WYOMING STATE GEOLOGICAL SURVEY

DIAMOND EXPLORATION TARGETS IN THE WYOMING CRATON, WESTERN UNITED STATES

by

W. Dan Hausel, Richard E. Kucera, Tom E. McCandless, and Robert W. Gregory

MINERAL REPORT MR97-2

1997

This report has not been reviewed for conformity with the editorial standards of the Wyoming State Geological Survey.

DIAMOND EXPLORATION TARGETS IN THE WYOMING CRATON, WESTERN UNITED STATES

by

W. Dan Hausel[1], Richard E. Kucera[2], Tom E. McCandless[3], and Robert W. Gregory[1]

[1] Wyoming State Geological Survey, Laramie, Wyoming.
[2] Consulting Geologist, Bellingham, WA.
[3] Center for Mineral Resources, Department of Geosciences, University of Arizona, Tucson, AZ.

ABSTRACT

The Wyoming craton in the western United States, is considered to be a favorable terrane for the discovery of diamonds deposits. The craton hosts a variety of ultramafic, ultrabasic, and ultrapotassic rocks, many of which have potential to host diamonds, and several of which are known to be diamondiferous.

The Wyoming craton includes two provinces: (1) the Wyoming Province and (2) the Colorado Province. The Wyoming Province consists of a stable Archean basement underlying much of Montana and Wyoming and extends into the adjacent states of Colorado, Utah, Idaho, and Nevada. The province continues north into southernmost Alberta and Saskatchewan. The Colorado Province is a cratonized Proterozoic basement terrane that underlies much of Colorado and a small portion of southeastern Wyoming. Although most exploration geologists would consider the Wyoming Province the most favorable terrane for commercial diamond deposits based on age, the Colorado Province has so far been the most productive province in the United States for diamonds.

The presence of numerous kimberlitic indicator mineral anomalies in stream sediments, anthills, and paleoplacers, and the occurrence of some geophysical and remote sensing anomalies within the Wyoming craton, suggest the possibility of many undiscovered, mantle-derived, igneous rocks of kimberlitic affinity, and that the known kimberlite, lamproite, and diamond fields will probably be extended with continued exploration.

INTRODUCTION

In 1996, a commercial diamond industry was finally established in the Wyoming craton after more than two decades of exploration and research activity. This event followed the commissioning of the Kelsey Lake diamond mine by Redaurum Ltd. along the Colorado-Wyoming border, which became North America's first diamond mine since 1906. The mine lies along the border with much of the mine in Colorado, and a small portion in Wyoming. Although nearly all of the production has been from the Colorado side, diamonds have been mined from both states.

In 1977, when the senior author began his career at the Wyoming State Geological Survey (WSGS), a commercial diamond mine in the Colorado-Wyoming region was not even considered a remote possibility by anyone, even though tiny microdiamonds had been accidentally discovered two years previously in a serpentinized garnet peridotite xenolith collected from a Wyoming kimberlite by M.E. McCallum from Colorado State University. Nearly everyone thought this was nothing more than a scientific curiosity. However, Daniel N. Miller, Jr., the former Wyoming State Geologist, had the foresight to establish a diamond research program for the State, in case of the remote possibility that a commercial diamond deposit might be found.

Following the initial investigations of the district by the WSGS in the late 1970s, the State of Wyoming received exploration proposals from five companies. Since the initial five proposals were received, Wyoming and Colorado have been explored by more than 30 companies, and more than 120,000 gem and industrial quality diamonds have been recovered including some of the largest stones found in the United States. The old adage in the mining industry that it typically takes *'20 years from discovery to mine development'* certainly applied in this case. A significant diamond industry in the future for the Colorado-Wyoming region must now be considered within the realm of possibility, especially with all the new evidence and anomalies that have been identified in the past two decades within the Wyoming craton. It is now apparent that this craton hosts one of the more important kimberlite-lamproite-ultramafic lamprophyre provinces in the country.

CRATONS

OVERVIEW

Although diamonds have been found in a variety of host rocks (see Hausel, 1996a), current exploration models suggest that kimberlites and lamproites are the most favorable targets to search for commercial quantities of diamond in cratonic environments. Cratons are considered favorable where they are underlain (or have been underlain) by thick, cool, lithospheric root zones that are thought necessary to produce magmas at depths within the diamond stability field of the upper mantle.

Much of Wyoming and Montana are underlain by a basement of Archean (>2.5 Ga) rock known as the Wyoming Province, which forms the core of the Wyoming craton (Figure 1). This terrane is considered favorable for diamond exploration even though portions of the lithospheric root have eroded through geologic time. The Wyoming Province is bounded along the south by cratonized basement Proterozoic volcanogenic gneiss and schist of the Colorado Province, and along the east by Archean-Proterozoic basement rocks of the Trans-Hudson orogen which stabilized in the Proterozoic (Goldich and others, 1966; Hausel and others, 1991). The Trans-Hudson orogen is interpreted as a Proterozoic fold belt that welded the Wyoming Province on the west, to the Superior Province to the east (Williams and others, 1986; Eggler and others, 1988).

Cratons represent stable continental cores that respond as rigid blocks to deformation, and possess gentle, cool, geothermal gradients thought necessary for the generation of mantle-derived magmas from the diamond stability field at depths of 90 to 120 miles.

This was emphasized by Clifford (1970) who suggested commercial diamond-bearing kimberlites tend to be confined to cratonic terranes that have been stable and relatively undeformed for more than 1.5 Ga.

Janse (1994) recommended that cratonic terranes be separated into regions of favorability to facilitate preliminary evaluation for diamonds (Figure 2). These include: (1) archons, or cratonic cores consisting of Archean basement last affected by a thermal event ≥2.5 Ga; (2) protons, or terranes of cratonized Early- to Mid-Proterozoic belts last affected by a thermal event with a minimum age 1.6 Ga; and (3) tectons, Late Proterozoic basement rocks last effected by a thermal event with a minimum age of 800 Ma that stabilized between 1.6 Ga and 800 Ma. Furthermore, archons should probably be separated into (a) platforms and (b) shields in that shield terranes have been the less productive of the two.

To date, the Archean provinces have yielded the richest diamondiferous kimberlites in the world. For example, kimberlites mined in the South African and Yukutian cratons, have yielded some of the highest value macrodiamonds in the world. Although diamondiferous lamproites appear to be uncommon in Archean terranes, the low-grade (~10 carats/100 tonnes) Majhagawan diamondiferous olivine-lamproite in India, was emplaced in Proterozoic country rock apparently overlying Archean basement gneiss along the margin of the Aravalli craton (e.g. Mitchell and Bergman, 1991). And some unusual South African 'kimberlites', known as Group II kimberlites which have yielded some high-value gemstones, appear to have lamproitic affinities (Peterson, 1996). These occurrences emphasize the importance of exploring all lamproitic, as well as kimberlitic rocks in Archean terranes.

The Early- to Mid-Proterozoic cratonized mobile belts, also represent attractive exploration targets for diamondiferous kimberlite and lamproite. These terranes were historically overlooked by exploration geologists, but because the discovery of several diamondiferous kimberlites and lamproites in these terranes in past two to three decades, these cratonized terranes are now targeted in many exploration programs. For example, within the past 20 to 30 years, the largest field of kimberlites in the U.S., the Colorado-Wyoming kimberlite field, was discovered in Proterozoic basement rocks of the Colorado Province. This province includes more than 100 kimberlites, many of which are diamondiferous. Kimberlites were also recently discovered in Proterozoic basement rocks along the margin of the Superior Province in the Upper Peninsula of Michigan. Twenty-six kimberlites (eight of which are diamondiferous) have been reported in this region (Northern Miner, 9/4/95). Diamondiferous kimberlite has also been described north of Montana in the Trans-Hudson orogen between the Superior and Hearne Provinces in Canada (Levinson and others, 1992).

In addition to kimberlite, the cratonized Proterozoic belts provide favorable terranes for diamondiferous lamproite. This was emphasized by the discovery of diamondiferous olivine lamproite at Argyle, Western Australia. The Argyle lamproite has a very high ore grade (680 carats/100 tonnes), although the average value of the diamonds are low compared to most commercial kimberlites. Diamondiferous olivine lamproites are also found in Proterozoic basement near Murfreesburo, Arkansas, far from any known Archean core. However, these lamproites appear to be subeconomic: the reported grade for the principal lamproite - the Prairie Creek intrusive, is only 0.52 carat/100 tonnes (Northern Miner, 2/17/97). Most lamproites, worldwide, have been emplaced in mobile belts where there has been some evidence of plate subduction (Peterson, 1996).

Late Proterozoic basement complexes are considered low priority in the search for diamondiferous kimberlite and lamproite, as diamondiferous host rocks in these terranes are rare. For instance, only trace amounts of diamond have been reported in kimberlite in the Grenville orogen near Noranda, Canada (Levinson and others, 1992). Although no verified diamondiferous host rocks have been found in the Appalachian Mountains near the southern portion of this orogen, the numerous reports of placer diamonds in this region suggests that some *in situ* diamond occurrences may have been overlooked (Hausel, 1995a,b).

Only two Archean terranes have been recognized in the United States: the Superior and Wyoming Provinces. These provinces may offer the highest potential for the discovery of commercial diamond deposits in the country. The Wyoming Province, in particular, has yielded hundreds of kimberlitic indicator mineral anomalies, some placer diamonds, some kimberlites, several lamproites, and some diamondiferous mafic to ultramafic breccia pipes. Diamonds have also been recovered from several kimberlites in the Early- to Mid-Proterozoic provinces along the margins of both the Wyoming and Superior Provinces. Because of the many anomalies, the Wyoming craton, which includes both the Wyoming and Colorado Provinces, is considered favorable for the discovery of additional diamond deposits.

WYOMING PROVINCE

Much of Wyoming is underlain by an Archean basement known as the Wyoming Province. This consists of Archean granite, gneiss, and supracrustal metamorphic rocks exposed in the core of several Laramide uplifts. Presumably the Archean basement continues under the Phanerozoic sedimentary basins between the uplifts, and underlies much of eastern Montana and continues north into Canada.

According to Eggler and others (1988), the Wyoming craton was established by 2.7 Ga, but was later affected by a regional metamorphic event recorded at 1.9 to 1.7 Ga. The boundary of the Wyoming Province is exposed in the Medicine Bow and Sierra Madre Mountains in southeastern Wyoming, as the Mullen Creek-Nash Fork shear zone. This shear, which forms part of the Cheyenne Belt suture, represents a continental-arc collision zone (Graff, 1978; Hills and Houston, 1979). The Cheyenne Belt separates the Wyoming Province to the north from cratonized (1.7 Ga) Proterozoic basement of the Colorado Province to the south. The Colorado Province south of the suture consists of volcanogenic island arc basement rocks and intrusive granites.

The boundary of the Wyoming Province continues eastward from the Medicine Bow Mountains into the central Laramie Range where it is masked by a 1.5 Ga anorthosite-syenite batholith, although sheared rocks in the Richeau Hills along the eastern flank of the anorthosite complex are thought to be part of the Cheyenne Belt. From the Laramie Range, the boundary continues under Phanerozoic sedimentary rocks of the high plains, and is projected to intersect the southward extension of the Trans-Hudson orogen near the Wyoming-Nebraska border.

The eastern boundary of the Province is not well exposed, and in the past has included the Black Hills of South Dakota. But geochronologic data show ages of the basement in western South Dakota have been largely reset to Proterozoic values of the Trans-Hudsonian event (Goldich and others, 1966). Isolated ages greater than 2.5 Ga in the Black Hills represent envelopes of an Archean basement that were thermally insulated during the Trans-Hudson orogeny, and did not result in the resetting of their isotopic compositions. Thus, the eastern boundary of the Wyoming Province essentially parallels the Wyoming-South Dakota border (Hausel and others, 1991; Sims, 1995).

From southeastern Wyoming, the southern boundary of the Wyoming Province continues westerly through northern Utah and into the Basin and Range of extreme northeastern Nevada, where relict Archean ages are reported in the core of the Eastern Humbolt Range (Lush and others, 1988). From Nevada, the province is interpreted to continue northward under sedimentary cover in eastern Idaho into southwestern Montana. Farther north, the province boundary is masked by younger thermal and structural events and by younger sedimentary and metasedimentary cover in Canada. The northern edge of the province coincides with a geophysical anomaly in Alberta that has been interpreted as a possible suture between the Wyoming Province and the Hearne Province of Canada (Hoffman, 1988; Houston, 1993).

Near the close of the Archean, a thick, cool, lithospheric mantle keel existed beneath the Wyoming Province. Such lithospheric roots are thought necessary to provide favorable conditions to produce magmas from depths within the diamond stability field. These conditions continued into Cretaceous time; however, Eggler and others (1988) and Eggler and Furlong (1991) suggest that portions of the lithosphere eastward towards the Great Plains were destroyed by Cretaceous to Eocene tectonomagmatism, such that remnants of the keel are interpreted to only exist in central Montana, southeastern Wyoming, and the Leucite Hills of southwestern Wyoming. However, based on the presence of numerous kimberlitic indicator minerals found in Wyoming, this would suggest that a substantial mantle lithosphere may have been preserved under a much larger region in Wyoming.

COLORADO PROVINCE

The Colorado Province forms a cratonized Proterozoic mobile belt of island arc metamorphic rocks lying along the southern boundary of the Wyoming Province. The Colorado Province contains the largest known field of kimberlites in the United States which includes more than 100 pipes, dikes, and blows (many of which are diamondiferous).

The Colorado Province consists of a 1.8-1.7 Ga metamorphic terrane disconcordantly intruded by 1.5 to 1.4 Ga granitic rocks (Peterman and others, 1968). The metamorphics are amphibolitic, quartzofeldspathic, and pelitic gneisses and schists that are part of an island arc succession which collided with the Wyoming Province 1.7 Ga ago. The collision boundary, which is marked by the Cheyenne Belt, is interpreted to intersect the Laramie Range, 50 to 70 miles north of the State Line district (McCallum and others, 1977; Karlstrom and Houston, 1984).

Kimberlites in the Colorado Province are found as far south as Boulder, Colorado, and as far north as Middle Sybille Creek, Wyoming (Figure 3), but only the Colorado-Wyoming State Line district kimberlites in the central portion of this region have yielded diamonds. However, sub-calcic G10 harzburgitic pyropes from the Iron Mountain district to the north, suggests those kimberlites may have also tapped the diamond stability field (McCallum and Waldman, 1991).

Much of the lithosphere under the Colorado Province to the south of the Wyoming Province, has thinned since Cretaceous time. However, a thick keel extended under the Colorado-Wyoming State Line district during the Paleozoic as is evidence by the presence of several Devonian age diamond-bearing kimberlites (Eggler and others, 1988). Eggler and others (1988) and Shaver (1988) proposed that a fragment of an Archean keel extended under the Proterozoic basement in this region, although samples from State Line kimberlites suggest the upper mantle at depth contains only 5 to 10%

harzburgite, which is more typical of a Proterozoic lithosphere (Coopersmith and Schultze, 1996).

THE COLORADO-WYOMING KIMBERLITES

OVERVIEW

The cratonized rocks of the Colorado Province enclose the largest known field of kimberlites in the United States. The majority of these intrusives are centered along the Colorado-Wyoming border and extend several miles south into northern Colorado and several miles north into southeastern Wyoming. More than 100 kimberlite intrusives and dozens of unexplored geophysical, remote sensing, and heavy mineral anomalies have been identified in this region.

Most kimberlites in the Colorado Province are early Devonian in age based on the presence of Paleozoic xenoliths, fission track dating of sphene (Larson and Amini, 1981) and zircon (Naesser and McCallum, 1977), and on Rb-Sr dating of phlogopite (Smith, 1979, 1983). However, some recent dates obtained from a few kimberlites suggest at least two episodes of emplacement may have occurred: (1) a Devonian episode, and (2) a Late Proterozoic event (600 to 700 Ma). In addition to these, other episodes of mantle-derived magmatism have been recognized in the Wyoming Craton (Hausel, 1996b).

The majority of the kimberlites occur within the State Line and Iron Mountain districts. A few scattered intrusives have also been found in the Estes Park region, the Boulder area of Colorado, the Sybille Canyon region of Wyoming, and the Missouri Breaks region of Montana. Some of these lie adjacent to several hundred square miles of terrane that has produced numerous kimberlitic indicator mineral anomalies in stream sediment samples suggesting that the known kimberlite fields are more widespread. Additionally, similar indicator mineral anomalies have also been identified along the flank of the Sierra Madre, in the Medicine Bow, Seminoe, Bighorn, and Uinta Mountains, and in the Green River Basin. To date, diamonds have been reported in kimberlites in the Colorado-Wyoming State Line district and in breccia pipes in the Green River Basin. Diamonds have also been found in the Medicine Bow Mountains and the Powder River Basin. There are also reports of diamonds from several other localities in Wyoming, Montana, and Idaho (Hausel, 1995a).

In addition to kimberlites, the Wyoming Craton also encloses the largest lamproite field in the United States, known as the Leucite Hills. The Leucite Hills are located in southwestern Wyoming and lie northeast of a highly anomalous 500 to 1,000 mi^2 region containing widespread kimberlitic indicator minerals found in ant hills, soils, stream sediments, and in the Bishop Conglomerate (Oligocene) (McCandless, 1982, 1984). This anomaly extends into extreme northwestern Colorado and northern Utah (McCandless and others, 1995). In addition to the Leucite Hills, other lamproites and some ultramafic lamprophyres have been identified in the craton in Montana and northern Utah.

STATE LINE DISTRICT

The State Line district is underlain by Proterozoic schists and granites of the Colorado Province and extends 5 miles north into Wyoming and 12 miles south into Colorado enclosing approximately 40 known kimberlites, most (if not all) are diamondiferous (Figure 4). The exposed Precambrian crystalline rocks in this region consists of 1.9 to

1.7 Ga metamorphic rocks that are disconcordantly intruded by 1.4 Ga granitic rocks of the Sherman and Log Cabin batholiths. The Log Cabin granite locally intrudes Sherman granite in the State Line district.

Much of the district is enclosed by the 9 mile-diameter, Virginia-Dale ring-dike complex that disconcordantly intrudes folded metamorphic rocks of the Colorado Province (Eggler, 1967). The ring-dike lies at the intersection of a major east-west trending aeromagnetic lineament with a north-south trending aeromagnetic anomaly. Woodzick (1987) interpreted these anomalies as manifestations of intersecting zones of structural weaknesses that may have provided conduits for kimberlite magmatism. The ring-dike, interpreted as a facies of the Log Cabin batholith, intrudes 1.4 Ga Sherman Granite and older metamorphic rocks (Eggler, 1967, 1968; Moll, 1982). The only post-Precambrian rocks found in the vicinity of the State Line district are arkosic sedimentary rocks of the Pennsylvanian Fountain Formation located along the margin of the district; and rare Cambrian, Ordovician, and Silurian sedimentary xenoliths found in some kimberlite diatremes (McCallum and others, 1979).

Both hypabyssal and diatreme facies kimberlite occur in the district, with only minor fragments of crater facies kimberlite reported in the Kelsey Lake intrusives. Diatreme facies kimberlite contains abundant subrounded to angular rock fragments with serpentinized macrocrysts of olivine and lesser enstatite, Cr-rich and Cr-poor pyrope garnet, diopside, picroilmenite, clinopyroxene-ilmenite intergrowths, and phlogopite. These occur in a finely crystalline matrix dominated by serpentine, with lesser carbonate, olivine, diopside, picroilmenite, phlogopite, perovskite, magnetite, Cr-rich spinels, hematite, apatite and zircon (Rogers, 1985; McCallum, 1991).

The hypabyssal facies kimberlite forms massive porphyritic rocks found in dikes, sills, and small plug-like bodies that represent root zones ('blows') of deeply eroded pipes. The mineralogy of hypabyssal kimberlite is essentially the same as diatreme facies; however, globular, emulsion-like segregations of serpentine and calcite are more abundant in the hypabyssal facies (Rogers, 1985). In addition, xenolithic fragments rarely exceed a few percent in the hypabyssal facies (unlike the diatreme facies), and where present, are typically well-rounded upper mantle and lower crustal nodules.

The kimberlites in the State Line district are generally poorly exposed, have negligible relief, and are deeply weathered. Erosional models suggest that many of the kimberlites may have been deeply eroded with as much as 50% of the original pipes having been removed through time (McCallum and Mabarak, 1976). Thus a significant potential for placer diamonds may occur downstream.

Geophysical surveys conducted over kimberlites in the district suggest that several kimberlites have been affected by weathering to depths of approximately 100 feet below the surface, although moderately fresh exposures are present at some sites. Many of the kimberlites are covered by colluvium and/or alluvium, and many have been recognized by the presence of grey, weathered, 'blue-ground' kimberlitic soils associated with grassy vegetation anomalies. Other kimberlites have been recognized by the presence of Lower Paleozoic xenoliths as well as mantle and lower crustal xenoliths and nodules of peridotite, pyroxenite, eclogite, granulite, and/or megacrysts of pyrope, ilmenite and/or diopside scattered on the surface (McCallum and Eggler, 1979; Hausel and others, 1979).

To date, more than 120,000 gem and industrial stones have been recovered from the district, with the greatest amount of diamonds being recovered from the George Creek, Sloan 1 and 2, and the Kelsey Lake kimberlites. The diamonds range from microdiamonds to a 28.3 carat octahedron (the 5th largest verified diamond found in the United States) (Table 1). Several other large diamonds have also been recovered from kimberlites in the district including 14.2, 10.5, 9.4, 6.2, and 5.51 carat gemstones, as well as several in the range of 1 to 3 carats. The gem to industrial quality ratios are favorable, with some deposits reporting as much as 65% gemstones (Figure 5).

The diamond population is dominated by colorless stones, although black, grey, brown, yellow, and lessor green and pink diamonds are reported (Rogers, 1985). Many of the colorless stones are high-quality gemstones, and information on colored diamonds is surprisingly lacking in that the 'Argyle pinks' mined in Australia, represent some of the more valuable gemstones on the market. The 'State Line pinks' appear to be rare, as little information is available on these diamonds.

Even though the State Line district has been explored for diamonds for more than two decades, considerable evidence indicates that some undiscovered kimberlites occur in the district. For example, Royal Gold announced in a Sept. 19, 1996 press release, that they had found indicator minerals in the district *"... in drainages where kimberlites were not previously known to exist"*. Of 73 samples collected by the company, indicator minerals were found in 17. Previously, Hausel and others (1988) had also reported finding kimberlitic indicator mineral anomalies north of any known kimberlites in the district.

Geophysical studies have provided evidence of possible blind and buried diatremes in the district. Some INPUT responses identified in an airborne survey flown in 1981, corresponded with some of the known kimberlites; however, the survey also detected conductivity and magnetic anomalies that were not associated with any known kimberlite (Figure 6). Several weak to strong magnetic responses were detected including a group of 10 to 12 prominent anomalies. These latter anomalies were interpreted as the manifestation of buried or *'blind'* kimberlite pipes (Paterson and MacFadyen, 1984). More recently, another airborne survey flown by Dighem for Fleck Resources Ltd., identified several EM and magnetic anomalies in a 4 mi^2 area in Wyoming and Colorado. The most promising was a 1,600 by 1,000 foot ovoid anomaly two miles north of the Kelsey Lake mine in Wyoming (Fleck Resource Ltd, Press Release, April, 15, 1997).

During ground geophysical studies, Hausel and others (1979, 1981) identified electrical conductors and weak to moderate magnetic anomalies associated with several known kimberlites. This led to the later identification of a buried kimberlitic blow in a drainage along the Schaffer kimberlite trend (Hausel and others, 1981) (Figure 7).

Remote sensing studies have also been successfully used in the search for kimberlite in the district. Hausel and others (1979) reported color and false color infrared anomalies associated with some kimberlites in the district. Later, more sophisticated studies identified color anomalies associated with several known kimberlites, and possibly associated with undiscovered kimberlite (Marrs and others, 1984; Marks, 1985; Woodzick, 1987).

The reported kimberlites in the district include the Kelsey Lake intrusives, the George Creek dikes, the Chicken Park kimberlites, the Sloan kimberlites, the Moen intrusive, the Nix kimberlites, the Maxwell pipes, the Diamond Peak kimberlites, the Pearl Creek intrusive, the Schaffer kimberlites, the Aultman pipes, and the Ferris kimberlites (Figure 4). All of the kimberlites that have been tested in the district, have proven to be diamondiferous (Figure 8); however, a few remain untested! Ore grades range from <0.5 to 46.1 carats/100 tonnes, with some bulk samples from the George Creek dikes yielding grades as high as 135.1 carats/100 tonnes (McCallum and Waldman, 1991) (Table 2).

Individual Kimberlites

Aultman 1 and 2: The Aultman 1 kimberlite was one of the first two diatremes discovered in the district. The pipe was identified in 1961 based on the presence of Lower Paleozoic xenoliths, but it wasn't until kimberlite was recognized at the Sloan 1 pipe in 1964 by M.E. McCallum, that the true significance of the xenoliths was ascertained. The Aultman 2 kimberlite was later discovered during mapping in 1978 (Hausel and others, 1981). These two kimberlites lie along a northwesterly trend in the northern portion of the district.

Bulk samples collected from the Aultman kimberlites in the early 1980s by Cominco American, yielded grades of only 1.09 carat/100 tonnes for the Aultman 1, and 0.33 carat/100 tonnes for the Aultman 2. An average grade of 1.0 carat/100 tonnes for the Aultman kimberlites was reported by McCallum and Waldman (1991).

Chicken Park kimberlites: The Chicken Park kimberlites include three relatively small blows of lower diatreme and upper hypabyssal facies kimberlite, and one dike of hypabyssal facies kimberlite that lie along a northeasterly trend. The largest intrusive is a small *'blow'* about 250 by 160 feet.

Three of the intrusives are outlined by vegetation anomalies, and the fourth was not exposed at the surface, but later discovered following stream sediment sampling and subsequent drilling (Rogers, 1985). Two hundred stream sediment samples were collected in this area, of which 12 contained picroilmenite and a few contained both picroilmenite and pyrope garnet. Many of the anomalous samples were collected immediately downstream from the intrusives and were in all probability derived from the exposed Chicken Park kimberlites. A few anomalous samples were also derived from the buried CK1 intrusive. Additionally, three anomalous samples were collected in ephemeral drainages upstream from the Chicken Park intrusives indicating that another buried intrusive, or intrusives, probably occurs in the area (Rogers, 1985).

The age of the Chicken Park kimberlites appear to be Late Proterozoic even though most kimberlites in the district are Early Devonian. Ar^{40}-Ar^{39} and Rb-Sr data from a kimberlite sample from Chicken Park yielded Late Proterozoic ages similar to the George Creek dikes and Green Mountain pipe (Lester P. Alan, personal communication, 1996).

Garnets from the Chicken Park kimberlites include sub-calcic, high-Cr, G10 harzburgitic pyropes along with a large population of calcic G9 pyropes. The ilmenite geochemistry shows intermediate to high MgO content with depletion in Cr_2O_3 suggestive of oxidizing conditions (McCallum and Waldman, 1991). The geochemistry suggests that the Chicken Park kimberlites represent low-grade diamond ore and that the diamond population should show signs of resorption. Bulk samples recovered from Chicken Park yielded 306 diamonds from a 296 tonne sample at an average ore grade of 6.7 carats/100 tonnes. The largest recovered diamond was a 2.6 carat industrial stone (McCallum and Waldman, 1991).

Diamond Peak kimberlites: Two kimberlites, known as the Diamond Peak intrusives, were identified following stream sediment sampling surveys in the vicinity of Diamond Peak. The DP1 kimberlite occurs in a small alluvial valley and is marked by limestone xenoliths with weathered kimberlite in animal burrows. The DP2 is a small intrusive

(<200 feet) marked by a topographic depression with an overlying vegetation anomaly (Carlson, 1983).

Ferris kimberlites: The Ferris 1 pipe was discovered in 1960 based on the presence of Lower Paleozoic xenoliths, but like the Aultman 1 kimberlite, it wasn't until the identification of kimberlite at the Sloan 1 pipe in 1964, that the true significance of these xenoliths was determined. During later mapping, the Ferris 2 intrusive was identified east of the Ferris 1. This kimberlite occurs as a small dike with exposures of weathered hypabyssal facies kimberlite (Hausel and others, 1981). Because of access difficulties, neither of the Ferris kimberlites have apparently been tested for diamonds.

George Creek kimberlites: The George Creek intrusives, located a few miles southwest of Kelsey Lake, were discovered following regional stream sediment sampling surveys which detected kimberlitic indicator minerals in nearby drainages. The pyrope populations included several sub-calcic, high-Cr, G10 harzburgitic pyropes with chemistries similar to diamond-inclusion pyropes. The ilmenite compositions indicated low oxygen fugacity suggesting favorable conditions for diamond preservation (McCallum and Waldman, 1991). Because of the favorable chemistry, efforts were made to find the source of the indicator minerals.

The kimberlites did not crop out on the surface. However, because of the orientation of the dikes (near vertical dip, striking perpendicular to the dip of the hillside), small puddles and springs of water emerged where the dikes were located. Apparently, the soils, saturated with snowmelt, had water moving downslope through the relatively permeable soils derived from the decomposed crystalline basement, and when the water encountered the clay-rich altered kimberlite, it was forced over the impermeable barrier, forming the small puddles and springs at the surface (T.E. McCandless, personal field notes). The extent of the kimberlites were outlined with VLF electromagnetic surveys which identified a northeasterly-trending buried conductor. The conductor was trenched exposing three, narrow, steeply-dipping kimberlite dikes (Carlson and Marsh, 1989).

The dikes were designated as the K1, K2, and K3 intrusions. These consist of hypabyssal macrocrystal phlogopitic kimberlite, and range in length from several hundred to about 3,000 feet, with widths of inches to 13 feet. Rb-Sr analysis of weathered, surficial material from one of the dikes yielded a preliminary age of 600 Ma (Carlson and Marsh, 1989) similar to the Chicken Park and Green Mountain kimberlites.

The dikes were diamond-rich and yielded more than 86,000 diamonds during bulk sample tests by Superior Minerals Company. Ore grades ranged from 18 to 135 carats/100 tonnes, and the K1 and K2 dikes yielded average grades of 46.1 and 31 carats/100 tonnes which are the highest average grades reported in the district (McCallum and Waldman, 1991).

The recovered diamonds show a low degree of resorption, and included octahedra, macles, aggregates, and dodecahedra (tetrahexahedra). The color of the stones included a high proportion of colorless diamonds with some yellow, brown, green, and grey diamonds (Falk, 1992). The majority of the diamonds were small, although some diamonds larger than 2 carats were recovered - the largest was 2.14 carats (U.S. Diamond Corp., press release, 1996).

Kelsey Lake kimberlites: Commercial diamond production began in 1996 in the State Line district, after Redaurum Ltd. placed two of the Kelsey Lake kimberlites (KL1 and

KL2) into production. These lie near the state line with much of the property located in Colorado. Most of the production has been from the Colorado side; however, diamonds have also been recovered from the Wyoming side. At least 26.35 carats (Harold Kemp, personal communication, 1997), including a 6.2 carat diamond (Howard Coopersmith, personal communication, 1997), have been recovered from Wyoming.

The Kelsey Lake group, initially identified as the Schaffer 1, 2, 6, 7, 8, and 9 kimberlites (Eggler, 1968; McCallum and others, 1975; McCallum and Mabarak, 1976) were apparently renamed the Kelsey Lake KL1, KL2, KL3, KL4, KL5, KL6, KL7, and KL8 intrusives by Coopersmith (1991). These are irregular-shaped pipes and fissures of diatreme facies with zones of hypabyssal facies and fragments of crater facies kimberlite. An apparent Devonian age for the Kelsey Lake kimberlites is in agreement with Early Devonian isotopic ages for most other pipes in the Colorado-Wyoming region (Coopersmith, 1993).

The indicator mineral geochemistry from the Kelsey Lake kimberlites provide conflicting data. The kimberlites have yielded abundant G9 pyrope garnets, lessor sub-calcic G10 Cr-pyropes, and high-Cr chromites which indicate the kimberlitic magmas originated within the diamond stability field. However, ilmenite compositions show Mg-depletion and Cr-enrichment similar to ilmenites from kimberlites at Iron Mountain, Wyoming *(ilmenite compositions are thought to provide information on the reducing/oxidizing conditions of the kimberlite magma, as well as a measure of diamond preservation)*. The ilmenite compositions suggest the Kelsey Lake magmas were oxidizing and that any diamonds should have been resorbed or destroyed during emplacement. However, the presence of many gem quality octahedral diamonds indicate the ilmenite compositions do not provide a reliable barometer on diamond preservation in these intrusives (Coopersmith and Schultze, 1996) (Figure 5).

The kimberlites and some alluvial material eroded from the pipes, have yielded many high-quality diamonds heavier than 1 carat in weight. Some of the larger recovered stones have included 6.2, 9.4, 10.5, 14.2 and 28.3 carat gemstones. The diamonds have predominately octahedral habit, and are for the most part are colorless with some honey-brown gemstones (Coopersmith and Schultze, 1996).

The two largest of the Kelsey Lake pipes (K1 and K2) cover nearly 20 acres of surface area, and are expected to yield approximately 125,000 carats/year. Two open pits are currently being developed at the mine which is expected to have a 12-year life (Ringold's Inc., 2/14/96). A resource of 16.9 million tonnes (Ringold's Inc., 2/14/96) to a depth of 320 feet, has been outlined in two pits (H.G. Coopersmith, personal communication, 1997).

The Kelsey Lake mill is designed to operate at 24 hours a day at 195 tonnes/hour, and process approximately 40,000 to 50,000 tonnes/month (Coopersmith and Schultze, 1996). The mill uses four rotary diamond pans, with the final diamond extraction occuring on two vibrating grease tables (H.G. Coopersmith, personal communication, 1997).

Maxwell pipes: Two kimberlites, known as the Maxwell pipes, lie near the Wyoming border in Colorado west of Kelsey Lake. The Maxwell 1 forms a topographic depression marked at the surface by limestone nodules and kimberlitic indicator minerals in the soil over the pipe. The intrusive covers a surface area of about 5.6 acres. The Maxwell 2 also forms a topographic depression and is marked by a pronounced vegetation anomaly

(Carlson, 1983). The Maxwell kimberlites were recently acquired by Redaurum Ltd, and will be bulk tested in the near future (Northern Miner, May 5, 1997).

Moen kimberlite: At least one kimberlite occurs near Highway 287. It is not known if this intrusive has been tested for diamonds.

Nix kimberlites: A group of four, small, intrusives south of the Wyoming border form the Nix cluster of kimberlites. These include the NX1 and NX3 kimberlites which are primarily brecciated diatreme facies kimberlite, and the NX2 and NX4 kimberlites which are massive hypabyssal facies kimberlite porphyry. A 300 pound sample collected from two of the kimberlites yielded microdiamonds (McCallum and others, 1977).

Pearl Creek: Pearl Creek is located south of George Creek. Multiple dikes up to 2 feet thick are reported on the property, and geophysical surveys indicate the dikes have a strike length of 6,200 feet. Microdiamonds were recovered from a 115 pound sample collected from the property (U.S. Diamond Corp., press release, 1996).

Schaffer complex kimberlites: A group of kimberlite diatremes and blows, known as the Schaffer complex, includes the Schaffer 3, 5, 5A, 5B, 5C, 5D, 10, 12A, 12B, 13, 15, 16, 17, 18, 19, and 20. These all occur in the Wyoming portion of the district (Hausel and others, 1981). The kimberlites are deeply weathered and poorly exposed, and occur as sporadic *'blue ground'* associated with some vegetation anomalies (Hausel and others, 1979).

The largest two diamonds recovered from the Schaffer complex weighed 0.985 carat and 0.86 carat, and were recovered from the southern part of the complex. Testing of the northernmost Schaffer complex kimberlites in 1981 yielded an average ore grade of 0.68 carat/100 tonnes; whereas the entire complex yielded an average grade of only 0.56 carat/100 tonnes (McCallum and Waldman, 1991). A bulk sample of only about 10,000 tonnes was taken from the entire complex.

Sloan kimberlites: Six kimberlites are found in or adjacent to the Rabbit Creek drainage area, about 10 miles south of the Colorado-Wyoming border. These include the Sloan 1, 2, 3, 4, 5 and 6. Only four of the kimberlites have been bulk sampled, to date.

The Sloan 1 diatreme was the first kimberlite pipe identified in the Colorado-Wyoming region. This kimberlite was identified by M.E. McCallum in 1964 from samples collected along the western edge of the pipe. The Sloan 2 kimberlite was discovered several years later by C.D. Mabarak following stream sediment sampling in the area (McCallum and Mabarak, 1976).

The Sloan 1 intrusive, which consists of diatreme facies kimberlite, has an areal extent of 500 by 1,800 feet and is one of the largest pipes in the district. The Sloan 2 is a dike-like *'blow'* about 200 by 2,000 feet in surface area, and consists of hypabyssal facies kimberlite (McCallum and Mabarak, 1976; Shaver, 1994).

The Sloan 1 and 2 kimberlites yielded a significant number of subcalcic G10 harzburgitic pyropes indicating a moderate potential for peridotitic diamonds. And even though the TiO_2/Na_2O geochemistry of the eclogitic garnets indicated low potential for eclogitic diamonds (McCallum and Waldman, 1991), the majority of the diamonds recovered from the Sloan 1 and 2, are E-type (eclogitic) diamonds (Otter and Gurney, 1989; Otter and others, 1991). An E-type diamond population is also supported by the presence of diamondiferous and diamond-graphite eclogite xenoliths in the kimberlite (McCandless and Collins, 1989; Otter, 1989).

The MgO:Cr_2O_3 contents of picroilmenite from the Sloan 1 and 2 kimberlites suggest the magmas were reducing and favorable for diamond preservation (McCallum and Waldman, 1991). The recovered diamonds range from well-preserved octahedra to highly resorbed tetrahexahedra with colors ranging from D to E (Dummett and others, 1988). In addition to the colorless diamonds, white, black, grey, yellow-brown, amber, and rare green, pink, and blue diamonds have been recovered (Otter and others, 1991).

Bulk sampling of the Sloan 1 and 2 kimberlites by Superior Minerals (and later with their joint venture partner Lac Minerals) resulted in the recovery of 21,546 diamonds in the 1980s (Oliver, 1990). More recent sampling of the Sloan 2 kimberlite by Royal Star Resources yielded 9,034 diamonds larger than 1 mm with a combined weight of 342.17 carats. These were recovered from 3,300 metric tonnes of rock resulting in an average ore grade of 12.68 carats/100 tonnes (Shaver, 1994). Cumulative production from the Sloan 1 and 2 kimberlites has totaled 30,580 diamonds.

The largest diamond recovered from the Sloan 1 and 2 kimberlites, was a 5.51 carat gemstone (Bernie Free, personal communication, 1994) (Figure 9). It was estimated that the diamond would produce a clear, white, brilliant-cut stone weighing at least 2 carats (Shaver, 1994).

Diamond resources, based on diamond grades and ore tonnage, were estimated at 15.3 million tonnes of ore at an average grade of 6.1 carats/100 tonnes for the Sloan 1 kimberlite. The Sloan 2 intrusive was estimated to contain a resource of 8.4 million tonnes at an average grade of 17.1 carats/100 tonnes (Oliver, 1990).

The Sloan 5 intrusive to the north of the Sloan 1 and 2, was bulk sampled in 1982. In total, 474 diamonds totaling 9.09 carats, were recovered from 904 tonnes (average grade of 1.0 carat/100 tonnes). Bulk sampling of the nearby Sloan 6 intrusive resulted in the recovery of 215 diamonds (total weight of 6.72 carats) from 500 tonnes at a grade of 1.3 carats/100 tonnes (McCallum and Waldman, 1991).

OTHER REPORTED KIMBERLITES AND RELATED ANOMALIES

Front Range

The Front Range in Colorado, forms a southern continuation of the Laramie Range in Wyoming. Kimberlites in the Front Range outside the State Line district include a single, 3 to 6.5 foot wide kimberlite dike 40 miles south of the district and south of Estes Park near Ramshorn Mountain (sections 1 and 12, T4N, R73W) (Figure 3). Preliminary testing of the dike yielded no diamonds (Hausel and others, 1985). Other kimberlite dikes are reported west of Estes Park in Hayden Gorge adjacent to Hayden Spire (40°21'30", 105°43'30") and southwest of Isolation Peak (40°12'30", 105°42') within the Rocky Mountain National Park (Braddock and Cole, 1990).

Green Mountain pipe: A single, 128-foot diameter diatreme, known as the Green Mountain pipe, intrudes Boulder Granite along the edge of the town of Boulder near the margin of the Front Range in north-central Colorado, 50 to 60 miles south of the State Line district (Meyer and Kridelbaugh, 1977). Similar material was reported 6 to 8 miles west of the diatreme by Whitaker (1898), although reconnaissance stream sediment sampling surveys in the area have not been able to verify the presence of any other kimberlites (Hausel and others, 1985).

The Green Mountain pipe yielded paleomagnetic, K-Ar, Ar^{40}-Ar^{39}, and Rb-Sr ages between 600 to 700 Ma (Alan P. Lester, personal communication, 1996). No diamonds have been reported from the kimberlite.

Colorado River

Several very small diamonds were reportedly found by a group of gold prospectors on the headwaters of the Santa Maris, a branch of Bill Williams Fork of the Colorado River (San Francisco Chronicle, Aug. 1, 1872). Based on the date of the report, this *'discovery'* is considered highly suspect as it may have been related to the 1872 diamond fraud (e.g., Hausel and Stahl, 1995).

Gros Ventre Mountains

A 7- to 9-carat, blue-white gem quality diamond was reportedly found in a prospect pit in the Gros Ventre Range and verified by a gemologist from Jackson. The prospect pit was dug in a hard, silicified, dark metamorphosed rock (J.D. Love, personal communication, 1981).

Southern Laramie Range (North of the State Line District)

The Front Range continues north into Wyoming where it is known as the Laramie Range. Several kimberlites and numerous kimberlitic indicator mineral anomalies have been identified in the Laramie Range extending from the State Line to the Elmers Rock greenstone belt in the central portion of the range. Nearly 300 kimberlitic heavy mineral anomalies have been identified over a 1,200 mi^2 area in the Laramie Range. Some of the highly anomalous areas include the Eagle Rock, Middle Sybille Creek, and Grant Creek areas and the Elmers Rock greenstone belt (Hausel and others, 1988). In addition, several kimberlites have been mapped in the Iron Mountain district along the eastern flank of the range. There is also an unverified report of a diamond found in the Blue Grass Creek area in the Elmers Rock greenstone belt (R.W. Marrs, personal communication, 1981). Reports of diamonds from the Sybille Canyon region, are also unconfirmed.

<u>Iron Mountain district</u>: The Iron Mountain district is located about 45 miles north of the State Line district and south of Sybille Canyon along the eastern flank of the Laramie Range. Smith (1977) mapped 57 hypabyssal facies kimberlite intrusives in what is known as the Iron Mountain kimberlite district. At least one kimberlite was tested by Cominco American Incorporated, but no diamonds were reported.

The Devonian age kimberlites occur as structurally-controlled dikes and blows emplaced in Sherman Granite (1.4 Ga) along a northeasterly trend that projects under the adjacent Phanerozoic sedimentary cover (Smith, 1977) (Figure 10). This suggests the possibility that undiscovered, buried, kimberlite intrusives may occur under the flanking Phanerozoic limestones, sandstones, and other sediments immediately east and west of the district. There is also a strong possibility that additional kimberlites may be hidden under Tertiary conglomerates that cover the western portion of the district, as the kimberlite trend projects under these conglomerates.

Both G9 and G10 peridotitic pyropes and Group I and II eclogitic pyrope-almandine garnets were recovered from the Iron Mountain intrusives. These indicate a moderately low probability for diamonds from harzburgitic and eclogitic sources. However, ilmenite compositions show Mg-depletion and slight Cr-enrichment which was thought to correlate with increased oxidation state of the kimberlite magma. According to McCallum and Waldman (1991), this would imply diamond preservation was unlikely.

However, the ilmenite compositions are similar to ilmenites from Kelsey Lake where diamonds are well-preserved (Coopersmith and Schultze, 1996). The similar ilmenite chemistry between Kelsey Lake and Iron Mountain suggest that ilmenite compositions are unreliable and probably do not provide a good indication of oxidation. As a result, the Iron Mountain district should probably be re-examined for diamonds.

Stream sediment samples collected in the district by the WSGS yielded anomalous results (Figure 10). A few of the anomalous samples were found immediately downstream from the Iron Mountain kimberlites. These included a sample in the W/2 section 18, T19N, R70W, about 0.5 mile downstream from one of the Iron Mountain kimberlites, which contained hundreds of pyrope garnets and lesser chromian diopsides. This sample and three others collected in Spring Creek along the western margin of the district, produced a mineral train over a distance of 2 miles; whereas a sample collected about 3 miles distant contained no indicator minerals suggesting a maximum transportation distance for pyrope garnet of less than 3 miles in this area.

However, indicator minerals recovered from three other anomalous samples probably did not originate from the known kimberlites in the Iron Mountain district. For instance, a sample collected in a tributary of Spring Creek (S/2 sec. 24, T 19N, R71W) contained some pyrope garnet. This tributary drains the slope west of the district, away from any known kimberlites. Two other samples collected in section 36, T20N, R71W along the northwestern margin of the district also contained rare indicator minerals. These two samples lie about 3 miles north of any known kimberlite, are separated from the Iron Mountain kimberlites by a topographic high. The results suggest the presence of undiscovered kimberlites in this region. Currently, the WSGS is investigating some elliptical depressions of unknown origin in this area.

Eagle Rock area: In the Eagle Rock (Happy Jack) area between Cheyenne and Wyoming, 35 stream sediment samples collected over 25 mi^2 yielded pyrope garnet, chromian diopside, and/or picroilmenite (Figure 11). Within this area, several samples collected immediately downstream from a cluster of beaver ponds in North Lodgepole Creek, northwest of Eagle Rock in sections 5 and 6, T15N, R71W, yielded kimberlitic indicator minerals over a widespread area. During air photo reconnaissance, a prominent circular structure (the Eagle Rock anomaly) was identified lying along a north, northwesterly-trending lineament. Field reconnaissance of the anomaly identified a small, topographic depression with associated vegetation anomaly similar to some kimberlites in the State Line district. However, this cryptovolcanic structure is soil covered with no exposed rock on the surface. A soil sample collected within the structure yielded only one pyrope garnet, thus the origin of this feature remains unknown (Hausel, personal field notes, 1990).

About 100 yards north of the Eagle Rock anomaly, a garnet peridotite nodule was reportedly found near the intersection of the northwesterly-trending lineament with an east-west-trending lineament (Larry Clark, personal communication, 1993). The origin of the peridotite also remains unknown, as no other mantle nodules could be found in this area.

In 1994, First Choice Exploration explored the Eagle Rock area and collected stream sediment samples based on the WSGS results, and followed-up with geophysical surveys. The company detected magnetic and resistivity anomalies associated with some beaver ponds, but was unable to intersect kimberlite during drilling (Northern Miner, 12/26/94).

Stream sediment samples collected along the North and Middle Branches of Middle Lodgepole Creek, an unnamed drainage located between the North Branch of Middle Lodgepole Creek and North Lodgepole Creek, and along South Lodgepole Creek by the WSGS also yielded several kimberlitic indicator mineral anomalies. The Eagle Rock area is considered highly anomalous and the results of the stream sediment sampling suggests the presence of several undiscovered kimberlitic intrusives.

Middle Sybille Creek: The Middle Sybille Creek (Sheep Rock) area lies several miles north of Eagle Rock, and about 6 miles northwest of the Iron Mountain district. A single, 40-foot diameter kimberlite, known as the Radical *'blow'*, was found in this area about 4 miles southeast of Sheep Rock along Middle Sybille Creek. The kimberlite crops out as hypabyssal facies kimberlite porphyry intruding Precambrian anorthosite (1.5 Ga) near the Wyoming Province boundary. A small sample (~200 pounds) collected by the WSGS, yielded no diamonds (Hausel and others, 1981).

Thirty stream sediment samples collected along Middle Sybille Creek and its tributaries in the vicinity of the Radichal kimberlite contained various amounts of pyrope garnet, chromian diopside, and/or picroilmenite. The indicator mineral anomaly extended 3.5 miles downstream, and 4 miles upstream from the kimberlite, indicating a potential for several undiscovered kimberlites in the area (Hausel and others, 1988; Woodzick, 1987) (Figure 12). Indicator minerals were also recovered from samples collected along Bear Creek, which drains north into North Sybille Creek, and from a tributary of Strong Creek to the south. Two other kimberlites were reportedly found in this region by a consultant, although this has not been verified by the WSGS.

Grant Creek: Samples collected in the Grant Creek drainage basin, northeast of the Middle Sybille Creek, were also highly anomalous (Figure 13). A group of stream sediment samples collected over a distance of one mile in the Grant Creek drainage in section 36, T21N, R71W, yielded numerous pyrope garnets, chromian diopsides, and/or picroilmenites (Hausel and others, 1988). Other heavy minerals of potential interest found in the samples included native gold, fluorite, and sapphire. The presence of abundant kimberlitic indicator minerals suggests a nearby, undiscovered, kimberlitic intrusive.

Pyrope garnets were also recovered from the Deadhead gravel pit in the immediate area (Bret Boundy, personal communication, 1995). Other indicator mineral anomalies have also been identified in nearby drainages.

Elmers Rock greenstone belt: One of the more impressive regions for abundant kimberlitic indicator mineral anomalies discovered by the WSGS lies within the Elmers Rock greenstone belt, north of Sybille Canyon. This greenstone belt could potentially host dozens of undiscovered kimberlites based on the stream sediment sampling surveys (Figure 14). Geologically, the region lies north of the Cheyenne Belt within the Wyoming Province, and is underlain by an Archean greenstone belt (Graff and others, 1982).

The indicator mineral anomalies are abundant and scattered over a large area. Some of the more impressive anomalies include samples collected north of the Wheatland reservoir on the Laramie River and Dodge Creek. Several samples from this area yielded common kimberlitic indicator minerals. Three of the more highly anomalous samples yielded 30, 85, and 129 kimberlitic indicator minerals as well as some gold, fluorite, and sapphire.

Another impressive anomaly found in the Laramie River drainage, east and north of Elmers Rock near the Wheatland tunnel in section 36, T 23N, R72W included samples with more than 10 indicator minerals, including one with more than 70 indicator minerals. A few of these samples also yielded some microscopic gold and sapphire. The anomalies in the greenstone belt continue north of the map area, where 6 of 7 samples collected in Duck Creek, also yielded kimberlitic indicator minerals.

Powder River Basin

Microdiamonds and some garnets were recovered from a coal seam near Gillette in the Powder River Basin of northeastern Wyoming (Finkelman and Brown, 1989). The source of the diamonds is unknown. However, with the recent discovery of Tertiary age mantle-derived breccia pipes in the Green River Basin of southwestern Wyoming, the possibility of similar pipes in the Powder River Basin should be considered. The Powder River Basin overlies the Wyoming Province.

Medicine Bow Mountains

The Medicine Bow Mountains in southeastern Wyoming, have produced kimberlitic indicator mineral anomalies as well as some detrital diamonds of unknown origin. However, the widespread occurrence of Proterozoic age quartz-pebble conglomerates, Tertiary conglomerates, and heavy vegetation, complicates exploration in this region.

In 1977, two near-gem octahedral diamonds were discovered in a gold placer on Cortez Creek in the northern Medicine Bow Mountains (Figure 15) (Hausel and others, 1985). Although no kimberlitic indicator minerals were found on Cortez Creek during follow-up sampling, indicator minerals were recovered from soil samples several miles south in Iron Creek, a tributary of South French Creek, by Superior Minerals Company. The samples contained numerous eclogitic and G9 peridotitic pyrope garnets that were rounded to subangular ranging from 500 to 1,000 microns in diameter. Similar garnets were also found in upper north French Creek in soils directly below the Ferris-Hanna Formation (Tertiary); however, the Ferris-Hanna Formation was never sampled (T.E. McCandless, personal notes, 1991). A diamond was also recovered from drill-core of Precambrian quartz-pebble conglomerate by Superior Minerals during exploration for a Witwatersrand-type gold deposit in the northern Medicine Bow Mountains (T.E. McCandless, personal notes, 1995).

Several miles east of the French Creek area, kimberlitic indicator minerals and some visible gold were recovered in the Libby Creek drainage, a short distance south of Barber Lake on the section line between sections 28 and 29, T16N, R78W (Figure 16). Indicator minerals were also recovered a few miles to the southwest at the mouth of Camp Creek in the E/2 section 10, T15N, R79W (Hausel and others, 1988).

Samples collected on Mullen Creek and the Middle Fork of the Laramie River (T15N, R78W), adjacent to the historic Centennial Ridge gold district did not yield any kimberlitic indicator minerals. However, a few of these samples yielded gold colors. Elsewhere, pyrope garnets were recovered from a gold placer on Douglas Creek about 0.5 mile downstream from the Bobbie Thompson campground in 1995 (Paul Allred, personal communication, 1995).

The available data indicates the Medicine Bow Mountains are highly anomalous. However, this region remains relatively unexplored for diamonds.

Seminoe Mountains

Eight pyrope garnets, four chromian diopsides, and some gold were recovered from a paleoplacer (Tertiary?) east of the North Platte River along the northeastern flank of the Seminoe Mountains greenstone belt in section 14, T26N, R84W (Hausel, 1994). The source of the indicator minerals was not determined, although the paleoplacer contained pebbles of banded iron formation similar to the Bradley Peak area to the west.

Within this region, a circular depression of unknown origin was found within Archean granite (Woody Motten, personal communication, 1996). Geophysical surveys over the structure produced a distinct EM conductor and a weak magnetic anomaly suggesting the presence of a pipe-like structure (Figure 17). However, no kimberlite or lamproite was found, and stream sediment samples collected within and immediately adjacent to the structure, did not yield any indicator minerals (Hausel, personal field notes, 1996). The origin of this depression is unknown.

Dixon

A sample of alluvium collected by Bret Boundy (pers. comm., 1995) from the Umbrella gravel pit near Dixon west of the Sierra Madre Mountains, yielded a few pyrope garnets. The source of the garnets has not been investigated.

Wind River Mountains

A diamond was reportedly found in the Beaver placers of the South Pass-Atlantic City mining district of the southern Wind River Mountains in the late 1800s (Hausel, 1991). According to historic newspaper reports, $1,000 was offered for the stone.

A second diamond (~2 cm across) was reportedly found on a flat between Tourist and Well Creeks one mile west of Mount Solitude in the central Wind River Mountains. This stone, known as the Moore diamond, was verified by a jeweler and later destroyed in a ranch fire (J.D. Love, personal communication, 1981). The Wind River Mountains remain unexplored for diamonds.

Green River Basin and Rock Springs Uplift

One of the largest lamproite fields in the world, lies along the northern flank of the Rock Springs uplift in southwestern Wyoming. This field is located northeast of an extensive kimberlitic indicator mineral anomaly that was first described by McCandless (1982). The anomaly covers 500 to 1,000 mi^2 of the Green River Basin of Wyoming and extends south into northeastern Colorado and along the northern flank of the Unita Mountains of Utah. This extensive anomaly suggests the presence of numerous undiscovered mantle-derived pipes.

The Green River Basin is a Tertiary basin filled in part with lacustrine sedimentary rocks. The eastern edge of the basin is marked by a gradual anticlinal uplift known as the Rock Springs uplift (Late Cretaceous-Paleocene), and the entire basin and Rock Springs uplift are interpreted to overlie basement rocks of the Wyoming Province.

<u>Leucite Hills</u>: Lamproites of the Leucite Hills lie along the northern flank of the Rock Springs uplift. This field includes several 3.1 to 1.4 Ma leucite-lamproite and olivine-lamproite volcanoes and plugs dominated by flows with lesser volcaniclastics. The lamproites initially erupted in the extreme northwestern portion of the field and progressed to the southeast through time.

The rocks which form the Leucite Hills consist of rare ultrapotassic mafic volcanics known as wyomingite (diopside-leucite-phlogopite lamproite), madupite (diopside-madupitic lamproite), orendite (diopside-sanidine-phlogopite lamproite), and olivine orendite (olivine-sanidine-phlogopite lamproite). Geochemically, these range from 42.65 to 56.34% SiO_2, 2.52 to 12.66% K_2O, and 5.8 to 12.75% MgO.

Individual flows vary in thickness from less than one foot to 122 feet and include vesicular lavas, scoria, autolithic intrusive breccias, lapilli tuffs, tuff breccias, and agglomerates. Although vents have been found in association with most flows, vent facies breccias are inconspicuous at South Table Mountain, North Table Mountain, Black Rock, and Hatcher Mesa (Ogden, 1979).

Petrographic studies show the Leucite Hills lamproites contain diopside, phlogopite, titanian-potassium-richterite, leucite, sanidine, wadeite, priderite, and/or olivine, with minor apatite, perovskite, ilmenite, armalcolite and spinel. Kalsilite and primary analcite have also been identified in some lamproites (Speer, 1985; Carmichael, 1967). The typical kimberlitic indicator minerals which are rare in lamproites, have not been identified in the Leucite Hills volcanics. However, a sediment sample concentrate collected along the northern margin of Endlich Hill yielded one pyrope garnet (W.D. Hausel, personal field notes, 1984).

The Leucite Hills volcanics exhibit similarities to leucite lamproites and olivine lamproites in Western Australia and Murfreesburo, Arkansas (Carmichael, 1967). In particular, Carmichael (1967) noted similarities between the Leucite Hills madupites and Arkansas olivine lamproites, and suggested the Leucite Hills may have been derived by the fractionation of a kimberlitic liquid.

Because of these similarities, the Leucite Hills are considered a potential diamond exploration target; however, only minor exploration activity has occurred, and one small sample of olivine-orendite lamproite breccia (<1 ton) collected from the northern edge of Endlich Hill yielded no diamonds (Robert Gregory, personal notes, 1995). Although no diamonds were recovered, the sample was too limited in size and extent to properly assess the diamond potential of the field. A few chromites recently recovered from the Leucite Hills and tested at the University of Wyoming microprobe lab, yielded chemistries similar to diamond inclusion chromites (Robert Kirkwood, personal communication, 1997), suggesting that the Leucite Hills need to be examined in greater detail.

Of the known lamproites in the world, olivine lamproites offer the greatest potential for significant diamond mineralization. Thus exploration should concentrate on the testing of the olivine orendites in the Leucite Hills, and on a search for buried and hidden lamproite. Olivine-rich lamproites tend to erode rapidly due to serpentinization and typically merge into the surrounding topography where they are easily overlooked.

Since madupitic lamproites contain magnetite, these rocks should yield detectable magnetic anomalies, while other lamproites may only yield weak magnetic anomalies. The olivine lamproite at Prairie Creek, Arkansas, for example, is magnetic and produced a distinct dipolar magnetic anomaly (Bolivar and Brookins, 1979). Whereas the lamproite tuffs from the Argyle olivine lamproite in Western Australia are only weakly magnetic (Atkinson, 1986).

Airborne magnetic and radiometric surveys have been used successfully in the location of lamproites, and INPUT surveys have been used successfully in the discovery of hidden lamproites in the Ellendale field, West Kimberley, Australia (Jaques and others, 1986; Atkinson, 1986). Similar geophysical surveys are recommended for the Leucite Hills.

The Leucite Hills enclose 22 known flows, dikes, necks, plugs, and cinder and pumice cones (Ogden, 1979) (Figure 18).

Black Rock: Black Rock is the easternmost lamproite of the Leucite Hills. Cross (1897) suggested Black Rock represented a plug; whereas, Smithson (1959) and Ogden (1979) described Black Rock as a basal pyroclastic olivine orendite overlain by a lava flow. The top 80 feet of the mesa consists of alternating layers of vesicular and nonvesicular lava. In all probability, the flows at Black Rock conceal an underlying vent.

Dunite nodules, and two generations of olivine phenocrysts, are reported at Black Rock (Speer, 1985). These include a phenocryst with a reddish reaction rim and an average composition of Fo_{90}, and a second phenocryst with an average composition of Fo_{86} (Carmichael, 1967).

Boars Tusk: Boars Tusk is a prominent volcanic neck composed of wyomingite that rises more than 300 feet above the valley floor. The agglomerate contains common Green River and Wasatch Formation shale and sandstone xenoliths, with occasional granite xenoliths and autobrecciated fragments of lamproite.

Cabin Butte: Cabin Butte is an orendite lava flow with a volcanic plug dome along its northern end (Ogden, 1979).

Deer Butte: Deer Butte forms a composite volcanic center with two cinder cones, three lava flows, and a vent exposed in its southern wall. The scoria from Deer Butte is composed of wyomingite, while the lava is predominately orendite (Ogden, 1979).

Emmons Mesa: Emmons Mesa is formed of orendite. The mesa includes a cone, at least two flows, and a overlapping flow that predates the cone. The cone contains xenolithic rock fragments composed of pyroxene, plagioclase, and phlogopite, and xenoliths of amphibolite, anorthosite, granulite, granite, and sedimentary rocks. Whereas the flow only contains granite and sedimentary xenoliths (Ogden, 1979).

Endlich Hill: Endlich Hill includes both olivine orendite flows and volcaniclastics. More than one population of olivine has been recognized at Endlich Hill (Cross, 1897; Carmichael, 1967). In addition to anhedral xenocrysts and subhedral to euhedral microphenocrysts, the lamproites at Endlich Hill enclose anhedral olivine mantled by phlogopite laths in disequilibrium with the host magma. These anhedral olivines are interpreted to represent upper mantle-derived xenocrysts (Carmichael, 1967). A small sample of volcanic breccia from Endlich Hill was tested for diamonds by the WSGS, and one small, clear, octahedron was recovered. The grain was identified by XRD as spinel, and no diamonds were found (W.D. Hausel, personal notes, 1984).

Hague Hill: Hague Hill forms a low-lying hill south of Endlich Hill. The lavas that form Hague Hill are composed of orendite (Ogden, 1979).

Hatcher mesa: According to Ogden (1979), Hatcher mesa is an eroded remnant of a small ponded lava flow. The center of the mesa is depressed by 6 feet relative to the edges indicating the surface sagged as the lava flowed back into the vent. Hatcher mesa is composed primarily of orendite, with wyomingite forming the basal part of the flows (Smithson, 1959).

The mesa is composed of light-to brownish-grey vesicular lava with small 2 mm phlogopite grains, and black to dark-green 2.5 mm clinopyroxene grains. In thin section, microphenocrysts of clinopyroxene, phlogopite, apatite and iron-titanium oxide with uncommon olivine occur in a groundmass of leucite, clinopyroxene, potassium richterite, apatite, priderite, wadeite, and glass (the absence of sanidine in these rocks distinguishes them as wyomingite). The olivine grains are unzoned and characterized by high $Mg/(Mg+\Sigma Fe^{2+})$ and Ni. In these respects, they are comparable to olivines from lherzolite and harzburgite mantle nodules in kimberlite (Barton and van Bergen, 1981)!

Whole rock analyses show relatively high K_2O, BaO, SrO, P_2O_5 and ZrO, and relatively low Na_2O and Al_2O_3 compared to a typical mafic volcanic rock (Barton and Bergen, 1981). The lavas contain the most abundant and diverse assemblage of xenoliths and xenocrysts in the Leucite Hills. According to Smithson (1959), the xenolith assemblage includes granite, norite, and mica schist. Inclusions of phlogopite, apatite, and glass similar to those at Black Rock, are also found at Hatcher Mesa.

Iddings, Weed, and Hallock Buttes: These occur as three small knobs of wyomingite that lie along a N40°W trend between Hague Hill and South Table Mountain. The buttes are apophyses originating from a dike in the subsurface (Ogden, 1979).

Matthews Hill: Matthews Hill forms an inconspicuous low-lying hill a short distance south of Boars Tusk. The hill is an remnant of a volcanic neck (Ogden, 1979).

Pilot Butte: Pilot Butte forms the westernmost known lamproite in the Leucite Hills. The madupitic lavas at Pilot Butte are silica-poor and magnesian-rich relative to other lavas in the Leucite Hills, and are enriched in Ba, Sr, Th and REE and depleted in Ni with lower K/Rb ratios than most phlogopitic lamproites (Mitchell and Bergman, 1991). Spinels from these lavas are chrome-poor (>1 wt% Cr_2O_3), magnesian (<5 wt% MgO), titaniferous (>10 wt% TiO_2) magnetites, and are unlike the chrome-spinels (9-58 wt% Cr_2O_3) found in the diamondiferous lamproites in Western Australia and Murfreesburo, Arkansas.

Spring Butte (Orenda Mesa): Spring Butte is considered the type locality for orendite. The butte forms a compound volcanic center of six cinder cones, six flows, and three dikes. Flow thicknesses range from 10 to 77 feet. The Spring Butte cones consist of welded clastic flows with ribbon and breadcrust bombs. Xenoliths found at Spring Butte include fragments of Ft. Union Formation sandstones with some rare anorthosites (Smithson, 1959).

Steamboat Mountain: Steamboat Mountain is formed predominately of orenditic aphanitic vesicular flows with lesser wyomingite, that encloses some sedimentary xenoliths. One glassy wyomingite sample collected from this mesa yielded 12.66% K_2O indicating this to be one of the most potassic lavas in the world (Carmichael, 1967).

Table Mountain: Table Mountain consists of North Table Mountain, South Table Mountain, and Middle Table Mountain. North Table Mountain is a volcanic mesa composed of a single flow with well-developed flow layering of light-grey orendite and dark-grey wyomingite. South Table Mountain forms a prominent mesa adjacent to North Table Mountain and consists of olivine orendite with some wyomingite. On the southern margin of North Table Mountain, a small volcanic plug known as Middle Table Mountain consists of greenish layers of madupite alternating with brownish layers of wyomingite (Odgen, 1979).

The flows on South Table Mountain are relatively MgO-rich due to the presence of phenocrystal and xenocrystal olivine. Small dunite xenoliths have also been reported in these rocks. The madupitic lavas from Middle Table Mountain are silica-poor and magnesian-rich relative to other lavas in the Leucite Hills and contain shale xenoliths (Speer, 1985).

Twin Rocks (Badgers Teeth): Twin Rocks forms five small projections of xenolith-rich lava along an east-west trend that rise from an inverted cone. These are part of a volcanic neck conduit which rose as apophyses from a subsurface dike. The bulk of the neck is formed of autobrecciated agglomerate which is texturally a wyomingite, but chemically similar to madupite (Odgen, 1979).

Zirkel Mesa: Zirkel Mesa forms the largest exposure of lamproite in the Leucite Hills. The mesa consists of six cinder cones rising more than 240 feet above the mesa surface that coelesce into a single, volcanic-capped, plateau (Ogden, 1979). Flow thicknesses vary from less than 3 feet to as much as 50 feet and are composed primarily of orendite (Kuehner, 1980).

Along the southeastern margin of the mesa, highly vesicular pumaceous phlogopite-lamproite exposed in a quarry, exhibits flow banding with common country rock xenoliths and an underlying basal rubble zone. The rubble zone lies on top of Almond Formation (Cretaceous) shale which has been baked along the contact.

Green River Basin Kimberlitic Indicator Mineral Anomaly: A significant kimberlitic indicator mineral anomaly occurs in the Green River Basin of southwestern Wyoming, extending southward into extreme northwestern Colorado and northeastern Utah (Figure 19). This region is underlain by a thick succession of Tertiary to Cretaceous basin-fill lacustrine and fluvial sediments which overlie basement rocks of the Wyoming Province. The anomalous area lies along a northeasterly trend with the Leucite Hills to the northeast, and the Kamas, Utah lamproites to the southwest, and covers an area of 500 to 1,000 mi^2. The significance of this anomaly was first recognized by McCandless (1982) who identified the mineral grains as mantle-derived minerals of possible kimberlitic origin.

The indicator mineral suite includes chromian diopside, chromian enstatite, pyrope garnet, pyrope-almandine garnet, ilmenite, chromite, and salitic pyroxene in anthills, soils, and in the basal conglomerate of the Bishop Conglomerate (Oligocene) along the flank of Cedar Mountain, Sage Creek Mountain, and on Diamond Peak in Colorado (McCandless, 1982, 1984). Extensive drainage sampling in the Unita Mountains to the south produced only a few indicator mineral anomalies, and no continuous mineral trains could be shown to exist between the Green River Basin and the Unita Mountains. In addition, salitic diopsides found in the Bishop Conglomerate were not found in the samples from the Uinta Mountains (McCandless and others, 1995).

Within this region, a number of anomalies have been identified. These include a well drilled to the north of Cedar Mountain in section 19, T15N, R111W, which was reported to have cut a trona-bearing unit at a depth of 2,700 feet. The geologist's log also described a bed in this unit that contained talc, chlorite, saponite, green hornblende and pyroxene (Love, 1963), minerals that are suggestive of an ultramafic rock. The pyroxene from the core was described as acmitic clinopyroxene (or at least an iron-rich pyroxene based on optical properties), similar to the acmitic clinopyroxene commonly found in the anthills, the Bishop Conglomerate, and at Hatcher Mesa.

The kimberlitic indicator minerals found in the Green River Basin have chemistries which suggest genesis from an upper mantle source; however, the chemistry also suggests low potential for diamonds in this region (McCandless and Nash, 1995;

McCandless and others, 1995). Based on the coexistence of pyrope and clinopyroxene in some samples, McCandless and Nash (1995) estimated ophacite/pyrope-almandine intergrowths originated at depths of 25 to 40 miles, and chrome pyrope/chrome diopside pairs originated at depths of 30 to 50 miles. For comparison, diamonds in the State Line district are thought to originate from depths as great as 90 to 120 miles.

The peridotitic pyropes recovered from anthills and conglomerates in the basin have G9 chemistry. Only two pyropes recovered from the area approach G10 composition indicating a low potential for diamonds from a peridotite source. Eclogitic pyropes from the area are even less encouraging as they contain no detectable Na_20 suggesting there is no eclogitic diamond potential. The chemistry of chromites found in the area also suggest low diamond potential (McCandless and others, 1995).

The source of the indicator mineral anomalies alluded researchers until the discovery of 10 cryptovolcanic breccia pipes along the southwestern flank of Cedar Mountain near the Utah border by Richard Kucera. The pipes lie along a 5 to 10 mile-long, north-south-trending lineament in the Bridger Formation (Eocene) (Figure 20). The largest diatreme in the group measures 400 by 700 feet and is a greenish-grey breccia with abundant lithic sedimentary fragments from underlying strata. Additionally, the breccias contain crystalline basement xenoliths, mantle-derived eclogite nodules, and kimberlitic indicator minerals.

The indicator minerals found in the breccia pipes are comparable to those found in the anthills and in the Bishop Conglomerate. Thus the pipes are interpreted as the source of some of the indicator minerals in the immediate area. However, the widespread distribution of indicator minerals in this region suggests the presence of dozens of similar, undiscovered pipes.

Indicator minerals are abundant in the pipes, and the grain size of the minerals are relatively small (average 2 to 4 mm) and of equivalent size to detrital mineral grains found throughout the basin. For comparison, kimberlitic indicator minerals and xenoliths from the State Line district kimberlites include pyrope-almandine megacrysts up to 5 inches across with some eclogite and peridotite nodules up to 10 inches across. In the State Line district, the indicator minerals typically exhibit maximum transportation distance of only 0.25 to 2 miles from a kimberlite source before complete dissagregation. Because of the similar size of the mineral grains in the DK pipes at Cedar Mountain to those in the anthills and conglomerates, this would suggest that numerous undiscovered pipes may be necessary to account for the widespread indicator mineral anomaly.

Indicator minerals recovered from the DK pipes and dikes include garnets, pyroxenes and oxides, along with some mini-xenoliths. Both peridotitic and eclogitic garnets occur in the mineral assemblage. Microprobe analyses performed at the University of Arizona indicate the mineral suite includes peridotitic garnets with dominantly calcic G9 pyrope compositions, and eclogitic pyrope-almandine garnets with low sodium ($\leq$0.06 wt.% Na_2O) content. All but one pyroxene from the suite yielded K_2O <0.07%. The exception was a calcic chromian diopside of peridotitic paragenesis that yielded 0.10% K_2O suggesting probable origin within the diamond cogenetic field. Ilmenites yielded 4.8 to 7 wt.% MgO, and 0.0 to 4.5 wt.% Cr_2O_3 typical of kimberlitic ilmenites (the compositions suggest favorable conditions for diamond preservation), and chrome spinels yielded 14.5 to 57 wt.% Cr_2O_3 and 0.0 to 19.7 wt.% MgO.

Thirteen garnet-pyroxene mini-xenoliths recovered from the DK pipe contained garnets with high almandine content suggesting a granulite (lower crustal) source. Four other xenoliths yielded magnesian pyrope-almandine (Group II) garnets of probable eclogitic origin. None of the garnets contained elevated Na_2O which suggests they originated at depths too shallow for diamond stability.

Selected breccia matrix samples yielded 67.66-44.08% SiO_2, 0.47-0.27% TiO_2, 9.86-5.25% Al_2O_3, 5.13-2.82% Fe_2O_3, 0.22-0.04% MnO, 14.95-4.29% MgO, 17.99-5.10% CaO, 1.75-0.57% Na_2O, 2.49-1.41% K_2O, 0.56-0.22% P_2O_5, 17.77-6.6% LOI, 0.14-0.07% Cr_2O_3, and 755-256 ppm Ni, and 5.44% CO_2 (Hausel and others, 1996). The MgO content is low and the SiO_2 content is high compared to an average kimberlite, and the chemistry also does not appear to be comparable to lamproite. However, the nickel and chrome signatures suggest contribution from a mafic to ultramafic source.

Back-scatter microprobe analysis completed at the University of Washington on the rock matrix shows cryptocrystalline silica. The matrix contains no identifiable magmatic component and may be the result of a gas-solid mixture which disrupted the overlying Bridger Formation (Tony Irving, personal communication, 1996). The data suggests these cryptovolcanic structures may represent disrupted sediments overlying mafic to ultramafic pipes at depth.

Guardian Enterprises completed a 6-hole drilling program on the DK pipe in 1996. A total of 1,250 feet of core was recovered, and a 3,000 pound bulk sample collected. The bulk sample was grease tabled by the WSGS, and no diamonds were recovered. However, a 200 pound core sample processed by the Saskatchewan Research Council, was reported to have yielded two diamonds. A third diamond was recovered from a sample concentrate collected by Richard Kucera north of the DK pipe. This diamond was described to have a maximum diameter of 2.2 mm with SI clarity and J color. The diamonds recovered from the core had maximum diameters of 1.07 mm and 0.13 mm. According to Guardian Resources (press release, 9/24/96), 48 other alluvial diamonds were recently recovered from sample concentrates collected from a new source other than the DK pipes. These were verified by a Diamonds Direct in Vancouver and reported to weight a total of 2.3 carats.

These latter diamonds have reportedly been found in an area where some other diamonds were reported in the past. These included a group of 5 diamonds rumored to have been found by Amselco in the early 1980s. Four diamonds were also reportedly found in the Butcherknife Draw area to the north several years ago (Paul and Jean Miller, personal communication, 1994). The Butcherknife Draw area lies within the area with abundant kimberlitic indicator mineral-bearing anthills. One of the diamonds, currently owned by a Green River resident, was reportedly cut in Germany and mounted in a ring. The stone measures 0.3 inch across and was apparently confirmed as diamond by a gemologist with a GEM diamond tester (Wayne Sutherland, personal communication, 1995). To date, none of the diamonds have been confirmed by the WSGS.

Although, geophysical surveys over one DK pipe showed the breccia to be conductive, the clay-rich Bridger Formation country rock produced higher conductivity than the pipe resulting in a relative conductivity low. Magnetic surveys yielded a weak, positive anomaly. A few topographic anomalies west of the DK pipes in the vicinity of Lonetree, Wyoming, were also investigated by geophysical surveys by the WSGS.

Lonetree anomalies *(sections 7, T12N, R113W, and sections 12, 13 & 24, T12N, R114W).* A group of circular topographic features were identified in 1994 (Gordon Marlatt, personal communication, 1994). Ground EM and magnetic surveys over a some of these yielded relatively high conductivity and very weak magnetic anomalies similar to the DK pipe (Hausel and Gregory, 1996). The source of the anomalies has not been determined.

Bighorn Basin

Several kimberlitic indicator mineral anomalies including pyropes with G10 compositions, were reportedly identified in conglomeratic sources in areas of Precambrian and Paleozoic exposures along the Bighorn and Owl Creek Mountains of northern Wyoming in the 1980s (Chuck Mabarak, personal communication, 1996). The G10 garnets were found in the most westerly conglomerates *(pyropes designated as G10, have compositions similar to diamond-inclusion garnets).* This area should be considered high priority in any diamond exploration program in the Wyoming Province!

MONTANA

INTRODUCTION

Alnöites, monticellite peridotites, carbonate-rich mica peridotites, monchiquites, lamproites, kimberlites, and isolated detrital diamond occurrences are reported in Montana. Many of these intrusives occur within the central Montana alkalic province of eastern Montana, which overlies the Wyoming Province (Hearn, 1989; Scambos, 1991). A few lamproites have also been found off-craton(?), in western Montana (Pete Ellsworth, pers. comm., 1996).

To the north of Montana, kimberlitic indicator minerals (pyrope garnet and chromian diopside) have been recovered from glacial till in the southwestern part of Saskatchewan close to the Montana border (Levinson and others, 1992). Indicator minerals have also apparently been reported in extreme northwestern Montana.

Diamonds have been reported in western Montana near the projected margin of the Wyoming Province. These include diamonds from Grasshopper Creek and Greenhorn Gulch in southwestern Montana (Sinkankas, 1959), a 12-grain, colorless dodecahedron from Nelson Hill at Blackfoot in northwestern Montana (Kunz, 1885), and a 0.22 carat flawed stone from the same region (Sinkankas, 1959).

In recent years, a 14-carat diamond which sold for $80,000 (Anonymous, 1990a), was found southwest of Great Falls near the town of Craig in west-central Montana. Other diamonds have been reported along the Missouri River to the south near Helena, including another relatively large stone that reportedly weighed 8 carats (Anonymous, 1990b).

One ultramafic intrusive in this region, that contains upper mantle xenoliths, occurs along the eastern shore of Holter Lake on the Missouri River northeast of Helena. The Ming Bar monchiquite contains abundant cognate metacrysts of olivine, pyroxene, and chromite with granulite, dunite, pyroxenite and peridotite nodules (Meen and others, 1986). Five placer diamonds were reportedly recovered nearby at Spokane Bar, and a 5 carat diamond was reported from Metropolitan Bar (Tony Irving, pers. comm., 1994). These localities; however, lie upstream from the Ming Bar intrusive.

LAMPROITE, KIMBERLITE, AND LAMPROPHYRE LOCALITIES

Western Montana

Ruby Slipper lamproite *(sections 3, 4, & 10, T11N, R14W).* The Ruby Slipper lamproite was mapped as a 1,800 foot-wide leucite basalt by Carter (1982), but was later identified as lamproite. The phlogopite lamproite intrudes Jefferson Formation (Devonian) and Tertiary basalts and rhyolites near Bearmouth along Bear Gulch in the Garnet Range in western Montana. It occurs as a aphanitic lamproite flow with phlogopite phenocrysts, overlying a breccia intersected during drilling (Pete Ellsworth, personal communication, 1996).

According to Ellsworth (1996), the pipe forms a prominent 1,500 foot circular knob, with crater facies volcaniclastics covered by talus and colluvium from the lamproite porphyry. Four other lamproitic prospects have recently been located in the region (Pete Ellsworth, pers. comm., 1996).

Eastern Montana

In eastern Montana, mantle-derived breccias and dikes have been found in the Missouri Breaks, Porcupine Dome, and Grassrange areas. More than 30 carbonate-rich dikes and breccia pipes are reported in the Porcupine Dome and Grassrange areas. A group of kimberlites also occur in the Missouri Breaks region.

Missouri Breaks: The Smoky Butte lamproites (27 Ma) lie 6.5 miles west of Jordan in northeastern Montana in the Missouri Breaks region. This complex consists of several lamproites emplaced along a N30°E trend (Figure 21). These are sanidine-diopside-richterite-phlogopite-lamproites which form a dike with swells up to 122 feet wide. The rocks include vesicular, massive, glassy, hypabyssal breccias, with minor tuffs and pyroclastics (Mitchell and Bergman, 1991).

Grassrange Field: A belt of ultramafic lamprophyres form the Grassrange Field 4 to 6 miles south of Winnet, near Yellow Water Reservoir in east-central Montana. According to Doden (1996), the belt consists of ultramafic lamprophyric diatremes and dikes that originally were described as lamproites by Mitchell and Bergman (1991).

Two intrusives in this belt, Elk and Yellow Water Buttes, are carbonated, ultramafic lamprophyres. Yellow Water Butte is formed of massive to brecciated, olivine-phlogopite-diopside-carbonated lamprophyre(?) and massive hypabyssal olivine lamprophyre (Doden, 1996). The Elk Butte vent-dike complex forms an intrusive breccia with lapilli tuffs (Mitchell and Bergman, 1991). Similar, but less extensive lamprophyre outcrops occur in the area (Hausel, personal field notes, 1994). Doden (1996) suggested that the Yellow Water breccias were formed from a highly gas-charged magma that rapidly ascended from the mantle and was virtually unaffected by crustal contamination.

Landusky-Zortman field: To the north of the Grassrange Field, a group of four kimberlites known as the Williams kimberlites, occur in the eastern part of an east-northeasterly-trending swarm of ultramafic alkalic intrusives (46 to 51 Ma) in north-central Montana. These rocks preceded the intrusion of Smoky Butte (27 Ma), 70 miles to the southeast.

The kimberlites enclose lherzolite, harzburgite, and dunite xenoliths. The Williams 1 diatreme is about 750 by 105 feet across. The Williams 2 kimberlite has a surface area of about 128 by 375 feet, with a zone of kimberlite breccia containing abundant

Paleozoic limestone and dolomite xenoliths. The Williams 3 diatreme is about 96 by 128 feet in surface area, and consists of kimberlite breccia, whereas and the Williams 4 is a dike-like diatreme, 1,216 feet long and 121 feet wide, of massive kimberlite with desultory zones of fragmental kimberlite (Hearn and McGee, 1983).

The kimberlites also contain xenoliths of Precambrian basement, upper crust (schist, gneiss, amphibolite), lower crust (granulite, mafic granulite, amphibolite), and the upper mantle (spinel peridotite, dunite, garnet peridotite), as well as typical kimberlitic indicator minerals. According to Hearn and McGee (1983) neither diamond nor eclogite has been found in these intrusives.

Analyses of peridotitic pyrope garnets from the Williams kimberlites yielded G9 compositions: no G10 pyropes were found (Hearn and McGee, 1983). However, P-T estimates from co-existing orthopyroxene-clinopyroxene pairs in some of the peridotite nodules suggested possible genesis within the diamond stability field (Fred Barnard, written comm., 1994).

Porcupine Dome Field: The Porcupine Dome Field in southeastern Montana, includes Froze-to-Death, Johnson Ranch, and Gold Buttes (Doden and Gold, 1993). Froze-to-Death Butte is a multiple vent complex located 9 miles northwest of Hysham. Gold Butte lies 25 miles northeast of Froze-to-Death Butte.

Mitchell and Bergman (1991) described Froze-to-Death Butte as massive hypabyssal intrusive breccias consisting of altered olivine-phlogopite-diopside-lamproite. In contrast, Doden (1996), indicated the rock does not resemble lamproite, but instead is an ultramafic lamprophyre (aillikites) sharing some affinities with kimberlite. In particular, the intrusive contains picroilmenite and garnet macrocrysts.

The picroilmenites have moderate MgO (5-13 wt%), low Cr_2O_3 (<0.7 wt%) and crystal rims enriched in MgO relative to the cores characteristic of kimberlitic ilmenites. Garnets from the Porcupine Dome area include two compositional and color ranges. One consists of a pink-orange garnet that resembles eclogitic garnet with compositions of 0.0-0.1 wt% Cr_2O_3, 1.0-4.5 wt% CaO, 8.1-13.2 wt% MgO, 22.8-30.8 wt% FeO, <0.06 wt% TiO_2, and <0.07 wt% Na_2O (Doden, 1996). The second type of garnet is reddish-purple and similar to peridotitic garnet with compositions ranging from 5.7-7.0 wt% Cr_2O_3, 4.7-7.0 wt% CaO, 18.6-21.6 wt% MgO, and 5.9-7.9 wt% FeO. The peridotitic garnet compositions primarily fall within the G9 compositional field; however a few have subcalcic G10 compositions (Doden and Gold, 1993).

Although the lamprophyres apparently sampled the diamond stability field, the picroilmenite compositions are depleted in Cr_2O_3 indicating oxidizing conditions prevailed in the magma. This may suggest diamond preservation was not favorable; however, the Cr-Mg contents may not provide a good indication of diamond preservation based on the results of ilmenites at Kelsey Lake, Colorado.

The relatively small volume of material associated with the buttes, suggest the buttes represent poor diamond exploration targets. However, since the magmas sampled the diamond stability field, the search for undiscovered (buried) pipes of olivine lamprophyre and lamproite in this region may be productive.

UTAH

INTRODUCTION

Lamproites, minettes, and mica-peridotites are all reported in Utah, although no diamonds are known. The northern portion of Utah is underlain by Archean rocks of the Wyoming Province. To the south, portions of the state are underlain by Proterozoic basement rocks.

KAMAS LAMPROITES

Lamproites in northern Utah, occur southwest of the Leucite Hills, and 40 miles east of Salt Lake City near Kamas. These occur along the southern margin of the Wyoming Province. The Moon Canyon lamproites (40 Ma) southeast of Kamas, consist of hypabyssal olivine-sanidine-diopside-richterite-phlogopite lamproite flows and sills. The Whites Creek lamproites (13 Ma), to the northeast of Kamas, include a series of small orendite dikes which have penetrated upper Cretaceous shales 2 miles northwest of the Uinta North Flank fault zone. These lamproites contain chrome spinel, phlogopite, and olivine. Compared to the Moon Canyon lamproites, the White's Creek have less SiO_2 and nearly twice the MgO content (Henage, 1972). It is not known if either of these have been tested for diamond.

IDAHO

INTRODUCTION

Much of Idaho lies west of the Wyoming Province, and as such, is considered low priority in diamond exploration. However, some diamonds have been reported from the west-central part of the State.

NEW MEADOWS

Shannon (1926), reported that the only authenticated diamonds found in Idaho were discovered in the Rock Flat gold mine at the head of Little Goose Creek Canyon 5 miles east of the New Meadows along the west-central border of the state.

Three small diamonds were reportedly found in the heavy mineral concentrates in this placer in 1913. The largest was a greyish colored octahedron with greasy luster that weighed 0.33 carat. Ilmenite, chromite, zircon, magnetite, garnet, monazite, and ruby were also reported in the concentrates with the diamond (Shannon, 1926). A later, 1947 unconfirmed report, suggested that a 19.5 carat diamond was also found at Rock Flat (Sinkankas, 1959). Although lamproite was recently reported in the vicinity of the placers, this has not been verified.

CONCLUSIONS

Evidence suggests that the Wyoming Craton, which includes both the Wyoming and Colorado Provinces, has high potential for the discovery of additional diamond deposits. To date, more than 100 kimberlites, numerous lamproites and several ultramafic lamprophyres have been found in the craton, and more than 120,000 diamonds, including some of the largest diamonds in the United States have been produced from this terrane. The hundreds of kimberlitic indicator mineral anomalies also support the high potential for the discovery of additional diamond deposits.

Much of the craton is underlain by basement rocks of the Wyoming and Colorado Provinces. These rocks provide good hosts for diamondiferous kimberlite and lamproite, and with the numerous anomalies reported in the region, this craton may represent one of the best exploration targets in North America. Unlike many other terranes currently being explored for diamonds in North American, the Wyoming craton has an established infra-structure which should keep the cost of exploration and mining relatively low.

REFERENCES

Anonymous, 1990a, Uncut 14-carat diamond found by Montana jogger: Associated Press, Sept. 10, 1990.

Anonymous, 1990b, Diamond find raises hope in Craig: Associated Press, Missoulian, Nov. 19, 1990.

Atkinson, W. J., 1986, Diamond exploration philosophy, practice, and promises: a review *in* Ross, J. and others, eds., Kimberlites and Related Rocks Volume 2, Proceedings of the Fourth International Kimberlite Conference, Perth, Australia: Geological Society of Australia Special Publication 14, p. 1075-1107.

Barton, M., and van Bergen, M.J., 1981, Green clinopyroxenes and associated phases in a potassium-rich lava from the Leucite Hills, Wyoming: Contributions to Mineralogy and Petrology, v. 77, p. 101-114.

Bolivar, S.L., and Brookins, D.B., 1979, Geophysical and Rb-Sr study of the Prairie Creek, Arkansas, kimberlite *in* Boyd, F.R., and Meyer, H.O.A., eds., Kimberlites, Diatremes and Diamonds, American Geophysical Union, Washington, D.C., p. 289-299.

Braddock, W.A., and Cole, J.C., 1990, Geologic map of Rocky Mountain National Park and vicinity, Colorado: U.S. Geological Survey Map I-1973 (scale 1:50,000).

Carlson, J.A., 1983, Exploration for kimberlite and geophysical delineation of diatremes, State Line district, Colorado/Wyoming: M.S. thesis, Colorado State University, 180 p.

Carlson, J.A., and Marsh, S.W., 1989, Discovery of the George Creek kimberlite dikes, Colorado *in* Proceedings of the Fourth International Kimberlite Conference, Perth, 1986, Kimberlites and related rocks, Volume 2, Geological Society of Australia Publication no. 14, p. 1169-1178.

Carmichael, I.S.E., 1967, The mineralogy and petrology of the volcanic rocks from the Leucite Hills, Wyoming: Contributions to Mineralogy and Petrology, v. 15, p. 24-66.

Carter, B.A., 1982, Geology of the Eocene volcanic sequence, Mt. Baldy-Union Peak area, central Garnet Range, Montana: M.S. Thesis, University of Montana.

Clifford, T.N., 1970, The structural framework of Africa *in* T.N., Clifford, and I.G., Gass, eds, African Magmatism and Tectonics, p. 1-26.

Coopersmith, H.G., 1991, Geology and exploration of the Kelsey Lake diamondiferous kimberlites, Colorado: Society of Mining Engineers Preprint 91-174, Denver, CO, 17 p.

Coopersmith, H.G., 1993, Diamondiferous kimberlite at Kelsey Lake, southern Wyoming Archean Province: Mid-Continent Diamonds, Geological Association of Canada, Edmonton, Canada, p. 85-88.

Coopersmith, H.G., and Schultze, D.J., 1996, Development and geology of the Kelsey Lake diamond mine, Colorado *in* T.B. Thompson, ed., Diamonds to gold - I. State Line Kimberlite district, Colorado, II. Cresson mine, Cripple Creek district, Colorado: Society of Economic Geologists guidebook series, p. 5-19.

Cross, W., 1897, Igneous rocks of the Leucite Hills and Pilot Butte, Wyoming: American Journal of Science, v. 4 no. 20, p. 115-141.

Doden, A.G., 1996, Ultramafic lamprophyres from Porcupine Dome, east-central Montana, and their potential for diamond: 32nd Annual Forum on the Geology of Industrial Minerals, Laramie, Wyoming, Abstracts w/Programs, p. 14-16.

Doden, A.G., and Gold, D.P., 1993, Kimberlite xenocrysts from the Porcupine Dome diatremes, east central Montana: evidence for multiple sources of garnet and evaluation of diamond potential: Geological Society of America, Abs. w/Prog., v. 25, p. A98.

Dummett, H.T., Fipke, C.E., and Blusson, S.L., 1988, Diamond exploration geochemistry in the North American cordillera *in* Exploration in the North American Cordillera: Joint Publication of the Geological Association of Canada and Association of Exploration Geochemists, p. 168-176.

Eggler, D.H., 1967, Structure and petrology of the Virginia-Dale ring-dike complex, Colorado-Wyoming Front Range: PhD dissertation, University of Colorado, 153 p.

Eggler, D.H., 1968, Virginia-Dale ring-dike complex, Colorado-Wyoming: Geological Society of America Bulletin, v. 79, p. 1545-1564.

Eggler, D.H., and Furlong, K.P., 1991, Petrochemical and geophysical evidence for old mantle lithosphere beneath Montana: Central Montana Alkalic Province: Montana Bureau of Mines and Geology Special Publication 100, p. 87-91.

Eggler, D.H., Meen, J.K., Welt, F., Dudas, F.O., Furlong, K.P., McCallum, M.E., and Carlson, R.W., 1988, Tectonomagmatism of the Wyoming Province: Colorado School of Mines Quarterly, p. 25-40.

Ellsworth, P.C., 1996, Submittal summary for the Bearmouth lamproite diamond prospect: consultant's report, Missoula, Montana, July 27, 7 p.

Falk, R.W., 1992, Physical characteristics of diamonds from the George Creek, Kelsey Lake, and Chicken Park kimberlites: M.S. thesis, Colorado State University, 188 p.

Finkelman, R.B., and Brown, R.D., 1989, Mineral resource and geochemical exploration potential of coal that has anomalous metal concentrations: U.S. Geological Survey Circular 1035, p. 18-19.

Goldich, S.S., Lidiak, E.G., Hedge, C.E., and Walthall, F.G., 1966, Geochronology of the midcontinent region - Part 2, northern area: Journal of Geophysical Research, v.71, p. 5389-5408.

Graff, P.J., 1978, Geology of the lower part of the Early Proterozoic Snowy Range Supergroup, Sierra Madre, Wyoming, with chapters on Proterozoic regional tectonics and uraniferous quartz-pebble conglomerates: PhD dissertation, University of Wyoming, 85 p.

Graff, P.J., Sears, J.W., Holden, G.S., and Hausel, W.D., 1982, Geology of the Elmers Rock greenstone belt, Laramie Range, Wyoming: Geological Survey of Wyoming, Report of Investigations 14, 23 p.

Hausel, W.D, 1991, Economic geology of the South Pass granite-greenstone belt, southern Wind River Range, western Wyoming: Geological Survey of Wyoming Report of Investigations 44, 129 p.

Hausel, W.D, 1994, Economic geology of the Seminoe Mountains mining district, Carbon County, Wyoming: Wyoming State Geological Survey, Report of Investigations 50, 31 p.

Hausel, W.D., 1995a, Diamonds, kimberlites, lamproites and related rocks in the United States, Exploration and Mining Geology, v. 4, no. 3, p. 1-28.

Hausel, W.D., 1995b, Diamonds and their host rocks in the United States, Mining Engineering, v. 47, no. 8, p. 723-732.

Hausel, W.D., 1996a, Pacific coast diamonds-an unconventional source terrane, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the North American Cordillera, Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April, 1995, p. 925-934.

Hausel, W.D., 1996b, Recurring kimberlite and lamproite magmatism in the Wyoming Craton - an overview: Geological Society of America Abstract no. 15234.

Hausel, W.D., and Gregory, R.W., 1996, Geophysical reconnaissance of the Lonetree circular topographic anomalies in the southern Green River Basin, Uinta County, Wyoming: Wyoming State Geological Survey Mineral Report MR96-5, 11 p.

Hausel, W.D., and Stahl, Sandy, 1995, The great diamond hoax of 1872 *in* Jones, R.W., ed., Resources of southwestern Wyoming, Wyoming Geological Association 1995 Field Conference Guidebook, p. 13-27.

Hausel, W.D., Edwards, B.E., and Graff, P.J., 1991, Geology and mineralization of the Wyoming Province: Society for Mining, Metallurgy, and Exploration of AIME, Littleton, CO., Preprint 91-72, 12 p.

Hausel, W.D., Glahn, P.R., and Woodzick, T.L., 1981, Geological and geophysical investigations of kimberlite in the Laramie Range of southeastern Wyoming: Geological Survey of Wyoming, Preliminary Report 18, 13 p.

Hausel, W.D., Kucera, R.E., McCandless, T.E., and Gregory, R.W., 1996, Diamondiferous breccia pipes in the southern Green River Basin, Wyoming: 32nd Annual Forum on the Geology of Industrial Minerals Program w/Abstracts, Laramie, Wyoming, p.23-24.

Hausel, W.D., Love, C.M., and Sutherland, W.M., 1995, Road log-Leucite Hills, Green River Basin, Wyoming *in* R.W. Jones and G.A. Winter, editors, Wyoming Geological Association 1995 Field Conference Road Logs, Resources of southwestern Wyoming, p. 45-53.

Hausel, W.D., McCallum, M.E., and Roberts, J.T., 1985, The geology, diamond testing procedures, and economic potential of the Colorado-Wyoming kimberlite province-a review: Geological Survey of Wyoming Report of Investigations 31, 22 p.

Hausel, W.D., McCallum, M.E., and Woodzick, T.L., 1979, Exploration for diamond-bearing kimberlite in Colorado and Wyoming: an evaluation of exploration techniques: Geological Survey of Wyoming, Report of Investigations 19, 29 p.

Hausel, W.D., Sutherland, W.M., and Gregory, E.B., 1988, Stream sediment sample results in search of kimberlite in southeastern Wyoming: Geological Survey of Wyoming, Open File Report 88-11, 11 p., (5 plates).

Hearn, B.C., Jr., 1989, Alkalic ultramafic magmas in north-central Montana, USA: genetic connections of alnöite, kimberlite, and carbonatite, *in* Kimberlite and Related Rocks, v. 1: Geological Society of Australia, Special Publication 14, p. 109-119.

Hearn, B.C., Jr., and McGee, E.S., 1983, Garnets in Montana diatremes: a key to prospecting for kimberlites: U.S. Geological Survey Bulletin 1604, 33 p.

Henage, L.F., 1972, A definitive study of the origin of lamproites: M.S. thesis, University of Oregon, 83 p.

Hoffman, P.F., 1988, United plates of America, the birth of a craton: Early Proterozoic assembly and growth of Laurentia: Earth and Planetary Science, Annual Reviews, v. 16, p. 543.

Hills, F. A., and Houston, R.S., 1979, Early Proterozoic tectonics of the central Rocky Mountains, North America: Contributions to Geology, University of Wyoming, v. 17, p. 89-110.

Houston, R.S., 1983, Wyoming Precambrian Province - example of the evolution of mineral deposits through time? *in* Roberts, Sheila, ed., Metallic and nonmetallic deposits of Wyoming and adjacent areas, 1983 conference proceedings: Geological Survey of Wyoming, Public Information Circular 25, p. 1-12.

Houston, R.S., 1983, Late Archean and Early Proterozoic geology of southeastern Wyoming *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., eds., Geology of Wyoming, Geological Survey of Wyoming Memoir 5, p. 78-116.

Houston, R.S., 1993, Late Archean and Early Proterozoic geology of southeastern Wyoming *in* Snoke, A.W., Steidtmann, J.R., and Roberts, S.M., eds., Geology of Wyoming, Geological Survey of Wyoming Memoir 5, p. 78-116.

Janse, A.J.A., 1994, Is Clifford's rule still valid? Affirmative examples from around the world, *in* Meyer, H.O.A., and Leonardos, O.H., eds., Diamonds-Characterization, Genesis, and Exploration, Campanhia de Pesquisa de Recursos Minerais Special Publication, Brazil, p. 215-235.

Jaques, A.L., Lewis, J.D., and Smith, C.B, 1986b, The kimberlites and lamproites of Western Australia: Geological Survey of Western Australia Bulletin 132, 268 p.

Karlstrom, K.E., and Houston, R.S., 1984, The Cheyenne Belt: analysis of a Proterozoic suture in southern Wyoming: Precambrian Research, v. 25, p. 415-446.

Karlstrom, K.E., Houston, R.S., Flurkey, A.J., Coolidge, C.M., Kratochvil, A.L., and Sever, C.K., 1981, Volume 1, A summary of the geology and uranium potential of Precambrian conglomerates in southeastern Wyoming: U.S. Department of Energy, Open File Report GJBX-139(81), 541 p.

Kuehner, S.M., 1980, Petrogenesis of ultrapotassic rocks, Leucite Hills, Wyoming: M.S. thesis, University of Western Ontario, London, Ontario, 197 p.

Kunz, G.F., 1885, Precious stones: Mineral Resources of the United States, U.S. Geological Survey, p. 723-782.

Larson, E.E., and Amini, M.H., 1981, Fission-track dating of the Green Mountain kimberlite diatreme near Boulder, Colorado: The Mountain Geologist, v. 18, no. 1, p. 18-22.

Levinson, A.A., Gurney, J.J., and Kirkley, M.B., 1992, Diamond sources and production, past, present, and future: Gems and Gemology, v. 28, no. 4, p. 234-254.

Love, J.D., 1963, Letter to W.H. Bradley dated April 25, 1963: Wyoming State Geological Survey files, 6 p.

Lush, A.P., McGrew, A.J., Snoke, A.W., and Wright, J.E., 1988, Allochthonous Archean basement in the northeastern East Humboldt Range, Nevada: Geology, v. 16, p. 349-353.

Marks, J.E., 1985, Multispectral remote sensing techniques applied to exploration for kimberlite diatremes, Laramie Range, Wyoming-Colorado: M.S. thesis, University of Wyoming, 164 p.

Marrs, R.W., Marks, J.E., Hausel, W. D., and Albert, K.E., 1984, Detection of diamond-bearing kimberlites in the Colorado/Wyoming Province: University of Wyoming, Remote Sensing Laboratory Open File Report, 70 p.

McCallum, M.E., 1991, The Sloan 1 and 2 kimberlite complex near the southern boundary of the State Line district of the Colorado-Wyoming kimberlite province *in* Frost, B.R., and Roberts, S., eds., Mineral Resources of Wyoming, Wyoming Geological Association 42nd Field Conference Guidebook, p. 229-250.

McCallum, M.E., and Eggler, D.H., 1979, Field guide for the Sloan and Nix kimberlites in the southern portion of the Colorado-Wyoming State Line kimberlite district *in* F.G. Ethridge, ed., Field guide to the northern Front Range and northeastern Denver Basin, Colorado: Geological Society of America 32nd annual field conference guidebook, p. 181-209.

McCallum, M.E., Eggler, D.H., and Burns, L.K., 1975, Kimberlitic diatremes in northern Colorado and southern Wyoming *in* Physics and Chemistry of the Earth, v. 9, Pergamon Press, N.Y., p. 149-161.

McCallum, M.E., Eggler, D.H., Coopersmith, H.G., Smith, C.B., and Mabarak, C.D., 1977, Field guide, Colorado-Wyoming State Line district: Second International Kimberlite Conference, Santa Fe, N.M., 23 p.

McCallum, M.E., and Mabarak, C.B., 1976, Diamond in State-Line kimberlite diatremes, Albany County, Wyoming, Larimer County, Colorado: Geological Survey of Wyoming, Report of Investigations 12, 36 p.

McCallum, M.E., Mabarak, C.D., and Coopersmith, H.G., 1979, Diamonds from kimberlites in the Colorado-Wyoming State Line district, *in* Boyd, F.R., and Meyer, H.O.A., eds., Kimberlites, Diatremes, and Diamonds: Proceedings of the Second International Kimberlite Conference, American Geophysical Union, Washington, D.C., p. 42-58.

McCallum, M.E., and Waldman, M.A., 1991, The diamond resources of the Colorado-Wyoming State Line district: kimberlite indicator mineral chemistry as a guide to economic potential, *in* Frost, B.R., and Roberts, S., eds., Mineral Resources of Wyoming, Wyoming Geological Association 42nd Field Conference Guidebook, p. 77-90.

McCandless, T.E., 1982, The mineralogy, morphology, and chemistry of detrital minerals of a kimberlitic and eclogitic nature, Green River Basin, Wyoming: M.S. thesis, University of Utah, S.L.C., Utah, 107 p.

McCandless, T.E., 1984, Detrital minerals of mantle origin in the Green River Basin, Wyoming, Society of Mining Engineers of AIME Reprint 84-395, 6 p.

McCandless, T.E., and Collins, D.S., 1989, A diamond-graphite eclogite from the Sloan 2 kimberlite, Colorado, USA *in* Kimberlites and Related Rocks, v. 2, Proceedings of the 4th International Kimberlite Conference, Carlton, Australia, p. 1063-1069.

McCandless, T.E., and Nash, W.P., 1995, Evaluation of kimberlitic indicator minerals with respect to igneous host, mantle conditions, and diamond potential, southwestern Wyoming, and northeastern Utah, USA: Exploration and Mining Geology, *in press.*

McCandless, T.E., Nash, W.P., and Hausel, W.D., 1995, Mantle indicator minerals in ant mounds and conglomerates of the southern Green River Basin, Wyoming *in* Jones, R.W., ed., Resources of southwestern Wyoming, Wyoming Geological Association 1995 Field Conference Guidebook, p. 153-163.

Meen, J.K., Eggler, D.H., and McCallum, M.E., 1986, Proterozoic granulite xenoliths from Ming Bar diatreme, Montana: Geological Society of America, Abstracts w/Programs, v. 18, p. 692.

Meyer, H.O.A., and Kridelbaugh, S.J., 1977, Green Mountain Kimberlite, Colorado: Second International Kimberlite Conference Abstracts, Santa Fe, New Mexico, p. 224.

Mitchell, R.H., and Bergman, S.C., 1991, Petrology of Lamproites: Plenum Press, New York, 447 p.

Moll, S.H., 1982, Reconnaissance geological mapping in north-central Colorado using multispectral gamma-ray data (abstract) *in* Remote sensing for exploration geology: International symposium on remote sensing of the environment, Second Thematic Conference summaries, p. 86-87.

Naesser, C.W., and McCallum, M.E., 1977, Fission-track dating of kimberlitic zircons: Extended Abstracts, Second International Kimberlite Conference, Santa Fe, N.M., unpaginated.

Ogden, P.R., Jr., 1979, The geology, major element geochemistry, and petrogenesis of the Leucite Hills volcanic rocks, Wyoming: PhD dissertation, University of Wyoming, Laramie, 137 p.

Oliver, D.H., 1990, Prairie Divide properties corporation, Sloan Ranch diamond project, Larimer County, Colorado summary report: unpublished consultant's report, Wyoming State Geological Survey files, 11 p.

Otter, M.L., 1989, Diamonds and their mineral inclusions from the Sloan diatremes of the Colorado-Wyoming State Line kimberlite district, North America: PhD dissertation, University of Cape Town, South Africa.

Otter, M.L., and Gurney, J.J., 1989, Mineral inclusions in diamonds from the Sloan diatremes, Colorado-Wyoming State Line kimberlite district, North America *in* Kimberlites and Related Rocks, v. 2, Proceedings of the 4th International Kimberlite Conference, Carlton, Australia, p. 1042-1053.

Otter, M.L., McCallum, M.E., and Gurney, J.J., 1991, A physical characterization of the Sloan (Colorado) diamonds using a comprehensive diamond description scheme, *in* H.O.A. Meyer and O.H. Leonardos (editors), Diamonds: Characterization, genesis and exploration volume 2, 5th International Kimberlite Conference, Companhia de Pesquisa de Recoursos Minerais, Brazil, p. 15-31.

Paterson, N.R., and MacFadyen, D.A., 1984, An airborne EM (INPUT)/magnetometer survey, State Line district, Colorado-Wyoming: Society of Mining Engineers of AIME Preprint 84-310, 11 p.

Peterman, Z.E., Hedge, C.E., and Braddock, W.A., 1968, Age of Precambrian events in the northeast Front Range, Colorado: Journal of Geophysical Research 73, p. 2277-2296.

Peterson, T.D., 1996, Lamproites in Searching for diamonds in Canada: Geological Survey of Canada Open File Report 3228, p. 79-86.

Rogers, J.A., Jr, 1985, Kimberlite exploration, Red Feather area, and petrology of the Chicken Park diatreme, northern Colorado: M.S. thesis, Colorado State University, 196 p.

Scambos, T.A., 1991, Isotopic and trace-element characteristics of the central Montana alkalic province kimberlite-alnöite suite: Central Montana Alkalic Province: Montana Bureau of Mines and Geology, Special Publication 100, p. 93-109.

Shaver, K.C., 1988, Exploration of the Sloan Ranch complex: a diamondiferous kimberlite prospect in northern Colorado: Mining Engineering, Jan., p. 45-48.

Shaver, K.C., 1994, Phase 1 underground exploration and mill testing of the Sloan Ranch diamondiferous kimberlite complex, Larimer County, Colorado: Royalstar Resources Ltd, company report, 39 p.

Shannon, E.V., 1926, Minerals of Idaho: U.S. National Museum Bulletin 131, p. 16.

Sims, P.K., 1995, Archean and Early Proterozoic tectonic framework of North-central United States and adjacent Canada: U.S. Geological Survey Bulletin 1904, 12 p.

Sinkankas, J., 1959, Gemstones of North America: Van Nostrand Company, N.Y., 675 p.

Smith, C.B., 1977, Kimberlite and mantle-derived xenoliths at Iron Mountain, Wyoming: M.S thesis, Colorado State University, Ft. Collins, Colorado, 218 p.

Smith, C.B., 1979, Rb-Sr mica ages on various kimberlites (abstract): Kimberlite Symposium II, Cambridge, England.

Smith, C.B., 1983, Rb-Sr, U-Pb, Sm-Nd isotopic studies of kimberlite and selected mantle-derived xenoliths: PhD dissertation, University of Witwatersrand, Johannesburg, South Africa, 436 p.

Smithson, S.B., 1959, The geology of the southeastern Leucite Hills, Sweetwater County, Wyoming: M.A. thesis, University of Wyoming, Laramie, 92 p.

Speer, J.T., 1985, Xenoliths of the Leucite Hills volcanic rocks, Sweetwater County, Wyoming: M.S. thesis, University of Wyoming, Laramie, 57 p.

Whitaker, M.C., 1898, An olivinite dike of the Magnolia district and the associated picrotitanite: Colorado Scientific Society Proceedings, p. 104-118.

Williams, H., Rivers, T., Hoffman, P.F., Monger, J.W., and Lewry, J.F., 1986, The making of North America: GSA Abstracts w/ Programs, San Antonio, TX, p. 789.

Woodzick, T.L., 1987, Geophysical and remote sensing characteristics of the Colorado-Wyoming kimberlite occurrences: PhD dissertation, Colorado State University, 300 p.

Table 1. Reported diamonds in the United States >2 carats in weight (modified from Hausel, 1995a,b).

Diamond	weight (carats)	State
Uncle Sam	40.42	Arkansas
Punch Jones	34.46	West Virginia
Star of Murfreesboro	34.25	Arkansas
Doubledipity	32.99	California
Kelsey Lake	28.3	Colorado
Howell	27.31	Arkansas
Dewey	23.75	Virginia
Terresa	21.25	Wisconsin
Rock Flat	19.5	Idaho
Enigma	17.83	California
Amarill Starlight	16.37	Arkansas
Eagle	15.37	Wisconsin
Star of Arkansas	15.24	Arkansas
Serendipity	14.33	California
Kelsey Lake	14.2	Colorado
Lewis & Clark	14.0	Montana
Dowagiac	10.875	Michigan
Kelsey Lake	10.5	Colorado
Kelsey Lake	9.4	Colorado
Unnamed	8.82	Arkansas
Unnamed	8.61	Arkansas
Unnamed	7.95	Arkansas
Ashley	7.75	Illinois
French Corral	7.25	California
Shell Bluff	7.11	Georgia
Unnamed	6.75	Arkansas
Saukville	6.57	Wisconsin
Gary Moore	6.43	Arkansas
Unnamed	6.30	Arkansas
Unnamed	6.25	Arkansas
Unnamed	6.2	Arkansas
Kesley Lake	6.2	Wyoming
Eisenhower	6.11	Arkansas
Unnamed	6.07	Arkansas
Williams Ferry	>6.0	Georgia
Milford	6.0	Ohio
Unnamed	5.9	Arkansas
Unnamed	5.76	Arkansas
Unnamed	5.63	Arkansas
Unnamed	5.58	Arkansas
Sloan	5.51	Colorado
Unnamed	5.19	Arkansas
Unnamed	5.15	Arkansas
Unnamed	5.08	Arkansas
Unnamed	5.0	Arkansas
Unnamed	5.0	Arkansas
Stanley	4.88	Indiana
Lee	4.61	Alabama
Shelby	4.37	Alabama
Dysortville	4.33	North Carolina
Daniel Light	4.25	Georgia

Skamania	>4.0	Washington
Brown County	4.0	Indiana
Peru	3.93	Indiana
Devine	3.87	Wisconsin
Jeopardy	3.9	California
Columbus	3.5	Georgia
Chicken Craw	3.15	Oregon
Salt Creek	3.06	Indiana
Little Indian Creek	3.0	Indiana
Union Crossroads	3.0	Tennessee
Chicken Park	2.6	Colorado
Malheur	2.5	Oregon
Prescott Siding	2.41	Alabama
McDowell	2.38	North Carolina
Gold Creek	2.28	Indiana
Mary	2.27	California
Moore	2.25	California
George Creek	2.14	Colorado
Burlington	2.11	Wisconsin

Table 2. Reported diamond recoveries of State Line district kimberlites (from McCallum and Waldman, 1991).

Site	Tonnes Processed	Total Stones	Average grade cts/100 tonnes	Range of grades cts/100 tonnes
Maxwell	300	28	<0.5	?
Aultman	1,859.5	132	<1.0	?
Schaffer group	3,892.6	227	<1.0	?
Chicken Park	295.9	306	6.7	?
Sloan 1	1,830.2	13,749	8.7	1.2-21.3
Sloan 2	807.6	16,833	18.4	2.2-59.8
Sloan 5	903.5	474	1.0	0.0-5.3
Sloan 6	500.0	215	1.3	0.2-4.8
George Creek K1	2,613.2	80,282	46.1	20.0-135.1
George Creek K2	416.1	8,873	31.0	18.1-86.8

Figure 1. Generalized geologic map of a portion of the Wyoming Craton. The craton, which includes an Archean core known as the Wyoming Province shown within the heavy dashed line, continues into southeastern Wyoming and northern Colorado as the Early- to Mid-Proterozoic cratonized Colorado Province (modified from Karlstrom and others, 1981 and Houston, 1983).

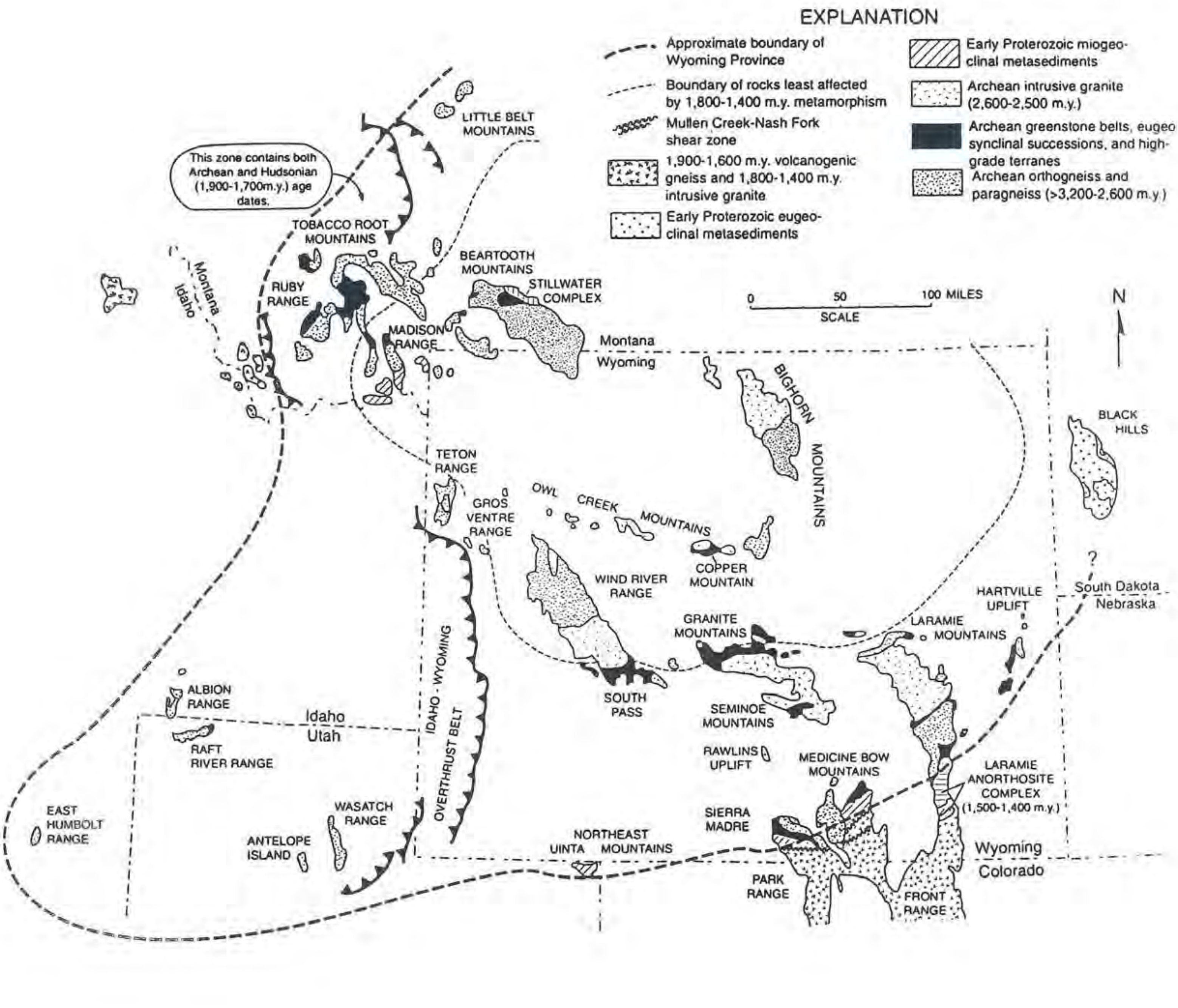


Figure 2. Generalized North American basement map showing subdivisions of cratonic terranes (modified from Levinson and others, 1992).

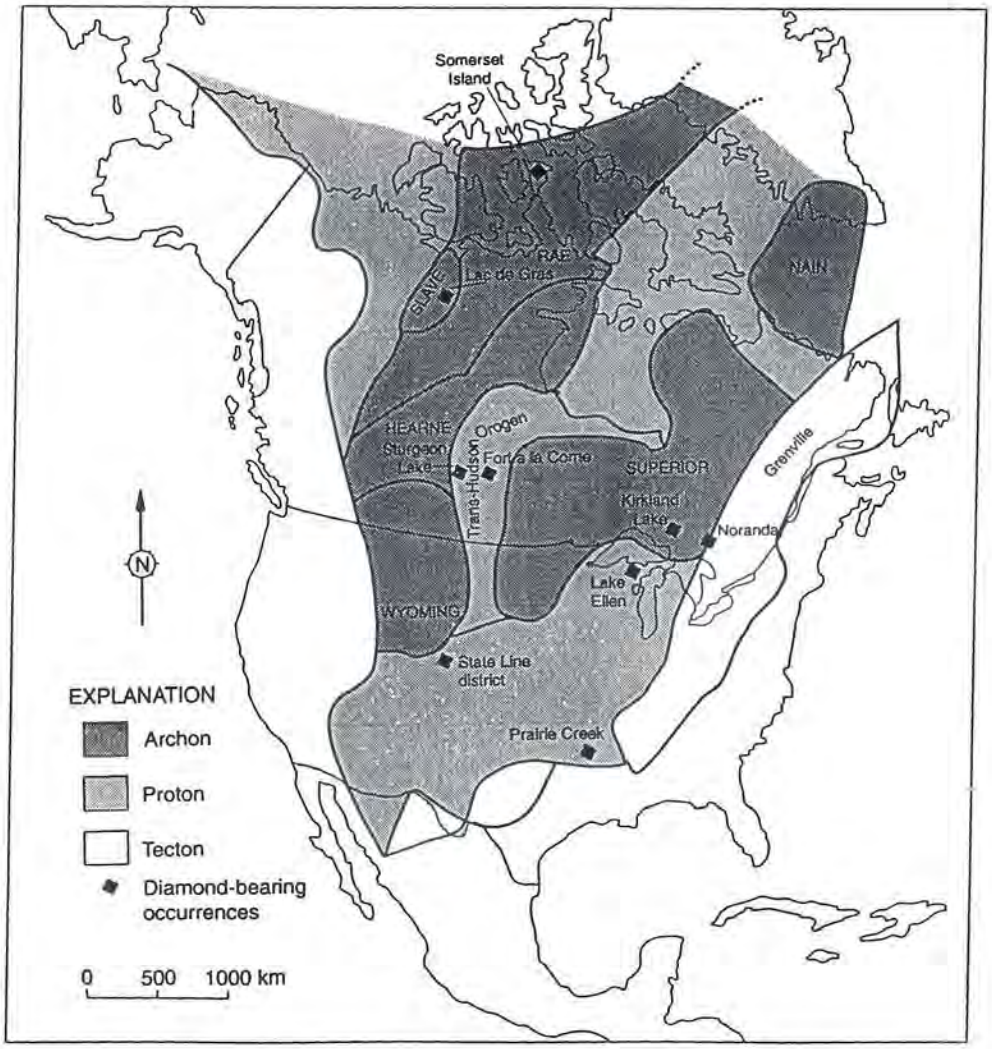


Figure 3. The Colorado-Wyoming region showing locations of known kimberlites, lamproites, cryptovolcanic structures, and related anomalous areas.

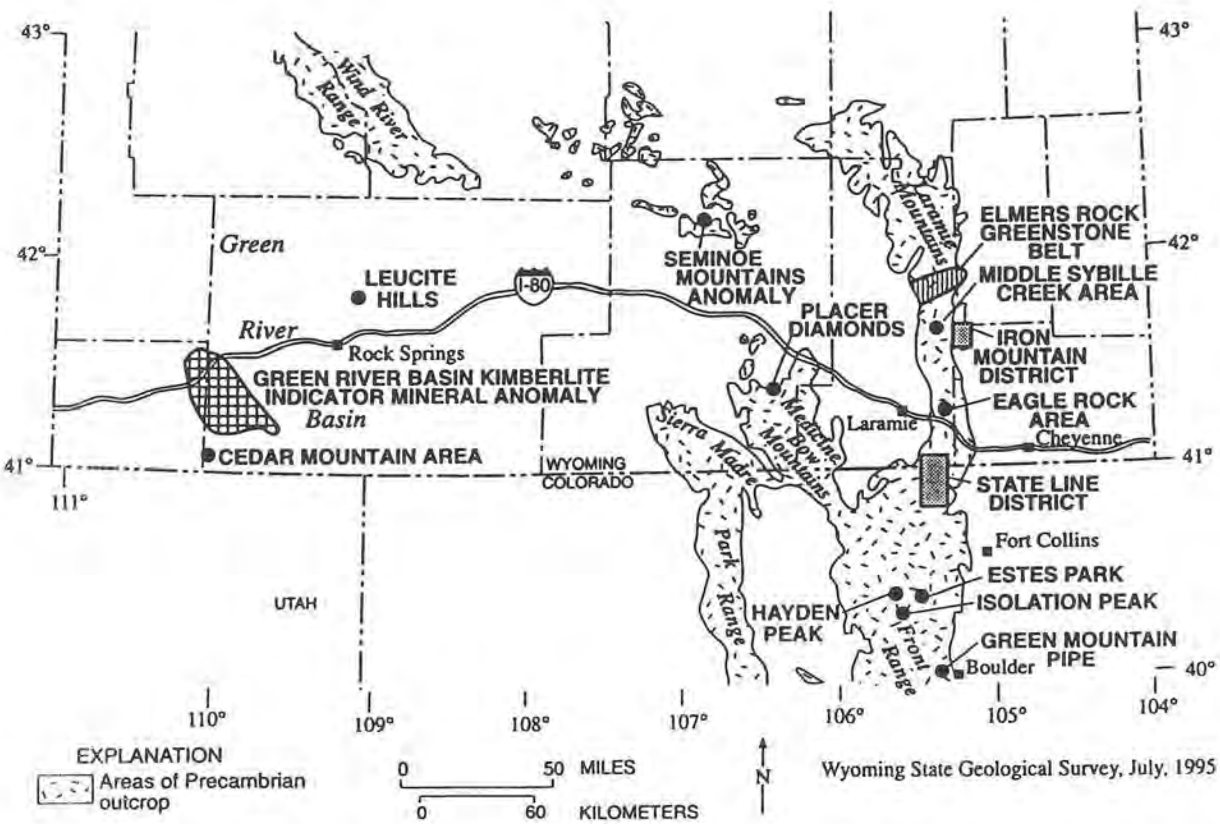


Figure 4. Location map of known kimberlites in the State Line district, Colorado-Wyoming.

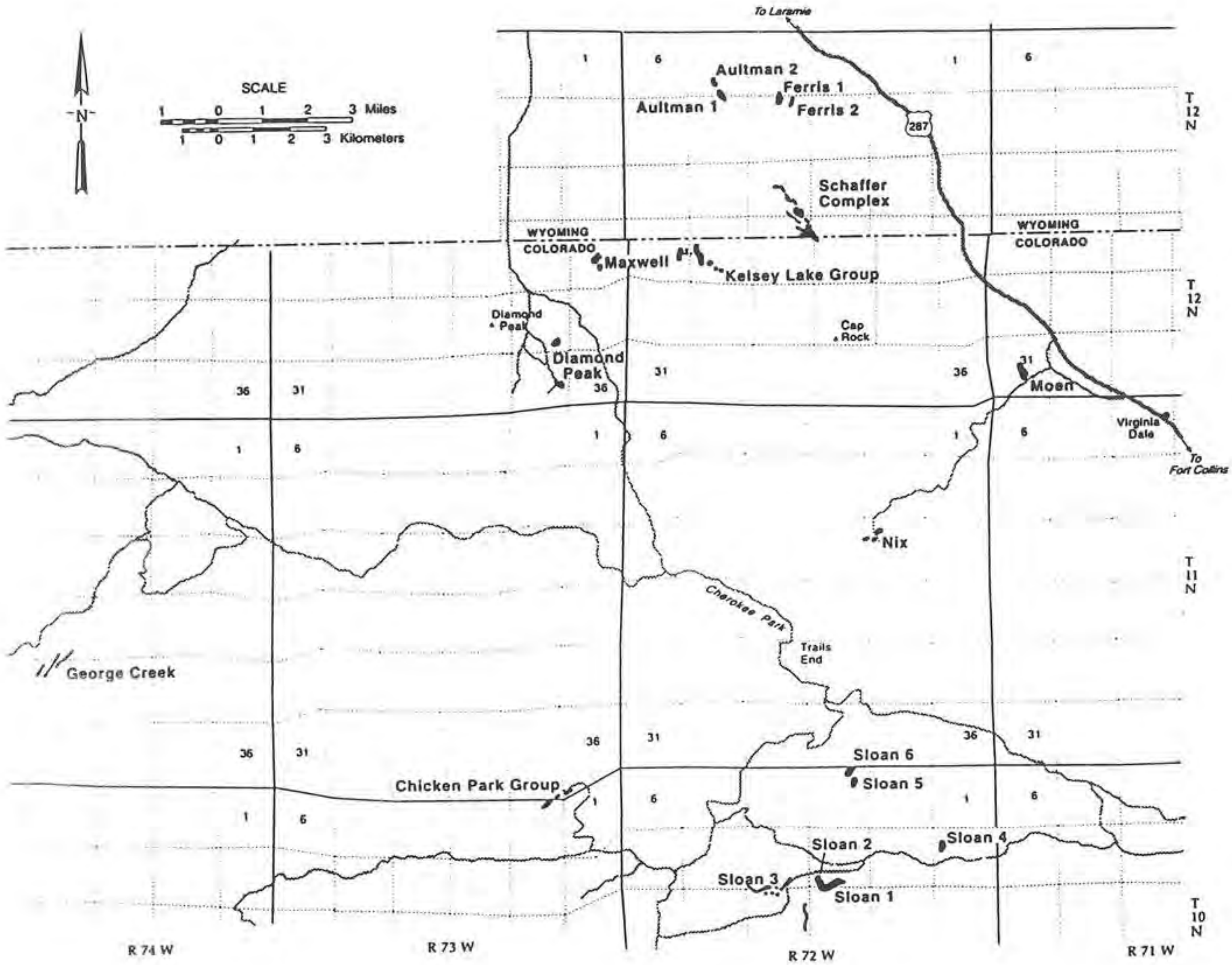


Figure 5. Gemstones from the Kelsey Lake diamond mine, Colorado-Wyoming State Line district. The diamonds in the photo include the second largest diamond found in the district, to date. The diamond, a 14.2 carat, high-quality gemstone, was valued at $250,000 (Casper Star Tribune, 12/30/95). A 28.3 carat gem diamond recently recovered from Kelsey Lake, was the 5th largest diamond found in the United States *(Photo courtesy of Howard Coopersmith and Redaurum Ltd)*.

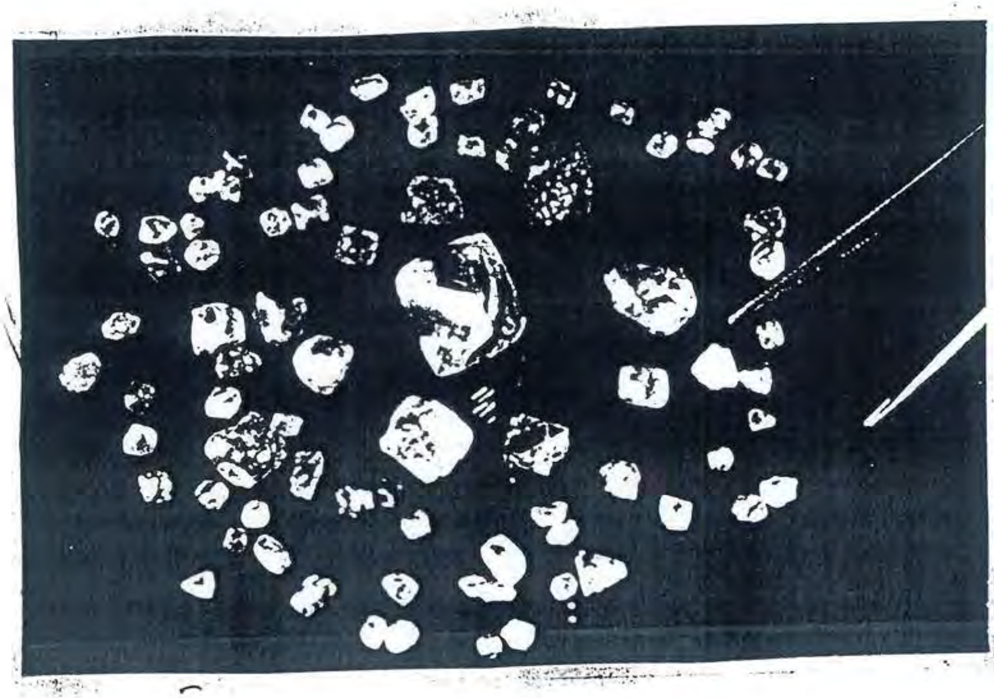


Figure 6. Interpretation of INPUT/magnetometer survey over the northern portion of the State Line district showing locations of known kimberlites (modified from Paterson and MacFadyen, 1984).

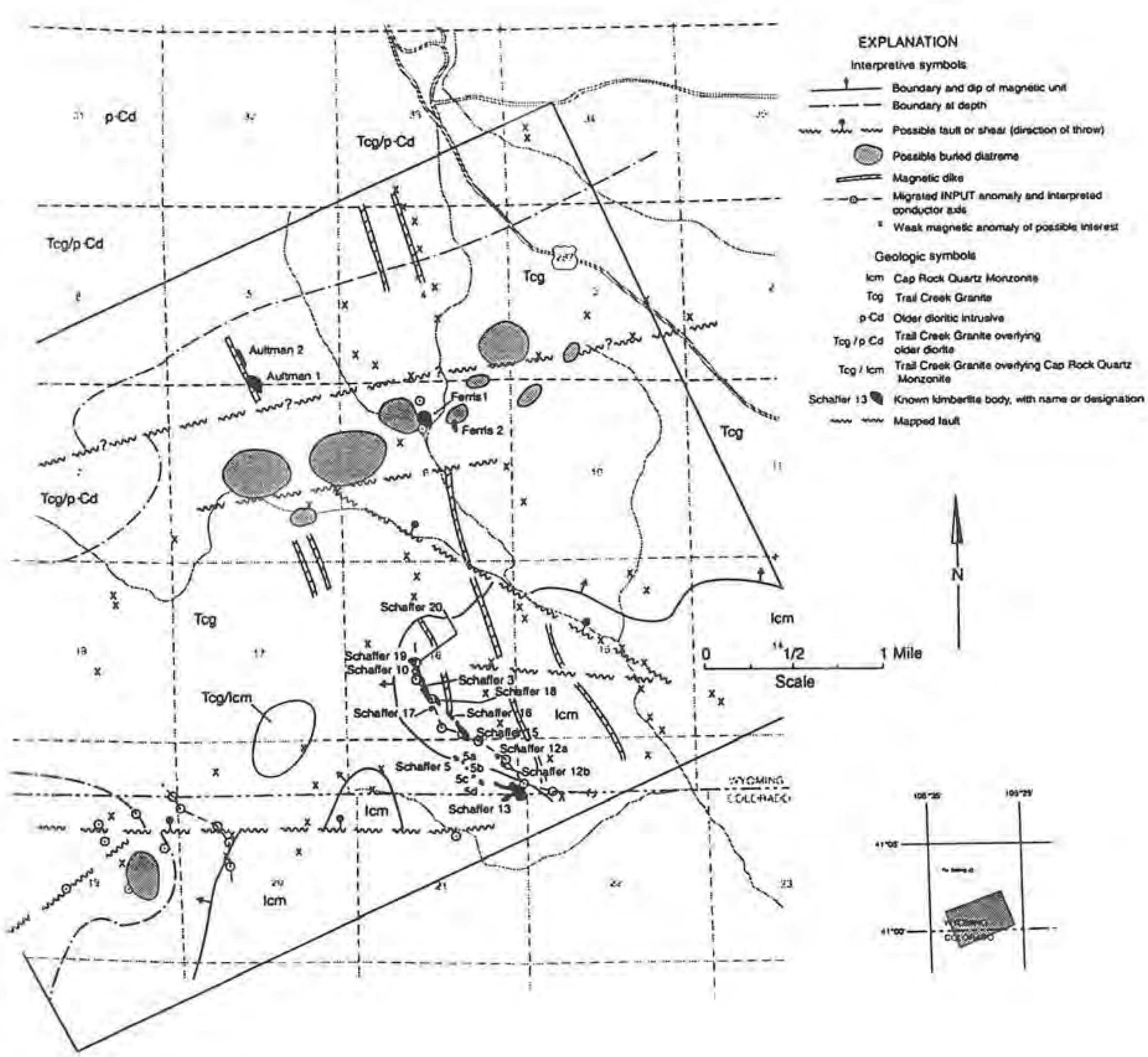


Figure 7. Conductivity contours measured in the SLSS drainage (S/2 sec. 16, T12N, R72W) in the State Line district, Wyoming. The conductivity contours indicated the presence of a buried kimberlite 'blow' between the Schaffer 16 and 18 diatremes, which was later trenched by Cominco American Inc. (modified from Hausel and others, 1981).

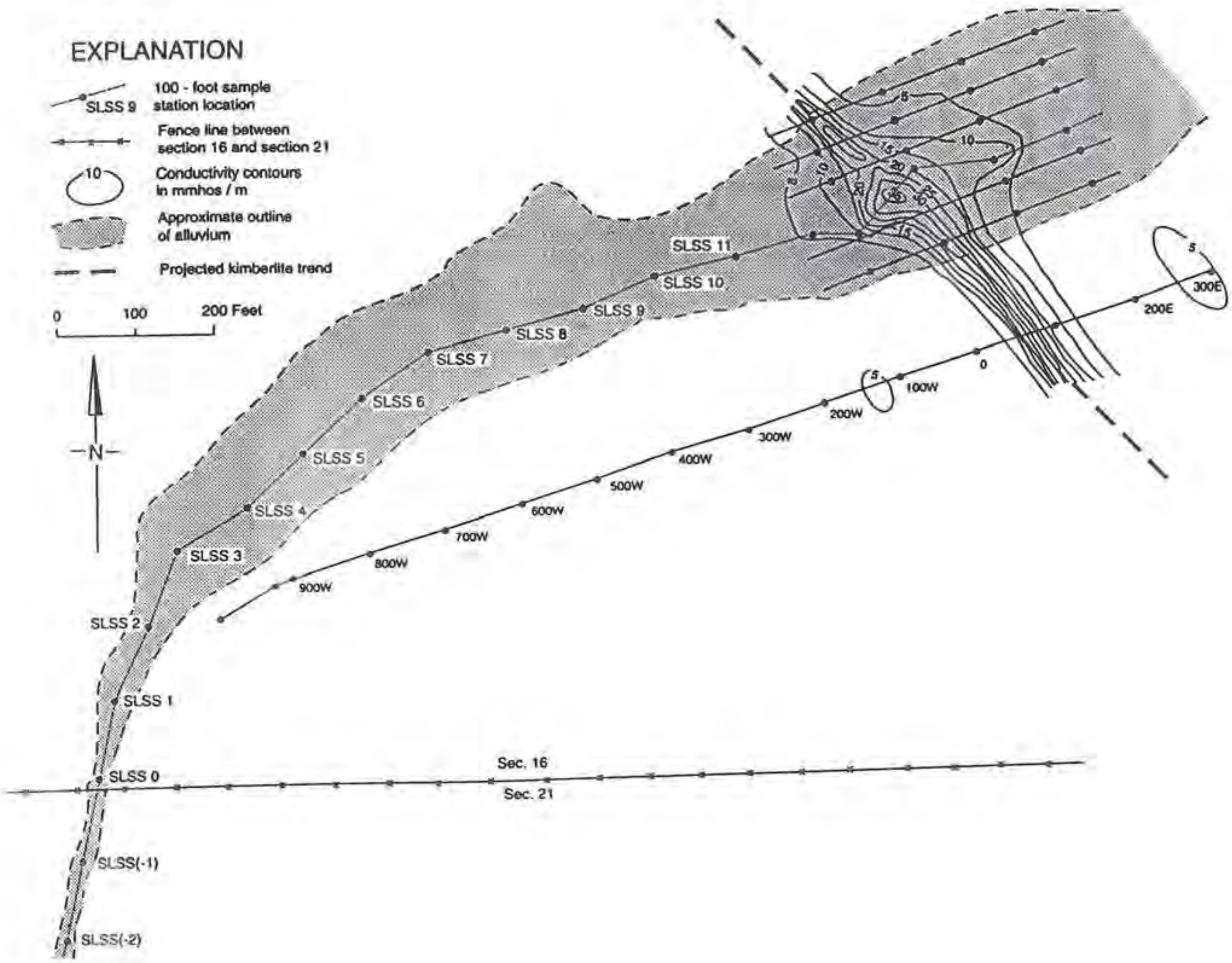


Figure 8. Diamonds recovered from the Wyoming portion of the Colorado-Wyoming State Line district. The large diamond in the center is a 0.86 carat gemstone (cm scale).

Figure 9. Diamonds from the Sloan 2 kimberlite, Colorado. The largest diamond recovered from the property weighed 5.51 carats.

Figure 10. Generalized geological map and stream sediment sample locality map of the Iron Mountain kimberlite district, Rock River 1:100,000 base map (modified from Smith, 1977). Kimberlitic indicator minerals were recovered from samples downstream, as well as upstream from the known kimberlites by Hausel and others (1988), suggesting the possibility of undiscovered kimberlite in this region.

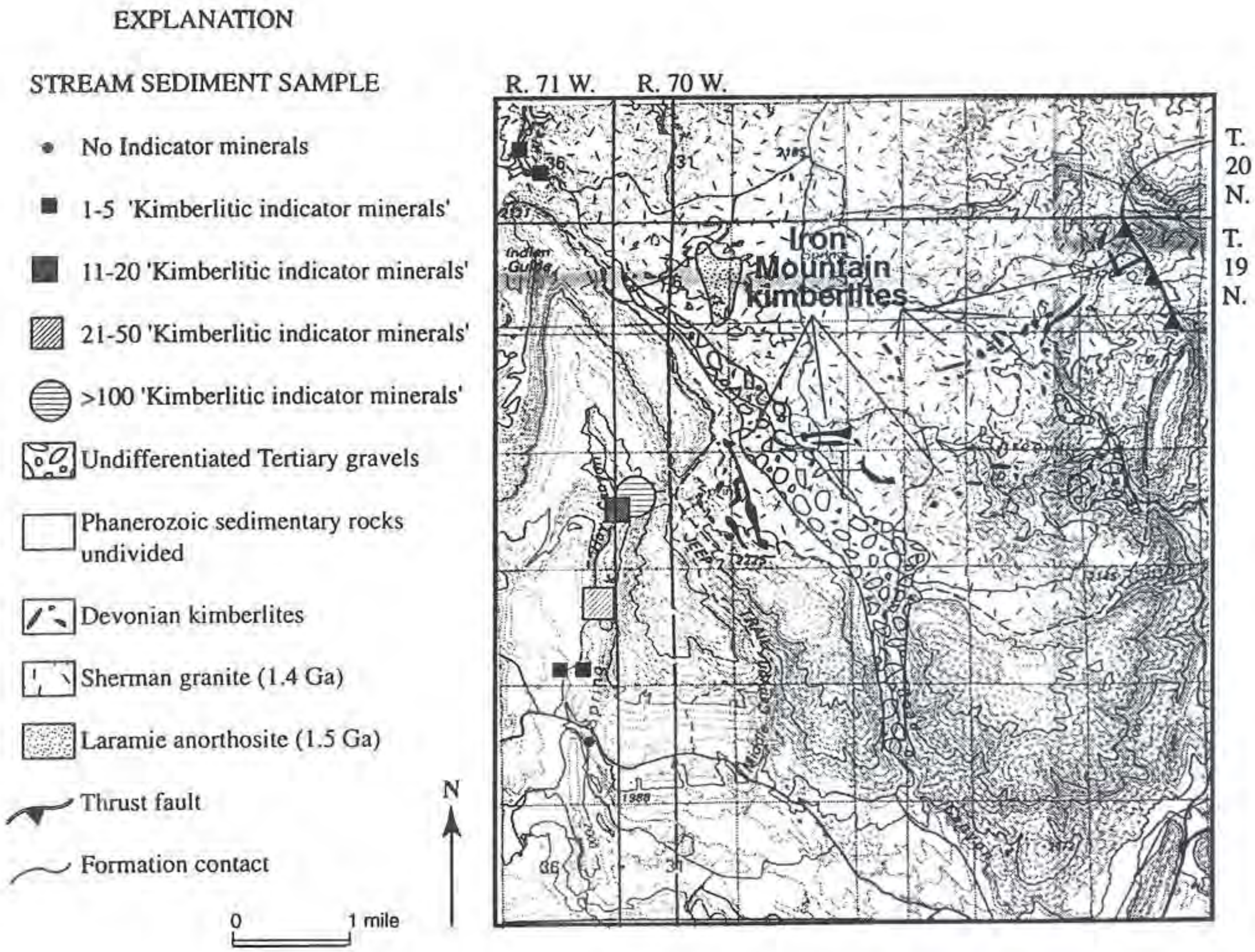
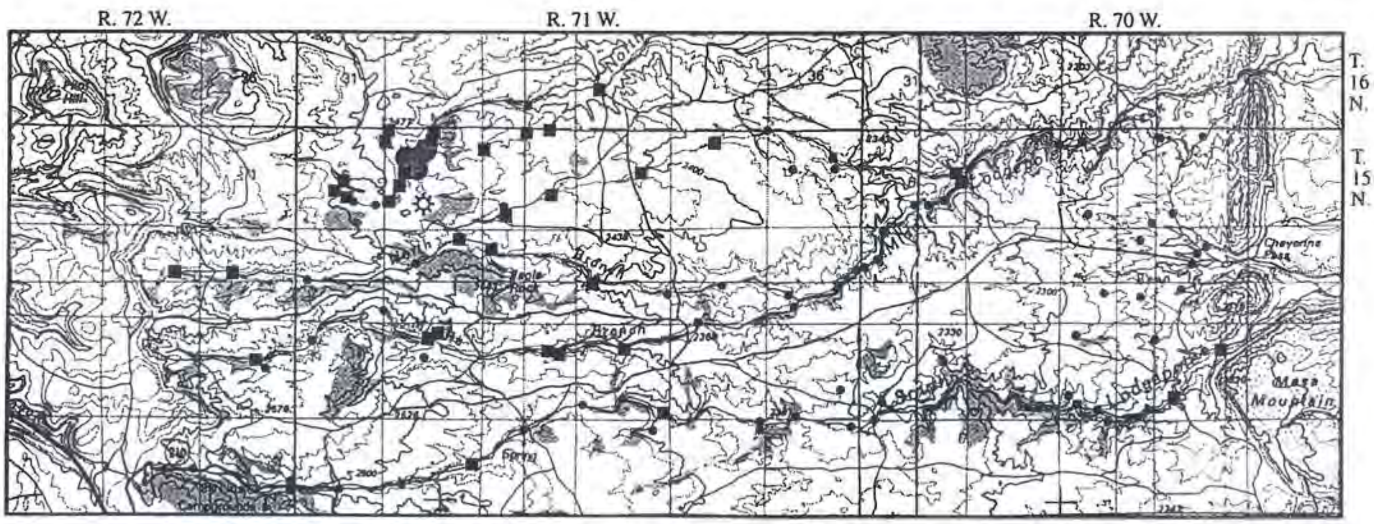


Figure 11. Steam sediment sample results from the Eagle Rock area, Laramie Mountains, Laramie 1:100,000 scale base map (modified from Hausel and others, 1988).



EXPLANATION

STREAM SEDIMENT SAMPLE

- • No indicator minerals
- ■ 1-5 'Kimberlitic indicator minerals'
- ● 6-10 'Kimberlitic indicator minerals'
- ☼ Eagle Rock anomaly

0 1 mile

N

Figure 12. Sample location map of the Middle Sybille Creek anomalous area, Rock River 1:100,000 base map (modified from Hausel and others, 1988).

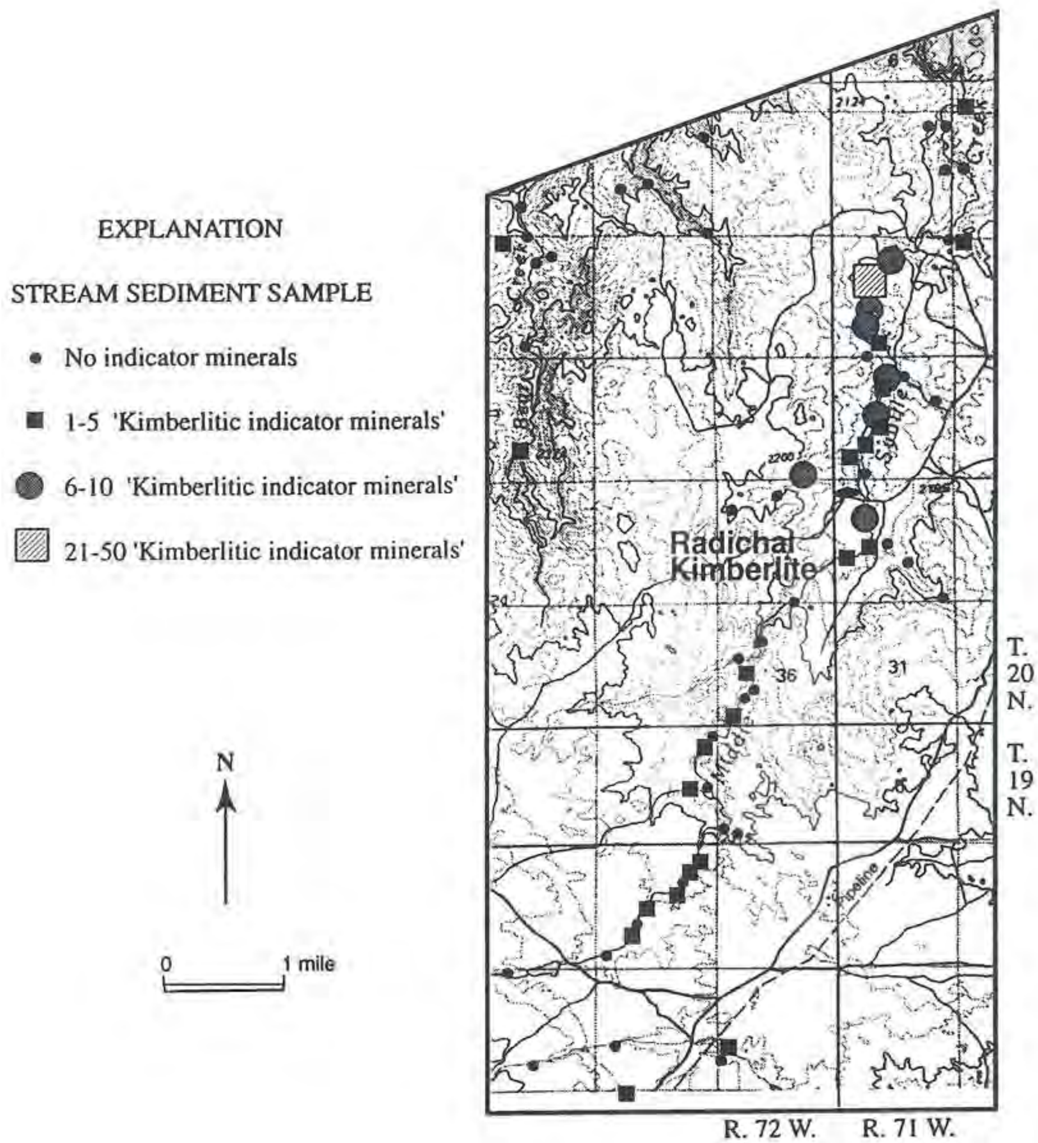


Figure 13. Stream sediment sample locations and results from the Grant Creek area, Laramie Range, Rock River 1:100,000 base map (modified from Hausel and others, 1988).

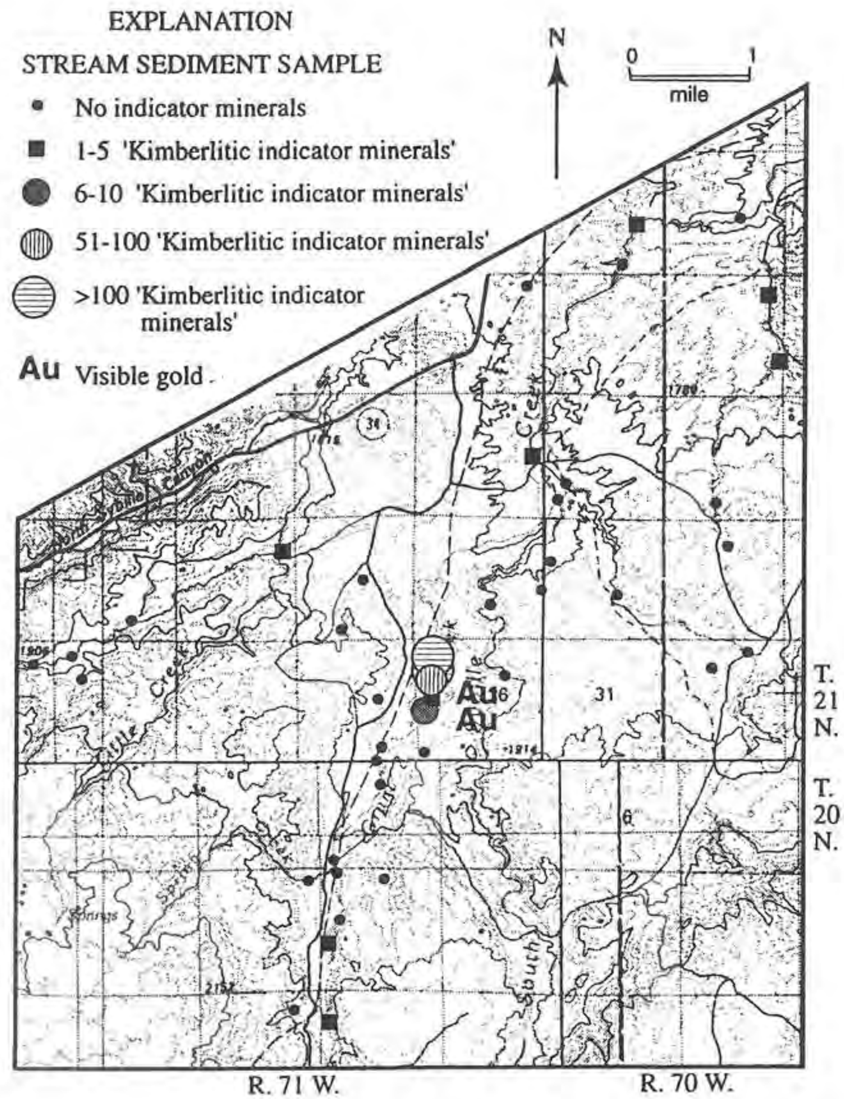


Figure 14. Stream sediment sample results from the Elmers Rock greenstone belt, central Laramie Range, Rock River 1:100,000 base map (modified from Hausel and others, 1988).

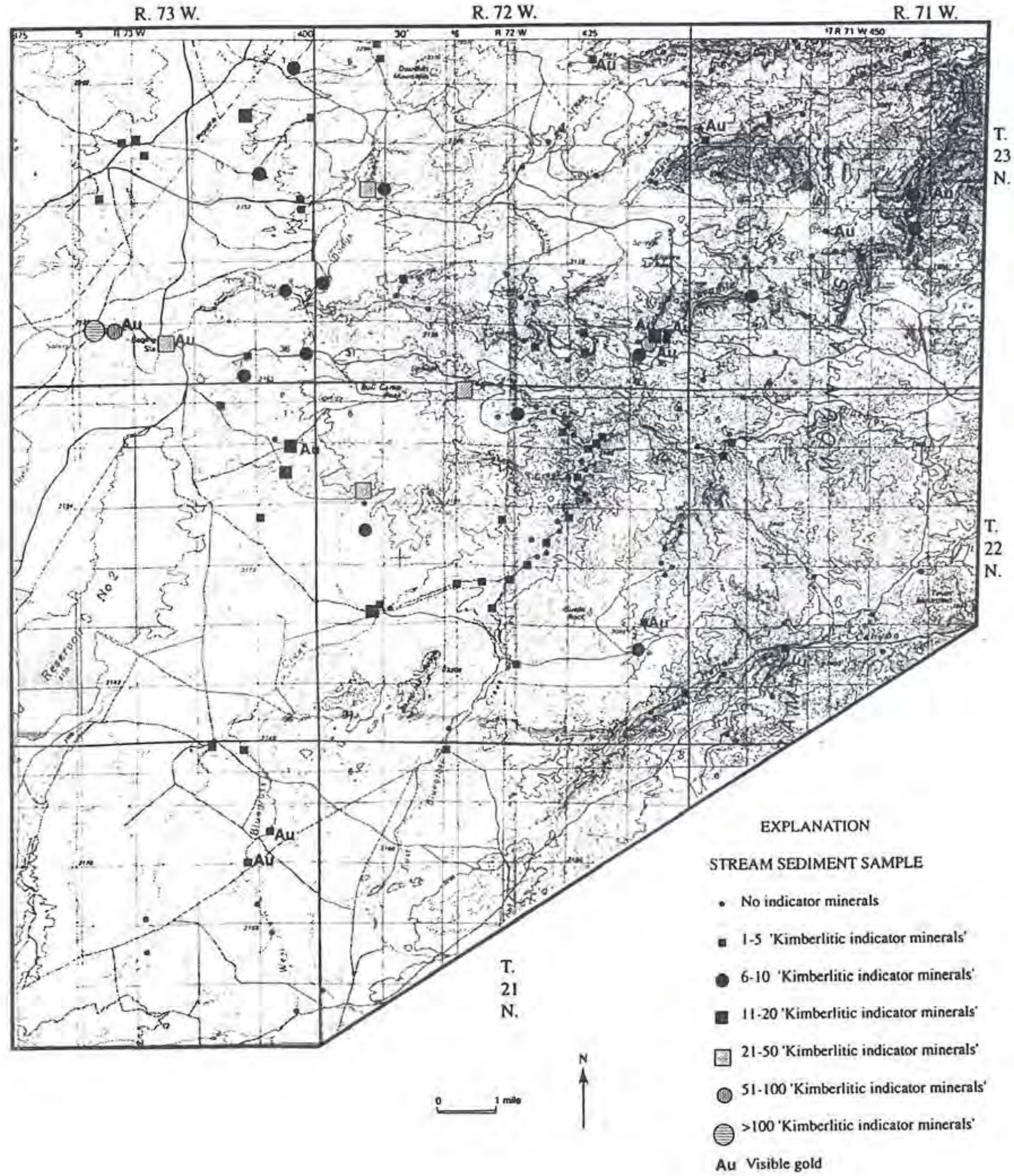
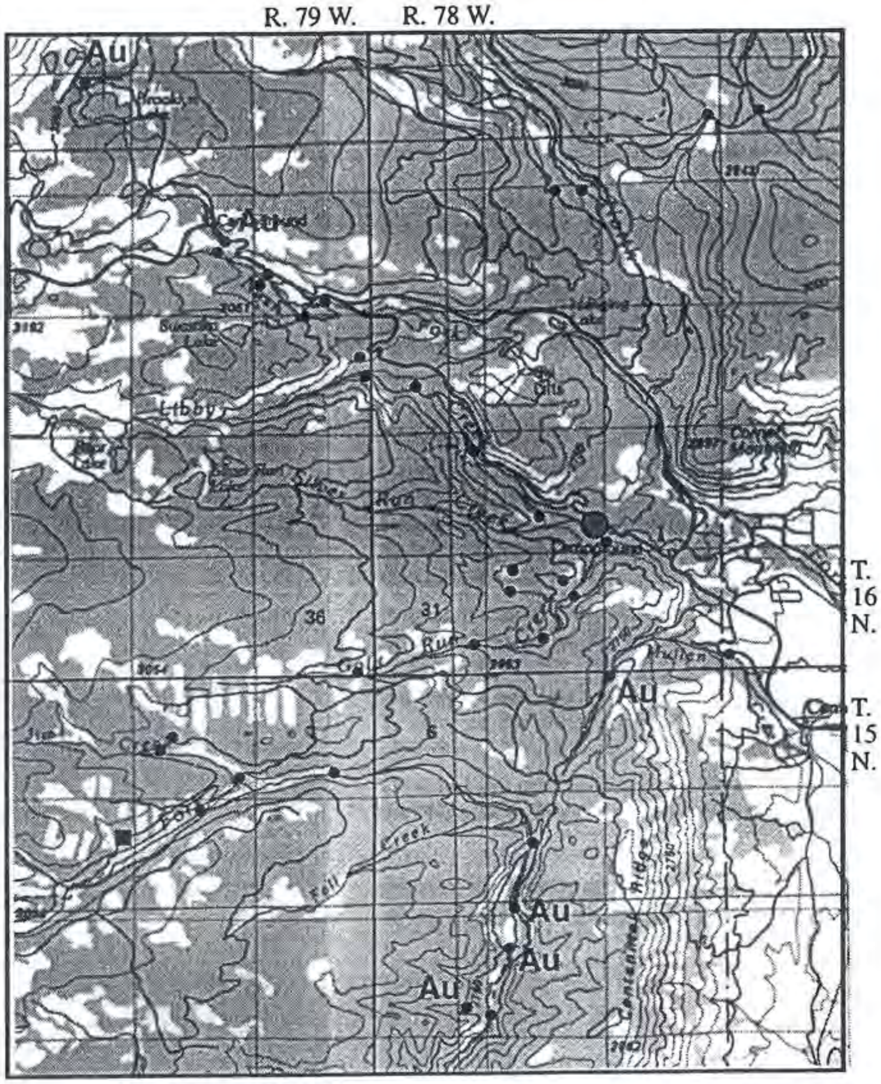


Figure 15. Placer diamonds from the Cortez Creek gold placer in the Mullison Park area of the Medicine Bow Mountains. These diamonds weighed 0.1 and 0.03 carat, and were recovered from a long-tom operated by Paul Boden in 1977 (mm scale).

Figure 16. Sample location map of a portion of the Medicine Bow Mountains, Saratoga 1:100,000 scale base map (from Hausel and others, 1988).



EXPLANATION

STREAM SEDIMENT SAMPLE

- ● No Indicator minerals
- ■ 1-5 'Kimberlitic indicator minerals'
- ⬤ 6-10 'Kimberlitic indicator minerals'
- **Au** Visible gold

N

0 1 mile

Figure 17. Conductivity and magnetic east-west profiles over the Seminoe Mountain anomaly, with geologic interpretation (W.D. Hausel, field notes, 1996).

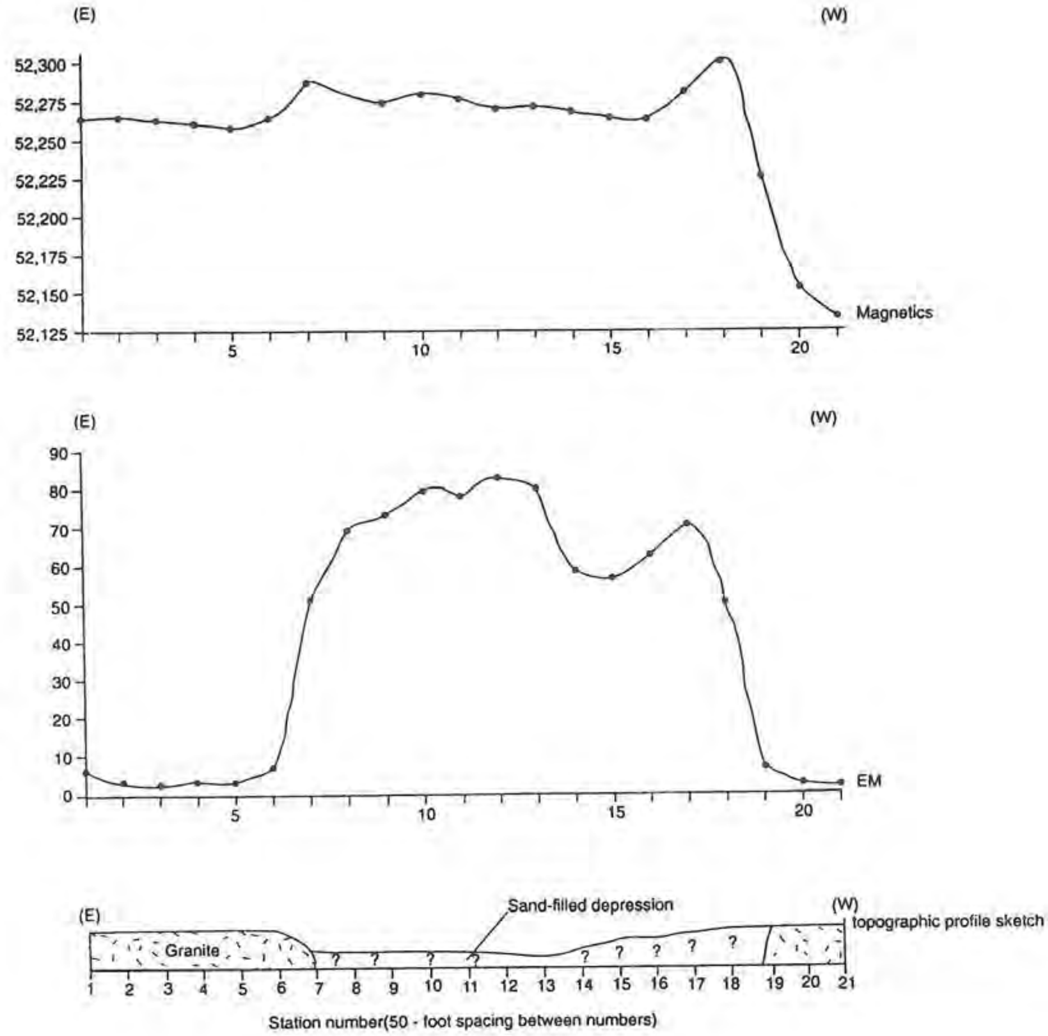


Figure 18. The Leucite Hills lamproite field (modified from Hausel and others, 1995).

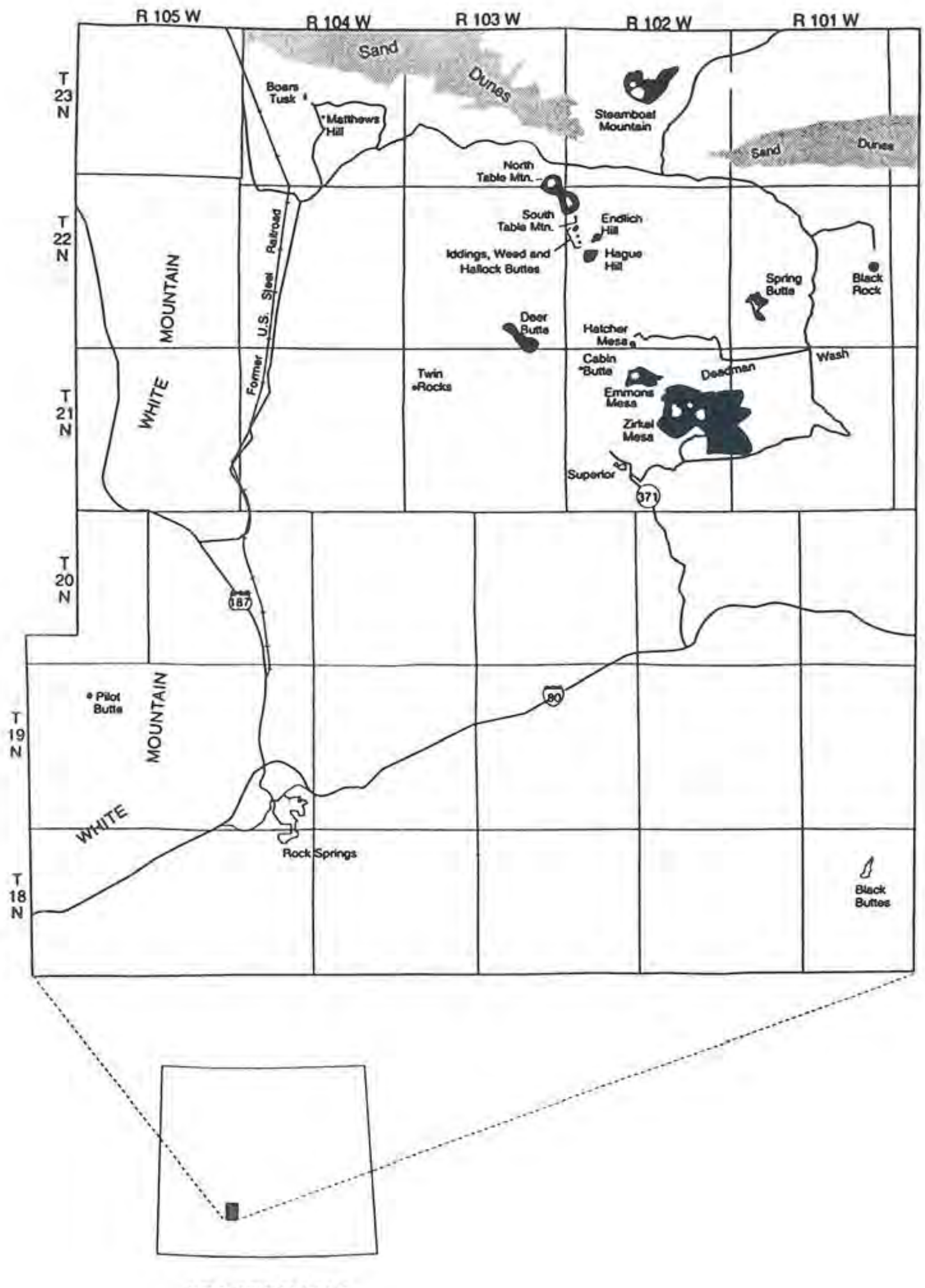


Figure 19. Simplified geologic map of the southern Green River Basin and north slope of the Uinta Mountains. Pre-Tertiary units are Unita Mountain group (PC), Paleozoic (Pz) and Mesozoic (Mz) sedimentary rocks. Tertiary sedimentary units are Green River Formation (gr), Bridger Formation (br), and Wasatch Formation (wa). Erosion surfaces are (es) earliest unit capping the Unita Mountains, followed by Bishop conglomerate (bc), erosional surfaces later than the Bishop conglomerate (eb), and the Browns Park Formation (bp). Pleistocene glacial moraines are (g). The projected trace of the North Flank Fault (NFF) shown as solid line. Flaming Gorge reservoir is removed for clarity. Kimberlitic indicator minerals found in ant mounds (circles), pediments and conglomerates (stars) and streams (squares). Approximate location of the Cedar Mountain breccia pipes (diamond) and Lone Tree anomalies (asterisk) (modified from McCandless and others, 1995).

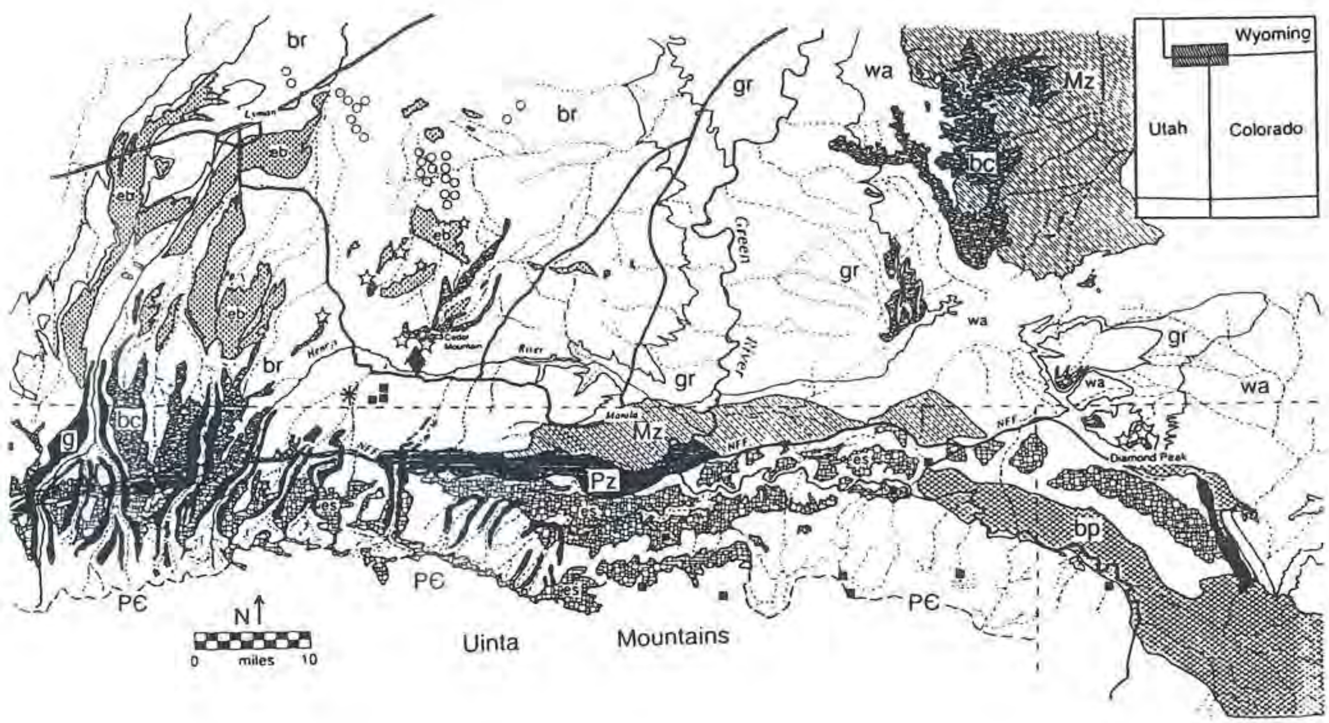


Figure 20. Photogeological map of the Cedar Mountain area showing locations of breccia pipes and dikes (geology by Richard E. Kucera, 1995-96).

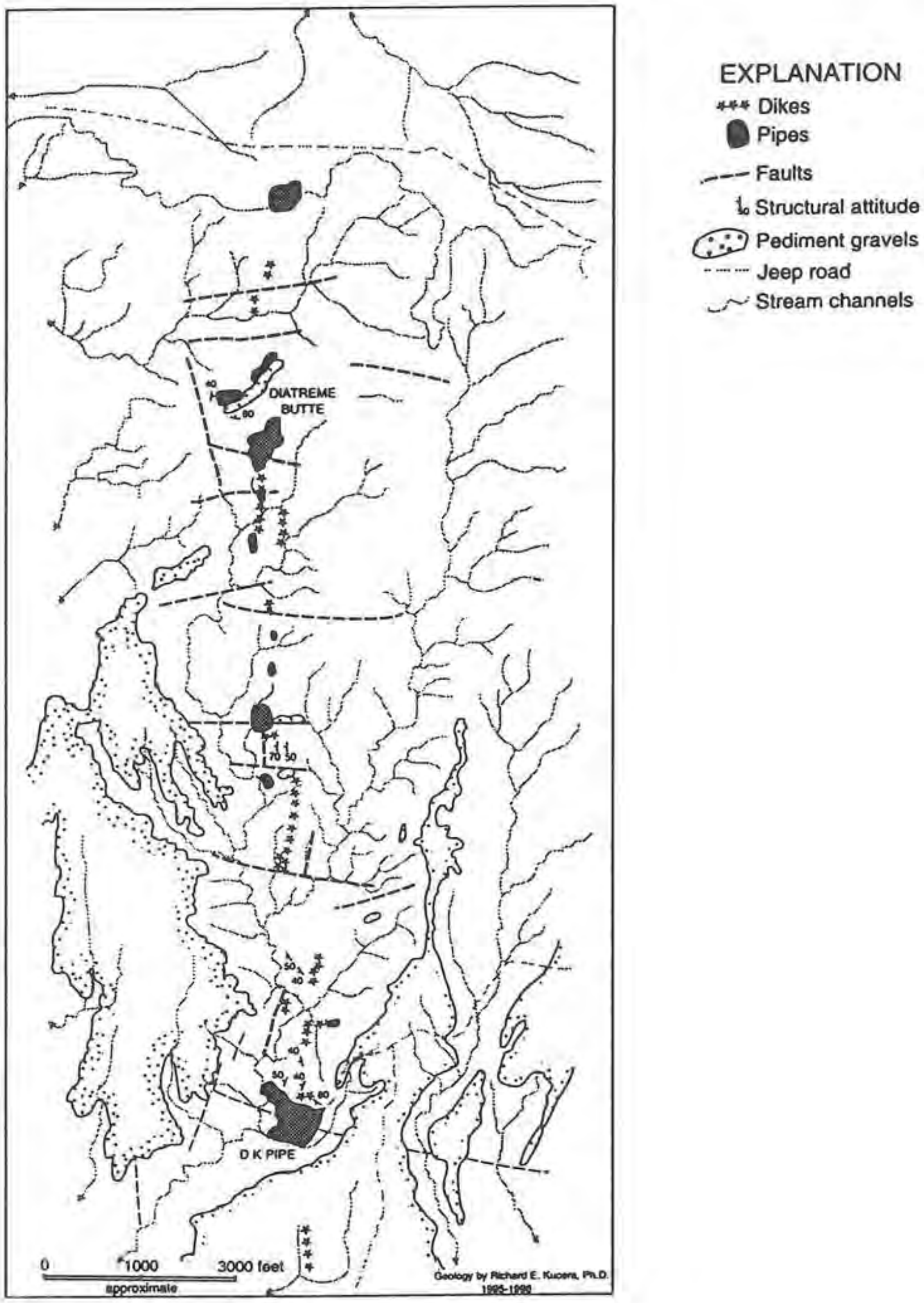


Figure 21. General map of the Wyoming craton showing locations of known kimberlites, lamproites, lamprophyres, cryptovolcanic structures, reported diamonds, and kimberlitic indicator mineral anomalies.