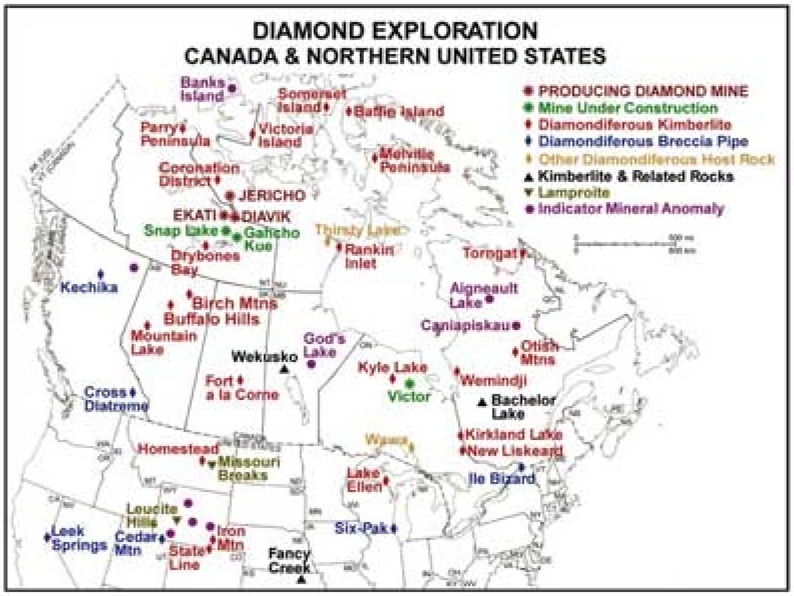
How To Locate Diamonds

by W. Dan Hausel

In a previous article ("Prospecting for Diamonds," May 2008 issue), characteristics were described that can be used to identify rough diamonds. This article focuses on the principal host rock for diamond and describes some gemstones (and kimberlitic indicator minerals) typically found with diamond. In follow-up articles, placer (secondary) diamonds will be discussed as well as how to prospect for primary diamond deposits.



Location map showing the diamond exploration regions and diamond mines in Canada and the US (from Hausel, 2008b).

Introduction

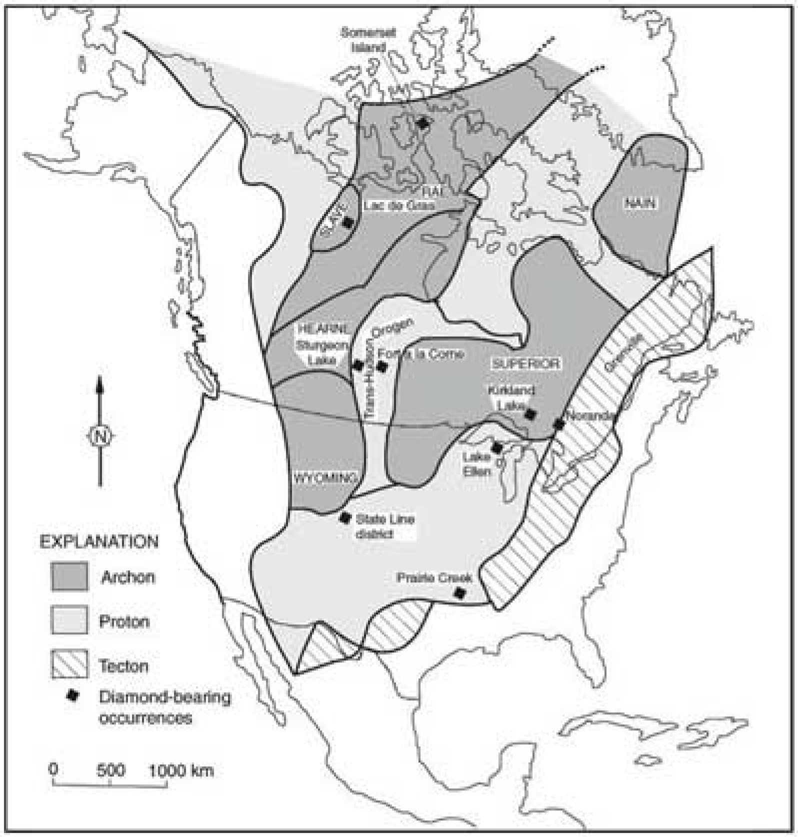
Following the discovery of a world-class diamond deposit in the Northwest Territories of Canada in 1991 (Krajick, 2000), one of the greatest mining rushes in the history of mankind ensued that continues to present day. A few thousand barren and diamondiferous kimberlites, lamproites and lamprophyres (the principal host rocks for diamond) have been discovered in Canada since the discovery of the rich Lac de Gras kimberlites at Ekati in the arctic north, and more are being found every month.

Since the 1991 discovery, three major mines—Diavik, Ekati and Jericho—were developed. Ekati began production in 1998, Diavik in 2003 and Jericho in 2006. But Jericho ran into problems. After a 2006 start-up with significant production that included a 59-carat gemstone, recovery was considerably lower than anticipated and mine costs rose followed by the company filing for bankruptcy in early 2008. Even with this one failure, other mines are under construction and/or permitted (Snap Lake, Gahcho Kue and Victor) with other properties in a feasibility stage.

The costs of mining in the arctic north are high. Capitalization for the Ekati mine alone was more than $1 billion. Prior to 1998, Canada had not produced a single diamond commercially, yet our neighbor to the north recently

surpassed South Africa in diamond production!
In 2003, rough Canadian diamond production amounted to 11.2 million carats valued at $1.7 billion, or about 15% of world production. And this doesn't even consider the value of the finished product. (Faceted diamonds set in jewelry are often >10 times more valuable than the rough stone.)

In 2003, the Ekati mine produced 3.7 million carats of rough diamonds: in the first quarter of 2008, the mine produced 620,000 carats including a 182.6-carat stone. Production at Diavik reached full capacity in 2005 at 8.27 million carats of rough diamond: in the first quarter of 2008, the mine produced 1.8 million carats.



Cratons are important terrains for diamondiferous kimberlite and lamproite. Typically cratons are subdivided into regions of favorability for commercial diamond deposits. The most favorable regions lie within Archons and Protons, while Tectons have low potential. Much of the US is underlain by the North American Craton (above). In addition to the craton, the west coast is underlain by a subduction zone that is considered favorable terrain for unconventional diamondiferous host rocks (Hausel, 1996). Thus there is potential for discovery of commercial diamond deposits in much of the US, although most of the country remains unexplored.

Diamond deposits occur in clusters. These clusters have been traced south to the US border. So why are we not seeing major discoveries in the US? The principal reason is politics. US mining laws are unfavorable for investors and mining companies. This, coupled with the US having one of the worst reputations in the world for exploration, mine and mill permitting, pose formidable obstacles to future exploration and development in the US. However, one can drive to most diamondiferous kimberlites and cryptovolcanic structures in the US and not worry about roads melting in the spring and summer months—this alone should offset some concerns and keep exploration costs considerably lower than in Canada. Even so, capital investment for exploration and development for diamonds in Canada has been more than 1,000 times higher than in the US. With so little money invested in US exploration, it is a wonder that any diamond deposits have been found. Yet, geological evidence supports that the Wyoming Craton (Colorado-Montana-Wyoming) is highly mineralized and likely to host hundreds to possibly thousands of diamond deposits.

Kimberlite from China showing a small, white diamond in the rock matrix. (Photo by the author.).

In the past few years, only minor diamond exploration has occurred in the US. Much of the exploration was centered in the Colorado-Wyoming State Line district, with lesser amounts in Montana and California.

Diamond Deposits

Most commercial diamond mines have been developed in kimberlite. A few have been developed in lamproite; lamprophyre awaits its first commercial discovery although it is likely that some will be found in the future, particularly since many diamondiferous lamprophyres have been found in the last few decades.

Secondary diamond deposits (placers) are found downstream from primary host rocks. For the weekend prospector, placers offer great potential. In the Colorado-Wyoming State Line district alone, there has to be hundreds of thousands if not millions of diamonds in the surrounding streams, since the majority of streams in this district drain 40+ diamondiferous kimberlites south into Colorado, yet there has been practically no effort to sample these. The west coast of the US (particularly California) is another place with considerable placer diamond potential. Hundreds of diamonds (many sizable) were found in past years by California gold miners (Hausel, 1998).

Sample of kimberlite breccia (top) with massive kimberlite (right) from the Sloan Ranch pipes in Colorado. The massive kimberlite contains a large megacryst of pyrope-almandine garnet. White foreign rock fragments (xenoliths) are found in the gray to greenish-gray serpentine rock matrix (photos by the author).

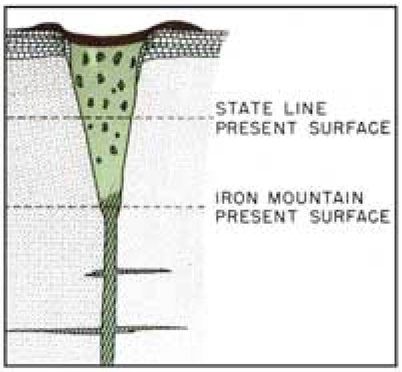
Kimberlite

Kimberlite is the principal host rock for diamond. If you are unfamiliar with kimberlite, you are not alone. Few geologists and prospectors are trained in prospecting for this rock type. It is easy to walk across an undisturbed diamond deposit and not realize it.

A few years ago I emphasized this when members of the Rocky Mountain Prospectors and Treasure Hunters Club in Fort Collins and the Rocky Mountain Association of Geologists from Denver attended a field trip where I walked 50+ attendees across 100 yards of diamond-bearing kimberlite after telling them I was going to do this and not one person saw the kimberlite until I showed them what they missed and this was one of the better kimberlite exposures in the region. This field trip was dubbed as the “Chicken Park death march” by some attendees because of the long hike we enjoyed that day.

Kimberlite is found at a number of places around the world, but the best place to find diamondiferous kimberlite is in very old continental regions that are known as cratons. Cratons are very old, stable continental cores that contain rocks older than 1.5 billion years. The largest craton in the world is the North American craton, which is actually formed of several smaller cratons. The North American Craton underlies large parts of Canada and the US. One way to find cratonic rocks is to search published geological maps for Precambrian rocks. If the Precambrian rocks are older than 1.5 billion years, you are likely within a craton; the older the rocks the better. These old rocks continue under the much younger sedimentary basins in the western US.

When kimberlite or its alterated rock or clay is found, it will appear to be out of place compared to the surrounding terrain and rock. This is because kimberlite is found in small dikes and pipes (the core of a kimberlite volcano) and is one of the rarest rock types on earth. Kimberlite is a hydrated, carbonated, olivine-rich rock in which most of the olivine has been altered to serpentine, a soft green replacement mineral. In general, kimberlite can be thought of as a serpentinite (a rock formed primarily of serpentine). But most serpentinites are not kimberlites.



Cross-section of carrot-shaped kimberlite pipe. The diameter of such pipes decreases to narrow feeder dikes at depth—usually within 2,000 to 5,000 feet of the earth's surface.

Kimberlites contain considerable carbonate such that when a drop of weak hydrochloric acid is placed on a fresh broken surface, the kimberlite will effervesce and emit CO2 gas. Kimberlites contain xenoliths and xenocrysts (rock fragments and crystals from country rocks) as well as some unusual minerals and rocks from great depth. Some of these minerals and rocks are extremely rare, some are gemstones and some are collector's specimens. For example, gem-quality diamond, Cape ruby (pyrope garnet), almandine garnet, spessartine garnet, Cape emerald (chromian diopside), and chromian enstatite are all gemstones that have been recovered from kimberlite. However, most gem-quality garnets and chromian pyroxenes are typically discharged to the mine tailings during mine operations.

Kimberlite is a volcanic rock that erupts in small maar volcanoes referred to as diatremes (or pipes). These pipes are not the typical volcanoes that most of us picture. Instead of forming a cone or hill, kimberlite volcanoes blast out circular depressions. At eruption, kimberlite magma is under such incredible pressure that it essentially explodes. Visualize a shot gun blast and this is probably what kimberlite would look like erupting from the earth, but on a much larger scale. As a result, kimberlites are highly fragmented and brecciated and contain foreign rock fragments that are a few inches to several yards across.

Kimberlitic indicator minerals from the Wyoming Craton. (Above left) A parcel of gemstones that include pyrope, almandine, and spessartine garnet along with chromian diopside (emerald green), picroilmenite (metallic with alteration crusts of leucoxene) and two small metallic chromites (bottom right) from a diamondiferous kimberlite in Colorado. Many of the purple garnets are probably diamond-stability garnets referred to as "G10 pyropes" by exploration geologists. Some of the orange garnets are also diamond-stability (eclogitic) garnets. Gem-quality faceted "Cape Ruby" (pyrope garnet) (upper right) collected from lamprophyre showing excellent transparency and color, and faceted pyrope garnets (lower right) from a diamondiferous lamprophyre in Wyoming. These extraordinary gems typically end up in mine waste tailings of diamond mines, even though they represent valuable gemstones. Many of the chromian diopsides like Cape Emerald are more attractive than most emeralds. (Photos by the author and Robert Gregory.)

Kimberlite pipes and associated dikes are typically small—the largest form circular anomalies 500 to 3,000 feet across. If there has been much erosion through geologic time, the kimberlite pipe will exhibit irregular to elliptical shape. In cross section, kimberlite pipes are carrot-shaped and narrow down to a root zone at a linear feeder dike.

Often small "blind diatremes" rise from kimberlite dikes that represent a magma bubble that lost upward mobility due to degassing along the dike. In the Colorado-Wyoming State Line district, a kimberlite with one of the highest diamond ore grades was the Sloan 2. This pipe was interpreted as a blind diatreme (McCallum and Mabarak, 1976). A group of blind diatremes were detected at shallow depths in Wyoming by a geophysical survey, yet none were ever tested, even though they are surrounded by diamond pipes and dikes. The location of these anomalies is shown on a map published by the author (Hausel, 1998).

Because of distinct differences in chemistry and hardness between kimberlite and most country rocks, many

When I discovered the Aultman 2 kimberlite in Wyoming in 1978, all that was visible was clay-rich gray soil known as blue ground (above). The kimberlite turned out to be a few hundred feet long, but there was little evidence for its existence other than the fortuitous digging from a single badger. (Below) The kimberlite-granite contact exposed in trench shows a knife-sharp contact (photos by the author).

kimberlites form small circular, elliptical, to linear treeless grassy parks or shallow depressions. Some of these will contain shallow ponds or lakes because kimberlite is much softer than the country rock and erodes faster. Blue clays (montmorillonite) produced during weathering (referred to as blue ground) are impervious to water and choke most woody vegetation. Dramatic vegetation differences between weathered kimberlite and the country rock may occur.

The grass growing in kimberlite in the early summer usually stands higher and is generally denser than surrounding areas. This is because the kimberlitic clays pond water near the surface and provide a good source of water for vegetation with shallow roots. In some cases, a kimberlite may be outlined by a small circular stand (bulls-eye) of aspen trees. The soil over the kimberlite will contain considerable montmorillonite (bluish to grey clay).

The majority of primary diamond mines around the world are developed in kimberlite such as Wesselton, DeBeers, Kimberley, Dutoitspan, Ekati and others. Placer (secondary) diamond deposits, particularly beach placers along the west coast of Africa, have also been productive. Lampietti and Sutherland (1978) reported that 10% of known kimberlites were mineralized with diamond. This statistic is no longer valid since as many as 50% of kimberlites found in Canada and Wyoming in recent years, and as many as 90% in Colorado, have yielded diamond. Even so, only a very small number of kimberlites contain enough diamonds at high enough value and grade to be mined. It was also suggested that <1% of all kimberlites contain commercial amounts of diamond (a statistic that is still valid). When economic, kimberlites may contain hundreds of millions to billions of dollars in gemstones.

Following a fracture that contains kimberlite will often lead to other kimberlite pipes, dikes or blind diatremes. When I mapped a group of kimberlites in the State Line, Iron Mountain, Indian Guide and Sybille Creek districts of Wyoming and Colorado, I found nine previously unknown kimberlites in the State Line district simply by paying attention to the structural trends. I discovered nearly 70% more kimberlite than had been identified in the Iron Mountain district in Wyoming, and found a few hundred cryptovolcanic depressions with characteristics similar to kimberlite in Wyoming and Colorado. A cryptovolcanic structure is simply a structurally-controlled circular depression that has characteristics similar to kimberlite but remains untested. This shows how important it is to follow fractures.

Reclaimed diamondiferous kimberlite in Wyoming fresh blue ground (photo by the author).

A kimberlite in Riley County Kansas, known as the Winkler, is so prominent and circular that it had originally been mapped as an impact crater. However, later work showed that the Winkler Crater was actually a kimberlite pipe.

Many kimberlites form shallow depressions. Some ponds that occupy kimberlite have abundant rounded boulders that are actually partially assimilated crustal and mantle xenoliths that were polished by the kimberlite as the magma erupted. In some cases, these have been misinterpreted as dry placers. When I discovered the Bowling Pin cryptovolcanic structure in Wyoming (a probable kimberlite), it contained numerous rounded cobbles stained by carbonate. The cobbles appeared to be out of place. It reminded me of the historic discoveries in the Kimberley region of South Africa, where some historic reports suggested that the diamondiferous kimberlites were actually a dry placer.

Summary

Kimberlites are a primary source for diamonds, but few people are trained to recognize these important deposits. Another important diamondiferous host rock known as lamproite has some similar characteristics as kimberlite, but many notable differences. Some similarities are so subtle, that many lamproites have been misidentified as kimberlite, such as the well-known deposits at Crater of Diamonds state park in Murfreesburo Arkansas. Others are quite distinct such as those found in the Leucite Hills of Wyoming. Wherever one finds diamondiferous kimberlite and lamproite, there are likely placer diamonds located downstream. Some of the richest deposits in the world have been placer diamond deposits.

Kimberlite at Iron Mountain photographed by the author in the early summer following an unusual period of rainfall (upper left). The kimberlite lies under the distinct dense grass on the left half of the photo.

Sources

Erlich, E.I., and Hausel, W.D., 2002, Diamond Deposits - Origin, Exploration and History of Discovery. Society of SME. 374 p.

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

Hausel, W.D., 1998, Diamonds & Mantle Source Rocks in the Wyoming Craton with Discussions of Other US Occurrences. Wyoming Geological Survey Report of Investigations 53, 93 p.

Hausel, W. D., 2008a, Prospecting for Diamonds in *ICMJ's Prospecting and Mining Journal*, v. 77, no. 9, p. 19-50.

Hausel, W.D., 2008b, Diamond Deposits of the North American Craton and Accreted Terrains. Wyoming Geological Association Guidebook (in press), 49 p.

Krajick, K., 2001, Barren Lands—An Epic Search for Diamonds in the North American Arctic: W.H. Freeman, 442 p.

Lampietti and Sutherland (1978) Lampietti, F.M.J., and Sutherland, D., 1978, Prospecting for diamonds–some current aspects, *Mining Magazine*, August, p. 117-123.

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

Some current diamond exploration activities in the US: www.abnnewswire.net/press/en/44155/DIAMONEX-LIMITED.html and http://www.deltamine.com/