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Epithermal gold deposits of the southwest Pacific

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Abstract

Since the freeing of the market price of gold in 1971, exploration for epithermal gold deposits in the southwest Pacific region has been intense, and has been encouraged by some major successes. Sufficient discoveries have been made to summarise what has been found to date, and to assess what implications may be drawn for future exploration. Data are tabulated for 137 epithermal precious metal deposits and prospects in Australia (30), Fiji (2), Indonesia (43), New Zealand (22), Palau and Yap (2), Papua New Guinea (18), the Philippines (19), and Solomon Islands (1).

Comparison of the character of epithermal deposits in the southwest Pacific with those in other regions (e.g., the northeastern Pacific margin) suggests that they are in most respects similar with, however, three differences: (i) through much of the region (especially the Philippines and Indonesia) low-sulfidation style deposits commonly show characteristics suggestive of formation at deeper levels than is typical elsewhere; (ii) high-sulfidation deposits appear to be more common than along the northeast Pacific margin; (iii) many of the largest deposits show atypical features, particularly those suggestive of a transition to porphyry or mesothermal conditions, or indicating overprinting of an epithermal system on a porphyry environment. These differences can be partly understood in terms of the tectonic setting and evolution of the volcanic arcs of the southwest Pacific, and the consequent hydrological conditions that existed during mineralization.

The results of exploration in the southwest Pacific indicate that, while the principles of formation of epithermal deposits still apply, deposit models developed in other tectonic/volcanic settings should not be rigidly applied. Gold explorers should first consider the character of the geologic environment at the time of mineralization to try to predict the hydrological conditions during mineralization. Once the likely volcanic environment and paleorelief have been established, then the types, distribution, and zoning of hydrothermal alteration, coupled with observations of deposit form, vein textures and mineralogy, will allow a judgement to be made on the level of system that is now exposed, and on the probable controls that localized mineralization.

The very dynamic character of the tectonic and volcanic setting throughout much of the southwest Pacific has resulted in deposits that reflect changes in the environment of the deposit, in some cases even while deposition was occurring. This has produced some deposits with unusual characteristics which could not have been predicted before exploration.

1. Introduction

Gold production from epithermal deposits in the southwest Pacific region dates from before the arrival of the earliest Europeans. In both Indonesia and the Philippines, pre-European civilisations were versed in the use of metals, and some recovery of gold from epithermal sources was taking place. Under the colonial regimes of the Spanish (and later the Americans) in the Philippines, the Dutch in Indonesia, and the British in many other parts of the region, gold mining contin-

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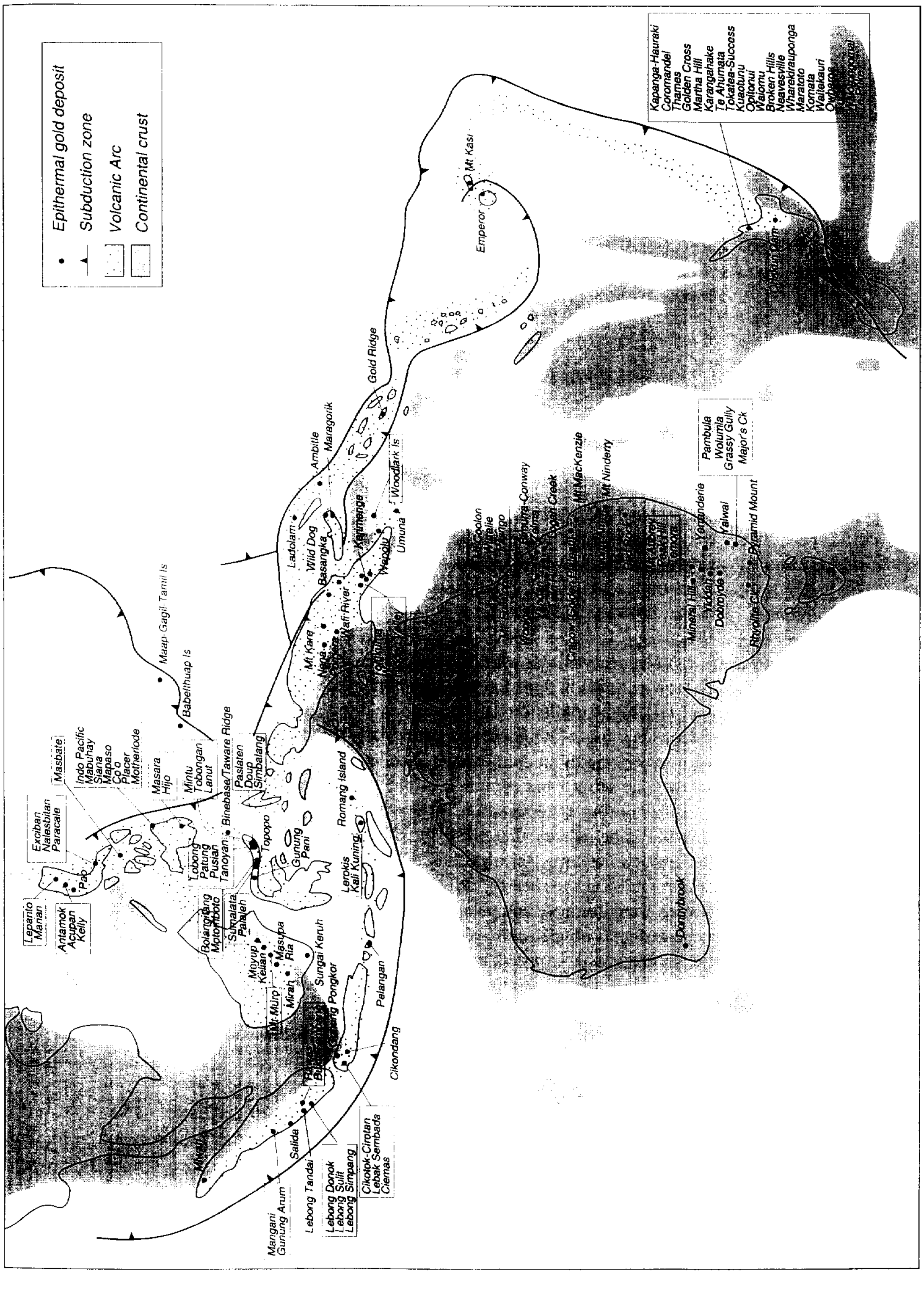

Fig. 1. Map of the southwest Pacific, showing the location of described epithermal deposits in relation to present-day subduction and volcanic arcs, and continental crust.

ued until the Second World War. Many mines that ceased operating during the war were not re-opened in the post-war period, and low gold prices discouraged exploration.

For much of the southwest Pacific region apart from Australia and New Zealand, the porphyry-copper boom of the late 1960s and 1970s was the first time that systematic exploration methods were used, although in general little attention was given to gold because of its low price. One result of this activity was the creation of a body of explorers familiar with the geology of the region, much of which had not been mapped, and experienced in operations there.

Freeing of the market price of gold in 1971 led to a heightened interest in exploration for gold, particularly in Australia. By the late 1970s, competition for favourable ground became intense, and consequently prospective ground further afield was sought. In addition, reassessment of target priorities focussed attention on epithermal gold deposits as having economically attractive tonnage and grade characteristics. This occurred at the same time as epithermal target models were being refined (Sillitoe, 1977; Buchanan, 1981; Berger and Eimon, 1983; Henley and Ellis, 1983). Intense exploration activity rapidly spread throughout the region, with interest encouraged by major successes (e.g., Porgera, Ladolam).

The situation today is one of active exploration, with local variations resulting from perceptions of geological favourability and the political and operational difficulties that apply. Sufficient discoveries have been made to allow a summary of them, and to assess what implications can be drawn for future exploration. In compiling a summary of the known epithermal gold deposits in the southwest Pacific, major problems were encountered owing to the variable amount and quality of information available. For that reason, much of the information given here will need to be updated as new data become available.

Available data on epithermal gold deposits in the southwest Pacific region are tabulated alphabetically by country name (Appendix). Palau and Yap have been grouped together. Deposit locations are shown in Fig. 1. In this paper the term deposit is used in the sense of mineral deposit, without necessarily implying economic significance.

2. Tectonic settings of epithermal gold deposits in the Southwest Pacific

The southwest Pacific is one of the most complex tectonically active regions of the Earth's crust (Howell et al., 1985; Carlile and Mitchell, 1994). The epithermal gold deposits found in the island arcs of the southwest Pacific region formed in the past, and so are not, in many cases, a product of the presently active arc setting. However, paleotectonic reconstructions (Hilde et al., 1976) show that they formed in similar tectonic settings to those that can be observed today.

The most common tectonic setting in the region results from subduction of an oceanic plate beneath another oceanic plate (Fig. 1). This process is presently operating in the Solomon Islands, the offshore islands of New Guinea, Palau, the Mariana Islands, and, in a very complex fashion, in the Philippines and Indonesia (Hamilton, 1979; Howell et al., 1985).

The complex geology of the Philippines results from convergent subduction occurring on both sides of the archipelago, producing a zone comprised principally of obducted slices of ophiolites through which island arc volcanism has occurred (Gervasio, 1968; McCabe et al., 1985; Hawkins et al., 1985). The oblique character of the subduction has resulted in major strike–slip faulting along the axis of the island chain (the Philippines Fault zone; Barrier et al., 1991).

Similarly complex interaction between plates has produced some of the islands of Indonesia, notably Sulawesi (Carlile et al., 1990; Carlile and Mitchell, 1994). The tectonics of Indonesia are further complicated by the presence of several micro-continental fragments (Barber, 1985) and by the change from the northward subduction of oceanic parts of the Australia–India Plate beneath the Sundaland Craton in the west (Sumatra, Java), to the southward subduction of the oceanic Pacific Plate beneath the Australian Craton to the east (West Irian).

As noted above, subduction of oceanic plates beneath continental plates is occurring in several parts of the region (Barber, 1985; Stauffer, 1985). The Australian Craton, which underlies the southern part of the island of New Guinea, is actively over-riding the Pacific Plate at a subduction zone to the north of New Guinea. The islands of Sumatra and Java (in part) overlie continental crust of the Sundaland Craton, which is overthrusting the north-migrating oceanic

Table 1
Characteristics of low and high sulfidation deposits

	Low sulfidation	High sulfidation
Form of deposits	Open space veins dominant Stockwork veining common Disseminated ore mostly minor Replacement ore minor	Veins mostly subordinate Stockwork veining minor Disseminated ore common Replacement ore common
Ore minerals	pyrite, sphalerite, marcasite, galena, electrum, gold (arsenopyrite, argentite, chalcopyrite, tetrahedrite)	pyrite, enargite–luzonite chalcopyrite, covellite, tetrahedrite–tennantite, gold (sphalerite, galena, tellurides)
Gangue minerals	quartz, chalcedony, calcite, rhodochrosite, adularia, barite, illite	quartz, kaolinite, alunite, barite
Common textures	veins, cavity filling, banded textures, vein breccias, drusy cavities, colloform structures, lattice texture, comb, cockade, cockscomb textures	wallrock replacement textures, drusy cavities, hydrothermal breccias, veins
Minor textures	wallrock replacement textures	banded textures
Dominant metals	Ag, Au, As, Hg	Cu, Ag, Au, As
Minor metals	Zn, Pb, Sb, Se	Pb, Hg, Sb, Te, Sn, Mo

Australia–India Plate. The very oblique angle of the subduction zone results in strong strike–slip fault movement in Sumatra.

In New Zealand, important gold mineralization occurs where the oceanic plate–oceanic plate subduction along the Tonga–Kermadec Trench passes beneath the continental crust of New Zealand, and the convergent motion changes to major strike–slip fault movement along the Alpine Fault. Active geothermal systems depositing gold in the Taupo Volcanic Zone are related to Recent volcanism there, and the economically important epithermal mineralization of the Hauraki Goldfield formed in Miocene to Pliocene volcanics, probably in a similar tectonic setting (Cole, 1987).

Epithermal gold mineralization, hot spring activity, and volcanism on Fergusson and Goodenough Islands of Papua New Guinea have recently been recognised to occur associated with continental extension tectonics with detachment faulting (Hill, 1989). It is not yet apparent how regionally significant this tectonic setting will prove to be.

3. Epithermal gold deposits of the region

A rigorous definition of the much-used term "epithermal" is very difficult (e.g., see Henley, 1991). As more information becomes available some of the characteristics of epithermal deposits (e.g., inferred depth of formation) originally cited by Lindgren (1922, 1933) are no longer valid. For the purposes of this review (see also White and Hedenquist, 1990), epithermal deposits are considered to be those which exhibit a low temperature of formation (ranging from 100 to 320°C, typically 170–280°), with characteristic hydrothermal alteration (Bonham, 1986; Hayba et al., 1985; Heald et al., 1987; Hedenquist, 1987), and with characteristic textures (Berger and Eimon, 1983). A shallow depth of formation may be inferred from these characteristics, but may not be essential in all cases.

Two distinct styles of epithermal gold deposits are recognised (Table 1). The best known style is variously referred to as adularia–sericite (Hayba et al., 1985; Heald et al., 1987), low sulfur (Bonham, 1986), or low-sulfidation style (Hedenquist, 1987). The second style is variously referred to as acid sulfate (Heald et al., 1987), high sulfur (Bonham, 1986), high-sulfidation (Hedenquist, 1987), or kaolinite–alunite style (Berger and Henley, 1989). A third type (alkalic type) was distinguished by Bonham (1986); it is here regarded as a subset of the low-sulfidation style. The problems of this diverse terminology are discussed by White and Hedenquist (1990). In the following text the terms high-sulfidation and low-sulfidation style are used, as they are based on the sulfidation state of associated sulfide minerals, which, along with characteristic hydrothermal alteration, reflects fundamental chemical differences in the epithermal environment. Characteristics of both styles are summarised in Table 1.

3.1. Australia

Continental Australia is now remote from active convergent plate margins, and epithermal deposits known in Australia are all much older than others found in the southwest Pacific region. The youngest epithermal deposit known in Australia is the Donnybrook prospect in Western Australia. There, very large low-sulfidation epithermal veins are associated with splays off the Darling Fault, a major regional fault that ceased activity in Cretaceous time following breakup of Gondwana (Veevers and Hansen, 1981). The chalcedonic veins are hosted by Archaean gneisses and amphibolites, and extend into the unconformably overlying Cretaceous Donnybrook Sandstone. Typical epithermal textures (Berger and Eimon, 1983) are present; including cockade textured breccias, and chalcedonic replacements of bladed calcite (lattice texture), however, the known gold mineralization is minor, and other elements typical of epithermal associations (As, Sb, Hg) are in very low abundance (Ward, 1986). The only igneous rock of similar age to the veins is very minor olivine basalt (Bunbury Basalt). This occurrence is important as it demonstrates that epithermal mineralization styles (albeit minor) can occur in tectonic settings which differ from the more typical convergent plate margin setting.

Most of the recognised epithermal deposits in Australia occur in the Palaeozoic Tasman Fold Belt of eastern Australia. Minor historical production has been recorded from a high-sulfidation deposit at Peak Hill, and low-sulfidation deposits at Yalwal, Panbula, and Red Rock (Drake) in New South Wales, and Cracow and Mt. Coolon in Queensland (Appendix, Part A).

Despite the known occurrence of deposits of epithermal character in Australia, little attention was given to exploration for epithermal gold deposits before the discovery of the Temora deposit in New South Wales, and the Pajingo deposit in Queensland. Temora is a high-sulfidation deposit hosted by early Paleozoic andesitic volcanics adjacent to a major regional structure, the Gilmore Suture (Thompson et al., 1986). A smaller, possibly similar deposit is located nearby at Dobroyde. Similar mineralization is also found at Rhyolite Creek in Victoria, where the host rocks are Cambrian rhyolites along a major structural axis (Raetz and Parrington, 1988a, b).

The discovery of the low-sulfidation Pajingo deposit in 1983 (Porter, 1988) led to intensive exploration activity in the northern Tasman Fold Belt, particularly in a long-recognised region of middle to late Paleozoic felsic volcanic rocks covering an area of approximately 400,000 square kilometers in north Queensland (Wood et al., 1990). The most important discoveries to date occur within the Drummond Basin, which occupies only a relatively small part of the volcanic province (Wood et al., 1990). The only significant historic epithermal gold producer in this region was the Koala Mine at Mt. Coolon. Apart from Pajingo, two additional substantial discoveries, since brought into production, were made at Wirralie and Yandan, and numerous other prospects have been located. All are low-sulfidation deposits displaying characteristic epithermal textures.

A striking aspect of this region is the excellent preservation of many features of the volcanic and mineralized environments (Cunneen and Sillitoe, 1989; White et al., 1989; Wood et al., 1990; Ewers et al., 1992), including surficial deposits such as airfall tuffs, welded and unwelded ignimbrites, hydrothermal eruption breccias, fluvial and lacustrine sediments and silica sinters.

3.2. Fiji

The Emperor mine at Vatukoula is one of the most important epithermal deposits of the southwest Pacific region. Extensive exploration of most of the islands of Fiji has so far produced only one significant new discovery, at Mount Kasi (Appendix, Part B), although additional mineralization has been located near the Emperor mine.

The Emperor mine, located on the island of Viti Levu, has operated since 1935, and represents one of the best known examples of low-sulfidation epithermal mineralization hosted by alkaline basic and intermediate volcanics, and localised by structures marginal to a caldera (Ahmad et al., 1987a, b; Anderson et al., 1987; Anderson and Eaton, 1990; Kwak, 1990; Eaton and Setterfield, 1993).

Mt. Kasi, on the island of Vanua Levu, is an advanced exploration prospect of high-sulfidation style (Turner, 1986), at which gold occurs in a quartz–vein stockwork within a funnel-shaped advanced argillic alteration zone.

3.3. Indonesia

The archipelago of Indonesia contains numerous deposits and prospects of epithermal character, some of which were known before European colonisation. Until recently there was little literature available on most of the recently discovered deposits (see Van Leeuwen et al., 1994); only major deposits and a few of the many relatively minor prospects are recorded here (Appendix, Part C). The most significant historical producer is Lebong Donok, in Sumatra (Kavalieris, 1988).

Several significant new discoveries have been made in Indonesia, the most important of which are Kelian (Ferguson, 1986; Hawke et al., 1988; Van Leeuwen et al., 1990), Mt. Muro (Simmons and Browne, 1988, 1990) and Masupa Ria (Thompson et al., 1994) in Kalimantan, Gunung Pongkor on Java (Sumanegara and Sinambela, 1993; Basuki et al., 1994), and Lerokis and Kali Kuning on Wetar (Sewell and Wheatley, 1994a, b). Other significant mineralization of both low- and high-sulfidation styles has been found in north Sulawesi (Carlile et al., 1990), and elsewhere (Van Leeuwen, 1994; Carlile and Mitchell, 1994), including the eastern arc from Flores to Wetar.

The Kelian deposit in Kalimantan (Hawke et al., 1988) is of particular interest. It has been shown to have had both magmatic and meteoric water sources, and it formed at relatively high temperature (280–310°C) and at unusually great depth (at least 900 to 1500 m) for an epithermal deposit (Van Leeuwen et al., 1990). Despite this, it still has a substantial vertical extent of at least 600 m.

Two important deposits have not been included as part of this compilation because their character suggests similarities to the Carlin-style deposits. We believe these are sufficiently different in character to warrant being regarded as a separate style of deposit, although in the past they have been included with epithermal deposits. Bau in Sarawak (East Malaysia) is an unusual deposit dominantly hosted by massive limestones intruded by many porphyry dykes. The mineralization varies from high temperature skarn, to low temperature styles with stibnite, orpiment, realgar, and native arsenic. The mineralization occurs either as veins (dominantly of calcite), or as zones of massive silicification of limestone (Wolfenden, 1965). Gold is disseminated through the silicified zones, but does not occur in the unsilicified limestone. This has suggested to some authors (e.g., Percival et al., 1990; Sillitoe and Bonham, 1990) that the deposits have affinities to the Carlin-type deposits of the western USA. The other important deposit with Carlin-style affinities is Messel, in the Ratatotok district of North Sulawesi (Turner et al., 1994).

3.4. New Zealand

Production of gold from epithermal sources in New Zealand recommenced recently after a lapse of some 36 years. Historical production from mines in the Coromandel Volcanic Zone was considerable (270 t Au, 1130 t Ag; Brathwaite, 1988), although the major part of that production came from the Martha Hill mine at Waihi, which has been re-opened. Other major producers were at Thames, Coromandel, and Karangahake (Appendix, Part D).

Exploration interest in the Coromandel region has been intense, however legal and bureaucratic obstacles and local opposition have combined to force many explorers to abandon the area. The one notable new exploration success there was the discovery, near historic workings, of the Golden Cross deposit (De Ronde, 1986; De Ronde and Blattner, 1988) which consists of a quartz stockwork overlying a massive silicified zone.

Two other regions of the North Island of New Zealand are of considerable exploration interest for epithermal targets. The Northland region has minor late-Tertiary rhyolite and basalt overlying a complex Mesozoic to Tertiary sedimentary basement. Epithermal veins and sinters are widespread in this region (e.g., at Puhipuhi, where 42 tonnes of mercury were produced from deposits in sinters and veins; Williams, 1974), however no economically significant discoveries of gold have yet been made.

The Taupo Volcanic Zone is well known for its geothermal activity (e.g., Henley and Ellis, 1983; Hedenquist, 1986), and many active hot spring areas are precipitating gold-enriched material (Weissberg, 1969; Hedenquist and Henley, 1985b; Brown, 1986; Krupp and Seward, 1987). Despite the technical difficulties of exploring in active geothermal areas, there has been substantial exploration interest in the region. The most significant find reported to date is at Ohakuri Dam (Henneberger, 1986; Henneberger and Browne, 1988), where the gold mineralized core of a recently extinct geothermal system is exposed at a very shallow (about 50 m deep) level of erosion.

The very small number of deposits recorded in the Appendix does not reflect the large number of epithermal prospects and minor historic producers known in New Zealand (Christie and Brathwaite, 1986; Brathwaite and Pirano, 1993). New Zealand offers exciting opportunities for epithermal exploration, and were it not for obstacles to exploration, this would certainly now be reflected in a substantial level of production.

3.5. Palau and Yap

Recent recognition of minor epithermal mineralization on Babelthuap Island of the Republic of Palau (Rytuba et al., 1987; Rytuba and Miller, 1990), and the islands of Maap and Gagil–Tamil in the state of Yap (Federated States of Micronesia; Rytuba et al., 1988), provide interesting examples of mineralization formed on isolated volcanic islands. Both are of low-sulfidation style; neither appears at present to be of economic significance (Appendix, Part E).

3.6. Papua New Guinea

Papua New Guinea has been the site of some of the world's most important recent gold discoveries. Of the known epithermal gold deposits, only Wau (Sillitoe et al., 1984) has a prolonged history of production. Deposits on Misima Island (Clarke et al., 1990) and Woodlark Island (Russell and Finlayson, 1987; Russell, 1990) have been mined in the past, and at Misima mining has re-commenced. All the other deposits shown in the Appendix, Part F are essentially grass-roots exploration discoveries, although in the case of Porgera evaluation took over 22 years (Henry, 1988).

All but two of the deposits listed (Nena and Wafi River) are of low-sulfidation style, although several have unusual characteristics. The giant Porgera deposit has a complex history, with early mesothermal mineralization, followed by late-stage epithermal mineralization (O'Dea, 1980; Fleming et al., 1986; Handley and Bradshaw, 1986; Handley, 1987; Henry, 1988; Richards, 1990; Richards and Kerrich, 1993; Richards and Ledlie, 1993).

The other giant discovery, Ladolam (on Lihir Island), also has unusual features, including the presence of a waning geothermal system with temperatures still exceeding 100°C within the ore zone. The deposit occurs within a Pleistocene caldera (Davies and Ballantyne, 1987; Moyle et al., 1990), where the very extensive disseminated gold mineralization has been deposited in a zone of hydrothermal alteration apparently initiated by influx of sea-water to the hot brecciated volcanic pile (Plimer et al., 1988).

3.7. Philippines

Despite its small area, for over 20 years the Philippines has consistently been one of the top eight gold-producing countries of the world. Although much of its gold production comes from gold-rich porphyry copper deposits, there are also many epithermal deposits of both low-sulfidation and high-sulfidation styles (Sillitoe, 1988, 1989). Many epithermal deposits in the Philippines are referred to in the literature, but few of them are described adequately. The deposits listed in the Appendix, Part G probably represent only a small proportion of the deposits known.

Most recorded epithermal deposits in the Philippines are of low-sulfidation style, although Sillitoe (1988) and Sillitoe et al. (1990) note some differences between many of them and the low-sulfidation deposits in Japan and New Zealand: the Philippine deposits have higher base metal contents, crystalline quartz rather than chalcedony, and an apparent lack of adularia.

One major high-sulfidation deposit occurs at Lepanto, where massive sulfide and quartz originating by acid leaching and replacement is adjacent to and overlying the large Far Southeast (FSE) porphyry copper deposit (Sillitoe, 1983, 1989; Garcia, 1991). Both deposits have the same age and are most likely related genetically (Arribas et al., 1995). Other deposits of high-sulfidation style are known elsewhere, including Nalesbitan (Sillitoe et al., 1990) but some do not appear to be mineralized appreciably (e.g., Trudu and Bloom, 1988; Mitchell and Balce, 1990).

The Philippines has long had a vigorous domestic mining industry; however, perceptions of the investment climate in the Philippines have resulted in fluctuations in exploration activity that are unrelated to the prospectivity of the country.

3.8. Solomon Islands

The Solomon Islands are the extension of the volcanic chain that hosts the major orebodies of Panguna (Cu–Au) and Lihir Island. Consequently, there has been strong exploration activity there until legislative changes made exploration less attractive.

Only one substantial (but still uneconomic) discovery has been made there, at Gold Ridge on the island of Guadalcanal (Appendix, Part H), although other prospects are known (Shatwell, 1987). Gold Ridge was discovered in 1938 and has been explored intermittently since 1974. It consists of an extensive area of hydrothermal alteration in which gold occurs in short, narrow veins within a zone of sericite alteration.

4. Comparison with other regions

Exploration for epithermal gold deposits does not have a long history in the southwest Pacific region, and many more deposits will undoubtedly be found as exploration continues. Sufficient deposits and prospects have been found to justify asking how similar this region is to other regions of epithermal gold mineralization (e.g., the cordilleran belts of the northeastern Pacific margin), or whether it differs significantly. With only a limited data base, any judgements of this kind are necessarily tentative.

The deposits considered here fall into two distinct groups, based on their age and geological setting. The deposits known in Australia are Paleozoic to Mesozoic in age, and now occur within a stable cratonic block. By contrast, the deposits in the rest of the region are Cainozoic in age, and are associated with volcanic arcs, some of which are still active. These two groups are considered separately.

4.1. Australia

The most important area of epithermal gold deposits presently known in Australia is within the Drummond Basin in north Queensland. Little is presently known about the controls on the deposits in the Drummond Basin (Henley and Adams, 1992). The deposits that have been investigated appear to have been formed at different times between late Devonian and middle Carboniferous time (Wood et al., 1990; Ewers et al., 1992), and a subaerial intermediate to acid continental margin volcanic arc or shallow back-arc rift is the most likely setting. Most epithermal gold deposits known in north Queensland are low-sulfidation style, and they generally resemble deposits in similar host environments elsewhere (e.g., New Zealand).

The other significant epithermal province in Australia is early to middle Paleozoic in age and occurs in the southern Tasman Fold Belt (the Lachlan Fold Belt). Most investigators regard the volcanic rocks in the Lachlan Fold Belt as having formed in an island arc or accreted plate margin (e.g., Cas, 1983; Scheibner, 1987). Other work (Coney, 1988, 1992; Coney et al., 1990) suggests that the Lachlan Fold Belt is unlike the accreted cordilleran fold belts described elsewhere (e.g., western USA), and may be an example of a setting which is not represented by present-day active environments.

The epithermal deposits known in the Lachlan Fold Belt are of both low-sulfidation and high-sulfidation style. Five low-sulfidation deposits are known (Mt. Aubrey, Panbula, Pyramid Mount, Yalwal, Yerranderie), of which only Mt. Aubrey and Pyramid Mount are recent discoveries. Four high-sulfidation deposits are known (Dobroyde, Peak Hill, Rhyolite Creek, Temora), of which all but Peak Hill are recent discoveries. Peak Hill, Rhyolite Creek and Temora are unusual deposits with an abundance of pyrophyllite, and are strongly deformed (e.g., Binns and Eames, 1988; Harbon, 1988; Raetz and Parrington, 1988a; Allibone, 1992). These deposits bear little resemblance to the relatively well known deposits of high-sulfidation style reported from other regions, e.g., El Indio, Chile (Siddeley and Araneda, 1986), Nansatsu deposits, Japan (Urashima et al., 1987; Hedenquist et al., 1994), and Summitville, Colorado (Stoffregen, 1987). White (1991) grouped them as a distinct sub-class. Their mineralogy indicates formation at temperatures of about 300°C (Masterman, 1994); this suggests a minimum depth of formation of at least 1000 m if hydrostatic conditions prevailed. It is likely that they were formed at greater depth than is commonly ascribed to epithermal deposits, and were thus more likely to be preserved during subsequent deformation and erosion.

4.2. *Cainozoic volcanic arcs*

Sillitoe (1988) noted that the epithermal gold deposits of New Zealand, Acupan and Antamok in the Philippines, and Wau–Edie Creek and Hidden Valley in Papua New Guinea, are all typical low-sulfidation style deposits: they are base-metal poor veins commonly with banded chalcedony, manganoan carbonates, and silver sulfides and sulfosalts. This description probably also applies to the occurrences on Palau and Yap, and Tolukuma Hill in Papua New Guinea.

Sillitoe (1988) also noted that many epithermal vein deposits elsewhere in the region, particularly the Philippines, tend to be richer in base metals, have crystalline quartz rather than chalcedony, and lack adularia. Sillitoe (1988) postulated that such deposits formed at greater depth than more typical epithermal deposits elsewhere.

To assess how similar or different the deposits of the southwest Pacific are to those of North America, mineralogical information in the Appendix was summarised as Table 2. Only deposits that have been studied sufficiently to provide useful information are listed, reducing the 138 deposits in the Appendix to 102 (84 low-sulfidation and 18 high-sulfidation). Similarly, 45 selected deposits from Buchanan (1981) were compiled as Table 3. Only deposits from the USA and Mexico are shown, and only those with sufficient information to recognise their style. Buchanan (1981) has too few high-sulfidation deposits for comparisons to be made, but the 102 low-sulfidation deposits from the southwest Pacific can be compared with the 45 from North America.

Where the two tables contain comparable data, in most cases there is no significant difference in the frequency of occurrence of minerals (note that these tables record the *occurrence* of minerals, but have no implications for their *abundance*). But several minerals show marked differences in frequency. As noted by Sillitoe (1988), adularia is less commonly observed in the deposits in the southwest Pacific region than in North American deposits (48% compared to 89%). Other marked differences are that the southwest Pacific deposits report less barite (13% cf. 24%), more chlorite (46% cf. 18%), more pyrrhotite (17% cf. 4%), somewhat more sphalerite (73% cf. 49%), galena (70% cf. 53%) and chalcopyrite (74% cf. 62%), more arsenopyrite (33% cf. 11%), less native silver (9% cf. 31%), more tellurides (23% cf. 6%), and less argentite (9% cf. 69%). With more data, some of these differences may disappear. However, most of these differences can be interpreted to indicate that, in general, deposits in North America are formed at shallower depths than those in the southwest Pacific, confirming the judgement of Sillitoe (1988).

Despite the general similarities with epithermal deposits elsewhere, the largest deposits in the region have a striking tendency to be atypical in their characteristics (Sillitoe, 1993). Porgera is transitional from mesothermal to epithermal, and is closely associated with alkaline intrusive porphyries (Fleming et al., 1986; Richards, 1990, 1992; Richards et al., 1991; Richards and Kerrich, 1993; Richards and Ledlie, 1993). Ladolam (Lihir Island) has extraordinary volumes of disseminated mineralization, apparently resulting from low-sulfidation fluids mineralizing a breccia initially altered by sea-water interaction (Plimer et al., 1988). Enargite has also been recorded there, suggesting high-sulfidation affinities. Kelian is relatively high temperature compared to most epithermal deposits. The present surface is at least 900 to 1500 m below the paleowatertable, yet it shows vertical extent of at least another 600 m (Hawke et al., 1988; Van Leeuwen et al., 1990).

Although few high-sulfidation deposits are being mined in the southwest Pacific region, they are widely recognised throughout the region. Many prospects of this style have proved to be frustrating exploration targets, as spectacularly developed alteration is commonly not accompanied by major gold mineralization. Notwithstanding this problem, the high rate of discovery of mineralization of this style suggests that high-sulfidation deposits are well represented within this region, especially when compared to western North America where, despite over a century of exploration, relatively few deposits of this style are known (Buchanan, 1981). By contrast they are relatively abundant in the Andes of Chile (Sillitoe, 1991). Indeed, rather than asking why they are relatively common in the southwest Pacific and South America, it seems more appropriate to ask why they are not more common in North America. The answer probably lies in the processes of magma generation and magmatic evolution that produce gold-enriched porphyry deposits in the southwest Pacific and South America, but not (or rarely) in North America.

In summary, it is concluded that the epithermal deposits of the Cainozoic volcanic arcs of the southwest Pacific are in most respects similar to those in other epithermal provinces, with, however, three differences:

(i) Through much of the region (especially the Philippines and Indonesia) low-sulfidation style deposits commonly show characteristics suggestive of formation at deeper levels than is typical elsewhere;

(ii) Many of the largest deposits show atypical features, particularly those suggestive of a transition to mesothermal conditions, or indicating overprinting;

(iii) High-sulfidation deposits are relatively common when compared to western North America.

5. Causes of differences

In epithermal deposits the hydrology of the parent hydrothermal system plays a crucial role in determining the sites of focussed fluid flow essential to produce economic concentrations of metals. It also determines the patterns of hydrothermal alteration associated with the ore deposits (Hanaoka, 1980; Taguchi et al., 1986; Allis, 1990; Reyes, 1990; Simmons, 1991).

Henley and Ellis (1983) distinguished generalised patterns of fluid flow in geothermal systems hosted by low relief, dominantly acid volcanic settings, and high relief, dominantly andesitic volcanic settings. Taking this approach a step further, Bogie and Lawless (1987) distinguished four different settings for geothermal activity: (1) silicic depressions; (2) andesitic stratovolcanoes; (3) cordilleran volcanics; and (4) oceanic volcanic islands. The characteristics of these geothermal settings, and their associated hydrothermal alteration and gold deposits are summarised in Table 4 and Fig. 2.

The characteristics of individual epithermal deposits, and their regional characteristics, can be largely understood in terms of the geothermal settings shown in Table 4. The relatively well known epithermal provinces along the eastern Pacific margin (particularly North America) are dominated by cordilleran settings, with local andesitic stratovolcanoes, and silicic volcanic depressions. Oceanic volcanic islands are absent. By contrast, the southwest Pacific region is dominated by andesitic stratovolcanic settings, with cordilleran and silicic volcanic depressions only locally important. Oceanic volcanic island settings are widespread (see Fig. 1), though few deposits are known in this setting.

The characteristics of many of the low-sulfidation deposits of the Philippines and Indonesia are consistent with deposits formed in the andesitic stratovolcanic setting. Active geothermal systems in the Philippines have been described by Reyes (1985, 1990), Reyes and Giggenbach (1992), and Reyes et al. (1993). A particular characteristic of this high relief setting is that there is a large degree of lateral flow in geothermal systems, up to 10 km or more. At the Palinpinon geothermal system, neutral-pH hot springs depositing silica sinter occur more than 5 km from the upflow zone, and several hundred meters lower elevation than the steam-heated acidic water and associated alteration that occur over the upflow zone (Reyes, 1990). The most favorable sites for mineralization will probably be within the upflow zone, which in this case occurs beneath a high-relief, intensely altered steam-heated cap. Zones of intense alteration at high relief are susceptible to erosion, which may rapidly expose the deeper parts of the epithermal system. In the andesitic stratovolcanic setting gold deposition occurs deep below the water table because the rising fluid is gas-rich (mainly CO_2 plus subordinate H_2S), and so boils at greater depth than gas-poor fluids (Henley et al., 1984; Hedenquist and Henley, 1985a). For example, the upper limit of CO_2 contents found in active hydrothermal systems (and epithermal deposits; Hedenquist and Henley, 1985a) is about 4 wt%; a 300°C fluid with this CO_2 content starts to boil at about 1800 m depth (in contrast to <1000 m for a low-gas fluid). The presence of gases such as CO_2 also depresses the fluid pH, thus inhibiting the formation of adularia (Henley et al., 1984).

Another characteristic of the andesitic stratovolcano setting is a common association with porphyry copper deposits, and with high-sulfidation epithermal deposits (Sillitoe, 1983). Both these deposit styles are well represented in the southwest Pacific, especially in the Philippines, parts of Indonesia and Papua New Guinea.

The presence of major deposits showing both higher temperature and epithermal mineralization is probably also a result of the tectonic setting. The Cainozoic history of the southwest Pacific has been marked by strong igneous activity associated with very rapid uplift and erosion. Rapid erosion of hydrothermally altered volcanic rocks may expose sites of high temperature mineralization deep below the volcano to shallow-level

Table 2

Mineralogy of selected epithermal gold deposits of the southwest Pacific. Mineral abbreviations: Chal = chalcedony; Ac
carb = iron carbonate minerals; Rhodon = rhodonite; Seri = sericite; Illit = illite; Smec = smectite; Kao = kaolinite; D
Gyps = gypsum; Bar = barite; Zeol = zeolite minerals; Epid = epidote; Chl = chlorite; Albite; Sulf = native sulfı
Cpy = chalcopyrite; Cov = covellite; Chalcocite; Bn = bornite; En = enargite; Luz = luzonite; Cin = cinnabar; Orp = o
muth = bismuthinite; Au = native gold; Ag = native silver; Elect = electrum; Mo = molybdenite; Selen = selenium m
Magn = magnetite; Hem = hematite

A. LOW SULFIDATION STYLE

DEPOSIT	Country	Style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodo	Seri	Illit	Smec	Kao	Dic	Pyro	Alun	Dias	Anhydr	Gyps	Bar	Zeol	Epid	Chl	A
Cracow	AUS	Lvd	X	X	X					X	X	X								X	X	X	
Grassy Gully	AUS	Lvs							X														
Major's Creek	AUS	Lv			X	X			X										X				
Mt. Aubrey	AUS	Lvs	X	X	X					X										X	X	X	
Mt. Coolon	AUS	Lv		X	X															X	X	X	
North Arm	AUS	Lvd	X						X														
Pajingo	AUS	Lvs	X	X	X		X			X	X	X	X		X							X	
Panbula (Pambula)	AUS	Lvs	X						X			X		X	X								
Red Rock (Drake)	AUS	Ldsv		X	X					X	X											X	
Wirralie	AUS	Ldv	X	X	X				X	X	X	X											
Wolumla	AUS	L?							X														
Woolgar	AUS	Lv																				X	
Yalwal	AUS	Lvs	X						X			X		X									
Yandan	AUS	Ld?	X	X	X					X		X											
Yerranderie	AUS	Lv			X				X												X		
Emperor	FIJI	Lvsd		X	X				X														
Bau	IND	Lvdb			X															X	X		
Cikondang	IND	Lvb			X				X	X	X											X	
Cirotan - Cikotok	IND	Lv		X	X	X		X	X	X												X	
Gunung Arum (Aurum)	IND	Lv																					
Gunung Pongkor	IND	Lv		X	X						X	X							X			X	
Kelian	IND	Lsvdb		X	X				X			X	X										
Lebong Donok	IND	Lv	X	X	X				X	X											X	X	
Lebong Simpang	IND	Lv								X												X	
Lebong Sulit	IND	Lvd				X																	
Lebong Tandai	IND	Lvbd		X	X					X	X										X	X	
Mangani	IND	Lsvbd	X	X	X	X		X															
Masupa Ria	IND	Lvs		X	X				X	X													
Mintu	IND	Lv								X												X	
Mirah	IND	Ld																			X	X	
Mt. Muro	IND	Lvs		X	X	X	X			X		X											
Muyup	IND	Lvbs	X	X	X		X			X	X	X	X									X	
Rawas	IND	Lvs			X				X	X		X											
Salida	IND	Lvb				X		X															
Taware Ridge	IND	Lsv								X													
Broken Hills - Golden Hills	NZ	Lvs		X	X				X	X	X	X							X		X	X	
Coromandel	NZ	Lv		X	X				X														
Golden Cross	NZ	Lbsv		X	X					X	X	X					X					X	
Kapanga - Hauraki	NZ	Lvs			X					X												X	
Karangahake	NZ	Lv	X	X	X	X			X	X	X											X	
Komata	NZ	Lv	X	X	X					X													
Kuaotunu	NZ	Lv			X					X		X			X								
Maratoto	NZ	Lvs		X	X	X			X	X													
Martha Hill (Waihi)	NZ	Lvs	X	X	X				X	X	X											X	
Neavesville	NZ	Lbsv	X	X	X				X	X	X										X	X	
Owharoa	NZ	Lv	X	X	X				X	X													
Te Ahumata (Great Barrier)	NZ	Lv	X		X				X	X	X	X										X	
Te Puke (Muirs Reefs)	NZ	Lv	X	X	X				X	X												X	
Thames	NZ	Lvbs			X				X	X	X	X	X	X	X	X			X		X	X	
Tokatea - Success	NZ	Lv		X	X					X												X	
Tui	NZ	Lv		X	X				X	X											X	X	
Waiomu	NZ	Lv			X	X			X								X		X			X	
Waiorongomai	NZ	Lv			X				X	X	X										X	X	
Waitekauri	NZ	Lv	X	X	X				X	X											X	X	
Wharekirauponga	NZ	Ls	X	X						X	X	X											
Ambitle	PNG	Lbs		X	X																		
Basangka	PNG	L?																					
Hidden Valley	PNG	Lsv		X	X	X															X	X	
Kerimenge	PNG	Lb		X	X	X			X										X				
Ladolam (Lihir Island)	PNG	L+Hd?	X	X	X												X						
Mount Kare	PNG	Lv			X				X														
Porgera	PNG	Lsbv		X	X															X			
Tolukuma	PNG	Lv	X	X	X	X	X			X	X	X						X				X	
Umuna (Misima Island)	PNG	Lsvb			X				X										X		X	X	
Wapolu	PNG	Lbsd		X	X														X			X	
Wau	PNG	Lsvd			X	X				X	X	X			X								
Wild Dog	PNG	Lvs	X		X				X			X		X							X		
Woodlark Island - Boniavat	PNG	Lvs	X			X																	
Woodlark Island - Busai	PNG	Lvs	X		X	X	X			X	X											X	
Woodlark Island - Kulumadau	PNG	Lvs	X	X	X		X			X	X								X			X	
Babelthuap Island	PAL	Lv			X				X														
Maap Island	PAL	Lv							X			X											
Acupan	PHIL	Lvs		X	X	X		X	X								X		X				
Antamok	PHIL	Lvs			X	X		X									X						
Co-o	PHIL	Lv							X	X									X				
Exciban	PHIL	Lv			X																		
Hijo	PHIL	Lvsb																					
Marian	PHIL	Lv	X		X	X			X													X	
Masara	PHIL	Lsdv			X																		
Masbate	PHIL	Lbd			X																		
Motherlode	PHIL	Lsbv								X		X			X	X						X	
Paracale	PHIL	Lvsb																					
Placer	PHIL	Lsbv	X		X				X	X	X	X										X	
Siana	PHIL	Ldbs			X					X												X	
NUMBER			28	40	63	18	6	5	39	43	22	23	4	4	6	2	5	1	11	5	17	39	
PERCENTAGE (n=84)			33	48	75	21	7	6	46	51	26	27	5	4	7	2	6	1	13	6	20	46	
DEPOSIT	Country	Style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodo	Seri	Illit	Smec	Kao	Dic	Pyro	Alun	Dias	Anhydr	Gyps	Bar	Zeol	Epid	Chl	A

* L=low sulfidation, d=disseminated, b= breccia, v=vein, r=replacement

lul = adularia; Carb = Ca, Mg carbonate; Mn-carb = manganese carbonate minerals; Fe-
c = dickite; Pyro = pyrophyllite; Alun = alunite; Dias = diaspore; Anhydr = anhydrite;
ır; Py = pyrite; Mar = marcasite; Pyrr = pyrrhotite; Sph = sphalerite; Gal = galena;
rpiment; Real = realgar; Aspy = arsenopyrite; Tet = tetrahedrite; Stibn = stibnite; Bis-
ıinerals; Tell = tellurium minerals; Hessite; Calav = calaverite; Argentite; Acanthite;

lbite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten	Stib	Bismuth	Au	Ag	Elec	Mo	Selen	Tell	Hessite	Calav	Argent
		X			X	X	X	X		X						X					X						X		
					X	X	X		X							X	X	X					X			X	X		
		X			X	X	X									X	X				X					X		X	
		X				X	X														X								
		X		X																									
		X	X	X	X	X	X															X	X	X	X				
		X			X	X	X														X	X	X			X	X		
		X			X	X	X		X							X	X	X			X		X						
		X			X	X	X										X	X					X						X
		X	X	X	X		X														X								
					X	X	X		X							X	X	X				X	X		X				
		X				X																							
		X			X	X	X		X							X	X	X				X	X		X				
		X					X														X								
		X			X	X	X	X	X							X	X					X							
		X	X		X		X									X	X									X		X	
		X			X									X	X	X			X										
		X			X	X										X													
		X			X	X	X									X					X		X			X			X
		X			X	X	X																X						
X		X																					X						X
		X		X	X	X	X						X			X	X						X						
		X			X		X																X		X				
		X			X	X	X														X								
		X			X	X	X																						X
		X			X	X	X																X		X	X			
		X		X	X	X	X																X		X				
		X																											
		X					X			X											X								
		X	X													X					X		X						
		X			X	X	X	X															X						
		X	X																X		X		X						
		X			X	X																							
					X	X																			X	X			X
		X			X	X										X					X								
		X	X																			X	X		X				
		X			X	X	X									X			X				X						
		X	X	X	X	X	X									X							X						
		X	X	X												X			X				X						
		X			X	X	X	X															X						X
		X			X		X																X						
		X	X	X	X	X										X							X				X		
		X			X	X	X															X	X				X		
		X	X	X	X	X	X									X	X						X	X					
		X	X		X	X	X																X	X			X		
		X	X										X										X						
		X	X	X	X	X	X										X		X				X						
		X																					X						
X		X			X	X	X				X		X				X		X		X		X	X		X			
		X	X	X	X	X	X									X							X				X		
		X	X		X	X	X						X				X				X								
		X	X		X	X	X									X	X			X	X		X			X			
X		X			X	X	X										X						X				X		
		X	X		X	X	X																X						
		X					X	X								X					X		X						
		X					X		X	X																			
		X	X										X						X		X								
		X			X	X											X				X								
		X	X		X	X	X									X	X				X								
	X	X	X				X			X	X	X				X	X	X						X		X			
					X	X															X	X							
		X		X	X	X	X																			X			
X		X	X		X	X	X									X			X				X						X
		X		X	X	X	X	X	X								X				X								
			X																		X								
		X	X		X	X	X										X						X						X
		X					X		X															X	X	X		X	
		X				X															X								
		X			X	X	X										X	X			X								
		X	X	X	X	X	X										X				X								
X		X			X	X	X														X					X			
		X					X																						
		X	X		X	X	X			X			X			X	X		X		X		X			X	X	X	
		X			X	X	X														X					X			
		X					X			X																			
		X			X	X	X									X					X			X		X			
		X	X		X	X	X									X					X								
		X			X	X	X							X	X		X						X			X	X		
		X	X		X	X	X														X		X						
		X			X	X	X														X								
		X																											
		X																								X			
		X			X	X	X														X								
		X			X	X	X							X	X		X	X	X				X			X			
		X			X	X	X														X		X						
5	1	79	27	14	61	59	62	6	8	6	2	1	6	3	3	28	25	8	10	1	35	8	43	7	9	19	10	4	8
6	1	94	32	17	73	70	74	7	9	7	3	1	7	4	4	33	30	9	12	1	42	9	51	8	11	23	12	5	9
bite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten	Stib	Bismuth	Au	Ag	Elec	Mo	Selen	Tell	Hessite	Calav	Argenti

ite	Acanthite	Magn	Hem	OTHERS
			X	amethyst
				petzite, chalcostibite
		X	X	ilmenite, altaite, petzite pyrargyrite-proustite
			X	stilbite, andradite, laumontite
				naumannite, allargentum, freibergite
			X	iodargyrite
				pearcite
			X	Pb-Sb sulfosalts, anatase
	X			stephanite, pearcite, proustite, arsenopolybasite, chalcostibite, naumannite, aguilarite
			X	graphite, celadonite
				stromeyerite, proustite, pyrargyrite, dyscrasite, bournonite, polybasite
				sylvanite, petzite, stibnite, native krennerite, roscoelite
				As, wollastonite, grossularite, andradite, diopside
			X	
				Ag tellurides, pyrargyrite, Sb minerals, cassiterite, stannite
				pyrargyrite
				trace base metal sulfides
				naumannite, berzelianite, truscottite
				selenides, As-Sb sulfosalts, Ag tellurides
				polybasite, stephanite, alabandite, stannite, Ag sulfosalts, CuTiAg selenide, Sn minerals, base metals
	X			
	X			inesite
	X			trechmannite, Ag sulfoselenides, aguilarite, Au-Ag-As-Se sulfosalts
	X			native As, Mn oxide
	X			pyrargyrite, pyrolusite, jarosite, sphene
				pyrargyrite, native As
	X			limonite, Mn oxides
	X			
	X			
				pyrargyrite
	X			
				pyrargyrite
				Au-Ag telluride, altaite, tetradymite, Au-pyrargyrite, Sb-sulfosalts, robinsonite, chalcostibite, bournonite, polybasite
			X	tetradymite, bismuthinite
				Au-Ag tellurides, Sb sulfosalts, bournonite, tetradymite
			X	digenite, cristobalite
			X	kutnahorite
				Mn
		X	X	proustite, freibergite, pyrargyrite, tellurides of Au, Pb, Hg, roscoelite, sulfates
				proustite, pyrargyrite, billingsleyite, freibergite, polybasite-pearcite, stromeyerite, uytenbogaardtite
		X		native Cu,
				talc
				Ag sulfosalts, cristobalite
			X	petzite, sylvanite, selenides, native Te, stannoidite, melonite
				Mn oxides
				Ag sulfosalt, kutnahorite
		X	X	
				Au-Ag telluride, clinochlore
				Te, Cu, V
			X	pyrargyrite, petzite, altaite, sylvanite, coloradoite, famatinite, proustite
				base metal tellurides, Mn oxides,
				base metal sulfides
				Au-Bi tellurides
				goldfieldite, Au tellurides, altaite
		X		
				Au Telluride, azurite, malachite
			X	
		X	X	Au-Ag tellurides, limonite
	10	6	16	
	12	7	19	
te	Acanthite	Magn	Hem	OTHERS

(p.t.o. for Table 2B)

B. HIGH SULFIDATION STYLE

DEPOSIT	Country	Style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodo	Seri	Illit	Smec	Kao	Dic	Pyro	Alun	Dias	An
Mt. MacKenzie	AUS	Hd			X				X	X	X	X		X			
Peak Hill	AUS	Hd							X		X	X		X	X		
Temora (Gidginbung)	AUS	Hd							X	X	X	X		X	X		
Zelma	AUS	H?							X	X				X			
Mt. Kasi	FIJI	Hvbd		X	X		X										
Binebase - Bawone	IND	H?d								X	X	X					
Kali Kuning	IND	Hd	X	X	X					X	X	X			X	X	
Lerokis	IND	Hd	X	X	X					X	X	X			X	X	
Miwah	IND	Hd															
Motomboto	IND	Hdbv													X		
Pelangan	IND	Hdvb							X		X	X			X		
Simbalang	IND	Hd															
Maragorik	PNG	Hb		X						X	X	X	X	X	X	X	
Nena (Frieda River)	PNG	Hd										X			X		
Wafi River	PNG	Hbd			X												
Lepanto	PHIL	Hvd										X			X		
Nalesbitan	PHIL	Hvbd?			X				X	X	X	X			X	X	
Pao	PHIL	Hd?										X					
NUMBER			2	4	6	0	1	0	6	8	9	12	1	5	10	4	
PERCENTAGE (n=18)			11	22	33	0	6	0	33	44	50	67	6	28	56	22	
DEPOSIT	Country	Style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodo	Seri	Illit	Smec	Kao	Dic	Pyro	Alun	Dias	An

* H=high sulfidation, d=disseminated, b= breccia, v=vein, r=replacement

Table 3
Mineralogy of selected North American epithermal deposits (from Buchanan, 1981). Deposits

A. LOW SULFIDATION STYLE

DEPOSIT	Country	Style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodon	Seri	Illit	Smec	Kao	Dic	Pyro	Al
Ocampo	MEX	LA			X										
Taylotita	MEX	LA		X	X										
Temascaltepec	MEX	LA		X	X										
Zucualpan	MEX	LA			X	X									
Aurora, NV	USA	LA		X	X										
Bodie, CF	USA	LA		X	X										
Buckhorn, NV	USA	LA		X											
Bullfrog, NV	USA	LA		X	X										
Cedar Mtn, NV	USA	LA		X											
Divide, NV	USA	LA		X					X						
Gilbert, NV	USA	LA		X	X										
Gold Circle, NZ	USA	LA		X	X										
Hayden Hill, CA	USA	LA		X											
Jarbridge, NV	USA	LA		X	X				X						
Katherine, CO	USA	LA		X	X				X						
Mogollon, NM	USA	LA		X	X										
Mohave, CA	USA	LA		X	X										
Monitor, CA	USA	LA		X					X						
National, NV	USA	LA		X	X				X						
Oatman AZ	USA	LA		X	X				X						
Ramsey-Talapoosa, NV	USA	LA		X	X										
Rawhide, NV	USA	LA		X											
Republic, WA	USA	LA		X	X										
Rochester, NV	USA	LA		X	X				X						X
Round Mountain, NV	USA	LA		X	X				X						X
Searchlight, NV	USA	LA		X	X										
Seven Troughs, NV	USA	LA		X	X										
Silver City, Delamar, ID	USA	LA		X	X				X						
Silver Peak, NV	USA	LA		X	X		X								
Stateline, UT	USA	LA		X	X										
Tonopah, NV	USA	LA		X	X	X		X	X						
Tuscarora, NV	USA	LA		X	X										
Wonder, NV	USA	LA		X											
El Tigre	MEX	LB			X										
Fresnillo	MEX	LB		X	X										
Guanacevi	MEX	LB		X	X			X							
Guanajuato	MEX	LB		X	X				X						
Pachuca	MEX	LB		X	X	X			X						
Yoquivo	MEX	LB		X	X										
Bohemia, OR	USA	LB		X	X										
Calico, CA	USA	LB			X		X								
Comstock, NV	USA	LB		X	X	X		X							
Creede, CO	USA	LB		X	X	X	X		X						
Eureka District, CO	USA	LB		X		X		X							
Lake City, CO	USA	LB			X	X			X						
NUMBER				40	37	7	3	4	14			0			[illegible]
PERCENTAGE (n=45)				89	82	16	6	9	31			0			[illegible]
DEPOSIT	country	style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodon	Seri	Illit	Smec	Kao	Dic	Pyro	Al

LA = base metals poor; LB = base metals rich

B. HIGH SULFIDATION STYLE

DEPOSIT	country	style*	Chal	Adul	Carb	Mn-carb	Fe-carb	Rhodon	Seri	Illit	Smec	Kao	Dic	Pyro	Al
Goldfield, NV	USA	H							X			X			[illegible]
Summitville, CO	USA	H													[illegible]

hyd	Gyps	Bar	Zeol	Epid	Chl	Albite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten	Stib	Bismuth	Au	Ag	Elec	Mo
					X			X							X	X	X						X	X			X			
		X						X			X	X	X	X	X		X						X	X			X			
								X						X			X										X	X		
					X			X	X			X	X	X	X	X								X			X			
		X						X						X	X	X	X	X						X						
	X	X		X	X			X			X	X	X	X	X															
X	X	X	X		X			X	X		X	X			X	X	X		X				X				X		X	
X	X	X	X		X			X	X		X	X	X		X	X	X		X				X				X		X	
		X		X	X		X	X									X													
								X	X		X	X	X	X	X		X	X				X	X				X			
		X						X									X						X				X			
								X									X										X			
		X						X	X		X			X	X			X					X				X		X	
	X	X					X	X	X					X	X		X	X												
								X		X	X	X	X				X						X				X		X	
		X						X			X		X				X	X									X			
		X			X			X							X	X	X										X			
				X	X			X	X								X	X						X			X			
2	4	11	2	3	8	0	2	18	7	1	8	7	7	8	11	6	15	6	2	0	0	1	8	5	0	0	14	1	4	0
11	22	61	11	17	44	0	11	100	39	6	44	39	39	44	61	33	83	33	11	0	0	6	44	28	0	0	78	6	22	0
hyd	Gyps	Bar	Zeol	Epid	Chl	Albite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten	Stib	Bismuth	Au	Ag	Elec	Mo

of identifiable style from USA and Mexico only. Mineral abbreviations as for Table 2, with addition of ruby silver

un	Dias	Anhydr	Gyps	Bar	Zeol	Epid	Chl	Albite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten
										X			X	X	X										X	
							X			X			X	X	X											
										X			X	X	X											
										X			X	X	X										X	
										X					X										X	
										X			X													
										X							X									
										X																
				X						X				X	X											
										X					X											
							X			X			X		X										X	
				X						X					X											
							X			X																
										X			X	X	X			X							X	
										X			X	X	X											
										X			X	X	X			X							X	
							X			X																
										X					X											
					X					X					X										X	
X										X		X	X		X									X	X	
X										X													X	X		
										X				X												
							X			X																
				X						X				X	X											
				X						X			X	X												
										X																
				X						X				X	X									X		
										X			X	X	X			X	X					X		
										X			X	X	X										X	
										X		X	X	X	X									X		
				X						X			X	X	X			X							X	
							X			X			X	X	X											
				X			X						X	X	X											
										X			X	X	X											
				X						X			X	X	X											
				X						X															X	
										X			X	X	X											
				X			X			X				X	X										X	
										X			X	X											X	
				X									X	X	X										X	
2				11	1		8			38	0	2	22	24	28	0	1	4	1				1	5	14	
4				24	2		18			84	0	4	49	53	62	0	2	9	2				2	11	31	
un	Dias	Anhydr	Gyps	Bar	Zeol	Epid	Chl	Albite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten

un	Dias	Anhydr	Gyps	Bar	Zeol	Epid	Chl	Albite	Sulf	Py	Mar	Pyrr	Sph	Gal	Cpy	Cov	Chalcocite	Bn	En	Luz	Cin	Orp	Real	Aspy	Tet	Ten
X				X						X					X										X	
X				X						X			X	X	X	X			X							

Selen	Tell	Hessite	Calav	Argentite	Acanthite	Magn	Hem	OTHERS
								malachite, azurite, cuprite
	X		X					digenite
				X				chlorargyrite, iodargyrite
X	X		X					guanajuatite, fuchsite, apatite
	X						X	goldfieldite, cassiterite, neodigenite, jarosite
								Ag sulfosalts, limonite, goethite, jarosite
X				X			X	dusserite, anglesite, perronite, tiemannite, proustite, opal, limonite, jarosite, goethite
X				X			X	dusserite, anglesite, perronite, tiemannite, proustite, limonite
	X			X				digenite
X	X							selenides, tellurides
								Cu, As
								melnikovite
	X	X						digenite, idaite, Au-Ag tellurides
						X		sinnerite
4	6	1	2	4	0	2	3	
22	33	6	11	22	0	11	17	
Selen	Tell	Hessite	Calav	Argentite	Acanthite	Magn	Hem	OTHERS

Stib	Bismuth	Au	Ag	Elect	Mo	Selen	Tell	Hessite	Calav	Argentite	Ruby Ag	Magn	Hem	OTHERS
		X		X						X				stephanite
		X	X	X						X	X			stromeyerite
				X						X	X			
										X	X			
		X	X			X				X				naumannite
				X						X	X			stephanite
		X	X											cerargyrite
				X										
		X	X		X					X	X			cerargyrite, powellite
		X								X	X			cerargyrite
		X	X							X	X			stromeyerite, polybasite
		X		X							X			stephanite, pyrolusite
		X		X		X	X			X	X			fluorite, naumannite
				X										post ore fluorite
										X				fluorite
		X								X				bournonite, jamesonite
X				X							X			stephanite
				X										fluorite
		X								X				cerargyrite
				X						X	X			cerargyrite
X		X	X	X		X				X				naumannite, stephanite, aguilarite
				X						X	X			tourmaline
		X												fluorite
		X											X	cerrusite, wolfenite
		X		X						X	X			
				X		X				X	X			fluorite, polybasite, naumannite, jamesonite, miargyrite
			X	X						X	X			
				X	X									fluorite
						X				X	X			stephanite, naumannite, polybasite
		X	X							X	X			stephanite, cerargyrite
		X		X						X				fluorite, cerargyrite, bromeyerite
		X								X				stromeyerite
		X	X	X						X	X			polybasite
				X						X	X			stephanite, fluorite
			X	X		X				X	X			aguilarite, naumannite,
		X		X						X	X			stephanite
		X	X	X						X				stephanite, stromeyerite
X		X											X	
X			X							X	X			cerargyrite, bromeyerite
		X								X	X			stephanite, poybasite
			X							X				fluorite, pyrargyrite
		X	X				X				X			fluorite
							X				X			
4		24	14	23	2	6	3			31	25		2	
9		53	31	51	4	13	6			69	56		4	
Stib	Bismuth	Au	Ag	Elect	Mo	Selen	Tell	Hessite	Calav	Argentite	Ruby Ag	Magn	Hem	OTHERS

Stib	Bismuth	Au	Ag	Elect	Mo	Selen	Tell	Hessite	Calav	Argentite	Ruby Ag	Magn	Hem	OTHERS
		X					X				X			famantite, goldfieldite,
		X												

Table 4
Characteristics of different settings. Summarised from Bogie and Lawless (1987), with additions. LS = low sulfidation, HS = high sulfidation

Characteristic	Silicic depression	Andesitic stratovolcano	Cordilleran volcanism	Oceanic volcanic island
Relief	Low (0–300 m)	High (500–2000 m)	High (500–3000 m)	Moderate (200–500 m)
Lithologies	Acid lavas surrounded by pyroclastic deposits and sediments. Local andesitic centres.	Andesitic lava flows and interbedded breccias, commonly with steep depositional dips. Local dacite domes.	Local andesitic centres and dacite domes on deformed basement.	Basaltic to andesitic lavas and fragmental rocks. Local limestone.
Calderas	Common, large.	Common, small.	Uncommon.	Common, small.
Intrusions	Not common, small, acidic.	Very common, mostly small. Diorite, some granodiorite.	Common, may be large. Diorite to granodiorite.	Common, small. Gabbro and diorite.
Relation of upflow to eruptive centres	Not closely related.	Closely related.	Not closely related.	Closely related.
Surface expression	Neutral pH hot springs with sinters in depressions, hydrothermal eruption craters.	Fumaroles and solfataras at high relief, acid springs on flanks, neutral springs at distance. Sinters rare.	Hot springs with sinters in depressions. Acid springs on flanks, neutral springs at distance. Hydrothermal eruption craters.	May have hot springs with sinters in calderas. Hydrothermal eruption craters.
Phase separation	In upflow, limited alteration from separated gases.	In upflow and lateral flow, very extensive alteration from separated gases.	In upflow, minor alteration from separated gases.	In upflow, minor alteration from separated gases.
Hydrothermal alteration	Mostly illite–smectite, minor kaolinite–alunite.	Widespread propylitic below, very extensive illite–smectite and kaolinite–alunite.	Mostly illite–smectite, minor kaolinite–alunite.	Mostly illite–smectite, minor kaolinite–alunite. Sea-water recharge may cause anhydrite deposition.
Deposit styles	Low-sulfidation deposits.	Low- and high-sulfidation deposits, porphyry copper deposits.	High- and low-sulfidation deposits, porphyry copper deposits.	Low-sulfidation deposits, although a high-sulfidation to porphyry copper association is recognised.
Gold deposition	In stockworks, discrete veins and breccias, especially at depth.	Dominantly in structurally controlled veins (LS), or permeable lithologies (HS).	In stockworks, discrete veins and breccias, especially at depth (LS), or permeable lithologies (HS).	In near-surface zones of high permeability.
Localizing controls	Permeable lithologies, faults, fractures, caldera margins.	Faults and fracture zones in competent lithologies (LS), or minor structures in crater, dome or maar settings (HS).	Faults, shears, fracture zones, mostly in basement rocks (LS), or in minor structurs in crater, dome or maar settings (HS).	Permeable lithologies, faults, fractures, caldera margins.
Example of setting	Central Taupo Volcanic Zone, New Zealand (Cole, 1987).	Mt. Ruapehu, New Zealand (Hackett and Houghton, 1989).	Amacan, Philippines (Barnett et al., 1985).	Curtis Island, Kermadec Group (Doyle et al., 1979).
Deposits (see Appendix)	Ohakuri Dam, New Zealand.	Woodlark Island, Papua New Guinea.	Acupan, Philippines. Lepanto, Philippines.	Laddam, Lihir Island, Papua New Guinea.

Table 5
Exploration methods applied to exploring different settings. Note: "Shallow" refers to a shallow level in the mineralized system, i.e. little or no erosion has occurred. "Deep" refers to a deep level in the mineralized system, i.e. it is deeply eroded (e.g. >400 m)

Setting method	Silicic depression	Andesitic stratovolcano	Cordilleran volcanism	Oceanic volcanic island
Geology	Recognition of veins and hydrothermal alteration patterns may directly locate mineralization. Vein texture and mineralogy may indicate depth of formation.			
	← Geological understanding is the basis for interpreting all other data sets. →			
Geochemistry	Shallow: Low level anomalism may be widespread, unrelated to economic deposits; may not reflect most favourable sites at depth. Indicator elements important. Response commonly obscured by younger cover (e.g. ash deposits).	Shallow: Alteration commonly rrelated to phase separated gases, so only volatile elements may be detected.	Shallow: Low level anomalism may be widespread, unrelated to economic deposits; may not reflect most favourable sites at depth. Indicator elements important.	
	← Deep: Anomalism related to mineralized structures. →			
Geophysics				
1. Magnetics	Effectiveness depends on the magnetic properties of the rocks. In epithermal environments, prospect-scale surveys are typically ineffective. Regional-scale surveys may be a very effective aid in geological mapping, and may define areas of hydrothermal alteration (recognized by magnetite destruction). Structures may be traced from unaltered areas into areas of hydrothermal alteration.			
2. Induced polarization	Shallow: Systems with abundant pyrite in hydrothermally altered cap rocks produce anomalies that are not related to gold mineralization. May be useful on a regional scale, rather than prospect scale.			
	← Deep: Contrasts in sulfide content may be a useful guide to mineralization. →			

3. Resistivity	← In active systems hot water will be detected as areas of low resistivity. →			
	Shallow: High resistivity silicified caps within low resistivity clay alteration may obscure economically significant features.	Shallow: Low resistivity clay alteration blanket obscures economically significant features.	Shallow: High resistivity zones may represent economically significant veins or silicification.	Shallow: High resistivity silicified caps within low resistivity clay alteration may obscure economically significant features.
	Deep: Narrow high resistivity linear features reflect veins or silicification, typically surrounded by low resistivity alteration.		Deep: Narrow high resistivity linear features reflect veins or silicifcation.	Deep: Low resistivity represents fresh rock, veins or silicification; high resistivity may be associated with disseminated mineralization.
4. Electromagnetics	← In active systems hot water will be detected as areas of high conductivity. →			
	Shallow: Conductive clay-altered zones detected: may detect contacts with low-conductivity zones, e.g. silicified areas or veins.			Shallow: Conductive clay-altered zones detected whether related to mineralization or not.
	← Can test below unaltered cover. →			
	← Deep: Conductivity contrasts between veins and wall-rocks may be detected. →			Deep: Conductive alteration zones detected whether related to mineralization or not.
5. Radiometrics	Detect outcropping radiogenic sources. Variations in potassium content can be detected. Adularia and sericite in alteration zones can be recognized as positively anomalous potassium channel responses. Hydrothermally altered potassium-rich host rocks may show local potassium depletion.			
6. Gravity	Gravity surveys detect anomalies related to (1) changes in the density of host rocks due to alteration, (2) basement topography, and (3) intrusions			
	Hydrothermal alteration causes a positive anomaly.	Hydrothermal alteration causes a negative anomaly.	Hydrothermal alteration may cause a negative or positive anomaly.	Hydrothermal alteration causes a negative anomaly.

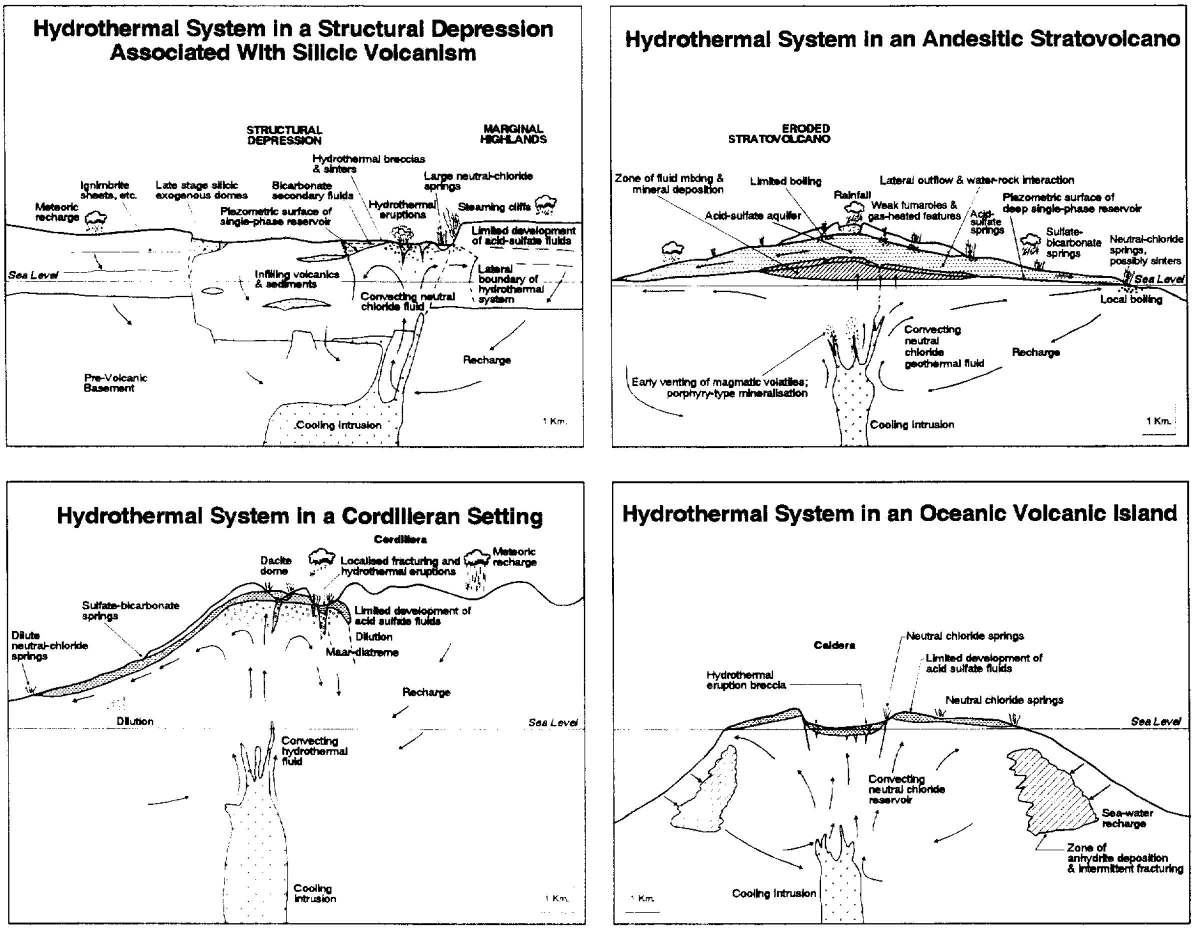

Fig. 2. Epithermal settings (re-drawn after Bogie and Lawless, 1987).

geothermal activity, providing opportunities for superposition of possibly unrelated mineralization, or for prolonged deposition in an evolving system (cf. Sillitoe, 1988, 1989, 1994). These conditions are not unique to the southwest Pacific region, they are simply more widely developed there than in many other regions.

6. Implications for exploration

The experience of the past fifteen years of exploration for epithermal gold deposits has a number of lessons for explorers. Previously unrecognised epithermal gold deposits have been found in Australia, despite the commonly held view that Australia was not prospective for this style of deposit because of its age and inferred depth of erosion. This illustrates that favourable geological environments of any age should be considered prospective. The presence of rocks of low preservation potential (e.g., air fall tuffs, poorly welded ignimbrites, reworked volcaniclastic rocks, sinters) indicates that subsidence and burial was rapid. Thus shallow depth mineralization, if present, could also have been preserved.

Epithermal deposits are normally considered to form at depths ranging from the surface down to about 1 km (e.g., Berger and Eimon, 1983). Several epithermal gold deposits are now recognised to have formed at greater depths or to extend to depths below the levels normally considered to be the lower limits of epithermal deposits, e.g., Kelian, Indonesia (Hawke et al., 1988; Van Leeuwen et al., 1990), and the Cripple Creek deposit, Colorado, can be inferred to have had a vertical extent of at least 1 km (Thompson et al., 1985; Thompson, 1992). This raises the possibility that ancient and/or deformed subaerial volcanic areas, previously regarded as unprospective for epithermal styles of mineralization, may warrant reassessment. It also points to the need for caution in applying standard definitions of epithermal mineralization (Lindgren, 1922, 1933; Berger and Eimon, 1983), as the characteristic mineralogy and associated alteration can be produced at higher temperatures and greater depths (Reyes, 1990) than those commonly recognised.

Recently improved understanding of epithermal deposits has been derived from studies of active geothermal systems (e.g., Henley and Ellis, 1983). In the geothermal environment epithermal deposits form as the chemical composition of the fluid responds to changes in pressure and temperature, and to wall rock composition. In general the principles of these changes are well understood (Henley et al., 1984), though we do not yet fully understand why some systems produce ore, and some, otherwise apparently identical, appear to be barren. The character and distribution of ore and wall-rock alteration are the most variable features of ore deposits, and are what makes each one unique. These aspects are dictated by the hydrology of the system, and whether the fluids are low-sulfidation (neutral pH and reduced) or high sulfidation (acid pH and oxidized).The tectonic setting is influential in determining the hydrology of the system, and how it changes with time.

For gold explorers is clearly necessary to first establish the character of the geological environment at the time of mineralization. From this the hydrological conditions that probably prevailed during mineralization of a particular area can be assessed, and consequently the likely forms and controls on mineralization. In general this should be possible by observation of the volcanic rock types present in the region, and interpretation of volcanic facies (Cas and Wright, 1987; Hackett and Houghton, 1989). Once the likely volcanic environment has been established (Table 4), then the types, distribution, and zoning of hydrothermal alteration, coupled with observations of vein textures and mineralogy, will allow a judgement to be made on the chemical nature of the system, on the level at which the system is exposed and on the probable localising controls.

The range of exploration methods available to explorers is limited, and different methods vary in effectiveness in different situations. In most instances, a combination of geological, geochemical and geophysical methods is used to build up a model of a possible orebody which can then be tested by drilling. Table 5 lists many of the methods available for exploration for epithermal gold deposits, and their use in different settings (see also Irvine and Smith, 1990; Allis, 1990).

Finally, the very dynamic character of the tectonic and volcanic setting throughout much of the southwest Pacific has resulted in deposits which reflect changes in the depositional environment even while deposition was occurring. This has produced some deposits with unusual characteristics which could not have been predicted prior to exploration. What we find is commonly not what we expect.

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Appendix Epithermal gold deposits of the southwest Pacific. Deposit type classification: L – low sulfidation, H – high sulfidation, v – vein, s – stockwork, d – disseminated iode, b – breccia

A. Australia

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Bimurra–Conway [Lvs]		Early Carboniferous andesitic and rhyolitic subaerial volcanics and sediments.	Pyrite. Recrystallised chalcedony, quartz.	Propylitic, silicification, sericite, illite, mixed layered clays, local adularia, alunite, minor pyrophyllite, late calcite.	Prospects occur in N–S zone, cut by NE trending lineaments.	Wood et al., 1990; Henley and Adams, 1992; Ewers et al., 1992
Cracow (Golden Plateau) [Lvd]	0.55 Mt @ 4.2 g/t Au [18.5t Au, 20t Ag, 1933–76] [58 000 oz Au, 1987–88].	Early Permian andesitic and basaltic volcanics, minor trachyte.	Sphalerite, bornite, gold, covellite, galena, chalcopyrite, hematite, hessite, minor pyrite and arsenopyrite. Quartz, adularia, chalcedony, zeolite, amethyst, carbonate.	Silicification, argillic, propylitic. Propylitic — quartz, chlorite carbonate, epidote, adularia. Argillic — quartz, illite, smectite, chlorite, adularia, carbonate, pyrite. Intermediate argillic — kaolinite, smectite, hematite.	Fractures and faults, dykes, and intersection of breccia bodies and faults.	Denmead, 1946; Dear et al., 1971; Brooks, 1974; Staff, 1989; Cracow Mining Venture Staff et al., 1990; Worsley et al., 1992
Dobroyde [Hd]	0.9 Mt @ 2.1 g/t Au.	Devonian andesitic to acidic subaerial volcanics and sediments.	Pyrite, arsenopyrite. Barite.	Kaolinite, pyrophyllite, sericite, illite, smectite, alunite, diaspore.	Shear zones, near major regional fault.	Australian Mineral Economics, 1988
Donnybrook [Lvs]		Cretaceous sandstone unconformably overlying Archean granite, gneiss, and amphibolite.	Chalcedony, quartz.	Silicification.	On splay structures to major regional fault, the Darling Fault.	Ward, 1986
Grassy Gully [Lvs]		Late Devonian peraluminous rhyolites.	Electrum, chalcopyrite, galena, sphalerite, chalcocite, tennantite, chalcostibite, arsenopyrite, tetrahedrite, trace hessite and petzite.	Sericite, silicification.	N–S trending faults probably related to rift graben faults.	Glaser and Keays, 1988
Logan Creek [Lvs]		Rhyolite and acid tuffs.	Chalcedony.	Silicification.		Register of Australian Mining, 1990–91
Major's Creek [Lv]	[820 kg reef gold, 1300 kg alluvial gold]	Early Devonian granite and adamellite.	Gold, Au–Ag tellurides, pyrite, arsenopyrite, magnetite, ilmenite, specular hematite, sphalerite, chalcopyrite, galena, altaite, tetrahedrite, petzite, calaverite, pyrargyrite–proustite. Quartz, sericite, calcite, barite, manganoan calcite.	Intense silica flooding and sericitisation adjacent to each vein.	Structurally controlled dykes and fractures acted as ascendent structures.	Wake and Taylor, 1988

Mineral Hill [L]	0.29 Mt @ 5.9 g/t Ag.	Late Silurian–Middle Devonian acid pyroclastics and sediments.			Lithological/structural controls.	Suppel and Chapman, 1986; Guy, 1990
Mt. Aubrey [Lvs]	0.12 Mt @ 3.35 g/t Au.	Early Devonian basic, acid, and intermediate subaerial volcanics.	Pyrite, gold, galena, chalcopyrite, pyrite. Chalcedony, quartz, adularia, quartz pseudomorphs after bladed calcite.	Propylitic, minor phyllic and argillic. Chlorite, epidote, pyrite, adularia, illite, prehnite.	Complex fault zone with faults, joints and fractures.	M. Dugmore, pers. commun., 1988; Suppel et al., 1990; Gilligan et al., 1991; Hopf, 1991a, b, 1992
Mt. Coolon [Lv]		Carboniferous andesitic volcanics unconformably overlying Devonian sediments and felsic volcanics. Granites intrude	Pyrite, pyrrhotite, hematite. Quartz, stilbite, andradite, adularia, laumontite, carbonates, epidote, zeolites.	Pyritization, silicification, chlorite, epidote, carbonate.	Shear zone	Morton, 1922, 1935; Malone et al., 1964; Australian Mineral Economics, 1988; Wells et al., 1989; Wood et al., 1990
Mt. Fullstop [Lv]		Carboniferous acid volcanics.	Quartz pseudomorphs of bladed calcite.	Silicification.	Regional structures, local faults.	Marton, 1991
Mt. MacKenzie (including North Knoll, Stockyard Creek and Clive Creek) [Hd]	North Knoll: 0.44 Mt @ 2.24 g/t Au, 18.2 g/t Ag. Southwest slopes: 0.43 Mt @ 2.52 g/t Au, 8.9 g/t Ag.	Middle to Upper Devonian acid and intermediate volcanics.	Gold, enargite, chalcocite, tetrahedrite, pyrite, tennantite, localised malachite, azurite, cuprite and bornite.	Central advanced argillic to argillic to outer propylitic. Localised silicification, quartz sericite–clay, quartz–sericite alteration. Pyrophyllite, kaolinite, chlorite, interlayered illite and smectite, carbonates.	Local lithological permeability, caldera ring fracture structure and NE trending fault intersections.	Dear, 1989; Register of Australian Mining, 1992–93
Mt. Ninderry [Hd?]		Mid to late Triassic intermediate to felsic volcanics.	Pyrite, weak indications of precious metal enrichment.	Core — quartz, kaolinite, alunite, dickite, pyrite, hematite. Outer — quartz, kaolinite. Propylitic, weak argillic.	Local breccia pipe and fracture sets. Arcuate structures from possible caldera.	Ashley and Andrew, 1992
North Arm [Lvd]	0.25 Mt @ 2.2 g/t Au [1073 kg Au+Ag, 1930–37].	Triassic andesitic, dacitic, rhyolitic subaerial volcanics.	Pyrite, native silver, electrum, freibergite, naumannite, marcasite, allargentum, sphalerite, chalcopyrite, pyrrhotite, galena, molybdenite. Chalcedony.	Zoned from inner potassic, sericitic, propylitic. Local advanced argillic.	NW trending quartz reefs in parallel fissures.	Murphy et al., 1976; Ashley, 1987a, b; Murray, 1990
Pajingo [Lvs]	1.4 Mt @ 12 g/t Au, 40 g/t Ag.	Devonian andesitic lavas and pyroclastics.	Pyrite, electrum, magnetite, silver, gold, iodoargyrite, hessite, sphalerite, galena, chalcopyrite. Chalcedony, quartz, adularia.	Propylitic overprinted by supergene kaolinite–alunite and hypogene clay alteration. Argillic on phyllic; illite, quartz, chlorite, interlayered illite–smectite, kaolinite, dickite. Silicification. Late pervasive carbonate; siderite, ankerite, dolomite.	Major fault structure dilational zones and intersection of faults.	Etminan et al., 1988; Porter, 1988, 1990; Australian Mineral Economics, 1988; Battle Mountain, 1989; Wood et al., 1990

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Panbula (Pambula) [Lvs]	[1.25t Au]	Late Devonian peraluminous rhyolites, overlying Ordovician flysch.	Pyrite, gold, electrum, galena, chalcopyrite, sphalerite, chalcocite, tennantite, arsenopyrite, tetrahedrite. Chalcedony.	Pyrophyllite, kaolinite, sercite. Silicification.	Mineralization in parallel faults possibly related to rift grabens.	McIlveen, 1974; Glaser and Keays, 1988
Peak Hill [Hd]	1.9 Mt @ 2.1 g/t Au [3.24t Au].	Ordovician to Silurian andesitic to dacitic volcanics, with sediments and sub-volcanic intrusions	Pyrite, tennantite, enargite, tetrahedrite, chalcopyrite, galena, sphalerite, digenite, chalcocite, covellite, calaverite, native Au Quartz, barite.	Quartz, sericite, pyrophyllite, pyrite, kaolinite, alunite, barite, smectite. Zoned from pyrophyllite core to kaolinite–alunite, then sericite, smectite and propylite. Au occurs around kaolinite–alunite zone.	Shear zone on volcanic-sedimentary contact. Cut by E trending faults. On major regional N–S structural zone	Bowman et al., 1979; Cordery, 1986; Clarke, 1987, 1990; Harbon, 1988; Masterman, 1994
Pyramid Mount [Lvs]		Early Devonian subaerial acid volcanics in faulted unconformable contact with Ordovician sediments.	Pyrite, arsenopyrite. Chalcedony, quartz, barite, alunite.	Silicification, propylitic, argillic, phyllic, advanced argillic.	Above shallowly dipping(?) unconformity adjacent to major fault.	Harrison, 1986
Red Rock (Drake) [Ldsv]	0.1 Mt @ 0.9 g/t Au, 66 g/t Ag.	Late Permian epiclastic pumice breccia unconformably overlying deformed sediments.	Pyrite, sphalerite, galena, chalcopyrite, electrum, tetrahedrite, tennantite, pearcite, argentite. Quartz, adularia.	Quartz, calcite, illite, smectite, chlorite. Silicified core, phyllic argillic.	Stratabound disseminations around a structural feeder zone.	Perkins, 1987
Rhyolite Creek [Hd]		Cambrian rhyolitic to dacitic volcanics overlying sediments along a major regional structural axis.	Pyrite.	Pyrophyllite, quartz, graphite.	Strongest anomalies near volcanic sediment contact.	Raetz and Parrington, 1988a, b
Temora (Gidginbung) [Hd]	2.76 Mt @ 2.59 g/t Au, 7.0 g/t Ag [5.2t Au, 7.4t Ag].	Ordovician to Silurian andesitic volcanics adjacent to a major regional structure.	Pyrite, enargite, loellingite, covellite, argentite, gold, native silver, chlorargyrite, iodargyrite.	Silicification — quartz, minor pyrite, enargite. Advanced argillic — quartz, alunite, pyrophyllite, minor kaolinite, quartz. Argillic/propylitic — quartz, kaolinite, minor mica–illite, smectite.	Adjacent to major regional fault zone. NNW trending shear zone.	Thompson et al., 1986; Lindhorst and Cook, 1990; Perkins et al., 1990; Gilligan et al., 1991; Allibone, 1992
Twin Hills [Lsv]	0.99 Mt @ 2.6 g/t Au.	Late Devonian to Early Carboniferous sediments.	Pyrite, marcasite. Chalcedony, bladed quartz, sericite, siderite, apatite, kaolinite.	Early carbonate — ankerite, siderite, dolomite with an overprinting silicification, localised kaolinite–alunite. Supergene illite–kaolinite.	Margin of half graben NNW trending fault corridor and subsidiary ENE fault intersection.	Alston et al., 1991; Register of Australian Mining, 1992–93
Wirralie [Ldv]	3.65 Mt @ 2.8 g/t Au.	Middle Devonian to Early Carboniferous volcaniclastic sediments.	Arsenical pyrite, bladed marcasite, argentiferous gold, Pb–Sb sulfosalts, sphalerite, chalcopyrite, pyrrhotite. Adularia, chalcedony, amethyst, quartz.	Oxidised zone — illite, smectite, kaolinite, haematite. Hypogene zone — quartz, illite, sericite, minor adularia, accessory anatase. Carbonates	Ore is in a tabular body conformable to enclosing strata. Network of veins.	Fellows and Hammond, 1988, 1990; Australian Mineral Economics, 1988; Wood et al., 1990

Wolumla [L?]		Late Devonian peraluminous rhyolites.	Electrum, native Ag, acanthite, stephanite, pearceite, proustite, arsenopolybasite, chalcopyrite, galena, sphalerite, chalcocite, tetrahedrite, arsenopyrite, chalcostibite, tennantite, selenides–naumannite, aguilarite.	Sericite, silicification.	N–S trending faults possibly related to rift graben faults.	Glaser and Keays, 1988
Woolgar [Lv]	2 t Au [0.7 t Au].	Proterozoic metasediments and granites, unconformably overlain by Late Paleozoic subaerial volcanics.	Pyrite, galena.	Chlorite.		Saint-Smith, 1922; Smart, 1973; Morrison, 1988
Yalwal [Lvs]	[2.5 t Au]	Late Devonian rhyolitic volcanics unconformably overlying Ordovician flysch.	Pyrite, arsenopyrite, electrum, sphalerite, galena, chalcopyrite, chalcocite, tennantite, arsenopyrite, tetrahedrite. Chalcedony.	Pervasive phyllic, silicification, zones of quartz–pyrophyllite–sericite. Kaolinisation.	N–S trending faults possibly related to rift graben faults.	Gibbons and Le Messurier, 1962; McIlveen, 1973, 1974; Glaser and Keays, 1988
Yandan [Ld?]	3.3 Mt @ 2.1 g/t Au.	Middle Devonian volcanics and volcaniclastic sediments.	Gold, pyrite, chalcopyrite. Chalcedony, adularia.	Inner illite/potassic, quartz, adularia, pyrite, bladed carbonate, graphite and chalcopyrite. Outer illite/mixed-layer clay/celadonite. Later kaolinite and hematite. Intense silica flooding at top of mineralization.	E–W striking feeder zone structure with host lithology porosity controls.	Western Mining Corporation Annual Report, 1988; Western Mining Corporation, 1989; Wood et al., 1990
Yerranderie [Lv]	[0.6 t Au, 341 t Ag, 28000t Pb]	Middle Devonian acid subaerial volcanics.	Pyrite, sphalerite, galena, arsenopyrite, tetrahedrite, chalcopyrite, stromeyerite, proustite, pyrargyrite, dycrasite, bournonite, silver, polybasite, covellite, chalcocite.	Quartz, sericite, epidote, clay, carbonate.	Fissures in E trending shear in fault. Collapsed caldera crater rim.	Herzberger, 1974; Fergusson, 1980; Suppel and Scheibner, 1990
Yiddah [?]				Phyllic — quartz, sericite, pyrite, kaolinite, chlorite, pyrophyllite.		Suppel and Chapman, 1986
Zelma (Mount Mary Ann) (Grasstree) [H?]	[4000 oz Au] 0.02 Mt @ 11.4 g/t Au underground; 0.03 Mt @ 4.7 g/t Au opencut.	Late Devonian to Early Carboniferous volcanics.	Native Au and Te, pyrite, calaverite, bornite, chalcopyrite, tennantite, minor marcasite, galena, guanajuatite, chalcocite, covellite. Quartz, fuchsite, apatite, chlorite.	Early regional — sericite–illite. Later — quartz–pyrophyllite and silica–pyrite.	Intersection of faults and shear coincident with subvertical heterolithic breccia pipe.	Bills, 1990; Murray, 1990

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Appendix (continued)

B. Fiji

Deposit [type]	Reserves [production]	Host geology	Mineral of ore	Wallrock alteration	Localizing	References
Emperor [Lvsd]	1.35 Mt @ 6.49 g/t Au [120 t Au, >40t Ag, 20 t Te].	Miocene shoshonitic basaltic and trachybasaltic volcanics, adjacent to caldera margin.	Pyrite, sphalerite, marcasite, chalcopyrite, tetrahedrite, calaverite, native tellurium, sylvanite, petzite, stibnite, arsenopyrite, krennerite. Quartz, adularia.	Silicification, quartz–roscoelite adularia–sericite, carbonates. Propylitic, rare potassic.	Faults, shears, "flatmakes", related to collapse of caldera margin.	Denholm, 1967; Colley, 1986; Ahmad et al., 1987a, b; Anderson et al., 1987; Australian Mineral Economics, 1988; Anderson and Eaton, 1990; Kwak, 1990
Mt. Kasi [Hvbd]	1.22 Mt @ 2.83 g/t Au [261,000 t @ 7.5 g/t].	Late Miocene andesitic and basaltic volcanics and intrusions; intruded by dacite domes.	Pyrite, luzonite, enargite, tennantite, tetrahedrite, gold tellurides, goldfieldite, cassiterite, bornite, neodigenite, covellite, bornite, chalcocite. Quartz, adularia, barite, pharmacosiderite, jarosite.	Advanced argillic, argillic, hematite + carbonate, propylitic. Remnant phyllic.	Hydraulic fracturing on numerous faults, main orebody at intersection of NW trending fault with cross fractures.	Turner, 1986; Taylor, 1987; Australian Mineral Economics, 1988; Corbett and Taylor, 1994

C. Indonesia

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Binebase–Bawone [H?d]	4.5 Mt @ 1.37 g/t Au, 8 g/t Ag, 0.3%.	Miocene andesitic volcaniclastics.	Pyrite, silver sulfosalts, chalcopyrite, covellite, sphalerite, galena, chalcocite. Barite, illite, gypsum.	Quartz–barite with accessory kaolinite, gypsum, illite, limonite, goethite and jarosite. Phyllic in permeable units; illite, quartz, chlorite, smectite, gypsum. Widespread propylitic; epidote–chlorite–pyrite.	Intersection of fault sets.	Carlile et al., 1990; Swift and Alwan, 1990; Van Leeuwen, 1994
Bolangitang [Lvsb]		Miocene andesitic volcanics.	Pyrite, gold. Quartz, carbonates.	Silicification, illite–pyrite. Propylitic.	E–W and NNE trending faults.	Carlile et al., 1990; Kavalieris et al., 1992; Carlile and Mitchell, 1994
Bukit Tembang [Lvs]	2.4 Mt @ 3.0 g/t Au, 45 g/t Ag.	Trachyandesitic lavas and tuffs.	Electrum, pyrite. Quartz, adularia, chalcedony.	Regional propylitic overprinted by illite, illite–smectite and kaolinite.	Veins and stockwork in preferentially fractured lavas.	Van Leeuwen, 1993, 1994; Carlile and Mitchell, 1994

Ciemas [Lv]	0.2 Mt @ 5 g/t Au, 20 g/t Ag.	Early Miocene andesitic volcanic and sedimentary rocks, intruded by dacite porphyry.	Pyrite, arsenopyrite, electrum, base metal sulfides. Chalcedony, quartz, carbonate.	Silica replacement around veins, in illite–smectite zone. Carbonate and propylitic alteration.		Van Leeuwen, 1994
Cikondang [Lvb]	0.43 Mt @ 10.9 g/t Au, 25 g/t Ag, 3.1% Zn [450–1,500 kg Au].	Sedimentary–volcanic pile adjacent to andesitic porphyries.	Pyrite, arsenopyrite, hematite phase, and pyrite, sphalerite, galena phase. Quartz.	Sericite, chlorite; illite, smectite and carbonate in upper levels.	Quartz breccia veins along N-NE trending structure.	Van Leeuwen, 1993, 1994; Carlile and Mitchell, 1994
Cirotan–Cikotok [Lv]	0.1 Mt @ 4 g/t Au [7.3 t Au, 22 t Ag].	Miocene andesitic and trachytic volcanics with Pliocene intrusions.	Pyrite, arsenopyrite, hematite phase, and pyrite, sphalerite, galena phase. Quartz.	Illite–sericite selvages to veins, grading to propylitic. Silicification.	On faults. Mineralized area about 400 sq. km.	Sunarya, 1987; J. Carlile, pers. commun., 1989; Van Leeuwen, 1993, 1994; Carlile and Mitchell, 1994; Marcoux and Milési, 1994
Doup [Lsd]	12 Mt @ 1.6 g/t Au.	Late Miocene porphyritic andesite and minor sediments.	Base metals, gold. Quartz, rhodochrosite, rhodonite.	Kaolinite, illite and pyrite envelop ore body. Propylitic.	Multi directional structures.	Kavalieris et al., 1992; Van Leeuwen, 1993, 1994
Gunung Arum (Aurum) [Lv]	[0.9 t Au, 6.5 t Ag]	Miocene andesitic volcanics.	Pyrite, chalcopyrite, electrum, sphalerite, galena, pyrargyrite. Quartz.			Sunarya, 1987; Carlile and Mitchell, 1994
Gunung Pani [Lsvbd]	30 Mt @ 1.35 g/t Au (inferred) [1 kg Au, 0.5 kg Ag].	Miocene rhyodacitic volcanics.	Pyrite, electrum, gold, minor base metals. Quartz, adularia.	Albite–chlorite–pyrite. Sericite carbonate. Argillic, quartz–adularia.	NNE and NE faults. Fissures and breccia zones.	Kavalieris, 1984; Carlile et al., 1990; Kavalieris et al., 1990; Van Leeuwen, 1993; Carlile and Mitchell, 1994
Gunung Pongkor [Lv]	6 Mt @ 17 g/t Au, 162 g/t Ag.	Miocene andesitc and basaltic volcanics and intrusions.	Electrum, argentite, pyrite, trace base metal sulfides. Quartz, adularia, carbonate, smectite, kaolinite, minor barite.	Propylitic, argillic, silicification. Smectite, kaolinite, barite, chlorite, albite.	NW trending veins. Faults and shear zones.	Van Leeuwen, 1993, 1994; Sumanegara and Sinambela, 1993; Carlile and Mitchell, 1994; Basuki et al., 1994

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Kali Kuning [Hd]	2.2 Mt @ 5.5 g/t Au. 146 g/t Ag, 60% barite.	Submarine dacitic and andesitic breccias, overlain by post mineralisation limestone (Pliocene).	Ore in stratiform baritic sands above mounds of massive sulfide. Sands: electrum, gold, tetrahedrite, dusserite, anglesite, cinnabar, perronite, tiemannite, proustite, sphalerite. Barite, opal, limonite, jarosite, goethite. Pyrite, marcasite, electrum, argentite, tetrahedrite, Ag-bearing galena. Quartz, barite, chalcedony, hematite, goethite. Massive sulfide: pyrite, marcasite, chalcocite, bornite, chalcopyrite, enargite, plumbojarosite, cerrusite, galena, sphalerite, scorodite. Anhydrite, gypsum.	Pervasive chloritic alteration of volcanics. Early illite–diaspore chlorite–adularia ± quartz + alunite. Later quartz, crystabolite, smectite, kaolinite, zeolite, carbonate, alunite.	Fault controlled basins on the flanks of felsic dome structures.	Carlile and Mitchell, 1994; Sewell and Wheatley, 1994a, b; Van Leeuwen, 1993, 1994
Kelian [Lsvdh]	Total resource 97 Mt @ 1.85 g/t Au; mineable 53.5 MT @ 1.97 g/t Au.	Eocene acid pyroclastics and sediments with small Miocene subvolcanic intrusions and breccias.	Pyrite, sphalerite, galena, chalcopyrite, arsenopyrite, tetrahedrite, pyrrhotite, electrum, cinnabar. Quartz, sericite, carbonates, adularia.	Early sericite–adularia, propylitic. sericite–clay–pyrite–carbonate–quartz. Kaolinite, dickite	Shear zones, contact between intrusions and volcanic sediments.	Ferguson, 1986; Hawke et al., 1988; Van Leeuwen et al., 1990; Van Leeuwen, 1993, 1994; Carlile and Mitchell, 1994
Lanut [Lvsb]	19 Mt @ 1.41 g/t (indicated).	Miocene andesitic volcanics interbedded with marine sediments.	Pyrite, arsenopyrite, gold. Quartz, adularia, calcite.	Adularia–illite grading out to chlorite–illite–pyrite. Kaolinite–pyrite overprint. Propylitic.	NW and NE trending faults. Veining.	Carlile et al., 1990; Van Leeuwen, 1993, 1994; Carlile and Mitchell, 1994; Kavalieris et al., 1992
Lebak Sembada [?]			Base metals. Quartz, rhodonite, rhodochrosite.			Carlile and Mitchell, 1994
Lebong Donok [Lv]	[2.9 Mt @ 14.3 g/t Au, 79 g/t Ag]	Miocene shales overlain by andesitic volcanics intruded by dacite.	Pyrite, chalcopyrite, sphalerite, naumannite, berzelianite, electrum. Chalcedony, quartz, adularia, calcite, truscottite.	Silicification. Chlorite, epidote, sericite, illite, pyrite.	Regional strike–slip Sumatran Fault. On margin of intrusion.	Van Bemmelen, 1949; Sunarya, 1987; Kavalieris, 1988; J. Carlile, pers. commun., 1989; Carlile and Mitchell, 1994; Van Leeuwen, 1994
Lebong Simpang [Lv]	[57 kg Au, 300 kg Ag]	Tertiary andesitic volcanic rocks.	Pyrite, chalcopyrite, sphalerite, galena, gold. Quartz.	Illite, chlorite, quartz, pyrite.	NE trending vein system.	Van Leeuwen, 1994

Lebong Sulit [Lvd]	[0.47 Mt @ 14.6 g/t Au, 22 g/t Ag]	Miocene andesitic and trachytic volcanics.	Pyrite, chalcopyrite, galena, sphalerite, argentite. Quartz, rhodochrosite.		Regional strike–slip Sumatran Fault. On contact between andesites and trachytes.	Sunarya, 1987; J. Carlile, pers. commun., 1989
Lebong Tandai [Lvbd]	0.3 Mt @ 12.2 g/t Au, 87 g/t Ag [2.5 Mt @ 15.6 g/t Au, 175 g/t Ag] [1988–90, 4.2 t Au, 19.4 t Ag].	Miocene andesitic and trachytic volcanics, intercalated sediments.	Pyrite, galena, sphalerite, selenides, As–Sb sulfosalts, chalcopyrite, electrum, Ag tellurides. Quartz, adularia, chlorite, carbonate, illite.	Illite, illite–smectite, pyrite. Epidote–chlorite.	E–W trending quartz breccia veins offset by sets of NW and NE trending faults. Regional strike–slip Sumatran Fault. On contact between andesites and trachytes.	Van Bemmelen, 1949; Van Leeuwen, 1993, 1994; Carlile and Mitchell, 1994; Jobson et al., 1994
Lerokis [Hd]	2.9 Mt @ 3.5 g/t Au, 114 g/t Ag, 40% barite.	Submarine dacitic and andesitic breccias, overlain by post mineralisation limestone (Pliocene).	Ore in stratiform baritic sands above mounds of massive sulfide. Sands: electrum, gold, tetrahedrite, dusserite, anglesite, cinnabar, perronite, tiemannite, proustite, sphalerite. Barite, opal, limonite, jarosite, goethite. Pyrite, marcasite, electrum, argentite, tetrahedrite, Ag-bearing galena. Quartz, barite, chalcedony, hematite, goethite. Massive sulfide: pyrite, marcasite, chalcocite, bornite, chalcopyrite, enargite, plumbojarosite, cerrusite, galena, sphalerite, scorodite. Anhydrite, gypsum.	Pervasive chloritic alteration of volcanics. Early illite–diaspore–chlorite adularia + quartz + alunite. Later quartz, crystabolite, smectite, kaolinite, zeolite, carbonate, alunite	Fault controlled basins on the flanks of felsic dome structures.	Carlile and Mitchell, 1994; Sewell and Wheatley, 1994a, b; Van Leeuwen, 1993, 1994
Lobong [Ls]		Miocene limestone and sedimentary units.	Gold, mercury, arsenic. Carbonates, chalcedony.	Solfataric alteration.	Veining.	Kavalieris et al., 1992
Mangani [Lsvbd]	[0.95 Mt @ 6.5 g/t Au, 265 g/t Ag]	Miocene andesite and carbonaceous shale.	Pyrite, argentite, electrum, polybasite, stephanite, galena, pyrrhotite, alabandite, sphalerite, stannite, Ag sulfosalts, chalcopyrite, Cu, Ti, Ag selenide, Sn minerals, base metals. Quartz, chalcedony, rhodonite, adularia, rhodochrosite, calcite.	Upper acid quartz–pyrite–clay, deeper propylitic.	N–S tensional fractures adjacent to Sumatran Fault System. Some veins on intrusive contact.	Kavalieris et al., 1987; J. Carlile, pers. commun., 1989; Carlile and Mitchell, 1994; Van Leeuwen, 1994
Masupa Ria [Lvs]	0.3 Mt @ 12.7 g/t Au, 85 /t Ag.	Tertiary andesitic volcanics.	Pyrite. Quartz, calcite. Adularia very minor.	Illite–sericite, overprinted by alunite–pyrophyllite. Silica cap.	On major regional lineament, localised by shear zones.	J. Carlile, pers. commun., 1989; Carlile and Mitchell, 1994; Thompson et al., 1994; Van Leeuwen, 1994
Mintu [Lv]	[1913–1931 3962 kg Au, 3989 kg Ag]	Miocene andesitic volcanics.	Pyrite, chalcopyrite, bornite, gold.	Narrow illite–pyrite envelope, grading to chlorite–pyrite, then chlorite.	Veining.	Carlile et al., 1990; Kavalieris et al., 1992

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Mirah [Ld]	Resource 3.8 Mt @ 2.12 g/t Au, 53 g/t Ag; mineable 2.7 Mt @ 2.0 g/t Au, 54 g/t Ag.	Tertiary andesitic volcanics.	Pyrite, enargite. Native sulfur, barite.	Argillic in shears, surrounded by chlorite–epidote.	N-NW trending shear zones with quartz veins.	Australian Mineral Economics, 1988; J. Carlile, pers. commun., 1989; Van Leeuwen, 1993, 1994
Miwah [Hd]		Pliocene sediments and andesitic volcanics.	Pyrite, enargite. Native sulfur, barite.	Laterally into quartz, quartz–pyrite, quartz–clay–pyrite, chlorite–epidote.		Carlile and Mitchell, 1994
Motomboto [Hdbv]	1–3 Mt > 1.5 g/t Au, 60 g/t Ag, 2% Cu.	Miocene andesitic volcanics and sediments, diorite.	Pyrite, enargite, luzonite, arsenopyrite, chalcopyrite, tetrahedrite, argentite, gold, galena, chalcocite, covellite, marcasite, digenite, sphalerite, tellurides. Quartz.	Silicification, advanced argillic core, to outer propylitic. Alunite and quartz with enargite.	Dacite dome and altered volcanics contact. Rift faults parallel to the Neogene Arc.	Carlile et al., 1990; Van Leeuwen, 1993, 1994; Kavalieris et al., 1992; Perelló, 1994
Mt. Muro [Lvs]	Total resource 10.4 Mt @ 3.8 g/t Au, 95 g/t Ag in 10 deposits; mineable 8.9 Mt @ 4.19 g/t Au, 93 g/t Ag.	Middle Tertiary andesitic volcanics with hypabyssal intrusions.	Pyrite, galena, chalcopyrite, sphalerite, covellite, electrum, acanthite. Quartz, adularia, calcite, rhodochrosite, siderite, inesite.	Phyllic, regional propylitic. Pyrite–carbonate–illite–quartz, kaolinite.	NNW trending Kerikil structures.	Simmons and Browne, 1988, 1990; Van Leeuwen, 1993; Ashton Mining, 1992
Muyup [Lvbs]	0.3 Mt @ 2.3 g/t Au.	Mid Tertiary Muyup Volcanics — andesitic to trachytic volcanics.	Gold, electrum, pyrite, marcasite, stibnite. Adularia, carbonate, chalcedony, quartz.	Silicification mantled by alteration envelopes. Quartz, adularia, interlayered illite–smectite, illite, chlorite. Late stage kaolinite, dickite, siderite.	NW trending fault structures, fractured margins of intrusions, hydrothermal breccias.	Wake, 1991; Van Leeuwen, 1994
Palaleh [L?]	[1896–1929 8152 kg Au, 5419 kg Ag]					Kavalieris et al., 1992
Paslaten [Lv]		Pliocene trachyandesite lava.	Gold. Quartz.	Propylitic.		Kavalieris et al., 1992
Patung [Lvb]		Late Miocene andesite and greywacke.	Gold. Quartz, manganese carbonates.	Propylitic.	Structures, veins and breccia dykes hosted by a diatreme.	Kavalieris et al., 1992
Pelangan [Hdvb]		Tertiary volcanics.	Pyrite, enargite, tetrahedrite, gold, tellurides, selenides. Quartz, alunite, sericite, barite.	Quartz, smectite, alunite, kaolinite.		Carlile and Mitchell, 1994; Van Leeuwen, 1994
Pusian [Lv]		Miocene basaltic andesite and greywacke.	Gold. Quartz, manganese carbonates.	Propylitic.		Kavalieris et al., 1992

Rawas [Lvs]		Tertiary andesitic to trachy-andesitic volcanics.	Pyrite, galena, sphalerite. Quartz, calcite.	Illite–sericite, with kaolinite overprinting. Propylitic regional.	On structures.	J. Carlile, pers. commun., 1989
Romang Island (including Kiahar, Pawawan, Joirtuna and Dedern) [Lvb]		Dacitic to rhyodacitic volcanics and granodiorite.	Gold, silver, minor lead. Quartz, chalcedony, barite, zeolites, fluorite.	Local silicification. Propylitic. Kaolinite.	Major N trending structural corridor, brecciated veins, altered intrusive bodies and adjacent to major lineaments are major enrichment zones.	Garwin and Herransyah, 1993
Salida [Lvb]	[3 t Au, 98 t Ag]	Miocene andesitic volcanics.	Tellurides, selenides, sphalerite, galena, argentite. Quartz, rhodonite, rhodochrosite.			Sunarya, 1987; Carlile and Mitchell, 1994
Simbalang [Hd]			Pyrite, enargite, gold, copper, arsenic. Vuggy quartz.	Extensive clay alteration.		Kavalieris et al., 1992
Sumalata [L?]	[1896–1908 1402 kg Au 155 kg Ag]					Kavalieris et al., 1992
Sungai Keruh [Lv]	Oxidised 3.3 Mt @ 1.14 g/t Au. Primary 1.0 Mt @ 4.08 g/t Au.	Tertiary potassic altered monzonite porphyry intruded into volcanic and sedimentary rocks.	Gold. Quartz–adularia.	Porphyry-related potassic alteration. Late carbonate veins.	In porphyry system.	Van Leeuwen, 1994
Tanoyan [Lsv]		Miocene andesite and epiclastic rocks.	Gold.	Propylitic.	Dilational offset on Dumoga Rift, stockwork and veining.	Kavalieris et al., 1992
Taware Ridge [Lsv]		Miocene andesitic volcanics.	Pyrite, arsenopyrite, galena, sphalerite, gold. Quartz.	Illite–pyrite–quartz.	NW trending faults.	Carlile et al., 1990
Tobongan [Lvsd]		Miocene andesitic volcanics.	Pyrite, gold. Quartz.	Silicification, propylitic, illite–pyrite.	Veining.	Carlile et al., 1990; Kavalieris et al., 1992
Totopo [Lv]		Late Miocene dacites, andesites and basalts.	Gold, minor silver.	Propylitic.		Kavalieris et al., 1992

D. New Zealand

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Broken Hills–Golden Hills [Lvs]	[1.7 t Au + Ag, Ag/Au = 1.3]	Pliocene rhyolitic flows and pyroclastics.	Electrum, silver, trechmannite, silver sulfoselenides, marcasite, pyrite, acanthite, aguilarite, goethite, Au–Ag–As–Se sulfosalts. Quartz, lepidocrocite, minor barite.	Silicification restricted to pyroclastics around breccia pipe. Adularia–sericitic (quartz, illite, adularia, pyrite), sericitic–argillic (illite, smectite, pyrite), propylitic (pyrite, calcite, albite, chlorite, epidote). Minor kaolinite, illite–smectite.	Fault bounded breccia pipe that acted as fissure and aquifer where veins were intersected.	Moore, 1979; Brathwaite et al., 1989

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Coromandel [Lv]	[12 t Au + Ag]	Oligocene sediments and Miocene rhyolitic/andesitic volcanics.	Pyrite, chalcopyrite, galena, arsenopyrite, native arsenic, electrum, acanthite, stibnite, sphalerite, manganese oxide. Quartz, adularia.	Propylitic, quartz–sericite–adularia. Carbonate.	Fault controlled extensional veins in block-faulted basement high.	Fraser and Adams, 1907; Williams, 1974; Christie, 1984; Brathwaite, 1988
Golden Cross [Lbsv]	stockwork zone 2.3 Mt @ 2.8 g/t Au, 13 g/t Ag; vein zone 3 Mt @ 7.2 g/t Au, 17 g/t Ag [12 t Ag + Au, Ag/Au = 3.3].	Miocene–Pliocene andesitic volcanics.	Pyrite, chalcopyrite, galena, sphalerite, acanthite, pyrargyrite, electrum, arsenopyrite, pyrrhotite, marcasite, pyrolusite. Quartz, adularia, calcite.	Adularia–sericitic (quartz, adularia, illite, pyrite), sericitic–argillic (quartz, illite, smectite, pyrite, chlorite), argillic (smectite, kaolinite, pyrite), propylitic (chlorite, calcite, illite, pyrite), anhydrite, jarosite, sphene. Silicified core with outer argillic envelope.	Local permeability. Regional NNE trending structural corridor. NE trending veins.	De Ronde, 1986; De Ronde and Blattner, 1988; Australian Mineral Economics, 1988; Hay, 1989
Kapanga–Hauraki [Lvs]	[7.4 t Au + Ag, Ag/Au = 0.4]	Miocene andesitic volcanics.	Pyrite, electrum, minor arsenopyrite, stibnite, pyrargyrite, marcasite, pyrrhotite, native As. Quartz, minor calcite.	Propylitic (quartz, calcite, chlorite, illite, pyrite).	N to NW trending veins, highest grades at intersection of veins and cross faults.	Brathwaite et al., 1989
Karangahake [Lv]	0.7 Mt @ 10.7 g/t Au, 48 g/t Ag [127 t Au + Ag, Ag/Au = 3.3].	Miocene–Pliocene andesitic volcanics and rhyolite lava.	Pyrite, sphalerite, galena, chalcopyrite, acanthite, argentite, covellite, electrum. Chalcedony, quartz, calcite, rhodochrosite, limonite, manganese oxides.	Core of strong silicification, grading outwards into propylitic (chlorite, calcite, illit,e pyrite, sphene, albite), adularia–sericite (quartz, adularia, illite, pyrite) sericitic–argillic (quartz, illite, smectite, pyrite).	Regional NNE trending structural corridor controlled by extensional faults and with parallel NNE trending veins.	Williams, 1974; Anstiss, 1984; Christie, 1984; Christie and Brathwaite, 1986; Brathwaite, 1989; Brathwaite et al., 1989
Komata [Lv]	[16.7 t Au + Ag, Ag/Au = 4]	Pliocene andesitic to rhyolitic volcanics.	Pyrite, acanthite, electrum, minor sphalerite, chalcopyrite. Quartz, adularia, calcite, chalcedony.	Adularia–sericitic (quartz, adularia, illite, pyrite), argillic.	NE trending sheeted veins.	Brathwaite et al., 1989
Kuaotunu [Lv]	[3 t Au + Ag, Ag/Au = 0.7]	Early Miocene andesitic volcanics and sediments.	Pyrite, electrum, arsenopyrite, marcasite, minor sphalerite, galena, pyrrhotite, hessite. Quartz pseudomorphs after calcite, quartz.	Sericitic (illite, quartz, pyrite), argillic (kaolinite, quartz, pyrite), advanced argillic (kaolinite, pyrite, alunite), propylitic.	N trending veins.	Brathwaite et al., 1989
Maratoto [Lvs]	[6 t Au + Ag, Ag/Au = 4, and 3 t Au + Ag, Ag/Au = 130]	Miocene andesitic and dacitic volcanics.	Sphalerite, galena, pyrite, hessite, chalcopyrite, acanthite, electrum, minor native silver. Quartz, calcite, rhodochrosite.	Adularia–sericitic (quartz, adularia, illite, pyrite), argillic.	N trending sheeted veins.	Brathwaite et al., 1989

Martha Hill (Waihi) [Lvs]	14.7 Mt @ 3.2 g/t Au, 33 g/t Ag [1100 t Au + Ag, Ag/Au = 6].	Miocene andesitic and dacitic volcanics.	Pyrite, sphalerite, galena, chalcopyrite, acanthite, electrum; trace marcasite, arsenopyrite, molybdenite, pyrargyrite, pyrrhotite, tetrahedrite. Quartz, chalcedony, minor adularia, calcite.	Inner adularia–sericite (quartz, adularia, illite, pyrite, sericite), outer propylitic (calcite, chlorite, pyrite). Sericitic–argillic (quartz, illite, smectite, chlorite, pyrite), silicification.	Parallel faults on complex volcano-tectonic depression structure. Associated NNW basement high. Veins parallel to strike of regional fault pattern.	Barker and Merchant, 1984; Brathwaite et al., 1986; Christie and Brathwaite, 1986; Brathwaite et al., 1989; Brathwaite and McKay, 1989; Jennings, 1992
Neavesville [Lbsv]	[964 kg Au + Ag, Ag/Au = 1.7]	Pliocene andesitic and rhyolitic volcanics interbedded with carbonaceous sediments	Electrum, sphalerite, hessite, galena, pyrite, chalcopyrite, molybdenite, marcasite. Quartz, chalcedony.	Silicification, adularia–sericitic (quartz, illite, adularia, pyrite), serictic–argillic (illite, smectite, pyrite), propylitic (pyrite, calcite, albite, chlorite, epidote).	Fractured and brecciated zones and breccia pipes produced by hydraulic fracturing.	Barker et al., 1980; Barker, 1989; Brathwaite et al., 1989
Ohakuri Dam [Lsd]		Quaternary rhyolitic pyroclastics.	Pyrite. Quartz, adularia, chalcedony.	Core: quartz–adularia–mordenite, later kaolinite. Illite, chlorite, mordenite, smectite, clinoptilolite, alunite.	Zones of more intense alteration associated with ENE trending lineaments. In Maroa Graben.	Henneberger, 1986
Opitonui [Lv]	[0.97 t Au + Ag, Ag/Au = 0.9]	Miocene andesitic and dacitic volcanics.	Pyrite, electrum. Quartz	Sericitic (illite, quartz, pyrite), propylitic.	E and N trending veins.	Brathwaite et al., 1989
Owharoa [Lv]	[3.9 t Au + Ag, Ag/Au = 1.3]	Pliocene–Miocene dacitic to rhyodacitic flows.	Pyrite, marcasite, electrum, acanthite, minor cinnabar. Quartz, chalcedony, quartz pseudomorphs after calcite.	Adularia–sericite (quartz, adularia, pyrite, illite).	NNE trending veins.	Brathwaite et al., 1989
Tokatea–Success [Lv]	[3.9 t Au + Ag, Ag/Au = 0.5]	Miocene andesitic and rhyodacitic volcanics.	Pyrite, electrum, minor arsenopyrite, pyrrhotite, marcasite, hessite, sphalerite, galena, chalcopyrite. Quartz, minor calcite, adularia.	Propylitic (quartz, calcite, chlorite, illite, pyrite).	Highest grades at intersection of faults and veins.	Brathwaite et al., 1989
Te Ahumata (Great Barrier) [Lv]	[1.3 t Au + Ag, Ag/Au = 4]	Miocene rhyolitic and andesitic volcanics.	Pyrite, pyrargyrite, electrum, minor chalcopyrite, sphalerite, galena, tetrahedrite, marcasite, stibnite, pyrrhotite. Quartz, chalcedony, quartz pseudomorphs after calcite.	Sericitic–argillic (quartz, illite, smectite, kaolinite, chlorite, pyrite), propylitic (chlorite, calcite, pyrite), silicification.	E and NNW trending veins.	Brathwaite et al., 1989
Te Puke (Muirs Reefs) [Lv]	[1.7 t Au + Ag, Ag/Au = 0.33]	Pliocene rhyolite and andesite.	Pyrite, electrum. Quartz, chalcedony, quartz pseudomorphs after calcite.	Adularia–sericitic (quartz, adularia, illite, pyrite), propylitic (chlorite, calcite, pyrite).	NNE trending veins.	Brathwaite et al., 1989

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Thames [Lvbs]	[72.5 Au + Ag. Ag/Au = 0.6]	Miocene andesitic to dacitic volcanics overlying Mesozoic sediments. High-level intrusions.	Pyrite, chalcopyrite, stibnite, sphalerite, Au–Ag telluride, altaite, electrum, tetradymite, Au–pyrargyrite, tetrahedrite, Sb-sulfosalts, galena, molybdenite, robinsonite, chalcostibite, enargite, bournonite, cinnabar, polybasite, gold. Quartz, barite.	Sericitic (illite, quartz, pyrite), sericitic–argillic (kaolinite, illite, pyrite, smectite), propylitic (chlorite, calcite, albite, epidote, pyrite), advanced argillic (alunite, kaolinite, dickite, diaspore, pyrophyllite, pyrite).	On marginal faults of Hauraki Graben. Highest grades at intersection of faults and veins.	Christie, 1984; Christie and Brathwaite, 1986; Merchant, 1986; Brathwaite et al., 1989
Tui [Lv]	[2.6 t Au + Ag. Ag/Au = 50]	Miocene andesitic pyroclastics.	Sphalerite, galena, chalcopyrite, pyrite, marcasite, tetrahedrite, minor native Au, tetradymite, bismuthinite, hematite, cinnabar. Quartz.	Adularia–sericite (quartz, adularia, illite, pyrite), propylitic (chlorite, epidote, pyrite, calcite).	NE trending veins.	Brathwaite et al., 1989
Waiomu (incl. Monowai) [Lv]	0.14 Mt @ 14 g/t Au 59 g/t Ag [1.5 t Au + Ag. Ag/Au = 3.5].	Mid–Late Miocene andesitic volcanics.	Au–Ag tellurides, pyrite, marcasite, galena, sphalerite, chalcopyrite, electrum, native Au, tetrahedrite, Sb sulfosalts, bournonite, bismuthinite, tetradymite, arsenopyrite. Quartz, calcite, anhydrite, rhodochrosite, barite.	Widespread propylitic; closer to veins — chlorite, clay–sericite, clay–cericite–quartz. Sericitic, argillic, propylitic.	N trending veins concordant with host volcanics.	Roberts, 1989; Brathwaite et al., 1989
Waitekauri (Jubilee, Scotia and Maoriland) [Lv]	[4.4 t Au + Ag. Ag/Au = 7]	Miocene andesitic and dacitic volcanics and lavas.	Pyrite, marcasite, sphalerite, galena, chalcopyrite, electrum. Quartz, calcite, chalcedony.	Adularia–sericite (quartz, adularia, illite, pyrite), propylitic (chlorite, calcite, pyrite, epidote). Silicification.	N trending veins.	Brathwaite et al., 1989
Waiorongomai [Lv]	[2.1 t Au + Ag. Ag/Au = 1.5]	Miocene dacitic ignimbrite and andesitic flows.	Pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, hessite, electrum. Quartz, minor calcite.	Sericitic (quartz, illite, pyrite), sericitic argillic (quartz, illite, smectite, chlorite, pyrite), propylitic (calcite, chlorite, epidote, albite, illite, pyrite).	Large N trending vein with intersections with minor veins, ore shoots at intersections.	Brathwaite et al., 1989
Wharekirauponga [Ls]	[964 kg Au + Ag]	Mid Pliocene rhyolitic volcanics.	Gold, pyrite, covellite, chalcopyrite, digenite, hematite, trace arsenopyrite, electrum. Chalcedony, adularia.	Core: quartz–adularia, peripheral: interlayered illite–smectite–pyrite, broad acid alteration; cristobalite, kaolinite, smectite.	Intersection of NNE and NW trending structures.	Rabone et al., 1989; Brathwaite et al., 1989

E. Palau and Yap

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Babelthuap Island (Palau) [Lv]	none available; assays up to 700 g/t Au.	Oligocene andesitic volcanics and dykes.	Pyrite, sphalerite, galena, chalcopyrite, gold, Au–Ag telluride. Quartz, albite, calcite, clinochlore.	Silicification, propylitic, sericite.	Shear zones.	Miller and Rytuba, 1986; Rytuba et al., 1987; Rytuba and Miller, 1990
Maap Island Gagail–Tamil Island (Yap) [Lv]	none available; assays up to 3.7 g/t Au.	Miocene? mafic volcanics on metamorphic basement	Pyrite, chalcopyrite, anomalous Te, Cu, V.	Silicification, kaolinite, sericite.		Rytuba et al., 1988; Rytuba and Miller, 1990

F. Papua New Guinea

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Ambitle [Lbs]		Pliocene–Pleistocene mafic to intermediate alkaline volcanics and intrusions. Oligocene limestone underlies.	Pyrite, chalcopyrite, bornite, chalcocite. Quartz, adularia, calcite.	Porphyry-style system overprinted by epithermal. Potassic, phyllic, argillic, advanced argillic.	Near caldera margin where NW trending boundary fault of graben intersected by NE trending faults.	Licence et al., 1987
Basangka [L?]		Middle Jurassic phyllite grade metasediments.	Gold, marcasite, stibnite, cinnabar, pyrite, base metals Quartz.	Sericitic, silicification, pervasive propylitic, potassic, advanced argillic.	NE trending fault zones and fault/breccia veins.	Mori, 1991
Hidden Valley [Lsv]	40 Mt @ 2.0 g/t Au, 30 g/t Ag.	Miocene granodiorite intruding Mesozoic fine-grained metasediments. Pliocene dykes (andesitic–dacitic) intrude.	Pyrite, sphalerite, galena, tetrahedrite, gold, hematite. Quartz, chlorite, epidote, adularia, kutnahorite.	Propylitic to strong phyllic, local argillic, carbonates.	Moderately dipping fault, basal tectonic breccia zone, and shallowly dipping granodiorite/metasediment contact. Fault zone acted as conduit.	Nelson and Christie, 1988; Australian Mineral Economics, 1988; Nelson et al., 1990
Kerimenge [Lb]	55 Mt @ 1.0 g/t Au	Pliocene dacitic porphyry.	Pyrite, arsenopyrite, sphalerite, galena, gold, chalcopyrite, tetrahedrite, marcasite. Quartz, manganocalcite, calcite, barite, adularia.	Sericite–quartz–pyrite overprinting regional propylitic, local argillic (clay, pyrite). Adularia.	Diatreme related dilational fractures. N trending Kerimenge Fault.	Hutton et al., 1990; Syka and Bloom, 1990
Ladolam (Lihir Island) [L + Hd?]	oxide ore 4.7 Mt @ 1.9 g/t Au; sulfide ore 168.2 Mt @ 3.48 g/t Au.	Alkaline volcanics within Pleistocene collapsed caldera on Pliocene volcanic basement. Monzonite intrusion.	Pyrite, chalcopyrite, arsenopyrite, tetrahedrite, tennantite, bornite, rare tellurides, marcasite, molybdenite, enargite, luzonite. Quartz, adularia, carbonates, sulfur, opaline silica.	Porphyry alteration overprinted by epithermal. Phyllic, argillic advanced argillic, silicic. Anhydrite.	Breccias and breccia pipes in collapsed caldera.	Davies and Ballantyne, 1987; Welsh and McCulla, 1987; Plimer et al., 1988; Moyle et al., 1990

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Maragorik [Hb]		Mid Miocene to Pliocene subaerial basaltic to andesitic lavas and volcaniclastic rocks, overlain and intruded by Pliocene high-K andesite domes and lavas	Gold, electrum, luzonite, tetrahedrite, chalcocite, covellite, pyrite, marcasite, sphalerite, possible tellurides. Barite, dickite.	Low T advanced argillic — opal, kaolinite, alunite, ± barite, ± pyrite. High T advanced argillic — quartz, pyrophyllite, dickite, ± diaspore, ± alunite, ± pyrite. Argillic — smectite, pyrite, interlayered illite/smectite, + silica, ± kaolinite. Adularia.	NE trending structures and possible caldera collapse structures. Localised by intersection of E–W fractures with permeable volcanic units.	Corbett et al., 1991; Corbett and Hayward, 1994
Mount Kare [Lv]		Late Oligocene to Late Miocene calcareous quartz sandstones with intermediate porphyritic intrusions.	Gold, sphalerite, galena, silver, manganese. Vuggy structure probably after bladed calcite.	Propylitic alteration, clay, sericite, carbonate	NNE and NNW trending faults, along the margins of the intrusions.	Brunker and Caithness, 1990
Nena (Frieda River) [Hd]	32 Mt @ 0.58 g/t Au, 2.3% Cu, 3.6 g/t Ag, 0.22% As	Middle to late Miocene andesitic volcanics and sediments of Frieda Complex, intruded by andesite porphyries.	Pyrite, marcasite, melnikovite, enargite, luzonite, covellite, plus supergene covellite and chalcocite. Quartz, barite, alunite	District scale advanced argillic: quartz–kaolinite–alunite–pyrite natroalunite, native sulfur. Silicic, gypsum	Frieda Complex is remnant of an andesitic stratovolcano in New Guinea Mobile Belt between two major structures, the Frieda and Lagaip Fault Zones. Permeable volcaniclastic units.	Whalen et al., 1982; Rogerson and McKee, 1988; Hall et al., 1990; Bainbridge et al., 1994; Elliott, 1994
Porgera [Lsbv]	84.4 Mt @ 5.8 g/t Au 11.3 g/t Ag, 0.73 % Cu (54.2 Mt @ 5.7 g/t Au recoverable).	Miocene calc-alkaline intrusions and breccias in Cretaceous carbonaceous sediments.	Auriferous arsenical pyrite, sphalerite, galena, proustite, chalcopyrite, freibergite, pyrargyrite, electrum, gold, tellurides of Au, Pb, Hg, pyrrhotite, magnetite, hematite. Quartz, adularia, carbonate, zeolites.	Phyllic, propylitic, silicification, carbonation, sulfates, roscoelite.	Faults, breccia zones, lithological contacts, intrusive margins.	O'Dea, 1980; Fleming et al., 1986; Handley and Bradshaw, 1986; Handley, 1987; Welsh and McCulla, 1987; Henry, 1988; Australian Mineral Economics, 1988; Handley and Henry, 1990; Richards, 1990, 1992; Richards and Ledlie, 1993; Richards and Kerrich, 1993
Tolukuma [Lv]	0.44 Mt @ 17 g/t Au, 46 g/t Ag, plus 0.12 Mt @ 16 g/t Au indicated.	Pliocene basic/intermediate volcanics in faulted contact with Cretaceous metasediments.	Pyrite, arsenopyrite, marcasite, stibnite, sphalerite, galena, chalcopyrite, argentite, electrum, proustite–pyrargyrite, billingsteyite, freibergite, polybasite–pearcite, stromeyerite, uytenbogaartite. Quartz, calcite adularia, clay, manganosiderite, siderite, albite, chalcedony.	Regional propylitic, structurally controlled phyllic and argillic. Quartz–albite–illite–chlorite–carbonate; adularia replaces feldspar; shallow overprint of kaolinite, gypsum, illite–smectite.	Intersection of NNW trending faults with circular feature. Locally, fault contact between metamorphics and volcanics.	Langmead and McLeod, 1990, 1991; Corbett et al., 1994a

Umuna (Misima Island) [Lsvb]	56 Mt @ 1.4 g/t Au, 21 g/t Ag [alluvial 6200 kg] [mined 426000t @ 10 g/t Au].	Cretaceous metabasalts, calc-silicate units and carbonate schists. Miocene andesitic and dacitic stocks, sills and dykes, and volcanics elsewhere on island.	Pyrite, chalcopyrite, galena, chalcocite, sphalerite, tetrahedrite, pyrrhotite, covellite, native copper, gold, magnetite. Quartz, barite, calcite.	Carbonates, chlorite, epidote, white mica.	Veins and breccias along Umuna Fracture Zone (fault).	Fleming, 1987; Welsh and McCulla, 1987; Australian Mineral Economics, 1988; Clarke et al., 1990; Lewis and Wilson, 1990
Wafi River [Hbd]	18 Mt @ 2.5 g/t Au.	Cretaceous metasediments intruded by a mid Miocene dacitic to andesitic porphyry complex.	Gold, galena, sphalerite, pyrrhotite, chalcopyrite, pyrite, electrum, enargite, tetrahedrite. Quartz, carbonates.	Silicification, advanced argillic, argillic, phyllic, potassium silicate, propylitic.	Breccias and breccias infilling diatreme. E–W trending fractures and degree of schistosity development.	Leach and Erceg, 1990; Funnell, 1990; Erceg et al., 1991
Wapolu [Lbsd]	1.9 Mt @ 2.4 g/t Au.	Cretaceous amphibolite and leucogneiss tectonically overlain by ultrabasic rocks, overlain by slide block of brecciated metamorphics. Quaternary calc alkaline and peralkaline volcanic rocks nearby.	Minor sulfides, gold, marcasite. Quartz, adularia, barite, chalcedony.	Silica–carbonate assemblages, clays, chlorite, talc, minor argillic.	Tectonic and hydrothermal breccia at shallowly dipping metamorphic–ultrabasic contact (decollement structure). High angle cross faults.	Billington, 1987, City Resources Annual Report, 1988; Australian Mineral Economics, 1988; McNeil, 1990, 1994
Wau [Lsvd]	3.1 Mt @ 2.6 g/t Au, 13 g/t Ag	Hydrothermal breccia cutting Pliocene ignimbrite	Pyrite, marcasite, argentite, electrum, silver sulfosalts, sphalerite, tetrahedrite, galena, chalcopyrite. Quartz, calcite, manganocalcite, carbonates.	Post-ore quartz–calcite–kaolinite–smectite–illite assemblages. Alunite, cristobalite.	Low-angle extensional faults resulting from subsidence around maar volcano. Near major regional fault.	Sillitoe et al., 1984; Carswell, 1990
Wild Dog [Lvs]	8.0 Mt @ 5.9 g/t Au.	Miocene to Recent subaerial andesitic Nengmutka Volcanics and minor sediments.	Au, Au–Ag, Bi tellurides (calaverite, petzite, sylvanite), bornite, chalcopyrite, pyrite, sphalerite, selenides, native Te, chalcocite, molybdenite, minor stannoidite, melonite. Calcite, chalcedony.	Silicification, argillic, phyllic, propylitic. Pervasive carbonate. Epidote, pyrite, hematite, sericite, kaolinite, pyrophyllite.	Regional NNW trending faults cutting apparent caldera structures.	Lindley, 1987; Lindley, 1990; Welsh and McCulla, 1987; Johnson, 1988; Australian Mineral Economics, 1988; Shiga and Higashi, 1993
Woodlark Island–Boniavat [Lvs]	[370 kg Au, includes alluvial]	Mid to Late Miocene calcalkaline and shoshonitic andesitic volcanics and subvolcanic intrusions; minor dacites. Covered by Quaternary limestones.	Gold, pyrite, galena, manganese oxides. Chalcedony, quartz, minor manganocalcite.	Regional propylitic with locally developed clay–pyrite.	E and NW trending structures; margins of feldspar porphyry dykes.	Williamson, 1984; Russell and Finlayson, 1987; Russell, 1990; Corbett et al., 1994a

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Appendix (continued)

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Woodlark Island–Busai [Lvs]	1.2 Mt @ 2.9 g/t Au [230 kg Au]	Mid to Late Miocene calcalkaline and shoshonitic andesitic volcanics and subvolcanic intrusions; minor dacites. Covered by Quaternary limestones.	Pyrite, sphalerite, galena, chalcopyrite, gold, tetrahedrite, tennantite, Ag sulfosalt. Quartz, chalcedony, calcite, dolomite, ankerite, kutnahorite, rhodochrosite.	Regional propylitic, overprinted by phyllic — illite–chlorite or mixed layer illite–smectite. Pyrite, quartz, carbonates.	NW trending dilational shear zone intersection with circular structure (possible caldera?).	Williamson, 1984; Russell and Finlayson, 1987; Russell, 1990; Corbett et al., 1994a
Woodlark Island–Kulumadau [Lvs]	0.8 Mt @ 5.4 g/t Au [2500 kg Au]	Mid to Late Miocene calcalkaline and shoshonitic andesitic volcanics and subvolcanic intrusions; minor dacites. Covered by Quaternary limestones.	Gold, pyrite, sphalerite, galena, chalcopyrite, tetrahedrite, magnetite, hematite, marcasite, pyrrhotite. Chalcedony, quartz, calcite, ankerite, minor barite and adularia.	Regional propylitic overprinted by phyllic — illite–chlorite or mixed layer illite–smectite — pyrite–carbonate.	Intersection of NW and NNE trending structures.	Williamson, 1984; Russell and Finlayson, 1987; Russell, 1990; Corbett et al., 1994a

G. Philippines

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Acupan [Lvs]	[84 t Au]	Late Cretaceouss metasediments overlain by Paleogene and Neogene andesitic volcanics. Miocene basic to acid intrusions. Ore hosted by granodiorite, gabbro, and Recent diatreme.	Pyrite, marcasite, electrum, arsenopyrite, sphalerite, galena, chalcopyrite, bornite, tetrahedrite, pyrargyrite, stibnite, cinnabar, petzite, hessite, altaite, sylvanite, calaverite, coloradoite, famatinite, proustite, gold, hematite. Quartz, barite, anhydrite, rhodonite, rhodochrosite, calcite, adularia.	Potassic, sericitic, propylitic, silicification.	E and NE trending faults.	Callow and Worley, 1965; Boirat and Stephan, 1985; Philippine BMG, 1986; Cooke and Bloom, 1990; Mitchell and Balce, 1990; Sawkins et al., 1979
Antamok [Lvs]	3.2 Mt @ 5.37 g/t Au [257 t Au, 150 t Ag].	Miocene sediments and andesitic to basaltic volcanics intruded by Miocene diorite.	Pyrite, sphalerite, galena, chalcopyrite, gold, base metal tellurides, manganese oxides. Quartz, calcite, rhodonite, rhodochrosite, anhydrite.	Silicification.	NW trending veins in complex intersecting fault zone.	Fernandez et al., 1979; Philippine BMG, 1986; Mitchell and Balce, 1990
Co-o [Lv]	0.7 Mt @ 7.1 g/t Au (to 150 metres).	Tertiary andesitic lavas and fragmentals.	Pyrite, chalcopyrite, bornite, base metal sulfides. Quartz, barite.	Regional propylitic, illite–sericite near vein, oxidation to depth of 80 metres.	E–W trending vein system and cross cutting NNE faults.	J. Carlile, pers. commun., 1989; Mitchell and Leach, 1991
Exciban [Lv]		Mid Tertiary basaltic to andesitic volcanics and shallow marine sediments, with dacitic dykes.	Pyrite, sphalerite, galena, molybdenite, chalcopyrite, arsenopyrite, gold, Au, Bi, tellurides. Quartz, calcite, dolomite.	Carbonates, white clays.	NNE trending normal faults, fractures.	James and Fuchs, 1990; Mitchell and Leach, 1991

Hijo [Lvsb]	3.0 Mt @ 2.7 g/t Au [1.2 t Au, 0.5 t Ag].	Volcanic wacke and sediments unconformably overlying thick fragmental volcanic sequence.	Pyrite, marcasite, gold, arsenopyrite, chalcopyrite, sphalerite, galena. Quartz, jasperoid.	Silicification, argillic.	On major faults, and fault intersections. Related to andesitic porphyry intrusions.	Philippine BMG, 1986; J. Carlile, pers. commun., 1986; Mitchell and Leach, 1991
Indo Pacific [L?]		Miocene hornblende andesite and andesite porphyry.		Illite–pyrite, with bordering propylitic.	Projected contact between granodiorite and peridotite.	Mitchell and Leach, 1991
Kelly [Lv + H?]		Middle Miocene andesite–dacite flows, overlain by late Miocene conglomerates, wackes, pyroclastics. Diorite intrusion.	Stage 1. pyrite, chalcopyrite, sphalerite, magnetite, goethite, covellite, hematite, trace Mn oxide. Stage 2. pyrite, chalcopyrite, bornite, tetrahedrite–tennantite, sphalerite, galena, hematite, gold, chalcocite, covellite	Pervasive propylitic alteration of andesites: chlorite, epidote, tremolite–actinolite. Early illite + muscovite; later pyrophyllite + diaspore + alunite. Gypsum, anhydrite and calcite veins. Secondary biotite, trace kaolinite. Smectite. Tourmaline.	Parallel east-trending quartz veins.	Comsti et al., 1990
Lepanto [Hvd]	4.9 Mt @ 3.4 g/t Au [39 t Au, 159 t Ag].	Pliocene diorite intrusion. Late Miocene pyroclastics unconformably overlying Middle Miocene volcaniclastics.	Pyrite, chalcopyrite, enargite, luzonite, sphalerite, gold, tetrahedrite, tennantite, petzite, calaverite.	Silicification, acid leaching, advanced argillic, potassic. Barite, kaolinite, alunite, pyrophyllite, diaspore.	Veins and veinlets in fault controlled elongate breccia body, and along unconformity. Coincides with basement regional anticline. Stockwork adjacent to major porphyry copper deposit.	Gonzales, 1967; Domingo and Sato, 1982; Australian Mineral Economics, 1988; Hedenquist and Garcia, 1991; Mitchell and Leach, 1991; Garcia, 1991; Claveria and Hedenquist, 1994; Mancano and Campbell, 1994. Arribas et al., 1995
Mabuhay [Lvbsd]	0.6 Mt @ 3.0 g/t Au.	Oligocene–Miocene sediments intruded by andesites; hydrothermal breccia.	Pyrite. Quartz.	Silicification, clay–pyrite.	NW trending fault cutting anticline, fractures, breccias.	J. Carlile, pers. commun., 1989
Mapaso [Lsbv]		Pliocene andesitic clastics and lavas, andesite porphyry stocks and dykes, unconformably overlying Miocene wacke, basalt and limestone.	Pyrite. Quartz.	Illite–quartz–chlorite–pyrite core, extensive propylitic.	Phillippine Fault Zone.	Mitchell and Balce, 1990
Marian [Lv]	0.7 Mt @ 5.1 g/t Au [up to 1982, 1.4 t Au, 1.3 t Ag]	Tertiary alkaline intrusions into Oligocene andesitic/trachytic volcanics and sediments.	Pyrite, galena, sphalerite, goldfieldite, chalcopyrite, tetrahedrite, Au tellurides, electrum, hessite, altaite, orpiment, realgar. Quartz, calcite, rhodochrosite, chalcedony (upper levels).	Quartz, sericite, clay, chlorite. Pyritization.	NE trending faults, later N trending faults, veins on fractures and shears. Peripheral to porphyry copper ore zone.	Alapan, 1982; Sillitoe and Gappe, 1984; Australian Mineral Economics, 1988; Mitchell and Leach, 1991

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Appendix (continued)

Masara [Lsdv]	3.3 Mt @ 8.6 g/t Au [5.4 t Au, 2.8 t Ag]	Pre-Tertiary andesitic volcanics, and Miocene to Pleistocene andesitic volcanics. Diorite intrusion.	Miocene porphyry-related pyrite, chalcopyrite, magnetite, quartz. Pleistocene epithermal pyrite, chalcopyrite, galena, marcasite, sphalerite, electrum, gold. Quartz, carbonate.	Silicification, propylitic, phyllic–argillic, carbonation.	Intersecting WSW/NNW fault systems, shears.	Philippine BMG, 1986; Malicdem and Pena, 1987; Mercado et al., 1987b; Mitchell and Leach, 1991
Motherlode [Lsbv]		Pliocene andesitic clastics and lavas, andesite porphyry stocks and dykes, unconformably overlying Miocene wacke, basalt and limestone.	Pyrite, Au tellurides, minor azurite, malachite. Quartz, kaolinite.	Illite–quartz–chlorite–pyrite core, extensive propylitic, minor advanced argillic, pyrite, diaspore, alunite.	Phillippine Fault Zone. Depost above basement anticline. NNW trending veins with breccias.	Mitchell and Balce, 1990; Mitchell and Leach, 1991
Nalesbitan [Hvbd?]	8.0 Mt @ 3–4 g/t Au.	Pliocene–Pleistocene andesitic/dacitic volcanics, hydrothermal breccias.	Pyrite, chalcocite, bornite, enargite, native gold, digenite, idaite, hessite, Au–Ag tellurides. Rare barite.	Silicification enveloped by advanced argillic — quartz, kaolinite–alunite, sericite, diaspore. Locally enveloped by illitic and into illite–chlorite–mixed layer clays–smectite–calcite. argillic, propylitic.	Fault strands acting as hydrothermal fluid pipes.	J. Carlile, pers. commun., 1989; Mitchell and Balce, 1990; Sillitoe et al., 1990; Mitchell and Leach, 1991
Pao [Hd?]		Mid Tertiary alkaline volcanics.	Enargite, luzonite, pyrite, marcasite, gold, sinnerite, tennantite.	Advanced argillic–quartz–pyrite–kaolinite, overprinting chlorite–epidote–magnetite. Silicification.	Broad anticline intersected by axial faults. Permeable and impermeable horizons.	Kavalieris and Gonzales, 1990
Paracale [Lvsb]	1.8 Mt @ 9.6 g/t Au [5.5 t Au, 9.5 t Ag].	Miocene granodiorite intruded into peridotite.	Pyrite, sphalerite, galena, chalcopyrite, gold, hematite. Quartz.		Faults. Mineralization peripheral to porphyry copper.	Sillitoe and Gappe, 1984; Philippine BMG, 1986; Mitchell and Balce, 1990
Placer [Lsbv]	[Estimated 3 t Au]	Pliocene andesitic clastics and lavas, andesite porphyry stocks and dykes, unconformably overlying Miocene wacke, basalt and limestone.	Electrum, sphalerite, galena, chalcopyrite, pyrite, magnetite, hematite, tetrahedrite, tennantite, Au/Ag tellurides, realgar, orpiment, stibnite. Quartz, chalcedony, limonite.	Illite–quartz–chlorite–pyrite core, extensive propylitic. Calcite, sericite, kaolinite, smectite, chlorite. Pervasive silicification around the ore zone.	Stratiform mineralisation in sedimentary breccias. NNE striking fault of the Phillippine Fault Zone.	Aquino, 1983; Mitchell and Balce, 1990; Mitchell and Leach, 1991
Siana [Ldbs]	4.2 Mt @ 5.05 g/t Au, 12 g/t Ag [1955–67 4.8 t Au, 8 t Ag].	Carbonaceous limestone, and sediments overlying basaltic volcanics of early Miocene? age.	Pyrite, sphalerite, galena, chalcopyrite, gold, electrum. Quartz, carbonates.	Chloritic, carbonate, silicification. Illite, pyrite.	Disseminated and vein-form replacement, vein network in fault zone. Ore grades only in limestone breccia. Deposit above basement anticline.	Philippine BMG, 1986; Mercado et al., 1987a; Mitchell and Balce, 1990; Mitchell and Leach, 1991

H. Solomon Islands

Deposit [type]	Reserves [production]	Host geology	Mineralogy of ore	Wallrock alteration	Localizing controls	References
Gold Ridge [Ls]		Pliocene basaltic andesite pyroclastics unconformable on Miocene sediments	Pyrite, arsenopyrite, gold, (trace Cu, Zn), manganese oxide. Quartz, calcite, dolomite	Inner sericitic with local silicification, outer propylitic.	NNE trending fractures.	Walshaw, 1982; Shatwell, 1987

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