EL CAPITAN PRECIOUS METALS, INC.
REPORT ON EL CAPITAN GOLD-PLATINUM PROJECT,
INCLUDING MEASURED RESOURCE CALCULATION,
LINCOLN COUNTY, NEW MEXICO

by

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APPENDIX 4

HYDROTHERMAL GOLD-PLATINUM GROUP METALS DEPOSITS

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HYDROTHERMAL GOLD-PLATINUM GROUP METALS

The history of mining of platinum group elements (PGE) is dominated exclusively by production of platinum and palladium with gold, chrome, nickel, copper and lesser PGE elements from magmatic segregation deposits in large ultramafic/mafic layered intrusions, mainly of Precambrian age. As a result, the majority of geologists are of the opinion that Pt, Pd are relatively chemically inert, extremely limited in geochemical mobility and restricted only to high temperature magmatic deposits of ultramafic/mafic composition. Beginning in the early 1970's, however, a few detailed studies provided surprising evidence that Pt, Pd could be mobilized in low temperature hydrothermal or aqueous fluids outside of ultramafic/mafic rocks (Stumpfl and Tarkian, 1976) and a gradual increase in multi-element analyses began to further demonstrate that significant Pt, Pd are present in a few deposits of classic hydrothermal character.

Today, significant Pt, Pd-bearing deposits, principally with Cu or U, have been identified in several geological environments completely removed from ultramafic/mafic rocks. Studies of these deposits have demonstrated unequivocally that these metals were transported and deposited from hydrothermal fluids of either magmatic or meteoric origin; in the largest deposits, Pt, Pd now constitute important economic metals. Of particular interest is the merging of results from geologic field studies and laboratory experiments that show that the hydrothermal fluids are of a special type: oxidized (high Eh) and acid (low pH) brines that transport Pt, Pd in a cogenetic association with Au in chloride chemical complexes.

The following are the major estimated reserves of platinum and palladium (after Macdonald, 1987):

	Age, Ma (millions of years ago	Grade Pt+Pd+Au(oz/t)	Total ounces Pt+Pd+Au
Bushveld Complex, South Africa	2,100	0.25	1,480,000,000
Great Dike, Zimbabwe	2,500	0.15	190,000,000
Noril'sk, USSR	250	0.12	150,000,000
Stillwater, Montana, U.S.A.	2,700	0.72	53,000,000
Sudbury, Canada	1,700	0.03	6,000,000

Lesser PGE deposits are known in serpentinites formed from altered ultramafics (Ural Mountains, USSR; Hitura, Finland), placers from ultramafic sources (Urals, USSR) and paleoplacers (Witwatersrand, South Africa); total PGE production as a by-product with gold from Witwatersrand is estimated at 290,000 ounces (Macdonald, 1987).

Studies of hydrothermal Pt, Pd deposits have been conducted by Mihalik and others (1974), Stumpfl and Tarkian (1976), McCallum and others (1976), Finch and others (1983), Werle and others (1984), Mutschler and others (1985), Borg and others (1987), Macdonald (1987), Lechler and others (1988), Eliopoulos (1991), Mernagh and others (1994) and Tarkian and Koopmann (1995). In 1976, Stumpfl and Tarkian concluded, "Evidence from the magmatic, metamorphic and sedimentary environments reveals one coherent and continuing theme: the mobility of platinum group elements at low (hydrothermal) temperatures in aqueous solutions". Laboratory research has now resulted in a comprehensive understanding of the thermochemistry of Pt, Pd solubility, transport and deposition under a range of hydrothermal fluid conditions through the work of Mountain and Wood (1987, 1988), Wood and others (1989, 1991, 1992) Sassani and others (1990), McKibben and others (1990), Jaireth (1992), Gammons and others (1993a, 1993b, 1995, 1996) and Evstigneeva and Tarkian (1996).

Classification of hydrothermal platinum, palladium deposits

The following if a preliminary classification of those hydrothermal platinum, palladium deposits and occurrences described to date in the geologic literature, including three deposits in Clark County, Nevada, all of which have been studied by the author.

HYDROTHERMAL PLATINUM, PALLADIUM DEPOSITS

A) FRACTURE/SHEAR ZONE HOSTED; PROBABLE FELSIC INTRUSION RELATED
    New Rambler, Wyoming; production: 171 oz Pt (0.13 oz/t Pt), 450 oz Pd (2.4 oz/t Pd)
    Bunkerville, Clark Co., Nev.; resource: 3,600 oz Pt (0.18 oz/t Pt), 2,900 oz Au (0.25 oz/t Au)
    Goodsprings, Clark Co., Nev.; production: 506 oz Pt, 762 oz Pd, 90,508 oz Au
    Crescent Peak, Clark Co., Nev.; from 3 cm vein: 26.9 oz/t Pt, 0.26 oz/t Pd, 5.4 oz/t Au
    Messina, South Africa; selected vein: 0.7 oz/t Pt, 3.7 oz/t Pd, 0.02 oz/t Au

B) PORPHYRY COPPER HOSTED
    1. Alkaline pluton hosted
        Allard stock, Colorado; Cu ore (13%): 0.05 oz/t Pt, 0.03 oz/t Pd, 0.02 oz/t Au
        Copper King Mine, Montana; Cu ore (16%): 0.25 oz/t Pt, 0.12 oz/t Pd, 0.009 oz/t Au
        Sappho, British Columbia; Cu ore (6%): 0.03 oz/t Pt. 0.02 oz/t Pd, 0.014 oz/t Au
    2. Calc-alkaline pluton hosted
        Skouries, Greece; mineralized-altered porphyry: 0.006 oz/t Pd, 0.09 oz/t Au
        Santo Tomas II, Philippines; reserves: 300,000 oz Pt (0.001 oz/t Pt); 1,700,000 oz Pd (.005 oz/t Pd); 19,000,000 oz Au (0.06 oz/t Au)

C) SEDIMENT HOSTED
    1. Carbonaceous shale hosted
        Kupferschiefer, Germany-Poland; 1 cm layer: 0.32 oz/t Pt (over 1.5 km strike length), up to 29.4 oz/t Pd, 88.2 oz/t Au
        Zambian Copperbelt, Zambia-Zaire; production to 1958: 50,000 oz PGE
        Kalahari Copperbelt, Namibia; Cu ore: up to 0.004 oz/t Pt. 0.02 oz/t Au
    2. Unconformity related
        Coronation Hill, Australia; resource: 50,400 oz Pt. (0.008 oz/t Pt), 176,400 oz Pd (0.028 oz/t Pd), 1,260,000 oz Au (0.20 oz/t Au)

Fracture/shear zone hosted; probable felsic intrusion related Pt, Pd deposits

This class includes small Pt, Pd occurrences in Cu-Au sulfide ores hosted in open space fillings in fracture or shear zones. The New Rambler and Bunkerville deposits are hosted in Precambrian rocks and occur with abundant felsic dikes and pegmatites; the Goodsprings area includes felsic plutons cutting Devonian host carbonates – the nearest pluton outcropping 5 km from the principal deposit. The above associations indicate that hydrothermal mineralization in these deposits is related to felsic intrusions.

At the **New Rambler**, Wyoming deposit, ten Pt-bearing Te, Bi, Sb minerals and electrum occur with chalcopyrite, pyrrhotite, pyrite, sphalerite and pentlandite. Mineralization was deposited from 270°-400°C fluids that produced three alteration assemblages of increasing intensity: propylitic, quartz-sericite-pyrite, silicification (McCallum and others, 1976). Evidence for hydrothermal mineralization includes: 1) fracture filling, 2) close association between ore and alteration, 3) Pt:Pd ratios characteristic of hydrothermal and not magmatic environments (Pt:Pd = 1:18 and Pt:Pd:other PGE = 100:1800:1; magmatic ratios typically average Pt:Pd = 1:1.5 and Pt:Pd: other PGE = 1:2:1). McCallum and others (1976) concluded that (magmatic) hydrothermal fluids leached metals from gabbro source rocks.

At **Bunkerville**, Clark Co., Nevada, located 100 km northeast of the Eldorado project, unidentified Pt, Pd and Au minerals occur with chalcopyrite, pentlandite, pyrrhotite, pyrite, polydymite ($NiNi_2S_4$), sphalerite and molybdenite in an alteration assemblage of hornblende, carbonate, quartz, chlorite, epidote, kaolinite and sericite. Beal (1965) concluded that (magmatic) hydrothermal solutions remobilized metals from mafic rocks.

At the Boss Mine, the principal Pt, Pd deposit in the **Goodsprings**, Clark Co., Nevada district, located 55 km west of the Eldorado project, Pt, Pd and Au minerals occur in veinlets and disseminations in bitumen (see Appendix T) in a quartz-plumbojarosite ($Pb(Fe(SO_4)_2(OH)_6)_2$)-Fe oxide assemblage with colloidal sulfates, chlorides, oxides and silicates, and elevated Fe, Ca, Cu, Pb, Ni, Ti and V (Jedwab and others, 1999). It appears that magmatically derived hydrothermal fluids were responsible for mineralization.

At **Crescent Peak**, Clark Co., Nevada, located 20 km southwest of the Eldorado project, a 3 cm Pt-Pd-Au-bearing Cu-Pb-Zn-Ag quartz vein includes pyrite, chalcopyrite, galena, sphalerite, covellite and acanthite; Lechler and others (1988) have reported native gold, ferronickel platinum (Pt_2FeNi) and iridian osmium (Os, Ir). The metalliferous quartz vein cuts altered biotite granodiorite which is a marginal facies of a zoned Mesozoic (?) stock with a granite core. The granodiorite host exhibits four potassic, two quartz-sericite and one clay hydrothermal alteration phase. The apparent paragenetic relations are: 1) early-stage widespread K-feldspar-muscovite pegmatization, 2) widespread biotite, pyrite, 3) biotite, Mg-chlorite overlapped by quartz-sericite with pyrite, chalcopyrite, covellite veinlets, 4) the above assemblage with pyrite, galena, sphalerite veinlets and 5) latest-stage clay altered quartz-sericite immediately adjacent to the Pt-Pd-Au-bearing quartz vein. The Pt-Pd-Au-bearing quartz vein appears to represent late stage, lower temperature deposition from a hydrothermal fluid which differentiated within a fairly typical calc-alkaline pluton hosted porphyry copper system.

Porphyry copper hosted

Porphyry copper deposits occur within or in roof rocks above felsic plutons. The two major plutonic rock categories based on chemical composition are alkaline, and calc-alkaline (a sub-division of subalkaline). The alkaline-subalkaline divisions are based on relative amounts of $K_2O + Na_2$) and SiO_2 as shown in Figure 1, below, from Philpotts (1990). Alternatively, alkaline plutons have been defined as those which have $K_2O + Na_2O > 0.3718$ $SiO_2 - 14.5$ (Muschler and others, 1985). The felsic alkaline rocks are distinguished by having relatively lesser SiO_2 (60%) and CaO (1%) and relatively higher Al_2O_3 (20%), K_2O (6%), Na_2O (7%), and Fe_2O_3 (3%). In contrast, the felsic calc-alkaline subdivision has relatively higher SiO_2 (70%) and CaO (2%) and lesser Al_2O_3 (14%), K_2O (3%), Na_2O (4%) and Fe_2O_3 (1%) than felsic alkaline or other felsic subalkaline rocks.
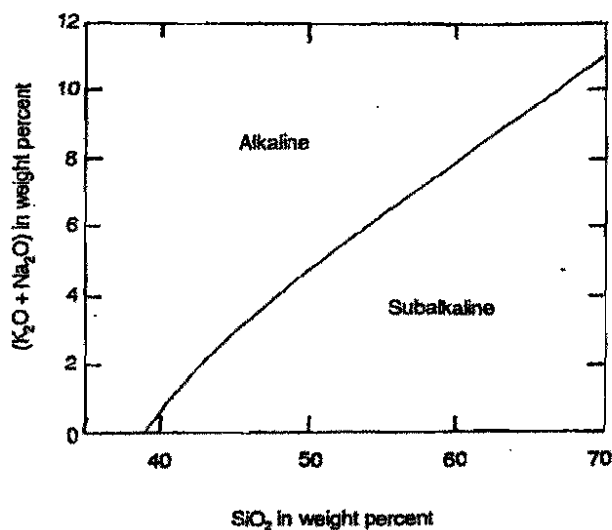

Figure 1. Alkaline and subalkaline plutonic rock
divisions based on $K_2O + Na_2O$ and SiO_2

<u>Alkaline pluton hosted porphyry coppers</u>

Hydrothermal Pt, Pd occur as minor constituents in Cu-Ag-Au porphyry copper mineralization in alkaline plutons in a belt that stretches through the eastern Rocky Mountains from southern British Columbia to Colorado (Finch and others, 1983; Mutschler and others, 1985). Alkaline intrusive rocks have long been recognized as indicators of continental rifting and extensional tectonic regimes. A detailed study of the **Allard stock**, Colorado at the south end of the Colorado Mineral Belt (Werle and others, 1984) showed that mineralization is localized in breccia pipes and stockworks in a complex epizonal 65-70 Ma age syenite intrusive suite which is greatly enriched in K_2O and Al_2O_3. Ore includes chalcopyrite, enargite, sphalerite, bornite, chalcocite, pyrite, magnetite, hematite, arsenopyrite, marcasite and galena with gangue minerals K-feldspar, quartz, calcite and fluorite in argillic, potassic and carbonate altered host rocks. Werle and others (1984) concluded that fractionation of syenitic magma produced a volatile-rich supercritical fluid that hydrofractured roof rocks releasing altering and mineralizing fluids that precipitated Pt, Pd-bearing Cu-Ag-Au ore minerals in breccia and stockwork.

<u>Calc-alkaline pluton hosted porphyry coppers</u>

At **Skouries**, Greece, Cu-Ag-Au porphyry copper mineralization is localized in veins, stockworks and disseminations in an 18 Ma age calc-alkaline granitic stock. Pd occurs in an unidentified state in chalcopyrite, pyrite, bornite, magnetite and native gold ore with quartz gangue in intensely silicified, potassic and phyllic altered host rocks. Eliopoulos (1991) concluded that the Skouries porphyry host is an I-Type granitoid which exhibits extensive chemical interaction with upper crustal rocks.

The **Santo Tomas II**, Philippines porphyry copper deposit contains a total of 2,000,000 ounces of low-grade Pt+Pd in 328 million tons of Cu-Au ore. Merenskyite ($Pd(Te,Bi)_2$) and native gold have been identified in bornite, chalcopyrite, pyrite, magnetite ore in a potassic and propylitic altered 9.2 Ma age diorite stock. Tarkian and Koopmann (1995) concluded that the diorite is an island arc/subduction related pluton from which a high salinity (35-60%) NaCl) fluid deposited metals from chloride complexes at 358°-520°C.

Sediment hosted

The sediment hosted category includes deposits which appear to have formed from dominantly acidic and oxidized meteoric basinal brines that leached and transported Pt, Pd, Au and other metals in Cl-complexes. Deposition occurred mainly by chemical reduction of the brines upon interaction with host strata (carbonaceous, pyritic, feldspathic) that contained reducing agents. It is important to point out that Pt, Pd, Au concentrations in carbonaceous shales appear to result only by deposition from hydrothermal fluids which have chemically interacted with the reducing environments that characterize these rocks; Pt, Pd and Au do not appear to represent intrinsic or primary constituents of these sediments (Coveney and others, 1992).

<u>Carbonaceous shale hosted</u>

A 1 cm thick layer at the base of the **Kupferschiefer** ("copper shale"), Germany, Poland, contains local high values in Pt, Pd and Au (Macdonald, 1987; Coveney and others, 1992; Mountain and Wood, 1988). The Kupferschiefer is a Permian (250 Ma), 1 m thick carbonaceous-calcareous bed that underlies an area of 20,000 km^2 and includes large areas of economic Au-Ag-Pb-Zn ore. The Kupferschiefer bed lies at a contact between underlying volcanics and red beds and overlying carbonates, evaporites and red beds. Mineralogy is principally bornite, chalcocite, chalcopyrite, galena, sphalerite, tetrahedrite and pyrite; minor metals are Ni, Co, V and Mo. It has been proposed (Jowett, 1986) that metals were supplied to a shallow sea by late diagenetic convecting meteoric fluids that leached metals from volcanic detritus in underlying strata, that thermal energy for convection was supplied by continental rifting and that deposition took place by reduction in organic-rich shale.

The **Zambian Copperbelt**, Zambia, Zaire, has produced Pt, Pd as minor constituents in Cu-Co-U ores in an extensive, few meters thick, 900 Ma age carbonaceous sulfide-rich shale and arkosic sandstone bed which lies on Archean granitic and metamorphic basement. Principal ore minerals are chalcocite, bornite, chalcopyrite, pyrite, carrolite (Cu,Co_2S_4) and linnaeite (Co_3S4). Fleischer and others (1976) proposed that surface waters carried detrital metal and metal-rich fluid, probably leached from copper in basement rocks, into a near-shore, carbon- and sulfur-rich sedimentary environment within which reduction resulted in precipitation.

Sediment-hosted stratabound Cu-Ag deposits in the **Kalahari Copperbelt**, Namibia, contain significant potential by-product Pt and Au (Borg and others, 1987). The deposits are hosted in carbonaceous pyritic shales in the upper levels of a 1300-950 Ma age volcanic-sedimentary succession deposited in a failed continental rift system. The basal unit of the succession rests on 2000-1600 Ma granite-metasediment basement and consists of felsic volcanics characterized by considerably enriched values in Pt and Au. Overlying red beds were derived by erosion of the basement and felsic volcanics but are now depleted of Pt and Au, as well as Cu and Ag. Borg and others (1987) concluded that Pt and Au were contributed to basal felsic volcanics from a rift-related mantle plume and that low temperature circulating Cl-rich basinal brines of low pH and high Eh leached metals from the overlying red beds, precipitating Cu and Ag with minor Pt, Au and Ni by reduction upon encountering overlying carbonaceous, pyritic shales.

<u>Unconformity related</u>

At **Coronation Hill**, Australia, a Pt-Pd-Au-U deposit is hosted in a fault zone in a variety of fractured and altered rock types within an Early Proterozoic (2500-1600 Ma) assemblage lying on an Archean basement of metasediments and felsic meta-igneous rocks. The Early Proterozoic section consists of basal carbonaceous shale, siltstone and carbonate overlain by chloritized volcaniclastics and carbonaceous shale; these units are intruded by quartz feldspar porphyry and quartz diorite and all of the above rock types have experienced early stage quartz-sericite-chlorite-kaolinite-sphene hydrothermal alteration. The altered units are overlain by a sedimentary breccia which in turn is capped by an unconformity (Kombolgie) above which lies a hematitic quartz sandstone (Carville and others, 1990). Principal minerals include very fine electrum, stibiopalladinite (Pd_5Sb_2) sudburyite (PdSb), native Pd, a Pt-Pd selenide $((Pt, Pd)Se_2)$,

a Pt-Pd-Fe alloy, rare native Pd, uraninite, pitchblende and minor pyrite; minor metals are Ni, Co. Ore minerals appear to have no lithologic control, occurring in quartz-dolomite-calcite-hematite veinlets and breccias and as disseminations in all of the rock types which lie below the Kombolgie unconformity. Mineralization was accompanied by hematite alteration of variable intensity that affected all rock types, including the hematitic quartz sandstone above the unconformity. Highly oxidized fluids are indicated by complete oxidation of chlorite to hematite. Mernagh and others (1994) concluded that both reduction and neutralization of an oxidized, acidic meteoric ore fluid resulted in precipitation of ore minerals in fractured reducing rock types lying beneath the Kombolgie unconformity.

Solubility, transport, deposition of platinum, palladium

Thermodynamic calculations (Mountain and Wood, 1987, 1988; Wood and others, 1989, 1991), analysis of data for modern geothermal systems (McKibben and others, 1990) and laboratory experimental results (Gammons and others, 1993, 1995, 1996; Estigneeva and Tarkian, 1996) over the past 12 years have contributed to an understanding of the solubility, transport and deposition of Pt, Pd. Research on a variety of Pt, Pd complexes, including chloride, hydroxide, oxyanionic, ammonia, thiosulfate, sulfite and polysulfide (Mountain and Wood, 1987), has clearly demonstrated that significant Pt, Pd solubilities under most geologically reasonable conditions may only be achieved in chloride complexes. Figure 2 shows $Eh(logfo_2)$-pH diagrams which demonstrate that the fields of the predominant aqueous Pt, Pd chloride species are restricted to acidic pH (Kaolinite or muscovite stable) and moderate-extreme oxidized Eh conditions (hematite stable) at 25°C. Mountain and Wood (1987) have shown that these fields are valid even at low chloride concentrations and up to 300°C (where the $PtCl_2^0$ field is greatly expanded). Wood and others (1992) further concluded that Pt, Pd chloride complexes may become increasingly important at magmatic temperatures of 400°C and higher.

The ubiquitous presence of significant Au with Pt, Pd in hydrothermal deposits underscores the importance of chloride complexes in the cogenetic solubility and transport of these three metals. Although a consensus has developed concerning the dominance of Au solubilities in bisulfide complexes, Figure 2 shows that the 1 ppm bisulfide ($Au(HS)_2^-$) field is located at acidic to alkaline pH's and is restricted to a lower Eh, more reducing range, removed from the Pt, Pd chloride complexes fields. Corresponding Pt bisulfide solubilities (in $Pt(HS)_4^{2-}$) in this field are only in the parts per trillion range, clearly indicating that no significant Pt solubility occurs in bisulfide complexes (Mountain and Wood, 19087). The cogenetic association of Au with Pt, Pd in hydrothermal mineral assemblages therefore requires that Au also be transported in chloride complexes when found in such assemblages. The coincidence of the 1 ppm solubility contours for Au with both Pt and Pd in chloride complexes shown in Figure 2 emphasizes that these metals were transported together in fluids from which Pt, Pd and Au-bearing hydrothermal deposits were formed.

Geologic evidence from a number of deposits and occurrences indicates that Pt, Pd and chloride complexes were destabilized upon encountering environments that brought about chemical reduction and/or neutralization of the oxidized and acidic hydrothermal fluids, thereby resulting in deposition. The dominance of Pt, Pd sulfide minerals in hydrothermal

assemblages suggests that sulfur was contributed to these minerals from the reducing environments that contained sulfur and into which the ore transporting fluids were introduced.

Summary of ore deposition in Pt, Pd hydrothermal deposits

An abundant literature on fluid inclusions from **magmatic related** fracture/shear zone hosted precious and base metals deposits and porphyry copper hosted ore deposits as well as results from thermochemical studies has demonstrated that chlorine is a common and significant element in the ore fluids from which these deposits formed. It is therefore reasonable to conclude, in addition to the evidence presented above, that Pt, Pd, Au (and Cu, etc.; Mountain and Wood, 1988), when found in these classes of deposit, resulted from transportation in and deposition from chloride complexes. The common occurrence of hydrothermal alteration assemblages in fracture/shear zone and porphyry copper deposits indicates that wall rocks were attacked by acidic fluids, confirming the acidic nature of the chloride complex-bearing fluids. Although the oxidizing character of the fluids is rarely exhibited in the minerals in deposits of these types, it is believed that sulfur in the sulfide assemblages has been derived by interaction and reduction of the ore fluids with sulfur-bearing wall rocks. This phenomenon is particularly well exhibited at the Santo Tomas II porphyry copper deposit where most of the sulfide ore is localized along a diorite-metavolcanic wall rock contact (Tarkian, 1995).

The clearest understanding of hydrothermal Pt, Pd ore deposition in **sediment hosted** deposits is provided by studies of the Coronation Hill deposit (Wilde and others, 1989; Carville and others, 1990; Jaireth, 1992; Mernagh and others, 1994). Jaireth (1992) and Mernath and others (1994) concluded that a very Ca-rich, atmospheric oxygen-saturated (highly oxidized), acidic, moderately saline meteoric brine (groundwater or sea water, based on isotopic data) transported Pt, Pd, Au and U in chloride complexes. Fluid inclusion evidence indicates that this fluid transported metal chloride complexes at 160°-225°C; similar Pt, Pd, Au, U elemental molar ratios in inclusions and ore indicate that metals were transported and deposited together from the same fluid (Wilde and others, 1988). It has been inferred that as the fluid migrated through the quartz sandstone aquifer above the Kombolgie unconformity it maintained a high oxidation state by progressively oxidizing Fe^{2+} minerals in the sandstone (magnetite, silicates), pushing a redox interface deeper into the aquifer and successively leaching and redepositing Pt, Pd, Au and U as it descended. Upon reaching strong redox barriers in feldspar-, magnetite- and graphite-bearing sediments or fluids containing methane or hydrocarbons beneath the unconformity, the chloride complexes became unstable, experienced chemical reduction, and precipitated ore minerals at 150°-170°C (Jaireth, 1972) in open space fractures in host rocks. Mernagh and others (1994) stressed that the ore forming process at Coronation Hill is genetically different from epithermal deposits that have resulted from ascending, deeper level, more reduced hydrothermal fluids. Data from several of the epithermal sediment hosted Carlin-type deposits in Nevada show that Pt, Pd values are not anomalous (Page and others, 1992); these
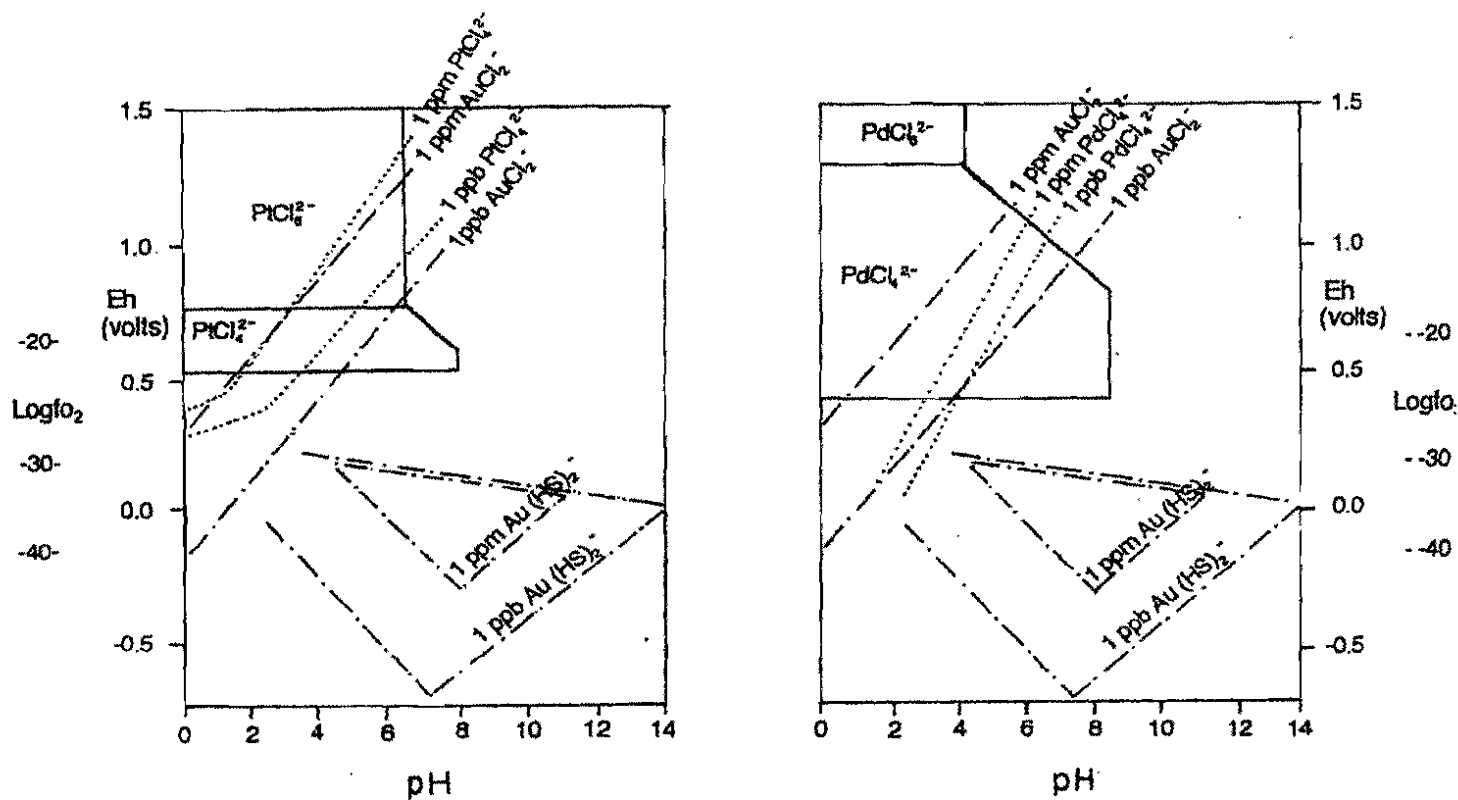
Figure 2. Eh (logfo₂)-pH diagrams for Pt and Pd at 25°C ($\sum$Pt, Pd=10 ppb, $\sum$Cl⁻=1.0 m). Solid lines separate fields of predominance of aqueous species of Pt and Pd. Also shown are solubilities at 1 ppm and 1 ppb for Pt, Pd and Au in chloride and bisulfide (Au only) complexes at 300°C ($\sum$Cl⁻=1.0 m, $\sum$S=0.1 m). Pt, Pd and Au solubilities as chloride complexes are similar; in the field of Au solubility in the bisulfide complex, however, Pt bisulfide complexes (not shown) are extremely low, in the range of 1 ppt (parts per trillion). Although fields shown are at 25°C, Mountain (1987) states that the Pt and Pd chloride fields shown provide an order of magnitude estimate of the total Pt, Pd solubilities as chloride complexes at 300°C. Figure 2 modified from Mountain (1987).

data tend to confirm that sediment hosted Pt, Pd-bearing deposits, such as Coronation Hill, are genetically distinct from the epithermal types.

As is the case for most classes of ore deposits, considerable speculation and debate has centered on the issue of the **source of metals** in the classes of deposits considered here. the hydrothermal Pt, Pd deposits appear to be divisible into those formed from magmatic fluids (fracture/shear zone hosted and porphyry copper hosted) and those formed from meteoric fluids (sediment hosted). In the case of porphyry coppers the magmatic hydrothermal fluids have clearly been generated by differentiation of plutons. Metals in these deposits were acquired from source rocks that were melted to produce magma. In the case of alkaline plutons, such as the Allard stock, rocks of these compositions are characteristic of continental rifts within which metals may have been derived from magma rising and differentiating from the ultramafic/mafic composition upper mantle or from the melting of basement rocks in the lower to upper crust. Calc-alkaline plutons, on the other hand, such as Santo Tomas II, generally represent magma generation by subduction of oceanic plates of dominantly mafic composition. Escape of magmatic fluids into fractured roof rocks, such as at Goodsprings or Crescent Peak, allows for deposition directly from these fluids or possible leaching of metals from country rocks traversed by the fluids, such as at New Rambler and possibly Bunkerville. In the case of the magmatic fluid types, metals have clearly been dominantly derived from the source rocks from which magmas were formed by melting; these source rocks may range from ultramafic to felsic and no specific composition appears to emerge, although the dominant association of major Pt, Pd deposits with ultramafic/mafic rocks would suggest that rocks of this composition probably supplied significant material to magmas.

Studies of sediment hosted Pt, Pd-bearing deposits provide a fairly clear picture of leaching and transport of metals in meteoric hydrothermal fluids. In the case of the Kupferschiefer and Kalahari deposits, underlying felsic volcanics and red beds in continental rift environments, have been identified as source rocks (Jowett, 1986; Borg and others, 1987). In the Kalahari situation, elevated levels of Pt, Pd in felsic volcanics have been attributed to a mantle plume that contributed these and other metals to felsic magma formed by melting of lower continental crust of mainly metasedimentary composition (Borg and others, 1987). In a similar manner, chlorite-altered volcaniclastics and quartz-feldspar porphyries underlying the Coronation Hill deposit (Mernagh and others, 1994) are probable source rocks for metals in this deposit. In the Zambian Copperbelt the ore beds lie on a metamorphic/granitic basement which appears to contain significant amounts of Cu-bearing veins and disseminations (Fleischer, 1976); this basement mineralization is a probable source for Pt, Pd and other metals in the deposits. The Kalahari example, supported by the Kupferschiefer, appears to provide the best clue as to source rocks for sediment-hosted hydrothermal Pt, Pd-bearing deposits: volcanic rocks that received metals by mixing with ultramafic/mafic magma introduced from the mantle in continental rift environments.

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