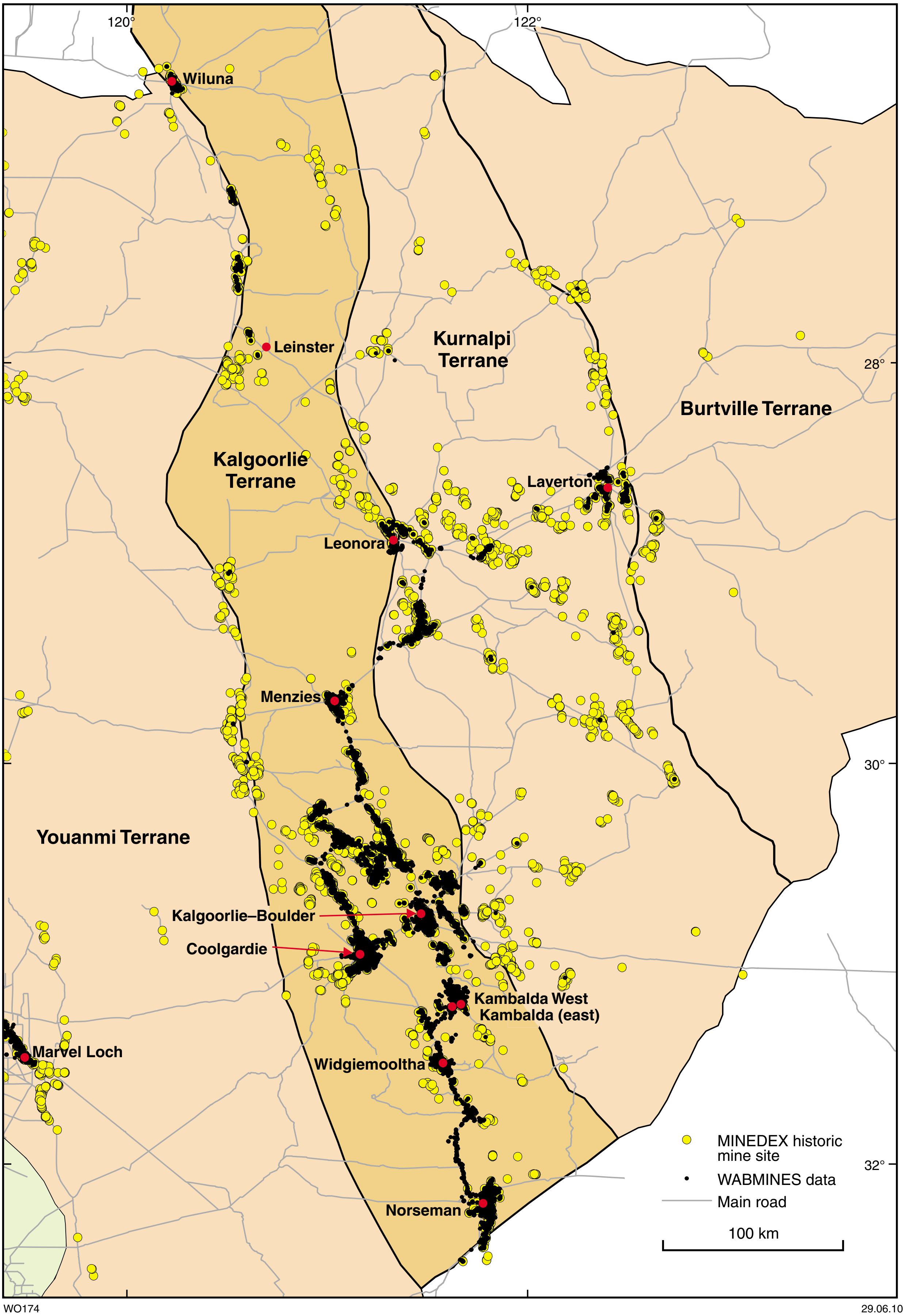

Figure 1.4 Location of WABMINES data in the Kalgoorlie Terrane showing the concentration of data around townsites and main roads, reflecting the strong safety emphasis of the abandoned mine sites project.

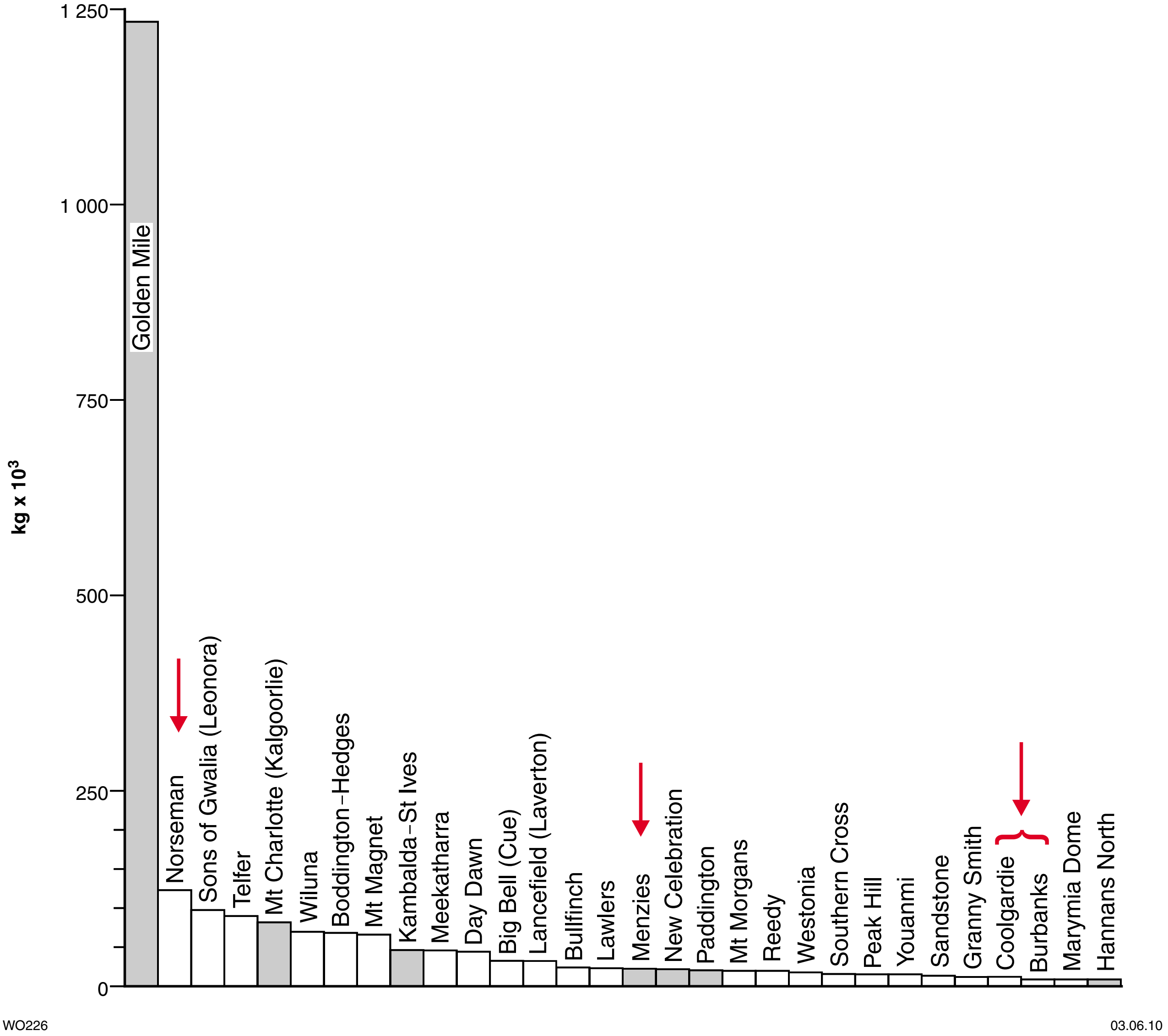

Figure 1.5 **Total gold production from individual Western Australian mines to 1991 (from Witt, 1993a). Arrows indicate three of the mining areas that are the subject of this study. Shaded mines are in the Menzies–Kambalda region of Witt (1993b).**

2) test the relationship between abandoned mine workings and regional-scale geological structures.

A secondary aim was to develop a qualitative measure of total gold production from measurements that can be made using abandoned mine workings. If it can be shown that such relationships exist then abandoned mine site data could be used as an additional dataset for exploration targeting new gold deposits.

1.4 Methodology

This study examines abandoned mine site data from the WABMINES database for the Menzies, Coolgardie, Widgiemooltha, and Norseman gold mining areas.

Mining-related features that represent the location of bedrock-hosted gold mineralization were selected from the WABMINES database using the Microsoft (MS) Access database software. These data were then processed using the Environmental Systems Research Institute (ESRI) ArcGIS 9.2 GIS software package to store and analyse the spatial distribution of gold workings and to estimate the former level of mining activity. The effectiveness of this latter estimate was tested by comparison with known historical gold production data.

The derived raster cell data were then presented as a series of pseudocolour hill-shaded images generated using the Earth Resources (ER) Mapper software package. Data smoothing was used to emphasize gold production patterns. Although the main emphasis was on the spatial distribution of the resultant trends, geological data were also extracted from the WABMINES database to help explain the trends, or to provide other information related to gold mineralization.

The interpreted trends and geological information derived from the abandoned mine site data were then compared to regional geological maps to determine the degree of correlation with known features at a regional scale.

Finally, an assessment was made as to the usefulness of the abandoned mine site data to improve the interpretation of regional geology related to gold mineralization and exploration.

1.5 Geological setting of the study areas

The study areas are all located between about 515 and 560 km east of Perth within the Kalgoorlie Terrane of the Eastern Goldfields Superterrane as defined by Cassidy et al. (2006) and shown in Figure 1.3. The Kalgoorlie Terrane forms the westernmost tectono-stratigraphic terrane of the Eastern Goldfields Superterrane (Cassidy et al., 2006), which approximates to the previously defined 'Eastern Goldfields Province' (Gee et al., 1981) of the Archean Yilgarn Craton and includes the region previously referred to as the 'Norseman–Wiluna greenstone belt'.

The Yilgarn Craton consists of metamorphosed volcanic and sedimentary rocks, granite, and granitic gneiss that formed mainly between about 3.05 and 2.62 Ga (Cassidy et al., 2006). Greenstone belts comprising metamorphosed volcanic and sedimentary rocks are distributed throughout the Yilgarn Craton but are most abundant in the Eastern Goldfields Superterrane.

The Kalgoorlie Terrane comprises predominantly younger (2.71 – 2.66 Ga) and minor older (>2.73 Ga) lithostratigraphic sequences (Cassidy et al., 2006), and can be divided into a number of structurally bound domains. The exact boundaries between these domains, and the status of the subdivisions (i.e. domain vs terrane) is still under discussion (e.g. Wyche, 2007). Overall, the domain boundaries reflect the general north-northwesterly structural trend of the greenstones and the anastomosing network of regional-scale faults. Structural complexity and poor outcrop have made stratigraphic correlation difficult. Nevertheless, a general greenstone stratigraphy has been determined for the Kambalda, Coolgardie, and Ora Banda Domains, comprising a lower basalt unit, overlain by a komatiite unit, in turn overlain by an upper basalt unit, followed by felsic volcanic and sedimentary rocks. This stratigraphy is unconformably overlain in some areas by the so-called 'late-basin' succession of clastic sedimentary rocks (Table 1.1; Swager et al., 1995).

The granites range in age from synchronous with emplacement of the felsic volcanic rocks to post-tectonic (Groenewald et al., 2000). The overall deformation history has been subject to a number of evolving interpretations (Groenewald et al., 2000). Swager et al. (1995) interpreted four main deformation events involving: D_1 thrusting, D_2 upright folding about north-northwesterly trending axes, D_3 sinistral transcurrent faulting, and D_4 continued east-northeasterly – west-southwesterly regional shortening. Subsequent authors have recognized significant periods of extension that were coincident with the emplacement of granites and the deposition of the late-basin successions (e.g. Blewett and Czarnota, 2007). Regional metamorphism at greenschist to amphibolite facies reached peak temperatures late during D_2 to D_3 transpressional deformation (Swager et al., 1995). Cratonization was completed by about 2.6 Ga, well before the intrusion of 2.4 Ga east-northeast trending Paleoproterozoic mafic dykes. Gold mineralization has been interpreted as late-orogenic and structurally controlled (Witt and Vanderhor, 1998; Groves et al., 2000; Blewett and Czarnota, 2007; Henson et al., 2007; Goscombe et al., 2007).

According to Cassidy et al.'s (2006) definition of the domains all the study areas are in different domains:

Table 1.1. General stratigraphy for the Kambalda, Coolgardie, and Ora Banda Domains

Stratigraphic succession		*Characteristic rock types*
🟦	Late basin succession	Polymictic conglomerate, immature sandstone, coarse trough cross-beds, and graded beds
Unconformity		
🟧	Felsic volcanic and sedimentary rock	Felsic volcaniclastic–sedimentary rocks, coarse sandstone to interbedded sandstone/siltstone. Rhyolite to dacite, locally andesite, tuff, agglomerate
🟩	Upper basalt	Komatiitic and tholeiitic basalt, massive, pillowed, and vesicular
🟪	Komatiite	Komatiitic basalt at top, thin komatiite flows with minor interflow sedimentary beds, overlying thicker komatiite flows and/or massive olivine adcumulate
🟩	Lower basalt	Tholeiitic and komatiitic basalt flows, subaqueous

SOURCE: after Swager et al. (1995)

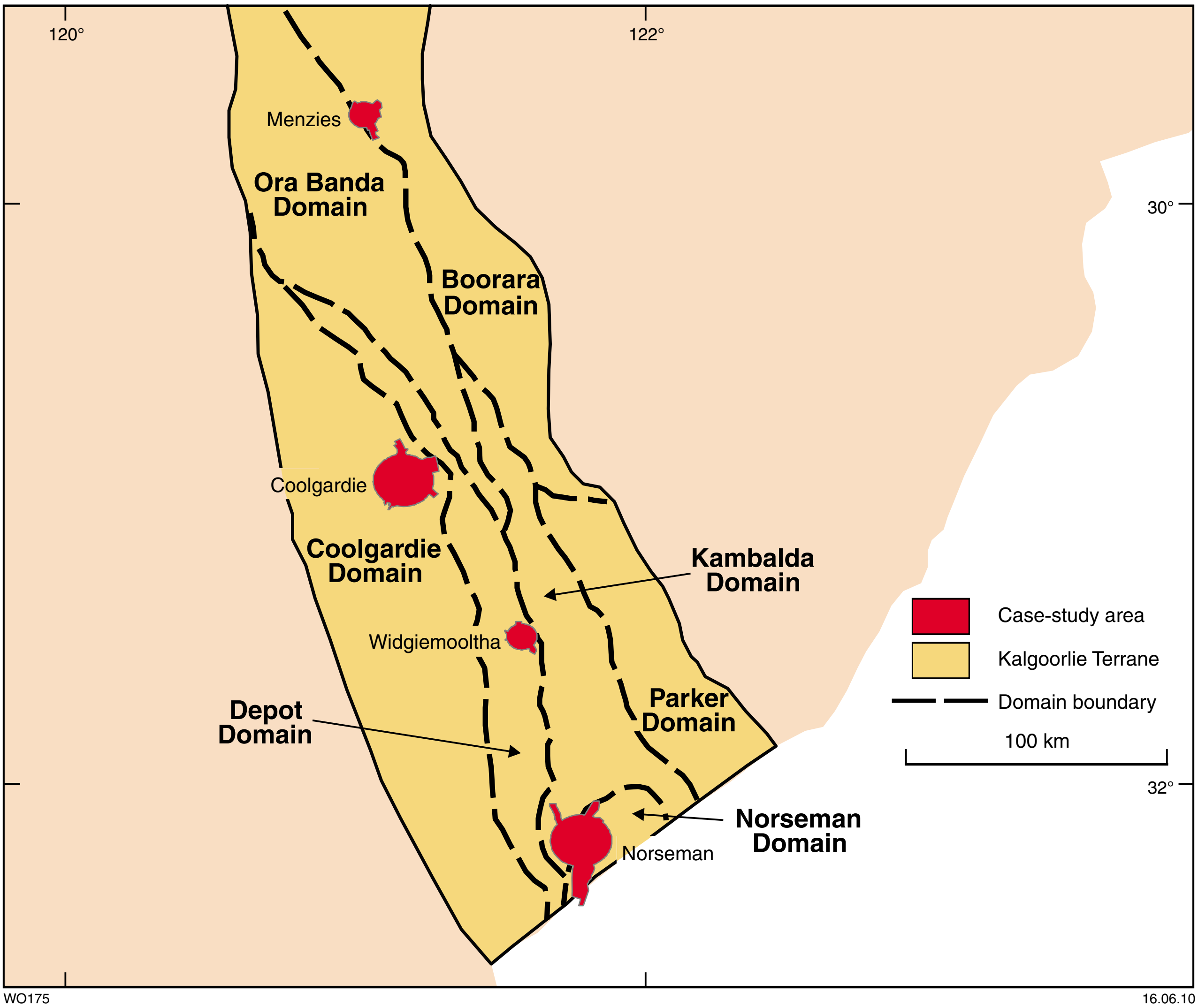

Figure 1.6 **Locations of case-study areas with respect to domain subdivisions within the Kalgoorlie Terrane of Cassidy et al. (2006).**

Menzies is within the Boorara and Ora Banda Domains, Coolgardie is in the Coolgardie Domain, Widgiemooltha in the Depot Domain, and Norseman in the Norseman Domain (Fig. 1.6).

The locations of the study areas with respect to interpreted regional geology are shown in Figure 1.7. Overviews of the geology of these areas are based upon a summary by Groenewald et al. (2000).

The Menzies study area, which lies mainly within a 5-km radius of the township, straddles the Ora Banda and Boorara Domains. In the Ora Banda Domain, a highly deformed sequence of ultramafic schist with minor amphibolite and an overlying felsic volcaniclastic unit is in faulted contact with various basalt units. A SHRIMP age date of 2691 ± 6 Ma (Nelson, 1995) from a felsic volcaniclastic unit indicates emplacement was synchronous with the Kambalda Domain (Kositcin et al., 2008). In the Boorara Domain the Menzies study area consists mainly of basalt that is underlain by felsic schist, and ultramafic rocks (Witt, 1993c).

About 140 km to the south of Menzies, the Coolgardie study area covers a 10-km radius around the townsite and extends along access roads a further one to two km to the southwest and southeast. The Coolgardie Domain has a similar stratigraphic sequence to the Kambalda and Ora Banda Domains, except that it lacks a regional upper basalt unit and so komatiite may be directly overlain by felsic volcanic and sedimentary rocks.

Widgiemooltha is about 70 km south-southeast of Coolgardie. The study area covers a radius of 5 km around the townsite. Widgiemooltha is within the Depot Domain and has a similar stratigraphy to Coolgardie. Repetition of the basalt–komatiite interval in this region has been attributed to structural stacking (Griffin, 1990).

The study area for Norseman covers a 10-km radius and extends some 15 km farther to the south along the Dundas Coach Road Heritage Trail. Norseman contains an older part of the stratigraphic sequence than that found in the other study areas. An age date of 2930 ± 4 Ma was obtained by Nelson (1995) from within the oldest

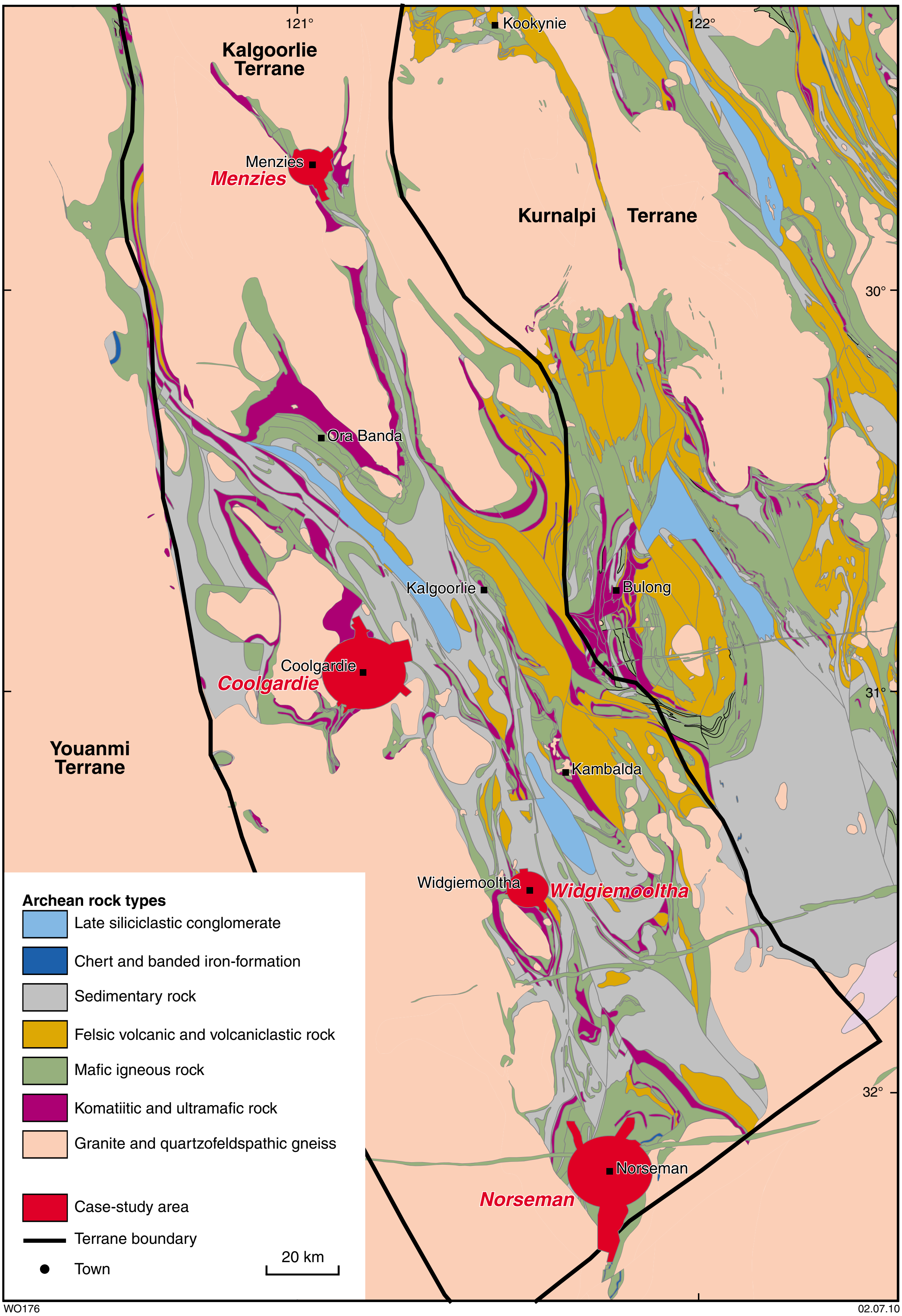

Figure 1.7 Study areas (highlighted in red) superimposed on simplified geology.

part of the stratigraphy, the Penneshaw Formation. The Penneshaw Formation consists of mainly amphibolite and massive to pillowed basalts with minor felsic volcanic and sedimentary rocks. The overlying Noganyer Formation comprises banded iron-formation (BIF), within clastic, partly felsic, sedimentary rocks intruded by gabbro sills. The Noganyer Formation is in turn overlain by massive basalt and minor ultramafic rocks of the Woolyeenyer Formation. The Mount Kirk Formation structurally overlies the Woolyeenyer Formation, and consists of a tightly folded sequence of sedimentary rocks intruded by major gabbro sills. Despite the relatively old age obtained from the Penneshaw Formation, the rocks in the Norseman area have been assigned to the Kambalda and Norseman Domains of the Kalgoorlie Terrane (Cassidy et al., 2006).

1.6 Previous work

Most published literature on abandoned mine sites relates to documenting and managing the environmental and, to a lesser extent, safety aspects of those sites.

The Western Australian inventory of abandoned mine sites program was documented by Ormsby et al. (2003) and includes preliminary examples of some interpreted trends of gold mineralization in bedrock within the central Coolgardie region, based on point data extracted from the WABMINES database. Ormsby et al. (2005) included the results of more sophisticated image processing of WABMINES data for the Coolgardie, Widgiemooltha, and Norseman regions, and outlined several possible applications of the data for exploration purposes. Nevertheless, this work did not attempt to establish the validity of the method used to infer the level of historic mining activity, nor was any rigorous attempt made to use abandoned mine site data in the interpretation of regional geology as it relates to gold mineralization and exploration.

1.7 Terminology

The Western Australian inventory of abandoned mine sites introduced a number of terms and abbreviations specific to the project and WABMINES database. These are defined in Appendix 1, which contains the glossary from Ormsby et al. (2003).

For most purposes, the term abandoned mine sites refers specifically to those sites referred to as historical mine sites in DMP's MINEDEX database (Cooper et al., 2002) although, for the purposes of WABMINES data collection, the term is more generally applied to any non-operational or shut-down mine site or quarry. An abandoned mine site typically comprises many tens of individual mine workings and associated mine features.

Each individual mining-related feature is recorded in the WABMINES database. WABMINES features are classified into one of the following groups: underground, opencut, shallow working, rehabilitated, dump, infrastructure, and under infrastructure (see Appendix 1 for definitions and Ormsby et al., 2003 for details). Some feature groups such as 'underground' are further subdivided into types such as shaft, open stope, and subsidence.

The term gold working is used interchangeably with gold excavation. Gold working means a WABMINES feature that appears to be excavated directly at the site of gold mineralization, and is distinguished from other mining-related features such as waste-rock dumps and batteries. A further distinction is made between bedrock- and alluvial-gold workings. Thus, a bedrock-gold excavation is an excavation made at the site of bedrock-hosted gold mineralization.

Bedrock-gold excavations comprise four specific kinds of WABMINES features defined as:

1) Shallow working: an excavation <2 m deep (Fig. 1.8a);
2) Shaft: an excavation of limited area compared with depth (Fig. 1.8b);
3) Collapsed shaft: currently <2 m deep, but showing evidence of greater original depth (Fig. 1.8c);
4) Open stope: open to the surface and formed primarily by the removal of ore from beneath (Fig. 1.8d).

The pile of waste rock that normally surrounds an excavation is called a bund in the WABMINES database. This waste rock may partially (partial bund), or fully encircle the excavation (full bund). Both maximum and minimum bund heights are recorded in the WABMINES database. A measure commonly used in this study is mean bund height, which is the mean of both maximum and minimum bund heights, as shown in Figure 1.9.

The WABMINES database stores most data in abbreviated form. For example, 'shallow working' is abbreviated to 'SHW'. For brevity, abbreviations were used in all data processing, and hence are referred to as such in the data processing procedures documented in the Appendices. However, these abbreviations are not used in the publicly available digital databases.

All bedrock rock types in the study areas have been metamorphosed but, consistent with common use, the prefix 'meta' has been omitted.

The following general abbreviations are used throughout the text:

DMP	Department of Mines and Petroleum
ECW	ER Mapper's Enhanced Wavelet Compression
ER	Earth Resources
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GML	Gold Mining Lease
GPS	Global Positioning System
GSWA	Geological Survey of Western Australia
MH	MINEDEX Historic Mine Site

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Figure 1.8 Typical examples of bedrock-gold excavations from the abandoned mine sites database: a) shallow working; b) shaft; c) collapsed shaft; d) open stope.

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Figure 1.9 A shaft surrounded by a full bund of waste rock showing maximum, minimum, and calculated mean bund heights.

MINEDEX	DMP’s mines and mineral deposits information database
MS	Microsoft
TENID	Tenement identification number
TIF	Tagged image file format
WABMINES	Western Australian abandoned mine site features database
WAROX	Western Australian field observation database

Chapter 2

Databases

2.1 Introduction

This study primarily involved the combination and manipulation of four GSWA digital databases — the WABMINES, MINEDEX, Dead Tenement, and the East Yilgarn Geological Information Series databases. Some information for the Norseman case study was also sourced from the South Yilgarn Geological Exploration Package. All data used are publicly available in digital form on the following DVD-based products: Geological Survey of Western Australia (2007, 2008, 2009).

The WABMINES, MINEDEX, and Dead Tenement databases are all available in Geological Survey of Western Australia (2008). However, for expediency they were sourced prior to release from internal GSWA databases. Further details on the individual databases and the methodology of data extraction are provided in Chapters 3 and 5, and Appendix 2.

2.2 WABMINES database

Terms used in the WABMINES database are explained in the glossary in Appendix 1, and all aspects of the database are documented in Ormsby et al. (2003).

Field-data collection for the case-study areas took place from 2002 to 2006. The data were stored in the GSWA corporate Oracle database as four tables:

1) location data (WAROX_SITES);
2) abandoned mine site-specific data (WAROX_WABMINES);
3) geology-related comments (WAROX_FIELDNOTES);
4) digital photographs (WAROX_PHOTOS).

The information (data fields) provided in these tables is the same as provided in the ‘WABMINES’ table in the DVD product MS Access ‘wabmines.mdb’ file (Geological Survey of Western Australia, 2008), except that the data are in abbreviated (coded) format for the ‘in-house’ database version used in this study. All abbreviations are listed in the glossary (Appendix 1). Subsequent data processing is described in Chapters 3 and 5.

The WABMINES DVD product (Geological Survey of Western Australia, 2008) also contains many historical georeferenced geological maps in ECW (ERMapper’s Enhanced Wavelet Compression) format from early published GSWA bulletins. These maps are named with an abbreviated publication title, number, and map or plate number. Maps used for reference in this study were as follows:

1) Bulletin 22 (Woodward, 1906) plate 1 — Menzies case study;
2) Bulletin 3 (Blatchford, 1899) plate 2 — Coolgardie case study;
3) Bulletin 107 (McMath et al., 1953) plates 1 and 9 — Coolgardie case study;
4) Bulletin 21 (Campbell, 1906) maps 1a and 1b — Norseman case study.

Since this study was completed, the WABMINES database has been incorporated into the GSWA MINEDEX database. However, the WABMINES data are identified as ‘abandoned mine features’ within MINEDEX and can be extracted as a separate dataset.

2.3 MINEDEX database

The MINEDEX database was established in 1985, and contains records of the locations and estimated mineral resources and ore reserves of mines and mineral deposits in Western Australia (Cooper et al., 2002). For this study, the MINEDEX database was extracted from the GSWA Oracle database into an MS Access file called ‘minedex.mdb’. This file is in the same format as that provided in the WABMINES DVD product (Geological Survey of Western Australia, 2008). The relevant tables within this file are:

1) location data (SITE_COORDINATES);
2) gold production data (HISTORIC_PRODUCTION);
3) mining tenement data (TENEMENTS).

The gold production data in the HISTORIC_PRODUCTION table pertains to pre-1985 gold production information derived from the *List of cancelled gold mining leases which have produced gold* (Department of Mines Western Australia, 1954) and gold production records from 1954 to 1985 held by DMP (Cooper et al., 2002). Gold production commencement and finish dates and cumulative production are given for each site. The TENEMENTS table provides information on the tenements to which the production records refer. All tables are linked by a common SITE_CODE. Further details on the MINEDEX database, and the data processing methodology are provided in Chapter 3.

2.4 Dead Tenement database

The boundaries of many expired mining tenements are included on an ArcGIS shapefile termed ‘deadten’, collectively referred to as the Dead Tenement database. The tenement boundary polygons are attributed with the tenement identification number (TENID), type, survey and tenement status, and STARTDATE, ENDDATE, and GRANTDATE. These are all self-explanatory, except perhaps for STARTDATE which is the date on which the tenement application was made. Most historic gold production was derived from Gold Mining Leases, the boundaries of which were surveyed. Unfortunately, not all former Gold Mining Lease boundaries are in the Dead Tenement database, although it is quite comprehensive in the case-study areas. The database is being continually updated as current mining tenements expire.

The dataset used in this study was extracted from the GSWA ArcSDE server on 13 April 2007. A comparable Dead Tenement database shapefile is included in the GSWA WABMINES DVD product (Geological Survey of Western Australia, 2008), and is also available for download from the data and software centre on the DMP internet website (www.dmp.wa.gov.au).

2.5 Geological databases

The East Yilgarn Geological Information Series (Geological Survey of Western Australia, 2009) is a digital compilation of GSWA 1:100 000-scale regional mapping in the East Yilgarn region. This database was used for all of the ‘1:100 000-scale regional mapping’ lithological units used in the case studies in this study.

The East Yilgarn Geological Information Series also includes a 1:500 000-scale interpretation of the Precambrian geology beneath younger cover, used in this study. Some additional interpretation was taken from the South Yilgarn Geological Exploration Package (Geological Survey of Western Australia, 2007).

Various cultural feature shapefiles such as roads, towns, and drainage were also sourced from the East Yilgarn Geological Information Series database.

Chapter 3

Pre-processing of GIS data for testing the relationship between the size of abandoned mines and total gold production

3.1 Introduction

If abandoned mines are to be used as a guide to future exploration or to identify major geological structures, it is important to determine if a relationship exists between the size of these mines and total gold production. It is likely that the largest mines are associated with the most productive structures so, in the absence of estimates for total gold resource, the total historical gold production has been used.

The Menzies area (Fig. 3.1) was chosen to test this hypothesis because this region offers the best combination of spatially related, historical gold-production data with substantial past gold production, and good-quality data on abandoned mine sites (i.e. the WABMINES database). Criteria for assessing the quality of the data include:

1) date of data capture (recent data are the most consistent and well attributed);
2) comparatively little rehabilitation of mine excavations (which destroys evidence of past mining activities);
3) early commencement date of most historical gold production (which results in more surface workings).

The boundary of the test study-area (area outlined in red in Fig. 3.1) represents the limit of WABMINES data collected during the 2005 field season (being the extent of data available when this work commenced) and the associated gold-mining tenements. The test study-area

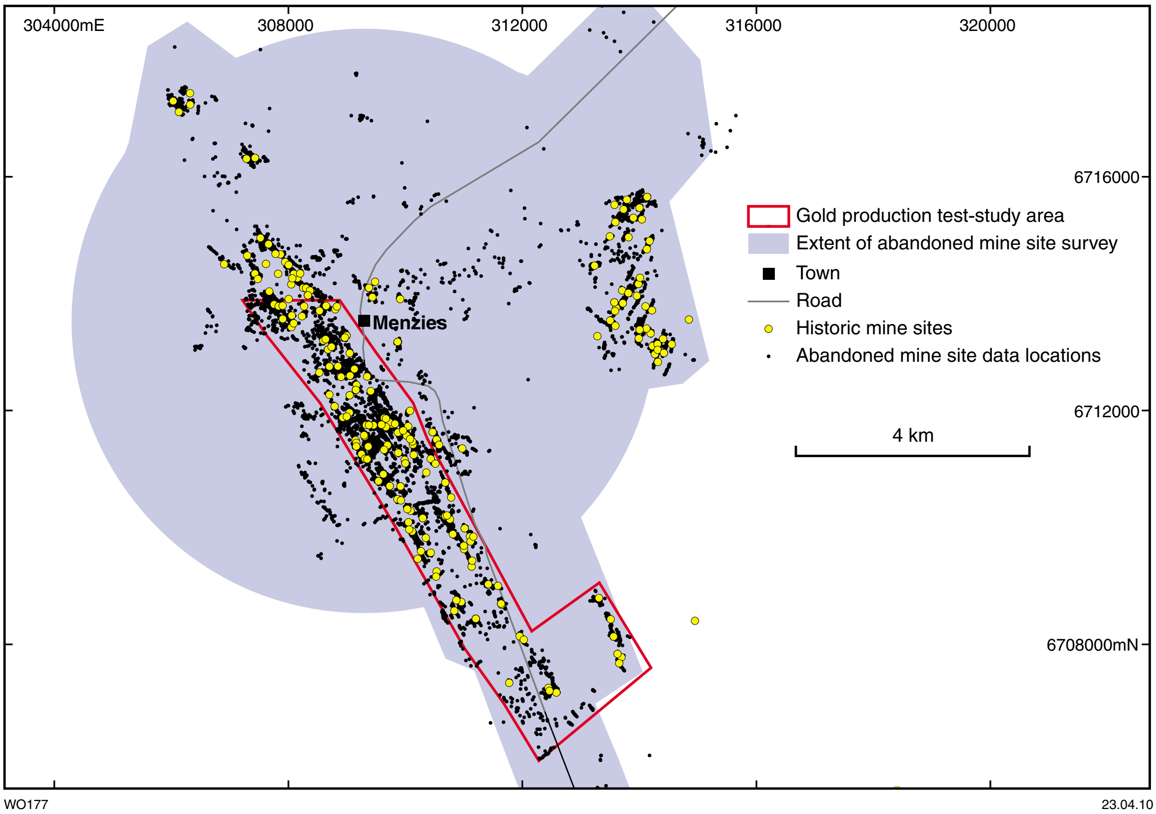


Figure 3.1. Location of the Menzies study area to test the relationship between the size of abandoned mines and total gold production.

follows the main line of workings along the Menzies shear zone and is truncated along an east–west line on the northern boundary to simplify the conversion of the data to raster format.

3.2 Overview of methodology

For most regional GIS-based studies on gold mineralization, gold deposits are assumed to be adequately represented as point entities (Knox-Robinson, 2000). A different approach was required for this study due to the small scale (tens of metres) of analysis necessary when comparing individual abandoned mine excavations from the WABMINES database with gold production data. At this mine-site scale, it is important to understand and to take into account the limitations of the available historical gold-production data.

All MINEDEX historical mine sites are recorded as point localities that were initially situated in the centre of the relevant tenement from which production was obtained. In this study, these tenements were all Gold Mining Leases that were granted under the Mining Act 1904 specifically for gold mining purposes. Gold Mining Leases existed until superseded by Mining Leases that could be used for all commodities under the new Mining Act 1978 in the mid-1980s. The system of government-run State batteries at mining centres, including Menzies, provided the means for processing most of the ore from the many smaller operators in a goldfield, and helped record gold production. Nevertheless, the same gold production is commonly reported in MINEDEX against multiple tenements, notionally from the same historical mine site. This repetition is due to a number of reasons including:

1) cumulative gold-production figures over a time period for the same land area (or mine site) being recorded under different tenement numbers during the life of the mine, most likely by the same owners;
2) 'undifferentiated' gold production from the same mining party being recorded for adjoining tenements;
3) 'undifferentiated' gold production from the same mining party being recorded from spatially separate tenements.

Difficulties arise from attempting to attribute production to a point locality when the production tenements span a large area, or a number of entirely different areas. Even if all production was from the same tenement, the centre of the tenement (and hence historical mine site) is commonly some tens to hundreds of metres away from the actual mine excavations. Part of the GSWA abandoned mine sites program involved relocating the point localities of MINEDEX historical mine sites so that they coincide with mine excavations. A judgement as to which locality was the most significant was necessary where multiple tenements were involved. However, in most cases it is not possible to reconcile fully the location of past gold production with any particular point locality at mining-tenement scale. This is partly because, at the time of mining, the precise location of gold production was rarely recorded. Infrequent inspections by the government geologist sometimes resulted in detailed mapping of a small proportion of the many thousands of workings in the goldfields, but even these were snapshots in time, and did not provide a complete record of past production localities.

More fundamentally, gold was produced from along one or more orebodies within a mining tenement or group of adjoining tenements that have a similar dimension (in plan view) to the tenements themselves. Hence, a point at the tenement scale could not satisfactorily represent the mine site. To overcome these limitations, it was necessary to attribute the gold production records to the entire area of the tenement (or tenements) from which the production was recorded.

Fortunately, there was a requirement for all Gold Mining Leases to be surveyed, so accurate lease locations are known for most leases in the study area. The accuracy of this early survey work can be attested to by the common experience of locating the remnants of wooden corner survey pegs by GPS within the margins of error of the satellite system. Although not all Gold Mining Lease locations are recorded in the GIS database layer depicting dead tenements, these records are comprehensive in the study area. The comparatively small size of Gold Mining Leases, which averaged around 4 to 5 hectares, also assisted the analysis in this study. Figure 3.2 summarizes the main processing steps described in this chapter:

> Step 1 (see Section 3.3) involved selection of the appropriate abandoned mine site data from the MINEDEX database, and combining three separate tables containing location, gold production, and tenement information into one database table.
>
> Step 2 required joining the gold production data from the MINEDEX database with the spatial locations of the respective Gold Mining Leases from the GIS database layer depicting dead tenements. Gold Mining Leases in this layer have a large degree of overlap because leases with differing shapes and orientations were granted at different times for the same locality. Consequently, it was not possible to simply add all gold production from the (vector) gold production GIS layer without first separating overlapping tenements into a chronological sequence of raster GIS layers that could be added by the ESRI ArcGIS software. This method, which was developed in the course of this study, is described in detail in Section 3.4 and has the potential for wider application in GIS-based prospectivity studies based upon both WABMINES and conventional GIS regional datasets.
>
> Step 3 is described in detail in Section 3.5. This step initially used a data processing procedure developed in a previous study (Ormsby et al., 2003, 2005) to select the appropriate detailed abandoned mine excavation data from the WABMINES database. The procedure, which is common to all mineralization-related applications of WABMINES data, is termed 'primary WABMINES data processing' to distinguish it from further application-

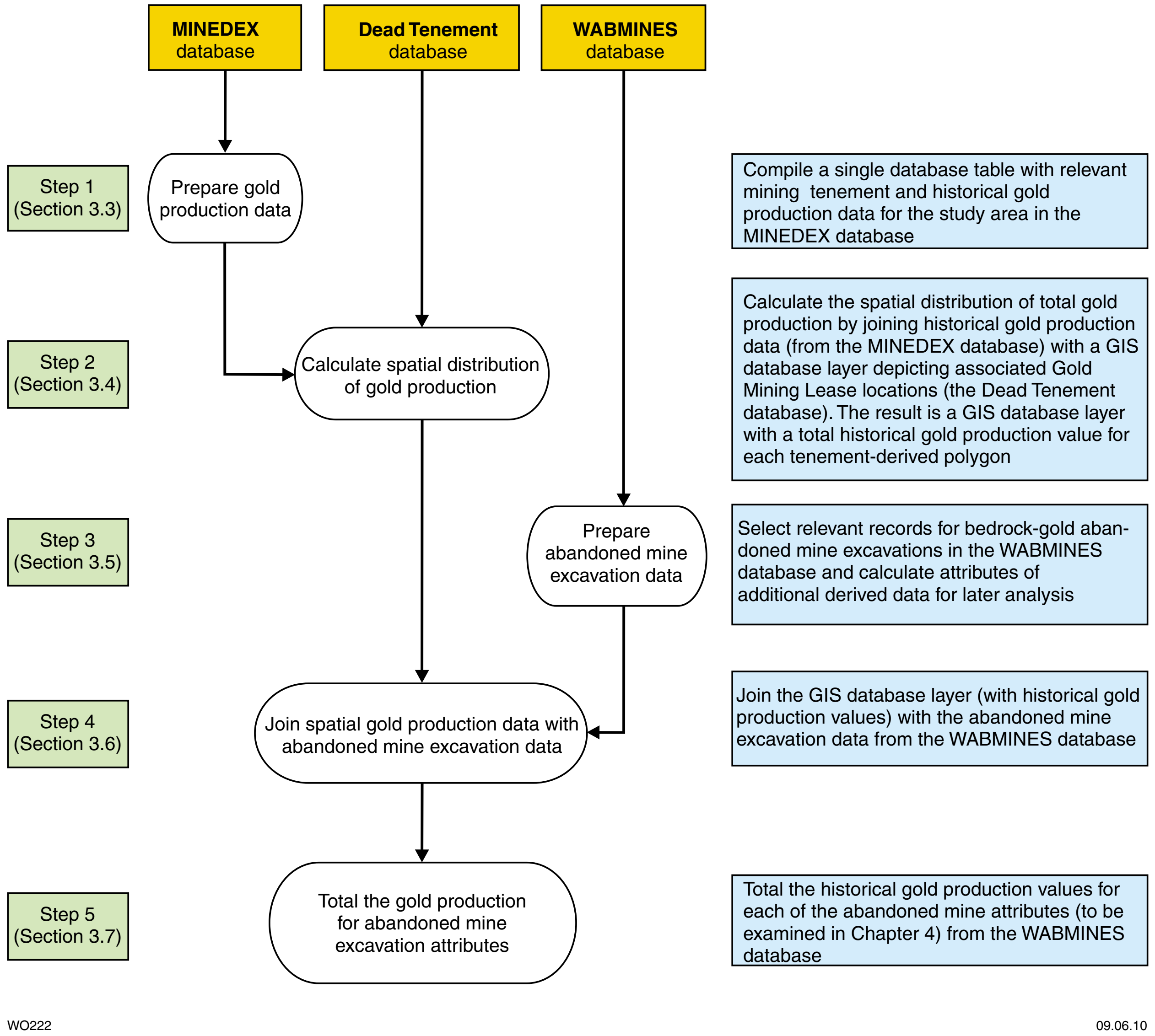


Figure 3.2 **Flow diagram showing the main pre-processing steps required before testing the relationship between the size of abandoned mine excavations and total gold production.**

specific processing that uses data derived from this processing step. Primary WABMINES data processing resulted in two database tables for bedrock-gold excavations and 'alluvial' gold excavations, respectively. The 'alluvial' gold excavations table includes all workings on surficial gold accumulations, and is not dealt with further in this study. However, the data have obvious potential for studies on these types of deposits and for prospecting.

Mine size can be estimated from the abandoned bedrock-gold excavations derived from the WABMINES database in two main ways using:

1) attributes of each mine excavation such as depth, length, width, and bund height (height of the pile of waste rock surrounding an excavation; see Fig. 1.9);
2) density of mine excavations.

'Derived WABMINES data processing' involved calculating the specific mine-size related measurements (mean depth, mean volume, and mean bund height) and appending these attributes to the bedrock-gold excavation table. The density of these bedrock-gold excavations was also calculated to produce two additional database layers showing the number of excavations per unit area for two very different land areas, namely 100 m^2 and 10 000 m^2.

Step 4 (see Section 3.6) used standard GIS-based data processing techniques to spatially join the GIS layer containing historical gold production (from step 2) to the abandoned mine excavation data (from step 3).

Step 5 (see Section 3.7) again involved a standard GIS-based data processing technique to summarize the historical gold production for each mine-size related attribute.

3.3 Preparing gold production data from the MINEDEX database

Three main steps were involved in transforming the MINEDEX database into a single database table with relevant mining tenement and historical gold production data (Figs 3.3 and 3.4). These are as follows:

1) historical MINEDEX records from the study area were selected from the 'SITE_COORDINATES' table which contains the locations of all (current and historical) mine sites in Western Australia;
2) production and tenement tables from the MINEDEX database were then linked to the historical records using a common key (the 'SITE_CODE');
3) All bedrock-hosted gold production records were selected.

Unless stated otherwise, all processing was carried out using queries within the MS Access database software.

3.3.1 Selecting relevant MINEDEX data

The MINEDEX database contains data about all mines and mineral deposits in Western Australia. In this study we are only interested in gold production from historical mine sites in the Menzies study area. The 'SITE_COORDINATES' table was queried to select only sites with historical mineral production (labelled 'MH' in the 'SITE_TYPE_CODE' attribute field). Unnecessary attribute fields were deleted so that only information relevant to this study was retained. Although it is possible to select study-area localities using map coordinates within MS Access database software, it is simpler and more concise to export the table into ESRI ArcGIS software and select the sites within the study area using a spatial query. The Menzies study area comprises 175 historical mine sites.

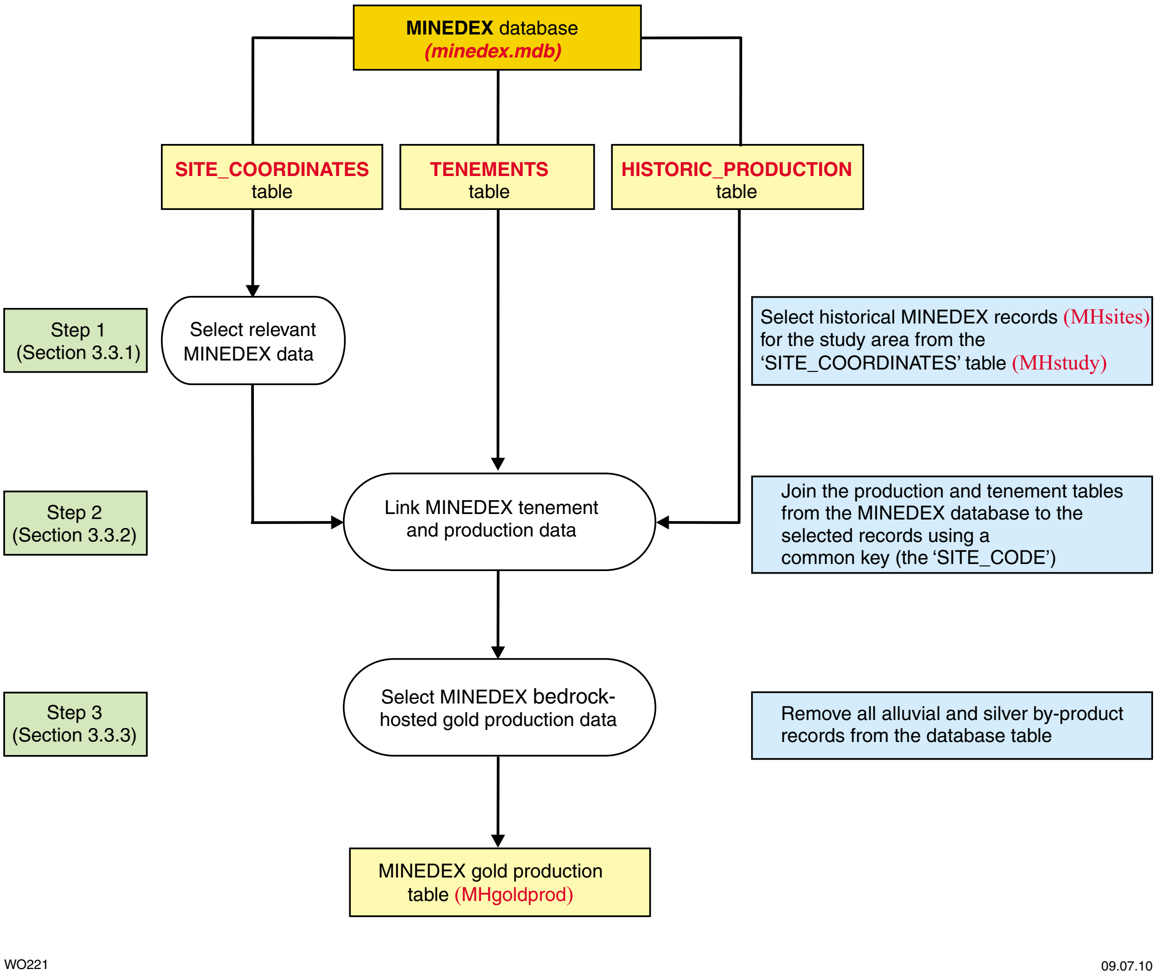
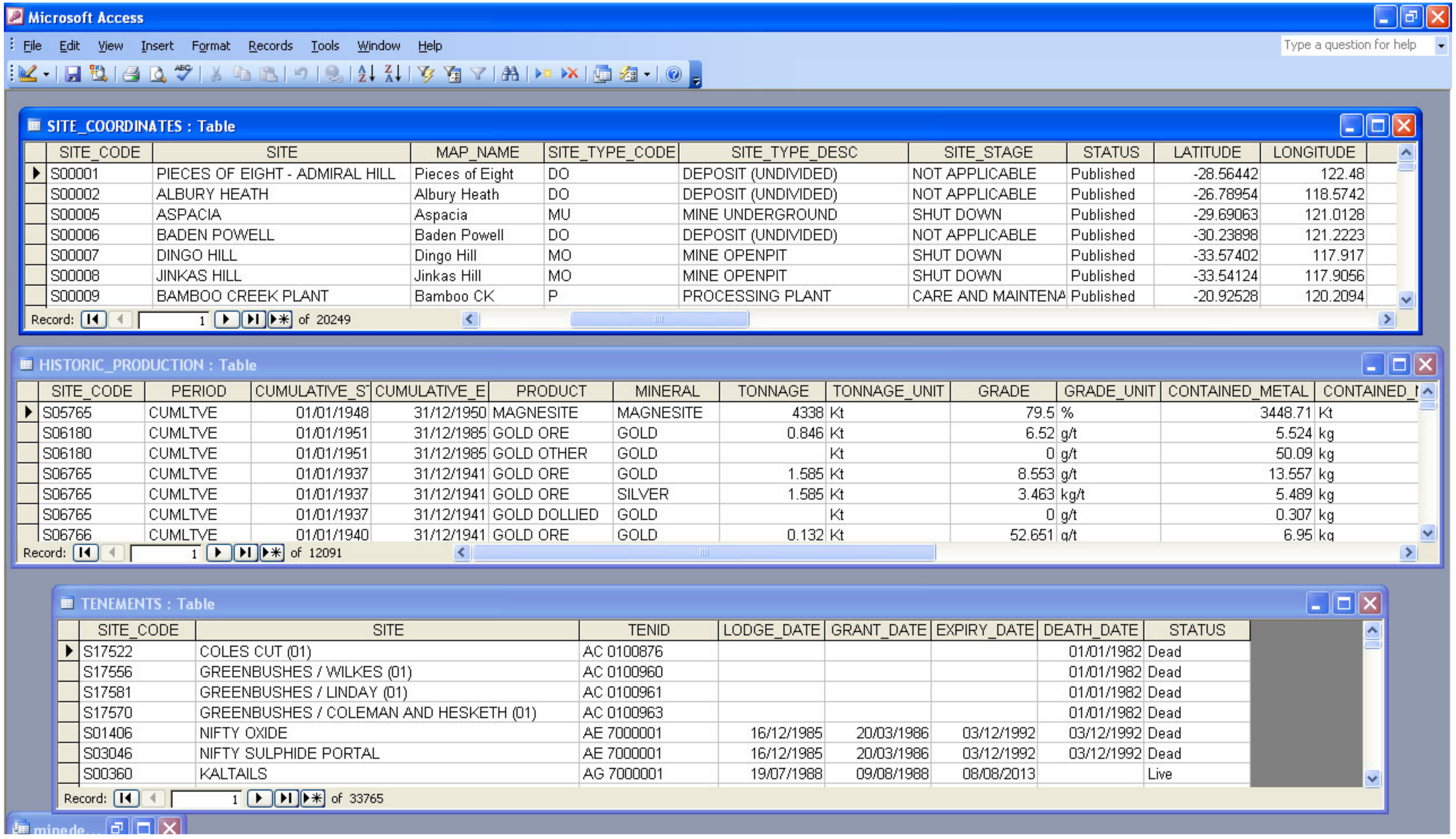


Figure 3.3 Flow diagram showing the main steps in processing the MINEDEX database (file name is in red italics) to produce a single table of tenement and gold production data. MS Access database table names are shown in normal red font.



SITE_COORDINATES : Table

SITE_CODE	SITE	MAP_NAME	SITE_TYPE_CODE	SITE_TYPE_DESC	SITE_STAGE	STATUS	LATITUDE	LONGITUDE
S00001	PIECES OF EIGHT - ADMIRAL HILL	Pieces of Eight	DO	DEPOSIT (UNDIVIDED)	NOT APPLICABLE	Published	-28.56442	122.48
S00002	ALBURY HEATH	Albury Heath	DO	DEPOSIT (UNDIVIDED)	NOT APPLICABLE	Published	-26.78954	118.5742
S00005	ASPACIA	Aspacia	MU	MINE UNDERGROUND	SHUT DOWN	Published	-29.69063	121.0128
S00006	BADEN POWELL	Baden Powell	DO	DEPOSIT (UNDIVIDED)	NOT APPLICABLE	Published	-30.23898	121.2223
S00007	DINGO HILL	Dingo Hill	MO	MINE OPENPIT	SHUT DOWN	Published	-33.57402	117.917
S00008	JINKAS HILL	Jinkas Hill	MO	MINE OPENPIT	SHUT DOWN	Published	-33.54124	117.9056
S00009	BAMBOO CREEK PLANT	Bamboo CK	P	PROCESSING PLANT	CARE AND MAINTENA	Published	-20.92528	120.2094

Record: 1 of 20249

HISTORIC_PRODUCTION : Table

SITE_CODE	PERIOD	CUMULATIVE_S	CUMULATIVE_E	PRODUCT	MINERAL	TONNAGE	TONNAGE_UNIT	GRADE	GRADE_UNIT	CONTAINED_METAL	CONTAINED_
S05765	CUMLTVE	01/01/1948	31/12/1950	MAGNESITE	MAGNESITE	4338	Kt	79.5	%	3448.71	Kt
S06180	CUMLTVE	01/01/1951	31/12/1985	GOLD ORE	GOLD	0.846	Kt	6.52	g/t	5.524	kg
S06180	CUMLTVE	01/01/1951	31/12/1985	GOLD OTHER	GOLD		Kt	0	g/t	50.09	kg
S06765	CUMLTVE	01/01/1937	31/12/1941	GOLD ORE	GOLD	1.585	Kt	8.553	g/t	13.557	kg
S06765	CUMLTVE	01/01/1937	31/12/1941	GOLD ORE	SILVER	1.585	Kt	3.463	kg/t	5.489	kg
S06765	CUMLTVE	01/01/1937	31/12/1941	GOLD DOLLIED	GOLD		Kt	0	g/t	0.307	kg
S06766	CUMLTVE	01/01/1940	31/12/1941	GOLD ORE	GOLD	0.132	Kt	52.651	g/t	6.95	kg

Record: 1 of 12091

TENEMENTS : Table

SITE_CODE	SITE	TENID	LODGE_DATE	GRANT_DATE	EXPIRY_DATE	DEATH_DATE	STATUS
S17522	COLES CUT (01)	AC 0100876				01/01/1982	Dead
S17556	GREENBUSHES / WILKES (01)	AC 0100960				01/01/1982	Dead
S17581	GREENBUSHES / LINDAY (01)	AC 0100961				01/01/1982	Dead
S17570	GREENBUSHES / COLEMAN AND HESKETH (01)	AC 0100963				01/01/1982	Dead
S01406	NIFTY OXIDE	AE 7000001	16/12/1985	20/03/1986	03/12/1992	03/12/1992	Dead
S03046	NIFTY SULPHIDE PORTAL	AE 7000001	16/12/1985	20/03/1986	03/12/1992	03/12/1992	Dead
S00360	KALTAILS	AG 7000001	19/07/1988	09/08/1988	08/08/2013		Live

Record: 1 of 33765

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Figure 3.4 Screen capture showing the three input MINEDEX database tables that were processed using MS Access database software to produce a single MINEDEX gold production table.

3.3.2 Compiling MINEDEX tenement and production data

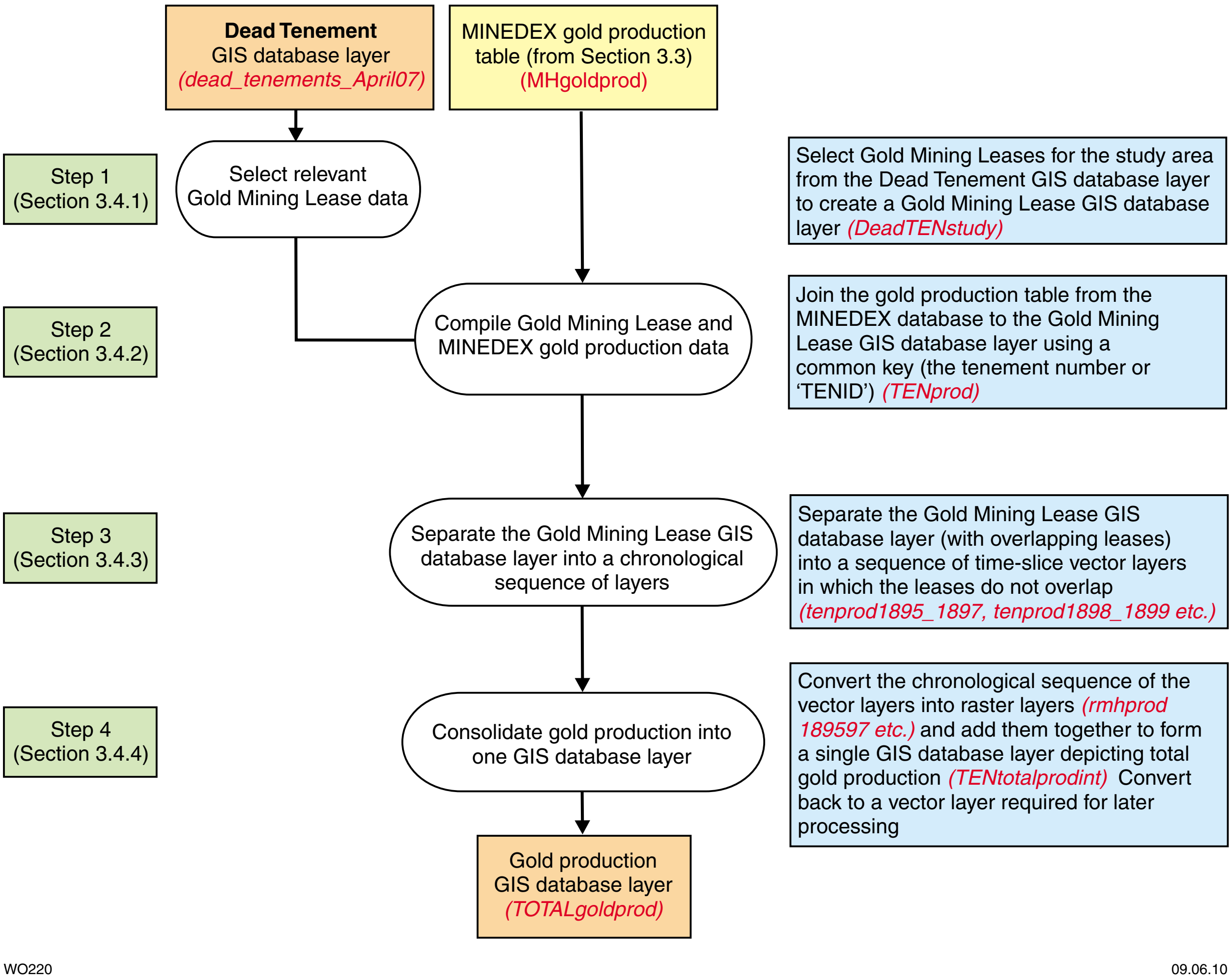
As records from the 'TENEMENTS' and 'HISTORIC_PRODUCTION' tables contain no spatial information, they needed to be joined to the historical mine site table (created in the previous step) using a common key ('SITE_CODE') to produce a single table of sites relevant to the study area. Again, unnecessary attribute fields in both tables were deleted.

3.3.3 Selecting MINEDEX bedrock-hosted gold production data

Silver was a by-product of gold production in the Menzies study area, so silver production needed to be removed, as well as alluvial gold production. Both 'GOLD ORE' and 'GOLD DOLLIED' values were retained as they represent non-superficial, hardrock, or bedrock-gold production. Dollied gold means gold produced as a product of small-scale hardrock mining or exploration by finely crushing (or dollying) the rock by hand.

3.4 Calculating spatial distribution of gold from Dead Tenement and MINEDEX databases

The GIS database layer depicting dead tenements is the key to spatially locating past gold production at the district scale in this study. The MINEDEX gold production data from Section 3.3 were combined with the spatial information from the Dead Tenement GIS database layer to form a single GIS layer attributed with gold production information. This process required the following four steps (Fig. 3.5):



Select Gold Mining Leases for the study area from the Dead Tenement GIS database layer to create a Gold Mining Lease GIS database layer *(DeadTENstudy)*

Join the gold production table from the MINEDEX database to the Gold Mining Lease GIS database layer using a common key (the tenement number or 'TENID') *(TENprod)*

Separate the Gold Mining Lease GIS database layer (with overlapping leases) into a sequence of time-slice vector layers in which the leases do not overlap *(tenprod1895_1897, tenprod1898_1899 etc.)*

Convert the chronological sequence of the vector layers into raster layers *(rmhprod 189597 etc.)* and add them together to form a single GIS database layer depicting total gold production *(TENtotalprodint)* Convert back to a vector layer required for later processing

Figure 3.5 Flow diagram showing the main steps in processing the Dead Tenement GIS database layer and the MINEDEX gold production table to produce a single gold production GIS database layer. File names used in this study are shown in red italics, and MS Access database table names are shown in normal red font.

1) Gold Mining Leases in the study area were selected from the Dead Tenement GIS database layer;
2) the resultant Gold Mining Lease GIS database layer was then joined to the MINEDEX gold production table using a common key ('TENID');
3) the Gold Mining Lease GIS database layer was separated into a chronological sequence of layers that do not overlap;
4) gold production was summed from each of the 'time-slice' layers.

As the Dead Tenement GIS layer is a polygon vector dataset, all data processing in this section was carried out using ESRI ArcGIS software.

3.4.1 Selecting relevant data from the Dead Tenement GIS database layer

Initially all dead tenements from the Dead Tenement GIS database layer that intersected the abandoned mine site data in the Menzies study area were selected. All Gold Mining Leases within the dead tenements were then selected, thereby removing more-recent tenements that relate to comparatively modern exploration and opencut mining from the 1980s. After the processing steps described above, 511 Gold Mining Leases were identified for the study area.

3.4.2 Compiling Gold Mining Lease and MINEDEX gold production data

The MINEDEX gold production table (from Section 3.3) was then joined to the Gold Mining Lease layer using the common tenement number ('TENID'). This generated 209 records, indicating that fewer than half of the granted Gold Mining Leases relate to bedrock-gold production. A single vector GIS layer now contained all recorded bedrock-gold production attributed to the mining tenements relevant to the study area (Gold Mining Leases, Fig. 3.6). As these tenements overlap, it was necessary to separate them into individual polygon vector layers before production could be added for each locality.

3.4.3 Separating overlapping Gold Mining Leases into a chronological sequence of layers

Gold Mining Leases were sorted by tenement number, using the unique sequential number given to each tenement at the time of application. This is a good approximation for the time sequence in which the tenements were actually granted, and was used in preference to sorting by grant date as some recorded grant dates were clearly incorrect. Records were then selected from the table in chronological order, and were grouped into spatially non-overlapping Gold Mining Leases. A chronological sequence of eighteen layers of non-overlapping tenements was then saved as separate vector layers ranging in grant time from 1895 through to 1974.

3.4.4 Consolidating gold production into one layer

Each tenement layer (in vector format) relating to a particular time interval was converted into a raster layer using a 10-m cell size and contained gold (i.e. gold metal production) field as the 'grid' value attributed to each cell. The selection of the cell size was primarily based on the spatial coordinate error associated with the WABMINES data. Gold production values were converted from kilograms to grams to remove decimal points, and blank or 'null' values were changed to zeros to enable a total gold production to be calculated by adding raster layers for each time interval. The result was a single layer with total gold production values attributed to each 10 by 10 m cell. Unfortunately, only a vector layer can be spatially joined in ESRI ArcGIS software with the WABMINES data, and this was required later in Section 3.6 (Fig. 3.2, Step 4). The format of the gold production database field needed to be changed from decimal to integer before it could be converted back into a polygon vector layer.

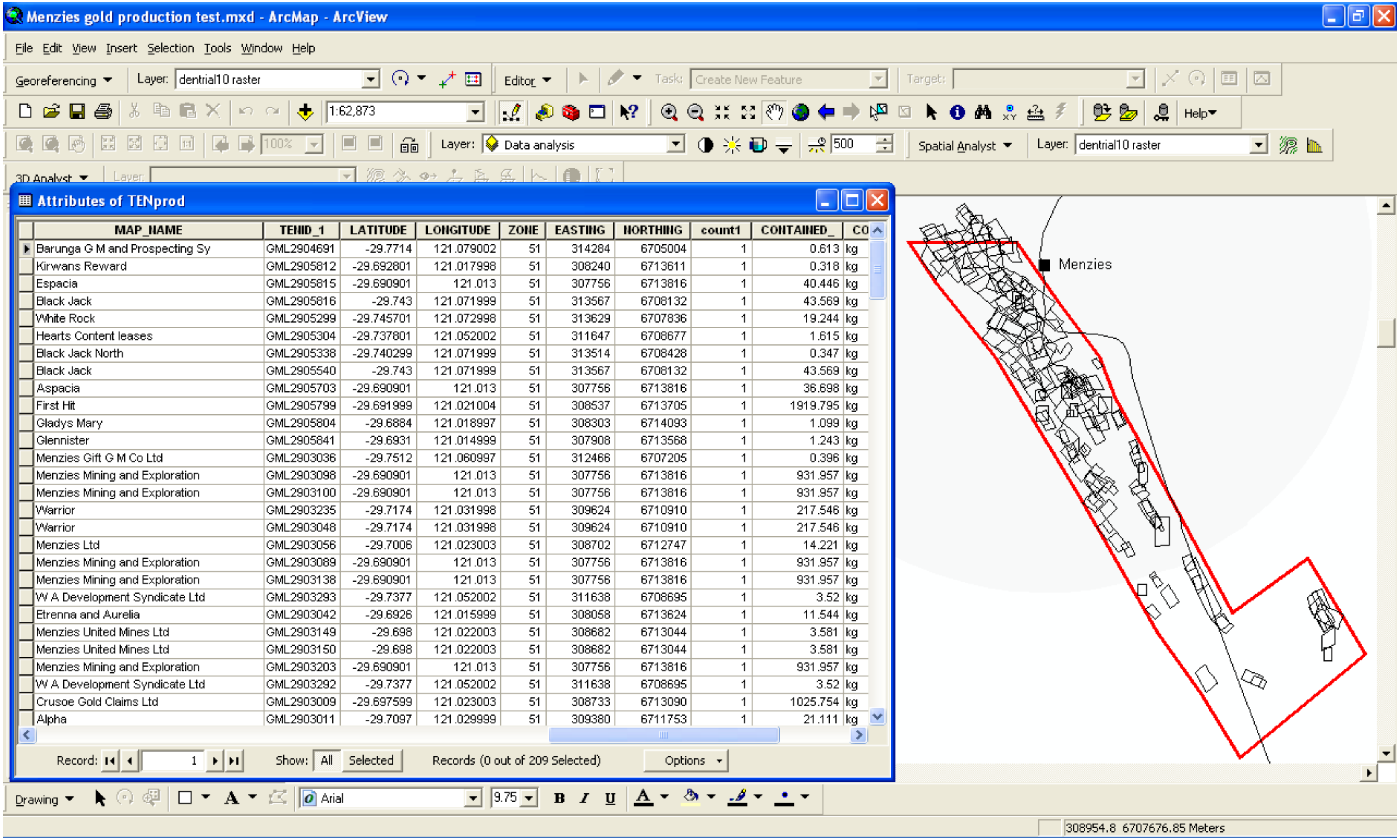
3.5 Preparing abandoned mine excavation data from the WABMINES database

To integrate the (bedrock) gold production GIS database layer from Section 3.4 with the abandoned mine site data related to bedrock-gold mineralization, carefully constructed queries to select the relevant records from the WABMINES database were required. The same primary WABMINES data processing procedure was applied to all the case-study areas in Chapter 5 to produce a bedrock-gold excavation table. The derived data processing calculated the specific mine-size related attributes (such as the mean depth and the density of bedrock-gold excavations) that were required for this study. All of this data processing was carried out using MS Access database software unless stated otherwise.

3.5.1 Primary processing of WABMINES data

A method to extract bedrock-gold excavations from the WABMINES database needed to be generated because:

1) the WABMINES database contains many features not directly related to workings such as remnants of buildings and rubbish dumps;
2) historical workings include linear features such as costeans and adits that are represented in WABMINES as a point at one end. This point is unlikely to coincide with gold mineralization;
3) some workings such as costeans were only exploratory in nature, and hence are unrelated to bedrock-gold production or mineralization;
4) historical workings included those based on surficial eluvial, colluvial, and alluvial gold accumulations;



MAP_NAME	TENID_1	LATITUDE	LONGITUDE	ZONE	EASTING	NORTHING	count1	CONTAINED_	CO
Barunga G M and Prospecting Sy	GML2904691	-29.7714	121.079002	51	314284	6705004	1	0.613	kg
Kirwans Reward	GML2905812	-29.692801	121.017998	51	308240	6713611	1	0.318	kg
Espacia	GML2905815	-29.690901	121.013	51	307756	6713816	1	40.446	kg
Black Jack	GML2905816	-29.743	121.071999	51	313567	6708132	1	43.569	kg
White Rock	GML2905299	-29.745701	121.072998	51	313629	6707836	1	19.244	kg
Hearts Content leases	GML2905304	-29.737801	121.052002	51	311647	6708677	1	1.615	kg
Black Jack North	GML2905338	-29.740299	121.071999	51	313514	6708428	1	0.347	kg
Black Jack	GML2905540	-29.743	121.071999	51	313567	6708132	1	43.569	kg
Aspacia	GML2905703	-29.690901	121.013	51	307756	6713816	1	36.698	kg
First Hit	GML2905799	-29.691999	121.021004	51	308537	6713705	1	1919.795	kg
Gladys Mary	GML2905804	-29.6884	121.018997	51	308303	6714093	1	1.099	kg
Glennister	GML2905841	-29.6931	121.014999	51	307908	6713568	1	1.243	kg
Menzies Gift G M Co Ltd	GML2903036	-29.7512	121.060997	51	312466	6707205	1	0.396	kg
Menzies Mining and Exploration	GML2903098	-29.690901	121.013	51	307756	6713816	1	931.957	kg
Menzies Mining and Exploration	GML2903100	-29.690901	121.013	51	307756	6713816	1	931.957	kg
Warrior	GML2903235	-29.7174	121.031998	51	309624	6710910	1	217.546	kg
Warrior	GML2903048	-29.7174	121.031998	51	309624	6710910	1	217.546	kg
Menzies Ltd	GML2903056	-29.7006	121.023003	51	308702	6712747	1	14.221	kg
Menzies Mining and Exploration	GML2903089	-29.690901	121.013	51	307756	6713816	1	931.957	kg
Menzies Mining and Exploration	GML2903138	-29.690901	121.013	51	307756	6713816	1	931.957	kg
W A Development Syndicate Ltd	GML2903293	-29.7377	121.052002	51	311638	6708695	1	3.52	kg
Etrenna and Aurelia	GML2903042	-29.6926	121.015999	51	308058	6713624	1	11.544	kg
Menzies United Mines Ltd	GML2903149	-29.698	121.022003	51	308682	6713044	1	3.581	kg
Menzies United Mines Ltd	GML2903150	-29.698	121.022003	51	308682	6713044	1	3.581	kg
Menzies Mining and Exploration	GML2903203	-29.690901	121.013	51	307756	6713816	1	931.957	kg
W A Development Syndicate Ltd	GML2903292	-29.7377	121.052002	51	311638	6708695	1	3.52	kg
Crusoe Gold Claims Ltd	GML2903009	-29.697599	121.023003	51	308733	6713090	1	1025.754	kg
Alpha	GML2903011	-29.7097	121.029999	51	309380	6711753	1	21.111	kg

Record: 1 Show: All Selected Records (0 out of 209 Selected) Options

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Figure 3.6 Screen capture showing the GIS database layer with overlapping Gold Mining Leases and part of the associated attribute table with bedrock-gold production data ('CONTAINED_') for each tenement ('TENID_1').

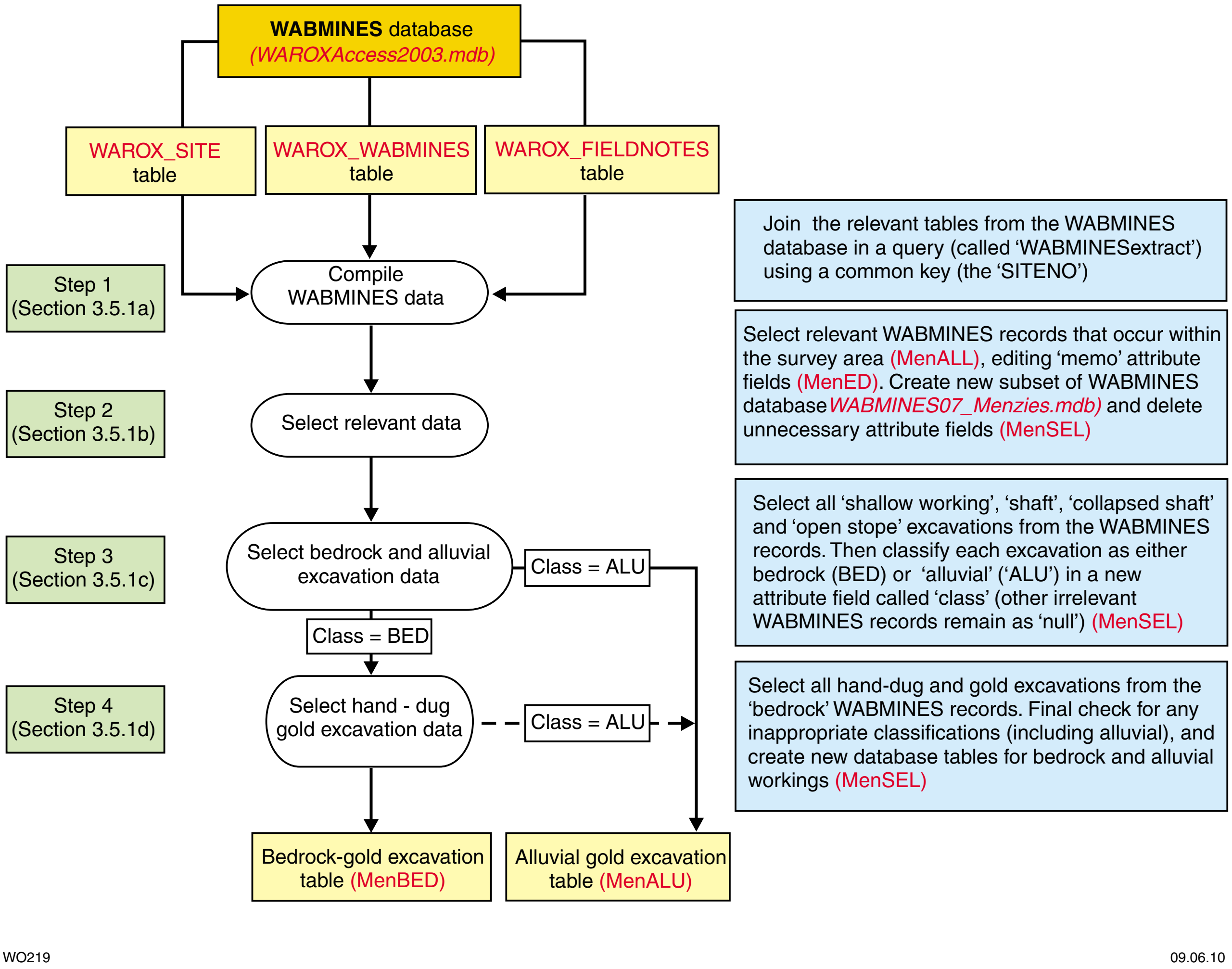


Figure 3.7 **Flow diagram showing the main steps in the primary processing of WABMINES data for the entire Menzies abandoned mine survey area to produce bedrock and alluvial gold excavation tables. File names used in this study are shown in red italics, and MS Access database table names are shown in red font.**

5) not all recorded excavations date from the era of historical gold production;
6) not all excavations were for gold.

The primary WABMINES data processing procedure is summarized in Figure 3.7, and is described in detail in Appendix 2. The selection of 'alluvial' gold excavations was a by-product of this process, but these data were not used in this study. The main steps are outlined below:

a) Compiling WABMINES data

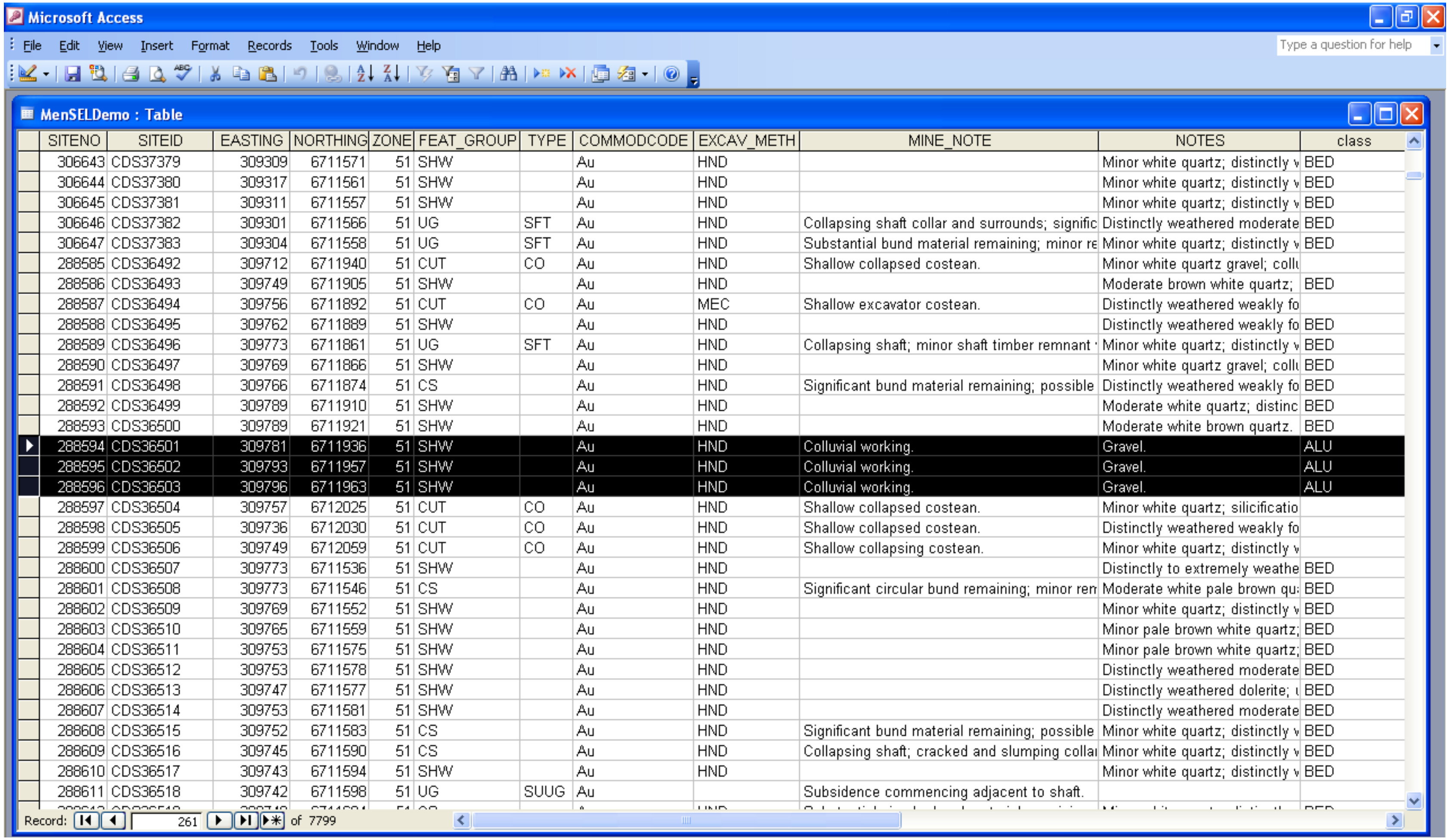
The WABMINES data used in this study were accessed via tables that were linked to the GSWA corporate Oracle database. A MS Access database query was made (in the WAROXAccess2003.mdb database) to access all WABMINES data except for photographs by joining the WAROX_SITE, WAROX_WABMINES, and WAROX_FIELDNOTES tables using a common key (the 'SITENO'). External users of WABMINES can obtain the same data from DVD already compiled into one table. The in-house data extract was chosen as it is in an abbreviated coded format, which facilitated data processing. All codes are listed in Appendix 1.

b) Selecting relevant WABMINES data

The initial selection of WABMINES records relevant to the survey area was made by constraining the MS Access query (called 'WABMINESextract') using longitude and latitude coordinates for the entire Menzies abandoned mine survey region. A new table was created (using a 'make table query') for this data extract, and was named 'MenALL'.

In MS Access database software, geological comments and other comments are stored in 'memo' format, which has no restriction on text length. Unfortunately, this format does not successfully convert to text that is readable in ESRI ArcGIS shapefiles. To enable the retention of most comments in shapefiles, another MS Access table (called 'MenED') was created with the 'memo' format changed to 'text', truncated at the maximum of 255 characters.

A new MS Access database was created specifically for the Menzies abandoned mine survey area called 'WABMINES07_Menzies', and the 'MenALL' and 'MenED' tables were imported into this new database.



SITENO	SITEID	EASTING	NORTHING	ZONE	FEAT_GROUP	TYPE	COMMODCODE	EXCAV_METH	MINE_NOTE	NOTES	class
306643	CDS37379	309309	6711571	51	SHW		Au	HND		Minor white quartz; distinctly v	BED
306644	CDS37380	309317	6711561	51	SHW		Au	HND		Minor white quartz; distinctly v	BED
306645	CDS37381	309311	6711557	51	SHW		Au	HND		Minor white quartz; distinctly v	BED
306646	CDS37382	309301	6711566	51	UG	SFT	Au	HND	Collapsing shaft collar and surrounds; signific	Distinctly weathered moderate	BED
306647	CDS37383	309304	6711558	51	UG	SFT	Au	HND	Substantial bund material remaining; minor re	Minor white quartz; distinctly v	BED
288585	CDS36492	309712	6711940	51	CUT	CO	Au	HND	Shallow collapsed costean.	Minor white quartz gravel; collu	
288586	CDS36493	309749	6711905	51	SHW		Au	HND		Moderate brown white quartz;	BED
288587	CDS36494	309756	6711892	51	CUT	CO	Au	MEC	Shallow excavator costean.	Distinctly weathered weakly fo	
288588	CDS36495	309762	6711889	51	SHW		Au	HND		Distinctly weathered weakly fo	BED
288589	CDS36496	309773	6711861	51	UG	SFT	Au	HND	Collapsing shaft; minor shaft timber remnant	Minor white quartz; distinctly v	BED
288590	CDS36497	309769	6711866	51	SHW		Au	HND		Minor white quartz gravel; collu	BED
288591	CDS36498	309766	6711874	51	CS		Au	HND	Significant bund material remaining; possible	Distinctly weathered weakly fo	BED
288592	CDS36499	309789	6711910	51	SHW		Au	HND		Moderate white quartz; distinc	BED
288593	CDS36500	309789	6711921	51	SHW		Au	HND		Moderate white brown quartz.	BED
288594	CDS36501	309781	6711936	51	SHW		Au	HND	Colluvial working.	Gravel.	ALU
288595	CDS36502	309793	6711957	51	SHW		Au	HND	Colluvial working.	Gravel.	ALU
288596	CDS36503	309796	6711963	51	SHW		Au	HND	Colluvial working.	Gravel.	ALU
288597	CDS36504	309757	6712025	51	CUT	CO	Au	HND	Shallow collapsed costean.	Minor white quartz; silicificatio	
288598	CDS36505	309736	6712030	51	CUT	CO	Au	HND	Shallow collapsed costean.	Distinctly weathered weakly fo	
288599	CDS36506	309749	6712059	51	CUT	CO	Au	HND	Shallow collapsing costean.	Minor white quartz; distinctly v	
288600	CDS36507	309773	6711536	51	SHW		Au	HND		Distinctly to extremely weathe	BED
288601	CDS36508	309773	6711546	51	CS		Au	HND	Significant circular bund remaining; minor rem	Moderate white pale brown qu	BED
288602	CDS36509	309769	6711552	51	SHW		Au	HND		Minor white quartz; distinctly v	BED
288603	CDS36510	309765	6711559	51	SHW		Au	HND		Minor pale brown white quartz;	BED
288604	CDS36511	309753	6711575	51	SHW		Au	HND		Minor pale brown white quartz;	BED
288605	CDS36512	309753	6711578	51	SHW		Au	HND		Distinctly weathered moderate	BED
288606	CDS36513	309747	6711577	51	SHW		Au	HND		Distinctly weathered dolerite;	BED
288607	CDS36514	309753	6711581	51	SHW		Au	HND		Distinctly weathered moderate	BED
288608	CDS36515	309752	6711583	51	CS		Au	HND	Significant bund material remaining; possible	Minor white quartz; distinctly v	BED
288609	CDS36516	309745	6711590	51	CS		Au	HND	Collapsing shaft; cracked and slumping colla	Minor white quartz; distinctly v	BED
288610	CDS36517	309743	6711594	51	SHW		Au	HND		Minor white quartz; distinctly v	BED
288611	CDS36518	309742	6711598	51	UG	SUUG	Au		Subsidence commencing adjacent to shaft.		

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Figure 3.8 Screen capture showing an example of selected attribute fields from the WABMINES database table. Highlighted records were classified as 'alluvial' ('class' = 'ALU') by the 'colluvial working' comments in the 'MINE_NOTE' attribute field. Note also that all costean records ('TYPE' = 'CO') will be excluded from either the bedrock or alluvial excavation tables by leaving a 'null' in the 'class' attribute field.

Unnecessary attribute fields such as 'VISIBILITY' were then deleted from the 'MenED' table in this new database, and a resultant table for Menzies abandoned mine site data called 'MenSEL', as generated.

*c) **Selecting WABMINES bedrock and alluvial excavation data***

The single WABMINES database table ('MenSEL') contains only relevant attribute fields from the Menzies abandoned mines survey area, but does include numerous abandoned mine sites records that are not directly related to gold mineralization, such as waste-rock dumps, rubbish dumps, and building remnants. Some excavations such as adits and costeans, whilst represented in WABMINES as a point at one end, are actually linear features, and their locations may bear no direct relation to gold mineralization. For these reasons, only the following WABMINES records were selected:

1) all shafts and open stopes (irrespective of 'FEATURE GROUP' classification of 'underground', 'rehabilitated', or 'under infrastructure');
2) all collapsed shafts;
3) all shallow workings (defined as less than 2 m deep).

New attribute fields called 'class' and 'count1' were created. The 'class' field was used to classify the abandoned mine features as either bedrock, or alluvial excavations, or 'null' indicating irrelevant record types such as waste dumps or buildings. All selected excavations were initially classified as 'BED' for bedrock in the 'class' field. The 'count1' field was populated with the value '1' so that it could be used later in Section 3.5.2d for calculating the density of excavations.

It was not always possible to identify the origin of a backfilled or rehabilitated abandoned mine feature in the field. These undifferentiated features could have originated as anything from an irrelevant recent exploration costean or drilling site, to items of interest such as shafts or open stopes. Therefore, the 'rehabilitated' and 'under infrastructure' feature groups were selected (from 'FEATURE_GROUP' attribute field), and their comments attribute fields ('MINE_NOTE' and 'NOTES') were checked to ensure that, with hindsight, no obvious shafts or open stopes were missed. Rehabilitated features with excessive length or very general comments not indicating the backfilling of an individual gold excavation were not selected.

'Alluvial' excavations were then identified from the comments fields by searching for 'alluvial', 'colluvial', or 'eluvial', or any other comments such as 'dry blowings' or 'calcrete workings' indicative of surficial origin. These were reclassified as alluvial using 'ALU' in the 'class' attribute field (Fig. 3.8). All 'alluvial' excavations in the WABMINES database were assumed to have been for gold.

*d) **Selecting WABMINES hand-dug gold excavation data***

Wherever possible, excavations are identified in the WABMINES database as being mechanically excavated if they have been obviously excavated by machinery, such as bulldozer- and excavator-dug pits. Clearly, these are of more recent origin than the vast majority of hand-dug workings sought in this study. Consequently, all bedrock shallow workings which were identified as being mechanically excavated were deselected (i.e. the 'class' attribute field was changed from 'BED' to 'null'), as were any other excavations with comments suggesting a more-recent origin such as 'borrow pit' or 'drill sump'.

As another check for records related to recent mining activities, the dimensions of all bedrock excavations were checked for excessive length to width ratios (possible costean), and for excessive length (possible sand or gravel pit, or alluvial working) and were reclassified accordingly.

Background information or field observations commonly enabled the commodity sought by prospectors to be identified in the 'COMODCODE' attribute field in the WABMINES database. Not all gold excavations were labelled as 'Au' in the 'COMODCODE' attribute field (especially in pre-2005 WABMINES data), but the absence of another commodity (i.e. a 'null') in this field can be assumed to represent gold. Consequently, all bedrock excavations not labelled as 'Au' or 'null' were deselected (i.e. the 'class' attribute field was changed from 'BED' to 'null'). A final check of the comments fields was made to ensure that no other commodities or inappropriate features (such as water shafts) were selected. A new database table was created for both the bedrock ('MenBED') and alluvial ('MenALU') gold excavations based upon the classification in the 'class' attribute field.

3.5.2 Processing of derived WABMINES data

Further processing of the bedrock-gold excavation table from the WABMINES database was required to derive the mine-size related attributes required for the data analysis in Chapter 4 as shown in Figure 3.9.

The following attributes of the size and extent of gold excavations were tested (Chapter 4) to determine if gold production correlates with:

1) excavation depth;
2) excavation volume (depth × length × width);
3) mean excavation bund height (height of pile of waste rock surrounding an excavation);
4) excavation density (number of gold excavations/unit area).

The relevant data were selected, and then the depth, volume, and bund height attributes were calculated for each bedrock-gold excavation in the following Sections a), b), and c). These steps were carried out using MS Access database software unless otherwise stated. The density of bedrock-gold excavations were then calculated (Section 3.5.2d), using the Spatial Analyst extension within ESRI ArcGIS software.

*a) **Selecting relevant WABMINES data***

The bedrock-gold excavation data in the 'MenBED'

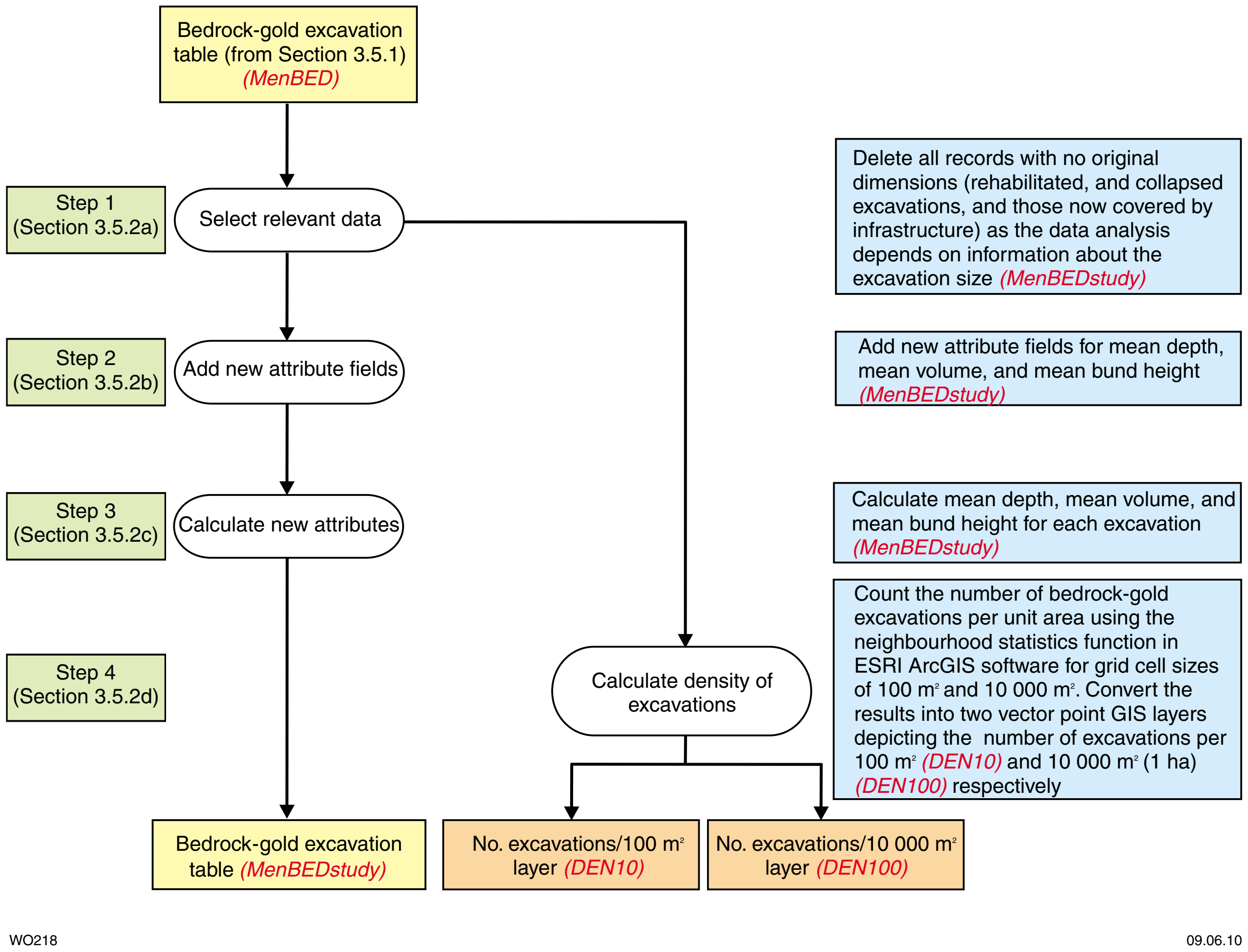

Figure 3.9 **Flow diagram showing the main steps in the processing of derived WABMINES data to produce a bedrock excavation table and two GIS layers depicting the density of excavations for differing land areas (100 m^2 and 10 000 m^2) suitable for the data analysis in Chapter 4. MS Access database table names are shown in normal red font and file names are shown in red italics.**

table covered the entire Menzies abandoned mines survey area. However, the study area is only a subset of the Menzies area. In order to select just those records relevant to the study area, the 'MenBED' table was imported into ESRI ArcGIS software and a spatial selection was applied to just those abandoned mine site features within the study area (to form a new table called 'MenBEDstudy'). The data were then imported back into MS Access database software for further processing.

As the original dimensions of most collapsed, or rehabilitated excavations, or those now covered by infrastructure are unknown, the corresponding records were deleted. The reason for deleting them is that the data analysis depends on information about the size of the excavations. All remaining records relating to shallow workings, 'underground' shafts, and open stopes were retained for analysis.

b) *Adding new WABMINES attribute fields*

The following three new attribute fields were created for the derived (or calculated) data that were required for the data analysis:

1) mean excavation depth — 'depth_m';
2) mean excavation volume — 'volume_m';
3) mean excavation bund height — 'bund_m'.

c) *Calculating new WABMINES attributes*

Depth for abandoned mine sites (WABMINES) features is recorded in the form of depth classes such as 'Deep' for 5 to 10 m. For quantitative analysis, the mean depth for each depth class was calculated, and this value was allocated to the 'depth_m' attribute field. It should be noted that most dimensions in the WABMINES database are field estimates. For practical purposes, the greatest depth category (extremely deep) is given to any working over 20 m deep. A nominal mean depth of 25 m was given to all of these workings.

The mean volume ('volume_m') field was populated with the volumes for each excavation calculated from the surface dimensions of the excavation and the mean depth. Finally, the mean bund heights were calculated from the 'BUND_MAX' and 'BUND_MIN' attribute fields, and stored in the 'bund_m' field.

*d) **Calculating the density of abandoned mine excavations***

To measure the density of abandoned mine excavations, the number of records detailing bedrock-gold excavations were counted per unit area. This was done by counting all the bedrock-gold records (using the ‘count1’ attribute field populated with ‘1’) using the neighbourhood statistics function of the ESRI ArcGIS software. Counting was performed for both 10 m and 100 m grid cell sizes, using a rectangular search area or ‘neighbourhood’ with the same dimensions as the grid cell size. The result was a pair of derived GIS layers depicting density of abandoned mine excavations in units of number of excavations per 100 m^2 and 10 000 m^2 (or 1 hectare), respectively. The two cell sizes used in the calculations were chosen to correspond to the approximate accuracy of the WABMINES input data (smaller size) and the same order of magnitude as the Gold Mining Lease input data (larger area). The two very different cell sizes were chosen to examine whether choice of area had an influence upon the results. The resultant GIS raster layers depicting density of gold excavations were converted to vector point layers, with a point located in the centre of each raster cell. It is necessary to have the layer in vector format so that it can be spatially joined to the Gold Mining Lease total gold production layer.

3.6 Joining spatial gold production data with abandoned mine excavation data

The result of processing the MINEDEX (Section 3.3) and dead tenement databases was a GIS layer depicting total gold production for Gold Mining Leases (Section 3.4). The database table associated with this layer was then spatially joined using ESRI ArcGIS software to the following three database tables obtained from processing the WABMINES database (Fig. 3.10):

1) The table with mine-size related attributes (mean depth, mean volume, and mean bund height) for abandoned bedrock-gold excavations in the study area (called ‘MenBEDstudy’);
2) the table associated with a GIS database layer depicting the number of bedrock-gold excavations per 100 m^2 land area (called ‘DEN10’);
3) the table associated with a GIS database layer depicting the number of bedrock-gold excavations per 10 000 m^2 land area (called ‘DEN100’).

The result of joining the first table (‘MenBEDstudy’) was a GIS layer and table that listed total gold production and measurements about the size of each abandoned bedrock-gold excavation (called ‘MenBEDstudyProd’). Joining the second and third tables (for the layers ‘DEN10’ and DEN100’) resulted in two further GIS layers and tables that listed total gold production for the centre of each grid cell (with areas of 100 m^2 and 10 000 m^2 respectively) against the number of abandoned bedrock-gold excavations per cell.

3.7 Totalling gold production for abandoned mine excavation data

Finally, statistics of total gold production for each class of measurement obtained in Section 3.6 were required

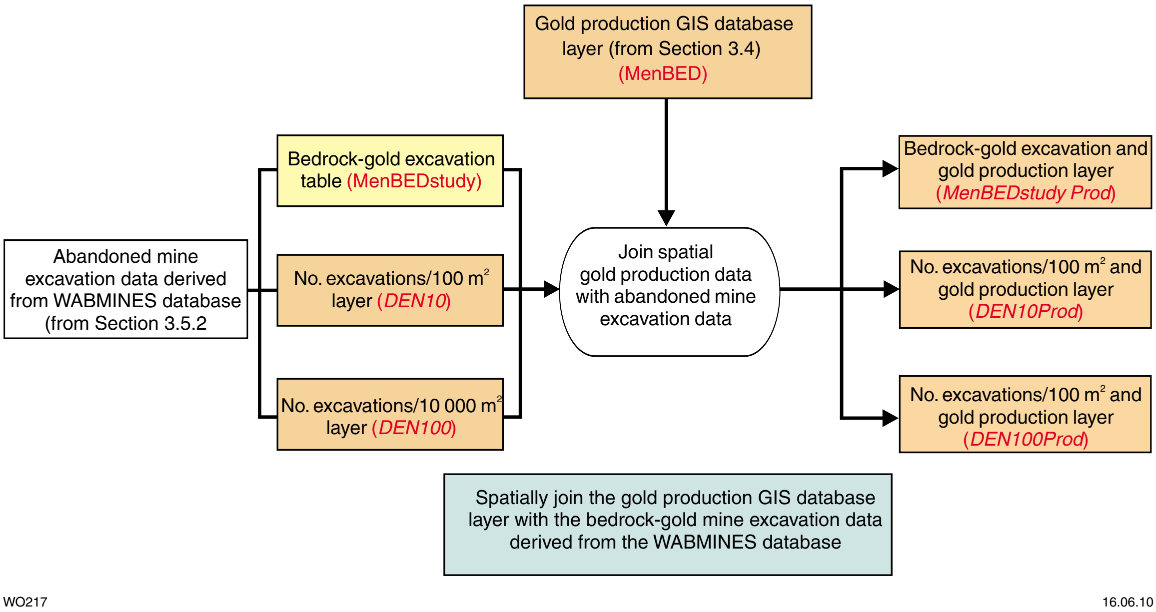

Figure 3.10 Flow diagram showing the process of spatially joining the abandoned mine excavation data derived from the WABMINES database with the gold production GIS database layer to produce three new layers and associated database tables in ESRI ArcGIS software that combine information from both sources. MS Access database table names are shown in normal red font and ArcGIS file names are shown in red italics.

for the data analysis in Chapter 4. Each of the five mine-size related attributes (mean depth, volume, bund height, number of excavations/100 m^2, and number of excavations/10 000 m^2) were summarized by total gold production using ESRI ArcGIS software. The result was a table for each measure showing the summated or observed value of gold production for each unique measurement value. These tables were exported from ESRI ArcGIS software in DBF format so they could be analysed using Microsoft (MS) Excel software.

Chapter 4

Testing the correlation between the size of abandoned mine excavations and total gold production

4.1 Introduction

This chapter describes the analysis of the data prepared in Chapter 3 to determine if there is a correlation between mine size determined from abandoned mine excavations and total gold production.

The following attributes of the size and extent of gold excavations were used in this study:

1) density of gold excavations (number of gold excavations/unit area);
2) excavation bund height (height of pile of waste rock surrounding an excavation);
3) excavation depth;
4) excavation volume.

A MS Excel spreadsheet with gold production statistics for each of the above attributes was constructed. Where necessary, the attribute values were grouped into classes (e.g. 3–5 excavations per grid cell) to provide a statistically meaningful sample size. Scatter plots with linear trend lines and calculated R-squared value were constructed using MS Excel software to test correlation between the measures of excavation size and gold production. The R-squared value is a measure of correlation between the independent variable (measure of excavation size) and dependent variable (gold production). A correlation is strongest and therefore the trend line is most reliable when the R-squared value is at or near 1. Where class intervals were used, the mean of the interval was calculated to facilitate accurate graphing and calculation of the R-squared value.

The gold production GIS database layer created in Chapter 3 (Section 3.4) is shown in Figure 4.1. A comparison between Figure 4.1 and a plot for each mine-size related attribute with colour-coded attribute values

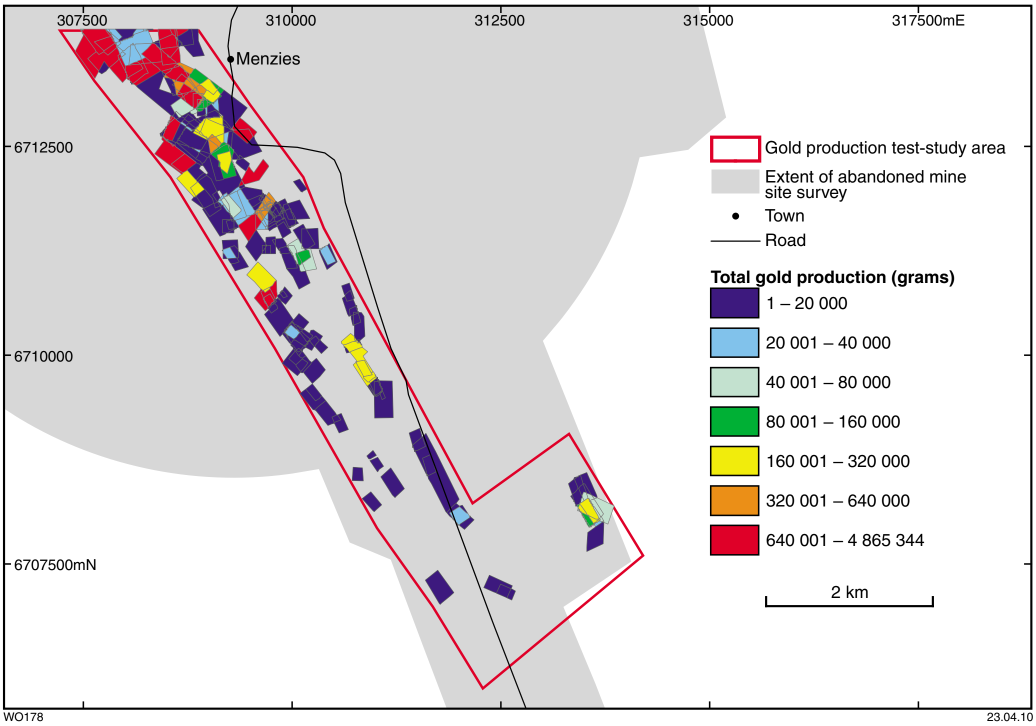

Figure 4.1 **Total gold production in the Menzies study area. This is the gold production GIS database layer derived in Chapter 3 (Section 3.4).**

provided a further check for spatial correlation between the attribute and total gold production.

4.2 Results and data analysis

4.2.1 Density of gold excavations

Before the advent of widespread mechanization, mining was very labour intensive. At least initially, vertical ore-haulage by windlass and kibble was most common. Well-preserved sites of intense early mining activity such as those at Menzies typically show many dozens of comparatively shallow vertical or steeply dipping excavations into weathered host rock along an orebody. Therefore, there may be a correlation between the density of gold excavations in these areas and total gold production.

To test this concept, the density of gold excavations was examined at two different scales, which, as discussed in Chapter 3 (Section 3.5.2), approximate the spatial accuracy of the excavation data and gold production data:

1) number of excavations per 100 m^2;

2) number of excavations per 10 000 m^2 (hectare).

Tables 4.1 and 4.2 give the results of data generated in Chapter 3 (Section 3.7) that summarize the total gold production for differing numbers of gold excavations for both 100 m^2 and 10 000 m^2 grid cell-sizes. In Table 4.2, the mean of the number of excavations per cell was calculated to facilitate accurate graphing and calculation of the R-squared value.

Figures 4.2 and 4.3 display these data as scatter plots that show the relationship between total gold production and the mean number of gold excavations per cell for 100 m^2 and 10 000 m^2 cell sizes, respectively.

Clearly, there is a good inverse correlation between the number of gold excavations per 100 m^2 grid cell and total gold production (Table 4.1 and Fig. 4.2). Note that there are only three cells in the highest class of four excavations per cell, therefore the result in this class is unreliable. The larger cell size of 10 000 m^2 (one hectare) produced more meaningful results due to the larger sample size in each class (Table 4.2 and Fig. 4.3), with some positive correlation between the number of excavations per cell

Table 4.1 **Gold production data for grid cell-size of 100 m^2 in the Menzies study area**

No. of excavations per cell	*No. of cells*	*Total gold production (g)*	*Total gold production per cell (kg)*
1	1 777	252 150 412	141.897
2	201	26 119 406	129.947
3	19	1 123 695	59.142
4	3	49 019	16.340
Total	**2 000**	**279 442 532**	

Table 4.2 **Gold production data for grid cell-size of 10 000 m^2 in the Menzies study area**

No. of excavations per cell	*Mean no. of excavations per cell*	*No. of cells*	*Total gold production (g)*	*Total gold production per cell (kg)*
1–2	1.5	215	27 246 958	126.730
3–5	4	128	11 200 560	87.504
6–8	7	56	6 105 865	109.033
9–13	11	36	5 010 091	139.169
14–30	20	39	6 055 847	155.278
Total		**474**	**55 619 321**	

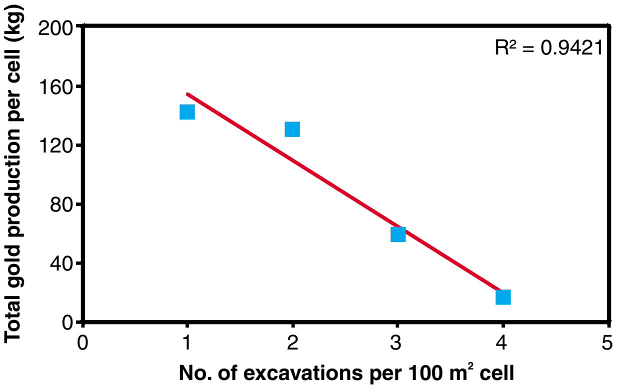

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Figure 4.2 **Total gold production per 100 m^2 grid cell versus the number of gold excavations per 100 m^2 grid cell in the Menzies study area.**

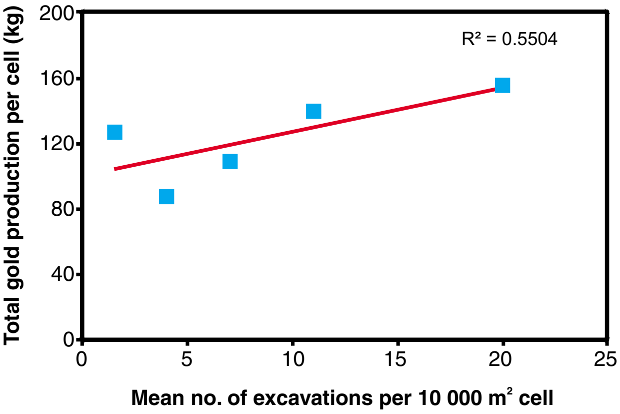

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Figure 4.3 **Total gold production per 10 000 m^2 grid cell versus the mean number of gold excavations per 10 000 m^2 grid cell in the Menzies study area.**

and total gold production indicated by the gradually rising linear trend line and moderate R-squared value.

The number of gold excavations for the 100 m^2 and 10 000 m^2 cell sizes are also shown in Figures 4.4 and 4.5 respectively. When compared to the total gold production in Figure 4.1, there also is a slight correlation between gold excavation density per hectare and total gold production (Fig. 4.5). However, the apparent inverse relationship between gold production and excavation density for the 100 m^2 cell size is less evident when plotted spatially (Fig. 4.4).

4.2.2 Bund height of gold excavations

Bund is the term given to the pile of waste material that surrounds most excavations. As a general rule, the more waste rock removed from an excavation, the larger the excavation. During excavation, a pile of waste rock was normally built-up around the collar of a shaft to minimize labour in removing it. The shaft collar was commonly shored up with timber, and extended upwards as the pile of waste rock grew higher. Consequently, bund height may be expected to be an indirect measure of excavation volume, shaft depth, and possibly gold production. Bund height may also have an advantage over shaft depth because it is less likely to be modified by shaft collapse. In addition, the bund height could also reflect the extent of horizontal workings (such as drives and crosscuts) emanating from the shaft. Note that (as discussed in Chapter 3, Section 3.5.2) bund height is actually a mean value calculated from the minimum and maximum bund heights recorded for each excavation.

Table 4.3 shows the results of data generated in Chapter 3 (Section 3.7) that summarize the total gold production for excavations grouped into classes of bund height. Figure 4.6 is a scatter plot that shows the relationship between total gold production and the mean bund height of gold excavations. Both Table 4.4 and Figure 4.6 illustrate that although overall there is no correlation between mean excavation bund height and gold production, there is a moderately positive correlation for bund heights of up to 0.95 m. When compared with Figure 4.1, Figure 4.7 shows that there is a weak correlation between mean gold excavation bund height and total gold production.

4.2.3 Depth of gold excavations

One of the most obvious measures of mine size is the depth of the excavation. Most of the gold orebodies mined by early prospectors in the Eastern Goldfields were steeply dipping, as evidenced by the steep to vertical dips of most of the abandoned shafts and open stopes. Many early excavations followed the dip of the mineralized vein or structure. Furthermore, the cost and effort involved in excavating a shaft beyond that required for prospecting purposes was in most cases only expended if some gold was being produced. Therefore, the depth of the working could be expected to show a relationship to gold production.

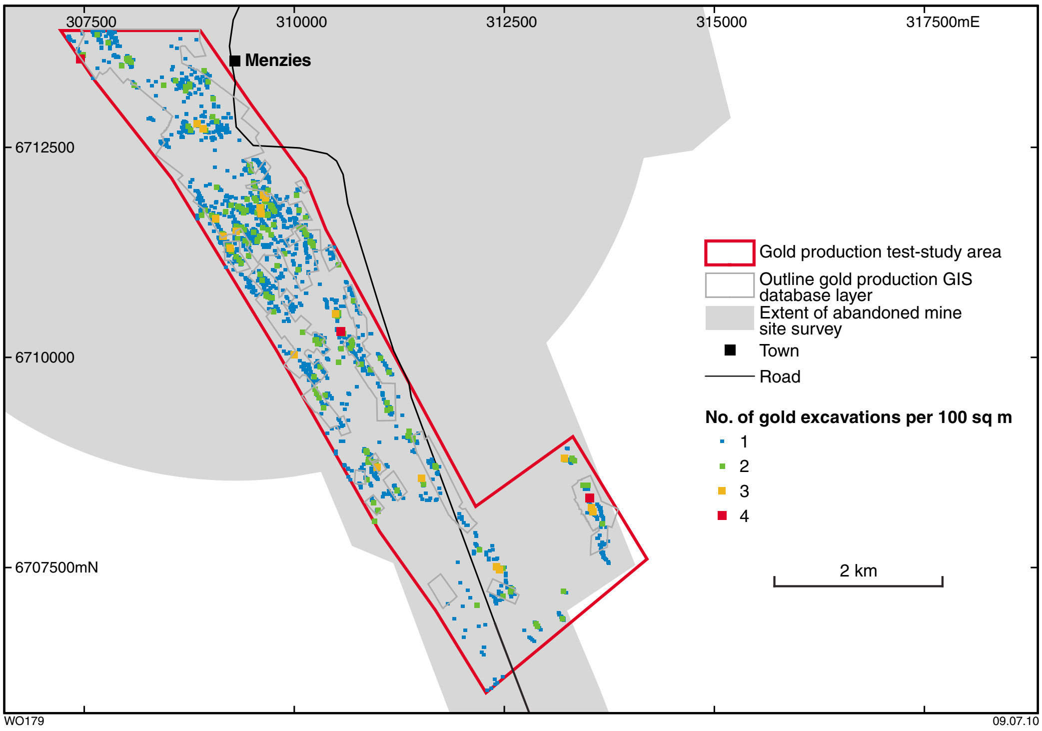


Figure 4.4 Density of abandoned gold excavations for a 100 m^2 grid cell size (no. of excavations per 100 m^2) in the Menzies study area. Displayed as point data (rather than 10 × 10 m grid cells) for clarity. Comparison with Figure 4.1 does not clearly show an inverse relationship with gold production.

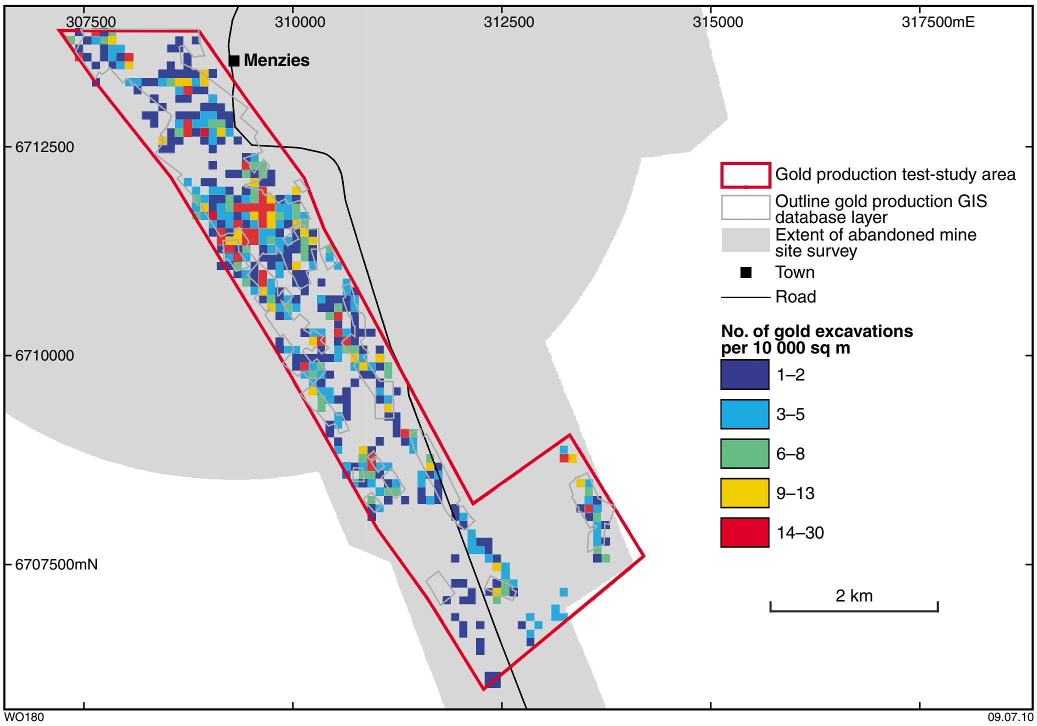


Figure 4.5 **Density of abandoned gold excavations for a 10 000 m² grid cell size (no. of excavations per 10 000 m²) in the Menzies study area. Displayed as 100 × 100 m grid cells. Comparison with Figure 4.1 does show a slight correlation with gold production.**

Table 4.3 Gold production data for differing excavation bund heights in the Menzies study area

Bund height interval (m)	*Mean bund height (m)*	*No. of excavations*	*Total gold production (g)*	*Total gold production per excavation (kg)*
0.00–0.24	0.1	1 558	202 451 995	129.944
0.25–0.49	0.35	191	28 742 525	150.484
0.50–0.99	0.73	283	45 542 928	160.929
1.00–1.99	1.48	179	23 572 688	131.691
2.00–3.25	2.48	37	4 691 072	126.786
Total		**2 248**	**305 001 208**	

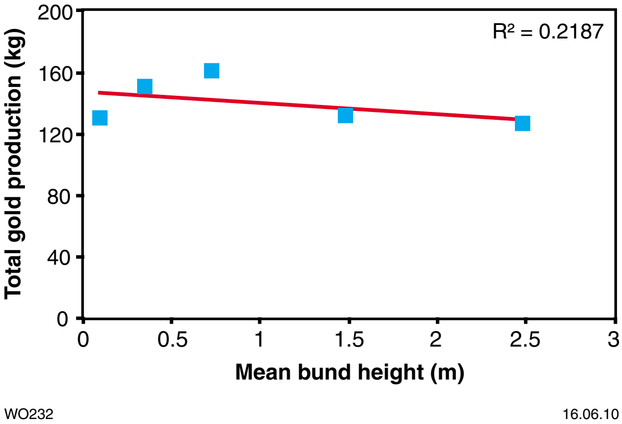


Figure 4.6 **Total gold production versus the mean bund height of gold excavations in the Menzies study area.**

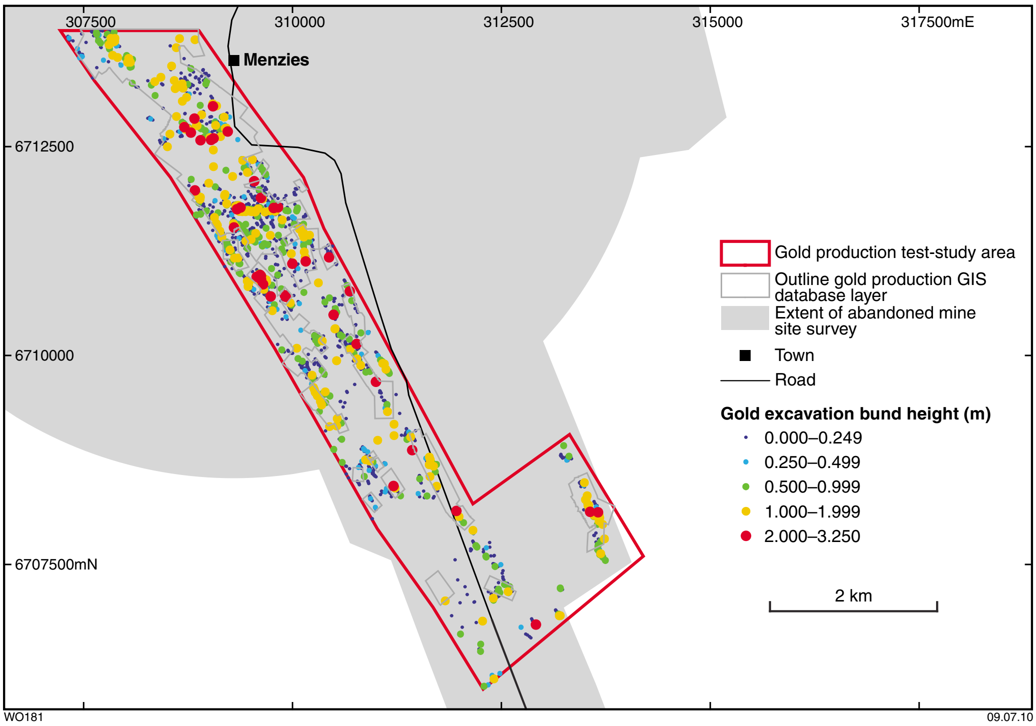


Figure 4.7 Mean bund height of abandoned gold excavations in the Menzies study area. Comparison with Figure 4.1 shows a weak correlation with gold production.

Table 4.4 Gold production data for differing excavation depths in the Menzies study area

Depth interval (m)	*Mean depth (m)*	*No. of excavations*	*Total gold production (g)*	*Total gold production per excavation (kg)*
0.0–0.49	0.25	1 177	150 593 999	127.947
0.5–0.99	0.75	298	35 024 935	117.533
1.0–1.99	1.50	101	13 142 281	130.122
2.0–4.99	3.50	365	45 447 812	124.515
5.00–9.99	7.50	206	41 516 892	201.538
10.00–19.99	15.00	80	11 096 585	138.707
>=20	25.00	21	8 178 704	389.462
Total		**2 248**	**305 001 208**	

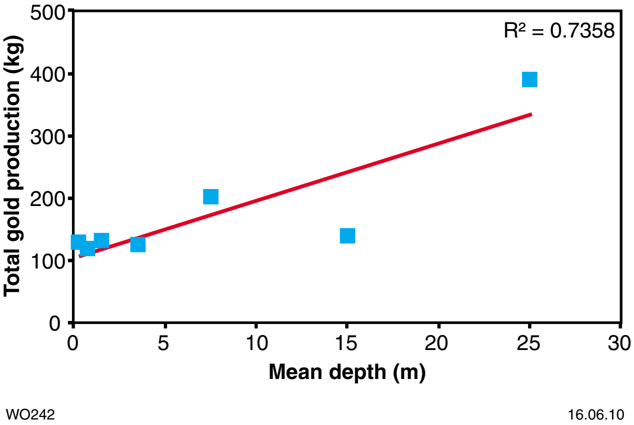


Figure 4.8 Total gold production versus the mean depth of gold excavations in the Menzies study area.

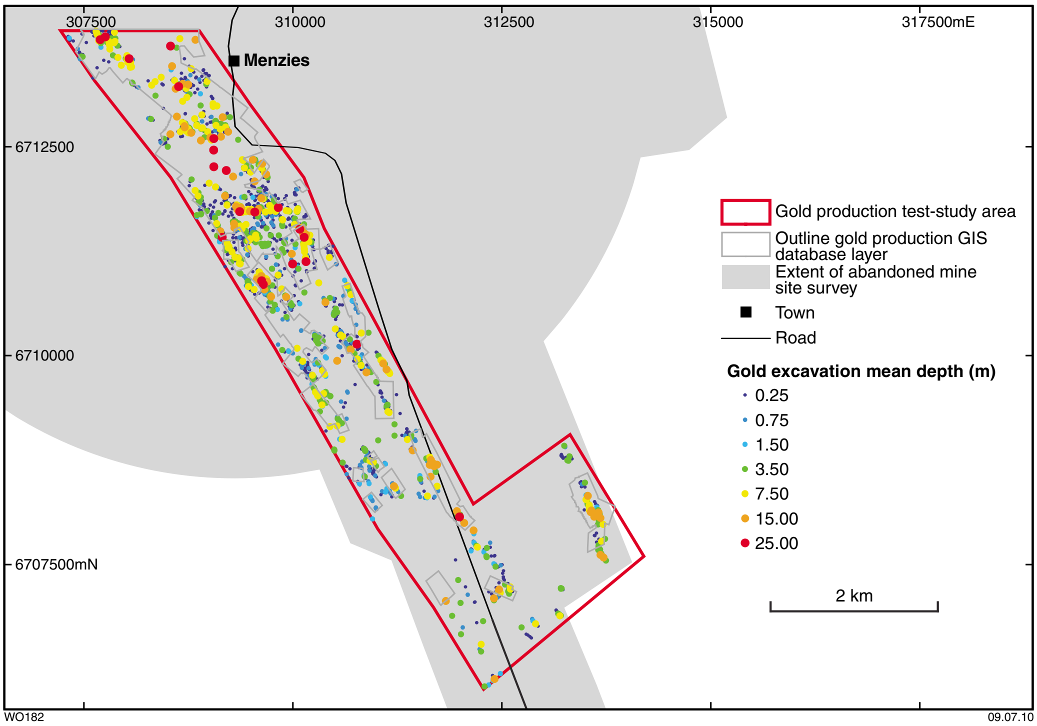


Figure 4.9 Mean depth of abandoned gold excavations in the Menzies study area. Comparison with Figure 4.1 shows that the deeper excavations are more common in the northern part of the study area where gold production was higher.

Table 4.5 Gold production data for differing excavation volumes in the Menzies study area

Volume interval *(m³)*	*Mean volume* *(m³)*	*No. of excavations*	*Total gold production (g)*	*Total gold production per excavation (kg)*
0.00 – 1.49	0.55	1 365	171 635 733	125.740
1.50 – 2.99	2.16	227	29 561 665	130.228
3.00 – 5.99	4.40	240	30 816 955	128.404
6.00 – 12.49	9.20	182	26 257 912	144.274
12.50 – 24.99	17.30	132	17 393 210	131.767
25.00 – 49.99	35.90	67	18 221 918	271.969
50.00 – 480.00	115.64	35	11 113 815	317.538
Total		**2 248**	**305 001 208**	

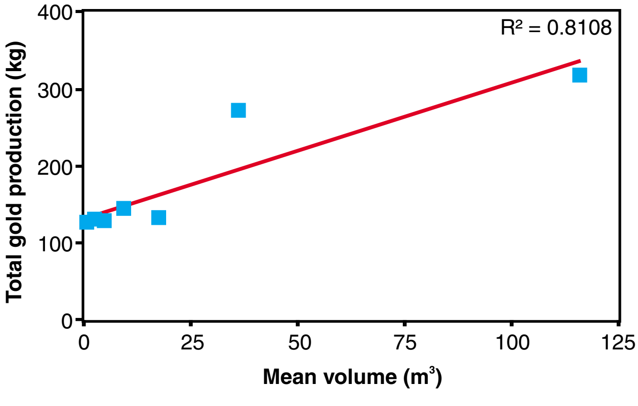


Figure 4.10 Total gold production versus the mean volume of gold excavations in the Menzies study area.

Table 4.4 gives the results of data generated in Chapter 3 (Section 3.7) summarizing the total gold production for excavations grouped into depth classes. Figure 4.8 is a scatter plot of data from Table 4.4 that shows the relationship between total gold production and the mean depth of gold excavations. Both Table 4.4 and Figure 4.8 illustrate a positive correlation between mean excavation depth and gold production. When compared with Figure 4.1, Figure 4.9 shows that the deeper excavations are more common in the northern part of the study area where gold production was higher.

4.2.4 Volume of gold excavations

Excavation volume can be expected to show a similar correlation to total gold production as mean excavation depth because most excavations have similar dimensions at the surface.

Apparent surface dimensions can be affected by the collapse of the collar of shafts, which may occur in highly weathered rock after the supporting timbers have deteriorated. The largest shafts had two or three compartments for the independent transport of miners and rock haulage. Consequently, the surface dimensions of these could be expected to be two to three times greater on average than the most common shafts. Open stopes are the surface expression of a mined ore cavity, and have potentially the largest surface area, although backfilling or partial collapse can reduce their depth. On balance, these factors could be expected to result in a stronger correlation between mean excavation volume and total gold production compared to mean depth.

Table 4.5 shows the results of data generated in Chapter 3 (Section 3.7) that summarize the total gold production for excavations grouped into excavation volume classes.

Figure 4.10 is a scatter plot that shows the relationship between total gold production and the mean volume of gold excavations. Both Table 4.5 and Figure 4.10 illustrate a positive correlation between mean excavation volume and gold production.

Gold excavation volume also shows a spatial correlation (Fig. 4.11) with total gold production (Fig. 4.1). Most notably, the excavations with the highest volumes are more common in the northern part of the study area where gold production was higher.

The comparatively high positive correlation between mean excavation volume and gold production is highly dependent upon the results for those excavations with volumes greater than 25 m^3 (Fig. 4.10). To gain an insight into the main contributing factors for these higher excavation volumes, mean dimensions for volumes of less than, and greater than 25 m^3 were calculated (Table 4.6). Mean length and width were about two times larger, and depth was over five times larger for excavations with volumes greater than 25 m^3 compared to those with smaller volumes.

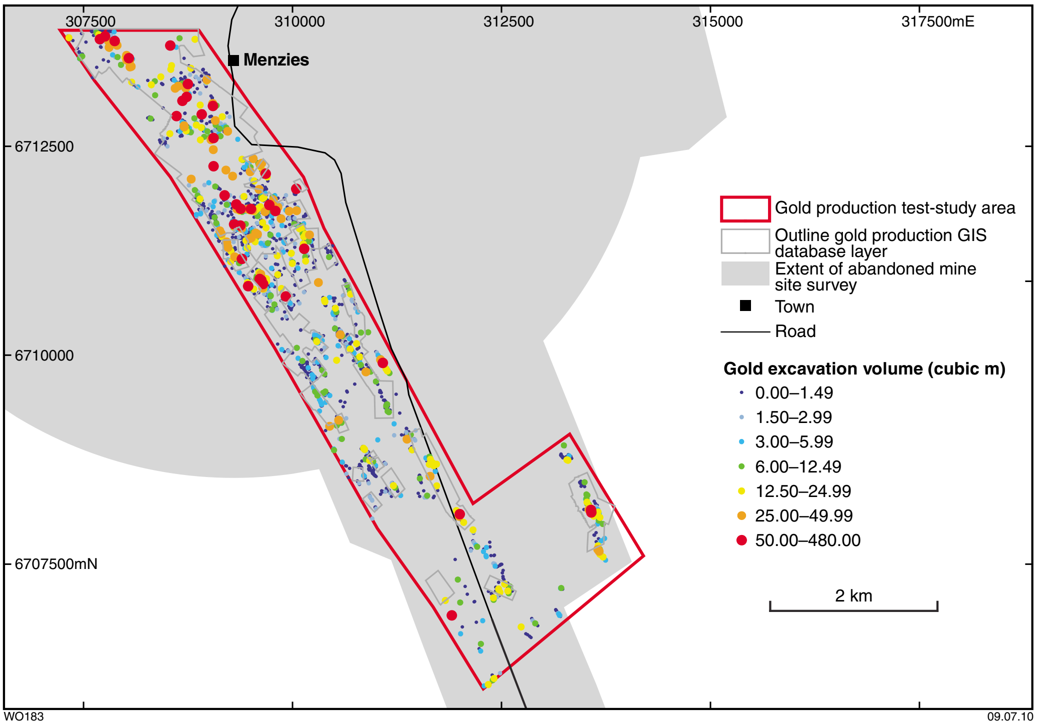


Figure 4.11 Mean volume of abandoned gold excavations in the Menzies study area. Comparison with Figure 4.1 shows that the excavations with larger volumes are concentrated in the northern part of the study area where gold production was higher.

Table 4.6 Comparison of the mean dimensions of two classes of gold excavation size based upon volume of the excavations

Volume class (m^3)	*No. of excavations*	*Mean depth (m)*	*Mean length (m)*	*Mean width (m)*
<25	2 146	1.95	1.7	1.0
>25	102	10.06	3.5	2.1

4.3 Comparison with qualitative gold production indicators

Apart from the density, bund height, depth, and volume of gold excavations, a number of other more subjective characteristics were recorded in WABMINES that are postulated to be measures of past gold production. These are in order of significance:

1) open stopes;
2) shafts with multiple compartments;
3) shafts with visible underground development away from the shaft;
4) shafts noted as being ‘major’ or ‘main’;
5) shafts with comments of having a substantial or significant bund.

Open stopes are direct indicators of past ore production because they are by definition the cavities remaining after the removal of ore.

Another good indicator that gold was actually extracted is the existence of two- or three-shaft compartments. These were created specifically to assist in the rapid removal of material from a deep shaft, including ore and waste. For this reason, it is most likely that all major ore-producing shafts did have multiple compartments. However, not all are preserved and observable.

Observable underground development (for example, stopes resulting from the removal of ore) is also postulated to be a good indicator of past gold production. Other underground developments that can be observed from the surface are near-horizontal drives following the mineralization, possibly leading to a stope, or, less commonly, development or exploration crosscuts.

A number of excavations were labelled as ‘main’ or ‘major’ shafts based upon annotations on historical maps, or the observation of a number of characteristics such as multiple compartments, extreme hole depth, the former presence of a large headframe and winder, the presence of a large waste dump, or tramway. These are all the types of characteristics that would be expected for a shaft associated with significant gold production.

Finally, shafts for which the WABMINES database entry includes references to a ‘substantial’ or ‘significant’ bund are also likely to have produced significant gold. Such comments indirectly indicate that a gold excavation has had a significant volume of waste material removed, implying that excavation costs were covered by ore production. These comments are additional to the measurement of bund height, and commonly mean that the bund material also covers a large area.

Apart from ‘open stope’, which is recorded in the WABMINES database under the attribute field of ‘TYPE’, all other comments were obtained from the ‘MINE_NOTE’ attribute field, and were tallied in the order of precedence listed above (Table 4.7). So, for example, if a ‘MINE_NOTE’ comment stated ‘major shaft with two compartments’, the ‘multiple compartment’ observation was the only one registered for that excavation. This method prevented multiple tallies for the same excavation, which would distort the total number of excavations for each class of gold excavation size. Totals for these interpreted production-related indicators are presented in Table 4.7 for various sizes of gold excavations for comparison purposes, and to assist with the interpretation of the quantitative data.

4.4 Discussion

Depth and volume of gold excavations both show a positive correlation with total gold production (Figs 4.8

Table 4.7 Comparison of the frequency of characteristics of gold excavations that may be correlated with gold production and various classes of excavation size based upon volume and depth

	No. of gold production-related excavations							
Class of gold excavation size	*Open stopes*	*Compartmented shafts*	*Shafts with underground development*	*‘Major’ or ‘main’ shafts*	*Shafts with substantial bunds*	*Total no. of production-related excavations*	*Total no. of excavations*	*Percentage of production-related excavations*
Volume >25 m^3	8	13	17	11	21	70	102	68.6
Volume <25 m^3	14	3	99	14	70	200	2 146	9.3
Depth >20.0 m	0	9	0	3	6	18	21	85.7
Depth 10–19.9 m	0	5	4	10	29	48	80	60.0
Depth 5–9.9 m	0	1	24	7	33	65	206	31.6
Depth <= 4.9 m	17	0	86	5	25	133	1 941	6.9

and 4.10). The density and bund height of gold excavations also display some, albeit much weaker, positive correlation with total gold production (Figs 4.3 and 4.6) under certain conditions (for areas of 10 000 m^2 and bund heights of less than 1 m, respectively). It is clear, therefore, that there is a relationship between mine size as determined from abandoned mine excavations and total gold production, but that some attributes of mine size are much more effective than others as a qualitative measure of total gold production.

Table 4.7 shows that 68.6% of excavations with volumes greater than 25 m^3 have production-related characteristics compared to only 9.3% for volumes less than 25 m^3. Table 4.6 shows that excavation depth is the main contributing dimension to excavation volumes over 25 m^3, highlighting the importance of depth.

The correlation between the deepest gold excavations and higher gold production is clearly demonstrated in Figures 4.8 and 4.9. As would be expected, the vast majority (85.7%) of the deepest excavations have gold production indicators (Table 4.7). Table 4.7 also indicates that many of the excavations with a depth of 5 m or less (mean depth 3.5 m or less) were not major contributors to gold production, and hence were probably mostly exploratory in nature. The very nature of early prospecting techniques, which relied upon being able to pan visible gold from crushed rock, could not be expected to have contributed much, if any, gold to the production figures. However, these exploratory excavations may still provide a useful guide to the location of gold mineralization that was sub-economic at the time they were made.

In comparison with working depth and volume, there is little overall correlation between bund height and gold production (Fig. 4.6). Nevertheless, there is a weak positive correlation for bund heights of up to 0.95 m. The lack of a positive correlation between bund height and total gold production for bund heights greater than one metre does require some explanation. A common field observation was that the additional volume of waste rock removed from deeper shafts was increasingly accommodated by a larger bund area in preference to height. Furthermore, the deepest shafts tended to have no bund at all because the volume of waste rock was so high that it was removed from the shaft area via an overhead tramway built on a linear dump of waste rock. Tramway-related waste dumps were recorded separately in the WABMINES database.

The relationship between the density of gold excavations and total gold production is scale-dependent. The number of gold excavations per hectare (10 000 m^2) does show a weak positive correlation with gold production (Fig. 4.3). This contrasts with the number of gold excavations for the much smaller 100 m^2 area, which shows a strong negative correlation with total gold production (Fig. 4.2). Note that despite sparse data in the highest excavation density class (Table 4.1), the apparent paradox may be correct, and may be due to the greater areal extent of larger gold excavations. A single shaft with substantial gold production would normally occupy at least a 100 m^2 area with associated waste material and infrastructure such as headframe, winder equipment, and possibly tramway. In contrast, more smaller excavations with less total gold production can occupy the same area. Nevertheless, as 89% of single gold excavations occupy only one 100 m^2 cell (Table 4.1) there is no practical value in knowing that some of them were the highest gold producers when most of these excavations clearly had lower gold production (compare Fig. 4.4 with Fig. 4.1).

A major shortcoming of using excavation volume as a measure of gold production is the large influence that surface dimensions can have on the calculated volume. Inconsistencies and inaccuracies in estimating length and width can have a disproportionate influence on this attribute. Original length and width data are not available for rehabilitated excavations nor for those that are now located under infrastructure. Furthermore, the length and width for many excavations inspected before 2003 were not recorded. Therefore, if these excavations are to be included in the measure, both original length and width will need to be estimated as well as original depth, thus introducing two more sources of error.

Depth of gold excavations is the best qualitative measure of total gold production. It is much more widely available than the original length and width of workings, and original depth can be estimated far more readily. Depth is also a simpler measure with less inherent error than volume and produces a more realistic result when compared to total gold production, wherein a more gradual progression from exploration-dominated to production-dominated excavations is indicated.

Exploration excavations could be expected to have been more common in localities where the gold mineralization was below the cut-off grade at which profitable mining could take place at the time they were made. Nevertheless, exploration excavations could be valuable indicators of gold mineralized structures that may lead to more profitable grades elsewhere, or may in themselves become economic with increased gold prices and improved technology.

4.5 Conclusions

1. There is a correlation between the size and extent of abandoned gold excavations and total gold production.
2. Depth of abandoned gold excavations is the best qualitative measure of total gold production.
3. Even shallow exploration excavations (prospecting pits) can be indicators of gold-mineralized structures.
4. A methodology has been developed for examining correlations between attributes in the abandoned mine sites (WABMINES) database and total gold production. This methodology has the potential for further application in prospectivity studies.

Chapter 5

Processing of GIS data for case-study areas

5.1 Introduction

Now that excavation depth has been established as a qualitative measure of total gold production, it will be useful to determine this for as many former mine workings as possible. The data analysis carried out so far was only applied to those excavations that have not subsequently been backfilled or collapsed to a much shallower depth. By including the large numbers of backfilled and collapsed excavations into the case-study datasets with estimated original depths (i.e. depths prior to backfilling or collapse), a more complete picture of total gold production can be inferred. This is especially useful for areas such as Norseman, where a large number of excavations have been backfilled.

This chapter firstly covers the primary data processing to select the relevant records from the WABMINES database as before, for each of the case-study areas (Fig. 5.1, step 1). However, in this chapter, all backfilled (rehabilitated) and collapsed excavations and those now under infrastructure were retained in the datasets. The secondary, or derived, data processing was used to estimate the excavation depth prior to backfilling or collapse, where necessary (Fig. 5.1, step 2). Further geological information (e.g. rock type) was also extracted from the WABMINES database to assist the investigation of regional-scale geological structures (Chapter 6).

The last part of this chapter examines different ways of presenting the data, using both plots of excavations (point

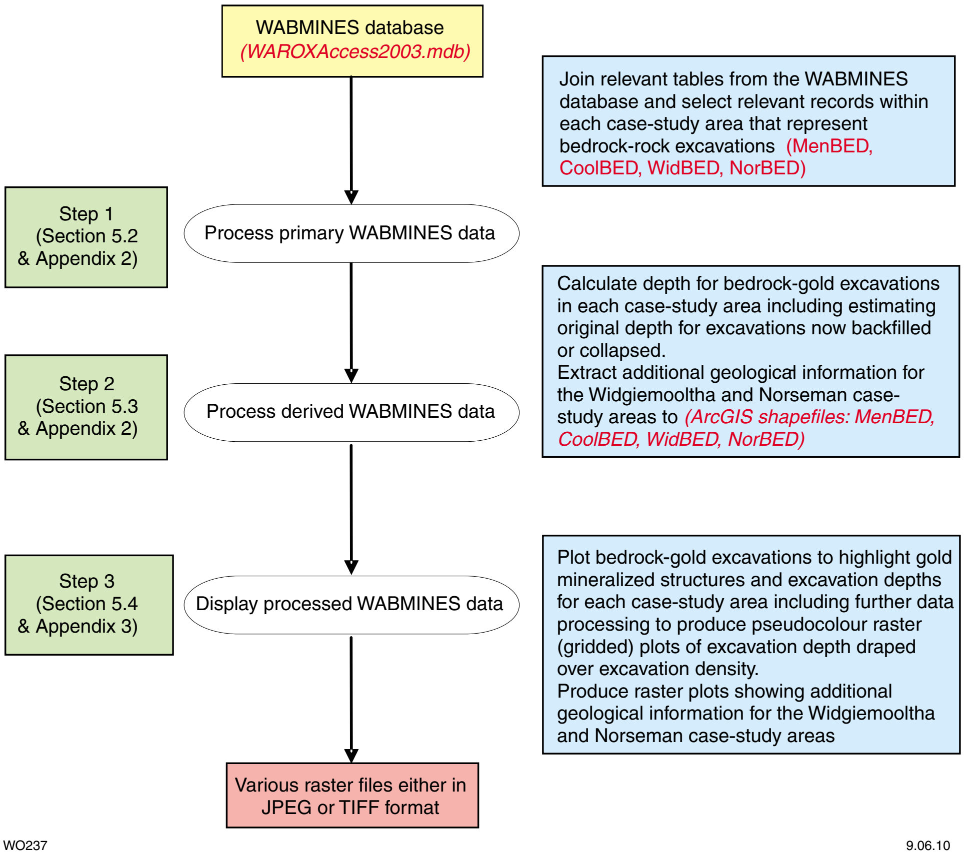


Figure 5.1 **Flow diagram showing the main steps applied to processing the WABMINES data for the case-study areas. MS Access database table names are shown in normal red font and file names are shown in red italics.**

vector data) and images derived from excavation data (raster data) to highlight both the spatial distribution of gold excavations and depth (Fig. 5.1, step 3). The aim is to select effective ways of presenting these data at various scales so that they can be used (Chapter 6) to examine the relationship between abandoned mine excavations and regional-scale geological structures for each of the case-study areas.

5.2 Primary processing of WABMINES data

Primary processing of WABMINES data is necessary to select only the relevant records or features that are likely to represent bedrock-gold excavations. This was carried out for all of the study areas using the same procedure as described in Section 3.5.1, Figure 3.7, and detailed in Appendix 2. Statistics for the number of bedrock-gold excavations in each of the case-study areas are listed in Table 5.1.

The comparatively low proportion of bedrock-gold excavations in the Norseman area (Table 5.1) is mainly due to the backfilling of large areas of unidentifiable excavations. Only those rehabilitated areas that were most likely to have been associated with former shafts were included in this study. Nevertheless, the Norseman area has the highest percentage of rehabilitated excavations of all the case-study areas (Fig. 5.2).

Variations in the proportions of shallow workings and deeper excavations (collapsed shafts and shafts) between the case-study areas (Fig. 5.2) may be partly due to differences in the rock hardness, and hence ease of excavation. Hence, the Menzies area, which has the highest percentage of shafts, may have comparatively soft, highly weathered, and foliated host rocks. The lower competency of these rocks may also contribute to the high proportion of collapsed shafts in Menzies.

5.3 Processing of derived WABMINES data

Further processing of WABMINES data is required mainly to estimate the original depth of collapsed shafts, rehabilitated shafts, and those excavations that are now under infrastructure. Additional geological information was also extracted from the WABMINES data for some areas. Figure 5.3 summarizes the data processing steps, which are explained in detail in Appendix 2. Step 1 was carried out using MS Access database software, and all subsequent steps used ESRI ArcGIS software unless otherwise stated.

Table 5.1 The number of WABMINES features and bedrock-gold excavations for each case-study area

Case-study area	*Total no. WABMINES features*	*No. bedrock-gold excavations*	*% bedrock-gold excavations*
Coolgardie	32 993	22 933	70
Norseman	16 098	7 617	47
Menzies	7 799	5 362	69
Widgiemooltha	5 754	3 503	61
Total	**62 644**	**39 415**	

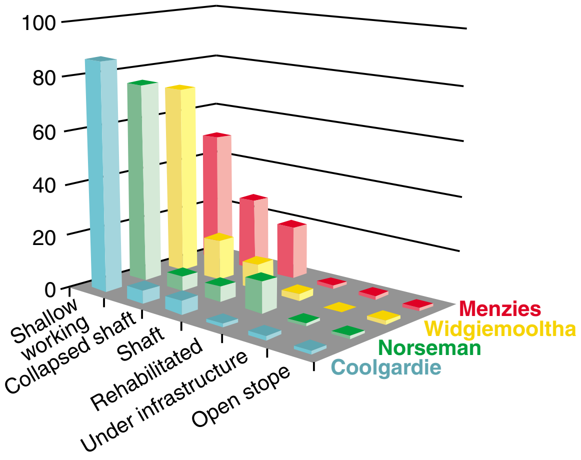


Figure 5.2 **The relative proportions of each type of bedrock-gold excavation in the case-study areas.**

5.3.1 Estimating depths of abandoned mine excavations

The actual depths of abandoned excavations are only known for those that have not been backfilled, collapsed, or been covered by infrastructure (i.e. shallow workings, shafts, and open stopes). Unless labelled otherwise (e.g. rehabilitated shaft, collapsed shaft), all shafts and open stopes discussed in this chapter belong to the ‘underground’ feature group in the WABMINES database. This means that they have not been backfilled, collapsed, or been covered by infrastructure.

Depth was estimated in the field to be within various ranges such as from 2 to 5 m. For the purposes of this study, each depth range was attributed a mean depth for each depth interval. As the depths of many of the deepest excavations are not known, and are difficult to estimate in the field, a nominal mean depth of 25 m was given to all excavations over 20 m deep.

Collapsed shafts are those that are currently less than 2 m deep, but show evidence of having originally been deeper. The main evidence for this is having a much larger bund surrounding the shaft than would be expected for such a shallow excavation. Original depth was estimated for collapsed shafts by comparing their mean bund height to those for shafts in the same case-study area of known depth.

Excavations that are now rehabilitated, or located under infrastructure, have been backfilled or removed. Unlike

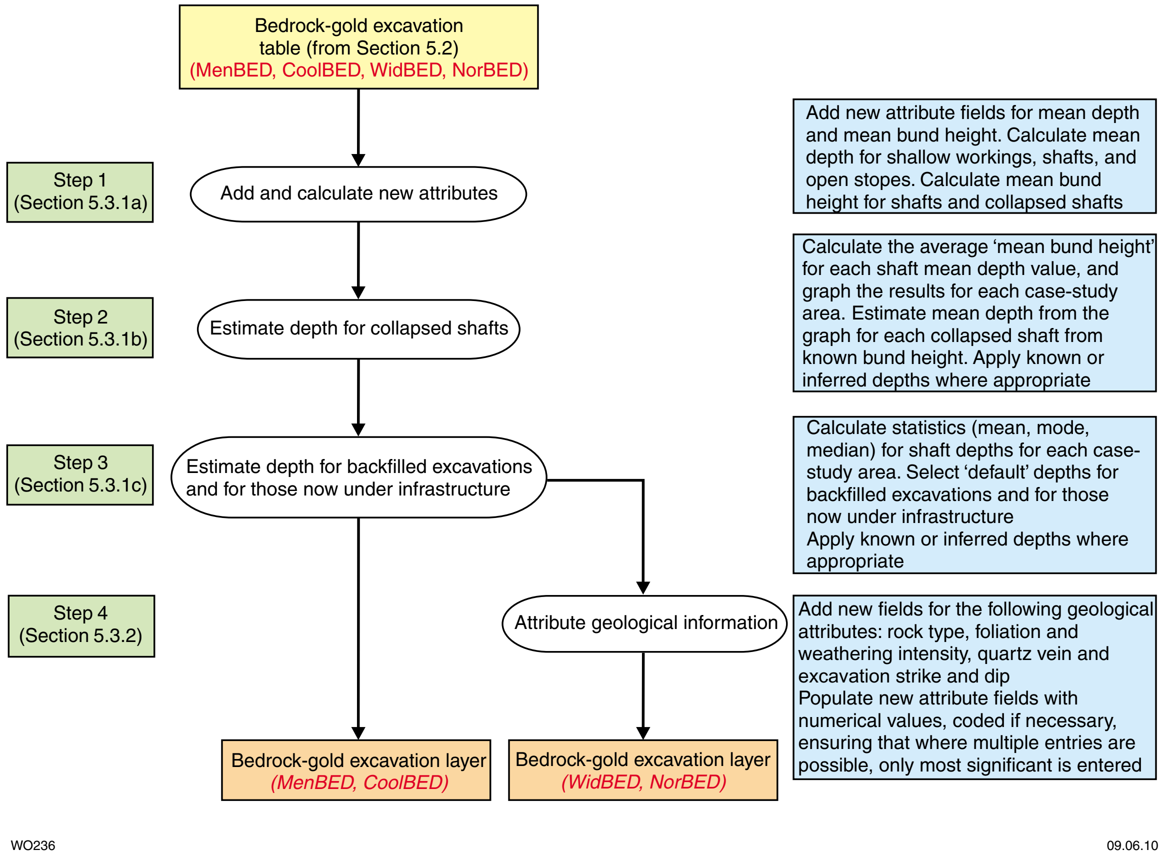


Figure 5.3 **Flow diagram showing the main steps in the derived data processing of WABMINES data to produce a bedrock excavation table for each case-study area attributed with original depth and additional geological information. MS Access database table names are shown in normal red font and ArcGIS file names are shown in red italics.**

collapsed shafts, there is normally no longer any in situ bund material remaining for these types of excavations. Original depth for most of these excavations was also estimated by using depth statistics for shafts located in the same study area.

a) Adding and calculating new WABMINES attribute fields

The following two new attribute fields were created for the derived (or calculated) data that were required for the estimation of depth:

1) mean excavation depth — (depth_m);
2) mean excavation bund height — (bund_m).

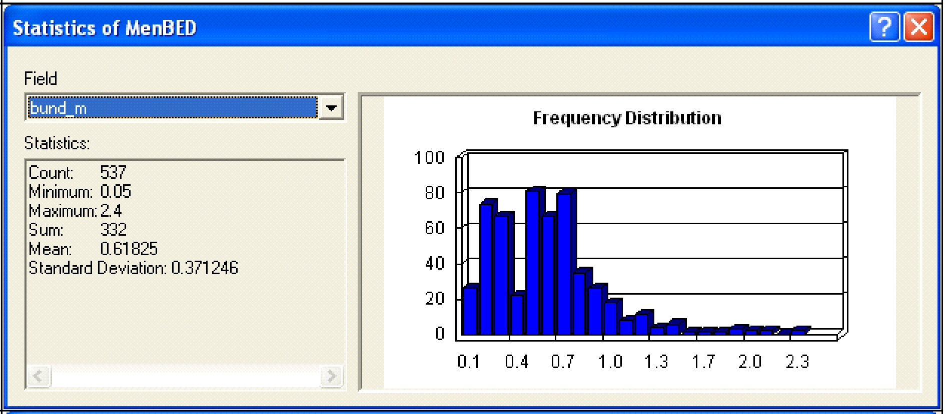
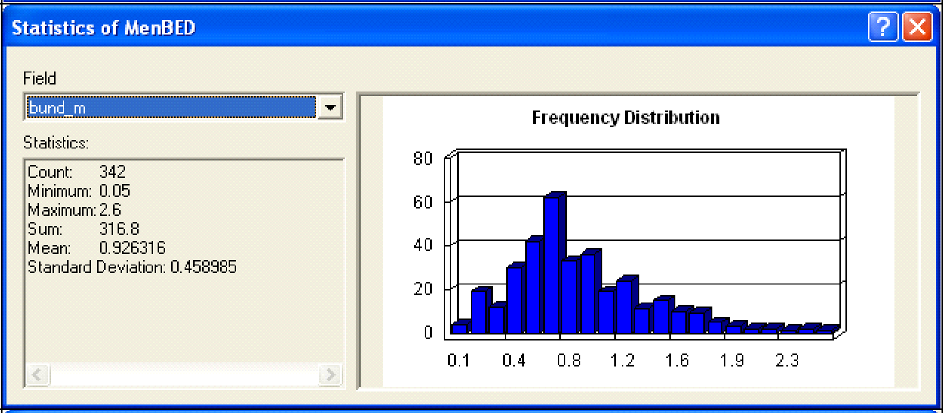
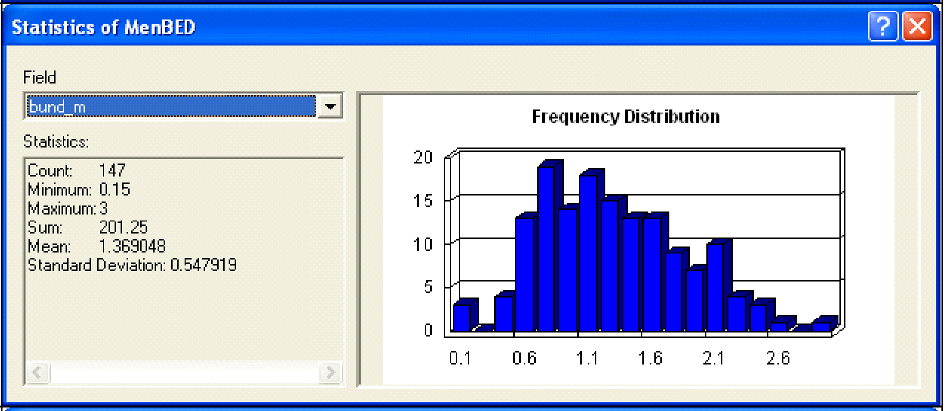
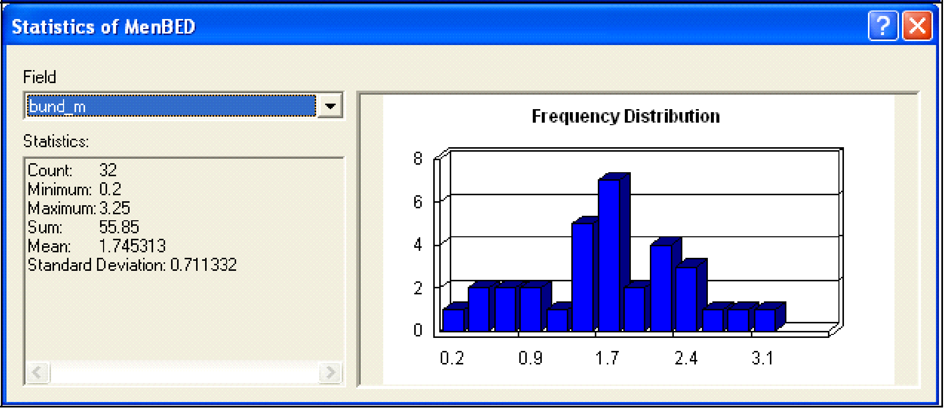
Mean depth was calculated for shallow workings, shafts, and open stopes, and mean bund height for all shafts and collapsed shafts using the same method described in Chapter 3 (Section 3.5.2).

b) Estimating depth for collapsed shafts

Original depths for collapsed shafts were estimated by comparing their mean bund height with bund height statistics for shafts of known depth in the same study area. Averages of (mean) bund heights were calculated for each shaft depth interval using the summarize function within ESRI ArcGIS software. Figure 5.4 shows an example of mean bund height statistics for shafts of increasing depth in the Menzies case-study area. Despite a range of mean bund heights in each depth class, there is clearly an overall increase in mean bund height with increased depth. These statistics are summarized in Table 5.2., which also lists calculated midpoint values for each mean depth interval.

Figures 5.5 to 5.8 show graphically the mean depth, calculated average bund height, and the respective midpoint values for shafts in each case-study area. These graphs show the systematic increase in average bund height with depth in all case-study areas. Therefore, for a known mean bund height, it is possible to estimate the most likely original depth interval (or mean depth) of a shaft that has subsequently collapsed. Although the relationship is an approximate one, it is sufficient for the purpose of this study, which is to gain a qualitative understanding of the spatial distribution of bedrock-gold excavation depth.

Original depth estimates for collapsed shafts were made using these graphs by finding the appropriate mean bund height interval (in Figs 5.5 to 5.8; labelled in red), and reading mean depth (labelled in black) for that interval. For example, a collapsed shaft in Menzies with a mean bund height of 0.9 m occurs in the 0.77 to 1.15 m mean bund height interval, and therefore has an estimated depth of 7.5 m.

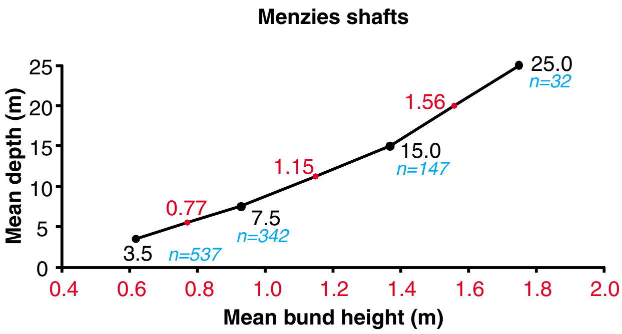
Mean depth	Mean bund height statistics
3.5 m	 Statistics of MenBED Field: bund_m Statistics: Count: 537 Minimum: 0.05 Maximum: 2.4 Sum: 332 Mean: 0.61825 Standard Deviation: 0.371246
7.5 m	 Statistics of MenBED Field: bund_m Statistics: Count: 342 Minimum: 0.05 Maximum: 2.6 Sum: 316.8 Mean: 0.926316 Standard Deviation: 0.458985
15 m	 Statistics of MenBED Field: bund_m Statistics: Count: 147 Minimum: 0.15 Maximum: 3 Sum: 201.25 Mean: 1.369048 Standard Deviation: 0.547919
25 m	 Statistics of MenBED Field: bund_m Statistics: Count: 32 Minimum: 0.2 Maximum: 3.25 Sum: 55.85 Mean: 1.745313 Standard Deviation: 0.711332

WO238 03.06.10

Figure 5.4 **Frequency distribution histograms and statistics for mean bund heights of shafts (shown on the x axes of the histograms) for increasing mean depth intervals (shown in the left-hand column) in the Menzies case-study area, which show a systematic increase in the mean bund height with increasing depth.**

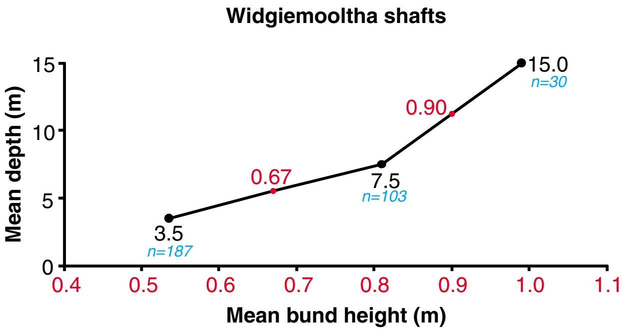
Table 5.2 **Shaft depth intervals, mean depth, and corresponding average bund height values for shafts in the Menzies case-study area with calculated midpoint values for mean depth and average bund height**

Depth interval *(m)*	*Mean depth* *(m)*	*No. of shafts* *(n)*	*Average bund height* *(m)*	*Midpoint for mean depth* *(m)*	*Midpoint for average bund height* *(m)*
2 – 5	3.5	537	0.62	–	–
	–	–	–	5.5	0.77
5 – 10	7.5	342	0.93	–	–
	–	–	–	11.25	1.15
10 – 20	15	147	1.37	–	–
	–	–	–	20	1.56
>20	25	32	1.75	–	–



WO230 16.06.10

Figure 5.5 **Graph of average bund height for each mean depth class for shafts in the Menzies case-study area. The number of shafts used to calculate average bund height is shown in blue. Mean depth values are shown in black, and midpoint bund height values are shown in red.**



WO229 16.06.10

Figure 5.7 **Graph of average bund height for each mean depth class for shafts in the Widgiemooltha case-study area. The number of shafts used to calculate average bund height is shown in blue. Mean depth values are shown in black, and midpoint bund height values are shown in red.**

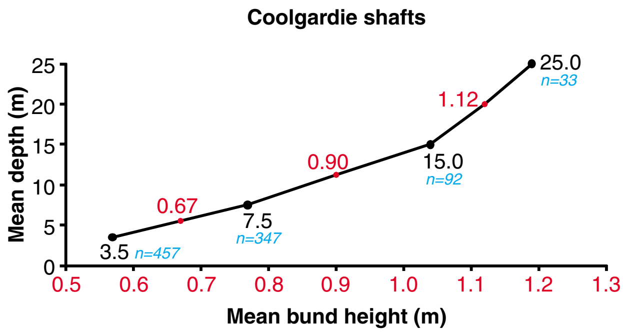


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Figure 5.6 **Graph of average bund height for each mean depth class for shafts in the Coolgardie case-study area. The number of shafts used to calculate average bund height is shown in blue. Mean depth values are shown in black, and midpoint bund height values are shown in red.**

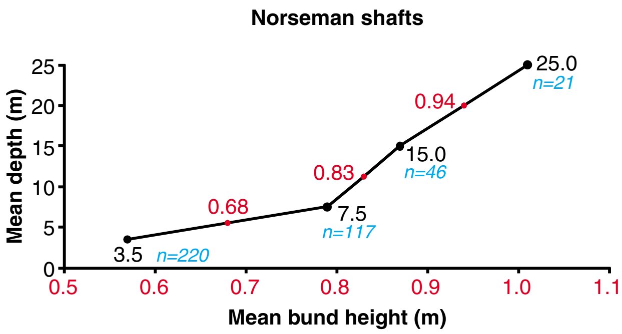

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Figure 5.8 **Graph of average bund height for each mean depth class for shafts in the Norseman case-study area. The number of shafts used to calculate average bund height is shown in blue. Mean depth values are shown in black, and midpoint bund height values are shown in red.**

After completion of the depth-estimation process for each case-study area, a check was made of the 'MINE_NOTE' attribute field in WABMINES database. All records with comments such as 'main shaft' or 'major shaft' were selected, and the mean depth attribute field was set to the default greatest mean depth of 25 m. This ensured that all of the most significant shafts were flagged as being deep irrespective of the bund height. Where historical maps were able to provide known depths, the appropriate depth categories were also attributed to the collapsed shafts.

c) ***Estimating depth for rehabilitated excavations and excavations located under infrastructure***
Initially, average and modal depths were calculated for all shafts in each case-study area. Depth data were then exported as DBF files, and the depth distributions for shafts were displayed graphically using MS Excel software (Fig. 5.9). These depth data show a highly skewed distribution, with the vast majority of shafts being comparatively shallow in all case-study areas. Calculation of median values was performed using MS Excel software.

Table 5.3 summarizes the depth statistics for each case-study area. The 'default' depth for rehabilitated shafts, and those now under infrastructure was chosen based upon the median value, which is more representative of the majority of shaft depths than the average depth due to the highly skewed nature of the data. Therefore, the 'default' depth was 3.5 m for all study areas, except for Coolgardie, where it was 7.5 m (Table 5.3). The reason for the higher median depth in Coolgardie is mainly due to the higher proportion of shafts with a mean depth of 7.5 m or more (Fig. 5.9). Table 5.3 shows that Coolgardie also has the highest average shaft depth for all the case-study areas.

After allocating all 'default' depths, the 'MINE_NOTE' comments were checked, and the 'depth_m' attribute field was set to the greatest depth category (25 m) for any records stating 'major' or 'main' shaft. Backfilled excavations with large volumes of remnant bund material were also allocated to the maximum depth category. This ensured that all of the most significant shafts were flagged as being extraordinarily deep, rather than merely having the 'default' depth. Similarly, where historical maps were able to provide known depths, the appropriate depth category was allocated to the excavation.

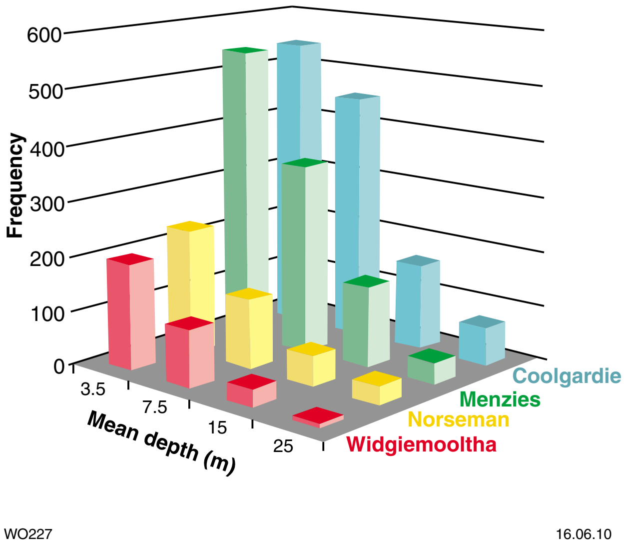

Figure 5.9 **Frequency distribution histogram for mean depth of shafts for all case-study areas.**
Footnote: Eighty-eight shafts in Coolgardie have a mean depth classification of 20 m (from an early discontinued scheme). For clarity, these depths were redistributed between the 15 and 25 m categories in proportion to the other shafts in these depth categories

5.3.2 Attributing geological information

The Widgiemooltha case-study area was chosen for extracting additional geological information from the bedrock-gold excavation database layer ('WidBED'). This was because the Widgiemooltha region has many well-preserved abandoned mine workings, and a substantial amount of geological information was recorded for these, particularly by the author (Geological Survey of Western Australia, 2008). It was anticipated that this additional information could assist in the investigation of regional-scale geological structures (Chapter 6).

All geological data were numerically coded to facilitate later data processing, so a new 'short integer' attribute field was added to the 'WidBED' shapefile for each geological attribute. The following seven geological attributes were examined in the Widgiemooltha case study:

Table 5.3 **Comparison of mean depth statistics for shafts for the case-study areas, and the default mean depth chosen to be applied to backfilled rehabilitated shafts or those now under infrastructure**

Case study area	*Total no. shafts*	*Mode Depth_m (m)*	*Median Depth_m (m)*	*Average Depth_m (m)*	*Default Depth_m (m)*
Coolgardie	1 234	3.5	7.5	7.8	7.5
Norseman	445	3.5	3.5	7.7	3.5
Menzies	1 076	3.5	3.5	7.1	3.5
Widgiemooltha	339	3.5	3.5	6.3	3.5

1) quartz vein strike and dip;
2) foliation intensity;
3) degree of weathering (intensity);
4) rock type;
5) excavation strike and dip.

All geological data except for excavation strike and dip (which have their own attribute fields) were sourced from the 'NOTES' or geological comments field of the 'WidBED' shapefile. Quartz vein orientation data were manually entered after selecting all records with comments including 'vein'. The degree of foliation, weathering, and rock type attribute fields were all populated using a combination of selection by attributes (using wild cards), the numerical code as listed in Table 5.4, and 'field calculator' (see Appendix 2 for details).

As a WABMINES record could have multiple entries for each attribute, such as two rock types, a hierarchy was established to determine the most significant attribute. Where multiple entries were recorded, the sequence of populating each attribute field was structured so that the most significant attribute overwrote previous entries. Table 5.4 lists each attribute in order of increasing significance. For example, the rock type 'black shale' was considered to be a very distinctive marker, therefore if the geological description included '…mafic and minor black shale', the mafic rock type would have originally been coded as '1' in the 'rock_type' attribute field, but this would be overwritten by '8' representing black shale.

The orientation of excavations (strike and dip) could be useful for gold exploration as it was commonly found to follow the mineralized vein or structure of interest. In the WABMINES database, strike is recorded for elongate features such as shallow workings and open stopes, but azimuth (dip direction) is recorded for shafts. Therefore, azimuth needed to be converted to strike for shafts.

5.4 Displaying the data

Effective presentation of the bedrock-gold excavation data can greatly facilitate the visual interpretation of the data, particularly with respect to regional-scale geological structures. Figure 5.10 summarizes the different approaches used in this study to display the data. The two main approaches were:

1) plotting bedrock-gold excavations (as points);
2) creating raster images showing bedrock-gold excavations.

The methodology and merits of the different approaches to displaying the bedrock-gold excavation data were examined, before selecting the optimum approach for use in examining their relationship with regional-scale geological structures (Chapter 6). Most data processing was carried out using ESRI ArcGIS software, although some raster image processing was completed using ER Mapper software.

5.4.1 Identifying the limitations of the data

Before making spatial interpretations based upon the bedrock-gold excavation data, it is important to understand and map the constraints on the spatial distribution of the data. Assuming that most significant surface gold mineralization was found, and tested, by early prospectors, the absence of bedrock-gold excavations could mean there was no mineralization at the surface. Therefore, there is a need to identify the constraints on the bedrock-gold excavation data that are not related to mineralization.

The first limitation is the spatial extent of the abandoned mine sites survey. In general, the survey covered all areas (even outside known historical mine sites) within 5 km of

Table 5.4 List of classes and numerical codes allocated for various attributes that were derived from the geological comments attribute field 'NOTES' in the WABMINES database

Attribute	*Classification*	*Code*	*Description in 'NOTES'*
Foliation	slightly	1	slightly or weakly foliated
	moderately	2	foliated
	strongly	3	strongly foliated
Weathering	extremely	4	extremely weathered
	distinctly	3	distinctly weathered
	slightly	2	slightly weathered
	fresh	1	fresh
Rock type	mafic	1	mafic, basalt, dolerite, gabbro or amphibolite
	ultramafic	2	ultramafic, komatiite or serpentinite
	felsic	3	felsic, porphyry, quartz–feldspar rock, volcaniclastic rock, rhyolite or dacite
	granite	4	granite
	pegmatite	5	pegmatite
	metasedimentary	6	metasedimentary, sediment, siltstone, sandstone, conglomerate, shale or slate
	chert	7	chert
	black shale	8	black shale

NOTES: Each class is listed in order of increasing significance down the page. Both foliation and weathering are numerically coded according to intensity, but the presence of fresh rock is considered more significant than weathered rock as it can provide information on depth of weathering

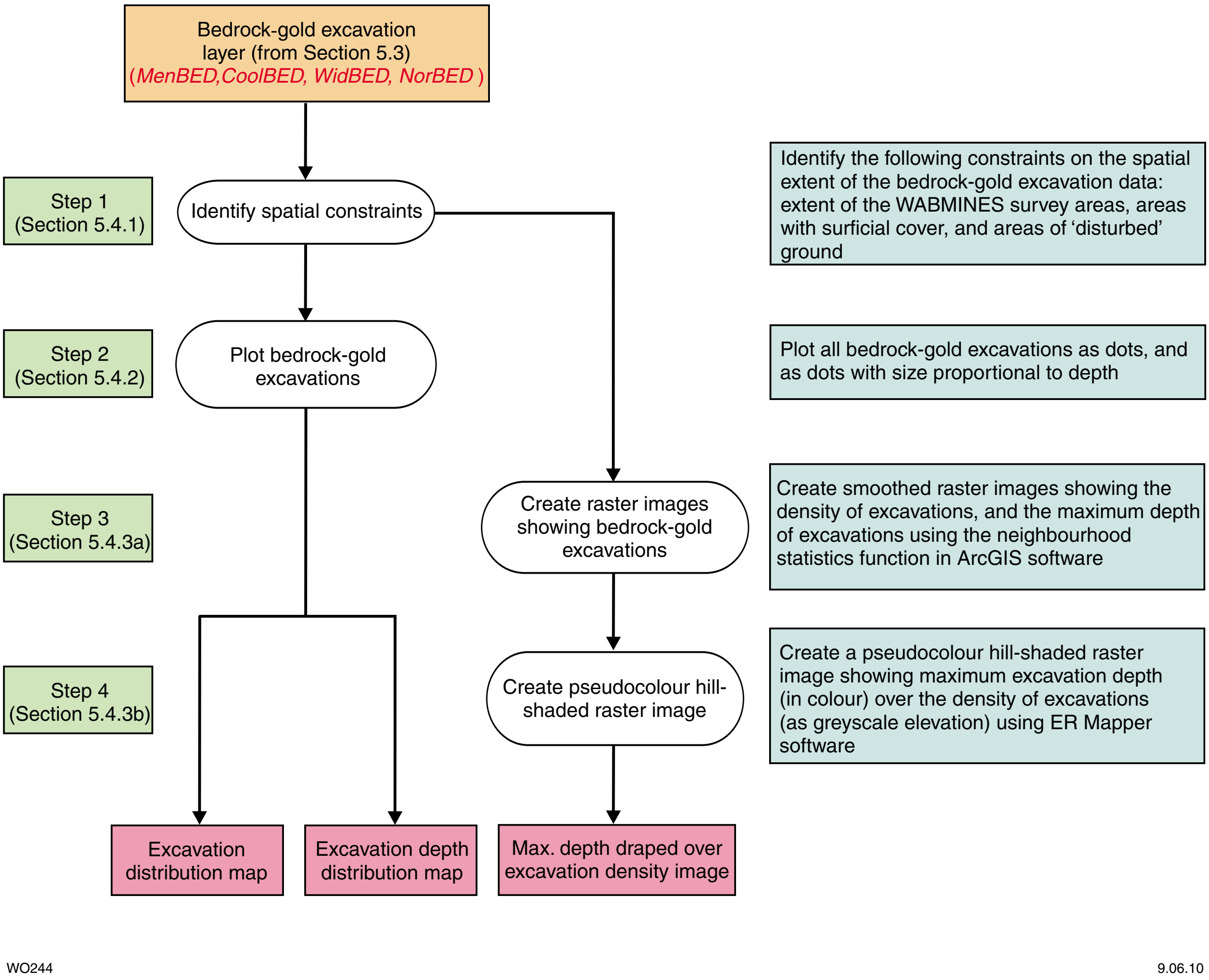

Figure 5.10 **Flow diagram summarizing the main steps in producing maps and images to present the bedrock-gold excavation data.**

Menzies and Widgiemooltha, and 10 km of Coolgardie and Norseman, and within one kilometre of main roads or specific tourist routes. However, this coverage extended beyond these boundaries in areas with nearby excavations or along continuations of excavations that originated within those boundaries.

The second constraint on the distribution of abandoned mine excavations is a geological one, and relates to the distribution of surficial regolith cover. With the rare exception of blind 'wildcat' excavations, historical prospecting methods relied upon outcrop or 'float' in areas of very shallow regolith cover to explore for bedrock gold. Consequently, the vast majority of bedrock-gold excavations are within areas with little or no regolith cover. All regolith units mapped within the East Yilgarn Geological Information Series (Geological Survey of Western Australia, 2009) that could be regarded as surficial cover were mapped as one of the following groups: alluvial, colluvial, lacustrine, sandplain, or sheetwash. These units were selected and grouped into a new GIS database layer.

The final constraint is cultural. Disturbed ground is one of the main reasons for the absence or paucity of abandoned mine excavations in otherwise historically very active abandoned mine sites. Areas of 'modern' mining are usually surrounded by a cleared, and later rehabilitated, area to allow access for earthmoving equipment, and infrastructure such as haul roads, processing plant, workshops, stores, administration buildings, and car parks. The extent of most of this disturbance is mainly visible as white areas on the decorrelation stretch Landsat image from the East Yilgarn Geological Information Series. Disturbed ground also includes townsites and other substantial areas of ground disturbance such as battery sites. Many, but not necessarily all, pre-existing abandoned mine excavations are removed from disturbed ground due to backfilling or excavation, so only a small proportion of the original excavations remain. For this reason, wherever possible, the locations of original excavations in the WABMINES database were obtained from historical mapping. In some areas such as townsites, very few if any, mine workings were ever excavated due to access constraints and real, or perceived, low prospectivity. Therefore, the absence or paucity of abandoned mine excavations in disturbed ground does not necessarily indicate little or no bedrock-gold mineralization.

5.4.2 Plotting bedrock-gold excavations

a) Plotting excavation distribution maps

The simplest way to visualize the spatial distribution of bedrock-gold excavations is to plot all excavations as points. If all points are shown as a small solid circle (or dot), the resultant plots for each of the case-study areas show patterns which may be related to geological structures (Figs 5.11–5.14). The dot size is deliberately small for viewing at regional scales to enable resolution of fine-scale detail. The major limitations of this approach are: the lack of information on excavation depth, and the loss of information on the density of excavations where they are closely spaced.

b) Plotting excavation depth distribution maps

Excavation depth plotted as a solid circle with size proportional to depth, gives an insight into the depth distribution of excavations and hence their relative importance with respect to past production (Figs 5.15–5.18). In each study area, the deeper excavations tend to be clustered, and potentially highlight those geological structures that were associated with higher gold production. A limitation of this approach is again the loss of information on the density of excavations, and of fine detail in the vicinity of the deeper excavations.

5.4.3 Creating raster images showing bedrock-gold excavations

Advantages of producing raster images rather than merely plotting excavation data include the ability to:

1) display the density of excavations but still retain fine-scale information on the distribution of excavations;
2) smooth the data, filter out noise, and enhance continuity;
3) create visually effective pseudocolour hill-shaded images that depict density of excavations and depth information.

Ormsby et al. (2005) previously developed the methods for producing these images. The data were initially processed using the Spatial Analyst extension within ESRI ArcGIS software, to create the raster images, which were modified using ER Mapper software to create the pseudocolour hill-shaded images.

A raster processing ‘mask’ was applied to restrict the neighbourhood statistics data processing to the spatial extent of the WABMINES survey for each study area. Using a processing ‘mask’ minimizes the output raster file size.

a) Creating density of excavation and maximum excavation depth images

Before processing the data, an extra depth field (‘depth_m_cm’) was added to the bedrock-gold excavation layer, and then populated with the mean depth converted into centimetres. This was necessary because the ESRI ArcGIS software requires integer values for producing raster files.

To measure density of excavations, the number of records detailing bedrock-gold excavations was counted per unit area. This was done in a similar way to that described in Chapter 3 (Section 3.5.2d) by summing each bedrock-gold record (using the ‘count1’ attribute field populated with ‘1’) using the ‘neighbourhood statistics’ function in ESRI ArcGIS software. But this time, counting was performed using a 10-m grid cell-size, and a circular search area or ‘neighbourhood’ with a radius twice the dimensions of the grid cell-size (i.e. 20 m). A grid cell-size of 10 by 10 m was selected to retain as much of the spatial information from the WABMINES data as possible within the limitations of the accuracy of the input data (±5 m).The effect of using a larger search radius than grid cell-size was to smooth the data, resulting in a GIS raster image depicting density of abandoned mine excavations in units of number of excavations per 1256 m^2 (area of 20 m radius search circle) centred on each 10 by 10 m grid cell. This degree of smoothing was found empirically to produce images with sufficient continuity between excavations to enhance linear trend lines of excavations, but not to overgeneralize the data and hence lose definition of the trend lines.

The GIS raster images depicting excavation depth were also created using the ‘neighbourhood statistics’ function of ESRI ArcGIS software using the same grid cell-size and search parameters as for the density of excavation layers. In this case, the maximum values in the ‘depth_m_cm’ field were used. Maximum depth values (for mean excavation depths) were used rather than the mean or sum of excavation depth, as they are independent of the number (and hence density) of excavations. The result of this approach is to highlight those areas that have at least a single deep shaft.

b) Creating pseudocolour hill-shaded images of maximum excavation depth over density of excavations

Pseudocolour hill-shaded images of maximum excavation depth (shown in colour) overlain on density of excavations (shown as an intensity or grey-scale ‘elevation’ layer) provide an effective way to visualize the processed WABMINES data. Most of the data processing was carried out using ER Mapper software. Details on the methodology are given in Appendix 3.

The maximum depth of excavation layer was initially converted into a smoothed pseudocolour layer using a Gaussian equalize transform within ER Mapper software, resulting in reddish hues for the greatest depth grading through a spectrum colour scheme to dark blue for no depth. The density of excavation layer was converted into a smoothed grey-scale intensity layer. Sunshading was applied to the density layer to give the impression of highest relief for areas with the highest concentration of excavations. Brightness and detail of the density of excavation layer was adjusted using a logarithmic transform function. In a final step, the pseudocolour layer representing the maximum depth of excavation was draped over the hill-shaded layer representing the density of excavations. All images were saved in georeferenced TIFF format with the highest practicable resolution of 2 by 2 m pixel size.

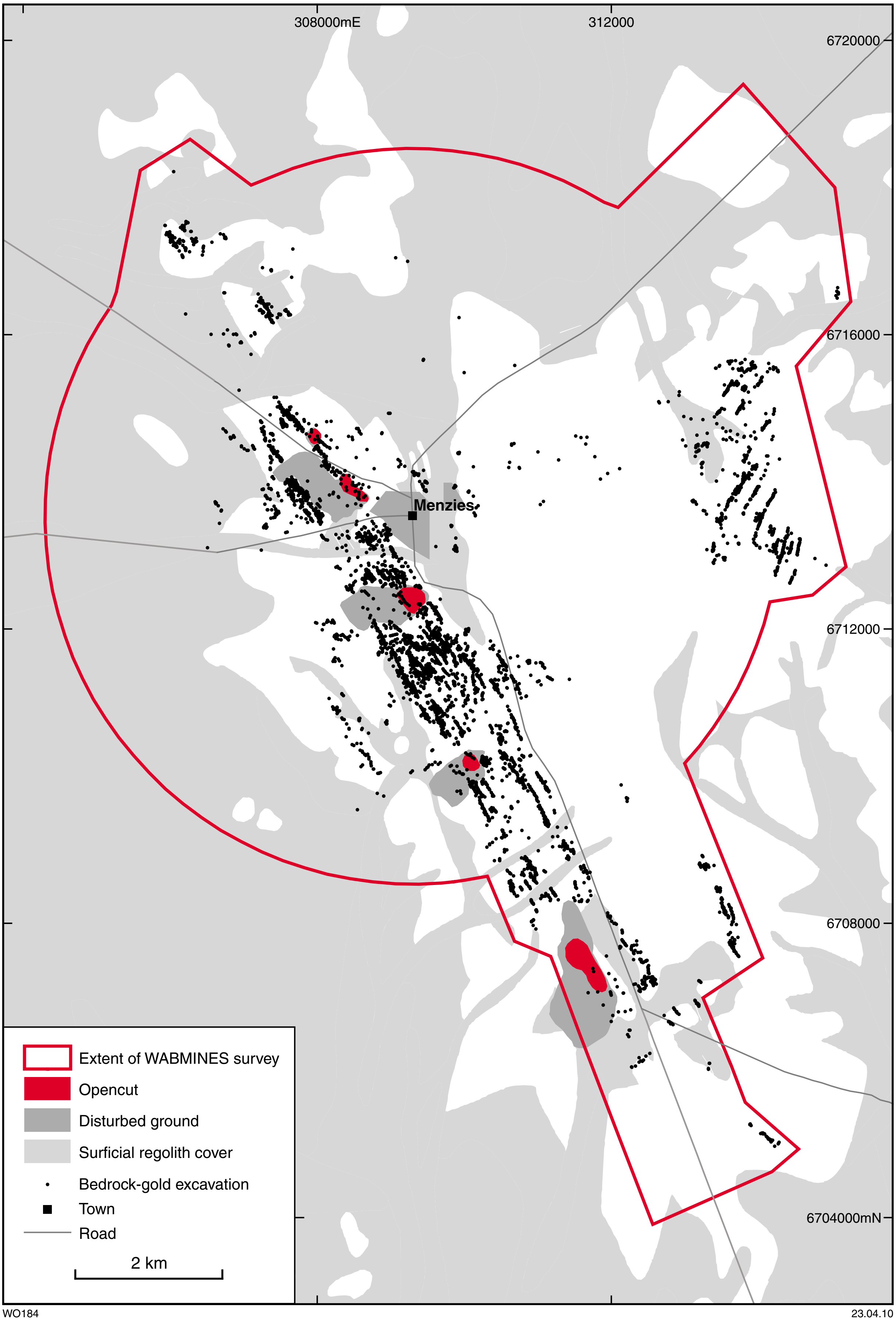

Figure 5.11 **Bedrock-gold excavations and extent of the Menzies case-study area. Many of these excavations form linear patterns that may be related to geological structures.**

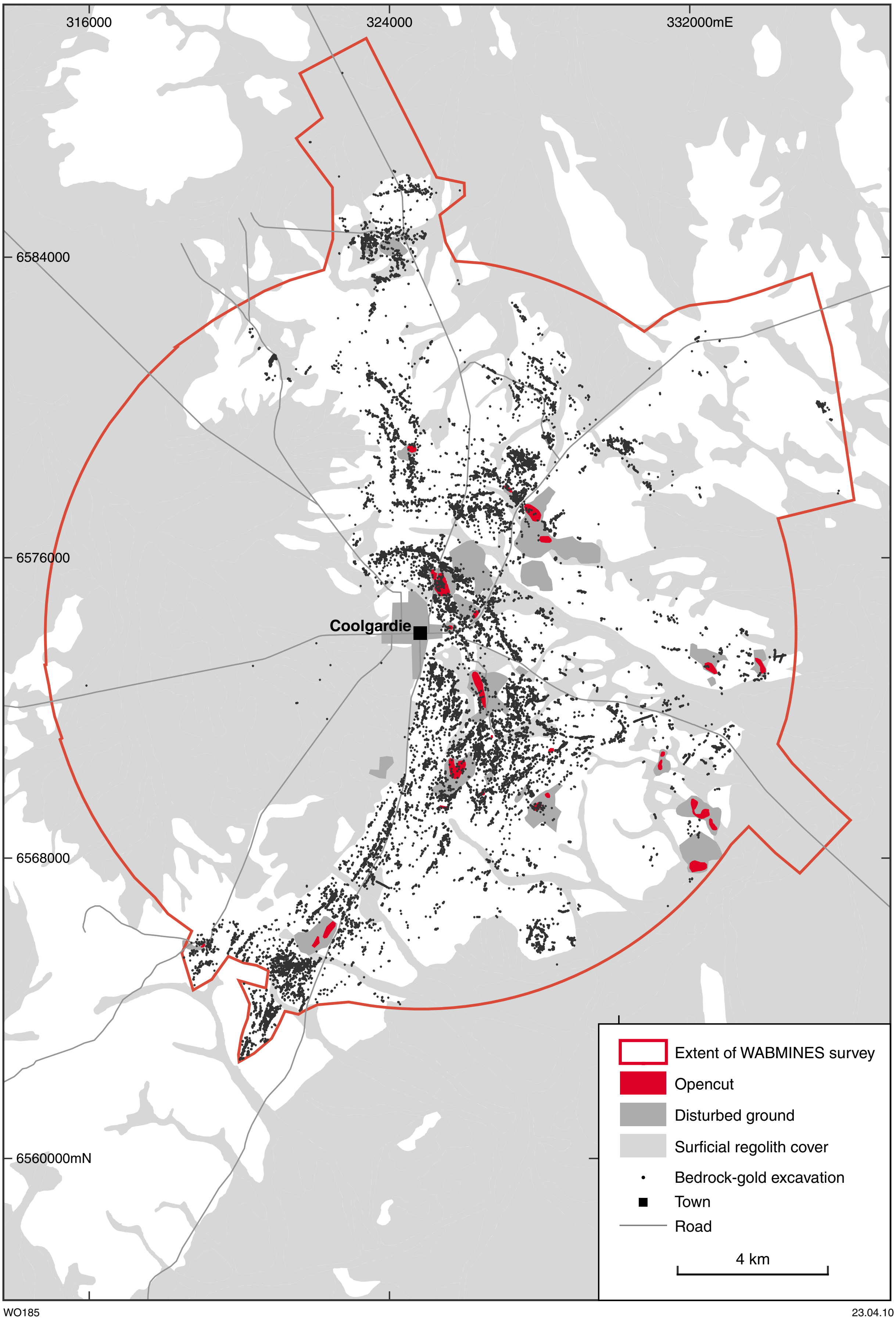

Figure 5.12 **Bedrock-gold excavations and extent of the Coolgardie case-study area. Many of these excavations form linear patterns that may be related to geological structures.**

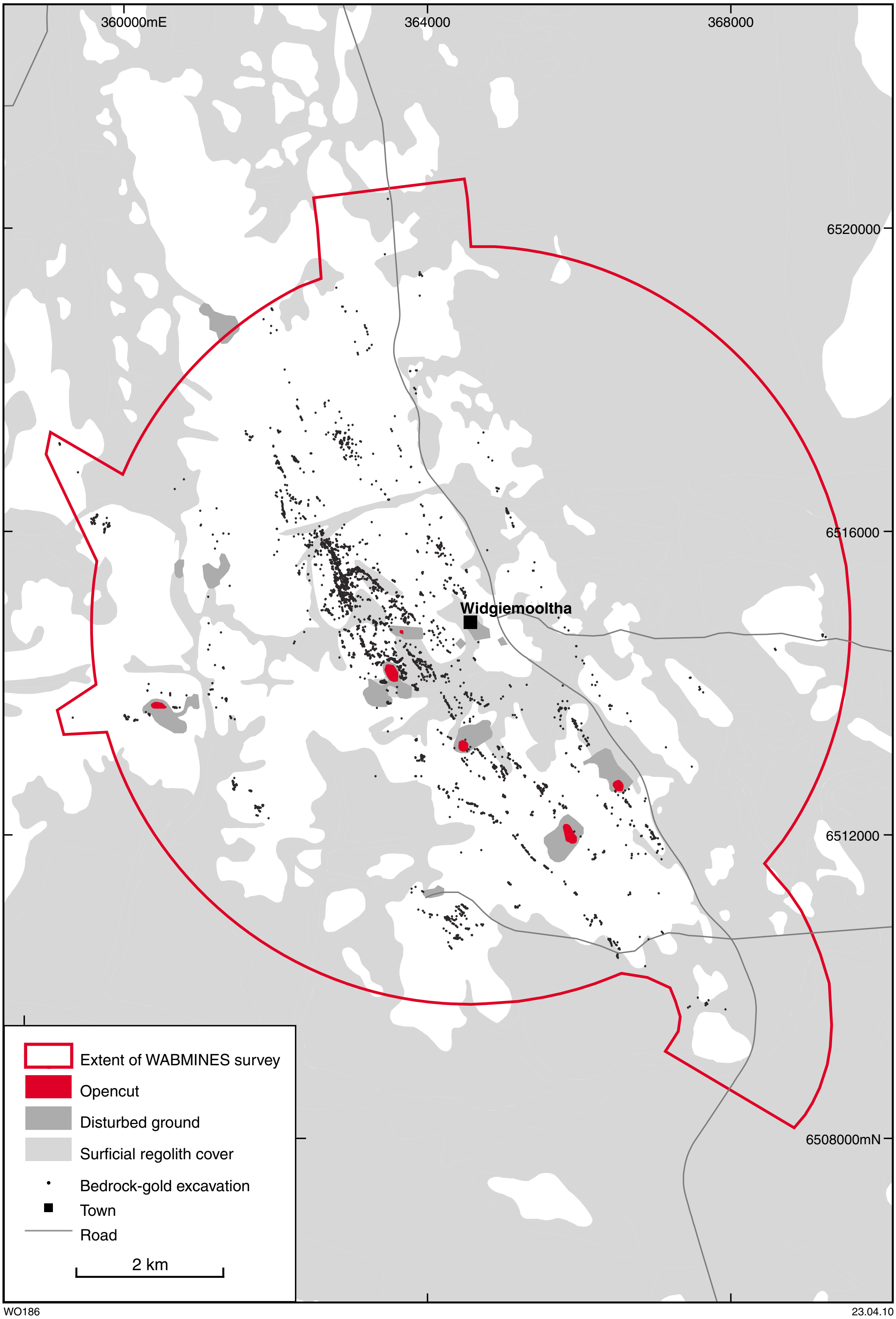

Figure 5.13 **Bedrock-gold excavations and extent of the Widgiemooltha case-study area. Many of these excavations form linear patterns that may be related to geological structures.**

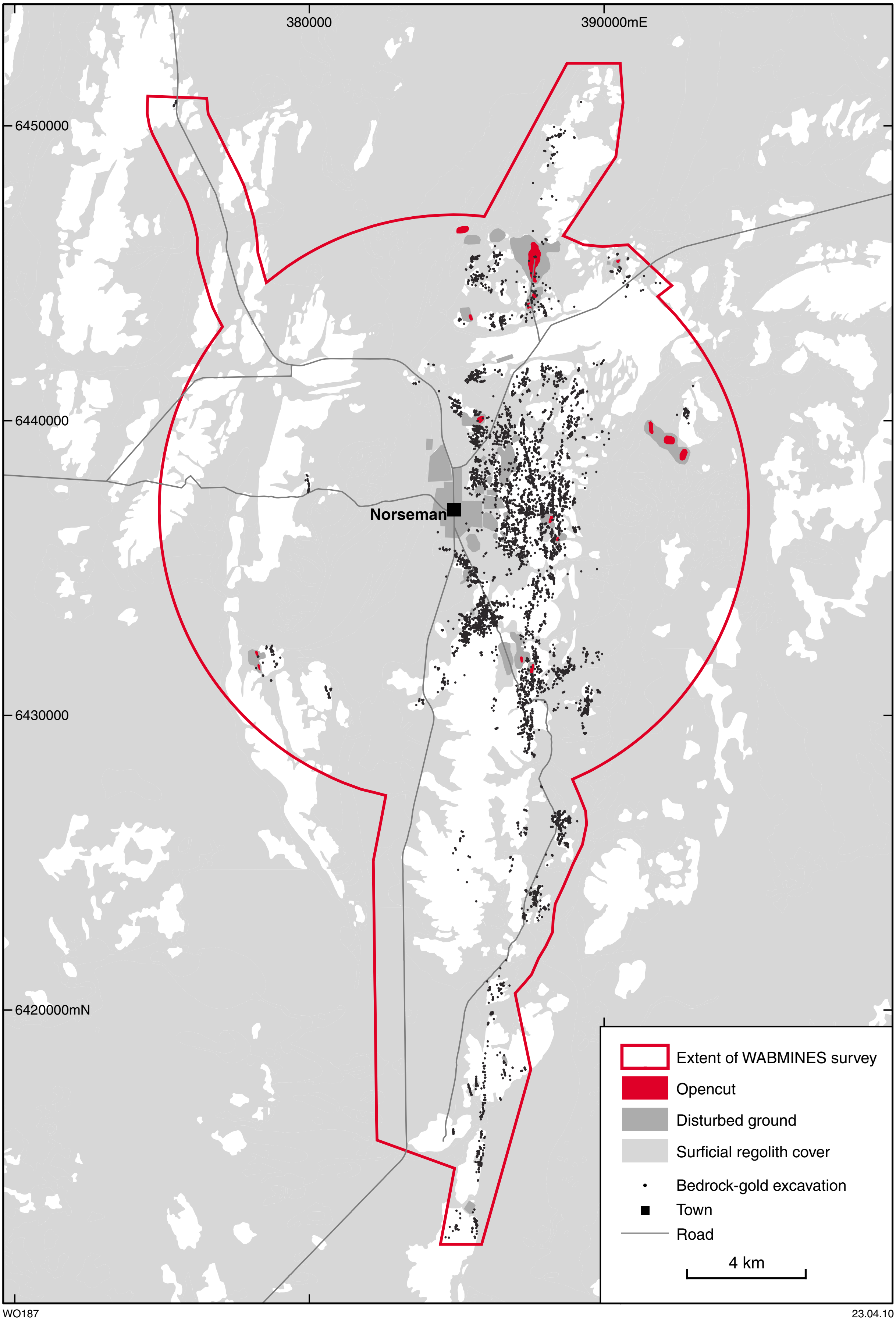

Figure 5.14 Bedrock-gold excavations and extent of the Norseman case-study area. Many of these excavations form linear patterns that may be related to geological structures.

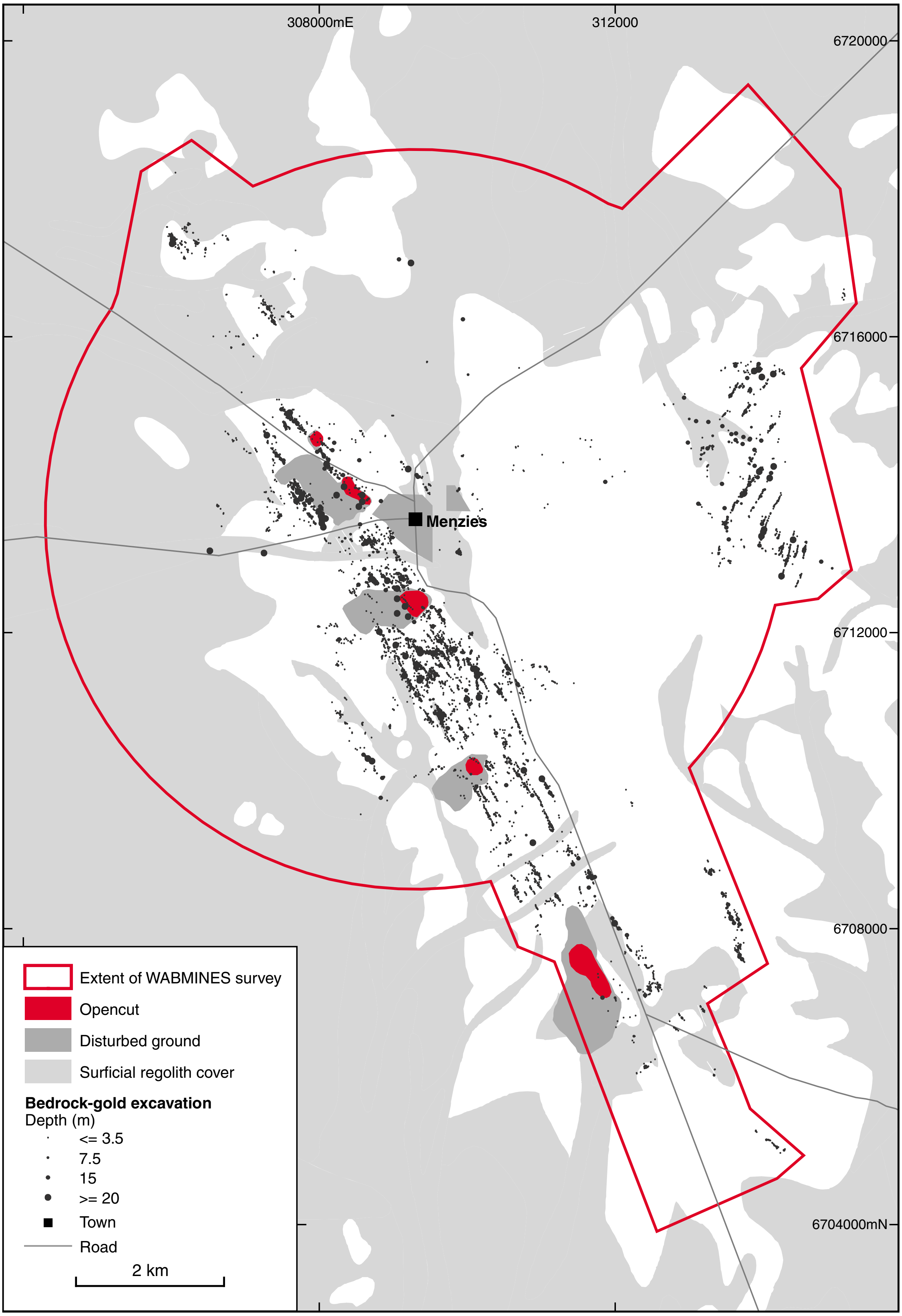

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Figure 5.15 **Bedrock-gold excavations and extent of the Menzies case-study area showing excavation depth. Dot size is proportional to the depth of excavation. The deeper excavations tend to occur in clusters, and may highlight some of the higher gold production geological structures.**

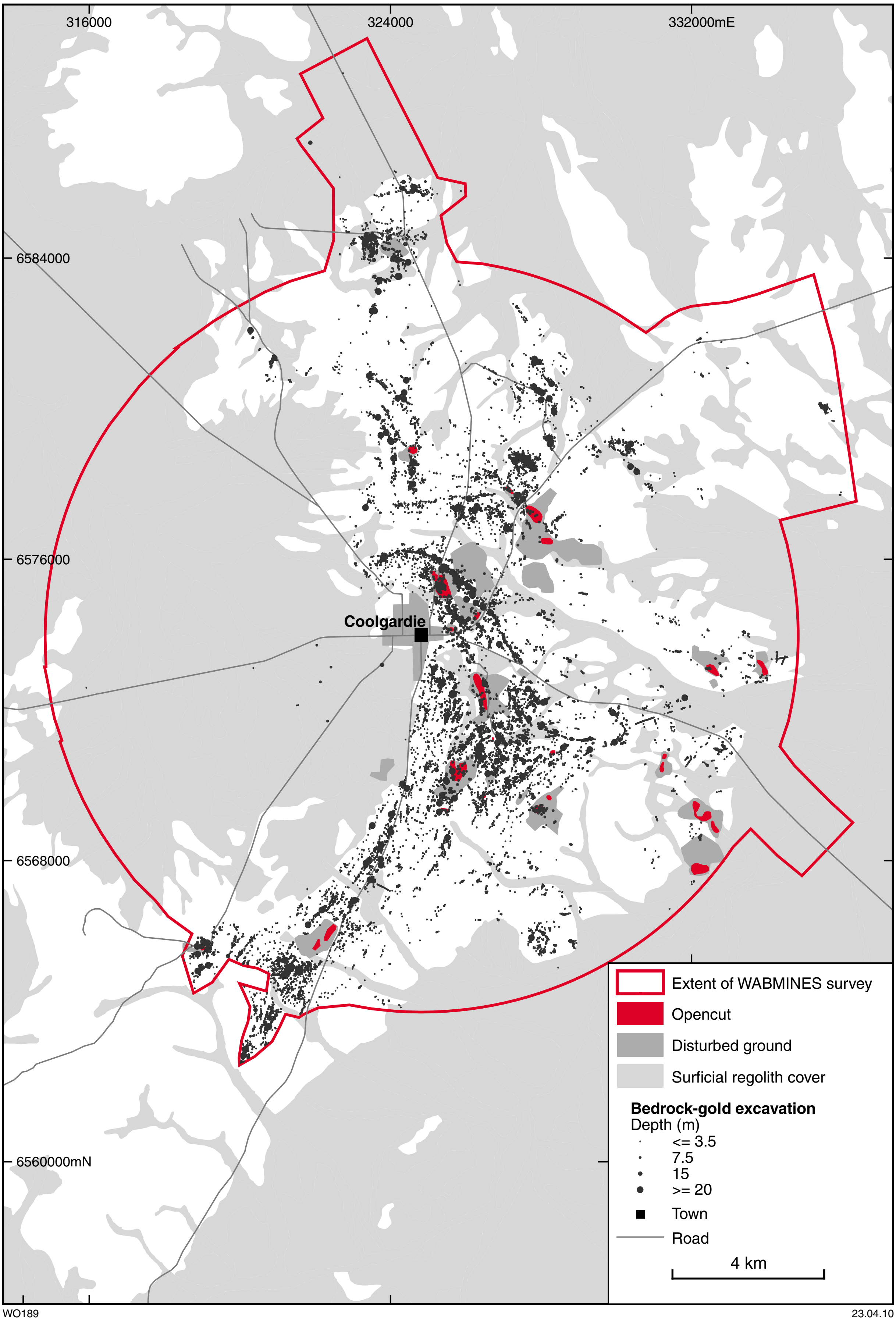

Figure 5.16 **Bedrock-gold excavations and extent of the Coolgardie case-study area showing excavation depth. Dot size is proportional to the depth of excavation. The deeper excavations tend to occur in clusters, and may highlight some of the higher gold production geological structures.**

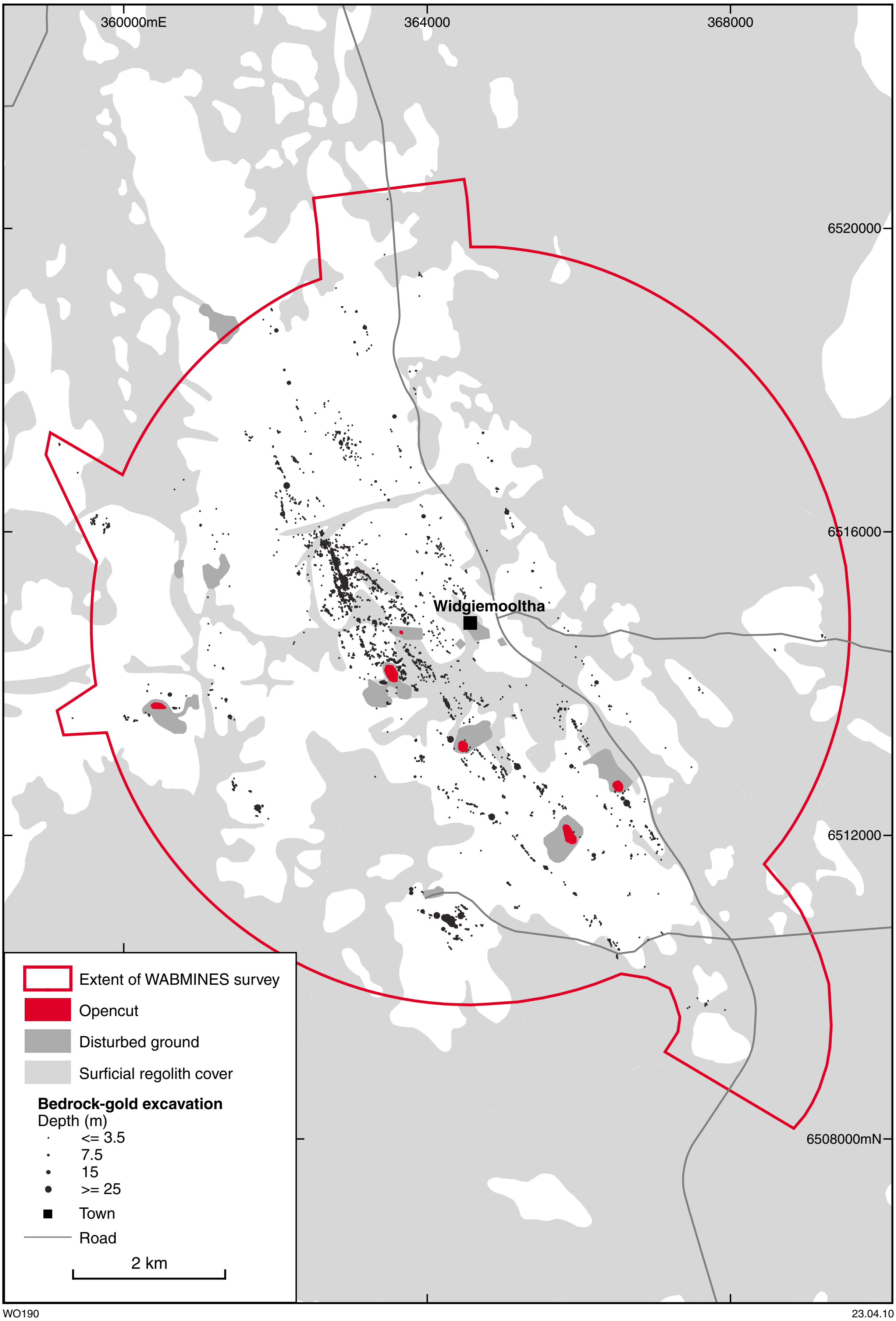

Figure 5.17 Bedrock-gold excavations and extent of the Widgiemooltha case-study area showing excavation depth. Dot size is proportional to the depth of excavation. The deeper excavations tend to occur in clusters, and may highlight some of the higher gold production geological structures.

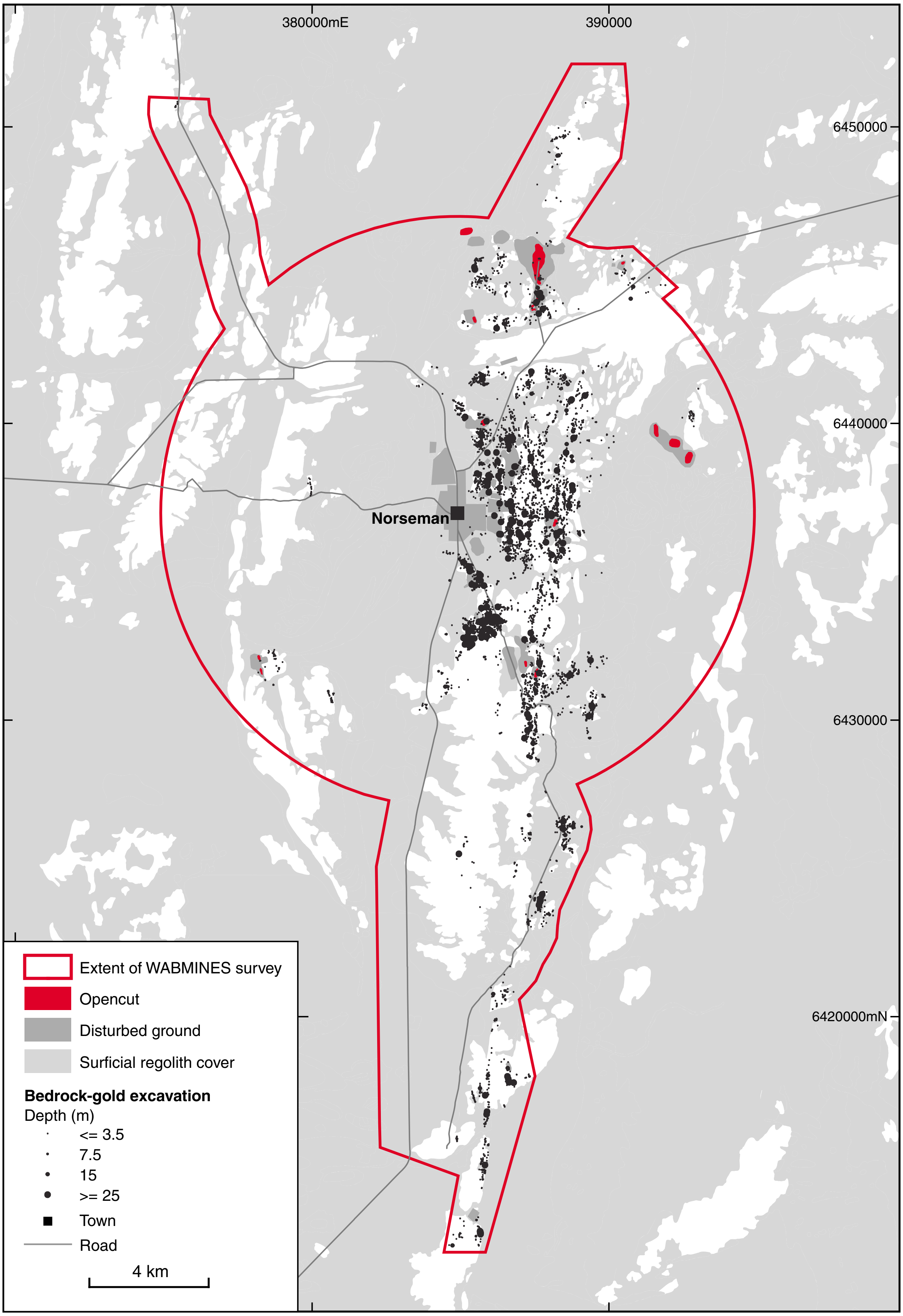

Figure 5.18 Bedrock-gold excavations and extent of the Norseman case-study area showing excavation depth. Dot size is proportional to the depth of excavation. The deeper excavations tend to occur in clusters, and may highlight some of the higher gold production geological structures.

Figures 5.19–5.22 show the resultant pseudocolour hill-shaded images for each of the case-study areas.

5.4.4 Selecting the most suitable presentation format

It is clear from examination of the excavation distribution plots (Figs 5.11–5.14) that they do effectively show linear and curvilinear trend lines at a regional scale.

The excavation depth plots (Figs 5.15–5.18) also effectively show the same trend lines at a regional scale, but have the advantage of highlighting those trends with deeper excavations that may be more significant with respect to gold production.

The pseudocolour hill-shaded images (Figs 5.19–5.22) also show the trend lines at a regional scale, but depth information becomes difficult to distinguish as the scale increases. Thus, the colour shading denoting excavation depth in Figure 5.21 (about 1:42 000 scale) is much more clearly distinguished than for Figure 5.22 (about 1:102 000 scale). Nevertheless, the pseudocolour hill-shaded images are more effective than excavation depth plots at showing detailed trend lines, and subtleties in variations of depth when examined at large scales (Fig. 5.23 is about 1:7 000 scale). For this reason, interpretation of trend lines of bedrock-gold excavations that may represent gold mineralized structures is best done initially at a large scale using pseudocolour hill-shaded images. The resulting detailed trend lines can then form the basis for the interpretation of regional trend lines when viewed at a smaller scale.

In summary, the most suitable presentation format depends upon the viewing scale. Pseudocolour hill-shaded images are most effective at large scales (e.g. 1:5 000), whereas excavation depth plots are most effective at small scales (e.g. 1:100 000).

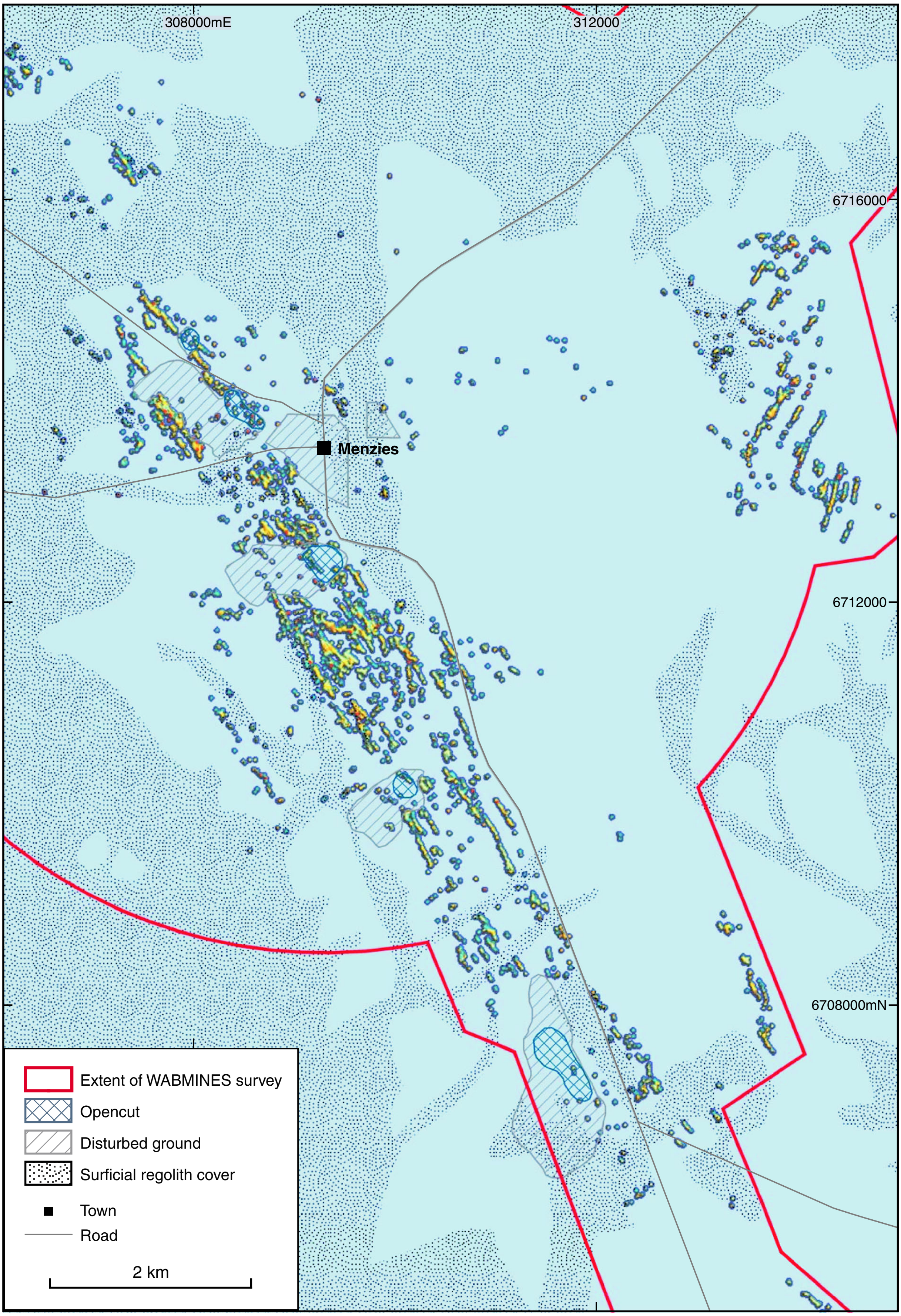

Figure 5.19 **Pseudocolour hill-shaded image showing maximum excavation depth in colour (warm colours represent greater depths) and density of excavations (higher relief indicates greater density) for the Menzies case-study area.**

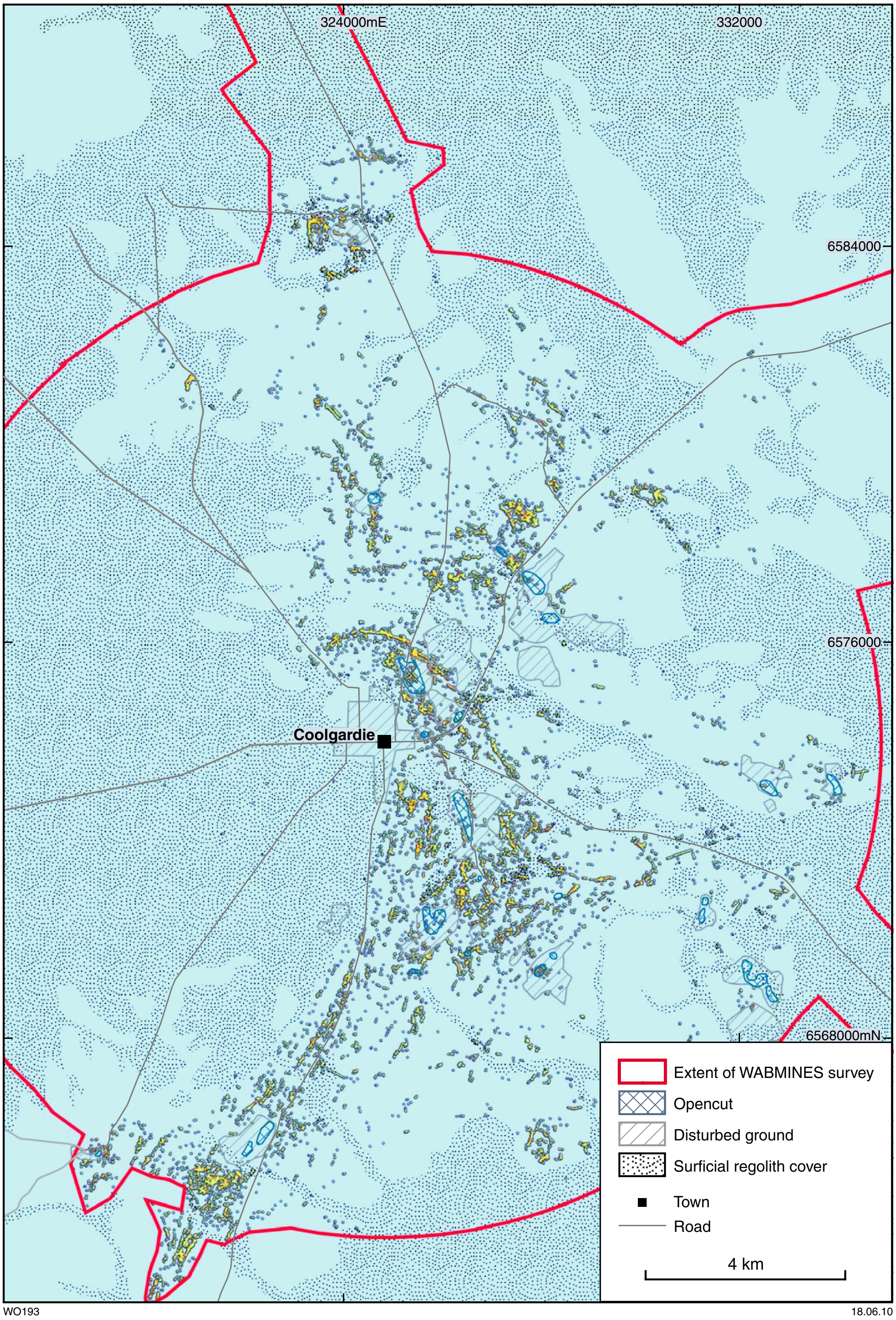

Figure 5.20 Pseudocolour hill-shaded image showing maximum excavation depth in colour (warm colours represent greater depths) and density of excavations (higher relief indicates greater density) for the Coolgardie case-study area

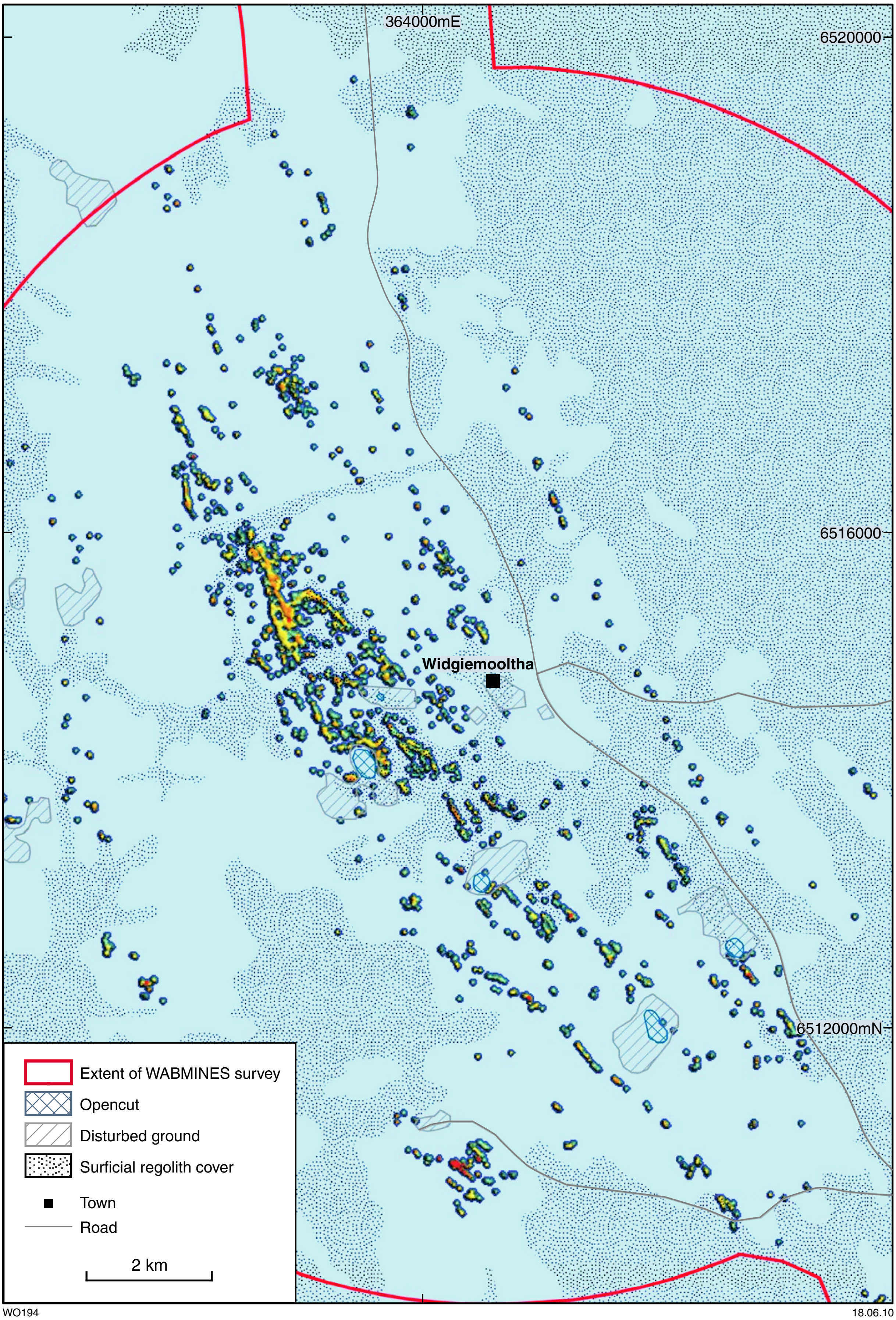

Figure 5.21 Pseudocolour hill-shaded image showing maximum excavation depth in colour (warm colours represent greater depths) and density of excavations (higher relief indicates greater density) for the Widgiemooltha case-study area

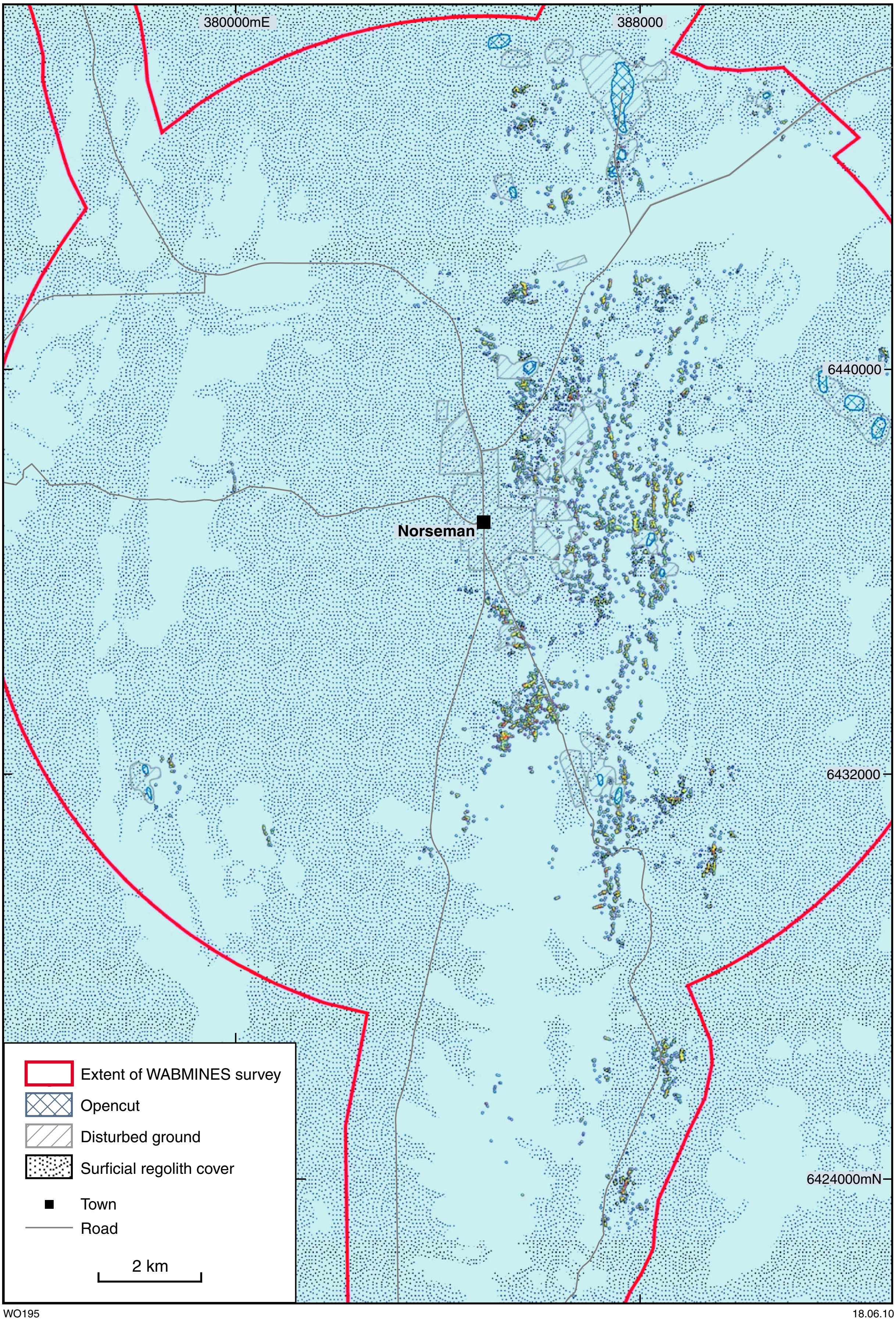

Figure 5.22 Pseudocolour hill-shaded image showing maximum excavation depth in colour (warm colours represent greater depths) and density of excavations (higher relief indicates greater density) for the Norseman case-study area

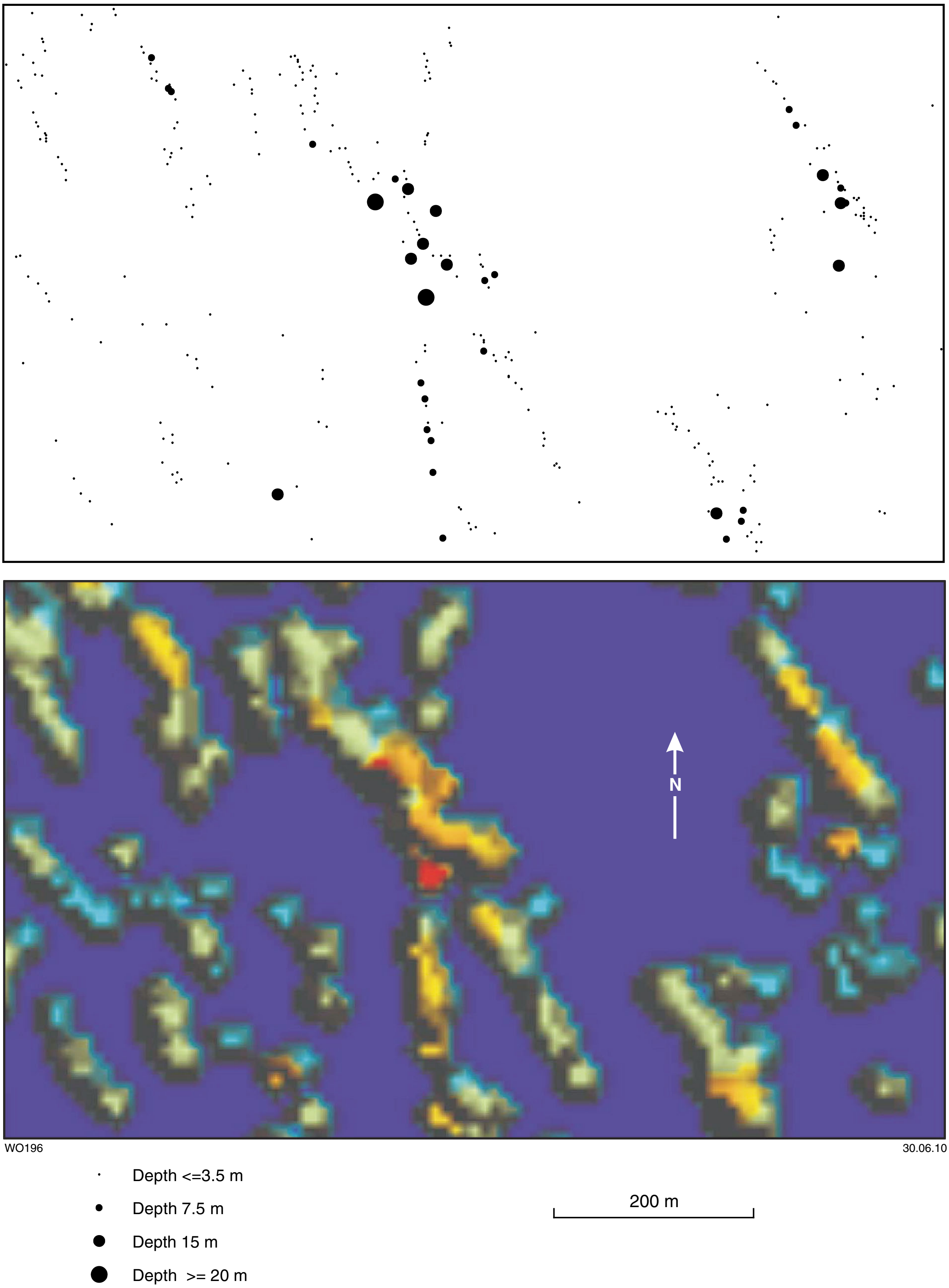

Figure 5.23 Comparison of WABMINES point data showing bedrock-gold excavations and the pseudocolour hill-shaded image of maximum excavation depth (in colour) over density of excavations (relief) for the same part of the Menzies case-study area. These plots are at about 1:7 000 scale

Chapter 6

Relationship between abandoned mine excavations and geological structures

6.1 Introduction

Having devised an effective method for presenting data on bedrock-gold excavations to infer the spatial distribution of past gold production, the next step is to examine the relationship between these excavations and regional-scale geological structures in the case-study areas. This should lead to a better understanding of geological structures that are directly related to gold mineralization, and therefore the identification of exploration targets.

Specific examples of correlations between bedrock-gold excavations and mapped geological structures were examined for each case-study area. These were compared with the information provided by the historic mine sites in the MINEDEX database which has formed the basis for previous regional-scale prospectivity studies in Western Australia (Knox-Robinson, 2000; Brown, 2002). Abandoned mine excavations were then used to identify other gold-mineralized structures that may not be apparent from regional mapping, and to identify new exploration targets.

6.2 Menzies case study

Historical gold production for Menzies was in excess of 25 tonnes (Swager, 1994). The largest historical gold producers were Yunndaga (8.7 t), Lady Shenton (5.8 t), and First Hit (2.5 t), all of which lie within the Menzies Shear Zone, and have been the subject of more-recent opencut mining (Fig. 6.1). Comparatively minor gold production of about 750 kg has also been recorded from the eastern Menzies region (Witt, 1993a).

Early mine geology was described by Woodward (1906), and Witt (1993a) provided a more-recent overview of geology for all mines with historical gold production of more than 5 kg. The rock type and structural controls on gold mineralization for the Menzies to Kambalda region were well documented by Witt (1993b,c). Witt (1993c) concluded that all gold deposits in the Menzies–Kambalda area are structurally controlled, with the character of the ore-bearing structures reflecting many factors — metamorphic grade, structural setting of the host rocks, and the orientations of structures within the regional and local stress fields being of prime importance. Witt (1993b) also provided information about other aspects of gold mineralization in the study area including alteration, ore fluid composition, and timing of mineralization.

The regional geology of the Menzies area was described by Swager (1994), and was summarized by Wyche (2003). Structure is dominated by the north-northwesterly trending Menzies Shear Zone (Fig. 6.1), which is defined by strongly foliated and lineated rocks and interleaving of rock types (Swager, 1994). East of the Menzies Shear Zone, the study area covers an open, southwest-plunging synclinal structure that is interpreted to have resulted from the emplacement of post-D_2 to syn-D_3 granitic rocks (Swager, 1994; Witt, 1993c).

Figure 6.1 shows the two areas that were examined in detail in this study.

6.2.1 Maranoa area

The Maranoa area is in the eastern Menzies mining district and covers an open synclinal structure within basalt (Fig. 6.2; Swager, 1994). The synclinal structure is interpreted to be bound by shallow south- to southwest-dipping thrust fault zones in the underlying shale and schists (Swager, 1994; Witt, 1993c). Figure 6.2 shows the largest historical mines in the area: Maranoa (288 kg Au), and Goodenough (264 kg Au; Witt, 1993a). The mineralization at Goodenough is associated with a 1 to 2-m thick zone of banded quartz–sulfide(–biotite) rock along the shallow south-dipping (thrust-faulted) contact of a felsic schist and the overlying basalt (Witt, 1993a). Significantly, Witt (1993a) noted minor mineralization along the margins of a crosscutting quartz–plagioclase–biotite porphyritic rock. The mineralization at Maranoa occurs along a steeply southeast-dipping, 0.2 to 2 m-wide shear zone that trends 035° within an altered mafic rock (Witt, 1993a).

Examination of the distribution of historic mine sites from MINEDEX in Figure 6.2 (map on left), reveals little information on the orientation or length of the mineralized structures. In contrast, the bedrock-gold excavation image (Fig. 6.2, map on right) clearly shows the dominant north-northeast trend of many of the mineralized structures (including the Maranoa structure), their surface strike extent, and their close association with similar trending mapped porphyritic rocks. These north-northeasterly trending structures within the competent basalt were interpreted by Witt (1993a) to have been extensional during the thrust faulting along the contact with the underlying, less competent, shale and felsic schist. Some of the bedrock-gold excavations in the Goodenough

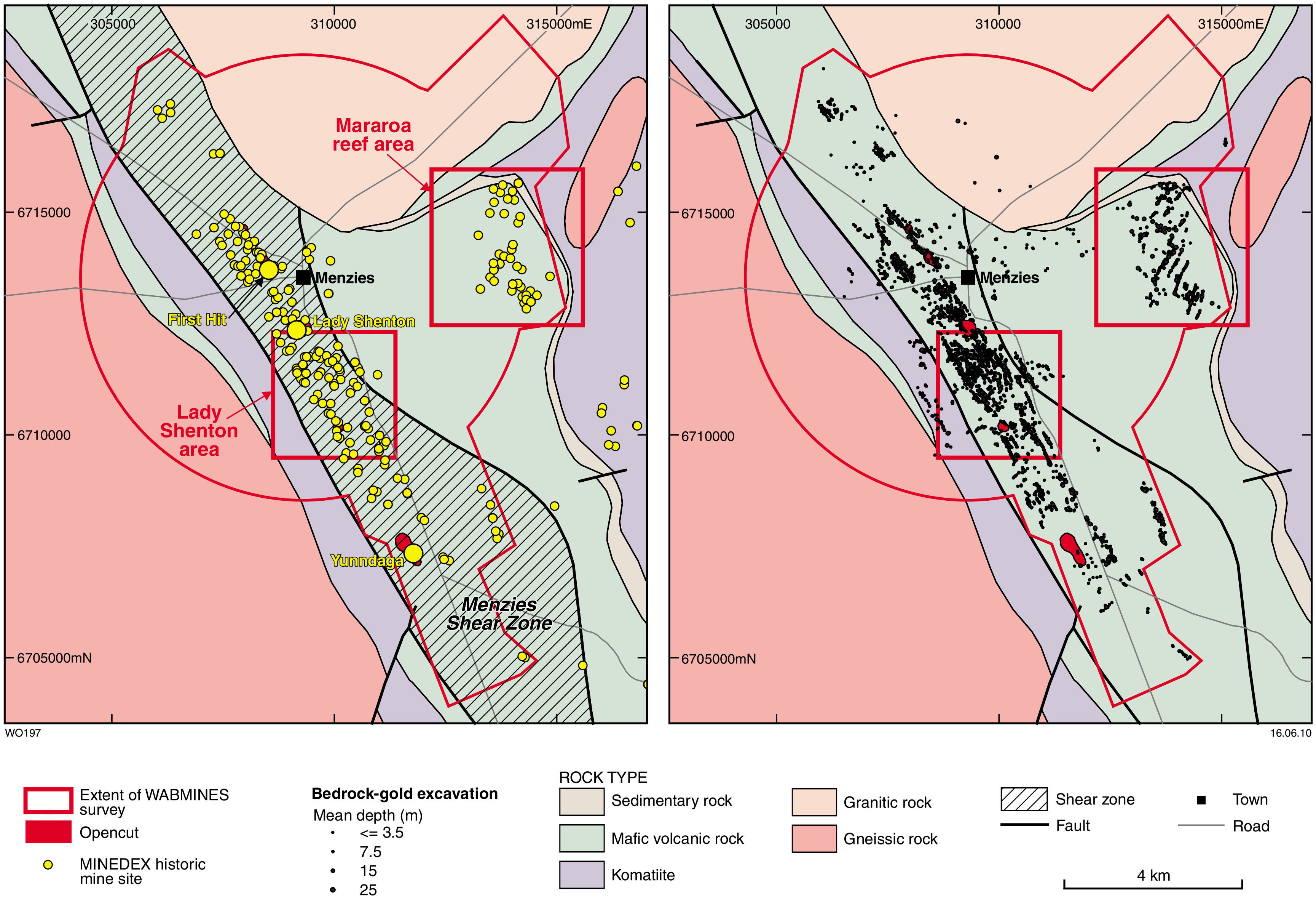

Figure 6.1 Menzies case-study area showing regional geology and the location of specific example areas. Left-hand map shows historic mine sites and major historical gold production sites plotted from the MINEDEX database. Right-hand map shows the bedrock-gold excavations.

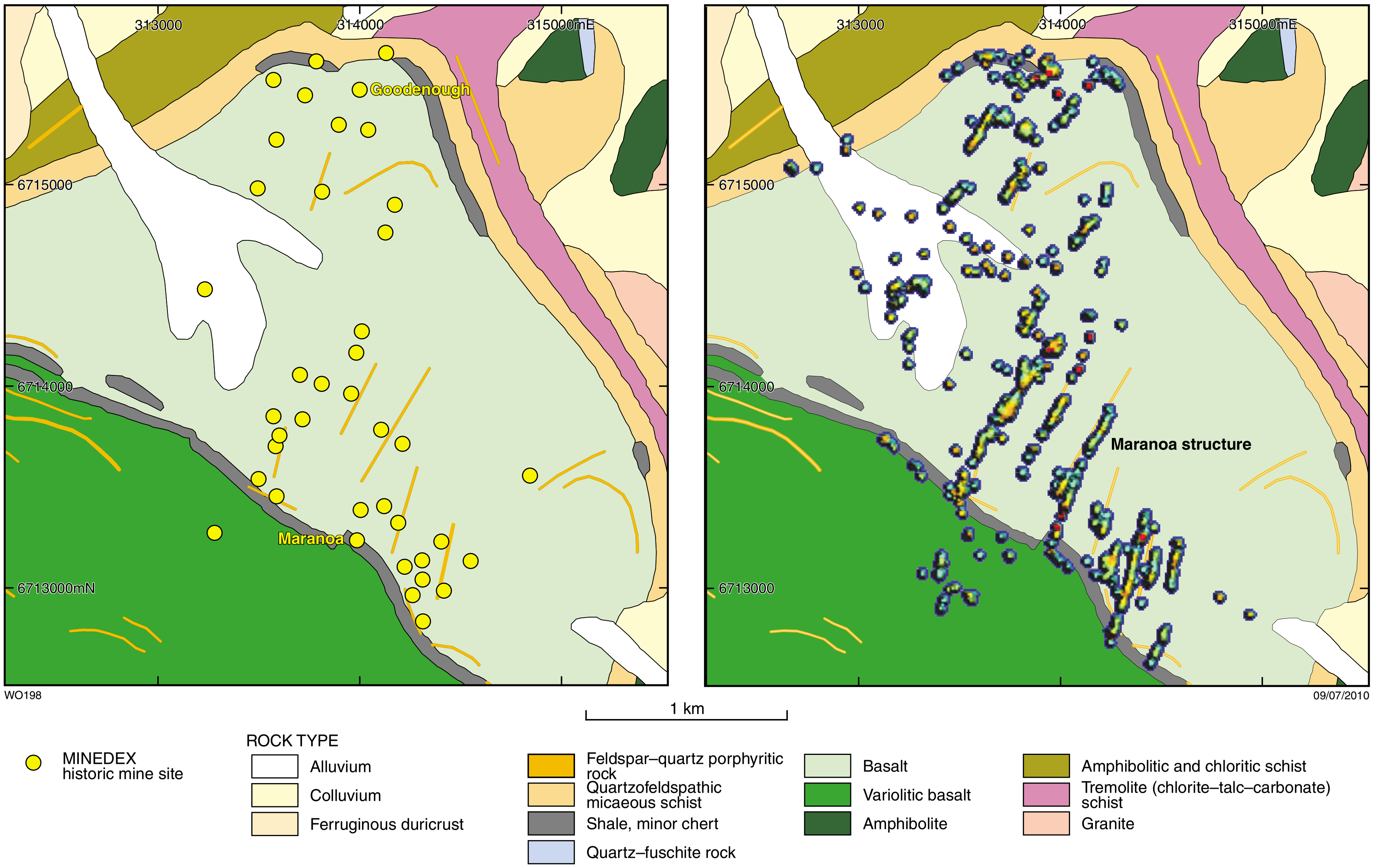

Figure 6.2 **Maranoa deposit and surrounding area, Menzies, showing 1:100 000-scale geology. Note the additional information provided by the bedrock-gold excavation data on the right-hand map compared to the MINEDEX historic mine sites (yellow dots) on the left-hand map.**

area also follow the nearly perpendicular thrust-faulted contact of the basalt with the shale and schist. Consistent with the previous finding of a correlation between gold production and excavation depth, both the Goodenough and Maranoa mine sites are marked by deeper (red coloured) excavations.

6.2.2 Lady Shenton area

The Lady Shenton area is located along the Menzies Shear Zone, just to the south of the former Lady Shenton mine (Fig. 6.1). The Menzies Shear Zone consists of strongly deformed and interleaved mafic, ultramafic, and sedimentary rocks that have been metamorphosed to mid- to upper-amphibolite facies, and undergone sinistral displacement (Witt, 1993a). The largest and richest mines within the Menzies Shear Zone (e.g. Lady Shenton) are located on banded brittle–ductile shears, which host lenticular pipe-like ore bodies that consistently plunge in the same direction as stretching lineations and slickensides, i.e. 30 to 40° to the south (Witt, 1993a). Both along and across strike from these banded shears, the mineralized structures are mainly quartz vein-dominated shear zones (Witt, 1993a). Mines described by Witt (1993a) that occur within the Lady Shenton area (Maori Chief, Lincoln, Ballarat Menzies, and Lady Harriet) are all associated with narrow (1 to 3-m wide) shears that strike broadly conformably with the Menzies Shear Zone (135 to 155°), and dip to the west at 70°.

The spatial distribution of historic mine sites in MINEDEX does not provide much information on the orientation or length of the mineralized structures (Fig. 6.3). The bedrock-gold excavation image clearly shows the north-northwest trend of most of the mineralized structures, which follow the broader trend of the Menzies Shear Zone, and a close spatial association between many of the excavations and the mapped sedimentary and ultramafic rocks. The thickest, westernmost sedimentary rock unit hosts the Yunndaga mine (Fig. 6.1) to the south of the Lady Shenton area, where the main rock type is fine- to coarse-grained arkose (Witt, 1993a). Nevertheless, the trends of many of the bedrock-gold excavations in Figure 6.3 are also slightly discordant, and have a more westerly strike than the mapped sedimentary and ultramafic rock boundaries. Woodward (1906) described the ‘belt’ as comprising ‘a series (of lodes) lying more or less parallel to each other, crossing the main belt diagonally upon a course rather more westerly’. Again, it is not possible to resolve these trends at this level of detail from the MINEDEX historical mine site data.

Figure 6.3 further illustrates a west-northwesterly trending structure (labelled ‘A’) in the upper part of the Lady Shenton area. Witt (1993a) noted that faults in this orientation, which apparently post-date the main movements on the Menzies Shear Zone, may be of importance to mineralization in this area as several mines, including Lady Shenton, appear to be on or close to these faults. There are also three other localities (labelled ‘B’, ‘C’, and ‘D’ in Figure 6.3) where mineralized structures appear to converge to form inverted ‘Y’ shapes. Figure 5.23 is an enlargement of locality C. At each of the locations, labelled ‘A’, ‘B’, and ‘C’, deeper excavations occur in the vicinity of the intersections of these structures, suggesting greater gold production occurred at these favourable structural sites.

6.3 Coolgardie case study

Total historical gold production from the Coolgardie case-study area is difficult to estimate as records are often incomplete. In particular, much of the early alluvial gold production was never officially reported (Blatchford, 1899), and reporting of gold production from the pre-Mining Act 1904 Hampton lands on the eastern side of the case-study area may be incomplete as there are no historic mine sites recorded in the MINEDEX database shown in this area, despite obvious historical mining activity. Nevertheless, official figures compiled by Hunter (1993) for the Bonnievale, Coolgardie, and Burbanks areas showed total gold production to be in excess of 35 t to 1971. These figures do not include subsequent gold production from the many recent opencuts. The largest historical gold producers were the Bayleys (8.4 t; Swager, 1990) and Burbanks mines (8.8 t; MINEDEX), followed by the Bonnievale (5.5 t; MINEDEX) and Tindals mines (3.7 t; McCormick and Hanna, 1990).

Early mine geology was recorded by Blatchford (1899), Blatchford (1913), and McMath et al. (1953). Blatchford (1899) described the gold as occurring in ‘lode formations’ that consist of ‘schistose rocks traversed by a network of quartz leaders’ without sharply defined boundaries, and as quartz reefs. In a later report, covering in part the Tindals and Burbanks mining centres, Blatchford (1913) described a third type of gold host: the ‘acid dyke’. McMath et al. (1953) regarded the gold mineralization to be post-folding in age, and genetically associated with the granitic intrusive rocks, noting that gold mineralization was ‘never very far removed’ from the contact with a major granite. McMath et al. (1953) also postulated that gold mineralization was associated with the intersections of east-northeasterly trending ‘cross-fold’ axes and the regional north-northwest trend.

Knight et al. (1993) examined district-scale controls on the gold mineralization, concluding that gold mineralization was broadly synchronous with peak metamorphism (to amphibolite facies), the main phase of granitic rock emplacement, and regional deformation within an east–west compressional far-field stress regime, but with local heterogeneous stress orientations. The following four modes of occurrence of gold mineralization were recognized by Knight et al. (1993):

1) sheared felsic porphyry–ultramafic rock contacts;
2) gabbro-hosted quartz-vein sets;
3) fault-bound quartz-vein sets;
4) laminated quartz reefs sited in brittle–ductile shear zones.

The regional geology for Coolgardie was described by Hunter (1993), and summarized by Wyche (1998). The general strike of the stratigraphy in Coolgardie is arcuate around syntectonic monzogranites that occupy the western part of the study area (Fig. 6.4). Stratigraphic units are

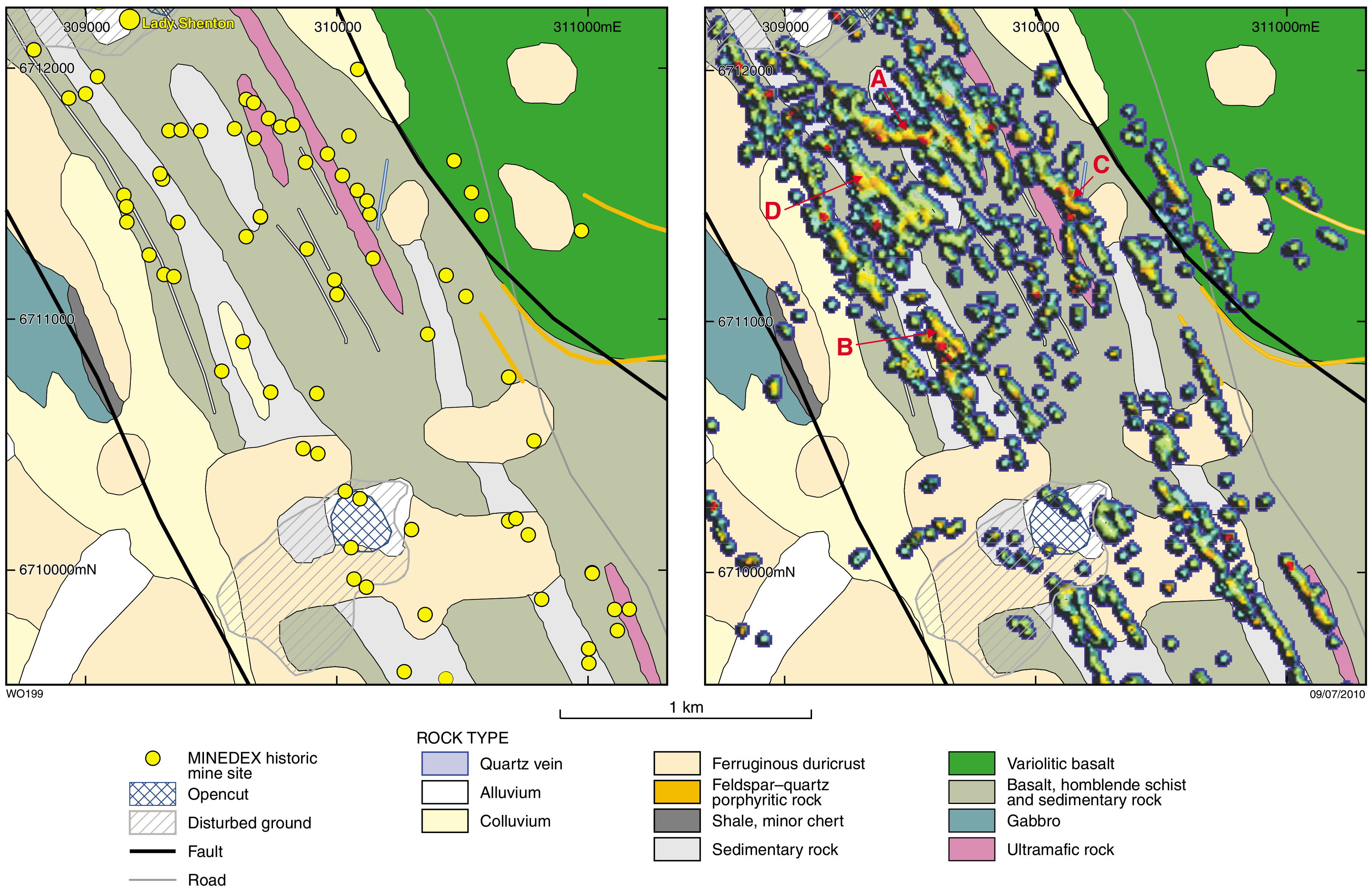

Figure 6.3 Lady Shenton deposit and the area to the south, Menzies, showing 1:100 000-scale geology within the Menzies Shear Zone. Note the additional information provided by the bedrock-gold excavation data on the right-hand map compared to the MINEDEX historic mine sites on the left-hand map. A west-northwesterly trending structure is labelled 'A', and three converging structures are labelled 'B', 'C', and 'D'.

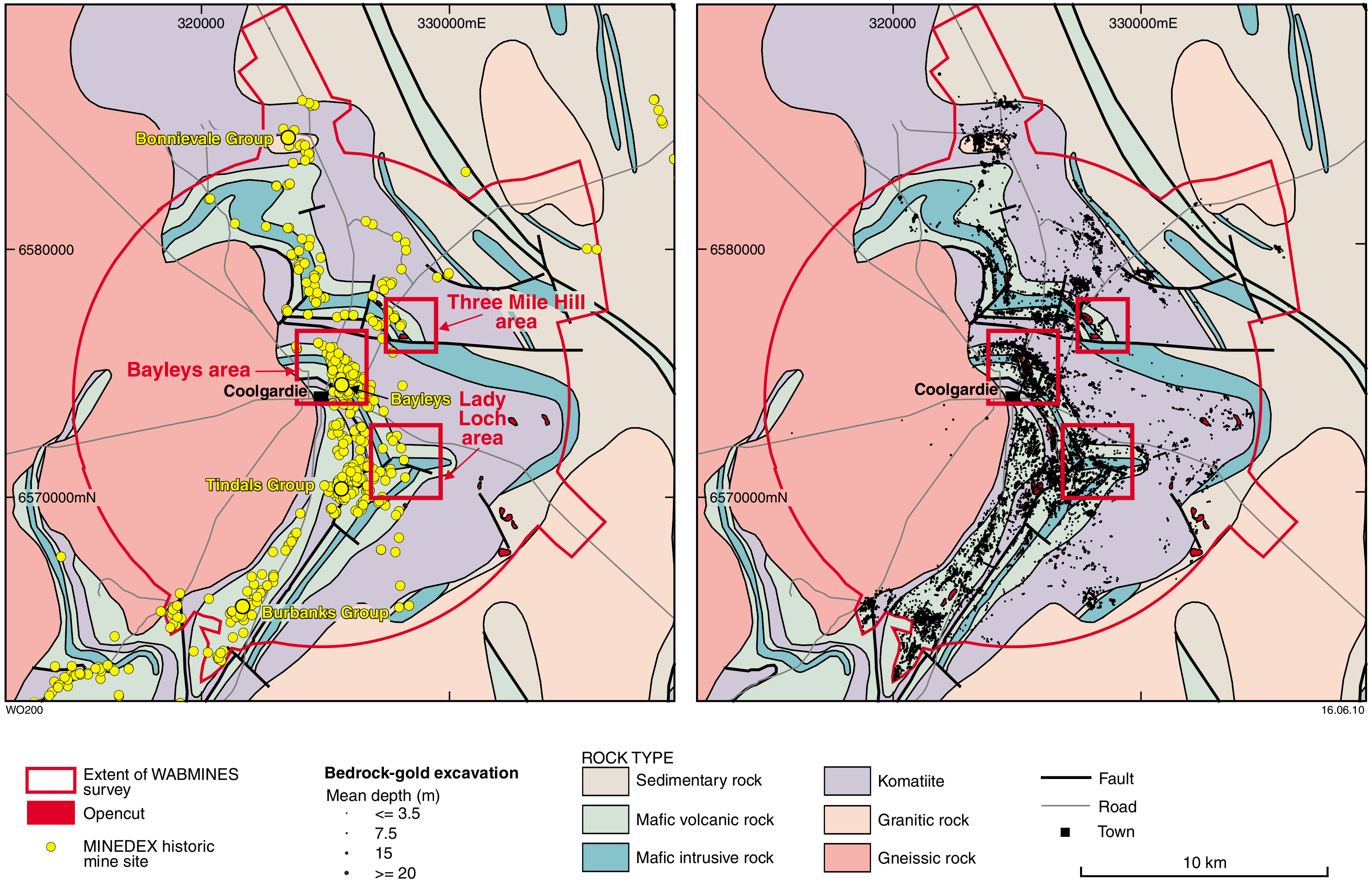

Figure 6.4 Coolgardie case-study area showing regional geology and locations of the example areas. Left-hand map shows the MINEDEX historic mine sites with the major historical gold production sites labelled. Right-hand map shows the bedrock-gold excavations.

summarized in Chapter 1 (Section 1.4). All units have steep dips and are metamorphosed at upper greenschist to lower amphibolite facies (Hunter, 1993). The main fault orientation is north-northeast, with common west to northwesterly trending faults (Hunter, 1993). Repetition of ultramafic–mafic sequences indicates the possibility of regionally extensive thrust faulting in the Coolgardie area (Wyche, 1998).

Figure 6.4 shows the three areas that were examined in detail in the study area.

6.3.1 Three Mile Hill area

The Three Mile Hill area is centred on an east-northeasterly trending fault with dextral displacement close to the relatively recently developed Three Mile Hill and Greenfields openpits (Fig. 6.5). A line of bedrock-gold excavations extends for about 400 m, crosscutting a pyroxene spinifex-textured basalt following the trend of the mapped dextral fault. A description in the WABMINES database (Site ID CDS11273) records a quartz vein up to 2 m thick, striking 240° and dipping to the northwest at 50° in an inclined shaft that follows the vein. This excavation, and two shallow open stopes in the area (Site IDs CDS11280 and CDS11298) confirm that the orientation of the feature sought in the bedrock-gold excavations follows the fault trend. This trend can therefore be used to refine the regional-scale mapping as shown in the right-hand image in Figure 6.5.

Works associated with the nearby Three Mile Hill and Greenfields opencuts have removed any other bedrock-gold excavations that may have been present further to the southwest. Both of these deposits were of the gabbro-hosted, quartz-vein-set type. Middleton (1990) described the gold mineralization at Three Mile Hill as tensional-fracture controlled, and stratabound to a particular unit within a northwest-trending 'layered metagabbro complex'. Gold mineralization in the Greenfields opencut also formed in sheeted veins along extensional fractures (Keele and Shelton, 1990).

6.3.2 Bayleys area

The Bayleys area covers the Bayleys gold deposit and other associated bedrock-gold excavations to the northeast of Coolgardie (Fig. 6.6). The more-recent Lindsays, Kings Cross, and King Solomon opencuts are also located in the Bayleys area. Knight et al. (1993) classified the Bayleys and King Solomon gold deposits as 'sheared porphyry–ultramafic rock contact' style of mineralization, the Lindsays deposit to the 'fault-bounded quartz-vein sets' mineralization style, and the Kings Cross orebody to their 'laminated quartz reefs' style. The example in this section focuses on the type of mineralization associated with the Bayleys deposit where the orebodies are hosted by laminated or bucky quartz reefs that form discontinuous pipe-like bodies within the ultramafic sequence (Swager, 1990).

Swager (1990) described the mine geology at Bayleys as being characterized by steeply north-northeasterly dipping basalt overlain by a thin (1 to 2 m) black shale layer, and variably deformed komatiitic rocks. Thin interflow black shale horizons are present throughout the ultramafic sequence, and dacitic or porphyritic albite bodies, averaging 10 m wide, occur along the black shale at the contact between the mafic and ultramafic sequences. Figure 6.6 shows that bedrock-gold excavations commonly follow this contact. In the eastern half of Figure 6.6, there is also commonly a second sub-parallel line of excavations to the north of the basalt–komatiite contact. These observations, combined with observed black shale occurrences in the excavations (labelled 'WABMINES black shale' in Figure 6.6), historic mapping (McMath et al., 1953), and current regional mapping, enabled the refinement of mapping of the shale unit as shown on the right-hand side of Figure 6.6. Better definition of this marker horizon resulted in more-precise mapping of the faults, particularly the Lindsays fault (Fig. 6.6), by the author.

6.3.3 Lady Loch area

The Lady Loch area is located to the east of the Tindals Group of mines (Fig. 6.4), and does not include any major historical mines. Nevertheless, this example provides further confirmation of the correlation between mapped faults and bedrock-gold excavations (Fig. 6.7). Two easterly trending faults in the central part of Figure 6.7 (labelled 'A' and 'B') show a good correlation with bedrock-gold excavations. The northernmost of these two structures (A) coincides with the former Lady Loch Extended gold mine, which was described in a Mines Department Sundry Mining Report dated 1896 (compiled as an Appendix *in* McMath et al., 1953) as a 'reef striking in an easterly direction' with a width of 5.7 m at the 16.15 m level where it consisted of 'four bands of quartz with intervening formations'. There is also another example of a northeast-trending fault apparently offsetting bedrock-gold excavations (labelled 'C' in Figure 6.7). On the southern side of this fault, a southeast-trending line of excavations follows a mapped antiform (D). Other features to note are northeast (E) and east trends (F and G) that may indicate further unmapped mineralized faults in these orientations, and the northeast-trending line of excavations along a shale unit (H). The latter mineralization has been mined relatively recently at the Boundary openpit (Fig. 6.7).

6.4 Widgiemooltha case study

The Widgiemooltha case-study area has had comparatively minor historical gold production, totalling only 450 kg (MINEDEX) but, as in the other study areas, there has been some more-recent opencut mining activity for gold. Today the region is best known for its nickel mining and exploration activity. Most historical gold production came from three mining groups, namely Host (now called Mount; 170 kg Au; MINEDEX), Flinders (117 kg Au; MINEDEX), and Cardiff Castle (111 kg Au; MINEDEX; Fig. 6.8).

There are no detailed accounts of early gold mining activity in the Widgiemooltha case-study area. However, Marston (1984) provided a compilation of the economic

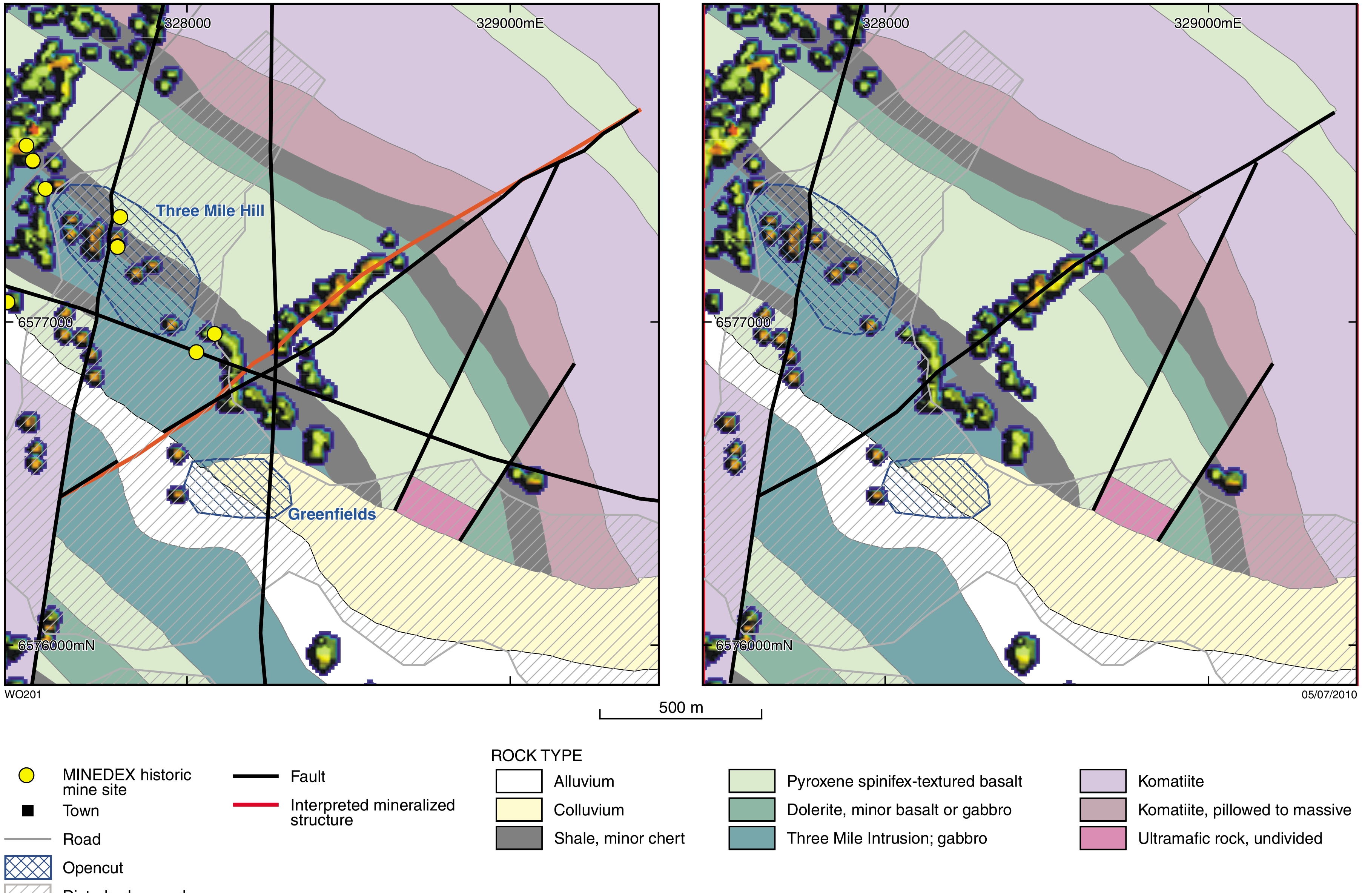

Figure 6.5 Three Mile Hill area, Coolgardie, showing 1:100 000-scale geology and bedrock-gold excavation data. The right-hand map shows the interpreted northeast-trending fault location based on the bedrock-gold excavation data. This fault is also shown in red in the left-hand map.

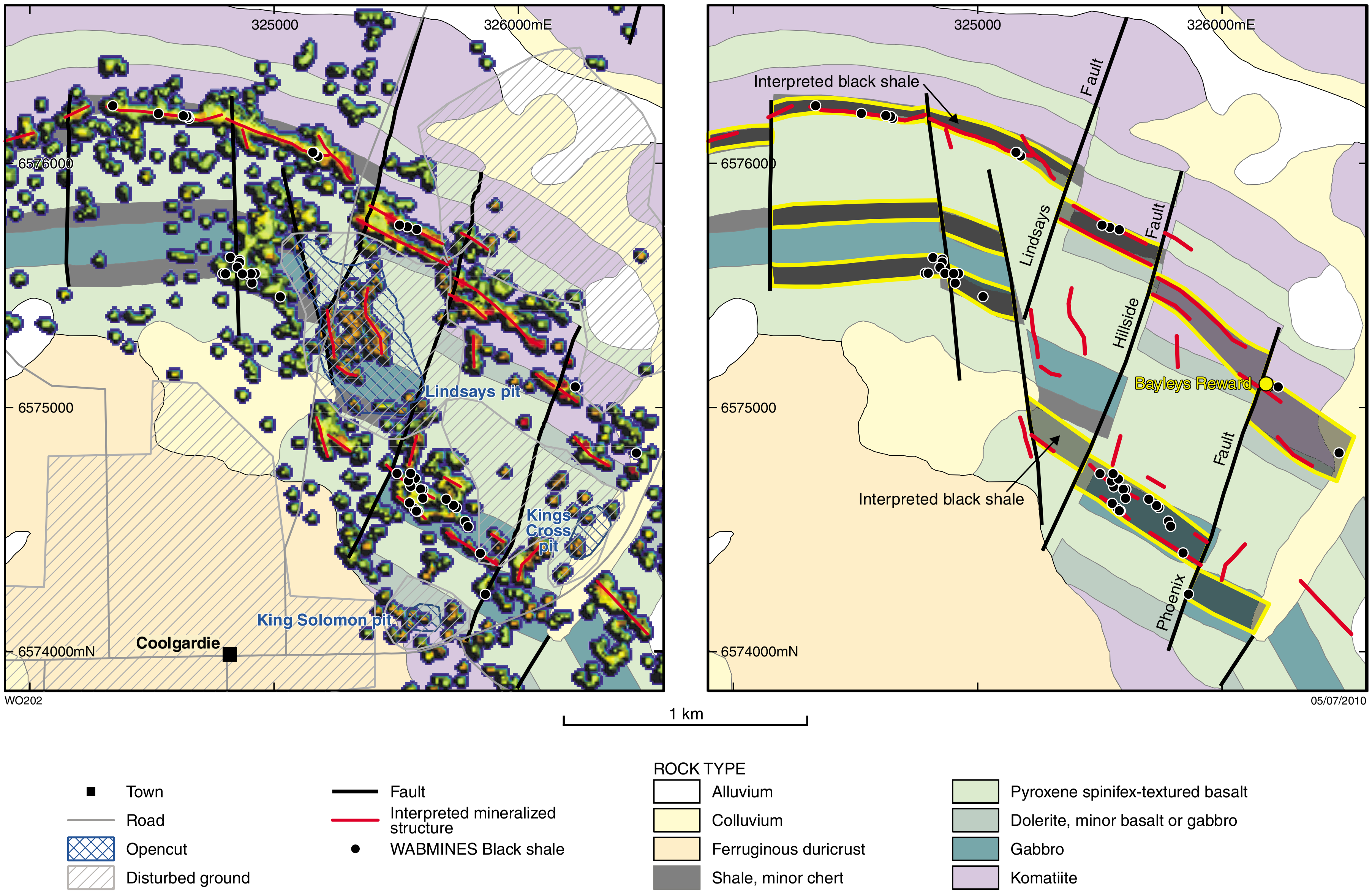

Figure 6.6 Bayleys area, Coolgardie, showing 1:100 000-scale geology and bedrock-gold excavation data. The right-hand map shows the shale and fault locations taking into account the shale-hosted mineralization interpreted from the bedrock-gold excavation data.

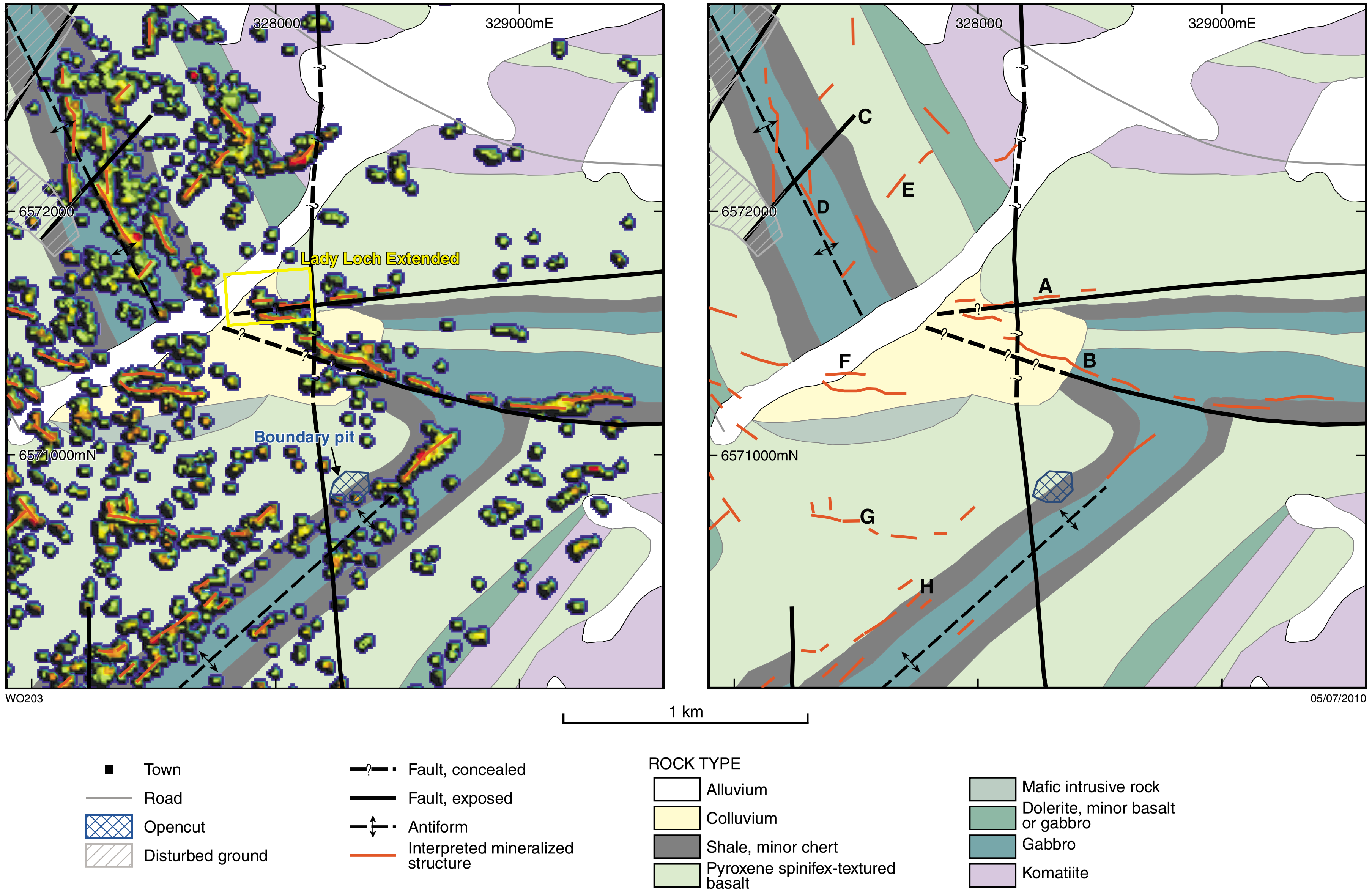

Figure 6.7 Lady Loch area, Coolgardie, showing 1:100 000-scale geology, bedrock excavation data, and interpreted mineralized structures. Interpreted structures A, B, C, and D correlate well with mapped structures, whereas E, F, G, and H probably represent additional unmapped structures.

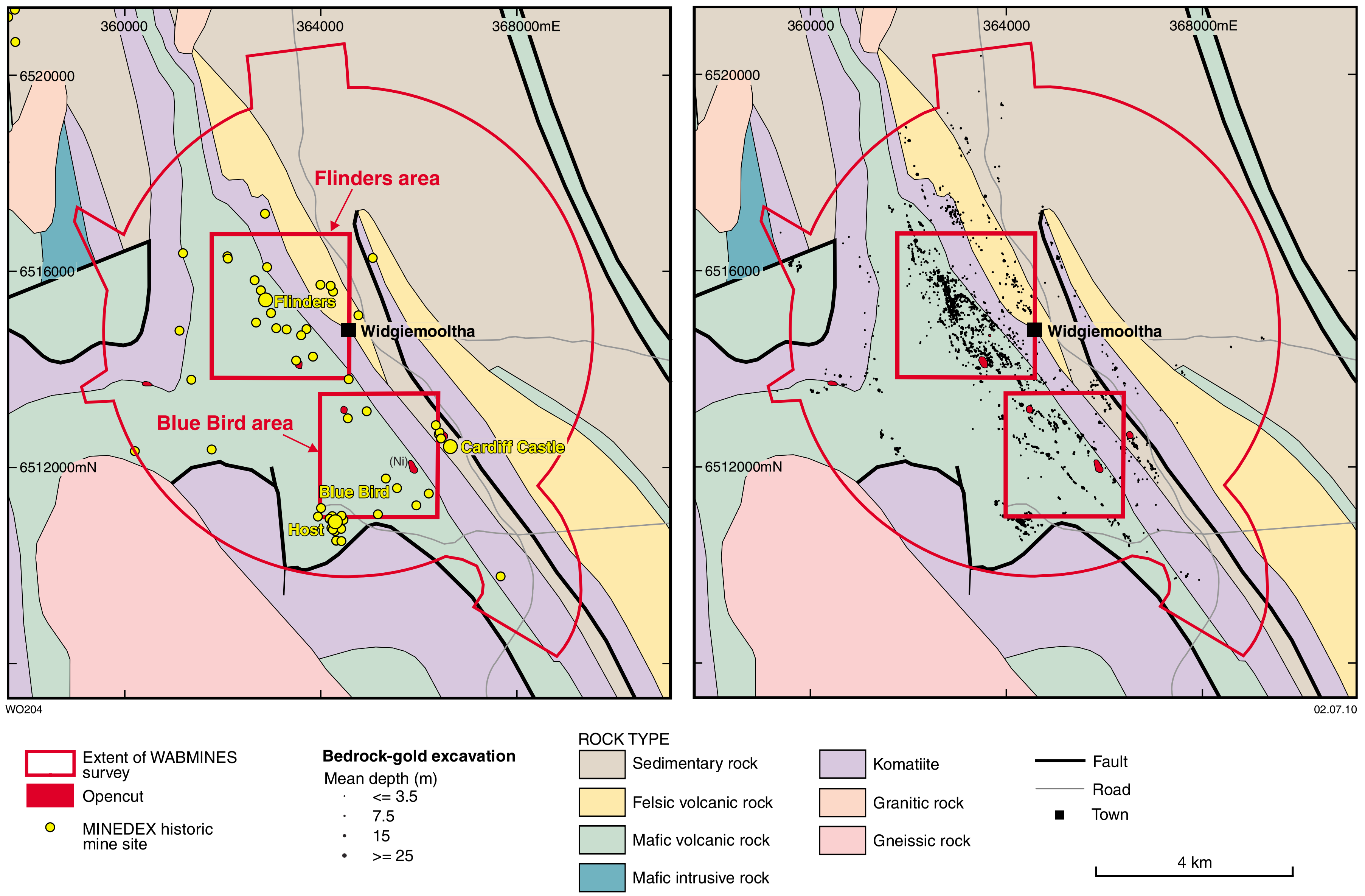

Figure 6.8 Widgiemooltha case-study area showing regional geology and the location of specific example areas. Left-hand map shows the MINEDEX historic mine sites with the major historical gold production sites labelled. Right-hand map shows the location of bedrock-gold excavations.

geology of the Widgiemooltha area in relation to its nickel mineralization. Marston (1984) and Griffin (1990) described the regional geology of the Widgiemooltha area. The study area lies to the northeast of a regional dome that is occupied by deformed syntectonic granitic rocks. The stratigraphy is summarized in Chapter 1 (Section 1.4). Stratigraphic units mainly strike northwest but trend westerly around the northern end of the dome (Fig. 6.8). Metamorphism reached middle amphibolite facies in the study area. Mapped faults tend to follow stratigraphic contacts. Repetition of the basalt–komatiite interval in this region has been attributed to structural repetition (Griffin, 1990).

Figure 6.8 compares the distribution of MINEDEX historical mine sites with the bedrock-gold excavations at a regional scale, and shows the two areas that were chosen for more-detailed examination. Note that the MINEDEX sites in the southeastern part of the study area (yellow dots in the left-hand map) give the impression of a northeast-trending structural control on the gold mineralization. Although there may be a higher level control in this orientation, the bedrock-gold excavations clearly show the northwest-trending structural control that dominates in this region.

6.4.1 Blue Bird area

The Blue Bird area is located between the Host and Cardiff Castle mining groups, and contains a number of northwest-trending gold-mineralized structures within the pyroxene spinifex-textured basalt (Fig. 6.9). Again, the bedrock-gold excavations more clearly delineate the close association of gold mineralization with thin, slightly discordant porphyritic monzogranite intrusions than do the MINEDEX sites.

6.4.2 Flinders area

The Flinders area is centred on the Flinders mining group where a cluster of bedrock-gold excavations remains comparatively undisturbed by more-recent mining and exploration activity. Figure 6.10 shows that the controls on the gold mineralization in this area are not apparent from either the MINEDEX sites, or the regional (1:100 000-scale) geological mapping. A north-northwesterly trending structure has been highlighted as a major mineralized structure based upon an alignment of deeper excavations (shown in red and orange hues on the pseudocolour image). The dominant mineralized structural trend is north-northwesterly, although a more northwesterly trend exists on the eastern side of the main excavations. An east-northeasterly mineralized trend is also apparent, crossing the major north-northwest structure at close to 90°. Other, smaller, similarly oriented trends lie close to the two small opencuts in the south.

The left-hand image in Figure 6.11 depicts rock types recorded during WABMINES data collection in the field. The data were initially processed as described in Chapter 5 (Section 5.3.2) whereby the most significant rock type was chosen for each WABMINES observation using the hierarchy listed in Table 5.3. The data were then further processed using the ‘neighbourhood statistics’ function in Spatial Analyst using the method described in Chapter 5 (Section 5.4.3a), except that the statistic type ‘majority’ was used instead of ‘maximum’. The result was that the most commonly recorded significant rock type within 20 m of each 10 by 10 m cell was depicted. This method resulted in much better resolution of the extent of the sedimentary rock than the regional mapping, and also in the delineation of an unmapped north-northwesterly trending felsic porphyritic rock (Fig. 6.11). The outcrop pattern of sedimentary rock defined in this way was interpreted to represent a north-plunging antiform. This interpretation is consistent with the mapped regional cleavage orientation (Fig. 6.11), and the trend and plunge of a minor fold shown near the northern margin of Figure 6.11. Furthermore, Marston (1984) depicted a regional north-plunging antiform to the south of the Flinders area — a possible interpretation also referred to by Griffin (1990), but not shown on GSWA regional maps.

The strike length of the major, interpreted mineralized structure (Fig. 6.11) appears to be controlled by the sedimentary rocks. The trend of the interpreted structure is subparallel to the axial trace of the interpreted antiform. Furthermore, the northwesterly trending mineralized structure is interpreted to follow sedimentary rocks along the eastern limb of the antiform. Mineralization partly follows the north-northwesterly trending felsic porphyritic rock to the south of the antiform.

The left-hand image in Figure 6.12 depicts the variability of foliation intensity as recorded in WABMINES. Data processing was carried out in the same way as for rock type, except that the statistic type ‘variety’ was used instead of ‘majority’ in the ‘neighbourhood statistics’ function. Experimentation showed that variation in foliation intensity produced more meaningful results than foliation intensity. This may indicate a narrow, shear-related structural control on mineralization that is better discriminated by examining variation in foliation rather than the dominant foliation intensity. Using variation in intensity also has the advantage of reducing the effect of subjective classification differences between geologists. Variation in foliation intensity shows a strong spatial correlation with maximum depth (compare Figures 6.12 and 6.10) and, by implication, gold production and endowment. The areas with highly variable foliation intensity in Figure 6.12 correlate well with the major mineralized structure, and the staggered, sub-parallel mineralized structure immediately to the west. Also note in Figure 6.12 the areas of high variation in foliation intensity close to the more-recent opencuts.

The same data-processing approach was applied to variation of weathering intensity and showed similar correlations (Fig. 6.12, right-hand image). Weathering intensity probably also reflects the location of mineralized structures because these weather to much greater depths than the surrounding host rock, particularly if sulfides are present. Contrasts in weathering intensity may also highlight areas where less-oxidized rock is brought to the surface from deep (i.e. productive) shafts.

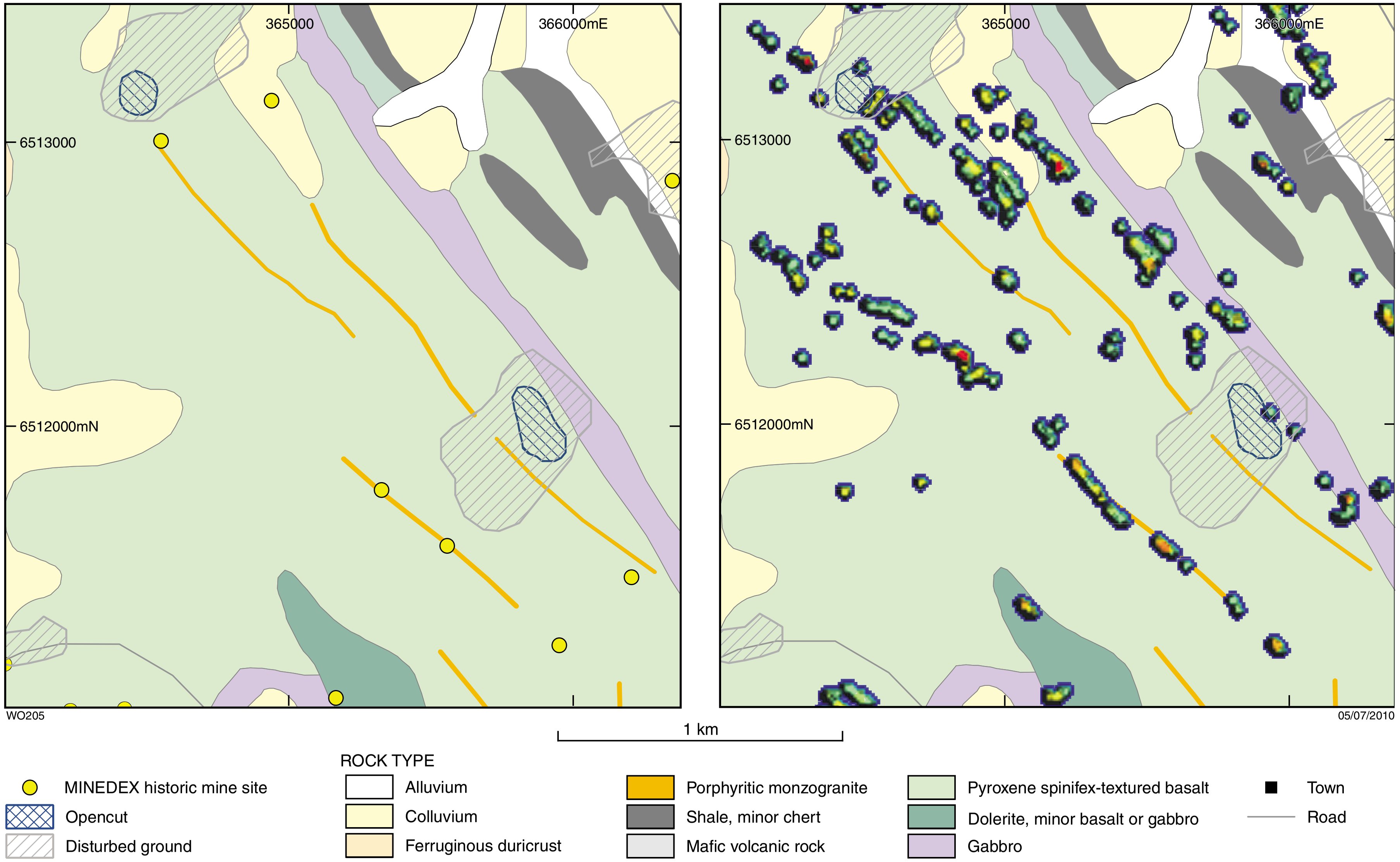

Figure 6.9 Blue Bird area, Widgiemooltha, showing 1:100 000-scale geology and MINEDEX historic mine sites (yellow dots, left-hand map). Note the additional information provided by the bedrock-gold excavation data on the right-hand map compared to the MINEDEX sites on the left-hand map.

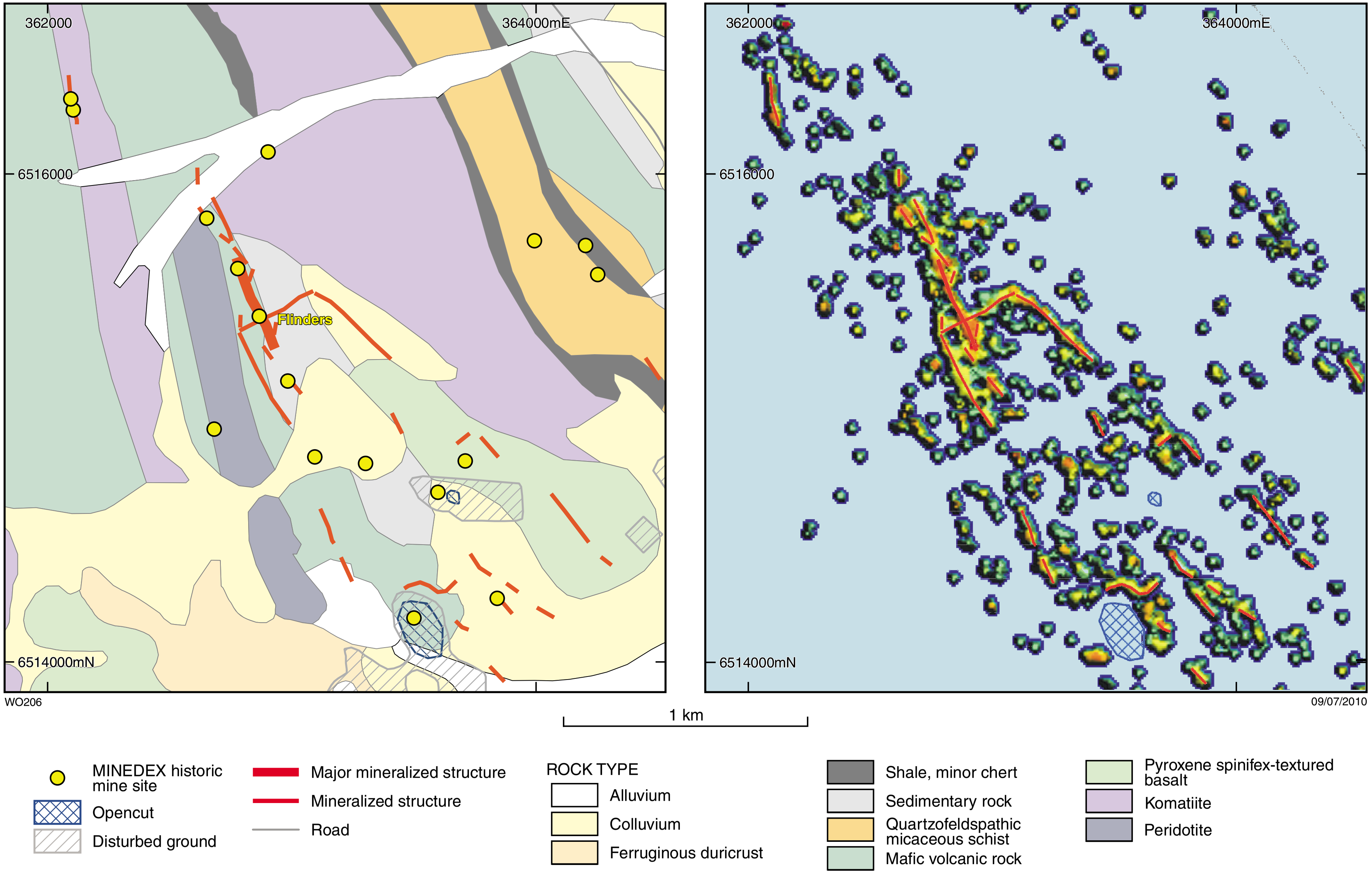

Figure 6.10 **Flinders area, Widgiemooltha. Controls on the gold mineralization are not readily apparent from either the MINEDEX historic mine sites (yellow dots, left-hand map) or the regional 1:100 000-scale geological mapping. However, alignment of deeper excavations (red and yellow colours) in the right-hand map indicates several major north-northwesterly trending mineralized structures and an east-northeasterly-trending structure.**

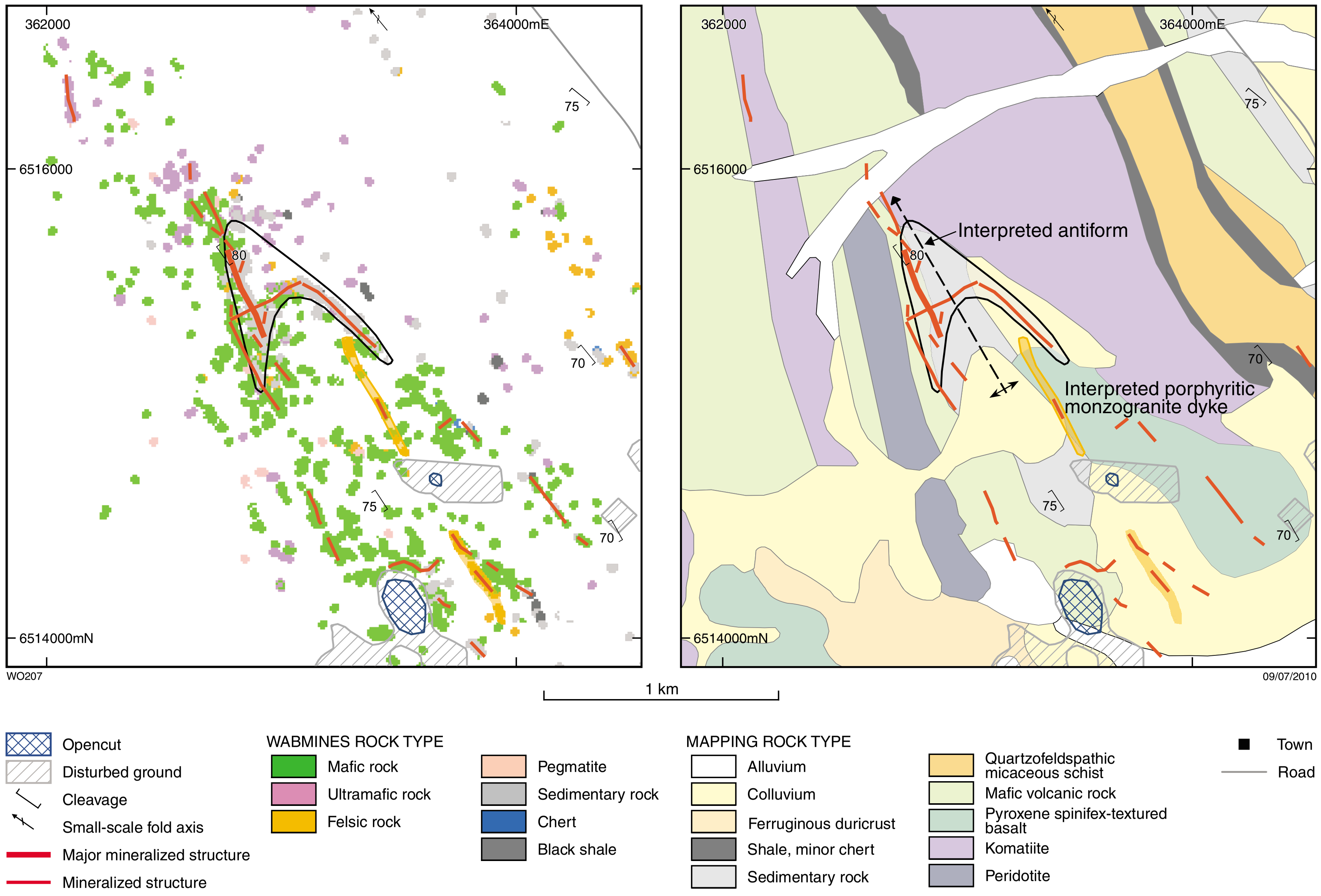

Figure 6.11 Flinders area, Widgiemooltha, showing the rock types recorded for the bedrock-gold excavations (WABMINES rock type; left-hand map), an interpreted north-plunging antiform in the sedimentary rock, and an interpreted north-northwesterly trending felsic porphyritic rock. Both features appear to control gold mineralization, but are not apparent on the 1:100 000-scale geological mapping (right-hand map).

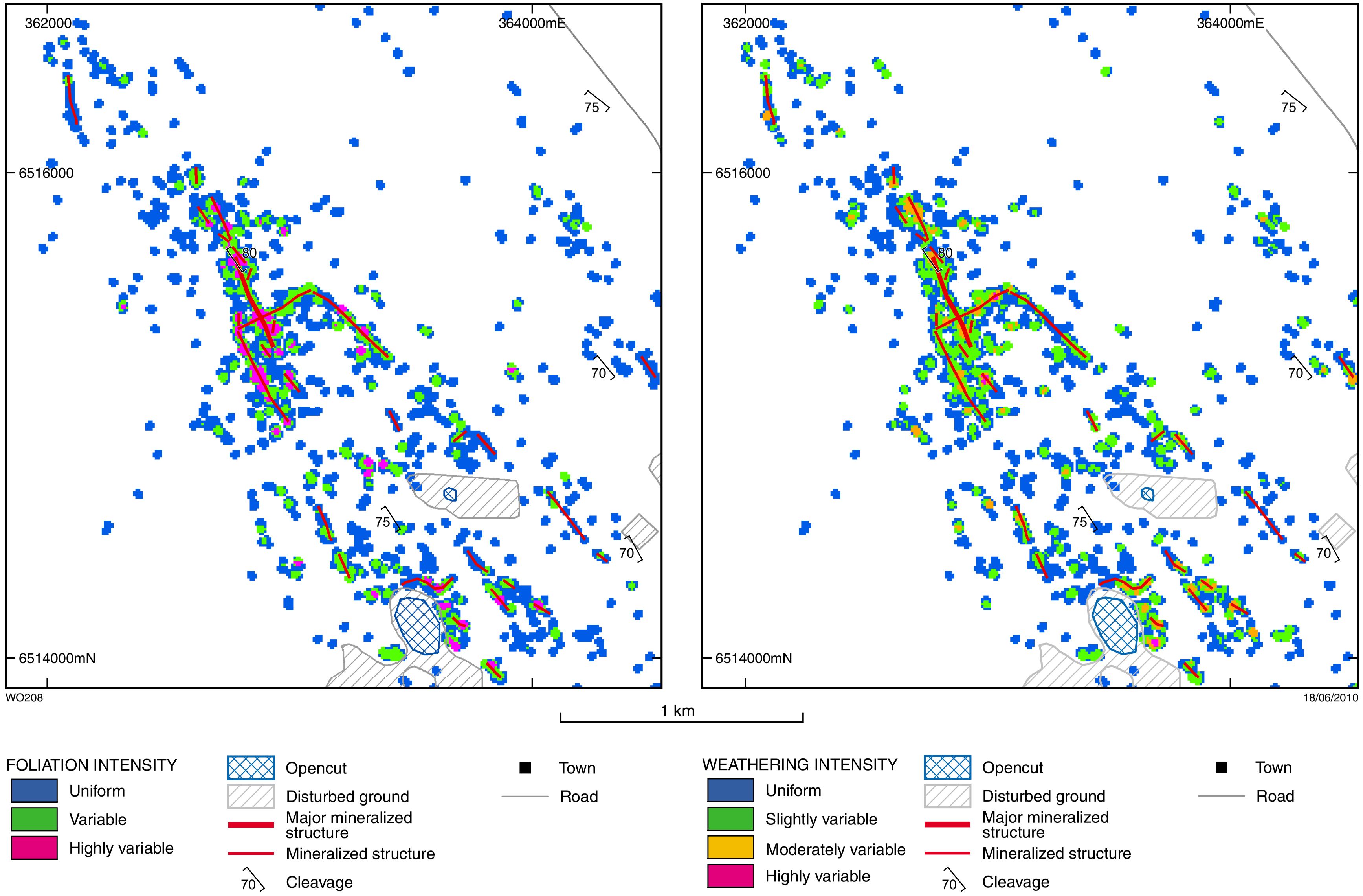

Figure 6.12 Flinders area, Widgiemooltha, showing variability in foliation intensity (left-hand map), and variability in weathering intensity (right-hand map). Both maps were derived from bedrock-gold excavation data. Note the correlation between areas with the highest variation in foliation and weathering intensity and the gold-mineralized structures.

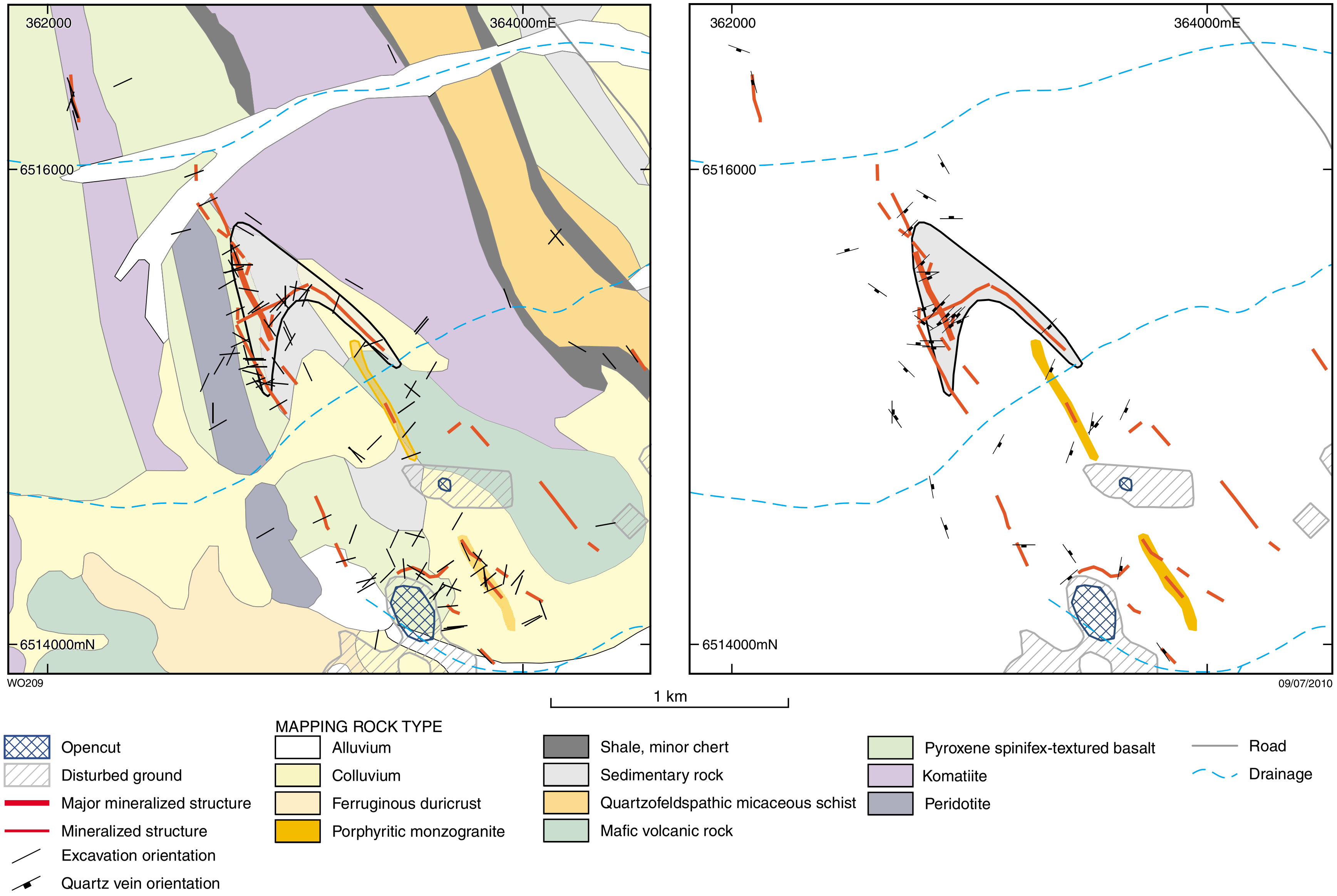

Figure 6.13 Flinders area, Widgiemooltha, showing the strike of bedrock-gold excavations (left-hand map), and the strike of quartz veins observed in bedrock-gold excavations (right-hand map). Note the dominant north-northeasterly strike of both the excavations and the quartz veins and their similarity to the drainage orientation as indicated by the creeks (blue dashed lines), suggesting a concealed north-northeasterly trending structural control.

Figure 6.13 depicts the strike of bedrock-gold excavations (left-hand map), and the strike and dip direction of quartz veins (right-hand map). Both plots show a dominant strike of east-northeast to northeast. Quartz veins in this orientation (the most common orientation; n=17, 040° to 090°) are between 1 and 10 cm thick, and dip towards the southeast at between 15° and 60° (averaging 38°). North-northwesterly to south-southeasterly striking veins are more steeply dipping, both to the east and west, and were up to 1.5 m thick. The most common north-northeast vein and excavation orientation, is sub-parallel to the crosscutting mineralized structures, and coincident with the nearby drainage (Fig. 6.13), indicating a possible east-northeasterly trending structural control.

6.5 Norseman case study

The Norseman area has been a major historical gold producer, with total production of about 132 t to June 1987 (Thomas et al., 1990). Unlike the other case-study areas, which remained essentially dormant for long periods since discovery, gold production has been continuous at Norseman since 1935. Until the mid 1990s, 85% of gold production took place on the Mararoa, Crown, North Royal, and Princess Royal reefs (Figs 6.14 and 6.15; Archer and Turner, 1998).

Campbell (1906) documented the early mine and regional geology. Western Mining Corporation Limited became involved in the Norseman area in the early 1930s and rigorously applied geological concepts to determine the geometry and controls on gold mineralization. Thomas et al. (1990) summarized the development of their geological concepts, and the extensive knowledge gained from these and other geological investigations in the district. Most gold production has come from north to north-northwesterly striking, east-dipping, laminated quartz reefs that are typically 0.5 to 2 m thick and several kilometres long (Thomas et al., 1990). These reefs transgress the west-dipping stratigraphy, and commonly follow a suite of east-dipping tholeiitic and high-Mg gabbroic dykes. The high-grade ore within these reefs is restricted to small-scale structurally controlled shoots, separated by wide areas of barren quartz or shears (Thomas et al., 1990).

Thomas et al. (1990) also described east-trending, subvertical reefs, typically less than 500 m long, which were historically much less significant gold producers. More recently, Archer and Turner (1998) highlighted the significance of east-trending, predominantly tensional ‘cross links’ such as found at the Bullen mine (Fig. 6.15), and mineralized veins and shears in other orientations that have been discovered in the 1980s and 1990s elsewhere in the district. Archer and Turner (1998) also discussed the role of intersections of reefs in the predominantly fine-grained mafic rocks with ‘gabbro’ intrusions in localizing high-grade ore zones.

Hagemann and Cassidy (2000) provided an overview of geological and mineralization-related studies in the Norseman area. These included detailed structural and textural studies by McCuaig et al. (1993) that established a post peak-metamorphic, synkinematic timing for hydrothermal alteration, quartz vein emplacement, and gold mineralization.

Doepel (1973) described the regional geology for the Norseman 1:250 000 geological map. Most of the study area is on the western limb of a major north-northwesterly plunging anticline. Stratigraphy is summarized in Chapter 1 (Section 1.4). Metamorphic grade increases from north to south, from upper greenschist to lower amphibolite facies (Hagemann and Cassidy, 2000). Faulting is mainly at a low angle to the stratigraphy with north-northwest, and northerly trends being dominant (Fig. 6.14). The stratigraphy and all earlier structures are cut by the east-trending Paleoproterozic Jimberlana Dyke, which is of mafic to ultramafic composition.

Two study areas, the general Mararoa reef area, and the eastern banded iron-formation area (Fig. 6.14) were examined in more detail.

6.5.1 Mararoa reef area

The Mararoa reef area (Figs 6.14–6.16) covers the major Mararoa (35.6 t Au) and Crown reefs (32 t Au), the Norseman reef (3.6 t Au), and the Mount Barker reef (0.1 t Au; Thomas et al., 1990; MINEDEX). All of these reefs dip to the east at about 60° and are hosted within moderately west-dipping basalt, gabbro, and thin interflow sedimentary rocks of the Woolyeenyer Formation. Essentially all gold production from these reefs has come from between the west-dipping Agnes Venture Slate, and the overlying Empress Slate, leading to the ‘favourable bed’ hypothesis (Thomas et al., 1990) that guided exploration in the region for many years. A consequence of this geometry is that mining became progressively shallower towards the east. The Agnes Venture reef, which had produced only 4.9 kg of gold up until 1903, was mapped by Campbell (1906) and is closely associated with the Agnes Venture Slate.

Many of the bedrock-gold excavations follow the mapped reefs shown in Figure 6.16, particularly the easternmost reefs where the excavations are shallower, and have been less disturbed by later development. Mine access, even for the deeper Crown and Mararoa reefs was commonly by inclined (or underlay) shafts that were sited close to the surface projections of the reefs.

6.5.2 Banded iron-formation area

The banded iron-formation area is in the eastern part of the Mararoa reef area (Figs 6.16 and 6.17) where gold mineralization associated with banded iron-formation (BIF) occurs within the sedimentary rock and dolerite–gabbro sill sequence of the Noganyer Formation. There is a correlation between the north-trending interpreted aeromagnetic trend lines (Geological Survey of Western Australia, 2007) and the bedrock-gold excavations (Fig. 6.17). BIF commonly has a magnetic response on aeromagnetic data due to the presence of magnetite. The BIF association of this type of mineralization is confirmed in the left-hand image, which shows all BIF occurrences in the abandoned mine site database for this area. Two recent opencut pits are located at the intersections of

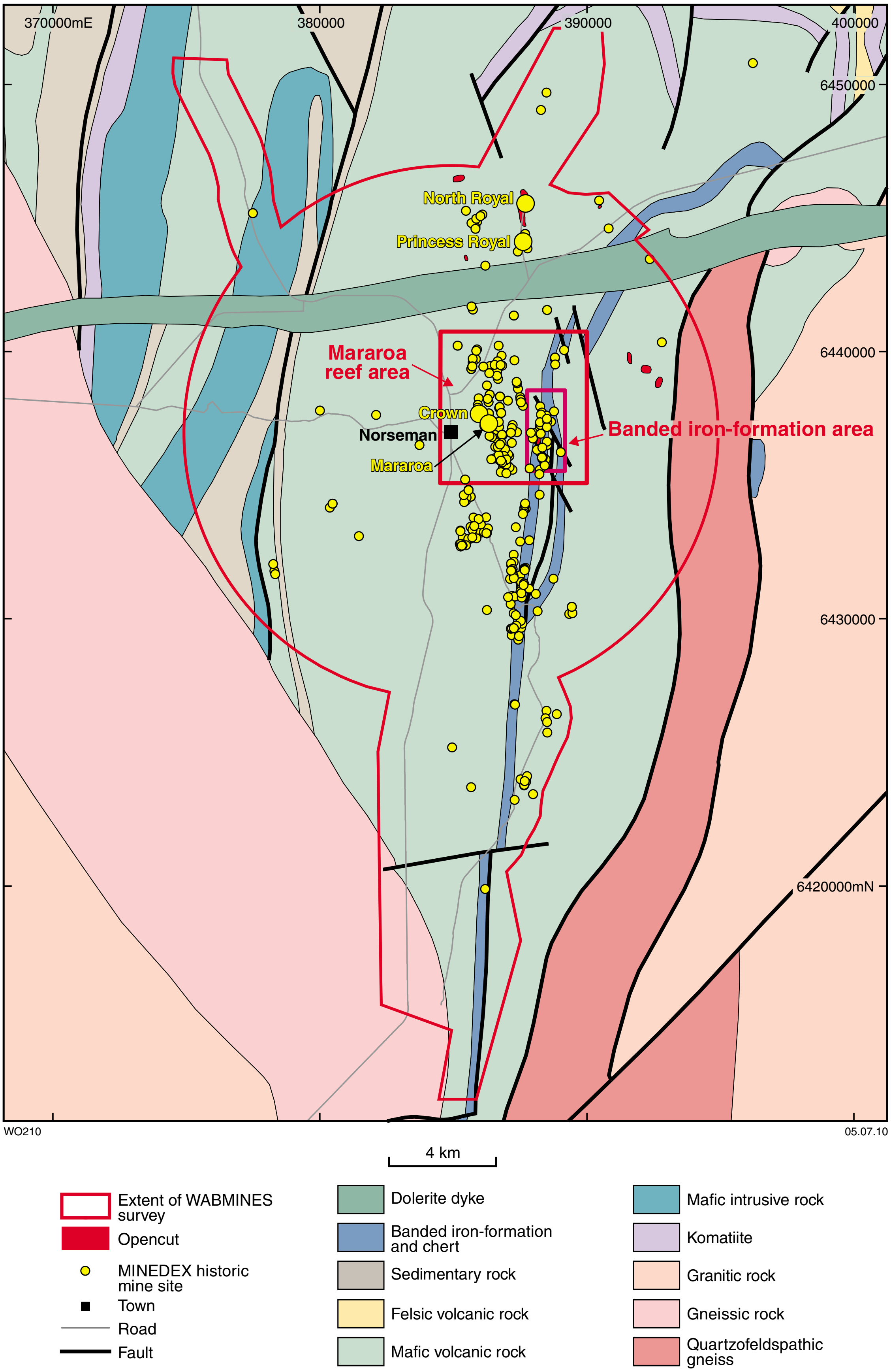

Figure 6.14 **Norseman case-study area showing regional geology, the location of the Mararoa reef area, banded iron-formation area, and the MINEDEX historic mine sites (yellow dots) with the major historical gold production sites (labelled).**

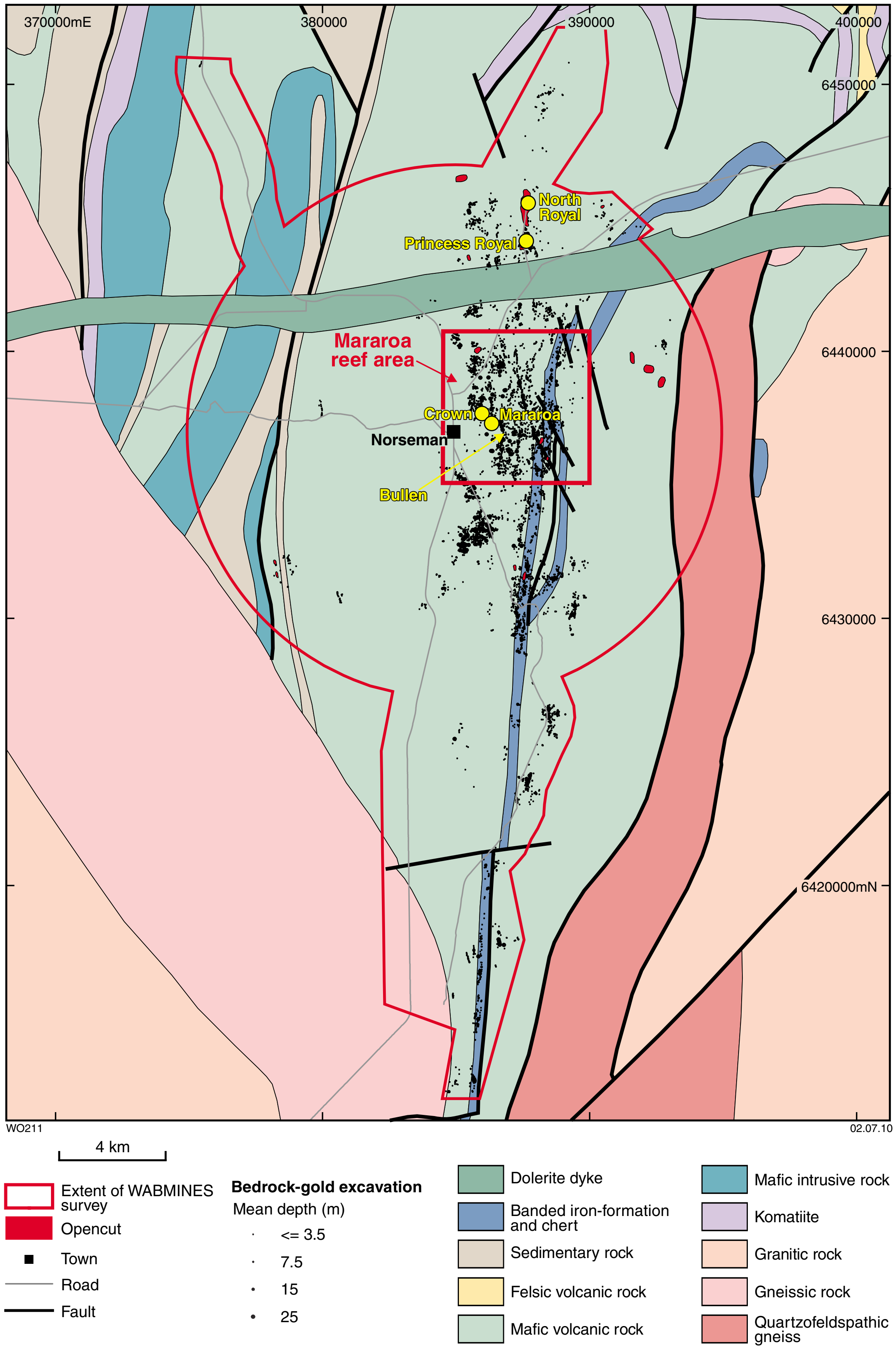

Figure 6.15 **Norseman case-study area showing regional geology, the location of the Mararoa reef area, the Bullen mine, the bedrock-gold excavations (small black dots), and the major historical gold production sites (yellow dots).**

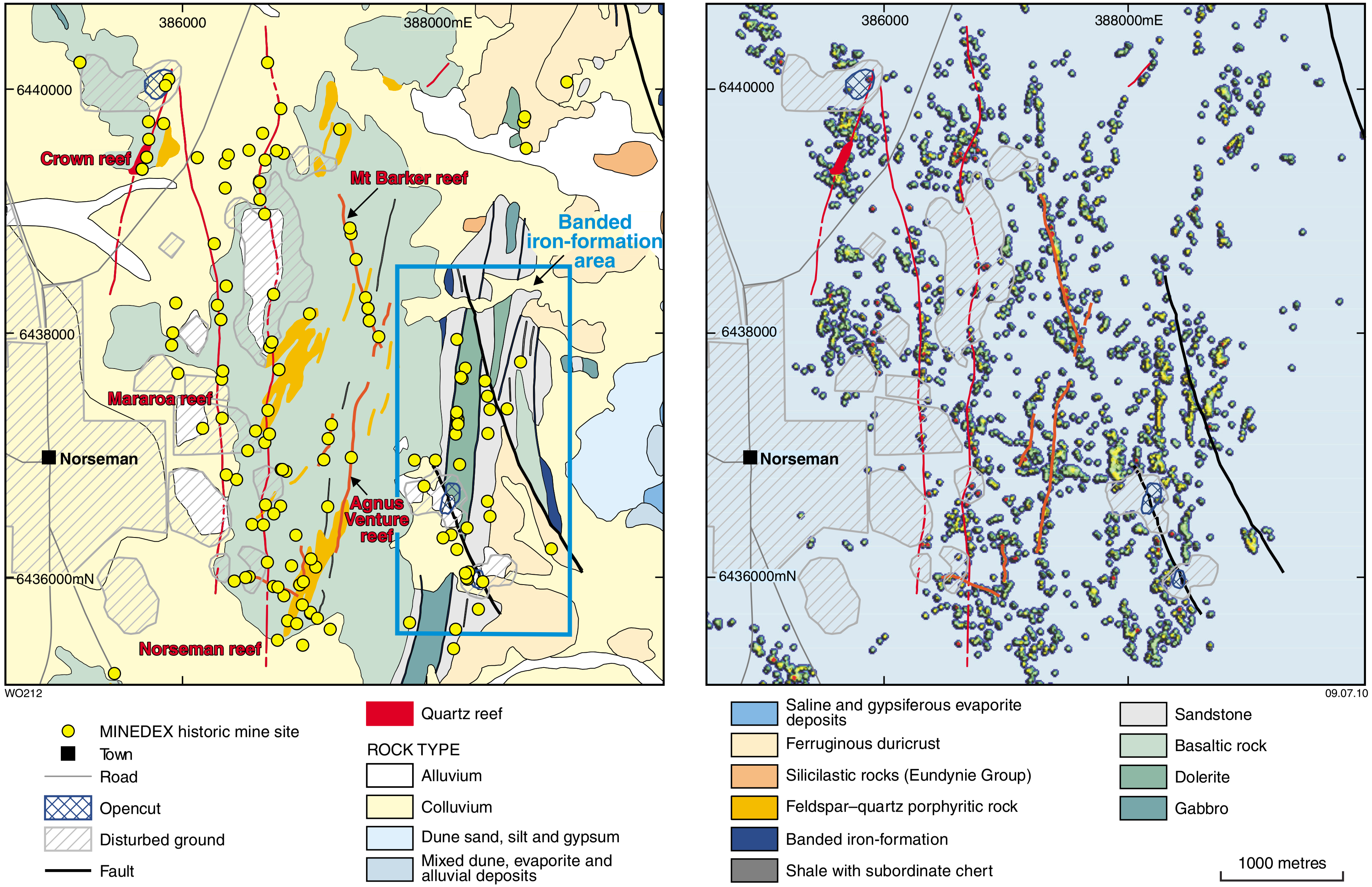

Figure 6.16 Mararoa reef area, Norseman, showing: 1:100 000-scale geology, MINEDEX historic mine sites (yellow dots), and major quartz reefs (left-hand map); bedrock-gold excavation data with the major quartz reefs (right-hand map). The location of the banded iron-formation area is outlined

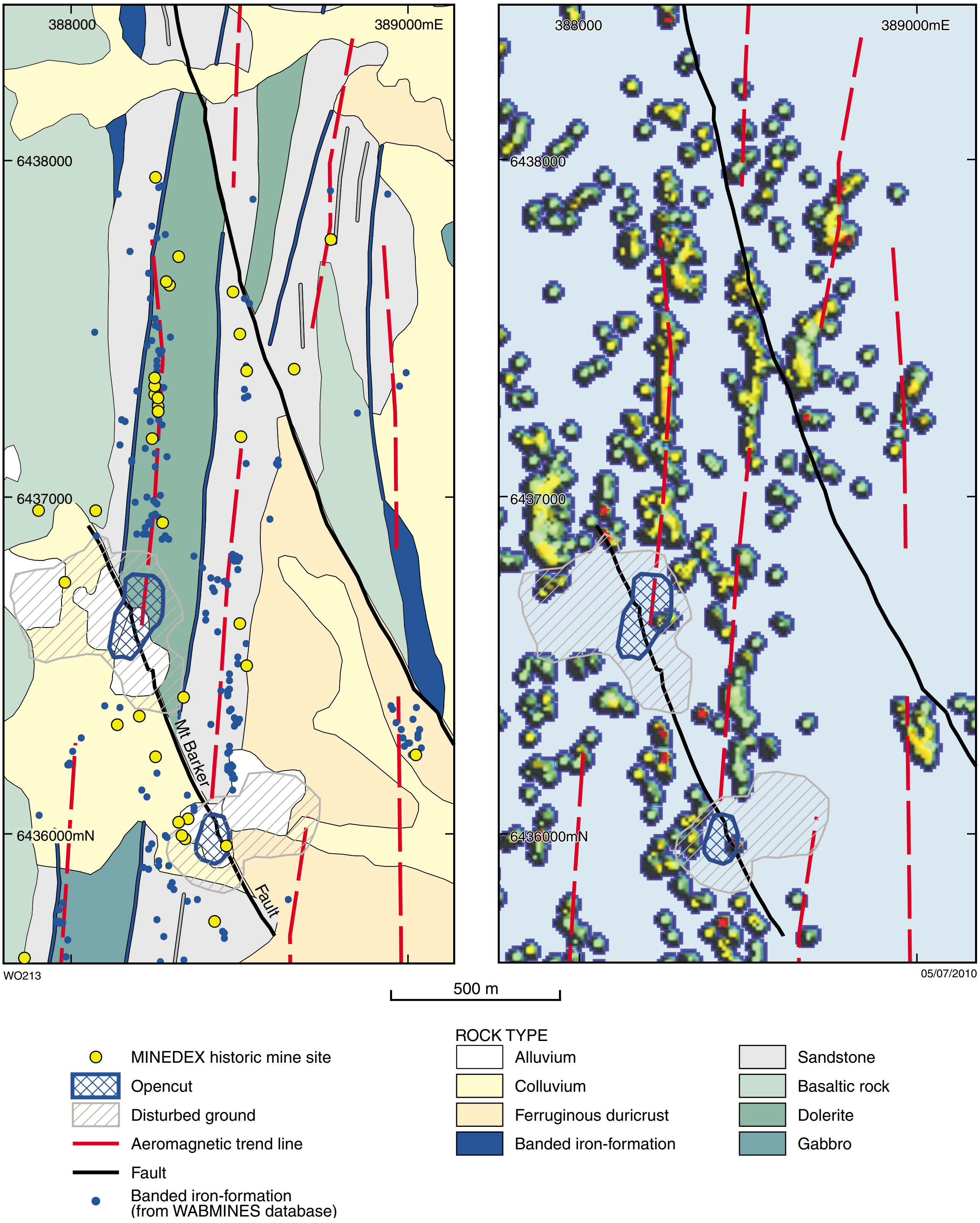

Figure 6.17 Banded iron-formation area, Norseman, showing 1:100 000-scale geology, MINEDEX historic mine sites, (yellow dots) and BIF-associated aeromagnetic trend lines (red lines; left-hand map), and bedrock-gold excavations, which correlate with the BIF-associated aeromagnetic trend lines (right-hand map). Note substantial areas of surficial cover on the eastern side (left-hand map) limits outcrop and hence excavations (right-hand map).

the aeromagnetic trend lines and the Mount Barker fault (Fig. 6.17), indicating a structural control for the gold mineralization related to BIF in this area.

6.5.3 Interpretation of the Mararoa reef area and definition of targets

The combination of mapped quartz reefs and BIF-related aeromagnetic trend lines with the bedrock-gold excavation data shows the gold-mineralization patterns in the Mararoa reef area (Fig. 6.18). Detailed mineralized structures were initially interpreted on the pseudocolour hill-shaded image based on the bedrock-gold excavations (left-hand image in Figure 6.18). A number of regional mineralization trend-lines were interpreted between the major western reefs and the eastern BIF-related trends in the central area. These are shown in red on the right-hand image of Figure 6.18. Some of these trend lines are extensions of existing mapped reefs such as the Mount Barker and the Agnes Venture reefs. Mapped porphyritic rocks and porphyry occurrences recorded at bedrock-gold excavations also show a weak spatial correlation with gold mineralization, as has been noted in all of the previous case-study areas.

Following the conclusion that areas of highly variable foliation and weathering intensity correlate well with mine depth (and by inference gold endowment) in the Widgiemooltha area, this analysis was repeated for the Mararoa reef area in Norseman. The methodology was the same, except that a neighbourhood radius of 40 m was used instead of 20 m, and cell sizes were increased to 20 by 20 m for clarity. These changes were found not to affect the outcomes but greatly enhanced the visualization of the results at this scale (Fig. 6.19). As for Widgiemooltha, this method reveals a correlation between increased variation in foliation and weathering intensity and areas of known gold production, particularly the Crown and Mount Barker reefs. Particularly noteworthy is the abnormally high variability in foliation and weathering intensity at the intersections of some of the interpreted mineralized-structure trend lines (circled in Fig. 6.19).

These conclusions are consistent with the observation by Archer and Turner (1998) that zones of intense structural complexity tend to occur where the reefs intersect north-northeasterly trending, and west-dipping, dacitic porphyritic rocks. However, Archer and Turner (1998) also noted that these intersections show even more variable gold grades than usual, and that in some reefs these can be zones of high grades, and in others, low grades.

Four exploration targets were identified at the intersections of interpreted structures (Fig. 6.20). Targets A, B, and C all lie along the Mount Barker reef or its interpreted structural extension. Two existing opencuts are at the intersections of the BIF trends and the Mount Barker fault, in a similar structural environment to targets A, B, and C. Note that deeper bedrock-gold excavations are located within targets A and B at, or near the intersections of, the interpreted north-northeasterly trending mineralized structures (faults and shear zones) and the Mount Barker reef. It is also apparent that Target A is located in a similar position in relation to an interpreted east-southeasterly trending structure as an opencut and the St Patricks area. The St Patricks area is characterized by deeper bedrock-gold excavations, and has been the subject of relatively recent exploration and mining activity. Target D is at the intersections of the Lady Jean and Agnes Venture reefs with another interpreted east-southeasterly trending structure. Target D is characterized by a combination of increased variability of weathering and foliation intensity (Fig. 6.19) as well as some deeper bedrock-gold excavations (Fig. 6.20).

6.6 Discussion

A direct association has been demonstrated between bedrock-gold excavations and mapped regional-scale geological structures in the Menzies, Coolgardie, Widgiemooltha, and Norseman case-study areas. The types of structures defined by bedrock-gold excavations vary considerably, even in the same case-study area. For example, at Menzies the bedrock-gold excavations follow tension-related structures in the Maranoa area, and sinistral shear zone-related structures in the Lady Shenton area. Therefore, bedrock-gold excavations can be used to infer the location of a variety of structures.

Bedrock-gold excavations (and hence gold mineralization) correlate with specific rock types such as BIF at Norseman, black shale and quartz–feldspar porphyritic rock in the Bayleys area (Coolgardie), and sedimentary rock in the Flinders area (Widgiemooltha). The Flinders example also indicates an association of gold mineralization with an interpreted plunging antiform. In some cases (e.g. Bayleys area in Coolgardie), the apparent control on mineralization by rock type probably also relates to associated structures that have localized in areas of strong competency contrast between adjacent rock types. Irrespective of the detailed control on mineralization, bedrock-gold excavations provide sufficient resolution of the stratigraphy in the Bayleys area to refine the mapping of unmineralized crosscutting structures.

The trend and strike length of mineralized structures defined by bedrock-gold excavations are not clearly apparent from the MINEDEX historic mine sites nor, in some instances, from the regional geological mapping. Additional mineralized structures, parallel to mapped regional structures, are interpreted from the bedrock-gold excavations (e.g. Lady Loch area, Coolgardie), or along the strike extension of mapped structures (e.g. Mount Barker reef, Norseman).

Bedrock-gold excavations enable the definition of subtle crosscutting mineralized structures in the Lady Shenton area at Menzies, Flinders area at Widgiemooltha, and in the Mararoa reef area at Norseman, which are not readily apparent from the regional mapping or from MINEDEX historic mine sites. Nevertheless, regional datasets may provide information that can identify subtle crosscutting structures that may be related to gold mineralization. For example, the drainage pattern from topographic mapping in the Flinders area at Widgiemooltha follows the trend of a mineralized structure defined by bedrock-gold excavations.

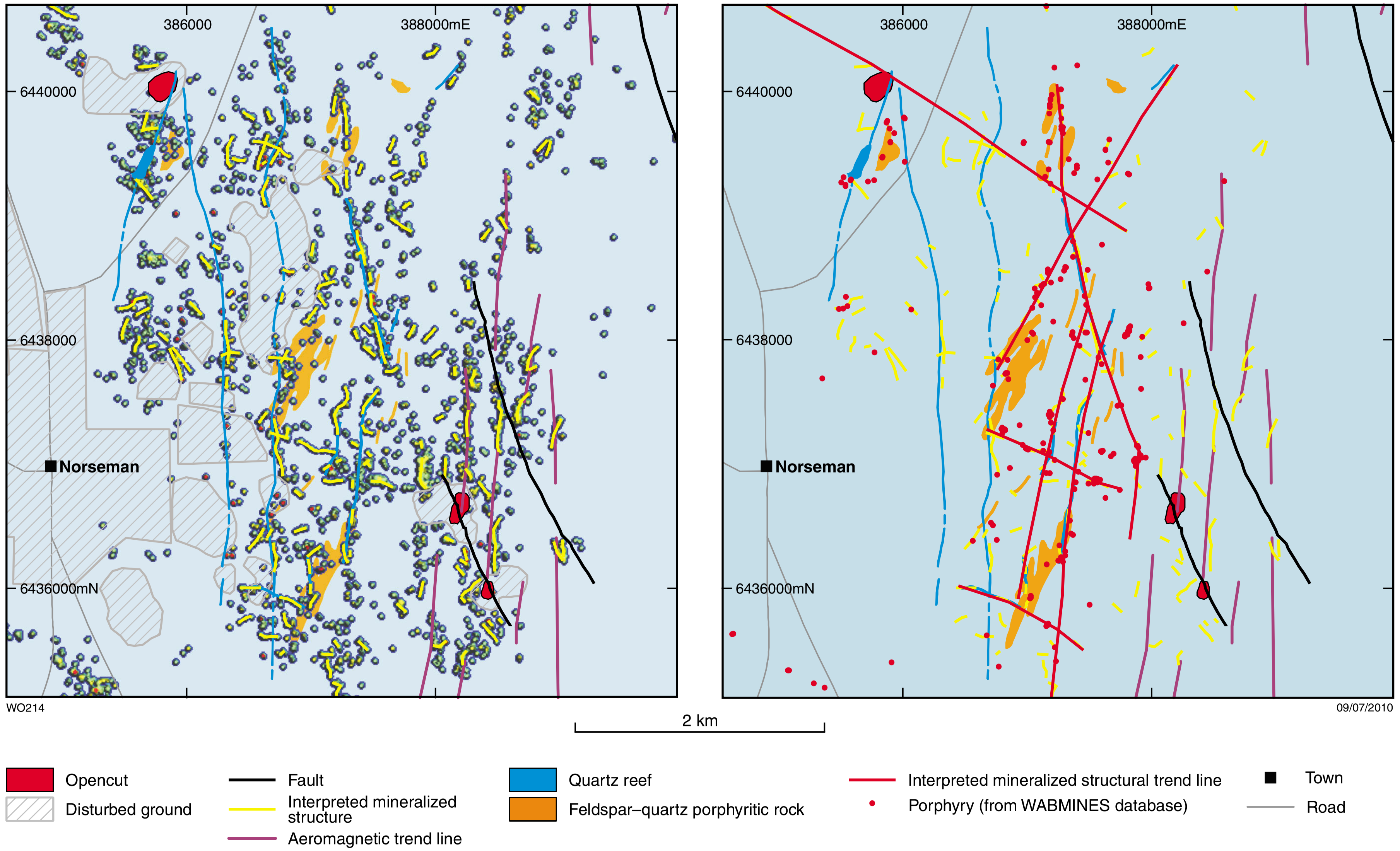

Figure 6.18 Mararoa reef area, Norseman, showing bedrock-gold excavation data and interpreted mineralized structures (left-hand map). The right-hand image shows interpreted regional mineralized structural trend lines and the porphyritic rocks that occur mainly between the mapped reefs and the BIF-associated aeromagnetic trend lines.

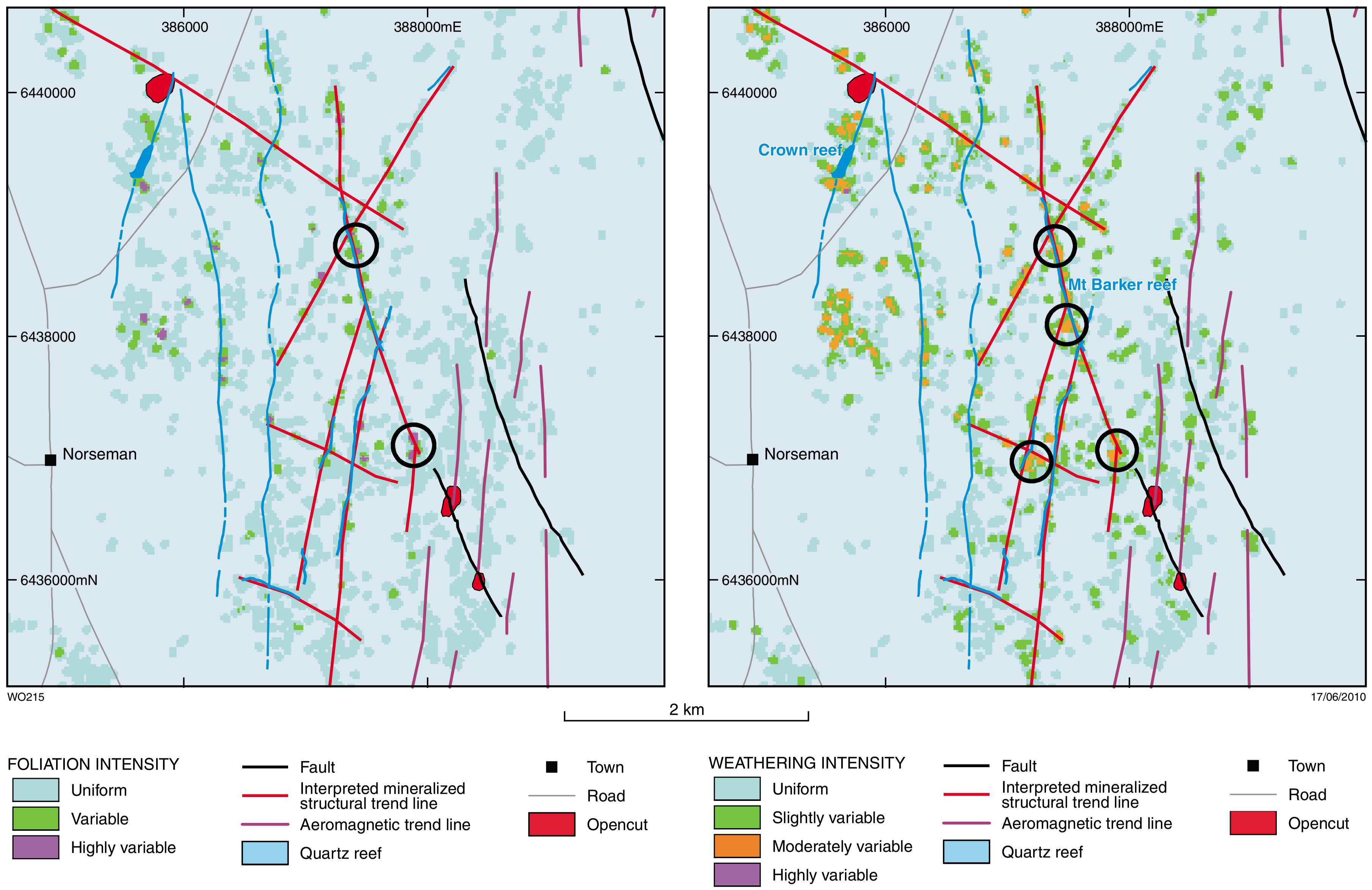

Figure 6.19 Mararoa reef area, Norseman, showing images depicting the variability of foliation intensity (left-hand map), and weathering intensity (right-hand map). Increased variability of both parameters is associated with the known mineralized reefs (particularly the Crown and Mount Barker reefs). Areas where high variability coincide with structural intersections are circled.

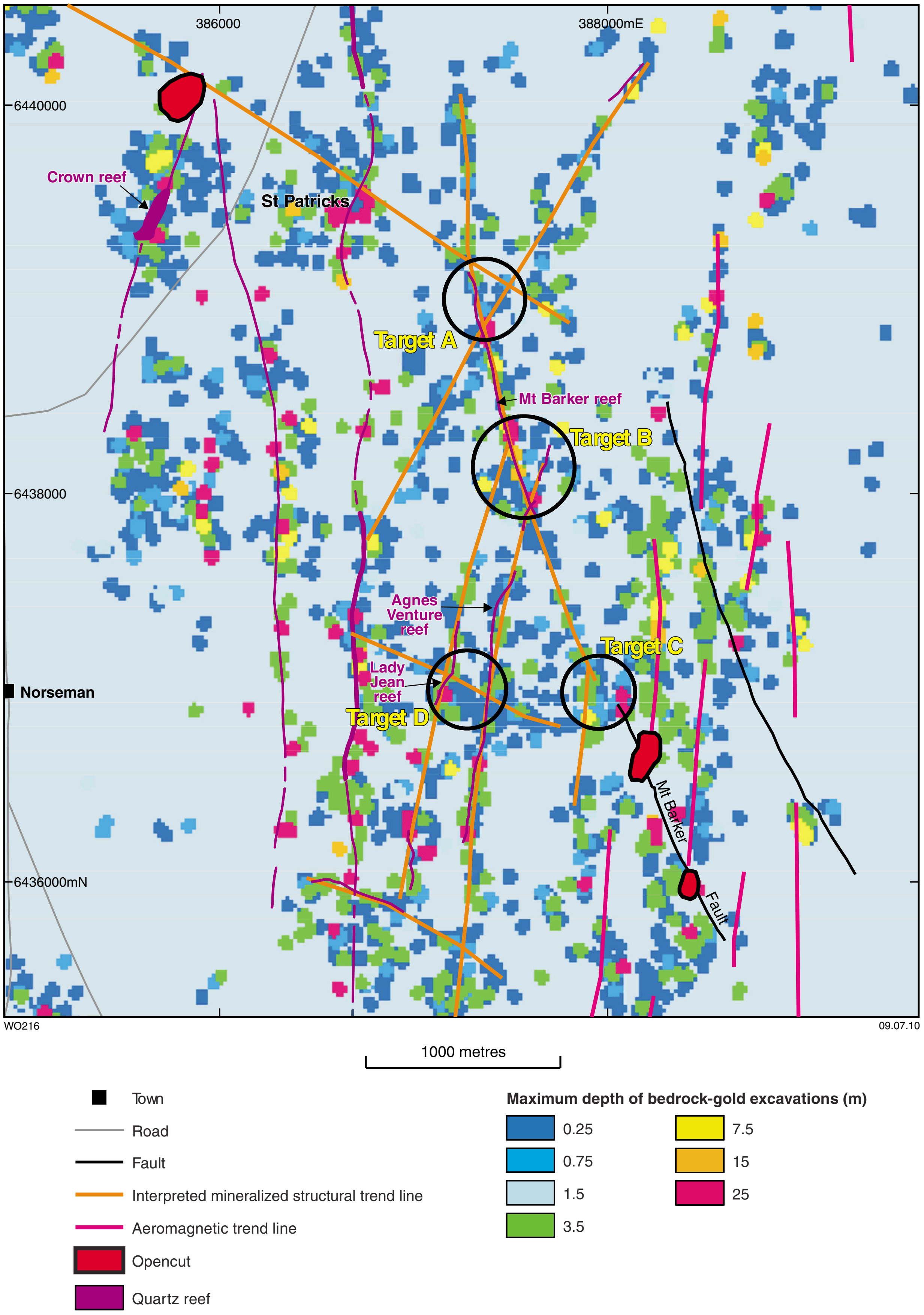

Figure 6.20 Enlargement of part of the Mararoa reef area, Norseman, showing exploration targets A to D, which are located at interpreted intersections between faults and shear zones and deep bedrock-gold excavations and/or zones of high variability in foliation and weathering intensity.

The intersections between some mineralized structures coincide with deeper bedrock-gold excavations (e.g. the inverted ‘Y’ structures in the Lady Shenton area, Menzies), suggesting greater gold production and hence favourable mineralization sites. Another example of mineralization at structural intersections is provided by the opencuts at the intersection of the mineralized BIF in Norseman with the crosscutting Mount Barker fault.

Structural intersections and deeper excavations interpreted to occur in favourable gold mineralization sites are associated with increased variation in host-rock foliation and weathering intensity at both Widgiemooltha and Norseman. These observations have enabled the identification of a number of exploration targets in Norseman that warrant further investigation.

Chapter 7

Summary and conclusions

A relationship between abandoned mine workings, gold endowment, and regional-scale geological structures must be demonstrated if these workings are to assist GIS-based studies on gold mineralization and regional geology. Only bedrock-gold excavations (rather than those seeking surficial alluvial or colluvial mineralization) were examined in this study as they were most likely to be directly associated with geological structures.

Some four case-study areas (Menzies, Coolgardie, Widgiemooltha, and Norseman) were selected within the Kalgoorlie Terrane of the Archean Yilgarn Craton where suitable data are available from the Western Australian abandoned mine site database (WABMINES database). The study areas represent a good geographical spread of well-documented mining centres of differing sizes, and are covered by a consistent series of regional geological maps, and digital databases.

In the absence of estimates for total gold resources, the total gold production was used as a proxy for gold endowment, and therefore a relationship was sought between the size of abandoned mines and associated gold production. The Menzies area was selected for testing this relationship as it has the best combination of spatially related, historical gold-production data with substantial past gold production, and good-quality data on abandoned mine sites.

At the individual mining tenement scale, it is not possible to fully reconcile the location of past gold production with a single location, as is common practice in regional-scale GIS-based prospectivity studies. A methodology was developed to overcome this problem by combining two GSWA databases (MINEDEX and Dead Tenement) and attributing total gold production to the respective past mining tenements. The result was a single tenement-based GIS database layer attributed with gold production information. Potential measures of mine size derived from the abandoned mine site database (density of excavations, mean bund height, mean depth, and mean volume) were then tested for a correlation with gold production. Both excavation depth and excavation volume were found to be related to total gold production. Of these, excavation depth was determined to be the best and most practical semi-quantitative measure of total gold production. The methodology developed for this test has the potential for wider application in GIS-based prospectivity studies on abandoned mine sites and other regional datasets.

Once excavation depth was established as a semi-quantitative measure for total gold production, a second method was developed for estimating original depth of collapsed mine shafts based on the height of their associated waste bunds. Estimated original depth was attributed to as many abandoned bedrock-gold excavations as possible, including those that have been backfilled or are now concealed under infrastructure. Various methods of data visualization were tested. Smoothed images in which maximum excavation depth is represented using a spectrum colour scheme and density of excavations is used to create a hill-shaded topographic or ‘elevation’ layer were found to be the most effective when examined at scales of less than 1:5 000.

A direct correlation was demonstrated between bedrock-gold excavations and mapped regional-scale geological structures in all the case-study areas. The trend and strike length of mineralized structures defined by the abandoned mine workings were commonly not apparent from plots of MINEDEX historic mine sites or, in some instances, from the regional geological maps. In some areas, interpretation of mineralized structures from the bedrock-gold excavations led to the identification of previously unmapped structures or extensions of mapped structures.

A number of exploration targets have been identified at Norseman where favourable structural intersections are inferred in areas with deeper excavations, greater structural complexity, or anomalous variations in foliation and weathering intensity.

Analysis of abandoned mine workings has enabled previously unrecognized geological structures that are directly related to gold mineralization to be identified, as well as the spatial patterns associated with them. In addition, this study has demonstrated a number of ways in which the analysis of abandoned mine workings can be applied to GIS-based prospectivity studies and to the generation of exploration targets.

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Appendix 1

Glossary of WABMINES attribute fields and categorical attribute values (after Ormsby et al., 2003)

In Table A1.1, attribute fields are shown in bold and corresponding categorical attribute values are shown in the section immediately below.

Table A1.1. Glossary of WABMINES database attribute fields and categorical attribute values

ATTRIBUTE/ *VALUE*	*Attribute name/* *Value name*	*Description*
SITENO	Site number	Unique database generated number for each site. Used to link records between tables
SITEID	Site identification	Unique name recorded by the user for each site, comprising the user's initials and a sequential number
OBSDATE	Observation date	Date on which the data were recorded
QMAPID	1:250 000 map	1:250 000 map reference index number
HMAPID	1:100 000 map	1:100 000 map reference index number
EASTING	Easting	Map Grid Australia easting reference in metres. Datum is Geocentric Datum of Australia 1994 (GDA94)
NORTHING	Northing	Map Grid Australia northing reference in metres. Datum is Geocentric Datum of Australia 1994 (GDA94)
PRECISION	Precision	Precision of the Global Positioning System (GPS) location in metres
DLAT	Degrees latitude	Latitude reference in decimal degrees. Datum is GDA94
DLONG	Degrees longitude	Longitude reference in decimal degrees. Datum is GDA94
FEAT_GROUP	Feature group	
CS	Collapsed shaft	Shaft currently <2 m deep, but showing evidence of greater original depth. Evidence may include substantial bunds and remnant collar materials
CUT	Opencut	Surface working in which the working area is kept open to the sky (American Geological Institute, 1997, henceforth referred to as AGI). In WABMINES, opencut features are pits/quarries >2 m deep and costeans/trenches of any depth
DU	Dump	Pile or heap of ore, coal, or waste at a mine (AGI, 1997). In WABMINES, dump types are: waste dump, rock and soil, topsoil, rubbish dump, ash dump, tailings, leach pad, and ramp/tramway
IN	Infrastructure	Basic facilities, equipment, roads, and installations needed for the functioning of a system (AGI, 1987). In WABMINES, infrastructure types are: buildings, headframe/winder, machinery, battery/mill, shaft footing, dam/sump, town remnant, chimney, and other
RH	Rehabilitated	Restored to a previous condition (Little et al., 1973). In WABMINES this mainly refers to remedial bulldozing and ripping. Where possible, the type of feature that has been rehabilitated is also listed under TYPE (e.g. shaft or costean)
SHW	Shallow working	Pit, cavity, hole, or other uncovered cutting produced by excavation and <2 m deep. Areas of multiple similar features can be recorded by a centroid location and the dimensions recorded in the MINE_NOTE section
UI	Under infrastructure	In WABMINES this refers to historic underground, opencut or infrastructure features that are now either beneath, or have been removed in the development of, more recent features. Usually located from aerial photographs, and historical and company maps
UG	Underground	Below the surface of the ground (Little et al., 1973). In WABMINES this refers to the following types of mining features: shaft, well, multiple shafts, open stope, adit, decline, subsidence, and collapsed drillhole
TYPE	Type	
AD	Adit	Horizontal or nearly horizontal passage driven from the surface for the working or dewatering of a mine (AGI, 1997). In WABMINES, the dip of the feature can be up to 20°
ASH	Ash dump	Inorganic residue after burning (Jackson, 1997). Commonly indicates the former presence of a boiler used for steam production
BM	Battery/mill	Battery: a series of stamps, commonly five, operated in one box or mortar, for crushing ores; also the box in which they are operated (AGI, 1997). Mill: a mineral treatment plant in which crushing, wet grinding, and further treatment of ore is conducted (AGI, 1997). In WABMINES, it may also include a power station or pump house
BU	Building	Office, workshop, house or shed not included under battery/mill
CD	Collapsed drillhole	Surface subsidence around a drillhole collar
CH	Chimney	Chimney: the passage or flue by which the smoke from a fire, etc., ascends (Little et al. 1973). In WABMINES, it refers to a chimney, smokestack or funnel
CO	Costean/trench	Costean: a trench cut across the conjectured line of outcrop of a seam or orebody to expose the full width (Nelson, 1995). Trench: in geological exploration, a narrow shallow ditch cut across a mineral deposit to obtain samples or to observe character (AGI, 1997)
DM	Dam/sump	Dam: any accumulation or storage of water, whether natural or artificial (W.A. Government, 1978). Sump: a pit or basin in which the returns from a borehole are collected and stored and in which the cuttings settle before recirculating the cuttings-free fluid (AGI, 1997)
HW	Headframe/winder	Headframe: the steel or timber frame at the top of a shaft that carries the sheave or pulley for the hoisting rope and serves various other purposes (AGI, 1997) Winding apparatus: the machinery and equipment used to lower and raise loads through a shaft (AGI, 1997)
LP	Leach pad	Leach pile: mineralized materials stacked so as to permit wanted minerals to be effectively and selectively dissolved by application of a suitable solute (AGI, 1997)
MA	Machinery	Machinery: includes all mechanical appliances of whatever kind used or intended to be used for any mining purpose (W.A. Government, 1978). In WABMINES this can include a boiler, pump or winder engine

Table A1.1. (continued)

ATTRIBUTE/ *VALUE*	*Attribute name/ Value name*	*Description*
MSH	Multiple shafts	Discontinued use. Referred to a group of shafts. From 1/1/02, all shafts are recorded as separate features
OS	Open stope	An underground working place either unsupported or supported by timbers or pillars of rock (Pryor, 1963). In WABMINES this refers to either a vertical or inclined underground excavation that follows the orebody, is open to the surface, and appears to have been formed primarily by the removal of ore from beneath
OTIN	Other infrastructure	Includes any infrastructure not covered by the types: battery/mill, buildings, chimney, dam/sump, headframe/winder, machinery, shaft footings or town remnant. Details should be included in the MINE_NOTE section
PI	Pit/quarry	Pit: a mine, quarry or excavation worked by the opencut method to obtain material of value (AGI, 1997). Quarry: an open or surface mineral working, usually for the extraction of building stone as slate, limestone, and so on. It is distinguished from a mine because a quarry usually is open at the top and front (AGI, 1997)
RD	Rubbish dump	Dump consisting of rubbish
RS	Rock and soil dump	Dump that consists of a mixture of rock and soil and hence is neither a waste dump nor a top soil dump
RT	Ramp/tramway	Ramp: an inclined approach; used loosely when applied to a loading ramp (AGI, 1997). Tramway: a roadway having plates or rails on which wheeled vehicles may run (AGI, 1997). In WABMINES, ramp applies to a loading ramp. Tramways are usually made of waste rock and adjacent to shafts
SF	Shaft footing	Footing associated with a shaft and/or headframe
SFT	Shaft	An excavation of limited area compared with its depth; made for finding or mining ore or coal, raising water, ore, rock, or coal, hoisting and lowering workers and material or ventilating underground workings (AGI, 1997). In WABMINES, current usage only includes workings >2 m deep. Prior to June 2002, did include shallower collapsed and rehabilitated shafts
SUUG	Subsidence	The sudden sinking or gradual downward settling of the earths surface with little or no horizontal motion (AGI, 1997). In WABMINES, refers to surface subsidence due to apparent internal collapse of underground feature
TADU	Tailings dump	Tailings: the gangue and other refuse material resulting from the washing, concentration, or treatment of ground ore (AGI, 1997). Tailings are normally held within a tailings dam. Tailings dam: one to which slurry is transported, the solids settling while the liquid may be withdrawn (AGI, 1997)
TR	Town remnant	Remains of a town site that either do not specifically fit into any of the following categories: buildings, chimney, dam/sump or rubbish dump, or are too numerous to warrant individual description
TS	Topsoil dump	Topsoil: the dark-coloured upper portion of a soil varying in depth according to soil type (Jackson, 1997). In WABMINES refers to a dump made primarily of soil. These dumps are normally set aside from the waste rock for rehabilitation purposes
WD	Waste dump	The area where mine waste or spoil materials are disposed of or piled (AGI,1997)
WE	Well	Discontinued use. From 1/1/02, all wells are recorded as shafts or dams/sumps. Well: a borehole or shaft sunk into the ground for the following purposes: obtaining water, oil, gas or mineral solutions from an underground source (AGI, 1997)
VISIBILITY	Visibility	
VI	Visible	Capable of being seen (Little et al., 1973). In WABMINES a feature is visible when it can be viewed from a moderate distance
PH	Partially hidden	Feature partially concealed from view from a moderate distance
HD	Hidden	Concealed (Little et al., 1973). In WABMINES a feature is hidden commonly by vegetation when concealed from view from a moderate distance
NX	No surface expression	Feature is not visible from a moderate distance because it does not project above ground level
VISUAL_IMP	Visual impact	
HI	High	Any large feature and some moderately sized features that are disturbed by recent activity, untidy, with rubbish, and in poor condition
MO	Moderate	Medium-sized feature that is either disturbed by recent activity or untidy with some rubbish and plant debris or in fair condition
LO	Low	Any small feature and some moderately sized features that are undisturbed by recent activity, tidy, without rubbish and in good condition
CONDITION	Condition	
GO	Good	For infrastructure features: remains that are structurally sound that may have some equipment in place, and the former functions of which are recognizable or capable of being interpreted. For mine workings: only applies to recently used and working shafts with everything still in place.
FA	Fair	For infrastructure features: remains that are in a state of collapse or decay, but the former functions of which are likely to be capable of being interpreted with a reasonable degree of certainty. For mine workings: extra features such as timbers, ladders, headframes, and well-built bund walls that are relatively wellpreserved and with no apparent subsidence

Table A1.1. (continued)

ATTRIBUTE/ *VALUE*	*Attribute name/* *Value name*	*Description*
PO	Poor	For infrastructure features: remains that are in a state of collapse or dispersal such that interpreting | their former functions is likely to be difficult or highly speculative. For mine workings: no extra features such as timbers, ladders, headframes, well-built bund walls etc or where such extra features are present, they are not well preserved. Dump, opencut, and rehabilitated features are all assigned poor condition. Ramps and tramways (dump category features) are assessed as for infrastructure.
FO	Footings only	Footing: a relatively shallow foundation by which concentrated loads of a structure are distributed directly to the supporting soil or rock through an enlargement of the base of a column or wall (AGI, 1997). For infrastructure features: any form of foundations with or without bolts where walls of buildings, or machinery are completely removed
LENGTH	Length	Estimated maximum length of a feature at ground level in metres. Refers to the longer dimension of an adit opening (portal) as though it were a near horizontal shaft
WIDTH	Width	Estimated maximum width of feature at ground level in metres. For features with a high length to width ratio such as costeans, an average width is given
DEPTH	Depth	Normally maximum depth except for features with a high length to width ratio, such as costeans where an average depth is given. For an adit, depth refers to the maximum distance excavated (beyond the portal or opening) as though it were a near-horizontal shaft
XS	Extremely shallow	0 to 0.5 m deep
VS	Very shallow	0.5 to 1 m deep
MS	Moderately shallow	1 to 2 m deep
MD	Moderately deep	2 to 5 m deep
DE	Deep	5 to 10 m deep
VD	Very deep	10 to 20 m deep
XD	Extremely deep	>20 m deep
SO	Shallow	Discontinued use after 28/2/00; 0 to 5 m deep
DD	Deep	Discontinued use after 31/7/02; >10 m deep
SH	Shallow	Discontinued use after 31/8/02; 0 to 2 m deep
HEIGHT	Height	Estimated maximum height from ground level to top of feature in metres
STRIKE	Strike	Direction or trend of a feature in degrees Grid. Used for trends of linear surface features such as costeans and the long axes of opencuts and dumps. Also can be used for planar underground features such as open stopes in conjunction with dip using the right hand rule (when facing the direction of the strike bearing, the dip is to the right). Use 0° for north
AZIMUTH	Azimuth	Dip direction of feature in degrees Grid. Used only for underground features, especially linear ones such as shafts and adits. Use 0° for north
DIP	Dip	Angle at which a feature is inclined from the horizontal. Assumed to be 90° for collapsed shafts, shafts, and open stopes unless stated otherwise. Used in conjunction with azimuth or strike, or for the average wall dip for opencuts and dumps
BUND	Bund	An embankment of earth or a wall constructed of brick, stone, concrete or other approved material to form the perimeter or part of the perimeter of a compound (W.A. Government, 1992). In WABMINES, a bund usually consists of the waste rock excavated from the working. For pits and quarries the bund is ally purposely constructed around the feature to minimise inadvertent public access
FUBU	Full bund	A full bund is a complete rock barrier at the surface around the feature
PABU	Partial bund	Portions of a rock barrier are present at the surface around the feature. For underground features a partial bund usually consists of the waste rock excavated from the working with a gap left for easy access. For costeans andtrenches, the adjacent pile(s) of waste rock are considered to be bunds
BUND_MAX	Maximum bund height	Maximum height of a bund around a feature in metres to one decimal place
BUND_MIN	Minimum bund height	Minimum height of bund around a feature in metres to one decimal place
EDGES	Edge stability	
FI	Firm	Stable edge in original condition
CR	Cracked	An otherwise stable edge weakening due to visible cracks
SS	Slight subsidence	Original edge slightly collapsed usually resulting in a reduced edge dip
UC	Undercut	Original edge weakened due to being undercut, resulting in an overhang
XSB	Severe subsidence	Original edge severely collapsed usually resulting in a considerably reduced edge dip and/or a considerable increase in the surface area of the feature at ground level
CC	Conical collar	Normally only applies to underground features or collapsed shafts where the edges collapse to form a conical-shaped depression. An extreme special case of edge collapse
UK	Unknown	Edge stability unknown as cannot be observed

Table A1.1. (continued)

ATTRIBUTE/ VALUE	*Attribute name/ Value name*	*Description*
BASE_COND	Base condition	
EM	Empty	For underground features, a large empty void (probable stoping or extensive underground workings) indicated by a distinctive hollow echo sound heard from an object hitting the bottom of the excavation (usually a shaft). Also has previously been used to indicate no material remaining, or rubbish or water inthe base of an opencut
OVBC	Oversize	Extraordinarily large rocks obtained from blasting, at the base of an excavation
ROBC	Rock	Rock or soil or sediment forming the base of an excavation (i.e. no significant rubbish and/or water and/or oversize material)
RUBC	Rubbish	Significant rubbish in the base of an excavation
TABC	Tailings	Tailings can be observed in the base of an excavation. See tailings dump for definition of tailings
WA	Water	Water in the base of an excavation
WR	Water and rubbish	Water and significant rubbish in the base of an excavation
EXCAV_METH	Excavation method	
MEC	Mechanical	Excavation has definitely been made by machinery (e.g. bulldozer, excavator or loader). Commonly indicated by the dimensions and shape of the excavation and the location and shape of the extracted material
FENCES	Fences	
OP	Open	Feature is partly surrounded by a fence of any type or condition. Type and condition should be described in MINE NOTES and be evident in photographs
FE	Fenced	Feature is completely surrounded by a fence of any type or condition except a locked gate. Type and condition should be described in MINE_NOTE and be evident in photographs
LG	Locked gate	Access to the feature cannot be easily gained through the fence. The only entrance is a locked gate. This type of fence is commonly high, of small-mesh construction and may have barbed wire around the top
SIGNS	Signs	
YSI	Yes	Warning sign is visible, clearly relating specifically to the recorded feature
SHAPE	Shape	
CN	Cone	Three dimensional, cone shaped. Used exclusively for dumps
OVL	Oval	Oval shaped in plan view. Mainly used for dumps or pits and quarries
RE	Rectangular	Rectangular shaped in plan view. Mainly used for dumps and assumed for excavations
SB	Slab	Three-dimensional shape with rectangular plan view and relatively low flat and level upper surface. Mainly used for tailings dumps and leach pads
OTSH	Other	Shape other than cone, oval, rectangular or slab, commonly meaning irregular. Used mainly for dumps. May be more fully described in MINE_NOTE
REVEG	Revegetation	
FURE	Full	Feature is vegetated in a similar manner to the surrounding undisturbed area
PARE	Partial	Some vegetation is established on the feature, but less than on the surrounding undisturbed area
NO	None	No vegetation at all is associated with the feature
UG_TIMBERS	Underground	Condition of the material (usually timber) used to support the collar of an underground feature timber condition
GOUT	Good	The material appears to be able to provide effective support for the collar. Collar: The term applied to the timbering or concrete around the mouth or top of a shaft (AGI, 1997)
POUT	Poor	The material is unable to provide effective support for the collar. Poor-condition timbers may include only minor remnants of the former collar
UG_ACCESS	Underground access	
LD	Ladder	Timber or metal ladder used for access in an underground feature is visible. Ladder is not necessarily safe to use
RP	Rope	Rope or steel cable used for access in an underground feature is visible. Rope is not necessarily safe to use
SR	Side ramp	Ramp used for accessing an underground feature
ST	Steps	Steps used for accessing an underground feature
OTUA	Other	An alternative form of access to an underground feature is visible, other than a ladder, side ramp, steps or rope. The form of access should be recorded in MINE_NOTE

Table A1.1. (continued)

ATTRIBUTE/ VALUE	*Attribute name/ Value name*	*Description*
UG_HEADFRM	Underground headframe condition	
GOUH	Good	Headframe for an underground feature is intact, secure, and is not likely to cause harm or injury
POUH	Poor	Headframe for an underground feature is either incomplete, insecure or collapsed
UG_SEAL_TY	Underground seal type	
CT	Concrete	Entrance to an underground excavation has been blocked largely by concrete. Concrete is usually in the form of a slab or block
ME	Mesh	Entrance to an underground excavation has been blocked largely by steel mesh
PAUS	Partial	Entrance to an underground excavation that is only partially blocked, irrespective of the material used
RUUS	Rubbish	Discontinued use after 31/7/02
SP	Steel plate	Entrance to an underground excavation has been blocked largely by steel plating
TM	Timber	Entrance to an underground excavation has been blocked largely by timber
TN	Tin	Entrance to an underground excavation has been blocked largely by tin
OTUS	Other	Entrance to an underground excavation has been blocked largely by something other than concrete, mesh, timber, tin or steel plate. The material should be described in MINE_NOTE
UG_SEAL_CO	Underground seal condition	
GOUE	Good	Entrance to an underground excavation has been blocked to the extent that the feature is inaccessible
POUE	Poor	Entrance to an underground feature has not been blocked to the extent, or in such a way as to prevent entry
OP_OPENING	Opencut opening	
YOU	Yes	One or more underground openings are visible with an opencut feature. The opening may be a shaft, stope or adit. If possible, these features are also described as separate sites
WATER	Water condition	
BK	Black	Water at the base of the feature is black in colour. Used mainly for opencut features
BN	Brown	Water at the base of the feature is brown in colour. Used mainly for opencut features
CL	Clear	Water at the base of the feature is colourless. Used mainly for opencut features
GN	Green	Water at the base of the feature is green in colour. Used mainly for opencut features
RAMP	Ramp condition	
GORA	Good	Ramp appears as though it can be safely accessed. Used mainly for opencut features and dumps
PORA	Poor	Ramp access to a feature is possible, but the ramp appears to be potentially hazardous due to either severe erosion or actual or potential side wall collapse. Mainly used for opencuts and dumps
LA	Limited access	Vehicular ramp access to a feature is difficult or impossible due to either an obstruction such as a trench, bund or fence or severe erosion. Mainly used for opencuts and dumps
DUMP MATER	Dump material	
Gvl	Gravel	Main dump material is gravel size (2 to 20 mm). Commonly, this material has been screened or crushed to meet this size range
OVDM	Oversize	Main dump material consists of extraordinarily large rocks obtained from blasting
RODM	Rock	Main dump material is larger than gravel, but may be highly variable in size. This is the most common size for material obtained from opencut and underground mining
Sd	Sand	Main dump material is sand size (1/16 to 2 mm), but does not include tailings
TADM	Tailings	Main dump material is tailings. See tailings dump for definition of tailings
OTDM	Other	Main dump material is not sand, gravel, rock, oversize, tailings or rubbish. The material type should be recorded in MINE_NOTE
DUMP_OTHER	Other dump waste	
CA	Cars	Dump either consists mainly of, or incorporates, old car bodies
GR	General rubbish	Dump either consists mainly of, or incorporates, general rubbish
OB	Old bottles/cans	Dump either consists mainly of, or incorporates, old bottles and/or cans
PL	Plastic lining	Dump either consists mainly of, or incorporates, plastic lining
SM	Scrap metal	Dump either consists mainly of, or incorporates, scrap metal
DISP_DIR	Dump dispersion direction	
N	North	Main dispersion direction of dump material is to the north

Table A1.1. (continued)

ATTRIBUTE/ *VALUE*	*Attribute name/* *Value name*	*Description*
NE	Northeast	Main dispersion direction of dump material is to the northeast
E	East	Main dispersion direction of dump material is to the east
SE	Southeast	Main dispersion direction of dump material is to the southeast
S	South	Main dispersion direction of dump material is to the south
SW	Southwest	Main dispersion direction of dump material is to the southwest
W	West	Main dispersion direction of dump material is to the west
NW	Northwest	Main dispersion direction of dump material is to the northwest
DISP_DIST	Dump dispersion distance	Estimated dispersion distance of dump materials in metres
MINE_NOTE	Mine notes	Comments relating to any non-geological aspects of the feature
NOTES	Field notes	Geological comments including rock types, degree of weathering, structural measurements, and types, dimensions and orientation of mineralization. Some records also contain observations on vegetation types

NOTES: WABMINES: Western Australian Abandoned Mine Site database
An empty field means either 'none' or 'null' (i.e. not recorded)

REFERENCES American Geological Institute 1997, Dictionary of mining, mineral and related terms: Virginia, USA, American Geological Institute, 646p.
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Little, W, Fowler, HW and Coulson, J 1973, The Shorter Oxford English Dictionary; on historical principles (3rd edition) *edited by* CT Onions *revised by* GWS Friedrichsen: Oxford, UK, Clarendon Press.
Western Australian Government 1978, *Mining Act, 1978*: Perth, Western Australia, Government Printer, Part 1, p. 8.
Western Australian Government 1992, W.A. Explosives and Dangerous Goods (Dangerous Goods Handling and Storage) Regulations: Perth, Western Australia, Government Printer, Part 1, Preliminary, r. 1.3., p. 2.

Appendix 2

Methodology for WABMINES data processing

1. Primary data processing

All primary data processing steps were carried out using MS Access database software unless stated otherwise.

1.1 Compiling data

For in-house GSWA use.

Use a 'select' query to view all data from the WAROX-WABMINES table, the WAROX-FIELDNOTES table, and appropriate location information (minimum of easting and northing and latitude and longitude) from the WAROX-SITE table, linking each table. Arrange the fields so that they are in a user-friendly order i.e. Site identifier information — location information — feature group and type — commodity code — dimensions — orientations — other fields — comments.

1. For obtaining data from DVD digital database. Select 'Access Data' button and open subfolder 'databases'. Copy MS Access database 'wabmines.mdb' to hard drive. Data are already in the correct format for using. Make a 'select' query to view all of the data.

1.2 Selecting relevant data

1. Define the area of interest in decimal degrees latitude and longitude using ESRI ArcGIS software (or GeoVIEWER if obtaining data from DVD digital database).

2. Enter the location criteria for latitude and longitude using 'between x and y' ensuring that use negative values for latitude with lowest number first, and run the query.

3. Make a 'make table' query from the 'select' query and save the table to the database, named after the locality using and abbreviated name e.g. 'MenALL'.

4. Copy this table and rename e.g. 'MenED'. Go into design for the renamed file and change the 'MINE_NOTE' and 'NOTES' field-data types from 'memo' to 'text' specifying the maximum field size of 255 characters. Save. This will truncate some text, but is necessary for the data to be converted into shapefiles later.

5. Export the data, as a DBF file. Import this DBF file into ESRI ArcGIS software and check that it covers the area that you intend to work on.

6. Make a new 'select' query called e.g. 'MenED Query' to reference the table that was created in step 5 above. Reduce this table to the following fields: 'SITENO', 'SITEID', 'OBSDATE', 'EASTING', 'NORTHING', 'ZONE', 'DLAT', 'DLONG', 'FEAT_GROUP', 'TYPE', 'COMMODCODE', 'LENGTH', 'WIDTH', 'DEPTH', 'HEIGHT', 'STRIKE', 'AZIMUTH', 'DIP', 'BUND', 'BUND_MAX', 'BUND_MIN', 'EXCAV_METH', 'MINE_NOTE', and 'NOTES'. Use 'make table' query and save using an abbreviated name e.g. 'MenSEL'.

1.3 Selecting bedrock and alluvial excavation data

1. Go into design for the new table (e.g. 'MenSEL') and create new fields called 'class' (text format with field size of 5), 'count1' (number format — double).

2. Create a new query called e.g. 'MenSEL Query' using all columns in the 'MenSEL' table. Use 'update' queries to select all shafts, collapsed shafts, open stopes, and shallow workings by doing the following:
   a) for all 'TYPE' = 'SFT' or 'OS' update 'class' to 'BED' (abbreviation for bedrock);
   b) for all 'FEAT_GROUP' = 'CS' or 'SHW' update 'class' to 'BED';
   c) change back to 'select' query and check 'MINE_NOTE' for all 'FEAT_GROUP' = 'RH' or 'UI' with 'class' = 'null' to see if any shafts or open stopes have been missed (sort alphabetically on 'MINE_NOTE'). In either case, if most likely is a shaft or open stope, enter 'BED' in 'class' column. Allow 'RH' where comments suggest that a (not several) shaft was present e.g. 'remnant bund material' or 'rehabilitation of working' or 'possible working' etc.

3. Use 'update' query to select all 'alluvial' workings by updating 'class' to 'ALU' (abbreviation for alluvial) for all 'MINE_NOTE' = '*alluvi*', or '*colluvi*', or '*eluvi*', or '*deep lead*', or '*dry blow*'. Also check 'NOTES' for the same.

Change back to 'select' query. For 'FEAT_GROUP' = 'SHW', double check 'MINE_NOTE' for any probable references to 'alluvial' workings such as 'along creek bed', 'duricrust workings', 'calcrete workings' etc. and change 'class' to 'ALU' (or 'null' if unclear) where deemed appropriate.

1.4 Selecting hand-dug gold excavation data

1. Remove any 'shallow working' 'bedrock' features that are mechanically excavated, of modern origin, or are misclassified (e.g. costeans, dumps, alluvial).

2. Use 'update' query for all 'FEAT_GROUP' = 'SHW', and EXC_METH = MEC, and 'class'= 'BED' to update 'BED' to 'null'.

3. Change back to a 'select' query and examine 'MINE_NOTE' ('not null') for 'FEAT_GROUP' = 'SHW' and 'class' = 'BED'. Sort alphabetically, and change 'BED' to 'null' (i.e. delete 'BED') if comments include anything that indicates more recent origin such as: 'borrow pit', 'bulk sample', 'soil sample', 'bulldozer, grader or loader scrape, pit or excavation', 'drill sump', 'rubbish dump', 'drill pad', 'relatively recent' etc. Also, check for any unwanted feature type descriptions such as 'costean' or 'bottle dump'.

4. Use the same 'select' query for checking entries with 'LENGTH' > 5 * 'WIDTH' (possible costean – generally assume costean if 'LENGTH' > 5 * 'WIDTH' unless comment to contrary), or 'LENGTH' > 10 m (possible borrow pit or alluvial working) change 'BED' to 'null' or 'ALU' as appropriate.

5. Remove any 'bedrock' features that are not for gold. Using 'select' query, sort on 'COMMODCODE' and for 'class' = 'BED', and change 'BED' to 'null' for all commodities that are not labelled 'Au' or 'null' (Use 'update' query if numerous).

6. Using the same 'select' query, for 'class' = 'BED', sort 'MINE_NOTE' and 'NOTES', and change 'BED' to 'null' if any commodity other than gold is indicated as the primary mineral such as: 'chalcedony', 'magnesite', 'calcrete laterite or ferricrete nodules/gravel', 'gravel pit', 'sand pit', 'water shaft' etc. Also double check for indications of more recent origin, inappropriate features (e.g. ventilation shafts) or alluvial/colluvial (change 'BED' to 'ALU').

7. Use 'select' query, for 'class' = 'BED', sort by decreasing 'LENGTH'. Check any lengths> 50 m, and change 'BED' to 'null' if 'FEAT_GROUP' = 'RH' and 'TYPE' = 'null', or where comments are too generalized.

8. Use 'make table' query and for 'class' = 'BED' save using an abbreviated name e.g. 'MenBED', and then for 'class' = 'ALU', save using an abbreviated name e.g. 'MenALU'.

2. Derived-data processing

Initially, all data processing was carried out using MS Access database software.

2.1 Adding new attribute fields and calculating new attributes

1. Go into design for the new table (e.g. 'MenSEL') and create new fields called 'depth_m' (number format — double), and 'bund_m' (number format — double).

2. Assign mean depths for observed shafts, open stopes, and shallow workings to the 'depth_m' field.
   a) Use 'select' query on appropriate table e.g. 'MenBED' to select for:
   'FEAT_GROUP' = 'UG' and 'TYPE' = 'SFT' or;
   'FEAT_GROUP' = 'UG' and 'TYPE' = 'OS' or;
   'FEAT_GROUP' = 'SHW'.
   b) Change to an 'update' query, ensure that 'DEPTH' is entered for each of the above three lines, and populate the 'depth_m' field as follows:
   'DEPTH' = 'XS', 'depth_m' = 0.25;
   'DEPTH' = 'VS', 'depth_m' = 0.75;
   'DEPTH' = 'MS', 'depth_m' = 1.5;
   'DEPTH' = 'MD', 'depth_m' = 3.5;
   'DEPTH' = 'DE', 'depth_m' = 7.5;
   'DEPTH' = 'VD', 'depth_m' = 15;
   'DEPTH' = 'XD', 'depth_m' = 25.
   Some pre-2003 data may also have the following:
   'DEPTH' = 'SH', 'depth_m' = 1;
   'DEPTH' = 'SO', 'depth_m' = 2.5;
   'DEPTH' = 'DD', 'depth_m' = 20.
   The 'depth_m' values are mean (or mid-point) depths for the above depth intervals.

2.2 Estimating depth for collapsed shafts

2.2.1 Calculating mean bund height for all 'underground' and collapsed shafts

1. Select bund heights for Underground Shafts and Collapsed Shafts using 'select' query on the appropriate table e.g. 'MenBED'. Some pre-2003 recordings had no 'BUND_MAX' values, hence exclude these. Use the following settings:
   'FEAT_GROUP' = 'UG' and 'TYPE' = 'SFT' and BUND = 'not null' and 'BUND_MAX' = 'not null' or
   'FEAT_GROUP' = 'CS' and 'TYPE' = 'null' and BUND = 'not null' and 'BUND_MAX' = 'not null'.

2. There are null values in the 'BUND_MIN' field. These must be changed to zeros for calculation purposes. Using a 'select' query, find these records by selecting 'BUND_MIN' = 'null'. Then change to an 'update' query and populate these 'BUND_MIN' values with 0.

3. Calculate the mean bund height by using the following formula in the 'bund_m' field of an 'update' query: ('BUND_MAX' + 'BUND_MIN')/2.

2.2.2 Summarizing mean bund height vs mean depth for 'underground' shafts

All remaining derived data processing steps are carried out using ESRI ArcGIS software unless stated otherwise.

1. Export the appropriate table (e.g. 'MenBED'), as a DBF file. Then import this DBF file into ESRI ArcGIS software and save as a shapefile.
2. Using 'select attributes', select 'FEAT_GROUP' = 'UG' and 'TYPE' = 'SFT'.
   a) Some pre-2003 recordings had no 'BUND_MAX' values, hence remove these from the selection: i.e. records with BUND = FUBU AND 'BUND_MAX' = 0.
   b) Some zero values exist for 'bund_m', hence remove these from the selection: i.e. records with 'bund_m' = 0.
3. Open attribute table and summarize on 'depth_m' for 'bund_m' using the average option, and ticking box for summarizing only on selected records. Save the output table as a DBF file e.g. 'depth_bund_av'.
4. Open DBF file using MS Excel software and create table (and optional graph) with midpoints for 'bund_m' as per the Table A.2.1

2.2.3 Allocating estimated original depth to collapsed shafts based upon mean bund height

1. Using 'select attributes', select collapsed shafts: 'FEAT_GROUP' = 'CS'.
2. Open attributes table and using field calculator set all mean depths to zero, i.e. 'depth_m' = 0.
3. Using 'select attributes' create a new selection with the following expression:

   'bund_m' > x AND "bund_m" <= y AND "FEAT_GROUP" = 'CS'.

   Where x and y are the minimum and maximum bund height midpoints respectively e.g. in the above table x = 0 and y = 0.77.
4. Open attributes table and using field calculator set mean depth to the appropriate value. For the above example this would be 'depth_m' = 3.5.
5. Repeat for all mean depths i.e. 3.5, 7.5, 15, and 25 m.
6. Using 'select attributes' create a new selection with the following expression:

   "FEAT_GROUP" = 'CS' AND "MINE_NOTE" LIKE '%main shaft%'.
7. Open attributes table and using field calculator set mean depth to 25 m, i.e.. 'depth_m' = 25.
8. Repeat steps 6 and 7 for the expression:

   "MINE_NOTE" LIKE '%Main shaft%', and for '%major shaft%' and '%Major shaft%'.
9. Using 'select attributes' create a new selection with the following expression:
   "FEAT_GROUP" = 'CS' AND "MINE_NOTE" LIKE '%depth%', (also try '%deep%').
10. Start editing the shapefile e.g. 'MenBED'. Open attribute table, examine selected records in 'MINE_NOTE' and edit 'depth_m' to match appropriate depth interval where comments indicate known original depth from historical records (ignore any comments about current depth) to a maximum of 25 m.

2.3 Estimating original depth for rehabilitated excavations and excavations located under infrastructure

All data processing steps are carried out using ESRI ArcGIS software unless stated otherwise.

Table A2.1 Example of a table used for determining midpoint values for average bund height

Depth interval (m)	*Mean depth (m)*	*No. of shafts (n)*	*Average bund height (m)*	*Midpoint for mean depth (m)*	*Midpoint for average bund height (m)*
2 – 5	3.5	537	0.62	–	–
	–	–	–	5.5	0.77
5 – 10	7.5	342	0.93	–	–
	–	–	–	11.25	1.15
10 – 20	15	147	1.37	–	–
	–	–	–	20	1.56
>20	25	32	1.75	–	–

NOTES: These are then used to estimate original depth for collapsed shafts with known mean bund height

2.3.1 Examining depth statistics for 'underground' shafts and estimating default depth

1. Using 'select attributes', select 'FEAT_GROUP' = 'UG' and 'TYPE' = 'SFT'.
    a) Open attributes table and summarize on 'depth_m' for 'count1' using the average option, and ticking box for summarizing only on selected records. Save the output table as a DBF file e.g. 'depth_stats'. Examine using MS Excel software and determine Mode. Graph if desired.
    b) Calculate statistics on 'depth_m' to determine Mean.
    c) Export selected records as a DBF file, open using MS Excel software, and use median function to calculate Median from the 'depth_m' column.

2. Determine the default depth — usually the median and mode will coincide — making this the logical choice.

2.3.2 Allocating original depth to excavations

1. Using 'select attributes', select all rehabilitated and under infrastructure workings i.e. 'FEAT_GROUP' = 'RH' and 'FEAT_GROUP' = 'UI'.

2. Open attributes table and using field calculator set all mean depths to the default depth.

3. Using 'select attributes' create a new selection with the following expression:
   "FEAT_GROUP" = 'RH' AND "MINE_NOTE" LIKE '%main shaft%' OR "FEAT_GROUP" = 'UI' AND "MINE_NOTE" LIKE '%main shaft%'.

4. Open attributes table and using field calculator set mean depth to 25 m, i.e. 'depth_m' = 25.

5. Repeat steps 6 and 7 for "MINE_NOTE" LIKE '%Main shaft%', '%major shaft%' and '%Major shaft%'.

6. Using 'select attributes' create a new selection with the following expression:
   "FEAT_GROUP" = 'RH' AND "MINE_NOTE" LIKE '%depth%' OR "FEAT_GROUP" = 'UI' AND "MINE_NOTE" LIKE '%depth%', (also try '%deep%').

7. Start editing the shapefile e.g. 'MenBED'. Open attributes table, examine selected records in 'MINE_NOTE' and edit 'depth_m' to match appropriate depth interval where comments indicate known 'original' depth from historical records (ignore any comments about current depth) to a maximum of 25 m.

8. No record should now have a null value for 'depth_m'. Sort on 'depth_m' to check. Any instances of zeros for 'depth_m' should be resolved, usually by using mode/median depths and reference to the 'MINE_NOTE' comments.

2.4 Attributing geological information

All data processing was carried out using ESRI ArcGIS software.

2.4.1 Adding new attribute fields

Open the attribute table for the appropriate shapefile (e.g. 'WidBED') and create the following new short integer attribute fields:

- 'foliat_int' — for foliation intensity;
- 'weath_int' — for weathering intensity;
- 'rock_type' — for rock type;
- 'qtz_vn_str' — for the strike of quartz veins;
- 'qtz_vn_dip' — for the dip of quartz veins;
- 'work_strike' — for the strike of excavations;
- 'work_dip' — for the dip of excavations.

2.4.2 Attributing geological data to new attribute fields

Refer to Table A2.2 for a list of classifications and numerical codes that are used for attributing foliation, weathering and rock type.

1. For attributing **foliation**.
    a) Using 'select attributes' create a new selection with the following expression:
       "NOTES" LIKE '%slightly foliat%'.
    b) Select 'field calculator' by right clicking on the 'foliat_int' attribute field, then set 'foliat_int' = 1 and press 'OK'. This will place the numerical code of '1' in all selected records that include a geological comment of 'slightly foliated'.
    c) Repeat steps (a) and (b) using '%weakly foliat%' instead of '%slightly foliat%'.
    d) Using 'select attributes' create a new selection with the following expression:
       "NOTES" LIKE '%foliat%' AND "foliat_int" = 0.
    e) Using 'field calculator' in the same way as for step (b), but this time set 'foliat_int' = 2.
    f) Using 'select attributes' create a new selection with the following expression:
       "NOTES" LIKE '%strongly foliat%'.
    g) Using 'field calculator' in the same way as for step (b), but this time set 'foliat_int' = 3.
    h) Using 'select attributes' create a new selection with the following expression:
       "NOTES" LIKE '%foliat%'.
    i) Check that all selected records have a value of either '1', '2', or '3' in the 'foliat_int' attribute field. If not, check 'NOTES', and code the missing values accordingly.

2. For attributing **weathering**.
    a) Using 'select attributes' create a new selection with the following expression:
       "NOTES" LIKE '%extremely weath%'.
    b) Select 'field calculator' by right clicking on the 'weath_int' attribute field, then set 'weath_int' =

Table A2.2 List of classes and numerical codes assigned for various attributes that were derived from the geological comments attribute field which is labelled 'NOTES' in the WABMINES database

Attribute	*Classification*	*Code*	*Description in 'NOTES'*
Foliation	slightly	1	slightly or weakly foliated
	moderately	2	foliated
	strongly	3	strongly foliated
Weathering	extremely	4	extremely weathered
	distinctly	3	distinctly weathered
	slightly	2	slightly weathered
	fresh	1	fresh
Rock type	mafic	1	mafic, basalt, dolerite, gabbro or amphibolite
	ultramafic	2	ultramafic, komatiite or serpentinite
	felsic	3	felsic, porphyry, quartz–feldspar rock, volcaniclastic rock, rhyolite or dacite
	granite	4	granite
	pegmatite	5	pegmatite
	metasedimentary	6	metasedimentary, sediment, siltstone, sandstone, conglomerate, shale or slate
	chert	7	chert
	black shale	8	black shale

NOTES: Classes are listed in order of increasing significance

4 and press 'OK'. This will place the numerical code of '4' in all selected records that include a geological comment of 'extremely weathered'.

c) Repeat steps (a) and (b) using '%Extremely weath %' instead of '%extremely weath %'. This is necessary as the selection query is case sensitive, and weathering is commonly the first item in the 'NOTES' attribute field.

d) Repeat steps (a), (b), and (c) for:
'%distinctly weath% (use code = 3);
'%slightly weath% (use code = 2);
'%fresh% (use code = 1).

e) Using 'select attributes' create a new selection with the following expression:
"NOTES" LIKE '%weath%'.

f) Check that all selected records have a value of either '1', '2', '3' or '4' in the 'weath_int' attribute field. If not, check 'NOTES', and code the missing values accordingly.

3. For attributing **rock type**.
   a) The 'rock_type' attribute field is populated in the same manner as for foliation and rock type using the description in 'NOTES', and the appropriate codes as listed in Table A.2.2. Start with code '1' and finish with code '8'. Ensure to use both upper and lower case rock types (e.g. '%basalt%' and '%Basalt%') in the selection queries. Use the full rock name with the following exceptions:
   for 'mafic' use '% mafic%';
   for 'komatiite' use '%komat%;
   for 'porphyry' use '%porph%;
   for 'quartz-feldspar rock' use '%feldspar%;
   for 'granite' use '%granit%;
   for 'metasedimentary' and 'sediment' use '%sediment%.
   b) Once completed, check the 'rock_type' attribute field for values of '0'. These will have rock types or spelling that was not included in the selection queries. Code as appropriate, but leave as '0' for irrelevant descriptions such as quartz, laterite, soil, and clay.

4. For attributing **vein orientation**.
   a) Using 'select attributes' create a new selection with the following expression:
   "NOTES" LIKE '%vein%'.
   b) Start editing and manually enter quartz vein strike and dip into the appropriate attribute fields. Where a range of dips are given, use an average. For no dip use '999' rather than '0'. For general orientations such as 'dip towards SE', use the general strike bearing (e.g. 045).

5. For attributing '**working strike**' and '**working dip**'.
   a) Select 'field calculator' by right clicking on the 'work_str' attribute field, then set 'work_str' = [STRIKE] and press 'OK'. This will place measured excavation strike into the 'work_str' attribute field.
   b) Some excavations use azimuth rather than strike. Using 'select attributes' create a new selection with the following expression:
   "AZIMUTH" > 90.
   c) Use 'field calculator' to set 'work_str' = [AZIMUTH]-90.
   d) Using 'select attributes' create a new selection with the following expression:
   "AZIMUTH" < 90 AND "AZIMUTH" > 0.
   e) Use 'field calculator' to set 'work_str' = [AZIMUTH]+270.
   f) Using 'select attributes' create a new selection with the following expression:
   "work_str" > 0.
   g) Use 'field calculator' to set 'work_dip' = [DIP].

Appendix 3

Methodology for producing pseudocolour hill-shaded images

1. Assigning co-ordinates to points

1. In ESRI ArcGIS software open the attribute table for the point vector file to be processed e.g. ‘dphmax10’and add two fields called ‘East’ and ‘North’ respectively (type is ‘double’ for both).

2. With the attribute table open, right click on the ‘East’ field, go to ‘calculate values’, in ‘field calculator’ click on ‘advanced’. In the ‘Pre-Logic VBA Script Code ‘area type the following expression:
   <Dim dblX As Double
   Dim pPoint As IPoint
   Set pPoint=[Shape]
   dblX=pPoint.X>
   In the text box beneath the variable ‘East=’ type ‘dblX’. Click ‘OK’.

3. Repeat for the ‘North’ field, substituting ‘Y’ for ‘X’ in the above expression.

4. Using MS Access database software, import the resultant DBF file into a new blank database.

5. Edit each table in ‘design view’ as follows:
   move ‘GRID_CODE’ to after ‘North’ field
   delete the ‘POINTID’ field,
   save and close.

6. Export each table as a comma delimited TXT file. Headings are not required.

2. Creating pseudocolour hill-shaded images

2.1 Loading text files into ER Mapper software

Using ER Mapper software, navigate to:‘utilities/import gridding formats/XYZ ASCII grid/import’ to import the text file created within MS Access database software. Use ‘volumes’ to map ‘input file/device name’. For geodetic datum: use ‘GDA94’, and for ‘map projection’: use ‘tranmerc’, then select ‘MGA51’ (or whatever zone is appropriate). Use ‘volumes’ to map ‘output dataset’ name.

This process creates an ERS file for each text file.

2.2 Creating a pseudocolour overlay

1. Select ‘view/algorithm’, to open a new algorithm window and algorithm box.

2. In the algorithm box, press the ‘load dataset’ icon, and in the ‘raster dataset’ box, navigate to the appropriate ERS file and press ‘OK’ to load the selected file.

3. To enable interaction with the whole dataset, select ‘view/quick zoom/zoom to all datasets’, and turn on ‘smoothing’.

4. In the algorithm box, press the ‘edit formula’ icon, and in the ‘formula editor’ box, clear any existing formulas and enter the following expression:
   <IF ISNULL(i1) then 0 else i1>and press ‘apply changes’. This will change the background colour from black to blue. Close the ‘formula editor’ box.

5. In the algorithm box, press the ‘edit transform limits’ icon, and in the ‘transform’ box, select ‘create default linear transform’, then change the ‘limits’ dropdown to ‘limits to actual’, and then change the minimum to 0.5 and leave the maximum unchanged. Press the ‘refresh images and histograms’ button. Select the ‘gaussian equalize’ icon, then close the ‘transform’ box.

6. Press the ‘refresh’ button to ensure that all changes have been applied.

2.3 Creating an elevation layer

1. Open a new window (‘file/new’ on ER Mapper toolbar), and open the ‘algorithm’ box (in ‘view’ on toolbar) then click ‘load dataset’, and load the appropriate ERS file (e.g. ‘den10’) for the elevation layer.

2. In the ‘algorithm’ box, right click on the ‘pseudo layer’ label of the ‘bottom layer’ and select ‘Intensity’.

3. Enter the formula:
   <IF ISNULL(i1) then 0 else i1> and press ‘apply changes’, then close the box. This will change the background colour later.

4. Select the ‘edit realtime sunshade’ icon in the ‘algorithm’ box , and tick the ‘do sun-shading’ box. Set the azimuth to 45°, and the elevation to 60°. Press ‘enter’, then close.

5. In the ‘algorithm’ box, select the ‘intensity’ layer, then select the ‘edit transform limits’ icon, and select the ‘create default logarithmic transform’ icon. Set the ‘actual input limits’ to ‘1’ for the minimum, and leave the upper limit at ‘255’. Drag the curve higher into the left top corner until the best (and a brighter) relief image is obtained (not too flat nor too dull). Zoom to view the grid closer up if necessary (but zoom out to all datasets afterwards). Press ‘enter’. Ensure that ‘smoothing’ is turned on.

6. Press the ‘refresh image and histogram’ icon to ensure that all changes have been applied then close ‘algorithm’ box.

2.4 Superimposing the layers

1. Create a new window and view the ‘algorithm’ box.

2. Using the ‘copy’ and ‘paste’ buttons in the ‘algorithm’ box toolbar, first copy and paste the elevation layer to the new window, then copy and paste the pseudocolour layer into the same new window.

3. Ensure that ‘smoothing’ is turned on and that the ‘intensity’ layer is at the base.

4. Press refresh to ensure that all changes have been applied.

2.5 Saving the image

1. Save the algorithm for future reference or adjustments.

2. Using ‘save as’ on the ER Mapper toolbar, save the current window as a ‘Geotiff/TIFF’ image, but first change the ‘X dpi’ and ‘Y dpi’ settings to ‘600 × 600’ to improve the output image resolution. Also change the pixel size to the smallest size possible (2 × 2 m is good), that still results in a manageable file size. Ensure that the ‘world file’, and the ‘maintain aspect ratio’ boxes are ticked.

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THE APPLICATION OF ABANDONED MINE SITE DATA TO THE INTERPRETATION OF REGIONAL GEOLOGY AND GOLD MINERALIZATION IN THE KALGOORLIE TERRANE, WESTERN AUSTRALIA

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