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Composite geophysical model for continental volcanic-hosted epithermal mineralization: Cox and Singer mineral deposit models numbered 25b, 25c, 25d, and 25e

by

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Summary and Explanation

Cox and Singer (1986) have presented a catalog that concisely summarizes the geologic, geochemical, ore-grade, and total tonnage characteristics for various types of mineral deposits. The catalog contains numerous numbered models that are organized according to the lithotectonic association of each deposit model, and it is intended to aid in mineral resource evaluations under various programs in the U.S. Geological Survey. The lack of geophysical parameters with most deposits is a serious omission. Work is currently in progress (Hoover and others, 1992) that will summarize geophysical characteristics for models corresponding to the Cox and Singer (1986) volume. Our report presents a geophysical summary for a composite of four of the Cox and Singer models for deposits related to subaerial felsic to mafic extrusive rocks. These four models are of the type of deposits classified by Lindgren (1933) as epithermal. These deposits yield precious metals as their chief commodity.

The Cox and Singer mineral deposit models and model numbers included in the present geophysical composite are: 1) Creede epithermal vein (25b), 2) Comstock epithermal vein (25c), 3) Sado epithermal veins (25d), and 4) quartz-alunite Au-Ag (25e). The Creede and Comstock epithermal vein models (models 25b and c respectively) are of the type often referred to as *quartz-adularia*, *adularia-sericite* or *low-sulfur* vein systems in the literature (Silberman and Berger, 1985; Heald and others, 1987; Henley (1991). The Creede type is distinguished by higher chloride content. The quartz-alunite Au-Ag model, in comparison, is sometimes referred to as a *high-sulfur* system. The Sado epithermal vein model (the Takeno deposit, Japan, being a well described example: Soeda and Watanabe, 1981) is a type chiefly found in Japan, known for silver sulfosalts and tellurides, and usually hosted in thick volcanic sequences. In the western United States, examples of the Sado epithermal vein type of deposit include Bruner, Nevada, and Hayden Hill, High Grade, and Winters, California (Cox and Singer, 1986). We have found no geophysical data across this type of deposit and include it here somewhat arbitrarily. From the description in Soeda and Watanabe, 1981, and Cox and Singer, 1986, this deposit appears to have characteristics shared with other models of our composite, as well as some characteristics of the Cripple Creek Au-Ag-Te deposit type. Closely allied deposits to those within our composite model in terms of geophysical signature include polymetallic veins containing sulfide ores of various base metals, hot springs Au-Ag deposits, and epithermal deposits of Au-Ag-Te, such as Cripple Creek, Colorado. Cripple Creek, although peripheral to our composite model, was the locality of one of the earlier gravity and magnetic studies across an epithermal system (Kleinkopf and others, 1970).

Mineral deposit models 25b, 25c, 25d, and 25e are discriminated in the Cox and Singer volume (1986) largely by geochemical signatures, petrology, or alteration variations that reflect compositional characteristics of the basement or magmatic source region or both. The geophysical signature of such compositional variation is subtle and unlikely to be detected with confidence using current geophysical methods. For these models, the major petrologic and structural characteristics that geophysics may discern are quite similar; thus, a composite model appears appropriate. Exceptions will be found; for example, compared to models 25b, 25c, and 25d, higher fractions of metallic sulfides are expected at certain levels in the epithermal quartz-alunite Au-Ag (Cox and Singer model 25e; also known as an "acid-sulfate" type of epithermal mineralization). Higher sulfur content may be expressed as greater pyritization, which will affect the electrical resistivity and especially the induced polarization response significantly. We believe, however, that specific variations such as these can easily be incorporated into the thinking of users of the generalized composite model presented.

The composite model is presented on the following pages in a format developed by the Branch of Geophysics (Hoover and others, 1992). The model description in this format is mostly self-explanatory. However, we provide some comments below that may clarify certain aspects of the composite model.

We relied on numerous sources of data to describe the geologic environment of the ore deposit (part B in the following model). Many of these sources relate to regional surveys across volcanic centers of the western United States. On a broad scale, it did not appear important that some of these volcanic areas have no known or producing ore deposits. For data on environments elsewhere, Irvine and Smith (1990) and Allis (1990) are recommended reading. They provide excellent summaries of the exploration data across volcanic regions and across specific epithermal prospects or deposits located mostly in the western and southwestern Pacific areas, including examples from New Zealand and Japan.

For the western United States, in contrast to a rather extensive literature on regional geophysical characteristics of volcanic environments, there is a relative sparsity of open literature on geophysics on the scale of individual deposits (see the conceptual geologic model in figure 1). Thus, to describe the geophysics on deposit scale (part C in the following section), particularly for electrical methods, we rely chiefly on recent and well-described examples from New Zealand and Japan. Our figures 2 and 3 are drawn from the literature on the Hishikari deposit of Japan, and the Golden Cross deposit of New Zealand. The Hishikari deposit (figure 3) is associated with a contemporary hydrothermal system and shows anomalously low resistivities due to the electrically conductive hot pore water. Nevertheless, the deeper penetrating (lower frequency) data at the Hishikari deposit show a qualitative resistivity pattern (higher resistivity over the silicified vein system) typical of other deposits where the hydrothermal system has long been inactive (figs. 1 and 3). Figure 4 is from the southwestern United States, taken from recent work across part of the Turkey Creek Caldera (Senterfit and Klein, 1992). Negligible mineralization has been discovered here; the results illustrate that a signature similar to that over mineralized veins can be found in relatively barren ring-intrusive environments. This highlights a warning often repeated (Allis, 1990; Irvine and Smith, 1990) that geophysical signatures in an epithermal setting (and elsewhere) are non-unique and exploration must involve multidisciplinary efforts.

Figures 2 and 3 show dipole-dipole resistivity and induced polarization (I.P.) responses as well as resistivity from electromagnetic surveys. The difference in units of measure for I.P. in figures 2 and 3 reflects details in the method of measurement (Telford and others, 1976, p. 708). Both time-domain I.P. measurements (units of msec) and frequency domain measurements (units of percent, or alteratively, mV/V) are commonly reported for I.P. results. There is no simple transformation from one set of units to the other unless the experimental data is completely available, which is uncommon. Because of the aforementioned facts, and because the I.P response is dependent on the fraction of disseminated conductors (usually sulfides) that is probably quite variable between deposits, we have not included I.P. in our illustration of an electrical model of figure 1.

Discussions by Irvine and Smith (1990) and Allis (1990) agree with our view that gravity and magnetic signatures may be quite variable according to particular geologic circumstances of deposit. Thus, at this point we prefer not to present illustrations for gravity and magnetics because they may be generally unrepresentative. For specific cases see Kleinkopf and others, 1979 (Silver Cliff-Rosita Hills area, Colorado); Davis and others, 1971 (Tonopah district, Nevada); Kleinhampl and others, 1975 (Bodie District, California); Ratté and others, 1979 (Mogollon District, New Mexico); Criss and others, 1985, (Yankee Fork District, Idaho).

We point out in section C below that remote sensing spectral imaging methods, radioactivity (ground and low-level airborne), and electrical methods all produce relatively predictable signatures, although not unique, over epithermal deposits of the type discussed here. Of these, only electrical methods have capabilities for sensing beneath significant overburden. Examples in the figures thus focus on electrical methods. Although there are deposit-environment dependent variations in electrical properties, particularly induced polarization, the chief characteristic of high-resistivity over the silicified ore zone, accompanied by low-resistivity in the flanking border alteration zones is consistently noted in all examples encountered. Although the characteristic just mentioned appears consistent, it is not necessarily unique to ore-bearimg veins, as indicated in fig. 4.

In developing the size and shape of the model (in the following section D), we consider the critical elements to be: 1) the mineralized (secondary hydrothermal gangue and ore) vein system (or fracture-vein system), 2) the ore zone within the vein system, and 3) the volcanic country rock. We used data from Buchanan (1981) and Heald and others (1987) to establish averages or limits on these elements. The resulting model parameters apply when structural control for the deposit consists of a system of linear faults and fractures. An alternate model could assume structural control that is composed of a roughly cylindrical zone of fracturing and brecciation resulting from tectonic or magmatic doming or collapse. This alternate model is not applicable for the 16 deposits discussed by Heald and others (1987), which had an average length:width ratio of 2.5. These deposits were all contained within

Cox and Singer models 25a, 25b, 25c, and 25e. For horizontal dimensions of the deposit, we used the dimension of ore zones of districts by Heald and others (1987), which we interpreted as the vein systems, in contrast to separated ore concentrations (our definition of ore zones) found within the vein system.

In part E, we provide a summary table of petrophysical data for the model. Data here are based on average values or probable ranges for small field samples for a large number of samples. We attempted to use linear averages for density, seismic velocity, and porosity, and geometric averages for resistivity, and magnetic properties; however, some references do not specify their method of averaging. Also, we would nominally prefer ranges specified at the 80 or 90 percentile level (Klein and Johnson, 1983; Klein and Wynn, 1984), to exclude outliers from anomalous samples; again, most sources do not provide such data. Queries in part D indicate that few samples were used, or that we provide "guesses" based on experience or inspection of various in-situ measurements (cross-sections or pseudo-sections) from the literature. We have kept the references for section E separate from the general references to facilitate usage of the table.

Finally, our comments on remote sensing in part F of the model are generalized and brief because this discipline is in an experimental state of rapid and complex evolution (Watson, 1985; Watson and Raines, 1989). Remote sensing has considerable potential for air- or space-craft borne geologic mapping of lithology and structure, primarily in sparsely vegetated areas. The applicability of remote sensing even in vegetated areas has some promise; research in remote sensing encompasses the use of spectral anomalies caused by the modification of vegetation by mineralized or altered soil (Collins and others, 1983). Remote sensing utilizes reflected or emitted electromagnetic energy with wavelengths from about one m (radar) through the infrared band and into the visible band at wavelengths of about 1 micrometer (μm), and thus has negligible penetration in most terranes. Any information on buried lithology of structure comes from inferences on the distribution of surface materials as inferred from remote sensing images.

For volcanic-hosted epithermal deposits considered here, the most promising area of remote-sensing application on deposit or district scale is surface alteration mapping. Current spatial resolution of such mapping is about 30 to 130 m (Watson and others, 1990; Watson and Raines, 1989). Traditionally, the approach has been to utilize the anomalous absorption bands of ferric iron, water, and hydroxyl complexes in the reflected energy band of .45 to 2.40 μm (Rowan and others, 1974, 1977; Collins, 1978) to identify areas of surface oxidation ("limonite mapping" in Watson and Raines, 1989). More recently, improved airborne instrumentation has produced narrow-band spectral resolution; this plus improved spectral information from laboratory studies of rocks and minerals promises identification of spectra of minerals specific to alteration versus other sources of hydrated iron compounds (Hunt, 1979; Hunt and Ashley, 1979, Hunt, 1989, Watson and Raines, 1989). Watson and others (1990) have presented data from the Carlin deposit area (sediment-hosted epithermal Au deposit) that points to the possibility of mapping silicified zones in volcanic rocks. These data were acquired with an airborne system utilizing the infrared region and is a substantial departure from previous approaches in alteration mapping.

We have found few published case histories that actually fulfill the promise of alteration mapping by remote sensing across epithermal deposits or prospects, and none for structural application. We point to the Goldfield quartz-alunite Au-Ag district (Nevada), and the nearby Cuprite deposit which has served as a testing ground for many of the approaches to alteration mapping by remote sensing (Abrams and others, 1977; Rowan and others, 1974, 1977; Collins, 1978). There is also a valuable study of alteration mapping in the Marysvale volcanic-hosted epithermal district in Utah which is most noted for volcanogenic uranium (Podwysocki and others, 1983). A briefer study, but valuable because it is over a quartz-adularia style deposit, is reported by Magee and others, 1986, for the Steeple Rock District, southeast Arizona-southwest New Mexico. One of the few cases where a full generalized geologic mapping interpretation was presented is for the Rodaiquilar quartz-alunite precious metal district in Spain (Moore and Liu, 1990).

COMPOSITE GEOPHYSICAL MODEL OF CREEDE, COMSTOCK, SADO, GOLDFIELD AND RELATED EPITHERMAL PRECIOUS METAL DEPOSITS

COX AND SINGER MODELS:

Creede epithermal vein (25b), Comstock epithermal vein (25c), Sado epithermal veins (25d), and quartz-alunite Au-Ag (25e).

- Models with related geophysical characteristics (Cox and Singer, 1986): Au-Ag-Te veins (22b), Polymetallic veins (22c), Hot springs Au-Ag (25a).

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A. Geologic setting (Cox and Singer, 1986)

- Continental, usually mid-Tertiary, felsic volcanic centers.
- Faulted, fractured, and brecciated, andesitic to rhyolitic lavas and tuffs, hypabyssal, porphyritic dacite to quartz monzonite intrusions.
- Deposits occur in the edifice of volcanic morphologic features, often near edge of volcanic center, or above or peripheral to intrusions.
- Deposits commonly cluster along regional fault systems, fault intersections, and related fracture zones.
- Commonly associated with resurgent caldera structural boundaries.
- Commodities: Au, Ag, Cu, Pb, Zn

B. Geologic Environment Definition

- Gravity lows are common over thick silicic volcanic rock sequences and caldrons. The presence of a deep, low-density granitic batholith within the basement rocks may contribute to the gravity low. (Ratté and others, 1979; Plouff and Pakiser, 1972, Steven and Eaton, 1975; Cordell and others, 1985)
- Short-wavelength magnetic anomalies are common over volcanic terranes because of variable magnetizations and polarizations. This pattern may contrast with an area of moderate to intense alteration that will display a longer-wavelength low, often linear in the case of vein systems, caused by destruction of magnetite. Local highs may be associated with hypabyssal intrusions. (Ratté and others, 1979; Wynn and Bhattacharyya, 1977; Irvine and Smith, 1990, Doyle, 1990).
- Radiometric highs may occur from regional potassic enrichment associated with silicic magmatism. Oxidized exposures of argillic alteration patterns may also be apparent in multi-spectral remote sensing images. (Marsh and McKeon, 1983; Podwysocki and others, 1983; Duval, 1989; Watson, 1985)
- Regional seismic (Vp) velocity for volcanic sequences is low compared to basement rock. Seismic reflections are generally incoherent and noisy because of signal scatter by volcanic layers and structure (Hoffman and Mooney, 1984; McGovern, 1983, Ackermann and others, 1988).
- Regional resistivity is generally low for weathered and altered andesitic to rhyolitic volcanic rocks as compared to high resistivity typical of buried intrusions or uplifted basement or carbonate sedimentary rocks (Frischknecht and others, 1986; Long, 1985; Senterfit and Klein, 1992)

C. Deposit Definition

- There are no consistent geophysical signatures to directly identify epithermal vein mineralization. However, several geophysical characteristics are diagnostic of favorable structures and alteration. These characteristics are best measured using closely spaced ground measurements. (Irvine and Smith, 1990; Allis, 1990; Doyle, 1990; Johnson and Fujita, 1985; Middleton and Campbell, 1979; Senterfit and Klein, 1992; Zonge and Hughes, 1991)
- Gravity highs will be caused by felsic intrusions within flow or tuff sequences, by structural highs of basement or carbonate rocks within the volcanic sequence, or by silicification of otherwise relatively low-density volcanic rock. Weak, local lows may follow zones of brecciation or fracturing. Weak, local highs may be found along dense silicic vein systems hosted by more porous volcanic rocks. On deposit-scale

investigations, high-precision gravity to resolve anomalies of the order of 1 mgal (to 0.5 rarely) would be required. (Irvine and Smith, 1990; Allis, 1990; Criss and others, 1985; Kleinhampl and others, 1975; Ratté and others, 1979; Locke and De Ronde, 1987)

- Magnetic lows will be associated with alteration; however, discriminating such lows from the background may be difficult on a deposit scale.
- Inferences from both magnetic and gravity signatures may be complicated by the effects of topography, spatial variability in alteration, and hidden faults, dikes and plutons.
- Radiometric anomalies are expected across epithermal veins because of potassic alteration, which is common in the upper levels of veins. (Marsh and McKeon, 1983; Pitkin and Long, 1977).
- Resistivity highs flanked by resistivity lows are characteristic of a simple and idealized quartz-adularia vein system with associated argillic to propylitic alteration. However, there may be geologic structures and petrologic complications that distort this ideal picture. More generally, resistivity lows will be associated with: 1) sulfides when concentrated and connected at about 5-percent volume or more, 2) argillic alteration, and 3) increased porosity related to wet, open fractures and brecciation. Resistivity highs will be associated with zones of silicification, intrusion, or basement uplifts. (Senterfit and Klein, 1992; Zonge and Hughes, 1990; Irvine and Smith, 1989; Allis, 1990; Doyle, 1990, Frischknecht and others, 1986)
- High induced polarization (IP) will follow zones of disseminated conductors such as metallic sulfides in veins and pyritization in veins, altered zones, or host (Zonge and Hughes, 1991). Other sources of high IP include crystal lithic tuff and certain distributions of clays and zeolites (Sumner, 1976, p. 58).

D. Shape and size of deposit (Buchanan, 1981; Heald and others, 1987):

Element	Shape	Average Size (Range)
Vein system, or district	lenticular, interlaced	3 km (1-9 km) width, 7 km (2-21 km) length, probably 2-4(?) km depth extent.
Ore deposit	lenticular, interlaced, discontinuous	width and length is highly variable, but a fraction (0.2?) of vein system; vertical extent of ore averages 500 m; paleodepths to initiation of ore (relative to original surface) is about 400 m (200 to 700 m).
Alteration halo	generally symmetric with the vein system, but wider on hanging wall, and possibly modified by syn- or post-vein faulting; siphon shape in cross-section, narrowing with depth; capped with siliceous sinter that is often missing because of erosion.	width is of the order of 2 or 3 times the width of the vein system, roughly centered linearly on the vein system, wider on hanging wall if appreciable dip is present.

E. Physical properties

Bracketed values are averages. Source references are indexed with trailing letters. Queried values are guesses.

Property [units]	**Deposit** [silicic - potassic vein]	**Alteration** A: argillic (illite-kaolin) P: propylitic (chlorite-minor kaolin)	**Volcanic host**
1. density [g/cm^3]	quartzite 2.6 (*a*)	?	rhyolite [2.5] (*a*) andesite [2.7] (*a*) tuffs 1.5-2.5 (*b*)
2. porosity [percent]	2-5?	5-20?	3-50 (*i* & *j*) (fig.22 in *j*)
3. susceptibility [emu-cgs/cm^3]	negligible?	negligible?	rhyolite [.3 x 10^{-3}] (*c, d*); undifferentiated Tertiary volcanic rocks: (Arizona) .05 x 10^{-3} - 5 x 10^{-3}, (northern Montana), [0.7 x 10^{-3}] (*f, g*).
4. remanent magnetization [cgs-emu/cm^3]	negligible?	negligible?	undifferentiated Tertiary volcanic rocks: (Arizona): .005 x 10^{-3} - 100 x 10^{-3}, (northern Montana): [11.1 x 10^{-3}] (*f, g*).
5. resistivity [ohm-m]	high; greater than 1,000?	A: low; less than 10? P: low; less than 100?	Tertiary volcanic rocks (Arizona): 20-2,000 (*e*).
6. Induced polar-ization (I.P.) [percent-frequency effect:PFE]	?	PFE > 10 with about 2 or 3-% disseminated sulfides (*h*).	Tertiary volcanic rocks (Arizona): < 5 (*h*).

7. seismic (Vp) velocity [km/s]	quartzite 5.37-5.63 (*i*)	lower?	wet tuffs: 2.61-3.92 (*i*); rhyolite: [3.27] 2.94-4.90 (*i*); volcanic breccia: 4.22 (*i*); (measurements at 0.1 kb; anisotropy is high (17-26% in some rhyolites with >10 (measured 18-32%) porosity.
8. radio-elements K [%] U, Th [ppm]	K: high? U, Th ?	K: high? U, Th ?K:	moderate to low? U,Th ?

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F. Remote sensing characteristics

- In areas of low to moderate cover, remote sensing images in the visible and infrared bands can be processed to identify exposures of oxidized argillic alteration, and anomalous silicification, although there is considerable room for non-unique discriminations for moderate to low-spectral-resolution systems (Rowan and others, 1974, 1977; Podwysocki and others, 1983; Watson, 1985, Watson, 1990, Raines and Watson, 1990). The basis of such discrimination are the following:
- a) In the visible through infrared wave-spectrum, ferric iron, water, and hydroxyl complexes have narrow (about 0.1 μm) and characteristic reflective minimums between 0.4 and 2.4 μm (Rowan and others, 1977).
- b) Silica-rich assemblages have emissivity minimums near 8-10 μm (Watson and others, 1990).
- c) These reflective and emissivity minimums can distinguished with moderate resolution (0.1 μm) airborne- or spacecraft spectral scanners.
- There are often distinctive spectral waveforms for other minerals and mineral assemblages (Hunt, 1989), that require high-resolution (.01 to .001 μm), spectral scanners, currently available only on airborne systems (Watson and Raines, 1989).

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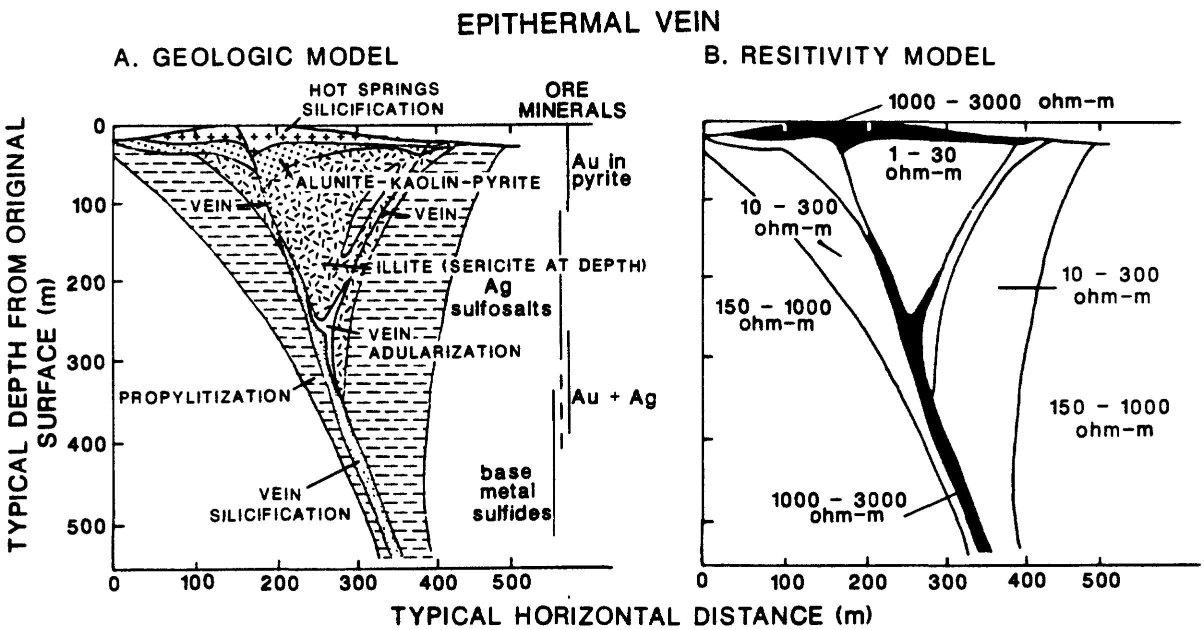


Fig. 1 -- Cross-section of a conceptual model for an epithermal vein. A) Conceptual model of alteration for an epithermal vein (adapted from Buchanan, 1981; Irvine and Smith, 1990); B) Inferred Electrical resistivity for the model shown in (A).

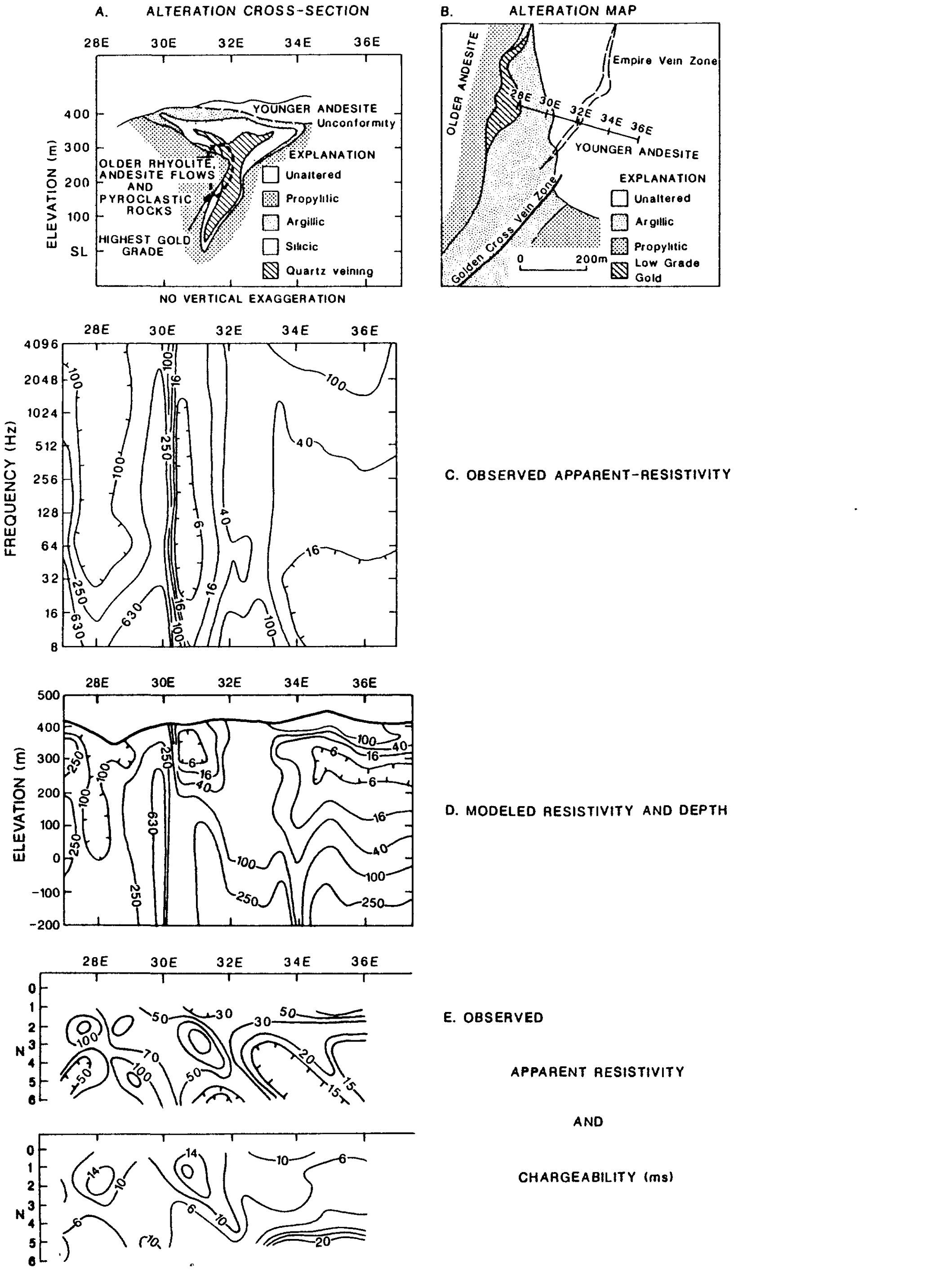
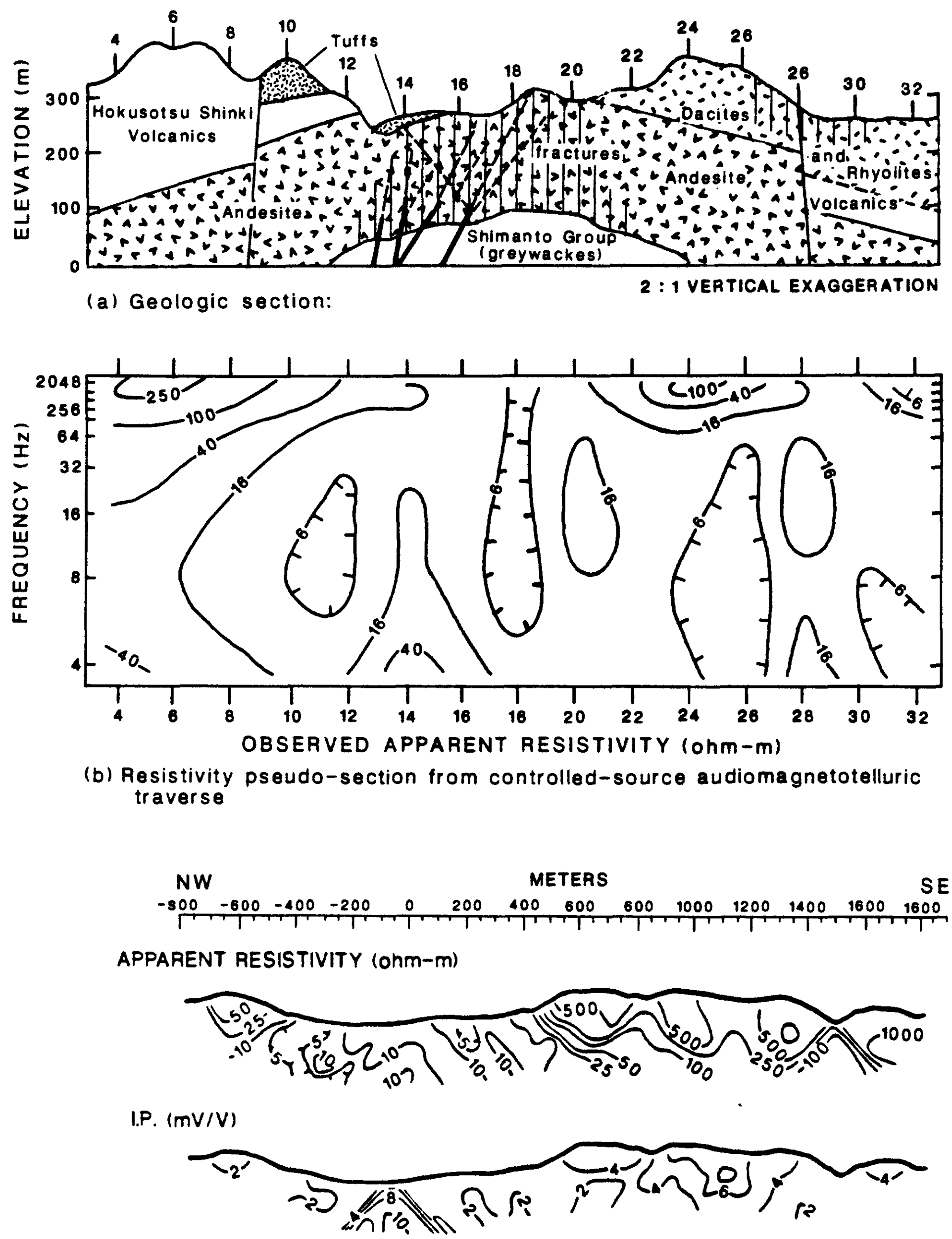


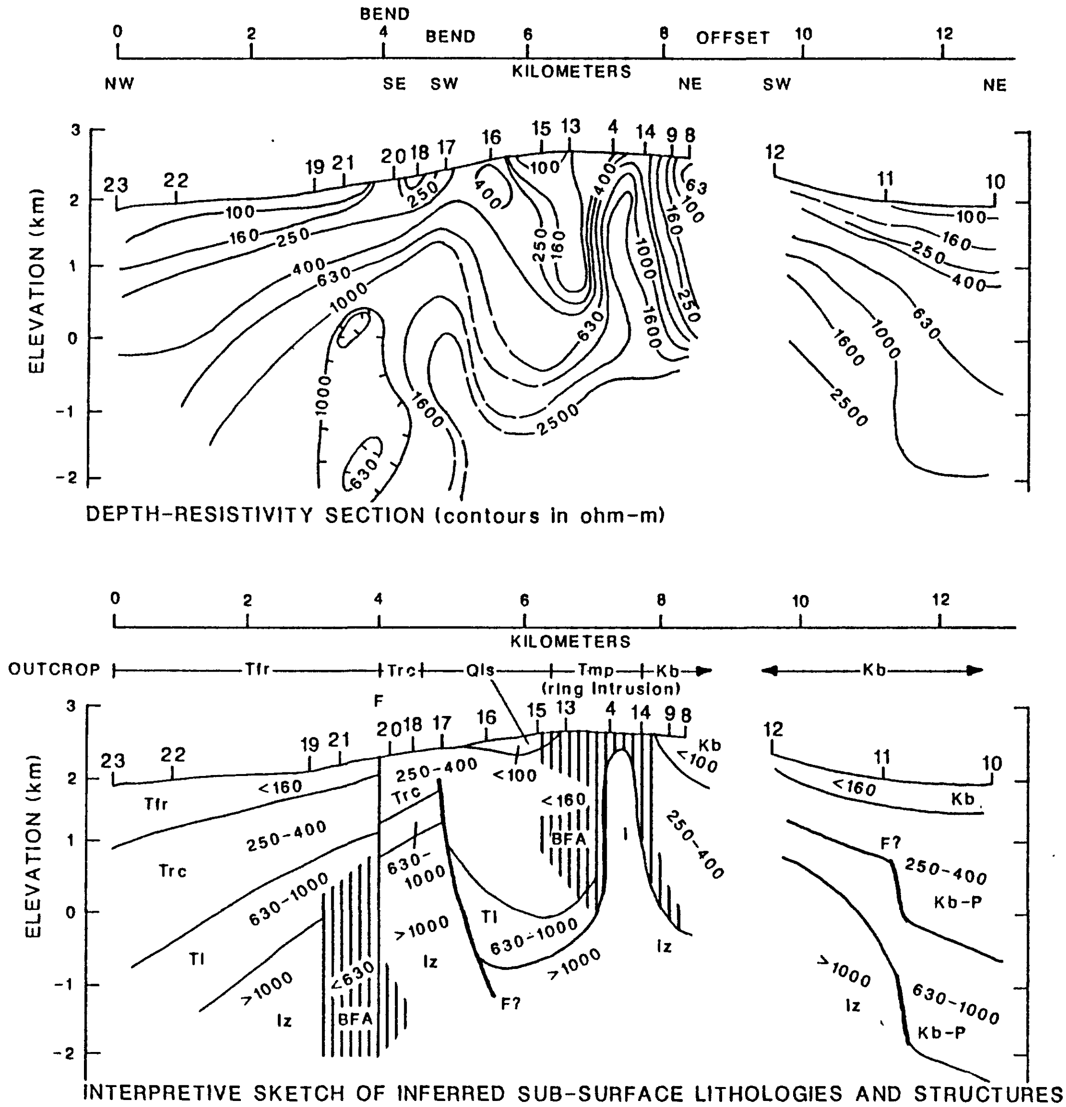
Fig. 2 -- Controlled source electrical surveys across the Golden Cross epithermal vein system on the northern coast of North Island, New Zealand (adapted from Zonge and Hughes, 1991; Allis, 1990; Hay, 1986). A) Simplified alteration cross-section. B) Simplified alteration map and location of electrical traverses. C) Pseudo-section of apparent resistivity vs. frequency from controlled-source audio-magnetotelluric (CSAMT) traverse. D) Depth-resistivity section resulting from inversion of data (C). On (C,D), shallow low-resistivity (< 40 ohm-m) marks alteration overlying high-resistivity (> 250 ohm-m) silicified zone. The vein system is bordered by moderate lows (< 100 ohm-m) indicating the lateral alteration halo. The andesitic to rhyolitic host rocks show resistivities varying from about 5 to 500 ohm-m. E) Pseudo-sections of apparent resistivity and induced polarization (changeability) vs. dipole number (N) from dipole-dipole traverse. Resistivity patterns in (E) are qualitatively similar to C when the diagonal correlations inherent in dipole-dipole pseudosections is considered. IP is relatively high (> 14 ms at dipole 31E) in the upper alteration zone and decreases in the silicified zone.

HISHIKARI EPITHERMAL GOLD DEPOSIT, KYUSHU, JAPAN



(c) Resistivity and induced polarization pseudo-sections from dipole-dipole traverse using 50m dipoles with maximum separations (n) of 6.

Fig. 3 -- Data from controlled-source electrical traverses across the Hishikari epithermal vein system in Kyushu, Japan (adapted form Zonge and Hughes, 1991; Allis, 1990; Kawasaki and others, 1986). (A) Simplified geologic section across the deposit. B) Pseudo-section of apparent-resistivity versus frequency across the deposit from CSAMT. C) Pseudo-section of apparent resistivity and induced polarization response from dipole-dipole traverse. The Hishikari deposit is within an active geothermal system thus resistivities are everywhere reduced because of conductive (enhanced temperature and salinity) pore waters (compare fig.2). Gold mineralization is found in veins in the Shimanto Group. Resistivity variations are associated with variable porosity, alteration, and temperature, with low resistivity found with the upper part of the fracture-vein system, and higher resistivities found at depth where pore-space filling (silification) becomes more important. High IP values across the vein generally correspond to high resistivity. Similar to fig.2, there is symmetry in the IP response, but the higher values, contrary to fig.2, are seen in the deeper part the vein system.



EXPLANATION

Qls	Landslide breccia	Tmp	Dacite porphyry
Trc	Welded tuffs	I	Intrusive rocks
Tfr	Moat lavas and tuffs	Iz	Intrusive rocks and/or Proterozoic basement
Tl	Welded tuffs and lava flows		
Kb	Sedimentary rocks (mostly clastic rocks of Cretaceous age)		
Kb-P	Sedimentary rocks (mostly carbonate rocks of Cretaceous and/or Paleozoic age)		
F	Fault		
BFA	Brecciation, faulting and alteration		
22	AMT station		

Fig. 4 -- Audio-magnetotelluric data across part of a caldera ring-fracture-intrusion system, Turkey Creek caldera, southeast Arizona. A) Depth-resistivity section from composited 1-D modeling results of natural source audio-magnetotelluric (scalar AMT) data across the northern structural boundary of Turkey Creek Caldera, a middle-Tertiary volcanic center in southeastern Arizona (adapted from Senterfit and Klein, 1992). There are no major mineral deposits known to occur along this traverse, although there is evidence of prospecting. A) Resistivity-depth section formed by contouring composited 1-D inversions at each sounding. B) an interpretation of the electrical section. High-resistivities at stations 4 and 14 are related to a ring-intrusion, with bordering lows inferred to be in part related to alteration. The pattern near this intrusion is very similar to that observed and inferred for epithermal vein deposits (figs 2 and 3). The sources of the resistivity patterns on (A) are related to similar processes that form a mineralized vein system, high-resistivity associated with silicic intrusion and bordering alteration caused by hydrothermal action after intrusion. Although there is the possibility that undiscovered deposits exist here, a key conclusion is that the electrical signature of epithermal systems may not change greatly between barren and mineralized systems.