CLOSE RESEMBLANCE BETWEEN THE ACTIVE GEOTHERMAL SYSTEM AT WAIRAKEI, NEW ZEALAND, AND THE TERTIARY EPITHERMAL AU-AG DEPOSIT AT ROUND MOUNTAIN, NEVADA, U.S.A.—EXCEPT FOR AMOUNT, POSITION, AND TIMING OF AU MINERALISATION

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The present geologic environment of the central Taupo Volcanic Zone (Fig. 1; Cole, 1979; Rogan, 1982; Wilson et al., 1984) strongly resembles the mid-Tertiary geologic environment of the Toquima caldera complex (Fig. 2; Boden, 1986; Sander, 1988, in press; Mills et al., 1987)—voluminous, calc-alkaline, rhyolitic ash-flow tuffs erupted from non-resurgent calderas, with abundant hydrothermal systems localised by caldera margins, by active faults, and especially by spatial coincidence of faults and caldera margins. Prevolcanic rocks in the central Taupo Volcanic Zone consist mostly of greywacke, whereas in the Toquima complex they consist of Paleozoic sedimentary and metasedimentary rocks and Mesozoic granite. Hydrothermal activity in both settings followed caldera collapse by less than a million years.

Individual modern geothermal systems of the central Taupo Volcanic Zone, represented by the Wairakei system (Steiner, 1977; Mitchell, unpub. data), also closely resemble individual epithermal systems at the Toquima caldera complex, represented by the Round Mountain deposit (Sander, 1988; in press). These systems are similar with respect to host rocks, size, hydrology (or paleohydrology), wall-rock alteration, and probably fluid chemistry. Both systems were formed by upwelling hydrothermal plumes, guided by faults and/or formational contacts, that expanded into large reservoirs within subhorizontal, volcanic aquifers. The source of heat to drive convection in both systems is at least a few thousand metres below the reservoir (or paleoreservoir at Round Mountain). At both systems, the reservoir (paleoreservoir) of hot water at 250° or more is three to five kilometres in diameter and 400 m or more below the surface (paleosurface). Reservoir fluids sampled by wells at Wairakei are exceedingly dilute (few tenths of a weight percent equivalent NaCl, with low ΣC, ΣS; Henley et al., 1984; Hedenquist and Henley, 1985). Fluids at Round Mountain are inferred to have been dilute also (a few tenths of a degree freezing point depression, at most) and low in ΣC (inferred from phase equilibria and fluid inclusion crushing studies; Sander, 1988).

In the reservoirs of both systems, propylitic alteration is the earliest hydrothermal alteration and is represented by the equilibrium assemblage quartz-adularia-albite-chlorite-calcite-pyrite-rutile-epidote. Propylitic alteration is per-

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vasive and directly dependent in intensity on local reservoir temperature (paleotemperature). Fracture-controlled potassic alteration overprints propylitic alteration at both systems and consists of quartz-K-feldspar-'white mica'-calcite-pyrite-rutile. At Round Mountain, hydrothermal fluids forming propylitic and potassic alteration were similar in composition; the only difference was the rate of cooling. Slow cooling from 250°C produced propylitic alteration, with albite and K-feldspar in equilibrium, whereas fast cooling produced potassic alteration with K-feldspar forming at the expense of albite (Sander, 1988). At high levels in both systems, intermediate argillic and silicic alteration occurs. At Round Mountain, this high-level alteration is the latest major alteration type at paleodepths of 400 to 500 m and may have occurred at temperatures of less than 180°C (Sander, 1988). At Wairakei, solfataric alteration is forming above a depth of 100 m at temperatures less than 175°C (Steiner, 1977; Mitchell, unpub. data).

The modern and Tertiary systems differ, however, with respect to their amounts and styles of gold mineralisation. Four of the five altered areas at Toquima have been mined, are being mined, or are likely to be mined for their large quantities of gold and silver. The total amount of gold in the system at Round Mountain, the largest of the five areas, is about 280,000 kg. The vast majority of this amount occurs in the orebody that supports the present open pit mine, about 191 million tons at 1.2 ppm gold. Gold there occurs in sheeted sets of quartz-adularia-pyrite veins that cut densely welded tuff and in their stratabound equivalents in more permeable horizons. Total gold in the system also includes 10,000 kg mined selectively decades ago at average grades of several parts per million and similar amount of placer gold eroded from exposed veins. Gold that constitutes the present orebody was deposited several hundred metres below the paleosurface in what would be called the reservoir of an active system (Sander, 1988). Deposition at Round Mountain occurred at the transition from propylitic to potassic alteration, as temperatures declined from about 265° to less than 200°C within the deep reservoir. Quartz-K-feldspar-pyrite-calcite were stable together throughout the transition. This assemblage establishes firm limits on changes in pH and fO_2 that could have accompanied cooling, leaving simple temperature decline as the major cause of gold deposition (Sander, 1988). The most important cause of this decline was disruption of reservoir conditions due to intrusion of cold groundwater along sets of fractures that developed in response to regional tectonic stresses. Boiling or mixing with descending acidic waters was unlikely to have been important, based on fluid inclusion evidence and arguments developed from phase equilibria (Sander, 1988).

In contrast, gold is being deposited at Wairakei in economically insignificant amounts, but locally at high grades, at shallow levels within 'hot spring' discharge features and geothermal production equipment (Mitchell, unpub. data). Gold also is being deposited in near-surface environments at other Taupo hydrothermal systems (e.g. Brown, 1986, at Broadlands; Krupp and Seward, 1987, at Rotokawa), but in the deep reservoirs of none of them have rock samples that contain elevated grades for significant intervals been reported. (Krupp and Seward (1987) do hypothesize that significant mineralization underlies Rotokawa discharge zones, but do not test the hypothesis with analyses of rock samples from drill holes). In the near-surface environments, quartz, K-feldspar, pyrite, and calcite are not stable together. Deposition is reported to be in response to boiling and/or mixing with acidic, near-surface waters (e.g., Henley and Ellis, 1983), or, in the case of production equipment, throttling (flashing). Gold grades encountered deep within the reservoir at Wairakei are commonly low (<0.01 to 0.04 ppm). In only two of 225 samples analysed for gold at Wairakei, did the gold content of reservoir rocks exceed 0.04 ppm. The two higher gold values (0.12 and 0.13 ppm) occur in core taken from well 54, in and adjacent to steep geothermal gradients that suggest local mixing with cooler groundwater (Mitchell, unpub. data).

White (1981) suggested four possible reasons why active geothermal systems are not obviously forming orebodies on the scale of those contained in their fossil equivalents, the epithermal systems. By limiting our comparison to the well-studied Taupo and Toquima systems, we can rule out three of the four—incomplete knowledge of active systems, excessively 'leaky' active systems, and markedly dissimilar geologic settings. The remaining reason—gold is paragenetically late in hydrothermal systems and has not been deposited yet in active systems—is a good explanation and can be restated in terms of recent findings at Round Mountain and Wairakei. In waxing or steady-state (active) systems, gold remains in solution at reservoir conditions or is dispersed at low grades. Small amounts at high grades are deposited near the surface as relatively small amounts of fluid rise into localised discharge zones. In contrast, large quantities of gold at minable grades are deposited (and are more likely to be preserved) within deep reservoirs of waning systems where continually upwelling hydrothermal fluid is cooled by groundwater over a protracted mixing history. Indeed, epithermal deposits *are* 'fossil' geothermal systems, and it is during the process of being 'fossilised' by the inundation described above that they become ore deposits.

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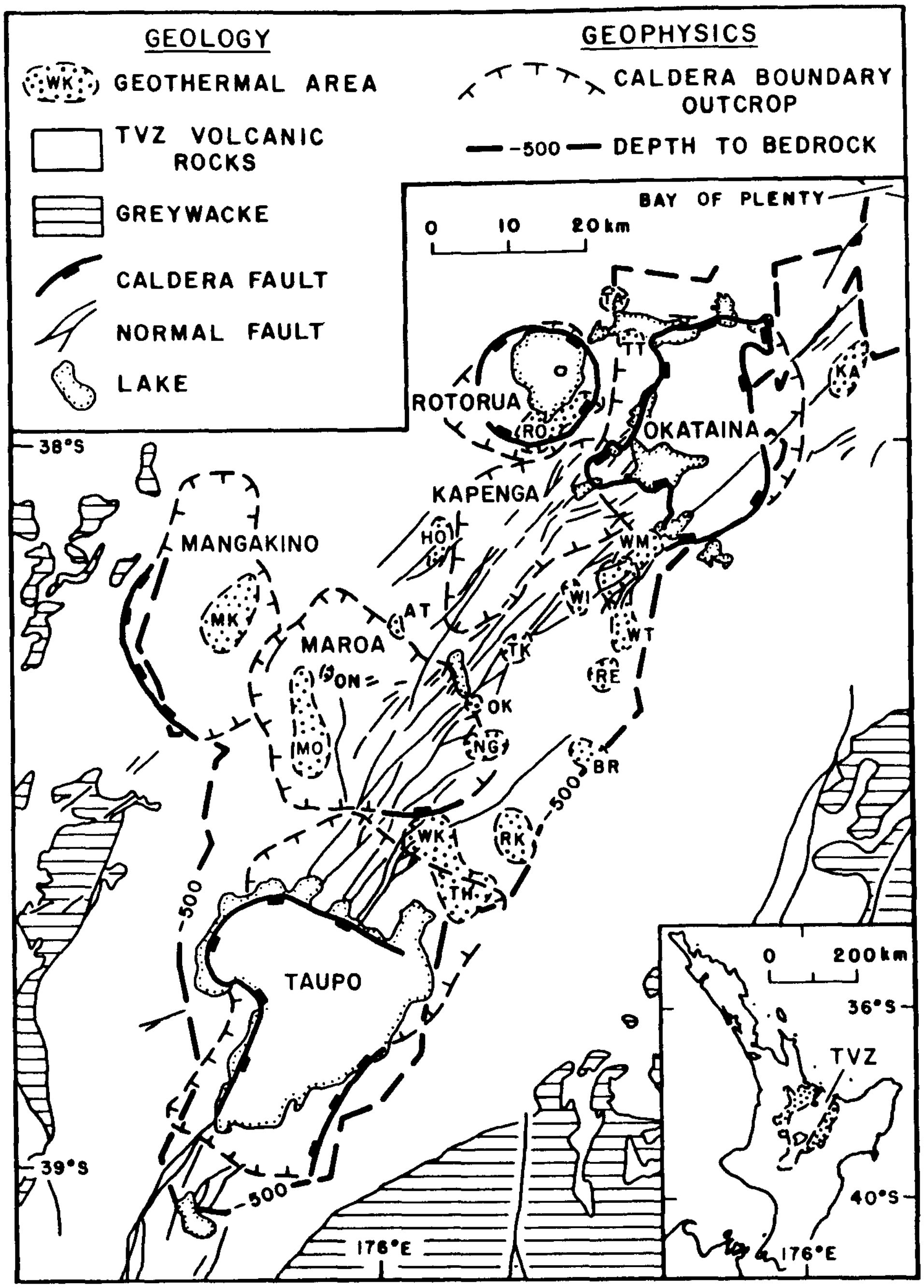

Figure 1: Location of the major caldera volcanoes and geothermal systems in the central Taupo Volcanic Zone. Stippled area in inset represents the approximate distribution of related volcanic rocks that occur outside the inferred graben. Sources of data from Wilson, et al., 1984; Mongillo and Clelland, 1984; and New Zealand Geological Survey, 1972. Geothermal areas: Atiamuri (AT), Broadlands (BR), Horohoro (HO), Kawerau (KA); Mangakino (MK), Mokai (MO), Ngatamariki (NG), Ongaroto (ON), Orakeikorako (OK), Reporoa (RE), Rotokawa (RK), Rotorua (RO), Tahara (TH), Taheke (TA), Te Kopia (TK), Tikitere (TT), Wairakei (WK), Waikite (WI), Waimangu (WM), and Waiotapu (WT).

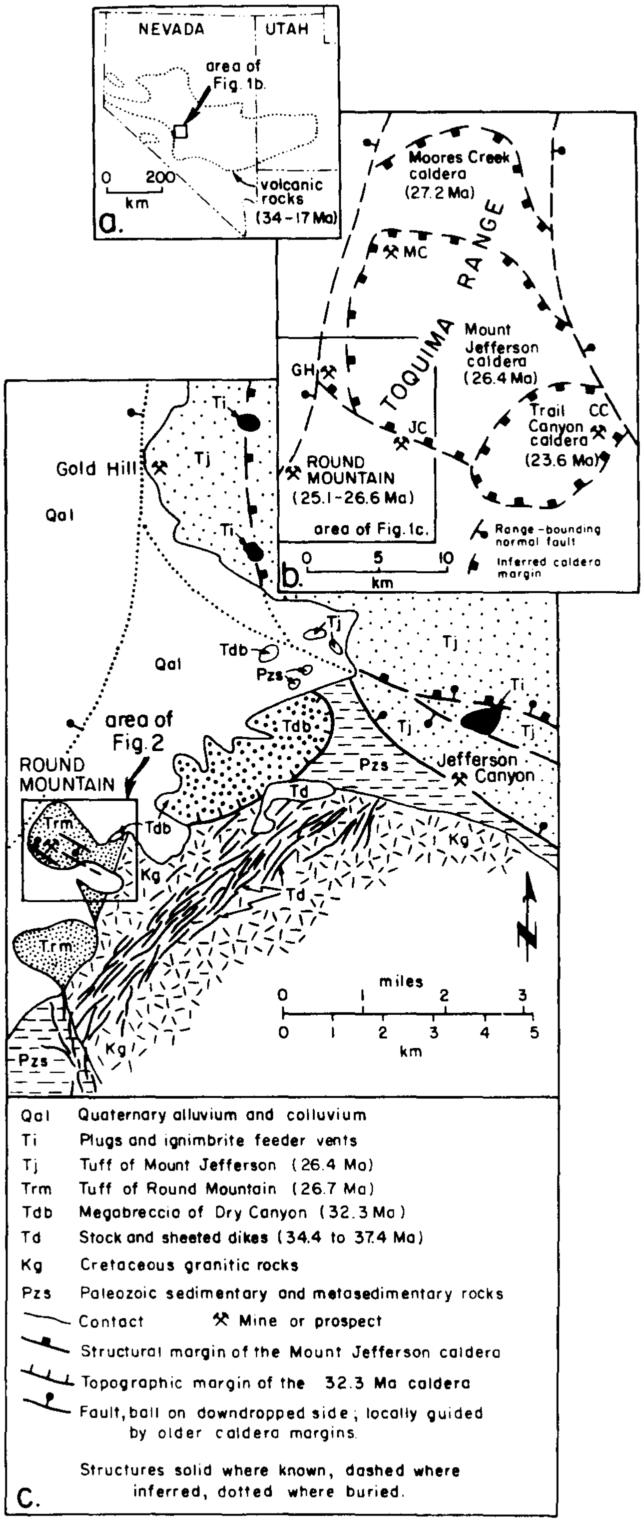

Figure 2: Location of the Round Mountain mine with respect to: a) Nevada, U.S.A.; b) the Toquima caldera complex (after Boden, 1986; other deposits: MC- Moores Creek, JC- Jefferson Canyon, CC- Corcoran Canyon, GH- Gold Hill); and c) geology of the western flank of the Toquima Range (after Boden, 1986, and Shawe et al., 1986).