THE GEOLOGICAL SURVEY OF WYOMING

Gary B. Glass, State Geologist

REPORT OF INVESTIGATIONS No. 31

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by

W.D. Hausel, M.E. McCallum, and J.T. Roberts

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PROLOGUE

In 1870, rumors of diamond discoveries in the Colorado-Wyoming territory initiated the first exploration activity for the precious stones in that region. Two years later, however, these rumors were exposed as "the great diamond hoax". A small area on the Colorado-Wyoming border south of Rock Springs had been salted with hundreds of diamonds, rubies, sapphires, emeralds(?), and, by extraordinary coincidence, pyrope garnets (Lowell S. Hilpert, personal communication, 1983).

More than 100 years later, diamonds were discovered approximately 25 miles south of Laramie, Wyoming near the Colorado-Wyoming state line in a kimberlite diatreme less than 200 miles east of the famous diamond hoax area. The discovery represents only the second authenticated occurrence of diamonds found in place on the North American continent (McCallum and Mabarak, 1976). The first, hosted by an ultrabasic diatreme, was at Murfreesburo, Arkansas (Miser and Ross, 1922).

INTRODUCTION

Only rocks of kimberlitic affinity are known to be primary sources of commercial diamond mineralization. This includes rocks classified as kimberlite, and with recent discoveries of diamondiferous ultrapotassic lamproites in Western Australia, it also includes olivine- and leucite-lamproites (Jaques and others, 1984). Diamond-bearing intrusives at Murfreesburo, Arkansas may also be lamproite (Bolivar, 1984; B.H.S. Smith and Skinner, 1984) although they have been classified by various investigators in the past as kimberlite and peridotite.

Kimberlitic diatremes form pipe-like intrusives that are roughly conical-shaped and taper downward to connect at depth to feeder dikes. Surface exposures of kimberlite range from small dikes, vein-like intrusives, and plugs to the largest known diatreme, slightly more than one mile in diameter.

The known kimberlite occurrences in the Colorado-Wyoming Province range from small dikes, plugs and small diatremes or "blows" to the largest intrusive, the Sloan 1 pipe, which has a 500-foot by 1,800-foot, irregular elliptical-shaped surface exposure. The kimberlite rock is of magmatic origin and contains xenoliths (and cognate nodules) from various depths within the earth's crust and upper mantle. Research has provided evidence that some ultramafic nodules in the kimberlite were formed at depths greater than 120 miles (Eggler and McCallum 1976; McCallum and Eggler 1976; Eggler, McCallum, and Smith 1979). Presumably, the kimberlite magma was generated from even greater depths.

At depths greater than 120 miles, the kimberlite magma source area lies well within the theoretical diamond stability field. However, fewer than ten percent of the known kimberlites worldwide contain diamond and fewer than two percent contain commercial amounts of diamond, i.e., in concentrations ranging from 0.01 ppm to 3.5 ppm (Atkinson and others, 1984).

The stability of diamond is constrained by pressure, temperature, and the oxygen fugacity in the host melt. Thus, the lack of diamonds in the majority of kimberlite occurrences is attributable to (1) an unmineralized mantle source area, (2) the instability of diamond in environments of low pressures and relatively high temperatures that are encountered as the magma ascends to the surface, and (or) (3) the oxidation of diamond to CO_2 under conditions of high temperature and moderate to high oxygen fugacity. Rapid magma ascent and rapid cooling has apparently preserved diamonds in some diatremes. Estimates of minimum magma velocity based on viscosity measurements suggest that kimberlite magmas may rise at velocities as great as 175 feet per second (Gregory, 1984). Some estimates suggest that kimberlite emplacement may have been achieved at velocities as great as Mach 3 (Hughes, 1982). Hughes points out that near-surface temperatures of gas-charged kimberlite melt may be as low as 0°C due to the adiabatic expansion of CO_2 gas; however, estimates of final magma emplacement temperature generally range from 300°C to 600°C (MacGregor, 1970). If kimberlite magma is initially mineralized, preservation of diamonds may be expected, only if the magma is emplaced at high velocity ascending to the surface without delays, and does not become too oxidizing.

Several publications describe efforts to predict diamond content from the chemistry of kimberlite and included xenoliths and xenocrysts, e.g. Dawson, 1968; Gurney and Switzer, 1973; Khar'kiv, 1976; Milashev, 1977; Sobolev, 1977; Pasteris, 1983; and Gurney, 1984. The apparent relationship between diamond content and kimberlite chemistry is an indication that the chemistry at the diamond source within the upper mantle is unique, and is at least in part preserved during ascent and emplacement.

Of about 100 kimberlite occurrences discovered to date in the Colorado-Wyoming Kimberlite Province, more than fifteen are diamond bearing and all of these occur within the State Line District (Figure 1). It is reasonable to expect that more kimberlite will be found in the Colorado-Wyoming Province. Stream sediment sampling by the Geological Survey of Wyoming and the Department of Earth Resources, Colorado State University has produced more than 50 anomalies in the southern Laramie Range. Additional anomalies have been recognized in the Front Range of northern Colorado. Undoubtedly, mining companies have also located numerous anomalies.

Placer diamonds were discovered in a Recent gold placer on Cortex Creek in the Mullison Park area of the northern Medicine Bow Mountains (Hausel, 1977). The source of these diamonds has not been determined. There are also unverified reports of diamonds found in the central Laramie Range, Sierra Madre, northern Wind River Range, South Pass area, Gros Ventre Mountains, and Granite Mountains, Wyoming (Fremont Clipper, 1893; Hausel, 1981), and in the southern Medicine Bow Mountains and Lusk area, Wyoming, and Poudre Canyon, Colorado (verbal reports to M.E. McCallum).

The search for additional diamond-bearing kimberlites in the Colorado-Wyoming region will probably continue for many years. Exploration techniques used to locate diamond pipes include a variety of methods, the most successful of which are stream sediment sampling and detailed geological mapping (Mabarak, 1975; Leighton and McCallum, 1979; Hausel, McCallum, and Woodzick, 1979b; Hausel, Glahn, and Woodzick, 1981).

GEOLOGIC SETTING

The geologic setting of the Colorado-Wyoming Kimberlite Province reflects several orogenic and intrusive events. The basement of the Province is fragmented and deformed, and consists of amphibolite-facies metamorphic assemblages intruded by variably sized plutonic bodies. In the southern portion of the Province, the basement rocks are predominantly 1.7 and 1.4 billion-year-

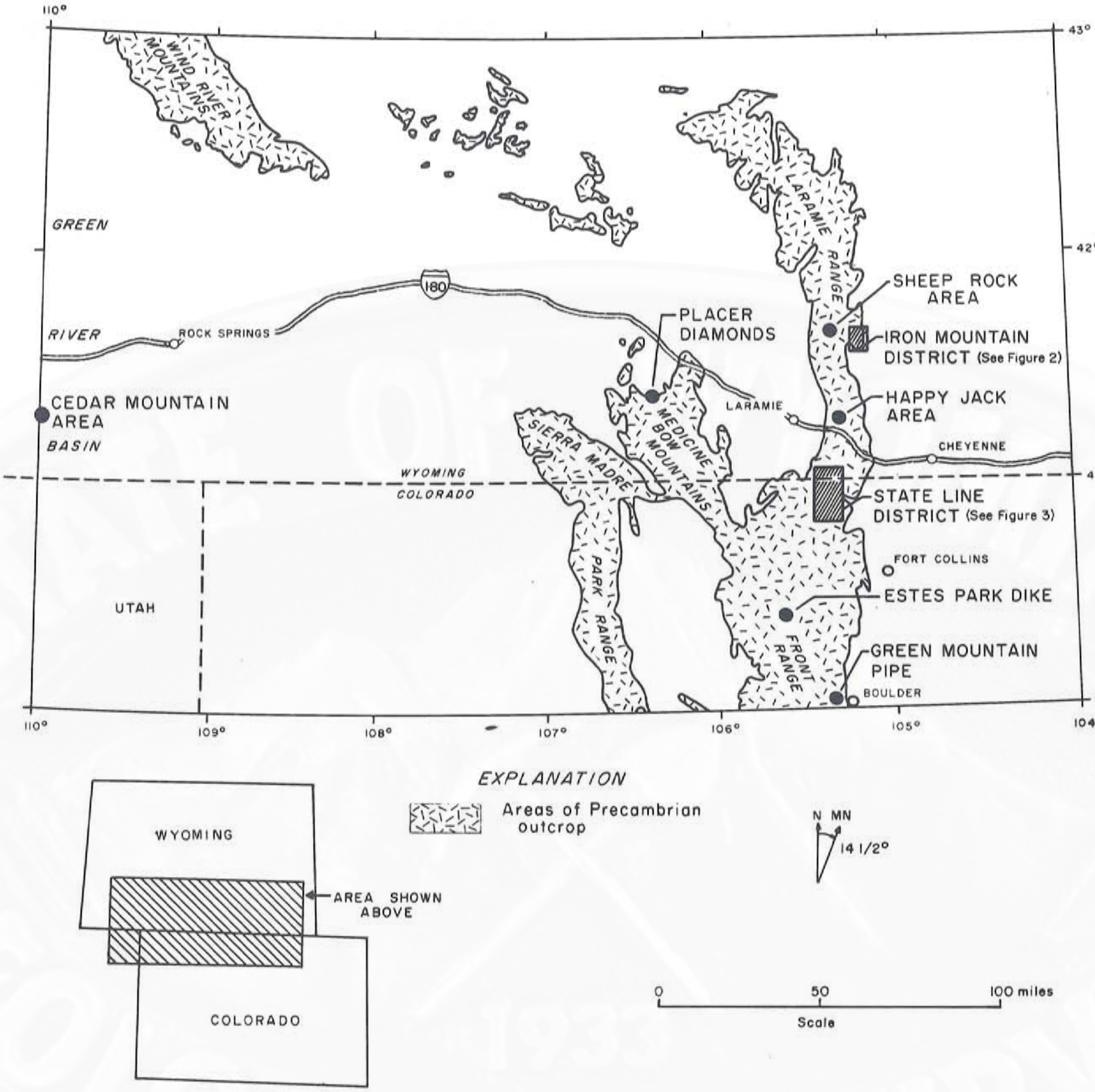

Figure 1. Location map of the Colorado-Wyoming (Devonian) Kimberlite Province and adjacent areas. This province includes single kimberlite intrusives in the Sheep Rock, Estes Park, and Green Mountain areas; at least 57 kimberlite occurrences in the Iron Mountain District and 40 occurrences in the State Line District; and heavy-mineral anomalies scattered throughout the province. Outside the province, placer diamonds in the Medicine Bow Mountains and heavy-mineral anomalies at Cedar Mountain in the Green River Basin are also of interest.

old plutonic rocks and a metasedimentary sequence that is apparently older than 1.8 billion years old (Peterman, Hedge, and Braddock, 1968). To the north, the metamorphics consist of amphibolitized, mafic to intermediate volcanics intruded by granodiorite and quartz monzonite stocks and dikes that are probably similar in age to the metasediments to the south (Klein, 1974; Hausel and Jones, 1982, p. 23-35).

At least two orogenic episodes are reflected in the metamorphic terrain of the Front Range. The first episode occurred at or before 1.8 billion years ago and produced isoclinal folds in the ancient sedimentary pile and was accompanied by regional metamorphism. The second recognized episode occurred 1.7 to 1.8 billion years ago and produced refolding and metamorphic overprinting of the basement and was associated with the intrusion of granitic plutons: the Boulder Creek batholith west of Boulder, Colorado (Peterman, Hedge, and Braddock, 1968) and the Rawah batholith in the western part of the northern Colorado Front Range and Colorado Medicine Bow Mountains (McCallum and Hedge, 1976).

A subsequent major plutonic event began with the emplacement of the Laramie Range Anorthosite Complex 1.4 to 1.53 billion years ago (Smithson and Hodge, 1972). This was followed by the emplacement of the Sherman Granite batholith (including the Trail Creek facies) and Silver Plume batholith (including the Longs Peak and Log Cabin facies) 1.39 to 1.45 billion years ago. Most granite facies and the anorthosite are cut by basalt and (or) andesite dike swarms dated at 1.35 to 1.42 billion years before present (Peterman, Hedge, and Braddock, 1968). Joint sets in the granites apparently controlled the emplacement of these later mafic dike swarms (Hausel, McCallum, and Woodzick, 1979b).

The next recognized orogenic event in the Province occurred during middle to late Paleozoic time. At least by the Mississippian Period, the Ancestral Rockies were uplifted (King, 1977). However, the emplacement of numerous kimberlite intrusives during the Devonian (Chronic and others, 1969; Naeser and McCallum, 1977; Smith, 1979, 1983) required deep fractures in the earth's crust that apparently developed prior to the Ancestral Rocky Mountain uplift. Intensive erosion during Late Devonian and (or) Early Mississippian time removed all traces of the early Paleozoic section except those scattered xenoliths of Silurian, Ordovician, and Cambrian rocks preserved below the Precambrian erosional surface within some kimberlite pipes. Erosion continued through Pennsylvanian and Permian times producing the arkosic sediments of the Fountain Formation presently exposed along the flank of much of the uplifted Front Range and Laramie Range.

Not only were the kimberlite occurrences eroded during the late Paleozoic, but denudation continued during the Late Cretaceous to the early Tertiary Laramide uplift, and has continued to the present time. The amount of kimberlite removed by erosion is not known, but the morphology of many of the kimberlite bodies suggests that several hundred to a few thousand feet may have been eroded (see McCallum and Mabarak, 1976, Figure 6, p. 7).

THE COLORADO-WYOMING KIMBERLITE PROVINCE

The Colorado-Wyoming Kimberlite Province contains approximately 100 kimberlite intrusives in a roughly 120-mile-long, north-south-trending area that extends from Boulder, Colorado in the south to Sybille Canyon in the central Laramie Range in the north (Figure 1). The Province includes five areas or districts where kimberlite has been identified -- the Sheep Rock area, Iron Mountain District, State Line District, Estes Park dike, and Green Mountain pipe -- and one region where a small circular structure was discovered during stream sediment sampling surveys -- the Happy Jack - Pole Mountain area.

Sheep Rock Area

The Sheep Rock area is 45 miles north of the Colorado-Wyoming state line and a few miles south of Sybille Canyon (Figure 1). The area is located within the U.S. Geological Survey Sheep Rock 7-1/2-minute Quadrangle and was mapped following the discovery of a small kimberlite intrusive (Hausel, Glahn, and Woodzick, 1981, plate 2).

This kimberlite is intruded into the Laramie Range Anorthosite Complex, which crops out over a 350-square-mile area in the central Laramie Range. In the immediate vicinity of the ultrabasic intrusive, outcrops of anorthosite and noritic anorthosite are extensive, and both rock types are cut by numerous granitic dikes and pegmatitic phases of the Sherman Granite batholith.

A single, small kimberlite plug or "blow" occurs as a 40-foot-diameter outcrop on the west flank of Middle Sybille Creek. This dense, porphyritic kimberlite occurrence was named the Radichal kimberlite after the present land owners (Hausel, Glahn, and Woodzick, 1981). Both magnetic and electromagnetic surveys indicate that this intrusive is magnetic (700-gamma-plus anomaly) and weakly conductive (Hausel, Glahn, and Woodzick, 1981; Memmi, McCallum, and Hausel, 1983). More than 500 pounds of rock from the Radichal kimberlite were collected by the Geological Survey of Wyoming. This material was tested for diamond mineralization, but no diamonds were identified.

Thirty stream sediment samples collected along Middle Sybille Creek and its tributaries contain various amounts of chromian diopside, pyrope garnet, and picro-ilmenite (heavy mineral indicators of kimberlite). These anomalous samples extend 3.5 miles downstream and 4 miles upstream from the Radichal kimberlite on three separate tributaries. Our inference is that more than one kimberlite intrudes the anorthosite at Sheep Rock.

Kimberlitic heavy mineral indicators are restricted in transport distance. For example, Leighton and McCallum (1979) concluded that, within the State Line District, the transportation distances of chromian diopside, pyrope garnet, and picro-ilmenite grains of greater than 1.5 mm diameter are 0.25 mile, 1 mile, and 1.5 miles, respectively. Greater transportation distances result in greater disintegration due to abrasion. Such results applied to the Sheep Rock area suggest the presence of several ultrabasic intrusives both up and down drainage from the Radichal plug.

Iron Mountain District

The Iron Mountain Kimberlite District is approximately six miles southeast of the Sheep Rock area, near Farthing, Wyoming. This district includes 57 kimberlite occurrences which intrude rocks of the Sherman Granite batholith (Smith, 1977; McCallum and Smith, 1978). Kimberlite at Iron Mountain occurs as structurally controlled "feeder dikes" and "blows" that represent the root zones of diatremes (Smith and others, 1979). The district was named after the Iron Mountain Titaniferous Magnetite District located four miles southwest of the known kimberlites.

The Iron Mountain District is situated within a south-plunging anticlinorium, the core of which is Precambrian Sherman Granite. Mississippian and younger sedimentary rocks nonconformably overlie the granite and flank the structure. On the northeastern side of the district, Sherman Granite has been thrust over Paleozoic rocks (Figure 2). The western side of the district is bounded by a south-plunging, asymmetri-

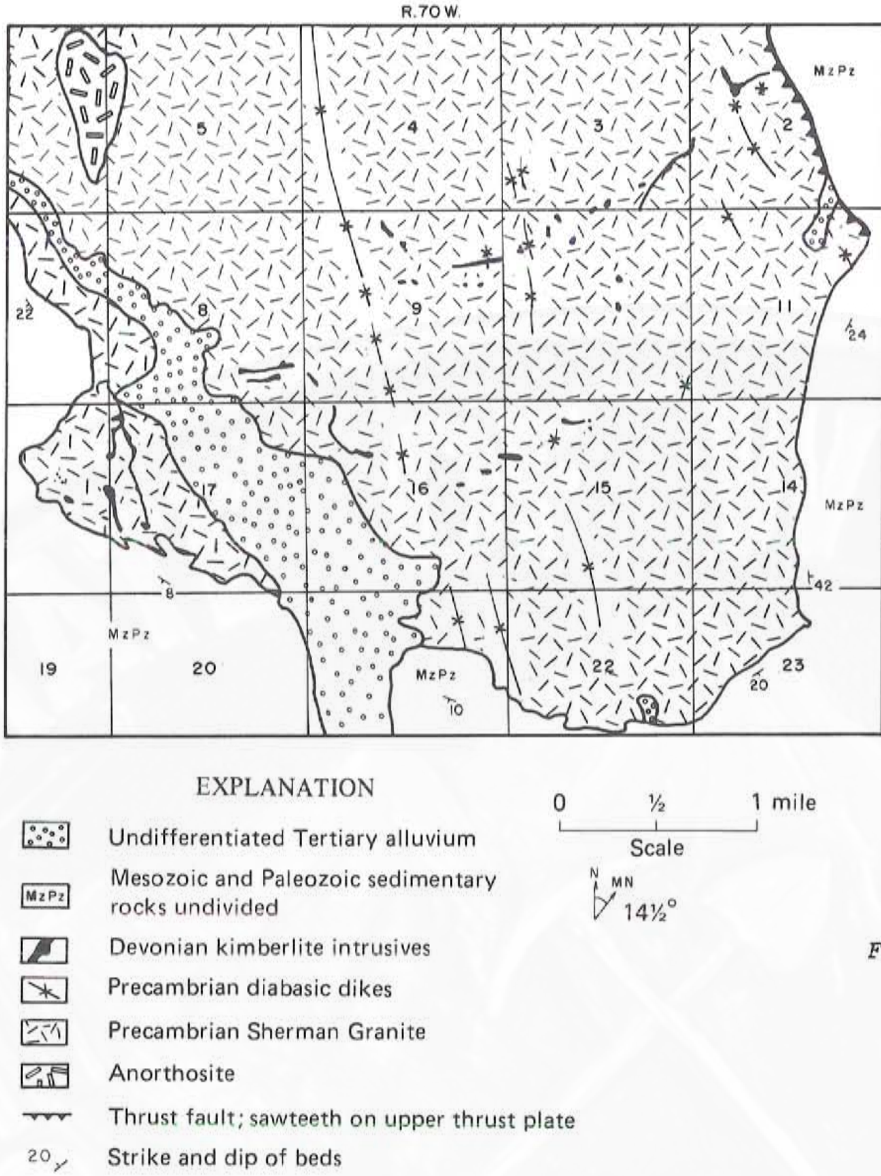

Figure 2. Generalized geologic map of the Iron Mountain district (T.19N., R. 70W.), after Smith, 1977. The synform in Paleozoic rocks, described in the text, is just west of the map area.

cal syncline in Paleozoic rocks that separate the Laramie Anorthosite and the titaniferous magnetite deposits on the west from the Iron Mountain Kimberlite District on the east (Smith, 1977). The Sherman Granite intrudes the Laramie Anorthosite (Peterman, Hedge, and Braddock, 1968), and anorthosite xenoliths occur locally in the granite.

Several late Precambrian diabasic and granitic dikes with general north-northwesterly trends intrude the Sherman Granite in the district. Some northeast-trending shear zones, probably of late Precambrian age, are evident in the northwestern corner of the district. Most structural features in the district apparently are Precambrian, although later east-west compressional deformation of Laramide age has complicated the structural trends.

The distribution of the Iron Mountain kimberlites defines a general northeasterly trend, and occurrences have been located over a distance of five miles. This northeasterly trend bisects the core of the anticlinorium. Individual kimberlite dike systems in the southwestern half of the district diverge from the overall trend and exhibit a predominantly north-northwest alignment. Individual dike systems in the northeastern half of the district trend east to northeast. Kimberlite dikes in the southwestern corner of the district project under the sedimentary cover, the oldest units of which are Mississippian. (Smith, 1977).

Although fifty-seven kimberlite occurrences have been mapped in the district, many "blow-like" features or enlargements along dikes are portions of the same dike system. Outcrops are scarce, but many of the dikes and "blows" can be mapped as continuous features on the basis of bluish-gray soil (blue ground), typical kimberlitic minerals (chromian diopside, pyrope garnet, and picro-ilmenite), fragments of serpentinized or carbonatized kimberlite and (or) peridotite, and vegetative and topographical differences. Most dike systems are traceable for several feet to several yards along the surface, and one dike extends nearly one mile.

A number of mined-out kimberlite pipes in South Africa have been observed to taper down and merge with dikes at depth. The pipes (diatremes) apparently originate from dikes located 6,000 to 10,000 feet below the surface, and extend upward as somewhat funnel-shaped structures. According to theoretical data and to observation, the maximum depth from the surface exposure of a diatreme to its "dike-feeder" system is 6,000-10,000 feet (Dawson, 1971; Frantsesson and Boris, 1983). Such a kimberlite-pipe model suggests that the linear dike systems with small "blow" enlargements at Iron Mountain represent deeply eroded "root zones" of diatremes.

No diamonds have been reported from the Iron Mountain kimberlites. Even if the original diatremes in the district were diamond bearing, they have been so deeply eroded that their richest portions would have long since been removed. Diamondiferous paleoplacer and placer deposits derived from this district are possible if some Iron Mountain kimberlites were diamondiferous. But because post-Devonian fluvial strata are generally absent in the region, there is little likelihood of finding such deposits.

State Line District

The State Line District is named for its location on the Colorado-Wyoming state line (Figure 1). The district, which covers about 80 square miles, extends 2.6 miles north into Wyoming and 12 miles south into Colorado and is approximately 6 miles wide (Figure 3). Some early prospecting in the district was conducted for potash feldspar, copper, zinc, and radioactive minerals (Sims and others, 1958; Osterwald and others, 1966), but there are no known authenticated reports of diamond discoveries prior to 1975. Kimberlite in the State Line District was first recognized by M.E. McCallum in 1964. Several studies followed because of the district's scientific and economic interest.*

The State Line District is dominated by a nearly-nine-mile-diameter, concentric structure known as the Virginia Dale ring-dike complex (Figure 3). The complex is considered by Eggler (1968) to be part of the Sherman Granite batholith that discordantly intrudes a sequence of folded metamorphic rocks, although recent work by Moll (1982) suggests that the complex may be com-

*These studies variously emphasized heavy mineral prospecting (Mabarak, 1975; Leighton and McCallum, 1979; Hausel and others, 1982; Brink, Albert, and Hausel, 1983; McCallum and Lincoln, 1983), remote sensing (McCallum, 1974; Marks and Marrs, 1983; Marrs, 1984; Marrs and others, 1984; Marks, 1985), geophysics (Puckett, 1971; Puckett and others, 1972; Hausel, McCallum, and Woodzick, 1979a, 1979b; Hausel, Glahn, and Woodzick, 1980, 1981; Carlson, 1983; Memmi, McCallum, and Hausel, 1983; Paterson and MacFadyen 1984), geology and geochemistry (Eggler, 1967, 1968; Chronic and others, 1969; McCallum and Eggler, 1971, 1979; McCallum, Eggler, and Burns, 1975; McCallum and others, 1977; McCallum and Mabarak, 1976; McCallum, 1979; Hausel, Glahn, and Woodzick, 1981), and mineralogy and petrology (Eggler and McCallum, 1973, 1974, 1976; McCallum, 1976; McCallum and Eggler, 1971, 1976; McCallum, Eggler, and Burns, 1975; McCallum, Mabarak, and Coopersmith, 1979; McCallum, and Mabarak, 1976; McCallum and Smith, 1978; Smith and others, 1979).

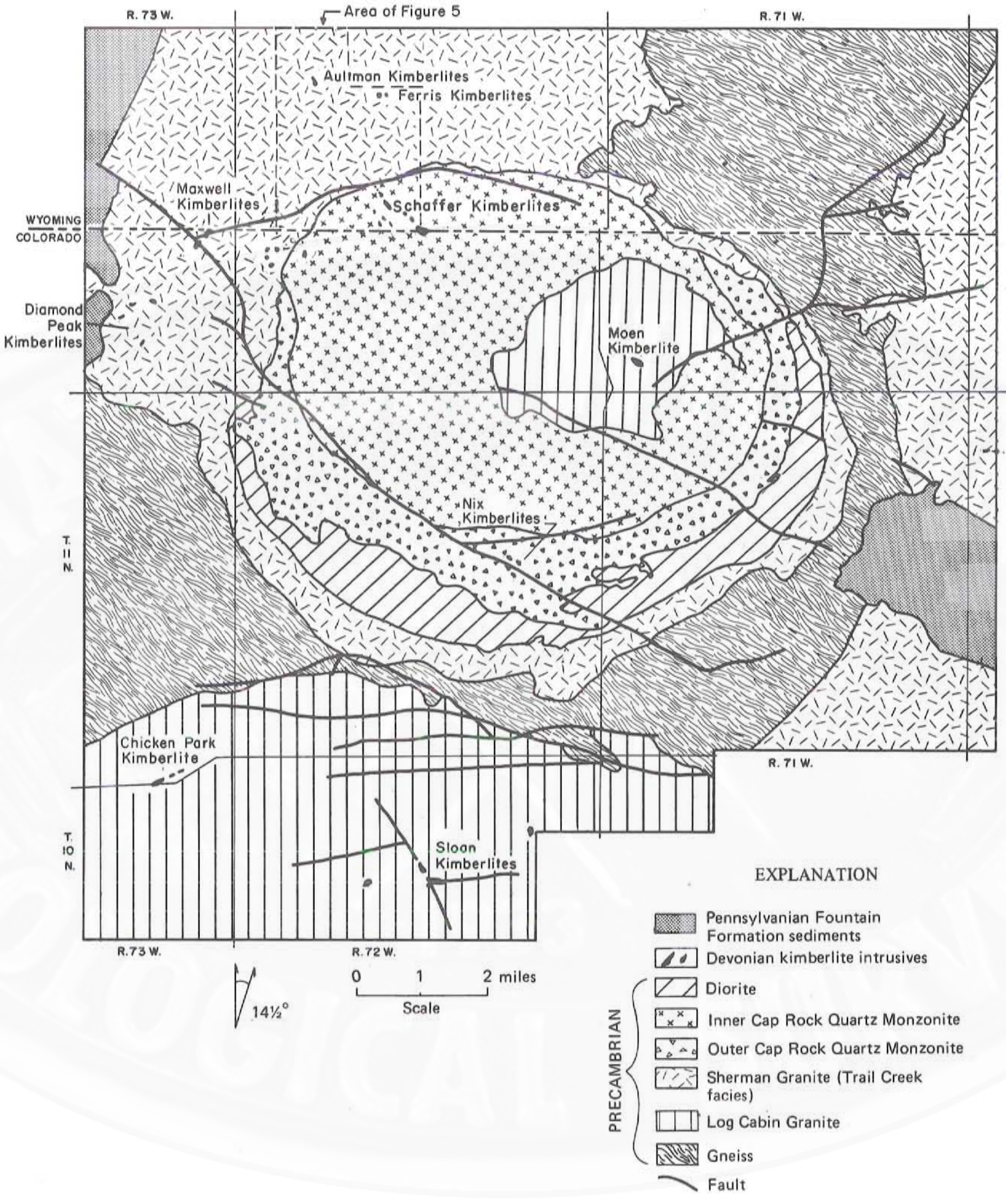

Figure 3. Generalized geologic map of the State Line District, Colorado- Wyoming, showing the Virginia Dale ring dike complex, after Eggler, 1967. Kimberlite locations from Marks, 1985, Figure 4.

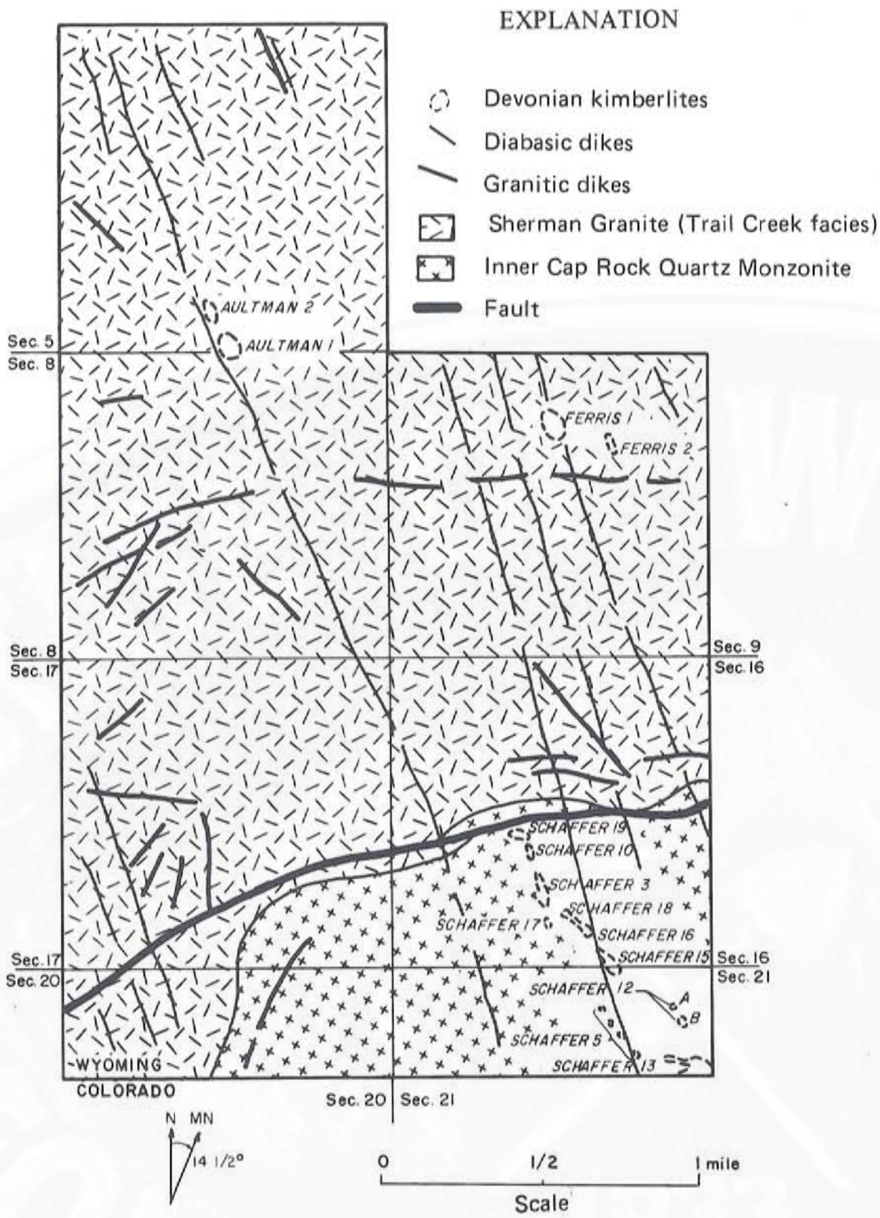

Figure 4. Generalized geologic map of the Wyoming portion (T.12N., R.72W.) of the State Line District, modified from Hausel, Glahn, and Woodzick, 1981, Plate 1. Recent tests of several of the intrusives shown on the map have resulted in the determination of low-grade diamond resources.

posed predominantly of Log Cabin granite. Eggler (1967, 1968) divides the complex into four zones: an outer ring dike, composed of the Trail Creek granite facies of the Sherman Granite which continues northward as a batholith; a composite zone of diorite, andesite (basalt), and metamorphic rocks [called diorite in Figure 3]; and two inner ring dikes of biotite quartz monzonite [Outer Cap Rock and Inner Cap Rock Quartz Monzonite in Figure 3]. South of the ring-dike complex is the Log Cabin granite batholith, which locally intrudes granite of the Sherman batholith.

Diabasic (basalt) dikes (see Figure 4) similar in composition to the Iron Mountain diabasic dikes crosscut metamorphic rocks and granites of the Sherman and Log Cabin batholiths. Similar dikes occur at least as far south as Golden, Colorado (120 miles south of the state line) and as far north as the Iron Mountain District, Wyoming. In many places, single dikes are traceable for more than one mile, both on the ground and on aerial photographs. These dikes trend north-northwest, are very linear, and reflect joint control (Eggler, 1967, 1968; McCallum and Mabarak, 1976; Hausel, McCallum, and Woodzick, 1979b). The diabasic and granitic dikes were apparently emplaced during igneous activity associated with and following intrusion of the Log Cabin and Sherman granites, and have roughly similar radiometric dates of 1.42 billion years; (Ferris and Krueger, 1964).

The sedimentary rocks nearest to the State Line District are sediments of the Pennsylvanian Fountain Formation. These nonconformably overlie Precambrian crystalline rocks north, east, and west of the district.

Approximately 40 kimberlite diatremes and dikes are known in the State Line area, and they range in size from a few feet wide (dikes) to nearly 1,800 feet in maximum dimension for the two largest diatremes (Sloan 1 and Schaffer 13 pipes) (McCallum and others, 1977). Buried or "blind" diatremes may be present along the northern edge of the district in the vicinity of the Aultman and Ferris diatremes. Airborne magnetic surveys have identified an east-west-trending group of pipe-like structures that are interpreted to lie near surface and to depths greater than 950 feet (Paterson and MacFadyen, 1984). A few kimberlites in the Colorado portion of the district show definite fault control, e.g. the Nix pipes and Sloan 1 and 2 pipes (Eggler, 1967; McCallum and Eggler, 1971; McCallum, Eggler, and Burns, 1975). Some of the Schaffer pipes in the northern half of the district (Figure 4) are aligned in a northwesterly direction several degrees oblique to the pervasive joints, suggesting that the reactivation of Precambrian structures may not have been important to the emplacement of these pipes. East of the Aultman pipes, the Ferris 1 diatreme cuts a Precambrian diabasic dike, suggesting that this older linear structure may have played a role in the emplacement of this pipe.

In general, outcrops of kimberlite are rare. Mapping is generally based on the presence of weathered kimberlite, blue ground, numerous mantle megacrysts, mantle and crustal nodules, vegetation differences (McCallum, 1974; McCallum and Mabarak, 1976; Hausel, McCallum, and Woodzick, 1979b; Hausel, Glahn, and Woodzick, 1981), and conductivity differences (Puckett, 1971; Puckett and others, 1972; Hausel, McCallum, and Woodzick, 1979a, 1979b; Hausel, Glahn and Woodzick, 1980, 1981; Carlson and McCallum, 1982; Carlson, 1983; Carlson and others, 1984). Alteration of host granite by kimberlite magma is minor to absent.

The State Line kimberlite outcrops commonly are elongate to ellipsoidal. The sizes of diatremes indicate that they are not as deeply eroded as the Iron Mountain kimberlite bodies. Two thousand to three thousand feet of vertical pipe column material (including the lower Paleozoic strata which covered the Precambrian crystalline rocks at one time) may have been removed by erosion (see McCallum and Mabarak, 1976, Figure 6, page 7). However, the presence of numerous Paleozoic xenoliths in the Ferris 1 pipe and its circular shape, suggest that this diatreme may not be as deeply eroded.

Many State Line kimberlites have been tested for diamonds by sampling the kimberlitic eluvium over the pipes. At least 15 pipes are known to be diamondiferous (McCallum and others, 1977; McCallum, Mabarak, and Coopersmith, 1979). Placers and paleoplacers in the State Line area have not been tested for diamonds.

Estes Park Dike

The Estes Park kimberlite dike, discovered by J.C. Cole in 1975, is located a short distance south of the town of

Estes Park, Colorado. The dike is approximately one to two yards wide, trends in a northerly direction, and has been traced about one quarter mile. The dike is composed of phlogopite-calcite-serpentinite kimberlite and is characterized locally by rounded megacrysts (1-5 centimeters in diameter) of partially chloritized phlogopite. Both megascopic and groundmass phlogopite have been dated by the Rb-Sr method as Devonian (Smith, 1979). Preliminary testing of the Estes Park kimberlite dike has failed to yield any diamonds.

Green Mountain Pipe

Immediately west of Boulder, Colorado, the Green Mountain pipe intrudes granite of the Boulder batholith. The initial discovery of the pipe was made by Whitaker (1898), who recognized its unusual characteristics and classified the feature as an olivinite dike with associated "picrotitanite" and pyrope garnet. The pipe was not classified as kimberlite until the late 1960's (Kridelbaugh and others, 1972; Boctor and Meyer, 1979). The pipe measures approximately 130 feet in diameter, is roughly circular in plan, and shows a distinct outline by a thicker vegetation cover than that which covers the host granite (Whitaker, 1898; Padgett, 1985). Whitaker reported that specimens of the same material were collected up to six to eight miles west of the pipe, but reconnaissance stream sediment exploration in the area by Padgett has failed to establish any such occurrences.

An attempt to date the age of intrusion was made by Kridelbaugh and others (1972) by using paleomagnetic data. Their data proved ambiguous, apparently because of rotation of the pipe during Laramide disturbances. A Devonian fission-track date on sphene from a granulite nodule in the Green Mountain kimberlite (Larson and Amini, 1981) is compatible with established ages of Front Range kimberlites (Naeser and McCallum, 1977; Smith, 1979).

Happy Jack-Pole Mountain Area

The Happy Jack - Pole Mountain area is located between Cheyenne and Laramie, Wyoming, in T.15N., R.70-72W., and is accessible from Interstate 80 or State Highway 210. The region is underlain by Sherman Granite, and exploration is hindered by thick lodgepole and aspen forests and by numerous beaver ponds.

A small circular structure, approximately 120 feet in diameter was discovered in this region during stream sediment sampling exploration. The structure has characteristics of some of the diatremes in the State Line District. It has a well developed vegetation anomaly and is controlled by a north-northwest-trending lineament. Electromagnetic and magnetic surveys show that the structure is weakly conductive and magnetic. Investigations are continuing.

OCCURRENCES OUTSIDE THE COLORADO-WYOMING KIMBERLITE PROVINCE

Medicine Bow Diamond Placer

Two diamonds, 1.5 and 3.0 mm in average diameter, have been found in stream sediment concentrates from a placer gold operation along Cortex Creek in the Mullison Park area, T.17N., R.81W., 20 miles east of Saratoga, Wyoming (Paul Boden, personal communication, 1977). These two diamonds were identified by x-ray diffraction at the Geological Survey of Wyoming's mineral laboratory. The larger diamond has a yellow tint, and the smaller is a clear octahedron with only minor inclusions. The two diamonds weigh 20.03 mg (0.1 carat) and 6.94 mg (0.035 carat) (Hausel, 1977).

In the Mullison Park area, undivided Tertiary sediments unconformably overlie Precambrian rocks. The Tertiary sediments in the park and along Cortex Creek were derived from adjacent and underlying Precambrian terrain and contain boulders and pebbles of quartzite, quartz, granite, gneiss, and diabasic rocks. No kimberlite has been recognized in the area, and the diamond source is not known. The problem is complicated by the presence of the Tertiary sediments as well as Proterozoic fluvial quartz-pebble conglomerate in the Gold Hill District to the southeast (Karlstrom and Houston, 1979). These metaconglomerates in the Sierra Madre and the Medicine Bow Mountains contain paleoplacers of uranium, thorium, and, locally, gold (Houston and Karlstrom, 1979; Karlstrom and others, 1981; Hausel and Harris, 1983), and the diamonds conceivably could have been derived from this source although the Tertiary sediments are also a potential source.

Cedar Mountain, Green River Basin

The Cedar Mountain area of the southern Green River Basin contains a six- to eight-square-mile region, in T.15N., R.111-112W., in which ant hills contain anomalous lower crustal - upper mantle megacrysts (pyrope garnet and chromian diopside) (McCandless, 1982, 1984; McCandless and Nash, in preparation). No diamonds have been identified, but only small samples from isolated sites have been tested (Hausel and others, 1982). The source area for these detrital minerals has not been determined.

DIAMOND TESTING

The Department of Earth Resources at Colorado State University and the Geological Survey of Wyoming are testing selected pipes for diamonds, but large-scale testing for economic potential is not feasible for either of these state institutions. Large-scale assessment has been conducted in the Colorado-Wyoming State Line District by Cominco American Incorporated and by Superior Minerals Company. Testing by the mining companies involves large bulk samples, concentrated and processed using Sortex X-ray separators and grease tables.

Testing at Colorado State University generally involves samples of less than 100 pounds of deeply weathered kimberlite. A sample is sieved to greater-than-3.3 mm, 3.3-1.5-mm, and less-than 1.5-mm fractions. The greater-than-1.5 mm fractions are examined visually for diamond and the less-than-1.5-mm fraction is sluiced (procedure described in McCallum and Mabarak, 1976, p. 22). The sluiced concentrate is further separated by a heavy liquid process and the resulting concentrate is dried and subjected to an acid bath treatment in 52 percent hydrofluoric acid for a period of two to four weeks. The acid is changed every four or five days. Residual material is examined under a microscope and under ultraviolet light for

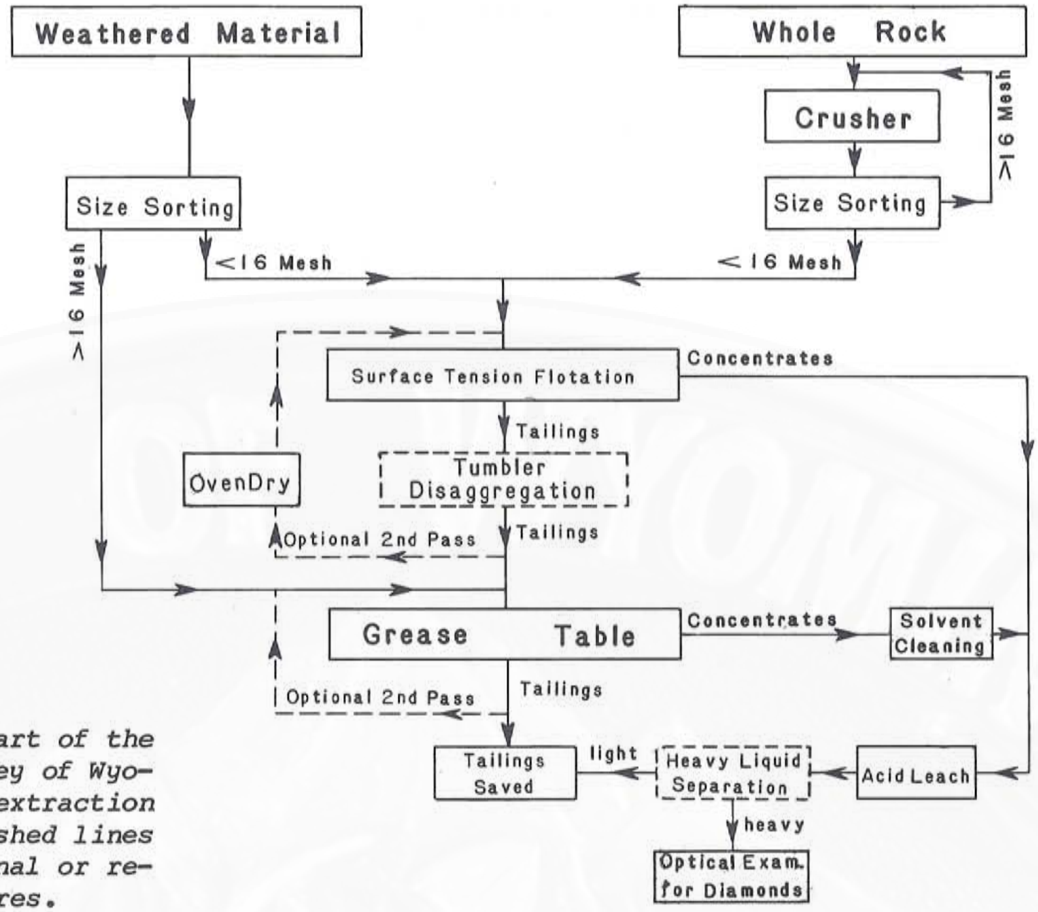

Figure 5. Flow chart of the Geological Survey of Wyoming's diamond extraction laboratory. Dashed lines represent optional or redundant procedures.

diamonds, which are hand picked from the sample.

Testing by the Geological Survey of Wyoming involves samples of as much as 500 pounds of weathered or whole-rock kimberlite (Figure 5). Weathered material is generally sorted into four or more size fractions. Coarse rock fragments may be crushed to less-than-16-mesh (1.19 mm) size and processed along with the rest of the sample. Whole-rock samples are crushed to less-than-16-mesh (1.19 mm) size and then further sorted into four or more size fractions. Samples are sorted on a mechanical sieve shaker with 8-inch-diameter, wire-mesh sieves. The size sorting facilitates an even, constant feed rate through the extraction apparatus. Separation into four size fractions using 16-, 40-, 70-, and 120-mesh (1.19, 0.42, 0.21, and 0.125 mm) sieves generally is adequate.

A limited amount of testing has been done using a tumbler to further disaggregate crushed rock samples. A round, five-gallon bottle is filled about half full with kimberlite and several pounds of steel shot (size BB, 0.18-inch diameter). The bottle is filled two-thirds full of water and placed on motor-driven rollers for 24 to 100 hours. After the shot is separated on a coarse wire mesh, the tumbled kimberlite is processed for diamonds. The effectiveness of the tumbling process has not been thoroughly evaluated, but the rather large amounts of mud and silt generated during the process is evidence that a degree of disaggregation does take place. Microscopic examination of such material tumbled for 70 hours does not show any appreciable particle size reduction, and only slight rounding of particles occurs. A diamond fragment tumbled in this same material was recovered by surface tension flotation and did not show any evidence of wear.

Surface Tension Flotation

Size fractions less than 16 mesh (1.19 mm) are fed to a surface tension (skin) flotation device which is designed to "float" small diamonds on the surface tension of water while allowing the water-wettable gangue to sink. The apparatus was built at the Wyoming Geological Survey and consists of a bucket about 10 inches in diameter and 12 inches deep with a water inlet in the base. After the bucket is filled with water and the top surface is leveled, a gentle stream of water rises from the inlet and flows radially over the edge of the bucket. A dry sample is fed from a vibrating disk suspended 4 to 10 millimeters above the water surface. As the sample falls off the disk onto the water below, most of the water-wettable gangue readily sinks to the bottom of the bucket while the nonwettable diamond is suspended by the surface tension of the water. The flow of water carries the diamond over the edge where it is caught in a concentrate pan fitted with a fine-mesh sieve at the water outlet.

In tests using a kimberlite matrix salted with freshly broken diamond fragments 0.65 to 1.3 mm in average diameter, 86 percent of the diamond fragments were recovered with this equipment. Other tests were performed to estimate the maximum distance that a diamond could be dropped before breaking the surface tension of flowing water. All freshly broken diamond fragments of 0.7 to 1.8 mm average diameter were caught in the surface tension (of flowing water) when dropped from heights of as much as 20 mm. A 1.5 mm, octahedral crystal dropped from a height of 10 mm floated in 83 percent of the trials; but when dropped from a height of 15 mm, it broke the surface tension and sank every time.

Grease Table

The grease table used in the Geological Survey's laboratory has five steps, each of which is five inches deep and 29 inches wide, set on risers two inches high. The table, set with the steps nearly horizontal, is mounted to a Wilfley Table drive head which imparts a side-to-side shaking motion. The steps are covered to a depth of one quarter to one half inch with a 10:1 mix of Vaseline and paraffin. A sample is mixed in a water stream at a constant temperature of 20°C and fed onto the top step of the table. As the sample flows across the greased steps, diamonds, being non-wettable (lyophobe) and grease attractive, tend to adhere to the grease while the water-wettable (lyophile) gangue is washed off the table into a tailings bin. The grease surface is skimmed frequently to collect any diamonds that have adhered to it -- preventing them from being swept off by the sample flow and lost in the tailings. The skimmed grease is melted in a tall beaker, and all mineral matter allowed to settle until the liquid is clear. The bottom and walls of the beaker are then chilled by immersion in cold water, so that the bulk of the grease can be removed without loss of the diamond concentrate. The remainder of the grease is removed by washing with organic solvents, followed by boiling in a solution of sodium hydroxide or sodium carbonate.

Tests of grease table recovery rates using kimberlite salted with diamond fragments and with octahedral and cubic crystals 0.65 to 2.0 mm in average diameter have given an overall recovery rate of 83 percent. Of the diamonds recovered in the tests, 90 percent adhered to the uppermost step of the table. Diamond fragments less than 1.0 mm in average diameter accounted for roughly two thirds of the losses. For sizes larger than 1.0 mm, there was no significant difference in the recovery rate of fragments versus whole crystals.

During the tests, the location of diamonds adhering to the grease was noted, and additional samples were run for up to one hour without the diamonds being dislodged.

Final Concentration

A concentrate obtained from the grease table or skin flotation unit contains considerable gangue, which is removed by adding hydrofluoric acid and aqua regia and heating over a steam bath for several days. The liquid is then carefully decanted through 325-mesh (0.044 mm) polyester sieve cloth. Calcium fluoride commonly precipitates from the hydrofluoric acid solution and is removed with a solution of ammonium hydroxide. The concentrate is then washed several times in distilled water and dried in a warm oven. At this stage, the concentrate consists mainly of zircon, garnets, diopside, oxides, and diamonds. If considerable low-density material is present, it can be floated off in a heavy liquid such as bromoform or diiodomethane. Finally, diamonds are extracted from the concentrate by hand, under a microscope.

ECONOMICS

Most of the Colorado-Wyoming kimberlite occurrences in the State Line District have been examined for diamond content. At least 15 kimberlites in the district have been found to be diamondiferous.

Cominco American Incorporated has examined several kimberlites in the Wyoming portion of the Colorado-Wyoming State Line District for commercial mineralization. A total of 8,800 short tons of kimberlite from the Aultman 1 and 2 pipes and the Schaffer 3, 5, 10, 12, 13, 15, 16, 17, 18, and 19 occurrences (Figure 4) were tested. Samples were processed through a heavy-media separation plant prior to extraction of diamonds from the concentrates with a Sortex X-ray separator. These preliminary tests indicate diamond grades of 0.005 to 0.01 carat per ton, with a gemstone-to-industrial stone ratio similar to many South African occurrences (Lincoln, 1983). In weight, the largest diamonds are nearly a carat, and maximum diameters are 6 to 8 mm (Lincoln, 1983). Although more detailed testing may reveal higher grade diamonds (thorough economic evaluation generally requires 10,000 to 50,000 tons per intrusive), it is doubtful that the grade of mineralization would increase substantially. Testing of the Sloan 1 and 2 pipes in Colorado by Superior Minerals Company has produced reported grades of 0.2(?) carat per ton (Gold, 1984).

Economic grades for diamond pipes worldwide are as low as 0.1 carat per ton and as high as the 6.8 carats per ton reported for the incredibly rich diamondiferous lamproites in Western Australia (Engineering and Mining Journal, November 1983, p. 120). On the basis of testing by Cominco American Incorporated and comparison with economic pipes worldwide, the State Line kimberlites represent a low-grade diamond resource with subeconomic mineralization.

Possible diamond placers in alluvial gravels and in paleoplacers hosted by Tertiary fluvial sediments and by the Fountain Formation arkoses have not been investigated to date. If several hundred to a few thousand feet of kimberlite have been eroded from the Colorado-Wyoming intrusives, it is probable that the richest portions of the pipes have been eroded and their diamonds transported to placer traps. The lack of reported placer diamond finds in this region is somewhat discouraging; it may reflect poor placer development or inadequate prospecting. This district clearly has not been prospected to the extent and in the detail that the gold placer fields of California were. There, numerous diamonds were discovered during historic placer gold mining.

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