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PACIFIC COAST DIAMONDS - AN UNCONVENTIONAL SOURCE TERRANE

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ABSTRACT

Several hundred diamonds have been found along the Pacific Coast of the United States in California, Oregon, Washington, and Alaska, for which no known source rock has been identified. The Pacific Coast is an atypical terrane for diamonds and is not considered favorable for the emplacement of diamondiferous kimberlite or lamproite. The postulated source is an obducted ophiolite or alpine peridotite interpreted to have been tectonically emplaced during plate collision.

Similar diamond occurrences have been identified at several other collision zones along plate margins in the world. Being derived from an organically rich oceanic slab, such deposits could be extremely high grade, although relatively small.

INTRODUCTION

Diamonds have been reported from many localities along the Pacific Coast of the United States in Alaska, California, Oregon, and Washington, for which there is no known source (Fig. 1). The source of the diamonds is complicated by the diamonds being found along an intensely deformed Phanerozoic plate margin. Much of the basement of the Pacific Coast represents an unstable accreted terrane that is not part of an Archean craton or cratonized Proterozoic mobile belt. Yet the Pacific Coast, and in particular northern California, has been the third most productive region in the United States for diamonds. Essentially, all of the diamonds have been recovered from modern placers and Tertiary conglomerates as a by-product of placer gold mining (Hausel, 1994, 1995a,b).

In addition to the Pacific Coast of the United States, plate margin alluvial diamond deposits have been reported at a number of localities around the world. It is unlikely that the source of some of these alluvial deposits was conventional kimberlite host rock in that known diamondiferous kimberlites are confined to Archean cratons and craton margins. The possibility that the diamonds were derived from diamondiferous lamproite or an unconventional host rock is more plausible. In particular, the unstable tectonic regime of the Pacific Coast suggests that an unconventional host rock may be a likely source.

Although commercial diamond deposits are primarily restricted to kimberlite, lamproite, and secondary deposits derived from these intrusives, diamonds have been reported from a variety of rock types. The conventional host rocks are kimberlites and lamproites; however, unconventional diamondiferous rocks include alpine and ophiolitic peridotites, meteorites, alkali basalts, alnöites, nephelinites, monchiquites, mugearites, dolerites, lamprophyres, altered lamproites, and both low-grade and high-grade metamorphic rocks (Janse, 1994; Nixon, 1995).

Conventional Host Rocks

Kimberlite and lamproite are commonly described as the primary host rock for diamond; however, these rocks only represent the transporting medium for most diamonds. Many octahedral microdiamonds in kimberlite and lamproite may be cognate, but most if not all macrodiamonds found in these rocks are considered as xenocrysts that yield unique age dates compared to the host kimberlite and lamproite. Kimberlites and lamproites yield 1.6 Ga to 1.0 Ma ages, but diamonds recovered from many of these intrusives date between 3.3 Ga to 300 Ma emphasizing their xenocrystic nature (Richardson et.al., 1984, 1990; Helmstaedt, 1993a; Barron et.al., 1994).

The primary source rock for the macrodiamonds in kimberlite and lamproite is eclogite, garnet harzburgite, and less commonly garnet lherzolite. These rocks are found in the mantle beneath cratons and occur as mantle xenoliths in the kimberlite and lamproite magmas. Many of the diamond-rich xenoliths probably disaggregate during transportation from the mantle to the earth's surface resulting in the dilution and dissemination of diamonds in the kimberlite and lamproite magmas (Kirkley et.al., 1991).

According to Mitchell and Bergman (1991) diamondiferous kimberlites are generally thought to be restricted to cratons, whereas diamondiferous lamproites occur on the craton margins *"in crustal domains which experienced Proterozoic to Archean accretional and/or other orogenic events. Kimberlites occurring in these mobile belts are typically subeconomic or barren of diamonds"*. Diamonds recovered from cratons are interpreted to have crystallized at depths of 150 to 200 km (1,000 to 1,300°C, 40 to 60 kb) at the base of a thick, cool, cratonic lithosphere (Boyd et.al., 1985). From these depths, the diamonds were transported as accidental xenocrysts in kimberlite or lamproite.

Kimberlite: Kimberlite is defined as a volatile-rich, potassic, ultrabasic hybrid igneous rock with variable mineralogy, which forms diatremes, dikes, and "blows" at the earth's surface. Most kimberlites are highly serpentinized and carbonated resulting in much of the primary mineralogy being destroyed during emplacement. The mineralogy of kimberlite has been described by Mitchell (1986).

The classical kimberlite forms a pipe-like structure that tapers down to a root zone ("blow") which originates from a feeder dike at about 2 km (1.2 miles) below the surface. The root is often controlled by intersecting fractures and swells upward into a carrot-shaped diatreme that may erupt at the surface producing a crater. In instances where the kimberlite magma degasses before reaching the surface, a blind diatreme may occur below the surface.

The root zones originate from an irregular dike complex and consist of one or more intrusive phases of hypabyssal facies kimberlite. Hypabyssal facies kimberlite is massive, subvolcanic, kimberlite with igneous texture that may contain enough country rock fragments to be termed a breccia. Diatreme facies kimberlite is formed of volcaniclastic breccias with country rock clasts, fragments of hypabyssal kimberlite, rare fragments of crater facies kimberlite, and pelletal lapilli in a matrix of serpentine and diopside. Crater facies kimberlite consists of pyro- and epiclastic kimberlitic material (pyroclastics, tuffs, and lapilli pyroclastics) (Mitchell, 1986). The crater facies is rarely preserved, and found only in pipes that have undergone little erosion since emplacement.

Not all kimberlites are diamondiferous. Where it occurs in kimberlite, the diamond content and size may decrease with depth in the pipe (Anonymous, 1956; Horlocker, 1978), although (Robinson, 1978) suggests that this is an enrichment feature and most kimberlites do not show a decline in diamond content with depth. About 10% of all known kimberlites are diamondiferous, and less than 2% have commercial quantities in concentrations less than 1 ppm (Lampietti and Sutherland, 1978). Grades of commercial kimberlite may range from as low as 10 carats/100 tonnes, to as high as 660 carats/100 tonnes in the rich portions of some crater facies kimberlite (Helmstaedt, 1993a). In addition to the ore grade of the rock, important considerations include the size and quality of the diamonds.

Lamproite: Diamondiferous lamproites have been known for many years, although these rocks did not attract serious exploration interest until the discovery of the Argyle lamproite in Western Australia, in 1978. Prior to this discovery, diamondiferous leucite lamproite was described as early as 1967, near Seguela, Ivory Coast by Dawson (1967), but little attention was given to these rocks.

Following the discovery of commercial diamondiferous lamproite in Western Australia, interest in lamproites greatly increased because of the very high grades encountered at Argyle (680 carats/100 tonnes). Some intrusives previously termed "kimberlites", "altered kimberlites", "metakimberlites", "minettes", "leucitites", and "mica peridotites" were re-evaluated and some were found to be lamproites. This included the Majhgawan vent in India, which produced diamonds as early as 1827, more than 40 years before kimberlite was discovered in South Africa. Other vents that were reclassified included the diamondiferous olivine lamproites near Murfreesburo, Arkansas; the diamondiferous lamproites at Kampamba, Zambia; the barren olivine lamproite sills at Hills Pond near Yates Center, Kansas; and the lamproite sills at Sisco, Corsica (Mitchell and Bergman, 1991).

The mineralogy of lamproites are quite unique compared to kimberlites, and the typical kimberlitic "indicator" minerals (pyrope garnet, chromian diopside, and picro-ilmenite) are uncommon in lamproite (Mitchell and Bergman, 1991). Kimberlites and lamproites are distinctly different rock types; however, there is an overlap in the gross chemical compositions of micaceous kimberlites and lamproites (Helmstaedt, 1993a; Kirkley et.al., 1991).

Lamproite forms extrusive, subvolcanic, and hypabyssal facies rocks that erupt at the earth's surface as small volcanoes with restricted flows. Where mineralized, diamonds in lamproites are primarily restricted to the pyroclastics, the magmatic phases (and sills) are notoriously diamond poor (Helmstaedt, 1993a). Presumably, many diamonds will burn, or resorb, in the high temperatures sustained in the lamproite flows. Robinson (1978) reports that oxidizing agents effectively attack diamond at temperatures below 1,000°C (1,825°F). In a recent test, the author burned a small industrial diamond in less than 120 seconds using an oxygen-rich flame from a Bunsen burner. Typically, many diamondiferous lamproites contain high amounts of modal olivine and Cr-rich spinels (Mitchell and Bergman, 1991).

Some altered olivine-lamproite dikes have also yielded diamonds. Such rocks in the Ivory Coast and NW Gabon are devoid of the usual kimberlitic indicator minerals and appear as talc or phlogopite schists. The Bobi lamproite dike in the Ivory Coast is locally very diamond rich with grades up to 1,000 carats/100 tonnes (Helmstaedt, 1993a). Other altered lamproites have been reported at Hills Pond, Kansas, and at Enoree, South Carolina, although these lamproites are currently mined for vermiculite and feed additive, and no diamonds are reported (Bergman, 1987).

Peridotite and Eclogite Nodules: Some peridotite and eclogite fragments (nodules) found in kimberlite and lamproite are considered to be the original source for most diamonds. The diamondiferous peridotites include pyrope harzburgites and less commonly pyrope lherzolites.

Some peridotite nodules recovered from kimberlite and lamproite have yielded grades of 30 carats/100 tonnes to 65,100 carats/100 tonnes. Eclogites often yield higher grades, and some have yielded grades of 1,700 carats/100 tonnes to as much as 3,700,000 carats/100 tonnes (Helmstaedt, 1993b). Compared to diamondiferous kimberlites and lamproites, some of these nodules are fabulously rich.

Unconventional Diamondiferous Host Rocks

Unconventional diamondiferous host rocks have been recognized at a number of localities around the world (Wilson, 1948; Kaminskiy and Vaganov, 1976; Dawson, 1979; Nixon and Bergman, 1987; Helmstaedt, 1993a). Many of these are considered as scientific curiosities, but others may play an important role in diamond economics in the future.

Unconventional host rocks include some alnöites which lack the characteristic kimberlitic indicator minerals and contain melilite and biotite mica (Helmstaedt, 1993b). Diamondiferous picritic monchiquites have been reported in Western Australia (Jaques et.al., 1986), and diamonds have also been reported in lamprophyres in Quebec (Helmstaedt, 1993b). In eastern Australia, many diamonds are associated with a variety of diatremes described as alkali basalt, nephelinite, nepheline mugearite, and dolerite (MacNevin, 1977; Sutherland et.al., 1985). Diamonds have also been recovered from alkali basalt in Kamchatka and Arkhangelsk (Barron et.al., 1994; Danielson, 1994), and from Late Cretaceous kimberlitic and lamproitic rocks in island arc host rocks from the Valaginsky Range of the Kamchatka arc (Seliverstov et.al., 1994).

In the Ural Mountains of the former Soviet Union, both alluvial diamonds and paleoplacer pyrope garnets have been found downstream from peridotites. Diamonds were initially identified in this region in the 1820s, and some placers along the western slopes of the middle Ural Mountains had been worked for diamonds near the turn of the century, and during the second World War (Dawson, 1967). Exploration for the source of the placers led to the discovery of diamondiferous picrites and limburgite breccias (Luk'yanova et.al., 1980).

Other rock types reported to yield diamonds include high-pressure metamorphic rocks. Where found, diamonds in these rocks are typically small. For instance, microdiamond inclusions averaging only 12.5 microns (0.125 mm) in size were discovered in garnets and zircons in garnet pyroxenites, garnet-biotite gneisses, and garnet-biotite schists of metasedimentary origin in the Kokchetav massif of northern Kazakhstan (Sobolev and Shatsky, 1990).

In China, diamonds have been recovered from eclogite lenses in Cambrian to Permian blueschists (Barron et.al., 1994). Diamonds were also identified in garnets in coesite-bearing eclogites, garnet pyroxenites, and jadeites in the Dabie Mountains of eastern China. These diamonds average only 10 to 60 microns and include grains up to 240 microns (2.4 mm). Other metamorphic diamonds were discovered northwest of the Ulaan-Baatar region of Mongolia. Initial bulk sampling recovered diamonds in the range of <0.1 mm to 1 mm in diameter at grades of 4,000 to 10,000 carats/100 tonnes (Helmstaedt, 1993a). This deposit is similar to the Kokchetav deposit in Kazakhstan (Ed Erlich, pers. comm., 1993).

Diamonds have also been reported in low-grade chloritic schists from the Birrimian greenstone belt in Ghana. These schists are interpreted as metamorphosed basalts, ultrabasic igneous rocks, and greywackes (Dawson, 1968).

Some stoney and iron meteorites and impactites contain isometric and hexagonal (lonsdaleite) diamond. Lonsdaleite has also been reported from the Popigay Depression in northern Siberia. The Popigay structure is interpreted as a astrobleme, although some researchers suggest the structure may instead be terrestrial (Ed Erlich, pers. comm., 1986).

Diamonds have also been found in alpine and ophiolitic peridotites and related ultramafic rocks along plate collision boundaries at several localities around the world. Portions of the Pacific Coast of the United States exhibit similarities to these types of deposits.

Diamondiferous Peridotite Massifs: Diamondiferous peridotite massifs have been reported at a number of localities in the world including Armenia, Australia, Canada, Indonesia, Kamchatka, Spain, and Tibet. Additionally, diamond placers have been reported in similar terranes downstream from peridotite massifs in the Appalachian Mountains and the Pacific Coast of the United States. The source of some of the diamonds in the peridotite massifs, ophiolites, and similar ultramafic belts, according to Pearson et.al. (1989), is highly magnesian chromite harzburgites. These harzburgites exhibit similarities to the diamondiferous peridotite xenoliths found in kimberlites, although garnet is usually lacking. Such deposits are found in some major collision zones having been tectonically emplaced from the base of the lithosphere (Pearson et.al., 1989).

The first discovery of diamondiferous harzburgite bedrock occurred in 1978, when diamonds were found in alpine peridotite the Koryak Mountains of northern Kamchatka (Helmstaedt, 1993a). The diamonds in the peridotite, as well as in alpine peridotites in Tibet, are thought to have formed during subduction and survived metastably during rapid tectonic uplift.

Diamonds have also been identified in peridotite in the Amasiyan-Sevan-Akerinsk ophiolite complex in the Lower Caucasus Mountains of southern Armenia. Like many of the other peridotite diamond deposits, there is a lack of associated high-pressure mineral indicators in this region (Nixon and Bergman, 1987).

Elsewhere, diamonds have been identified in a metamorphosed, layered, mafic-ultramafic complex near Kaya, Burkina Faso in western Africa. This complex consists of metamorphosed dunite overlying a sequence of layered amphibolites, metaperidotites, metapyroxenites, and biotite-plagioclase gneiss (Helmstaedt, 1993a).

In Kalimantan, Indonesian Borneo, diamonds have been mined from alluvial deposits since the early part of the 1700s, and diamonds have also been found in Upper Cretaceous and Eocene conglomerates and sandstones (Dawson, 1967). The diamonds are mainly gemstones, and production averages less than 10,000 carats per year (MacNevin, 1977). One report in the San Francisco Chronicle (August 1, 1872) claimed that a nearly priceless diamond was found in this region. The diamonds were traced to Lower Cretaceous peridotite breccia which intrudes the Bobaris peridotite massif in the Pamali River area of southeastern Borneo. This breccia was investigated by Anaconda Minerals and found to be a wedge of scree derived from ophiolite (Dawson, 1989). The Pamali breccias lie within a geosyncline and were intruded during a orogenic cycle (Dawson, 1980).

In Australia, diamonds have been reported in Devonian peridotite at Heazelwood in northwestern Tasmania (Wilson, 1948). The peridotite is part of a 48 km (30 miles) long, 3 to 8 km (1.9 to 5 miles) wide complex with associated gabbro and pyroxenite. North of Tasmania in the Sidney Basin of New South Wales (NSW), approximately 500,000 carats have been recovered from alluvial deposits and Tertiary conglomerates as a by-product of tin mining, and diamonds have also been found in several mafic intrusive breccias (MacNevin, 1977; Barron et.al., 1994). The breccias include dolerite, nephelinite, nepheline mugerarite, and alkali basalt (MacNevin, 1977; Jaques et.al., 1986; Dawson, 1989; Anonymous, 1994). The NSW coast lies near the Australian plate margin and many of the intrusives lie within the Tasman fold belt considered to be an atypical regime for kimberlite magmatism (Dawson, 1989).

Some of the NSW diamonds were recovered from intrusive breccias interpreted to have sampled a diamondiferous subducted oceanic slab. Possibly, fragments of the slab were tectonically emplaced west of the diatremes since alluvial diamonds in the Bungara field of northeastern NSW are thought to have originated from serpentinized peridotites in the Great Serpentinite Belt. The diamonds at Bungara are found in channels near numerous faults and thrusts marked by serpentinite and other basic and ultrabasic rocks (MacNevin, 1977).

Diamonds from NSW are unusually hard (Wilson, 1948), contain mineral inclusions of coesite and grossular garnet (Sobolev, 1985), and are the youngest diamonds ever dated. A set of five diamonds yielded an average date of 300 Ma (S.R. Lishmund, written comm., 1994). These diamonds are interpreted to have formed at relatively shallow depths (80 km) in a cool, subducted, organic-rich, oceanic slab (Barron et.al., 1994).

Such high pressure peridotites have been recognized at other localities along plate margins. Possibly, one of the more intriguing peridotite massifs, located in Morocco, may have important implications in the exploration of plate margin alluvial diamond deposits such as those found along the Pacific Coast.

The Beni Bousera peridotite massif in Morocco was derived by partial fusion of a upper mantle fragment at 1,500°C and 25 kb (80 km depth) followed by re-equilibration in the spinel lherzolite field with decreasing temperatures and pressures (Kornprobst, 1969). Recently it was discovered that this complex contains graphite pseudomorphs after diamond in garnet clinopyroxenite (Pearson et.al., 1989).

The graphite octahedra are confined to four garnet clinopyroxenite magmatic cumulate layers in the ophiolite. Portions of this complex may have initially contained as much as 15% diamond, or approximately 10,000 times as many diamonds per unit mass of rock than any known kimberlite intrusive. The pyroxenite lenses are on a scale of a few centimeters to a few meters thick and form only 2 to 5% of the massif. Two of the layers are greater than 2 m (6.4 ft) thick and contain orange pyrope-almandine garnet with compositions comparable to those found in diamond-bearing eclogites, and omphacitic pyroxene porphyroclasts with minor plagioclase, spinel, and sulfide. The graphite-bearing garnet clinopyroxenite layers, along with wehrlites, lherzolites, and diopsidites, form an intercalated horizon up to 16 m (51 ft) thick at the apex of the massif. Pyroxenites in the massif re-equilibrated at 10 kb and 1,000°C (32 km depth), so it would appear that the tectonic emplacement did not occur fast enough to preserve diamond (Pearson et.al., 1989, 1993). However, a similar peridotite massif, the Ronda peridotite in Spain, was reported to contain diamond and graphite pseudomorphs (Barron et.al., 1994). Recent reports indicate the Rhonda diamonds may have instead been spinel and zircon (Nixon, 1995).

High pressure peridotites have also been recognized in the Coastal Ranges of southeastern Oregon and northern California, although no diamonds have been found *in situ* in the complexes (Medaris and Dott, 1970; Medaris, 1972). The mineral assemblages include forsterite, aluminous enstatite, chromian diopside, and $MgAl_2O_4$-rich spinel indicative of the spinel lherzolite field. Spinels from these peridotites are highly aluminous and comparable to spinels from Beni Bousera. The textural relationships indicate re-equilibration at 1,200°C over a pressure range of 19 to 5 kbs (60 to 16 km depth). The peridotites are interpreted to represent oceanic upper mantle material emplaced in as a solid thrust wedge in the western margin of the Cordilleria during late Mesozoic (Medaris, 1972).

PACIFIC COAST DIAMOND OCCURRENCES

The Pacific Coast of the United States, and in particular northern California, has been the third most productive region in the United States for diamonds, and has also produced the fourth largest documented diamond in the United States (Hausel, 1994, 1995a,b). Yet this region has not received much exploration interest for diamond. To date, no source rock has been identified, although potential source rocks would include lamproite, other mafic or ultramafic diatremes, alpine and ophiolitic peridotites, or paleoplacers. Most diamonds found in this region were recovered from modern and Tertiary placers and paleoplacers.

Alaska

Only a few diamonds have been reported in Alaska. These include diamonds found northeast of Fairbanks in eastern Alaska, and diamonds found in Goodnews Bay along the Pacific Coast in southwestern Alaska (Fig. 1).

In eastern Alaska, three diamonds were recovered from a placer gold prospect on Crooked Creek in the Circle mining district northeast of Fairbanks in 1982. The diamonds weighed 0.3, 0.83, and 1.4 carats. No 'kimberlitic' indicator minerals were found (Forbes et.al., 1987), and the lack of indicator minerals suggests the diamonds either originated from a lamproite or a similar intrusive, or the stones are distal.

In southwestern Alaska, two diamond inclusions were found in a native platinum nugget at Goodnews Bay. A third microdiamond was recovered from a core sample of bottom sediments in the bay (Forbes et.al., 1987). The source of these diamonds is unknown, but the possibility of an association with a mafic intrusive is considered.

California

Diamonds were discovered in 1849 near Placerville in central California. A few years later in 1852, diamonds were discovered in the Cherokee hydraulic gold placer mine 14.5 km (9 miles) north of Oroville in northern, California. Following these discoveries, diamonds were also reported in gold placers in Amador, Nevada, Plumas, and Trinity Counties. In total, more than 600 diamonds (both gem and industrial stones) have been documented from 15 different counties in California (Hill, 1972; Hausel, 1995b) (Fig. 1). Potentially, hundreds or even thousands of diamonds reported to the tailings in some of the hydraulic gold mines because of the relatively low specific gravity of diamond (3.5).

The majority of the diamonds have been found north of 36°N latitude. Nearly all of the diamonds have been found in the Sierra Nevada and the Klamath Mountains downstream from serpentinized peridotite complexes and melanges (Storms, 1917). Less than one percent have been found in beach sands. The close association of the majority of the placer diamonds with serpentinized ophiolite suggests possible preservation of diamonds in an obducted peridotite slab. In this same region, pyrope garnet and chromian diopside have been recovered from stream sediments, and chromian-diopside-bearing pyroxenite and peridotite have been found *in situ* (Hausel, 1993).

Placerville, California: Several diamonds have been reported east of Sacramento in the Placerville area in east-central California. Diamonds are also reported in the Volcano and Fiddletown areas about 48 to 65 km (30 to 40 miles) southeast of Placerville (Turner, 1899). According to the available records, at least 50 diamonds were recovered from the Placerville region as a by-product of gold mining. The diamonds were white, canary yellow, light green, and blue, and weighed from 0.1 carat to 1.82 carats: 13 of the stones weighed more than 0.95 carat (Hill, 1972). Some stones were gem in character, since a few were cut and mounted in rings, and one diamond (7.1 mm) sold for $300 (1885 price). Another diamond recovered from a tunnel driven into auriferous gravels capped by a 15.5 to 140 m (50 to 450 ft) thick lava bed at Forest Hill weighed 1.5 carats and was reported to have good color (Kunz, 1885).

South of Placerville, diamonds were recovered from ancient river channels. At one of these locations, more than 60 diamonds (the largest weighed 1.5 carats) were recovered from a paleoplacer 12 m (38 ft) below a bed of volcanic ash in Jackass Gulch at the town of Volcano. At Fiddletown, diamonds were recovered from gravels underlying volcanic ash at Loafer Hill (the largest was approximately 1.33 carats). Indian Gulch, east of Amador City, is also cited as a diamond locality. According to Kunz (1885), four diamonds were recovered from grey-cemented gravel underlying a layer of lava or ash. The pale colored Evans diamond, weighing about 1 carat, was found on the surface of gravel at Rancheria, 6.4 km (4 miles) northwest of Volcano, in 1883. In 1934, the Echols diamond, a stone weighing about 2.5 carats was found near Plymouth, 32 km (20 miles) south of Placerville (Hill, 1972). Turner (1899) claims that serpentinite pebbles were frequently found in the placer gravels.

Oroville, northern California: Most of the Californian diamonds were recovered from hydraulic placer gold mines at Round Mountain north of Oroville (Fig. 2). Since 1853, more than 400 diamonds and about 600,000 ounces of gold were recovered from the mining operations situated near the Feather River (Pemberton, 1983). This district is dominated by Round Mountain which forms a prominent flat top mountain capped by the propylitically altered, Miocene age, Lovejoy Basalt. The basalt overlies Tertiary(?) age, gold-bearing, diamondiferous conglomerate.

Diamonds were initially washed from the conglomerate along the north end of Round Mountain at the Cherokee placer. The diamondiferous gravels at Cherokee flats were reported to contain a variety of heavy minerals including platinum, almandine garnet, epidote, gold, limonite, magnetite, pyrite, quartz, rutile, topaz, and zircon. In

One of the diamonds, the Doubledipity, weighed 32.99 carats, and is the fourth largest documented diamond found in the United States (Kopf et.al., 1990; Hausel, 1994). The diamond is yellowish brown, and essentially opaque except on the edges where it is translucent and does not fluoresce (Kopf et.al., 1990).

In addition to the Doubledipity, at least four other large diamonds were recovered from Hayfork Creek. These included the Enigma (17.83 carats), the Serendipity (14.33 carats), a poorly documented diamond discovered in the 1860s that was about a half inch in diameter estimated to weigh 10 to 15 carats, and the Jeopardy diamond (3.9 carats). The Enigma diamond is described as triangular and bounded by two cleavage surfaces indicating it was originally larger (Kopf et.al., 1990).

In addition to these large diamonds, countless numbers of small diamonds have been reported in the black sands of the Trinity River. Kunz (1885) reported diamonds were found in much of the area drained by the Trinity River, as well as in the banks of the Smith River. Diamonds were also reported in gravels of Hamburg bar near the Oregon border (Blank, 1934). Sinkankas (1959) reported microdiamonds were found in the black sands of the Trinity River near its junction with the Klamath River.

The placers in this region also carry gold, platinum-group metals, and chromite. Recently, pyrope garnet and chromian diopside (heavy mineral indicators of mantle material) were also reported from the Trinity River area (Edgar J. Clark, pers. comm. to Horst Gudemann, 1993). Both of these minerals (in particular chromian diopside) tend to disaggregate during stream transport over relatively short distances. Chromian diopside-bearing pyroxenite was also identified in the Hayfork Creek region (Hausel, 1993).

Other reported diamonds in California: In northeastern portion of the state, near the Nevada border, a few diamonds were found west and north of Lake Tahoe. These included a 7.25 carat stone recovered from French Corral in Nevada County west of Lake Tahoe (Heylmun, 1985). Two other stones included a 1.33 carat diamond, and a 1.25 carat stone described to be remarkably free of flaws though slightly yellowish in color (Kunz, 1885).

North of Nevada County, diamonds ranging from microscopic to about 2 carats in weight have been reported from four localities in Plumas County. These were found at Gopher Hill, Spanish Creek, Sawpit Flat, and Nelson Point. At the latter two localities, the diamonds were recovered from Tertiary fluvial gravels.

Diamonds reported along the Mexican border in southern California included three diamonds recovered from a sluice on Hatfield Creek in the flats of the Little Three Mine near Ramona. The stones were about 3.2 mm (0.125 inch) in diameter (Sinkankas, 1959). Another diamond was reported from Imperial County on the Mexican border, but the discovery was never authenticated (Sinkankas, 1959).

In the south-central portion of the state, small diamonds have been reported a few kilometers north of Coalinga (Blank, 1934); however, these grains may instead be quartz (Murdoch and Webb, 1966). A single crystal was also found nearby in Alpine Creek in 1895, although the diamond was never authenticated (Sinkankas, 1959).

Oregon

Kunz (1885) reported placer diamonds were found in the black sands in the vicinity of Coos Bay, Oregon (Fig. 1). Another report indicated diamonds had also been recovered from gold-bearing gravels in southwestern Oregon (Anonymous, 1981). The number of recovered diamonds was estimated to be about 100, and most were yellowish in color and included some good quality diamonds up to 3 carats in weight, with a few larger stones of inferior quality (Blank, 1934). Microscopic diamonds have also been reported in beach sands along the coast of Oregon at several localities. The diamonds were thought to have originated from peridotites (Anonymous, 1961).

Another report described a 3.15 carat gemstone found prior to 1930 that was recovered from a craw of a chicken taken from a ranch near Gresham, Oregon. The diamond was high-quality and cut into a 1.12 carat gem (Birdsall, 1986). A diamond found prior to 1938 near the town of Wedderburn at the mouth of the Rogue River of southwestern Oregon weighed 0.60 carat, was described as a flattened hexoctahedron with minor carbon inclusions (Anonymous, 1981). The diamond was placed in the U.S. National Museum (Holden, 1944).

A diamond recovered from a gold placer in Josephine County along the California border weighed nearly 3 carats (Anonymous, 1961). Two additional poor-quality yellow stones were found on Josephine Creek (Birdsall, 1986). A 2.5 carat diamond was found in 1870 in a gold placer in Malheur County in eastern Oregon. The diamond was dark in color and described as bort (Anonymous, 1961; Birdsall, 1986).

The source of the Oregon diamonds is unknown, although vast areas in the coastal ranges are underlain by peridotite (Birdsall, 1986). Whether or not peridotites are the source of the diamonds is unknown, but it is interesting to note that peridotites in this region (Vondergreen Hill, Carpenterville, Signal Butte, and Snow Camp peridotites) contain high-pressure mineral phases indicative of derivation within the spinel lherzolite field of the upper mantle.

These peridotites contain forsterite, aluminous enstatite, diopside, and $MgAl_2O_4$-rich spinel. Clinopyroxenes contain 0.66 to 1.33% Cr_2O_3, and some spinels are highly aluminous and comparable to spinels from the Beni Bousera peridotite massif in Morocco. The bulk chemistry, textural relations, and mineral chemistry of the peridotites are all consistent with derivation from the upper mantle at a depth of approximately 60 km (38 miles). The peridotites were brought up by mantle upwelling beneath a Mesozoic ridge system, but during the initial stage of upwelling, high-temperature recrystallization resulted in the breakdown of alumina-rich pyroxenes with accompanying formation of spinel and less aluminous matrix pyroxenes (Medaris, 1972).

The peridotites were later tectonically emplaced by thrusting into the western margin of the Cordillera. The spreading oceanic plate subsequently was consumed in a trench or was accreted onto the continental edge of the American plate (Medaris, 1972). Although the peridotites formed at relatively high pressures, the initial pressures of formation, and the later effects of recrystallization, are not favorable for the preservation of diamond in these particular peridotites.

Washington

Microscopic diamonds have been reported in black sands along the coast of northwestern Washington, and one macroscopic diamond was reported from

1866, diamonds were also found in gravels along the west bank of the Feather River about one mile north of Oroville. Soon afterwards, diamonds were recovered from conglomerate at nearby Thompson Flat, Yankee Hill, and Morris Gulch (Hill, 1972).

In 1882, State Mineralogist Henry Hanks was convinced that diamonds would become an important by-product of hydraulic gold mining. The mine manager of the Cherokee placer mine echoed Hanks in the belief that diamonds would become an important by-product of gold mining if some other recovery method was used to extract the diamonds, since hydraulics washed almost everything from the sluice boxes including platinum which has a specific gravity more than six times as great as diamond.

In 1906, the U.S. Diamond Company sunk a 56 m (180 ft) shaft in what was claimed to be kimberlite. The shaft reportedly intersected a rich pocket of diamonds, although it is questionable as to whether any diamonds were recovered (Rosenhouse, 1975) or that kimberlite was ever intersected. Presently, kimberlite is not known in the area (Heylmun, 1985), although eclogite has been reported nearby (Murdoch and Webb, 1966), and recently was drilled by a major diamond exploration company, although no diamonds were recovered from the eclogite.

The largest recorded diamond from the Oroville area was found in 1868. The stone, known as the Moore diamond, weighed 2.25 carats. However, local folklore claims the largest diamond weighed 6 carats and was found outside the entrance of the Spring Valley mine at Thompson Flat (Rosenhouse, 1975).

At Thompson Flat, 3.2 km (2 miles) north of Oroville, diamonds were found in placer diggings in an old Tertiary channel, and a few stones were recovered from modern drainages (Hill, 1972). A rather famous diamond was recovered from a placer 4.8 km (3 miles) northwest of Yankee Hill that was cut in Boston into a 1.5 carat stone and mounted in a ring. The original stone would have been in excess of 3 carats.

Diamonds from the Oroville area have been surprisingly good quality being relatively free of flaws and possessing good brilliance. One stone sold for $500 (1885 prices) and another was a *"fine Cherokee diamond set in a ring"*. Another diamond found 2.5 km (1.5 miles) northwest of Yankee Hill in 1861, had been cut in Boston. The color of the stones included pure white, rose, and yellow (Hill, 1972). However, many have a yellowish tinge that detracts from their value (Heylmun, 1985).

Some additional diamonds found in 1931 included a 0.5 carat stone found in the Cherokee mine by a prospector, two diamonds of unknown weight, and a 2 carat 27 point diamond (Blank, 1934). Additional diamonds were found in the Cherokee pit in 1958 by an employee of the California Division of Mines and Geology. Several diamonds probably went unnoticed, as Kunz wrote in 1885 that *"... Mr. Carpenter, accompanied by the Assistant State Geologist, found several diamonds in the possession of people in the Oroville area, who had no idea what they were"*.

Trinity River-Hayfork Creek area, northern California: The largest diamonds in the state were recovered from a tributary of the South Fork of the Trinity River known as Hayfork Creek located in the Klamath Mountains of northern California. These diamonds include both cubes and octahedrons with morphological features suggesting they were subjected to disequilibrium conditions within the diamond stability field. Most of the large diamonds are industrial grade crystal aggregates coated with encrustations suggesting minimal transport distance from the source rock.

southwestern part of the state. This diamond, found in a gold placer along the Oregon border in 1932, weighed more than 4 carats. The stone was a pale yellow octahedron (Blank, 1934).

EXPLORATION MODEL

The source of the diamonds along the Pacific Coast of the United States is predicted to be serpentinized peridotite derived from an obducted mantle slab, or possibly from mafic diatremes. The Pacific Coast is characterized by a tectonically unstable, relatively thin, Phanerozoic crust. This tectonic regime is unfavorable for diamondiferous kimberlite and probably unfavorable for diamondiferous lamproite, although barren lamproites closely associated with continental collision have been identified along the Mediterranean rim in Europe (Mitchell and Bergman, 1991). Thus, the possibility of lamproite can not be dismissed.

Theory suggests that diamonds may form along plate collision boundaries at about half the pressure required for diamonds in cratonic environments. Estimates of depth of diamond formation in this type of environment are 80 to 90 km (22 to 25 kb) (Barron et.al., 1994). Diamonds along a subducting plate are envisioned to have formed from carbon-rich sediments and associated ophiolites. Such diamonds may be of similar size, yield anomalous age dates, and possibly occur in a variety of unconventional host rocks.

Potential source rocks include eclogitic lenses in alpine and ophiolite peridotites that exhibit high pressure mineral phases and lack evidence of re-equilibration at shallow depths. Other possible host rocks may include diatremes that sample the diamondiferous peridotite slab at depth. In all probability, such diatremes would host low-grade diamond resources, as the diamonds would tend to disseminate and resorb in the magma following disaggregation of the accidental slab fragments. Transportation may involve accidental capture of the diamonds by the rapidly rising magma as it cuts through the diamondiferous portion of a subducted slab prior to forming a diatreme at the surface, and/or by upward thrust migration of material from the oceanic plate following plate collision.

The diamond content of eclogitic lenses in a peridotite massif can be very high as evidence by Beni Bousera, in which portions of the garnet peridotite lenses contained abundant suspected diamonds prior to re-equilibration. In order to preserve the diamonds, the emplacement of the slab needs to be rapid as re-equilibration at high temperatures will result in diamond resorption. According to Barron et.al. (1994) these diamondiferous rocks would be associated with prograde blueschist rocks, confirming that the subducted slab was thick and cool, and should lie between the blueschists and island arc volcanics.

Possibly, the targets could be evaluated based on petrological and mineralogical studies aimed at determining the presence of pink or orange garnets in alluvials, diatremes, or peridotites. The garnets should have elevated sodium levels (>0.1%) with high Ti/Na ratios. Pyroxenes may have high K_2O (>0.1%) and elevated Na_2O and Al_2O_3 (Barron et.al., 1994), and spinels should have high Al_2O_3 (Medaris, 1972). Serpentinized melange terranes are considered low priority targets in that tectonic underplating is normally associated with temperatures too high for diamond to remain stable (Barron et.al., 1994).

CONCLUSIONS

The Pacific Coast of the United States has similarities to some plate collision zone diamond occurrences found elsewhere in the world. Instead of scattered, rare, kimberlite pipes or lamproite plugs, possibly the source of many of the diamonds along the Pacific Coast is an obducted ophiolite slab with lenses of diamondiferous eclogite, pyroxenite, or peridotite.

The diamond grade of such a slab would be affected both by the original grade of the source terrane, as well as resorption of diamonds during tectonic emplacement. Diamond resorption could have profound effects. Although, based on the size and number of diamonds found along the Pacific Coast, if such a slab is responsible for the diamonds, it appears diamond preservation has been favorable.

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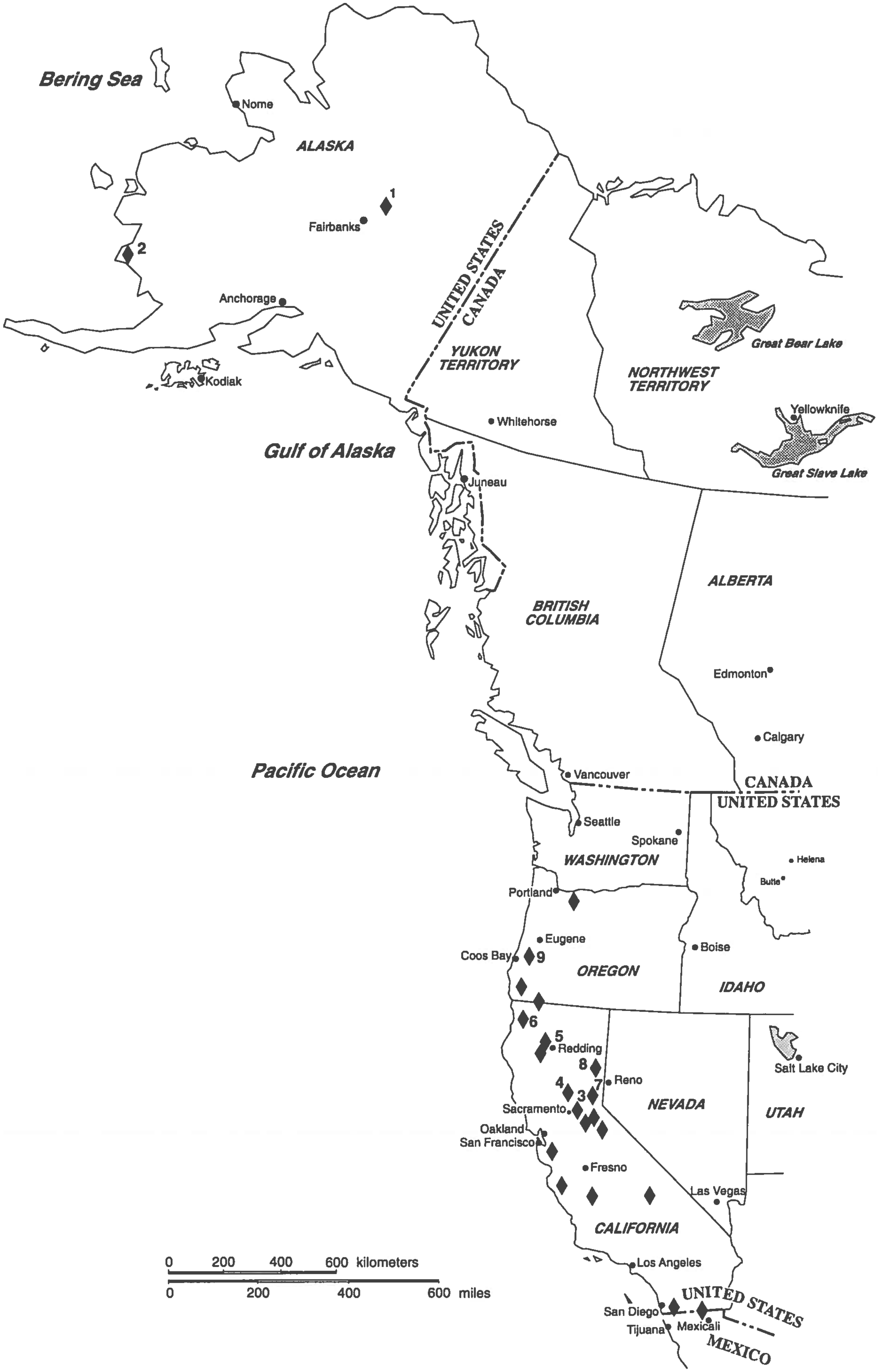

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NORTHWEST TERRITORY
Great Bear Lake
Whitehorse
Yellowknife
Great Slave Lake
Gulf of Alaska
Juneau
BRITISH COLUMBIA
ALBERTA
Edmonton
Calgary
Pacific Ocean
Vancouver
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UNITED STATES
Seattle
Spokane
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Portland
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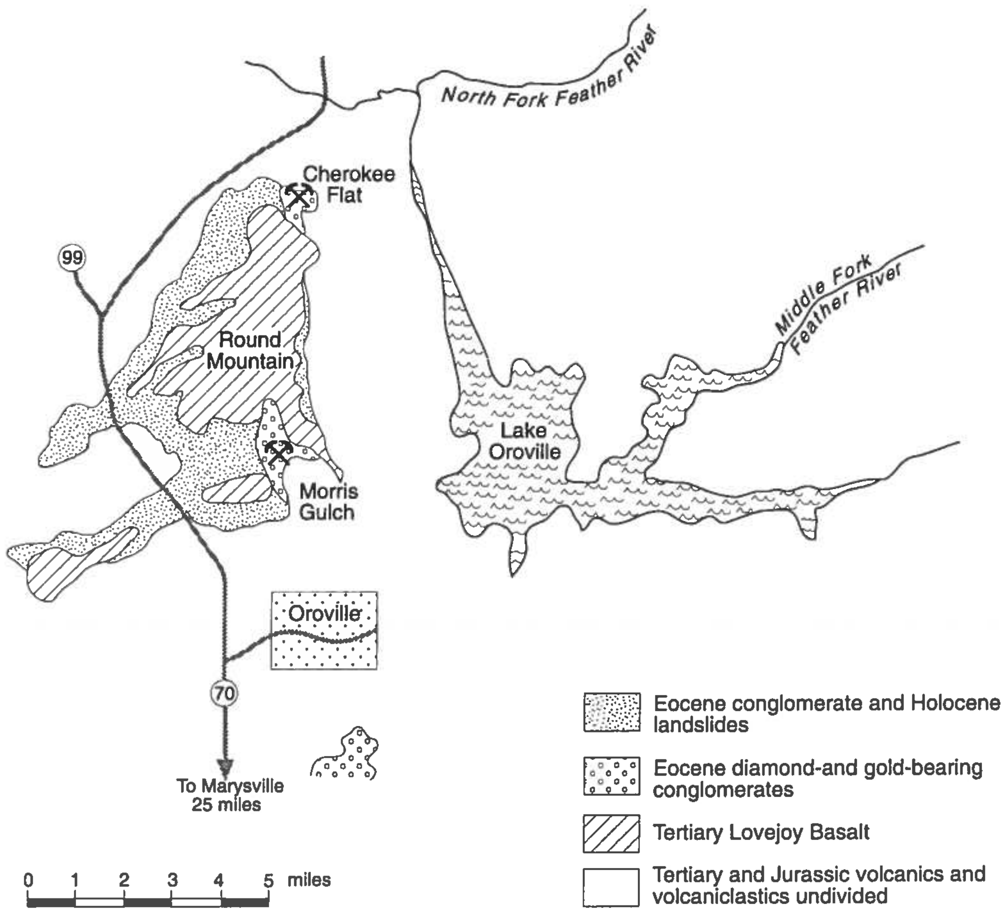
North Fork Feather River
Cherokee Flat
99
Round Mountain
Morris Gulch
Lake Oroville
Middle Fork Feather River
Oroville
70
To Marysville 25 miles
0 1 2 3 4 5 miles
Eocene conglomerate and Holocene landslides
Eocene diamond-and gold-bearing conglomerates
Tertiary Lovejoy Basalt
Tertiary and Jurassic volcanics and volcaniclastics undivided

Fig. 1. Reported diamond localities along the Pacific Coast of the United States. Some of the more interesting occurrences are: 1. Crooked Creek, 2. Goodnews Bay, 3. Placerville area, 4. Oroville area, 5. Trinity River-Hayfork Creek, 6. Smith River, 7. French Corral, 8. Plumas County, and 9. Coos Bay.

Fig. 2. Sketch map of the Oroville area showing the location of Cherokee Flat (from Saucedo and Wagner, 1992).