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GEOCHEMICAL PROSPECTING WITH HEAVY-MINERAL CONCENTRATES USED TO LOCATE A TUNGSTEN DEPOSIT

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By P. K. Theobald, Jr., and C. E. Thompson

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ABSTRACT

Rapid field chemical analysis of heavy-mineral concentrates panned from stream gravels provides a reconnaissance prospecting technique for many of the ore minerals that are resistant to chemical and mechanical decay. This technique involves three steps: areal reconnaissance by sampling the mouths of major streams to locate drainage basins with anomalous metal content; tracing an anomaly through a drainage basin by sampling the main stream and tributaries, proceeding upstream until the anomaly is terminated; and tracing the metal away from the stream to the bedrock source by conventional geologic or geochemical prospecting techniques. On the eastern slope of the central part of the Front Range, Colo., a previously unsuspected tungsten anomaly was traced through the Clear Creek drainage basin to West Fork Clear Creek and Woods Creek and was isolated in an avalanche slope on the southeast side of Red Mountain. The anomaly was traced by chemical analysis of the fine fraction of debris on the avalanche slope to a huebnerite deposit near the crest of the peak. Despite sampling and analytical problems this technique is valuable for locating mineralized ground because of its speed and low cost.

INTRODUCTION

Use of the gold pan—or a similar device—for prospecting has been a standard technique for centuries (Hill, 1746). The addition of heavy-mineral studies to sedimentary petrography and greater interest in the heavy accessory minerals of igneous and metamorphic rocks is leading to greater interest in and expansion of the technique (Mertie, 1954).

Geochemical prospecting methods have long been sought that will reveal anomalous amounts of metals miles from their bedrock source. Analyses of both stream water and stream sediment have been used extensively with some success, but the most successful regional reconnaissance technique is still the ancient process of gold panning. If carefully applied, this technique may be expanded so that the concentrates obtained include a wide variety of resistant ore minerals that may be traced through a drainage basin to their source in the same manner originally used for gold prospecting.

Sigov's (1939) procedure for general heavy-mineral prospecting in Russia was based on the mineralogic analysis of concentrates panned in an "Asiatic ladle." The mineralogic approach has been extensively developed by the Russians and appears as the "schlich" methods in Ginzburg's (1957) general text for geochemical prospecting.

In the United States, mineralogic analysis of concentrates has been used extensively in the search for placer deposits. Recently, W. C. Overstreet (oral communication) has used mineralogic data acquired from heavy-mineral concentrates panned from alluvium to outline certain general features of the metamorphic rocks in an area of 4,000 square miles in the southeastern Piedmont province. During this and subsequent work, he has supplemented the mineralogic analyses with spectrographic and chemical analyses for elements whose ore minerals may be easily overlooked.

Complete mineralogic analysis of concentrates is both slow and costly; it is rarely used on a large scale except in the U.S.S.R. Other methods currently in use where the ore mineral sought is not conspicuous are selective staining of mineral grains and spectrographic analyses of the concentrates. Sigov (1939) gives staining methods for scheelite and cassiterite but points out that spectrographic analyses are cheaper than using a stain. Visual estimation of the proportion of a mineral in a stained concentrate usually leads to overestimation.

Spectrographic analyses are probably best used for initial reconnaissance. The method gives reliable estimates of many elements with a single analysis, is relatively cheap and fast, and requires only a small sample (20-50 milligrams). Its chief disadvantages are the lack of portability of the equipment for an analysis at each locality, the time consumed for completion of single analyses, and the poor sensitivity for several elements (notably zinc and tungsten).

Rapid field chemical analyses of the concentrates allow anomalously high concentrations of metals to be detected and followed when the ore minerals are inconspicuous owing to their appearance, small grain size, or low level of concentration. This rapid technique has led to the discovery of a deposit of huebnerite, the manganese-rich end member of the wolframite series, near the crest of Red Mountain in the western part of the Clear Creek drainage basin, Clear Creek County, Colo. The tungsten anomaly was first found along the eastern limit of the Front Range more than 45 miles downstream from the deposit.

PROPOSED TECHNIQUE

Rapid field chemical analyses developed for use in geochemical prospecting for specific elements in soils offer an ideal method to overcome the problems encountered in techniques used to date. The most rapid of these, the so-called cold tests, are not suitable because the elements are too tightly fixed in oxide, sulfide, or silicate minerals; but any of the specific tests that will effect solution of the ore minerals are acceptable.

The proposed prospecting technique is based on the premise that any ore deposit at the bedrock surface, even if covered by soil, colluvium, or alluvium, is providing sediment to the drainage system within which it occurs. Many of the ore minerals have a high specific gravity and are resistant to chemical and mechanical decay. These will travel into the drainage system and will be concentrated with other heavy minerals. They will persist for many miles downstream from the source, and samples taken from heavy-mineral-rich gravels in streambeds and terraces near the mouths of streams should include minerals from any ore deposits drained by the streams.

Samples are taken from gravels in preference to other stream sediments, because gravels have the greatest proportion and variety of heavy minerals. Usually a gravel bar or riffle in the stream bed can be found in which more than 50 percent of the material is greater than one-quarter of an inch in mean diameter. The sample is shoveled from such a bar, and pebbles and cobbles are removed. The remaining material, which has a median diameter in the coarse sand or granule range, is panned. Samples of approximately the same size are taken at each locality, and the heavy minerals are concentrated by panning. Only a crude approximation of the proportion of heavy minerals is made, since this is a function of the sediment type and the environment of deposition. During the present work a single, heaping 12-inch pan of gravel, weighing about 10 kilograms, was taken and concentrated at each locality. The weight of the concentrate below the junction of Clear Creek with West Fork Clear Creek, in the unglaciated area, generally ranged from 50 to 100 grams and was a function of the amount of magnetite and ilmenite. Above this junction, in the glaciated area, concentrates rarely exceeded 10 grams and were often less than 1 gram. The smallest concentrates were obtained from the gravels in cataracts flowing down the steep glaciated valley walls.

Magnetite was removed from each sample with a hand magnet before analysis. For tungsten, this procedure removes any contamination due to tungsten steels, and it would be well to retain this step when other metals used in ferroalloys are being sought.

The first series of analyses in an area is intended only to outline specific streams for further study. Streams 10-50 miles long seem the optimum size for the initial reconnaissance; each of these is sampled at its mouth, and the concentrates are analyzed. On the basis of this preliminary work, a figure may be selected for a given element above which a value is considered anomalous and below which a value is considered "background." An anomalous value in the initial analysis is checked with a few samples near the original locality. If confirmed, the anomaly is followed upstream, samples of gravels being collected from the mouth of each major tributary and from the main stream just above this tributary until the source area of the metal is located.

Concentrates are packaged and labeled for laboratory study after the field analysis is completed. Selected analyses are checked by more precise laboratory methods, and additional chemical or spectrographic analyses are made as desired. The concentrates are then available for mineralogic studies. Because most of the grains in the concentrate contain only one mineral, several separations using heavy liquids (we have used both bromoform, specific gravity 2.9, and methylene iodide, specific gravity 3.3) and electromagnetic separators will provide a series of smaller concentrates each of relatively simple mineralogy.

APPLICATION OF PROPOSED TECHNIQUE IN THE FRONT RANGE

An area in the east-central part of the Front Range, Colo., was chosen to test the technique in the field. The initial samples were taken from five streams at the eastern limit of Precambrian crystalline rocks from Bear Creek on the south to Boulder Creek on the north (fig. 1). A tungsten anomaly on Clear Creek was then traced through the drainage basin, and a reconnaissance of the entire drainage basin was made. Application of the technique resulted in the discovery of a huebnerite deposit in the western part of the drainage basin.

Clear Creek heads at the Continental Divide in the west-central part of the Front Range, Colo., and follows a generally eastward course to join the South Platte River just north of Denver, east of the Front Range. The major part of the drainage basin is underlain by Precambrian crystalline rocks that constitute most of the Front Range. About a quarter of the way downstream from its head, the stream crosses the Front Range mineral belt. The richest part of the mineral belt, which is drained by Clear Creek and its tributary North Clear Creek includes a group of base- and precious-metal districts, generally free of tungsten minerals—the Alice, North Gilpin, Central City, Empire, Lawson-Dumont, Idaho Springs, Silver Plume, and Argentine mining districts described by Lovering and Goddard (1950, pl. 4). Small pockets of scheelite have been prospected at several localities, but none of these is economically important.

The upper reaches of the stream pass over glacial drift, and the valleys are broad and generally flat floored and steep walled. Within this glaciated area, resistant rock shoulders interrupt the valleys, and the streams plunge past these impediments in cataracts commonly confined to narrow, deep gorges. The most impressive of the cataracts are just above the junction of Woods Creek (fig. 2) with the West Fork of Clear Creek, on both streams, and just above Georgetown and South Clear Creek and Clear Creek. Similar rapid, confined reaches are on both Clear Creek and the West Fork of Clear Creek just above their junction, where the streams breach the lowest conspicuous moraines.

Below the junction of the West Fork of Clear Creek and Clear Creek, the stream enters a series of canyons that, in general, become deeper and more sinous to the east. At Golden the stream leaves the crystalline rocks and the canyon and follows an open valley carved in sedimentary rocks to its junction with the South Platte River.

The streams flowing parallel to Clear Creek—Bear Creek on the south, and Coal Creek, Ralston Creek, South Boulder Creek, and Boulder Creek on the north—have similar topographic and geologic relations. With the exception of Boulder Creek, however, they do not penetrate the mineral belt. Boulder Creek drains the Boulder County tungsten, Grand Island, Magnolia, and Gold Hill districts.

Analytical Procedure for Tungsten

The method used to determine tungsten at the sample site is a modification of the method developed by F. N. Ward (1951). As portability and speed are more important than precision when prospecting with heavy minerals, much of the equipment was changed or eliminated, although the same reagents were used. A lucite scoop drilled to hold 0.6 gram of flux on one end and 0.25 gram of soil or concentrate on the other was used instead of a balance. Culture tubes scored at various volumes were used in place of pipettes. Neither filtration of the sample nor use of a hot-water bath was needed in this simplified procedure. No standard solution or standard series used for estimation of unknowns was necessary. A bunsen-type burner using light-weight disposable tanks of liquefied petroleum was preferred to the gasoline stove recommended by Ward.

The procedure follows: Part of the concentrate is taken directly from the gold pan and dried, and 0.25 gram is measured with the scoop and transferred to a 16- by 150-millimeter culture tube. The flux is added, and the sample and flux are sintered over the burner. The sodium tungstate formed during the sinter is dissolved with 5 milliliters of water, and a aliquot is transferred to another culture tube after the residue has settled. This aliquot is diluted to 5 milliliters; the stannous chloride and potassium thiocyanate solutions are are added; and the tube and contents are warmed. The tube is cooled; the potassium thiocyanate solution and isopropyl ether are added; and the tube is shaken to extract the yellowish-green tungsten thiocyanate complex into the ether layer. A little experience is necessary to be able to estimate the tungsten content by the intensity of the color without reference to standards; but artificial standards may be made, or the culture tubes containing the complex may be carried from one locality to the next to make a direct comparison of the color intensity.

Molybdenum, where present, produces an amber-colored thiocyanate that masks the tungsten color. This interference can usually be eliminated by the procedure outlined by Ward (1951, p. 3). Differences in sulfur content from sample to sample can be detected from the black gummy sinter formed if sulfur is present.

Concentrates from the Eastern Limit of Precambrian Crystalline Rocks

A segment of the east slope of the Front Range in Colorado extending from Bear Creek on the south of Boulder Creek on the north was chosen to test the technique. The initial reconnaissance samples were taken at the eastern limit of the Precambrian crystalline rocks on Bear Creek, Clear Creek, Coal Creek, South Boulder Creek, and Boulder Creek. The relation of these streams to the Front Range mineral belt was known, and maximum variation in metal content was expected. Bear Creek and Coal Creek, which do not intersect the mineral belt, were expected to provide an estimate of background. South Boulder Creek drains a relatively weakly mineralized part of the mineral belt and was expected to have intermediate metal content. Clear Creek drains the central, base- and precious-metal-rich segment of the belt, and Boulder Creek drains the tungsten-rich part of the mineral belt. These streams were expected to be rich in metal, with maximum tungsten content on Boulder Creek. A lower tungsten content was expected on South Boulder Creek.

Magnetite-free heavy-mineral concentrates from each of these streams were analyzed spectrographically by E. F. Cooley and U. Oda, of the U. S. Geological Survey, and field chemical determinations were made for tungsten and lead. The results of the spectrographic analyses for 11 of the 28 elements determined are in table 1, and the tungsten contents are shown on figure 1.

The tungsten content of the sample from Boulder Creek is so great that contamination was suspected from the mill at Tungsten. Terrace gravel in a roadcut was sampled to check the value obtained in the stream, and the drop from 5,000 parts per million in the stream to 200 ppm in the terrace apparently reflects the contamination. Both of these values have been repeated in other field samples. Compared with the 40, 20, and 60 ppm in concentrates from Bear, Coal, and South Boulder Creeks, either of the values from Boulder Creek is anomalous, particularly as the 60 ppm on South Boulder Creek probably reflects tungsten minerals from the southern part of the Tungsten district, and small pockets of scheelite are contributing tungsten to the other two streams.

The 300 ppm on Clear Creek is above the concentration found in the terrace on Boulder Creek and an order of magnitude above what is considered to be a high background established on the other streams. Although small scheelite prospects are scattered throughout the Clear Creek drainage basin, these should not contribute more to Clear Creek than similar small deposits contribute to the adjoining streams. The anomalous value was repeated in additional samples nearby. Clear Creek, therefore, provided an unexplained anomaly to be traced to its source.

The spectrographic analyses (table 1) bore out, out, in general, the expectations from panning and field chemical analysis. The base and precious metals—lead, zinc, silver, copper—are highest in the concentrate from Clear Creek. The relatively high lead, zinc, and copper concentrations on Bear Creek are somewhat surprising, but may reflect small sulfide-bearing veins in the vicinity of Idledale, only 2 miles upstream from the sample locality. The high tin content of the concentrate from Clear Creek does not come from any known deposits. One possible explanation is that the tin comes from the same source as the tungsten, but this remains as an anomaly that should be checked further. Molybdenum varies only slightly, considerably less than was expected. The molybdenite is probably comminuted during vigorous stream transport to very fine cleavage flakes which because of their habit and size are not concentrated with the other heavy minerals. Manganese, cobalt, nickel, and cadmium are included as examples of elements that did not show appreciable variation. The significance of the chromium variation is not known.

Table 1.—Data on selected elements from spectrographic analyses of heavy-mineral concentrates from streams along the east edge of the central part of the Front Range, Colo.

[Analyses in parts per million, by E. F. Cooley and U. Oda, U. S. Geological Survey]

Creeks	Pb	Zn	Ag	Cu	Sn	Mo	Mn	Co	Ni	Cr	Cd
Bear	100	500	<2	150	70	15	>10,000	30	20	300	50
Clear	500	10,000	70	700	100	30	>10,000	50	30	700	<50
Coal	100	<200	<2	50	50	20	10,000	30	20	700	70
South Boulder	70	<200	<2	30	20	20	7,000	30	30	1,500	50
Boulder:											
Stream	70	<200	<2	30	50	10	7,000	20	30	500	<50
Terrace	50	<200	<2	50	30	20	10,000	30	30	1,000	70

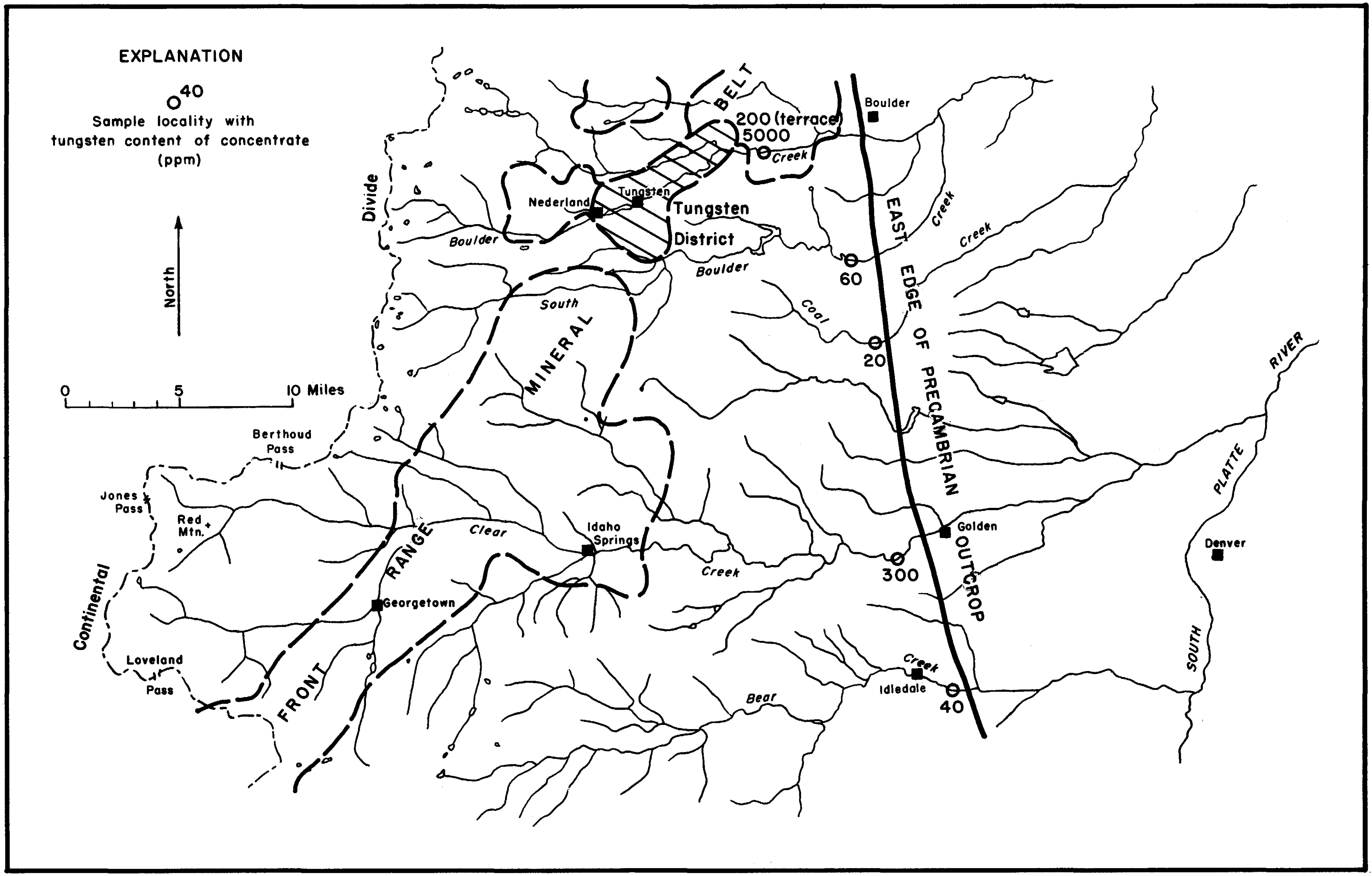

Figure 1.—Tungsten content of concentrates from streams along the east edge of the Front Range, Colo.

Distribution of Tungsten along Clear Creek

The anomalous tungsten value at the eastern limit of the Precambrian rocks on Clear Creek was checked at the original locality, and also by a pair of samples within the next few miles upstream. The 6 analyses ranged only from 200 to 400 ppm of tungsten, confirming the lack of variation of the anomaly. These and subsequent tungsten analyses were made by the rapid field technique, though some analyses were confirmed in the laboratory.

Clear Creek and West Fork Clear Creek

The anomaly was traced upstream by samples being taken at the mouths of major tributaries and at more widely scattered localities along the main stream (fig. 2). By the end of the first day in the field at this stage of prospecting, the anomaly had been traced as far as Empire. On part of a second day the anomaly was traced onto Woods Creek where the tungsten content of the concentrate increased abruptly to 1,000 ppm.

The anomaly was initially attributed to scheelite, as this mineral was conspicuous when the samples were checked with an ultraviolet light. Upstream, however, the amount of scheelite decreased while the anomaly remained unchanged. By splitting the concentrates in a strong electromagnetic field, wolframite and scheelite were separated, and their relative importance was estimated. At the mouth of Clear Creek, 20 percent of the anomaly results from huebnerite and 80 percent results from scheelite. The initial anomaly is, therefore, principally the result of scheelite whose main source remains unknown. Since the scheelite content of the concentrates gradually decreases upstream, it is likely that the scheelite is gradually accumulating downstream from a large number of small deposits. Conversely, the huebnerite content of the concentrates gradually increases upstream, accounting for 20 percent of the tungsten at the mouth, 50 percent above the Fall River, 80 percent at Empire, and 100 percent on Woods Creek.

Headwaters of West Fork Clear Creek

The extreme tungsten content, 1,000 ppm, at the mouth of Woods Creek, coupled with the high of 150 ppm on the West Fork of Clear Creek above Woods Creek prompted more detailed sampling in this area. (See figure 3.) The first sample, from the tailings pond of the Urad molybdenum mine, eliminated the molybdenum deposit as the major source of tungsten, though the tailings do contain some huebnerite. A sample from the first tributary, Ruby Creek, also contained anomalous tungsten, but not as much as in the main stream above Ruby Creek. The three low samples on the main stream and tributaries upstream from Ruby Creek gave an upstream limit for the anomaly. The known molybdenite deposit on the slopes of Red Mountain, the huebnerite in the Urad mine tailings, and intense alteration of the country rocks made the southeast side of Red Mountain seem the likely source for the tungsten; so the next sample was taken about halfway between Ruby Creek and the most headward sample, below an avalanche slope at the southwest end of Red Mountain. This sample, at 80 ppm, was higher than the upstream sample, but not comparable with the sample above Ruby Creek. The stream distance to Ruby Creek was split, and the sample taken from just below another prominent avalanche slope, this time near the middle of Red Mountain. This sample contained more than 1,000 ppm tungsten. To confirm the suspected source on Red Mountain, a concentrate was panned from the rubble at the base of the avalanche slope. The result was similar to but more intense than that in the adjoining stream. The concentrate was taken back to the laboratory, and the analysis confirmed at greater than 1 percent tungsten.

The headwaters of West Fork Clear Creek seem to drain a generally tungsten-rich area. Tungsten mineralization on the slopes of Red Mountain is verified not only by the major anomaly but also by the 80 ppm on Woods Creek half a mile upstream from the anomaly, and by the 200 ppm in the stream draining north along the west side of Red Mountain. The several high-tungsten samples—the 100 ppm on Ruby Creek (fig. 3), 140 ppm on the small tributary of West Fork Clear Creek below the junction with Woods Creek (fig. 3), and 200 ppm on a small stream north of West Fork Clear Creek directly opposite the 200 ppm at the west end of Red Mountain (fig. 3) must be taken to indicate extensions of the tungsten-rich area outward from Red Mountain proper. An 800 ppm on a small tributary (not shown on any illustration) at Empire (fig. 2) may be within this area.

The effect in the stream concentrates of the molybdenite deposit at the Urad mine is confined to the immediate neighborhood of the deposit. As little as 15 ppm of molybdenum could be recognized by its interference with the tungsten analysis, and this was noted in only 3 of the samples. One of these, containing 16 ppm, was near the head of Fall River (fig. 2). The sample at the mouth of Woods Creek has the largest concentration of molybdenum—more than 1,000 ppm. This is due in large part to contamination by tailings from the Urad mill; the concentrate from the tailings contains conspicuous molybdenite. The other molybdenum-rich concentrate, 30 ppm, is from Woods Creek just above Ruby Creek. This may also be contamination—from an abandoned tramway that extended down the slope from the upper workings of the Urad mine and crossed the creek just above the sample locality. Three other concentrates from Ruby Creek and the tributaries of West Fork Clear Creek north of Red Mountain contain less than 4 ppm of molybdenum.

Clear Creek Drainage Basin Outside Anomalous Area

Samples were taken from North Clear Creek, Fall River, Chicago Creek, South Clear Creek, and the headwaters of Clear Creek to gain information on the distribution of tungsten in the entire drainage basin and to provide samples for future studies. In all, 73 samples were collected, concentrated, and analyzed for tungsten. The frequency distribution of tungsten contents (fig. 4) serves to establish background for Clear Creek more definitely. The distribution curves are undoubtedly biased in favor of the high values, because of selective sampling within the anomaly. Indeed, if samples from the main stream of Clear Creek and the headwaters of West Fork Clear Creek are eliminated, only 3 values remain in the 100- to 200-ppm range. One of these three is a concentrate from a small intermittent stream south of Idaho Springs that is just south of the sample at the mouth of Chicago Creek and forms a fifth branch in the middle of the stream with four branches (fig. 2);

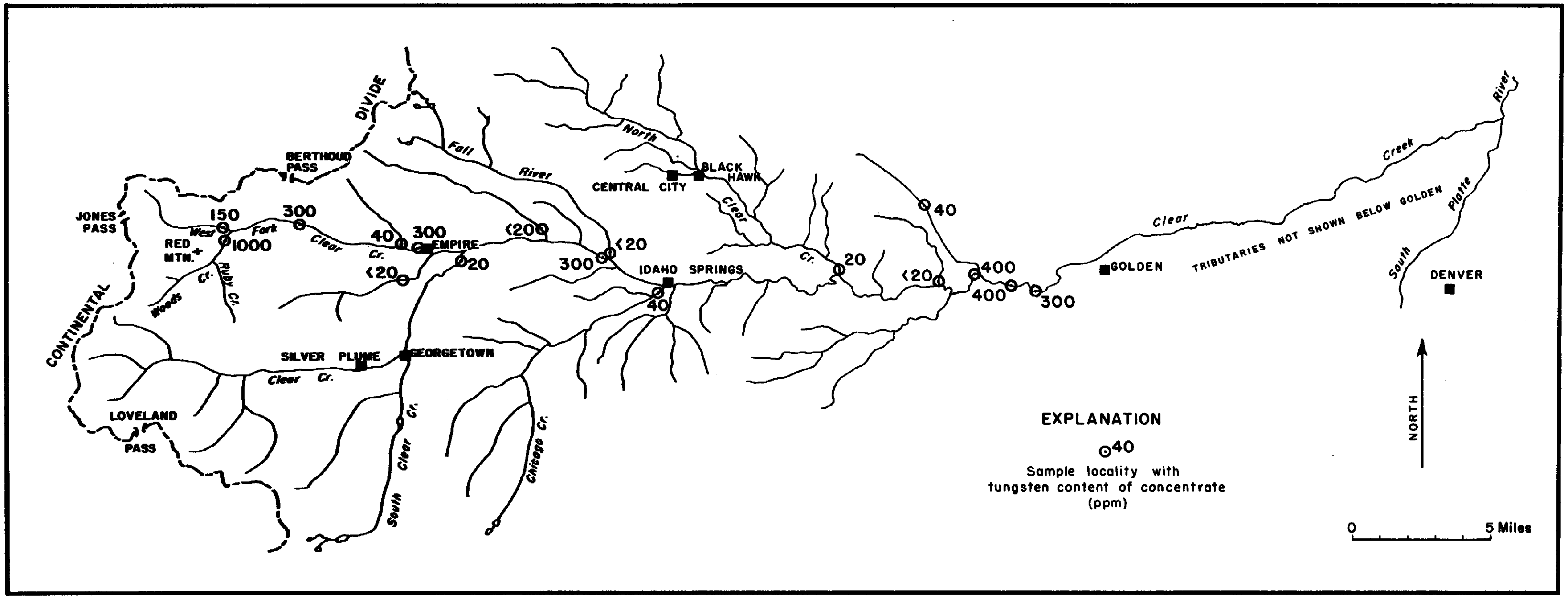

Figure 2.—Tungsten content of concentrates along Clear Creek, Colo.

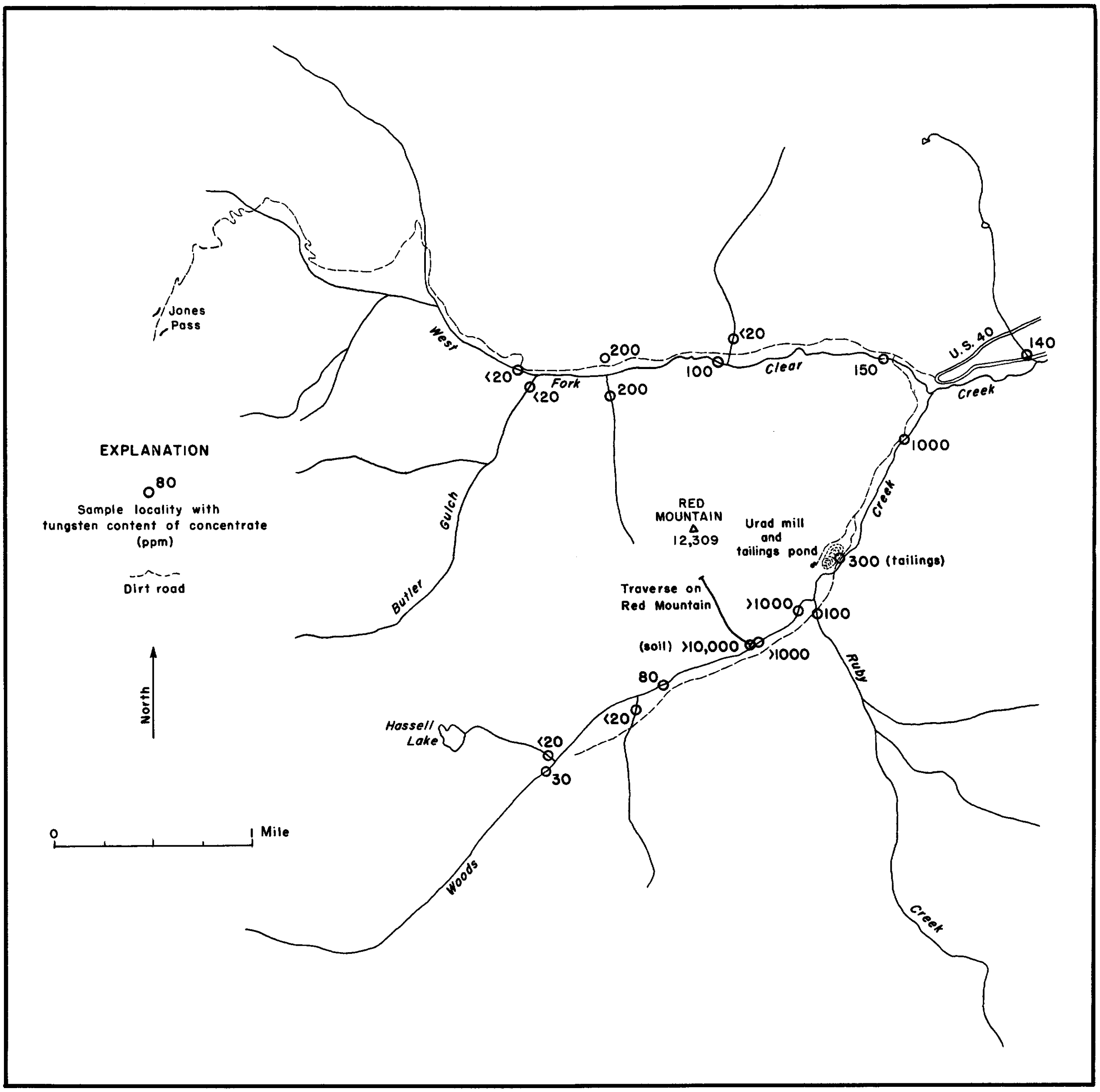

Figure 3.—Tungsten content of concentrates from the headwaters of West Fork Clear Creek, Clear Creek County, Colo.

the other two are from the main stream of Clear Creek just below Georgetown, and from the major forked tributary to Clear Creek about 4 miles above Silver Plume (Quayle Creek).

Most values above 100 ppm are from samples on tributaries of West Fork Clear Creek in and adjoining the anomaly. The highest value not in the anomaly, 800 ppm, is on a small stream that enters West Fork Clear Creek from the north in the town of Empire (fig. 2). This is the only value in excess of 200 ppm that is not part of the principal anomaly. It represents an area that deserves further investigation, but which will be difficult to prospect because of the extreme disturbance of the stream and adjoining slopes by placer and lode mining.

The frequency distribution serves best to establish that the analyses we have considered in following the principal anomaly represent only the high end of a strongly skewed distribution. True background is 20 ppm or less, supporting the expectation expressed in the preceding section that with the exception of Coal Creek samples from all the streams display enrichment of tungsten. For a complete study of tungsten distribution in this area, sources should be sought for all samples containing 40 ppm or more. Indeed, the tungsten anomaly produced by wolframite alone at the mouth of Clear Creek is only 60 ppm, and this has been shown in this report to be a valid anomaly.

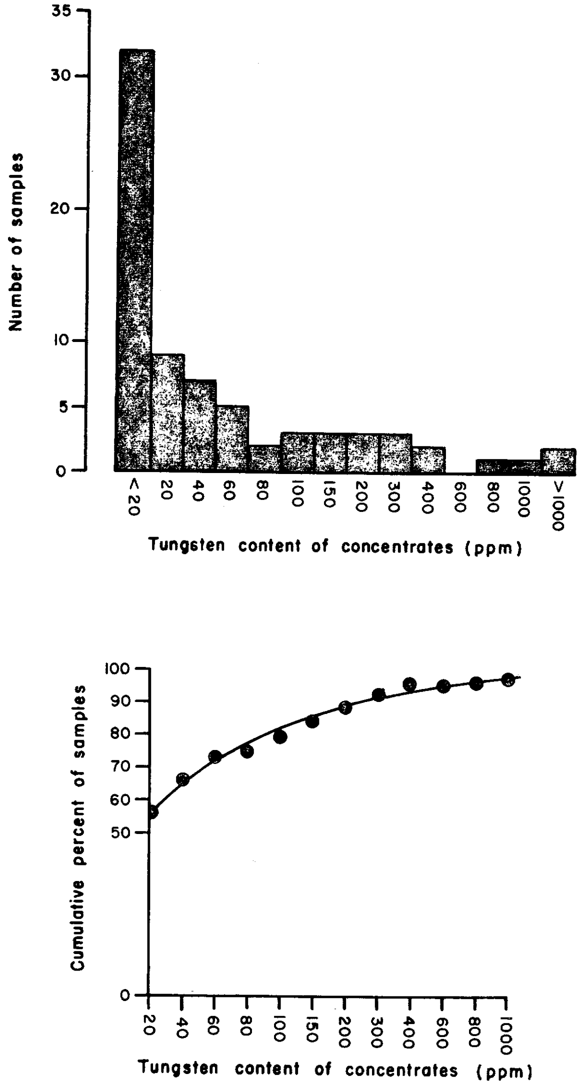

Figure 4.—Frequency distribution of tungsten content of heavy-mineral concentrates from 73 localities from the Clear Creek drainage system, Colorado.

Tungsten Deposit on Red Mountain

The tungsten deposit has not been found in place; however, the anomaly has been traced up the slope of Red Mountain to a point where huebnerite is conspicuous in the float and the talus itself could be considered marginal ore.

Geochemical Exploration for Tungsten

The steep talus-covered southeast slope of Red Mountain offers a challenge to any form of prospecting. Because of the heavy cover by lateral moraine and talus, standard geologic methods yield little beyond generalized conclusions. Geochemical methods based on residual soils are not applicable; not only has everything on the slope been transported, but the mere act of climbing the talus dislodges a startling quantity of debris. Two avenues of attack appear promising: deep-rooted plants may penetrate the surficial debris and accumulate metals from the underlying bedrock, and avalanche and landslide debris on the avalanche slopes could, with caution, be substituted for residual soils. The latter was chosen because the stream anomaly had been traced into this material.

The tungsten-rich avalanche slope is a narrow, almost treeless 30° chute rarely more than a few hundred feet wide and with more than 1,500 feet of relief. It has a crudely cirquelike head just south of the main crest of Red Mountain. From this oversteepened somewhat broadened head, the chute changes little in width, slope, or direction for a vertical distance of 1,000 feet. At its base, the chute widens, and the slope becomes more gentle. Below the oversteepened segment, most of the chute is covered by a long narrow cone of poorly sorted angular debris that probably is a rock slide. The slide surface flattens at the base of the chute and continues up the opposing slope for a short distance to terminate in an arcuate ridge of rubble concave northwestward toward Red Mountain. Woods Creek has cut a gorge 20-40 feet deep through the lowest part of the slide.

Lateral moraine, conspicuous in other parts of the valley, apparently was removed before the slide debris accumulated, for the fragments in the slide are of local derivation and lack the rounded or smoothed forms characteristic of the morainal material. Material at a given locality in the slide could have come only from a bedrock source upslope from the slide or covered by the slide. Upslope from a metal source in a covered vein, the anomaly could be expected to drop off abruptly only if the vein crossed the slide at right angles and perpendicular to the general slope—at this place, trending northeastward.

A traverse was made on the avalanche slope with these conditions in mind. Samples were taken at 200-foot intervals up the slope, and the vertical distance between sample sites was determined with a hand level. The average horizontal distance between localities is about 175 feet. The first sample taken at the base of the slope coincides with the last sample taken during work along the stream described in the preceding section. The straight course and nearly constant 30° slope are evident in the plan and profile of the traverse (figs. 5 and 6).

The samples were screened to pass 30 mesh, and part of the fine fraction was analyzed for tungsten at the site. The unused part of the fine fraction was saved for spectrographic analysis.

The first sample taken at the base of the slope contains 150 ppm of tungsten (table 2 and fig. 5) compared with 1 percent (10,000 ppm) in the concentrate, indicating a concentration ratio of about 70 to 1 during panning. For the next 1,000 feet up the slope, the tungsten content of the "soil" gradually increases to 300 ppm. Two hundred feet beyond this point, at locality 7, the "soil" contains more than 0.1 percent (1,000 ppm) tungsten. The value for all samples above locality 7—1,200 feet of traverse—was above 0.1 percent, and the value was still high where the traverse was stopped.

Semiquantative spectrographic methods are sufficiently sensitive to be used for tungsten in all the samples upslope from locality 5, and both field chemical

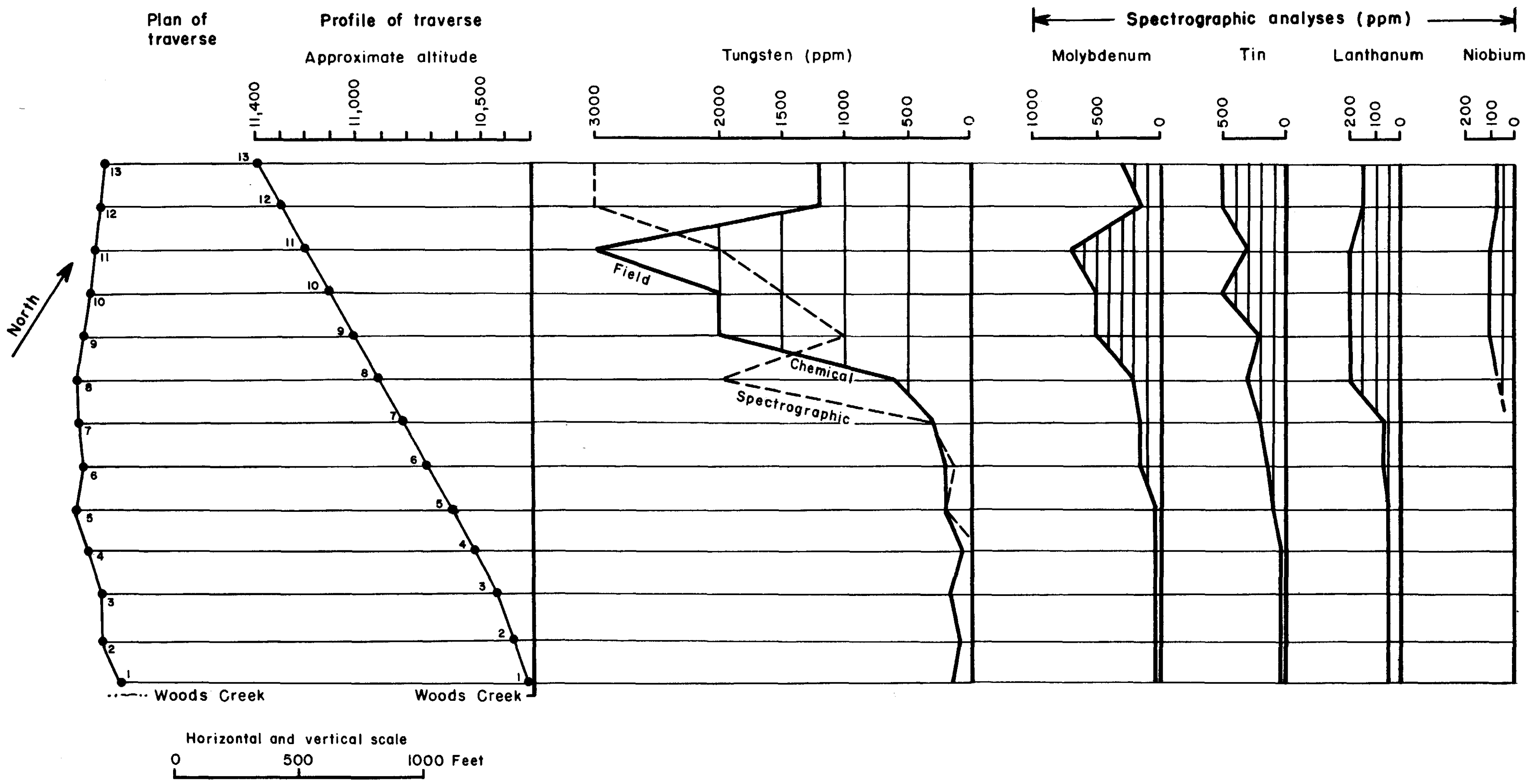

Figure 5.—Plan and profile of a traverse up the southeast slope of Red Mountain, Clear Creek County, Colo., showing analytical data for tungsten and associated elements.

and spectrographic data are available for this part of the traverse (fig. 5). Agreement between the 2 methods is excellent below 500 ppm. Above 1,000 ppm the curves do not agree so well, but there is unanimity in the richness of this part of the traverse; only at locality 8 do the 2 methods disagree as much as 3 reporting steps. Both methods report a six-step, logarithmic breakdown for each order of magnitude (10, 15, 20, 30, 50, 70). The tungsten content of the upper part of the traverse is more than an order of magnitude above that of the lower part, and the tungsten content of the lower part of the traverse is at least an order of magnitude above background. Thus the anomaly is firmly established by both analytical methods.

The tungsten distribution within the samples was determined by splitting each sample into two size fractions—less than 32 mesh but greater than 200 mesh, and less than 200 mesh—and separating the coarser of these into two specific-gravity fractions by means of bromoform (table 2). The bromoform (sp gr 2.9) concentrate is similar to that produced in the gold pan although less dense—the separation in the pan is nearer a specific gravity of 3.5 (Theobald, 1957). The tungsten anomaly is produced by the concentration of huebnerite grains in the size range greater than 200 mesh. Inspection of the concentrates indicates that average grain size of the huebnerite is less than 100 mesh though near that size but that most of the huebnerite grains are attached to or included in quartz fragments whose average size is near 50 mesh. More than 60 percent of the tungsten is in the heavy coarse fraction in most of the samples even though this fraction constitutes less than 10 percent of all the sample and is usually less than 5 percent of the sample.

The contribution of the fine fraction to the total tungsten content of the samples never exceeds 30 ppm and is least in the richest samples. It probably results from very fine-grained huebnerite that is somewhat more concentrated toward the base of the slope. The light coarse fraction varies in its contribution to the total tungsten content from less than 20 ppm along the lower part of the traverse to more than 1,000 ppm at the upper end of the traverse. This relatively constant increase in the proportion of the tungsten in the light fraction is most readily explained by the lack of comminution necessary to release huebnerite from quartz in the upper part of the slope and may be taken as direct evidence of proximity to the source.

Huebnerite was separated by gravity, and by electromagnetic and chemical means, from a composite of the heavy coarse fractions described above. It was not possible to obtain 100 percent purity, but contaminants were limited to about 5 percent, mostly of interlocking quartz grains. Analysis of the concentrate yields an Fe : Fe + Mn ratio of 0.16, indicating huebnerite, the manganese-rich end member of the wolframite series.

Metals Associated with Tungsten

A group of elements with related variation is indicated by examination of spectrographic data from the traverse on the southeast slope of Red Mountain (fig. 5 and table 3). This group includes molybdenum and tin, common associates of wolframite-series minerals in ore deposits, and manganese, a major constituent of huebnerite.

The molybdenum increases upslope from 30 ppm to 700 ppm in a manner almost identical with the tungsten. Unlike the tungsten, the molybdenum is principally found in the 200-mesh fraction of the samples, presumably as finely divided cleavage flakes of molybdenite. The tin is thought to be in cassiterite, which is concentrated with the huebnerite in the heavy coarse fraction of the samples. The huebnerite itself is rich in tin.

DISCUSSION OF METHOD

Analyzing heavy-mineral concentrates from stream gravels is an excellent technique for locating and tracing anomalies of those metals whose ore minerals are of high specific gravity and are resistant to chemical and mechanical attack. The chemical and mineralogic data obtained are valuable in predicting the general characteristics of the deposits sought and the general characteristics and distribution of heavy accessory minerals in the country rocks. The technique is simple, but interpretations must be tempered

Table 2.—Distribution of tungsten among size fractions and specific gravity fractions of samples from a traverse Red Mountain

[Heavy fractions analyzed spectrographically by E. F. Cooley, U. S. Geological Survey, the remaining analyses by chemical method]

Sample site	Bulk tungsten analysis (ppm)	Less than 200 mesh		Greater than 200 mesh[1]				Computed bulk tungsten analysis (ppm)
				Light fraction		Heavy fraction		
		Weight percent	Tungsten (ppm)	Weight percent	Tungsten (ppm)	Weight percent	Tungsten (ppm)	
1 -------	150	81.3	40	17.6	20	1.1	7,000	110
2 -------	80	74.2	20	24.2	40	1.6	5,000	100
3 -------	175	77.3	<20	21.4	60	1.3	5,000	90
4 -------	60	74.0	<20	24.2	80	1.8	5,000	120
5 -------	200	58.1	20	37.6	160	4.3	10,000	500
6 -------	200	90.6	20	6.3	100	3.1	5,000	170
7 -------	300	58.6	40	35.0	600	6.4	10,000	900
8 -------	600	45.8	40	48.3	400	5.9	7,000	600
9 -------	2,000	17.0	40	74.7	600	8.3	>10,000	>1,200
10 -------	2,000	29.5	60	62.0	600	8.5	>10,000	>1,200
11 -------	3,000	24.7	20	66.7	800	8.6	10,000	1,400
12 -------	1,200	18.1	20	71.4	1,600	10.5	>10,000	>2,000

[1] Separation with bromoform at about sp gr 2.9.

Table 3.—Spectrographic analyses of less than 30-mesh material from a traverse on the southeast slope of Red Mountain, Clear Creek County, Colo.

[Analyses in parts per million, by E. F. Cooley and U. Oda, U. S. Geological Survey]

Element	Locality												
	1	2	3	4	5	6	7	8	9	10	11	12	13
W	<100	<100	<100	<100	200	150	300	2,000	1,000	1,500	2,000	3,000	3,000
Mo	30	30	30	30	30	150	150	200	500	500	700	150	300
Sn	20	10	15	10	100	150	200	300	200	500	300	500	500
La	50	50	50	50	50	70	70	200	200	200	200	150	150
Nb	<50	<50	<50	<50	<50	<50	<50	70	100	100	100	70	70
Si	300,000	200,000	300,000	70,000	150,000	200,000	300,000	500,000	500,000	>500,000	>500,000	500,000	500,000
Ti	2,000	1,500	1,500	1,000	1,000	1,500	1,500	3,000	3,000	2,000	3,000	2,000	2,000
Mn	5,000	1,000	1,000	1,000	1,000	1,500	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Mg	5,000	3,000	3,000	2,000	2,000	3,000	3,000	3,000	2,000	2,000	2,000	2,000	1,500
Ni	7	5	7	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cr	20	20	30	10	10	20	20	20	10	10	10	10	10
Ba	500	300	300	200	150	200	200	500	150	150	150	100	70
Sr	50	30	50	30	30	50	30	30	10	10	15	15	<10
Pb	300	150	200	150	200	500	700	3,000	1,000	700	700	700	700
Cu	30	20	50	10	15	50	50	50	50	30	30	20	20
Ag	<1	<1	<1	<1	1	1	1	1.5	1	1	1	1	1

with both geologic and chemical knowledge. The greatest value will be obtained from the data when the work is either performed or carefully evaluated by men experienced in the fields of geology and chemistry.

The anomaly due to huebnerite along the lower part of Clear Creek would probably have been overlooked had not the scheelite been present to enhance the total tungsten content of the samples. However, the huebnerite content of the initial samples is anomalous, and the tungsten content due to huebnerite is equally anomalous above Idaho Springs, and probably throughout the anomaly.

Sampling errors can be great because the technique is based on the appearance of anomalies in detritus; that is, the metal determined by the chemist is present in discrete mineral grains that are richer in the element than the remainder of the grains. The average grain size of the concentrates analyzed is near 80 mesh, so that a few grains more or less of the metal-carrying mineral may make a sizable difference in the analytical result, particularly if the anomaly is of low magnitude. For this reason, interpretations should not be based on single determinations, and critical or questionable samples should be checked by completely new samples. The greatest variation of this type encountered while sampling Clear Creek was on West Fork Clear Creek just above Empire, where the original field analysis, 800 ppm, was reduced to 300 ppm on more careful splitting of the concentrate for analysis in the laboratory. At two other localities analytical results of 150 and 300 ppm in the field were reduced to 40 and less than 20 ppm respectively by more careful sample preparation in the laboratory. None of these affected the rate of progress while following the anomaly, and all were conspicuous erratic values. At the mouth of Woods Creek the combination of high sulfur, molybdenum interference, and possibly a sampling error led to a low field estimate of 400 ppm tungsten. This is the only example of the reverse error, and it did not affect the tracing of the anomaly.

The initial reconnaissance data was repeated by three different groups of people, none of whom were familiar either with gold panning or with the analytical procedure. The variation in these four independent analyses (table 4) is negligible. When the sampling problem is realized, these results are surprisingly uniform.

The unusual assemblages of minerals and elements that are found in heavy-mineral concentrates may require revision of analytical methods. The example of molybdenum's interference with the tungsten determination is but one of many such combinations. This interference was never completely removed from the sample at the mouth of Woods Creek, but it was successfully avoided in the samples above the Urad mill. A combination of interferences prevent successful chemical determination of the tin content of the concentrates.

Table 4.—Replicate tungsten analyses of concentrates obtained by 4 independent groups at 4 localities along the eastern limit of the Front Range, Colo.

Creek	Tungsten content (ppm)			
	Field			Laboratory
	1	2	3	4
Bear	<20	20	<20	40
Clear	200	200	400	300
Coal	<20	<20	20	20
Boulder:				
Stream	>400	>4000	>4000	5000
Terrace	300	300	300	300

The advantages of the technique are the mobility of the field team and the speed with which an anomaly may be traced and the source located. One man can easily carry the equipment and reagents necessary to make over 100 determinations for tungsten. If a geologist and a chemist work as a team, the analyses at no time need be more than one sample behind a collection. Such a team accomplished the initial reconnaissance, traced the anomaly along Clear Creek, isolated the anomaly on Woods Creek, and traced the anomaly to the huebnerite source on Red Mountain in only 5 days.

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