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PLATE 1.

RAPID EVALUATION OF HEAVY MINERALS IN STREAM SEDIMENTS OF THE PRAIRIE DIVIDE AREA OF NORTHERN COLORADO: A TOOL FOR KIMBERLITE EXPLORATION

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ABSTRACT

Stream-sediment samples from a 259 km^2 (100 mi^2) area in the vicinity of Prairie Divide in Larimer County, northern Colorado, were evaluated for heavy-mineral content. The sampling program was undertaken to evaluate the effectiveness of indicator mineral trains as a rapid test in kimberlite exploration; the Sloan kimberlite diatremes occur in this area. Pyrope garnet, picro-ilmenite, and chrome-diopside were the principal indicator minerals sought in the study. Assemblages of heavy minerals in the stream sediment clearly reflect the presence of two of the Sloan diatremes, and a previously unmapped pipe was recognized.

INTRODUCTION

A rapid stream-sediment sampling survey designed to test the effectiveness of indicator heavy minerals as a viable tool for kimberlite exploration in the northern Colorado-southern Wyoming kimberlite district was conducted in the Prairie Divide area of Colorado. The sampling area, which is approximately 259 km^2 (100 mi^2), centers in the vicinity of the Sloan diatremes and encompasses portions of T. 9 N., R. 73 and 73 W., and T. 10 and 11 N., R. 71, 72, 73 W. in northern Larimer County. Two hundred eighteen samples were collected and analyzed for pyrope garnet, picro-ilmenite, and chrome-diopside, indicator minerals of kimberlite.

GENERAL GEOLOGY

Kimberlite diatremes of the State line district in northern Colorado and southern Wyoming penetrate granitic rocks of the Log Cabin and Sherman batholiths (fig. 1). Peterman and others (1968) established that these plutons are approximately 1.4 m.y. old and that they intrude a metamorphic sequence that is approximately 1.75 b.y. old. Our sampling area (Prairie Divide study area) is underlain predominantly by rocks of the Log Cabin pluton, although the majority of the State Line kimberlite district is situated within the Virginia Dale ring-like complex portion of the Sherman batholith (fig. 1).

Blocks of Ordovician and Silurian sediments preserved in kimberlite provide the only record of early Paleozoic sedimentation in the district, as Late Silurian and (or) Early Devonian erosion destroyed all other evidence. Diatreme emplacement, therefore, is considered to have taken place prior to the erosional event, probably during Late Silurian or Early Devonian time (Chronic and others, 1969; McCallum and Eggler, 1971; McCallum and others, 1975). A Devonian age has been supported by fission track dating of zircons from the kimberlite (Naeser and McCallum, 1977).

Jointing and faulting apparently played a prominent role in kimberlite emplacement. The Sloan diatremes 1 and 2, centrally located in the sampling area (pl. 1), are definitely fault controlled (McCallum and Eggler, 1971; McCallum and others, 1975; McCallum and Mabarak, 1976a, b).

PROCEDURES

Stream-sediment samples were collected from every drainage basin in the Prairie Divide area. Wherever possible, samples were collected on a spacing of not more than 0.8 km (0.5 mi) along significant streams. Each sample was sieved and panned where water was available at the collecting site in order to reduce bulk and increase concentration of the heavy-mineral fractions. Most samples weighed 2.7-4.5 kg (6-10 lbs). Sample splits of about 0.5-0.9 kg (1-2 lbs). were removed in the lab and were retained for further analysis.

Each sample was then passed through a sluice to further concentrate the heavy-metal fraction; total concentrates generally ranged from 4.5-0.1 g (0.01-0.02 lbs). After removal of magnetic mineral constituents (primarily magnetite and ferro-ilmenite), the samples were scanned optically for the presence of garnets, picro-ilmenite, and chrome-diopside. Refractive indices of garnets were determined so that pyrope (R.I. <1.760) could be distinguished from other garnet varieties. Garnet color also served as a useful criterion in making this distinction: the non-pyrope garnets in this area are invariably shades of reddish-brown, whereas pyropes are lavender, dark red, or yellow.

Picro-ilmenite was separated from the more common ferro-ilmenite by magnetic means. A conventional bar magnet was repeatedly placed in very close proximity to each sample, until no more magnetics could be removed.

As a test of the efficiency of this technique, known weights of ferro-ilmenite and picro-ilmenite were mixed together, and then magnetically separated with a conventional bar magnet. This procedure achieved a 103 percent separation of the original ferro-ilmenite weight. The removal of an excess 3 percent with the magnetic fraction is attributed to entrapment of picro-ilmenite grains by ferro-ilmenite aggregates rather than to magnetic susceptibility of some picro-ilmenite. Thus, a simple magnetic separation procedure appears to be an effective method of isolating picro-ilmenite, at least in our samples.

Chrome-diopside grains break down very quickly during stream transport and are therefore a useful indicator of close proximity to kimberlite source. In the Prairie Divide area, chrome-diopside rarely survives downstream transport greater than approximately 0.4 km (0.25 mi). The probability of encountering chrome-diopside in large-scale sampling programs is small, at least during initial sampling phases. When the mineral is encountered, however, the kimberlite source almost certainly is in close proximity.

An alternate method of concentrating the heavy-mineral fraction from the stream sediments directly or of attaining a clean split after sluicing is to utilize heavy-liquid techniques. Average specific gravities of the principal indicator minerals are as follows: pyrope, 3.5; ilmenite, 4.7; and chrome-diopside, 3.2. **Tetrabromethane (CBr_4; density, 2.96) can be conveniently used in this regard; however, the heavy mineral splits obtained by sluicing in this study were adequate for reasonably accurate optical evaluation.**

RESULTS

A large percentage (48 percent) of the samples are at least to some extent **garnetiferous.** The vast majority of the garnets are almandine, a variety that is characteristic of metamorphic terrane. Eight of the samples contain pyrope, and most of these sample sites are directly downstream from the Sloan diatremes 1 and 2 (pl. 1).

In general, it would be expected that ilmenite will survive a greater transport **distance than pyrope.** This expectation was realized in the study area. Transported garnets were detected as far as 2.4 km (1.5 mi) downstream (sample 51, pl. 1) from the Sloan diatreme 2, and rare picro-ilmenite was detected about 4.0 km (2.5 mi) from a diatreme near Blacktail Point (SD4, pl. 1) that was discovered during the course of this study. However, pyrope was detected no farther than about 2.0 km (1.25 mi) downstream from the new kimberlite source. Chrome-diopside was encountered in only 3 samples (45, 46, and 61), **each of which was less than 0.4 km (0.25 mi) from a kimberlite** source.

Table 1 presents the results of the sample analyses and indicates the presence or absence of indicator minerals. Garnet type is specified, and relative abundances of garnets and magnetic minerals in each sample are also categorized.

Point counts were run on the eight samples containing kimberlitic indicator minerals, and the results of those analyses are presented in table 2. A total of 100 point counts was made on each sample, and the presence of each heavy mineral is expressed as a percentage of the total nonmagnetic heavy-mineral fraction. Garnets and magnetic minerals were removed from the samples prior to the point counting operation and are consequently not reported in the table. However, approximate percentages of these two constituents are presented in table 1. Picro-ilmenite was present in <1 percent in only 3 of the samples (44, 46, and 59). Chrome-diopside was not encountered during point counting, although it is present in minute quantities in samples 45, 46, and 61.

The presence of the pelitic metamorphic assemblage in the area is well documented by the abundance of almandine (commonly euhedral) in many of the stream-sediment samples (table 1). No clear patterns of almandine concentration are evident, but this probably reflects the occurrence of metamorphic rocks in rather small bodies within granitic rocks of the Log Cabin pluton. Some almandine garnets might also be derived from the granitic rocks in the area.

Sample 43 is the only sample that clearly indicates the presence of previously unmapped kimberlite. Two small basins upstream from the sample locality were sampled (pl. 1, sec. 12, T. 10 N., R. 71 W., samples 45a and 45b) in an effort to better define the location of the kimberlite. Although these samples were not point counted, both contained abundant pyrope, uncommon to common picro-ilmenite and rare chrome diopside. Furthermore, a small picro-ilmenite nodule (~1.25 cm (1/2 in.) mean diameter) was recovered in the surface wash of one of the basins.

Although the systematic heavy-mineral analysis of stream sediments in drainage basins appears to be an effective method for locating kimberlite, it must be emphasized that the technique is far from foolproof. One factor that is critical to successful exploration is the selection of sampling density. Widely spaced sample sites (that is, more than 3.2 km (2 mi)) would likely result in failure to find all but the largest kimberlite occurrences in Colorado-Wyoming kimberlite province. **Even with the sample density of approximately 0.8 km (0.5 mi) utilized in this study, no indicator minerals were detected in samples collected from drainages in the general vicinity of the Sloan 3 kimberlite, a small pipe that was previously discovered by Mabarak (1975) who used an even denser sampling pattern (approximately 0.4 km (0.25 mi) intervals) in his work. It would be impractical, however, to sample large areas using a site density similar to that employed by Mabarak. We suggest that a 0.8-1.6 km (0.5-1 mi) sampling interval would be adequate for preliminary surveys, and once target areas have been established, these areas should be resampled at closer intervals.**

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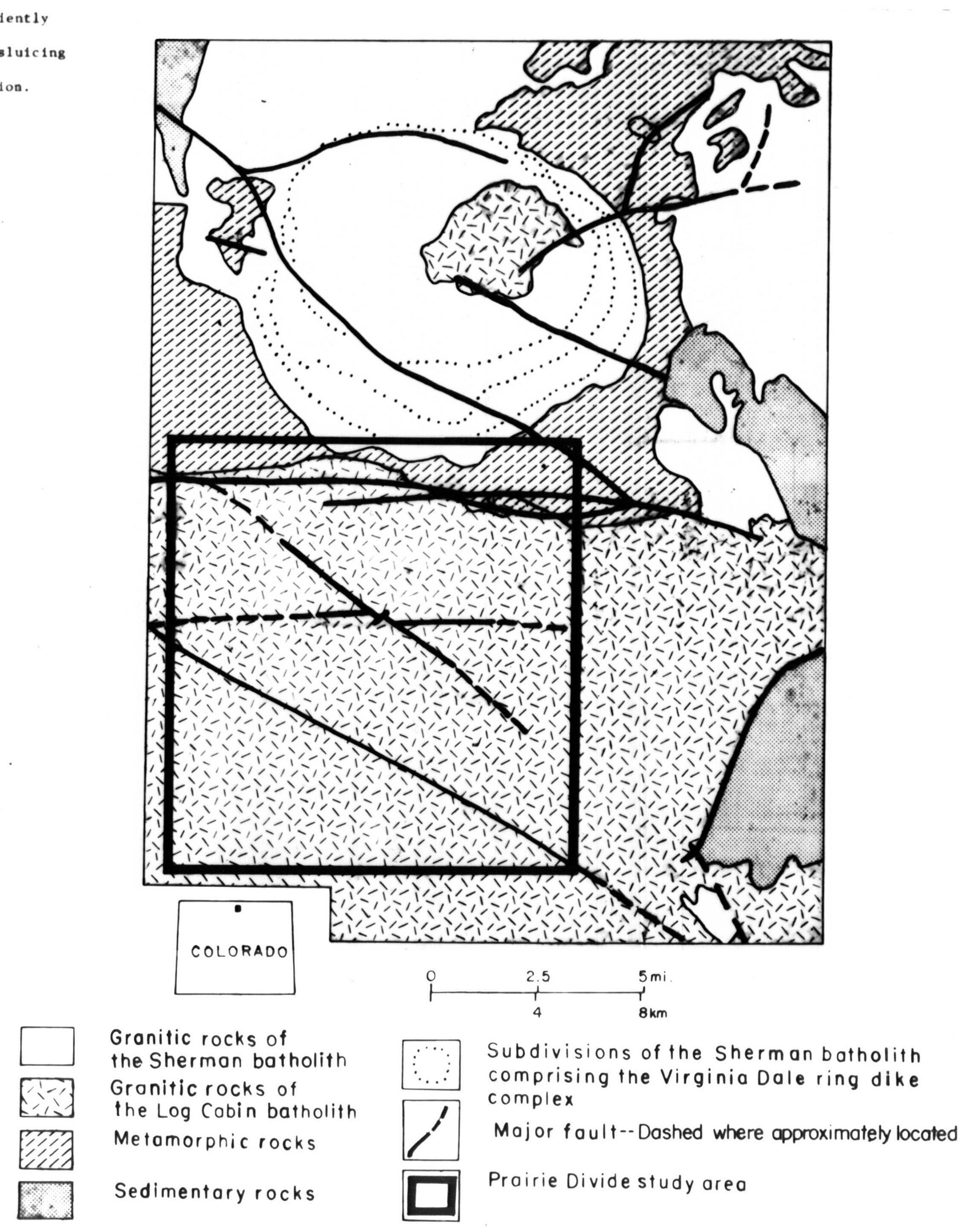

Figure 1 — Index map to the study area of this report (modified from Eggler, 1968 and Burbank and others, 1975)

Table 1.--Heavy-mineral concentration in stream-sediment samples from the Prairie Divide area of northern Colorado.
[Alm, Almandine; Py, Pyrope; A, Abundant (>15%); VC, Very Common (~10-15%); C, Common (~5-10%); U, Uncommon (~1-5%); R, Rare (<1%). Leaders (-) indicate not present].

Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside	Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside
1V	Alm	R	R	-	-	31V	Alm	R	U	-	-
2V	Alm	U	U	-	-	32V	Alm	A	R	-	-
3V	-	-	U	-	-	33V	Alm	C	R	-	-
4V	-	-	R	-	-	34V	Alm	A	C	-	-
5V	-	-	R	-	-	35V	Alm	A	R	-	-
6V	-	-	C	-	-	37V	Alm	R	C	-	-
7V	-	-	U	-	-	38V	-	-	R	-	-
8V	-	-	U	-	-	39V	-	-	U	-	-
9V	-	-	R	-	-	40V	-	-	U	-	-
10V	-	-	VC	-	-	43V	¼Alm	R	U	-	-
11V	Alm	R	U	-	-	44V	-	-	A	-	-
12V	-	-	R	-	-	45V	-	-	R	-	-
13V	Alm	A	U	-	-	46V	Alm	R	R	-	-
14V	Alm	A	C	-	-	47V	-	-	A	-	-
15V	Alm	R	U	-	-	48V	-	-	A	-	-
16V	Alm	A	VC	-	-	49V	Alm	R	A	-	-
17V	Alm	VC	R	-	-	50V	-	-	VC	-	-
18V	Alm	A	C	-	-	51V	-	-	A	-	-
19V	Alm	A	A	-	-	52V	-	-	R	-	-
20V	Alm	VC	C	-	-	53V	-	-	R	-	-
21V	Alm	C	R	-	-	54V	-	-	U	-	-
22V	Alm	VC	U	-	-	55V	-	-	VC	-	-
23V	Alm	A	R	-	-	56V	-	-	C	-	-
24V	Alm	VC	R	-	-	57V	-	-	R	-	-
25V	Alm	U	U	-	-	58V	-	-	A	-	-
26V	Alm	U	U	-	-	59V	-	-	R	-	-
27V	Alm	U	C	-	-	60V	-	-	R	-	-
28V	Alm	A	R	-	-	61V	Alm	R	C	-	-
29V	-	-	R	-	-	62V	Alm	R	A	-	-
30V	Alm	C	R	-	-	63V	Alm	A	R	-	-

Table 1.--Heavy-mineral concentration in stream sediment samples from the Prairie Divide area of northern Colorado--Continued

Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside	Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside
64V	-	-	A	-	-	94V	-	-	VC	-	-
65V	Alm	C	U	-	-	95V	-	-	U	-	-
66V	-	-	R	-	-	96V	Alm	R	A	-	-
67V	Alm	R	R	-	-	97V	Alm	C	A	-	-
68V	-	-	C	-	-	98V	Alm	VC	VC	-	-
69V	Alm	R	U	-	-	99V	Alm	A	A	-	-
70V	-	-	A	-	-	100V	Alm	A	A	-	-
71V	-	-	R	-	-	101V	-	-	A	-	-
72V	-	-	U	-	-	102V	Alm	VC	VC	-	-
73V	-	-	U	-	-	103V	-	-	U		
74V	-	-	U	-	-	104V	-	-	A	-	-
75V	-	-	VC	-	-	105V	Alm	VC	VC	-	-
76V	Alm	A	C	-	-	106V	Alm	VC	A	-	-
77V	Alm	U	VC	-	-	107V	-	-	A	-	-
78V	Alm	A	VC	-	-	108V	Alm	VC	VC	-	-
79V	Alm	R	U	-	-	109V	-	-	A	-	-
80V	Alm	R	U	-	-	110V	Alm	VC	VC	-	-
81V	-	-	U	-	-	111V	Alm	R	A	-	-
82V	-	-	C	-	-	112V	Alm	C	VC	-	-
83V	-	-	C	-	-	113V	-	-	A	-	-
84V	-	-	C	-	-	114V	-	-	A	-	-
85V	-	-	C	-	-	115V	-	-	VC	-	-
86V	-	-	U	-	-	116V	-	-	U	-	-
87V	-	-	A	-	-	117V	-	-	A	-	-
88V	-	-	A	-	-	118V	-	-	C	-	-
89V	Alm	R	VC	-	-	119V	-	-	C	-	-
90V	Alm	R	U	-	-	120V	-	-	C	-	-
91V	-	-	R	-	-	121V	-	-	R	-	-
92V	-	-	U	-	-	122V	-	-	U	-	-
93V	-	-	R	-	-	123V	-	-	A	-	-

Table 1.--Heavy-mineral concentration in stream sediment samples from the Prairie Divide area of northern Colorado--Continued

Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside	Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside
124V	-	-	U	-	-	18	-	-	R	-	-
125V	-	-	A	-	-	19	-	-	R	-	-
126V	-	-	R	-	-	20	-	-	U	-	-
127V	-	-	R	-	-	21	Alm	A	C	-	-
128V	Alm	R	A	-	-	22	Alm	R	R	-	-
129V	-	-	R	-	-	23	Alm	C	U	-	-
130V	-	-	A	-	-	24	Alm	A	U	-	-
131V	-	-	VC	-	-	25	Alm	U	U	-	-
132V	-	-	U	-	-	26	Alm	C	U	-	-
133V	Alm	R	C	-	-	27	Alm	VC	R	-	-
134V	-	-	R	-	-	28	-	-	U	-	-
135V	-	-	R	-	-	29	Alm	R	VC	-	-
136V	-	-	U	-	-	30	Alm	R	R	-	-
1	Alm	U	R	-	-	31	-	-	VC	-	-
2	-	-	R	-	-	32	-	-	R	-	-
3	Alm	C	C	-	-	33	-	-	R	-	-
4	-	-	VC	-	-	34	-	-	R	-	-
5	-	-	C	-	-	35	-	-	R	-	-
6	Alm	VC	U	-	-	36	-	-	R	-	-
7	-	-	R	-	-	37	-	-	U	-	-
8	Alm	VC	A	-	-	38	-	-	R	-	-
9	Alm	A	A	-	-	39	Alm	R	R	-	-
10	-	-	U	-	-	40	Alm	R	U	-	-
11	-	-	U	-	-	41	Alm	R	U	R	-
12	-	-	C	-	-	42	-	-	VC	-	-
13	Alm	VC	C	-	-	43	Alm	VC	A	-	-
14	Alm	R	R	-	-	44	Alm+Py	A	C	R	-
15	-	-	U	-	-	45	Py	A	VC	C	R
16	Alm	VC	C	-	-	46	Alm+Py	VC	U	C	R
16	Alm	A	C	-	-	47	Alm	VC	A	-	-

Table 1.--Heavy-mineral concentration in stream sediment samples from the Prairie Divide area of northern Colorado--Continued

Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside	Sample no.	Garnet type	Garnet abundance	Magnetics abundance	Picro-ilmenite	Cr-diopside
48	Alm	A	A	-	-	78	Alm	VC	U	-	-
49	Alm	C	R	R	-	79	-	-	R	-	-
50	-	-	R	-	-	80	Alm	R	C	-	-
51	Py	C	R	-	-	81	-	-	R	-	-
52	Alm	R	U	-	-	82	-	-	C	-	-
53	Alm	C	A	-	-	83	-	-	R	-	-
54	Alm	VC	VC	-	-	84	-	-	U	-	-
55	Alm	R	U	-	-	85	-	-	U	-	-
56	Alm	C	C	-	-						
57	Py	R	U	-	-						
58	-	-	U	-	-						
59	Alm+Py	VC	R	C	-						
60	-	-	R	-	-						
61	Alm+Py	A	U	VC	R						
62	-	-	U								
63	Alm	U	VC	-	-						
64	-	-	R	-	-						
65	Alm	A	C	-	-						
66	Alm	R	U	-	-						
67	Alm	R	R								
68	Alm	A	C	-	-						
69	Alm	A	VC	-	-						
70	Alm	U	C	-	-						
71	Alm	U	C	-	-						
72	-	-	C	-	-						
73	Alm	A	A	-	-						
74	Alm	U	VC	-	-						
75	-	-	U	-	-						
76	-	-	R	-	-						
77	-	-	VC	-	-						

Table 2.--Abundance of nonmagnetic heavy minerals in stream-sediment samples containing kimberlite indicator minerals.
[Other heavy-minerals detected include 4 percent zircon in sample 57 and 20 percent monazite in sample 61. Leaders (-) indicate not present.]

Sample no.	Amphibole, pyroxene (percent)	Hematite (percent)	Picro-ilmenite (percent)	Garnet 1/
44	79	5	16	A
45	100	-	-	A
46	57	-	43	VC
49	100	-		C
51	100	-	-	C
57	76	10	-	R
59	67	20	13	VC
61	80	-	-	A

1/ Garnets were removed prior to the point counting procedure; A, abundant (>15 percent); VC, very common (10-15 percent); C, common (5-10 percent); and R, rare (<1 percent).