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Review of the use of magnetic concentrates in geochemical exploration

by

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ABSTRACT

Magnetic concentrates recovered readily by hand magnet from alluvial sediments or panned concentrates have been used successfully in exploration as a geochemical sample medium for Cu, Zn, Co, Cr, Mo, Ni, V, Sn, and Be, particularly in arid environments where alluvial sediments may be contaminated by aeolian debris. Opportunity for this use arose recently as chemical and spectrographic techniques were developed to determine the abundances of a variety of trace elements in Fe-rich media. The use of analytical data from magnetic concentrates was introduced as one of several anomaly-enhancement techniques based on heavy minerals and intended to identify blind ore deposits. An extensive literature, reviewed here, on the relation of the chemical composition of the mineral magnetite, a main component of magnetic concentrates, to geologic conditions of origin, facilitates the interpretation of trace-element data in the context of ssociation with ore deposits.

INTRODUCTION

The term "magnetic concentrates" as used here refers to those minerals in panned concentrates that have a magnetic permeability considerably greater than one, a positive magnetic susceptibility, and that are attracted to a permanent magnet. These characteristics permit the magnetic fraction to be separated simply from the less magnetic components of concentrates. Magnetic concentrates are typically employed in exploration for ore deposits as a medium for chemical or spectrographic analysis. Therefore, magnetic concentrates have come into use rather recently as techniques have evolved for the determination of trace amounts of elements in a background of overwhelmingly abundant Fe. Concentrates, however, have a long history of use based on the identification of wanted minerals as well as chemical analyses. This history is examined below for perspectives on the introduction of magnetic concentrates as a sample medium in mineral exploration, for examples of the use of concentrates in various forms, and for access to the literature.

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BACKGROUND

Heavy-mineral concentrates

Various techniques of anomaly enhancement have come to be used in geochemical exploration as a way to detect ore deposits whose surface expression may be subtle. These techniques include physical and chemical means of selective concentration of the wanted elements, of which the oldest and simplest means is the preparation of heavy-mineral concentrates by panning. Minerals with densities greater than about 2.8 have come to be called heavy minerals. This terminology derives from the late 1800's and early 1900's when various solutions, molten salts, and organic fluids of high density were investigated to perfect convenient laboratory procedures to separate small quantities of accessory minerals, whose densities are generally 2.8 or greater, from the large bulk of rock-forming minerals, such as quartz and feldspar, whose densities are 2.7 or less. More than three dozen materials have been recommended for this purpose (Sullivan, 1927) among which the most widely accepted fluids are bromoform (tribrom-methane, $CHBr_3$), which has a density of 2.87 at 20°C, and acetylene tetrabromide (tetrabrom-ethane, $C_2H_2Br_4$), the density of which is 2.96 at 20°C. Methods by which minerals are separated in heavy liquids are described in laboratory manuals for sedimentary petrography (Krumbein and Pettijohn, 1938; Milner, 1952). The method is known as heavy-liquid separation, and the minerals that sink in these liquids are referred to as heavy minerals. The aggregate of heavy minerals resulting from the separation is called a concentrate, a term familiar from older forms of mineral beneficiation.

Panning

Use in the laboratory of heavy-liquid separation was devised as a substitute for common field or mill methods for preparing concentrates. Panning is the most widely used field method for which heavy-liquid separations became a substitute, because panning is awkward as a laboratory technique. Also, panning was thought to be poorly suited for the recovery of minerals having densities between 2.8-5.5. Actually, minerals in this range of density can be recovered well enough for exploration by the panning method (Sigov, 1939; Junner, 1943, 1955; Mertie, 1954; Theobald, 1957; Zantop and Nespereira, 1979), as is shown by extensive and continued use of the pan, in its several variants, for prospecting and gem mining throughout the world (Griffith, 1960; Guiques and Devismes, 1969; Grey, 1976).

Panning is usually applied to samples weighing 5 kg or more, whereas heavy-liquid separations are generally used with samples of a few 100 g or less. Probably the size of samples and the inconvenience of panning, more than the observed recoveries in the range of densities of the ore minerals, have promoted the use of heavy liquids in the laboratory. Where concentrates must be prepared in the field, and an easily cleaned and readily transported instrument for making the concentrate is required, panning is an effective technique. These properties are also characteristic of a mechanical gravity concentrator--the Goldhound 18--used in exploration for scheelite and cassiterite in the Arabian Shield by Riofinex Geological Mission to introduce a greater element of objectivity in mineralometric surveys (Sale, 1983). Taggart (1945) noted that a skilled panner ". . . will make a lower grade of tailing on any ore amenable to gravity concentration than can be made in the most elaborate gravity mill. The concentrate will not, however, be of as high grade as can be made in a mill." Heavy-liquid separations are used in the laboratory on raw concentrates panned in the field if further separation is needed. From these panned concentrates the magnetic concentrates are prepared by the removal of the most magnetic minerals with a hand magnet.

As a technique for concentrating heavy minerals, panning is of great antiquity. Clear descriptions for the separation of cinnabar from sand by panning have survived for 2300 years (Theobald, 1957). Prospecting by the use of hand-picked heavy minerals is even more ancient than panning and is older than recorded history. Pebbles of native copper--heavy minerals, indeed--were sought along with other geologic trade materials such as turquoise and lapis lazuli in southwestern Asia about 10,000 years ago (Wertime, 1973a., 1973b). These old methods of heavy-mineral prospecting are now included among the modern techniques of geochemical exploration (Hawkes, 1957; Hawkes and Webb, 1962; Lyon and Tuddenham, 1959; Erickson and Marranzino, 1960; Overstreet, 1962; Gonzalez, 1967; Brundin, 1969; Beus and Grigorian, 1977, p. 83; Cillik, 1977; Ossenkopf and others, 1979; Callahan, 1980; Kuerzl and Pohl, 1980; Whitlow and D'Agostino, 1980; Atkinson, 1983).

Influence of geomorphic history and climatic regimes

The geomorphic history of the materials contributing heavy minerals to the sampled area should be understood, because in areas having pediment and terrace deposits, inverted topography, glacial drift, and fossil or active dune fields and sand sheets, the original source of the heavy minerals may be a considerable distance from the site of sampling (White and Stromquist, 1970; Hehuwat, 1976; Brondi and others, 1977; McPherson, 1978; Schumm, 1978; Granath, 1983). These heavy minerals are anomalous with respect to the rocks underlying the sample site (White and Stromquist, 1970; Grey, 1976). Hydraulic conditions of the depositional system influence the relative proportions of the species of heavy minerals in various classes of sedimentary materials (clay, silt, sand, and gravel) from a given source rock; hence, samples used for the preparation of concentrates need to be taken with regard to the systematic use of sediments having similar maximum grain size (Inman, 1949; Danilchik and Tahirkheli, 1959; Overstreet and others, 1968; Asad, 1970; Saks, 1976; Adams and others, 1978; Khmeleva and Ivochkina, 1978; Sutherland, 1982).

Climatic regimes, including weathering in the arid environment, bear on the distribution of primary and secondary heavy minerals in concentrates (El Shazly and others, 1977; Butt and Smith, 1980; Lahti and Govett, 1981;

Learned and others, 1981; Ryall and Taylor, 1981). Heavy-mineral surveys were thought to be particularly adapted to humid subtropic and tropic regions where rocks were deeply weathered, because many heavy minerals resist weathering. That opinion is justified (Altmann and Serre-Ratsimandisa, 1970; Hummel and others, 1970; Minas Kuyumjian and Bressan, 1976). However, surveys in other climatic regimes, particularly in the arid subtropics and tropics, alpine deserts, and the arctic, have shown heavy minerals to be a useful geochemical sample medium in all climatic zones, including regions such as the Sahel where present arid regimes are imposed on rocks that were previously deeply weathered under former humid conditions.

The use of heavy minerals in geochemical exploration is usually related to drainage systems, because heavy minerals from a sample of alluvium are derived from rocks in the drainage basin upstream from the sample site, and because heavy minerals from a net of drainage basins give excellent representation of a region, even in arid lands or in areas covered by glacial till (Brown and others, 1967; Brundin and Bergstrom, 1977; Callahan, 1974; Granath, 1978, 1983; duBray, 1981; Woolf, 1983). Other sedimentary materials have also been suitable sources of heavy minerals for exploration. Examples include regolith (Light, 1955), lake-shore deposits (Folinsbee, 1955; Piispanen, 1981), marine beaches and sea-floor sediments (Zenkovich, 1960; Emery and Noakes, 1968; Moore and Silver, 1968; Pisarski, 1968; Hazelhoff-Roelfzema and Tooms, 1969; Keyser, 1972; Reimnitz and Plafker, 1976; Delegation of the Phillipines, 1978; McPherson, 1978; Moore, 1979; Palma, 1979), and desert sand (Griffitts and Alminas, 1968; Gharaibeh, 1969; Grey, 1976; Theobald and others, 1975; Watts, Alminas, and others, 1978a, 1978b, 1978c; Watts, Hassemer, and others, 1978; Hassaan and Al-Hawary, 1979; Mosier and Allcott, 1979). Heavy minerals from unweathered bedrock and from saprolite represent only the source rocks in the immediate area of the sampling site, but successful regional surveys have been based on these materials (Overstreet and others, 1963; Erickson, Mosier, and Viets, 1978; Erickson and others, 1979; Mertie, 1979).

Connection with exploration for placer deposits

Where concentrates are used as a geochemical sample medium, where the survey is based on the identification of mineral species, and where the material processed for the concentrates is eluvium, alluvium, or lake or marine beach deposits, search techniques for lode deposits of the wanted minerals overlap and are an extension of preliminary procedures used in exploration for placer deposits (Raeburn and Milner, 1927; Griffith, 1960). The association of techniques is sufficiently close for much of the technical literature on exploration and evaluation of placers, particularly the early literature which is too vast for summary here, to bear also on the use of heavy minerals as a sample medium in geochemical surveys for lode deposits (Junner, 1943; 1955; Fitch, 1952; Haile, 1954; Guigues and Devismes, 1969; Granath, 1978; Hosking and Rabelink, 1978; Kamel and others, 1980; Dissanayake and Nawaratne, 1981; Piispanen, 1981).

Density of sample net

The density of the sample net depends on the purposes to be served by the survey, the probable size and distribution of ore bodies, lengths of mechanical dispersion trains of ore and indicator minerals, and the scale of the survey. If concentrates are obtained from alluvium, and thus are tied to the drainage net, they can be taken at wider intervals than concentrates from sources such as residual soil, saprolite, or unweathered rock and still give equivalent representation. It has been observed, however, that the same area sampled at different scales yields markedly different distributions of elemental anomalies. In the Sonoran desert of Mexico, Theobald (1983) found that at a map scale of 1:250,000 prominent arrays of anomalies define linear patterns of the regional structural control of hydrothermal systems. When the scale for sampling was expanded to 1:50,000, the anomalies were found to occupy concentric subcircular patterns that define gross zoning of elements in a large hydrothermal system, but at a scale of 1:10,000 or larger, the arrays of anomalies return to a linear pattern and define local structural controls.

In general, heavy-mineral surveys are conducted at map scales of 1:50,000 to 1:500,000, and the areas covered are large. The density of the sample net may range from one sample per 100 sq km for very large areas surveyed at a scale of 1:500,000 (Sigov, 1939) to various densities from one sample per 50 sq km to one sample per 3 sq km for large areas (Zantop and Nespereira, 1979; Hallenstein and others, 1981), to as many as three or more samples per sq km (Freise, 1910). Even with as open a sample net as one in about 75 sq km, results of an early USGS geochemical survey of the Arabian Shield provided basic insights into the geochemical framework of the Shield that have defined suites of elements directly related to mineralization and identified those parts of the distribution of single elements most likely to be related to mineral deposits (Theobald and Thompson, 1983) At a scale of 1:250,000, concentrates taken from alluvium on a net of one sample site per 8 sq km appear to afford a good balance between time and effectiveness in defining major target areas suitable for detailed exploration. If residual soil, saprolite, or unweathered rock is the source of the concentrate, then two to six or more samples per sq km may be needed where the map scale is large (Overstreet and others, 1963; Grey, 1978). Thus, the density of a sample net can be modified to suit the geologic conditions.

Weight of sample

The weight of the original sample from which the concentrate is made is not so important as is a standardized amount of original sample at all sites and a reasonably consistent approach to the grain size of the material to be processed for the concentrate. Samples of alluvium can be smaller than ones from saprolite or unweathered rock because of the tendency toward preconcentration in alluvial sediments. Commonly used weights of alluvium are 2-10 kg (Overstreet and others, 1968; duBray, 1981;

Hallenstein and others, 1981; Sale, 1983; Theobald, 1983; Theobald and Thompson, 1983), but surveys based on saprolite or unweathered rocks generally require 15 kg (Overstreet and others, 1963) and, under conditions of extreme sparsity of heavy accessory minerals in the rock, may require samples weighing as much as 500 kg to yield 20-30g of concentrate (Mertie, 1979).

Where the exploration is for rarely present minerals, native gold for example, particular attention must be paid to the size of the original sample to insure that it gives adequate meaning to the results of the analyses (Fischer and Fisher, 1968; Clifton and others, 1969; Harris, 1982).

EXPLORATION BASED ON THE IDENTIFICATION OF HEAVY MINERALS--MINERALOMETRIC SURVEYS

Systematic use of heavy-mineral surveys for mineral exploration is sometimes said to have begun with the work of D. T. Day (1905a, 1905b, 1907) or with that of Day and R. H. Richards (1906a, 1906b) on the mineralogical composition of concentrates from the Pacific drainage of the United States. Their work is predated, however, by pioneering investigations on the geologic use of heavy minerals in Brazil by Orville A. Derby who, beginning in 1889, demonstrated panning as a way to recover accessory minerals from weathered and unweathered rocks and in relating heavy minerals in stream sediments to their geologic provenance (Derby, 1889, 1891, 1898, 1902). Following Derby in Brazil was Ferdinand Freise (1910) who made a study of 46 varieties of heavy minerals in thousands of concentrates to locate sources of rare metals. About the time of Day and Richards, Derby, and Freise, systematic heavy-mineral surveys were also begun in Africa (Dunstan, 1906; Junner, 1943, 1955), Asia (Dunstan, 1910; Scrivenor, 1911), and Australia (Ball, 1905; Dunstan, 1905).

From World War I through World War II use of the method declined, with the exception of variations on exploration for beach placers, although surveys were continued in Africa (Kitson and Felton, 1930; Besairie, 1933; Junner, 1943, 1955; Conradie and Rabie, 1944), Asia (Shibata and Kimura, 1923; Iimori and others, 1935; Richardson, 1939; Sigov, 1939; Staatz, 1947), Australia and New Zealand (Jack, 1928; Hutton, 1940, 1945), and North America (Waters, 1934; Bullard, 1942; Pardee and Park, 1948). The purpose of these surveys was to discover deposits of gold, diamonds, cassiterite, ilmenite, rutile, zircon, or monazite, or to identify source areas of heavy minerals in stream and beach deposits, but an indicator-mineral concept was also present. As noted by Richardson ". . . knowledge of minerals typically associated with a valuable commodity such as gold or cassiterite facilitates the search for it." In later years the use of indicator minerals in heavy-mineral exploration for diamonds, Au, Sn, and Ti was widely adopted (Creitz and McVay, 1949; Beazley, 1950; Bobriyevich and others, 1971; Frantsesson, 1974; Alekseyevskey and others, 1976; Gocht, 1976; Lampietti and Sutherland, 1978; Bradley, 1979; Yevdokimov and Bagdasarov, 1982).

The era between the World Wars was also a period of development in techniques for the use of heavy minerals in sedimentary petrography and for correlation of rock units (Milner, 1922, 1952; Brammall, 1928; Smithson, 1930; Ewing, 1931; Boswell, 1933; Bramlette, 1934; Evans and others, 1934; Krumbein and Pettijohn, 1938; Carroll, 1941; Kesler, 1944). Applications of mineralogy in alluvial prospecting were also formalized (Raeburn and Milner, 1927).

A new impetus in the use of concentrates for mineral exploration arose after World War II when the search for radioactive deposits stimulated interest in files of earlier-collected concentrates (Junner, 1955). Typical examples of this exploration are to be found in reports from Africa

(Besaire, 1953; Guigues, 1955; Emberger, 1956; Illy and Launey, 1955; Behier, 1958), Asia (Fitch, 1952; Anjaneyulu, 1953; Shen, 1956; Zenkovich, 1960; Schmidt and Asad, 1963; Tan and Yu, 1968; Ahmad and others, 1975; Damodaran, 1976), and North America (Overstreet and others, 1968; Good, 1978; Mertie, 1979). These surveys renewed an interest in heavy minerals as a means of exploration for ore deposits and of improving insights into local or regional inventories of mineral raw materials (Wilford, 1953; Haile, 1954; McCartney and others, 1965; Newberg, 1967; Guigues and Devismes, 1969; Gleeson, 1970; United Nations, 1970, 1971).

The period also was one of rising demand for titanium, zirconium, and the rare-earths with concomitant expansion of exploration for deposits of ilmenite, rutile, monazite, and zircon in marine beach deposits. Understanding of the processes forming these deposits is useful for their relevance to detrital minerals in geochemical samples, but the literature is so vast that any summary here would be deficient. Large lists of appropriate references covering the period to about 1960 can be found in reports on the ores of titanium (Welch, 1959) and monazite (Overstreet, 1967). Later publications included in the literature cited of this report contain extensive references to the subject.

The conceptual basis for the use of heavy minerals in prospecting is that most ore minerals have high densities which permit them to be separated by gravity techniques from waste geologic materials such as rocks, soils, or alluvium. Exploration conducted by means of panned concentrates has evolved from the purely mineralogical examination of concentrates known as mineralometric surveys (Freise, 1910; Waters, 1934; Yoho, 1952; Overstreet and others, 1968; Zantop and Nespereira, 1979; Callahan, 1980; Hallenstein and others, 1981) to the study of the mineralogy, ultra-violet fluorescence, radioactivity, and trace-element chemistry of the concentrate or of some mineralogical fraction thereof (Ahmad and others, 1975; Andac and Mucke, 1975; Gocht, 1976; Kamel and others, 1980; Pan and others, 1980; Stendal, 1980; Oenal, 1981; Atkinson, 1983; Sale, 1983). Even where one mineral is the focus of a mineralometric survey covering very large areas, as the 600,000 sq km searched for diamond pipes in Australia (Atkinson, 1983), and the concentrates are examined for other economic mineral species and are analyzed for trace elements, many hundreds of previously unrecognized mineralized localities may be discovered.

Mineralogical examination of the concentrates can be made in temporary facilities in the field or in central laboratories at permanent facilities distant for the area being surveyed (Besairie, 1933; Behier, 1958; Overstreet and others, 1968; Guigues and Devismes, 1969; Grey, 1976; Sale, 1983). Procedures are simple and well known where the survey is focused on one mineral, such as gold, cassiterite, scheelite, or cinnabar, but methods of identification increase in complexity as the amount of required mineralogical data is enlarged. Highly evolved laboratory procedures have been developed for the examination of concentrates (Parfenoff and others, 1970), but simple methods can also be applied with great advantage (Overstreet and others, 1968; Guigues and Devismes, 1969; Devismes, 1979).

Results of the mineralogical examinations of the concentrates, when quantified, plotted on maps, and interpreted in the context of regional geology and geomorphology, will identify mineralized areas and areas with positive anomalies for indicator minerals of ore deposits. Also defined will be major lithologic units, zones of regional metamorphism, and geochemical provinces (Overstreet and others, 1968; Guigues and Devismes, 1969; Herz and others, 1970; Cillik, 1977; Mosier and Allcott, 1979; Stendal, 1980; Whitlow and D'Agostino, 1980; Hallenstein and others, 1981; Atkinson, 1983; Sale, 1983).

Negative results can also be useful. For example, the absence of particular resistate ore minerals from the concentrates combined with a lack of typical indicator minerals for those ores can be used to lower the priority of the area for further exploration by other methods.

EXPLORATION BASED ON THE CHEMICAL COMPOSITION OF CONCENTRATES

Other forms of analysis of concentrates began in a large way in the 1940's with ultraviolet procedures to detect scheelite and with radiometric determinations to distinguish thorium and uranium (DeMent, 1945; Junner, 1955). Assays for gold and analyses for tin had been in common use long before World War II, but improvements in methods of trace-element analysis and the development of rapid procedures for semiquantitative spectrographic analysis provided the basis for determining a large variety of elements in low concentrations in various geologic materials, among them different types of concentrates.

In mineralometric surveys for lode deposits, the sought minerals, for example native gold, cassiterite, scheelite, or cinnabar, are recognized to have come by mechanical dispersion from primary sources more or less complicated by metamorphic events. This concept was carried over into interpretations of the results of geochemical surveys, and the heavy minerals were regarded as having been derived from primary sources through mechanical dispersions (Beus and Grigorian, 1977, p. 83) without secondary effects of chemical dispersion. Detrital magnetite was observed to absorb ions of Mn, Cu, Pb, and Zn from water (Fujigaki, 1967), and locally the presence of magnetite in stream sediments used as geochemical samples was shown to have an unfavorable effect on the results of geochemical prospecting (Saigusa and Tono, 1976).

The scavenging effect of hydrous Mn-Fe oxides on base and indicator elements in streams was seen to produce false anomalies where the hydroxides were an abundant component of stream sediments (Canney, 1967). These secondary components, particularly when their abundance was enhanced in panned concentrates, were soon identified as powerful media for the interpretation of secondary chemical dispersion (Chao and Theobald, 1976; Nowlan, 1976; Carpenter and others, 1978; Watts, Alminas, and others, 1978a, 1978b, 1978c). Mechanical and chemical procedures were introduced selectively to analyze them (Alminas and Mosier, 1976; Watts, Hassemer, and others, 1978; Filipek and others, 1981; Robinson, 1981).

Chemical analysis of heavy minerals, either as the raw concentrate or as some fraction of the raw concentrate, including hand-picked grains, has rapidly become an accepted procedure in geochemical exploration, especially where stream sediments may be contaminated by aeolian debris (Theobald and Thompson, 1959; Theobald and others, 1967; Boyle, 1968; deGrys, 1970; Neuerburg and others, 1971; Bugrov, 1974; duBray, 1981; Overstreet and others, 1984). Mechanical concentration ratios obtained by panning enhance geochemical anomalies and can bring the abundances of sparsely present elements within the detection limits of the method used for analysis (Goni, 1966; Beus and Grigorian, 1977). Although most heavy minerals in concentrates from areas underlain by igneous and metamorphic rocks originated in those rocks, the geomorphic history can cause major displacement from the sources (White and Stromquist, 1970), or secondary processes can introduce heavy hydrous oxides of manganese and iron enriched in other metals. In a later detrital cycle, magnetite of igneous or metamorphic origin may absorb metal ions from circulating water and by this secondary process become enriched in ore metals not genetically connected with the magnetite (Sullivan, 1907; Fujigaki and others, 1967; Saigusa and Tono, 1976). Insoluble heavy residues from limestone that include heavy minerals of hydrothermal origin have been analyzed for minor elements that are below their respective limits of determination in the rock, which results in the discovery of large blind deposits of Pb and Zn (Erickson and others, 1978).

Raw concentrates

Raw concentrates as obtained from the pan have been a popular geochemical sample medium in many surveys, including ones in the Arabian Shield, because considerable time is saved if further processing of the concentrate is not undertaken. This is probably the most successful concentrate for use where beryllium is the main element sought (Griffitts and Cooley, 1978a, 1978b); but where the objective of the geochemical survey is a broad spectrum of elements, the results are somewhat restricted by the presence of quartz, feldspar, magnetite, and many rock-forming minerals of intermediate density and magnetism.

Nonmagnetic concentrate

The term nonmagnetic concentrate can refer to several products derived from the raw concentrate by further processing. For example, low-density minerals (quartz, feldspar, beryl) can be removed by processing in heavy liquids to yield a cleaned concentrate retaining ferromagnetic minerals (magnetite, chromite, pyrrhotite, some ilmenite) and paramagnetic minerals (biotite, amphiboles, pyroxenes, garnets, and other femic rock-forming species). Removal of the ferromagnetic minerals by hand magnet leaves a concentrate relatively enriched in the rock-forming minerals with densities greater than 2.8, in the secondary iron and manganese oxides including pseudomorphs after pyrite, and sulfide minerals. Extraction of the paramagnetic minerals by use of the Frantz Isodynamic Separator or similar equipment set to divide the concentrate into two fractions, one magnetic at 0.6 amp or less, and the other nonmagnetic at 0.6 amp or more, results in a cleaned nonmagnetic concentrate relatively enriched in monazite, sphene, rutile, thorite, cassiterite, hematite, limonite, pyrochlore, microlite, scheelite, barite, pyrite, molybdenite, and most other sulfide ore minerals (Rosenblum, 1958, fig. 1) that may be present in the source area. By the removal of the low-density minerals, the ferromagnetic minerals, and the paramagnetic minerals which usually constitute 90 percent or more of the concentrate after removal of quartz, feldspar, and ferromagnetic minerals, dilution of the wanted elements in the nonmagnetic concentrate is reduced by an order of magnitude. Background values of the wanted elements are also reduced by an order of magnitude, and interference from iron is greatly reduced, which causes improved ease and precision of analysis (Theobald, 1983, written commun.).

Nonmagnetic concentrates cleaned of quartz, feldspar, and the ferromagnetic minerals tend to display residual enrichment in Fe, Mg, Ca, Ti, Mn, Co, Cu, La, Nb, Pb, Sc, Sn, W, Y, and Zr, as well as depletion in B, Ba, Be, Cr, Ni, Sr, and V, compared with the original raw concentrates from the southern Asir (Overstreet, Assegaff, Jambi, and others, 1983). Other areas with other types of rocks and with pronounced mineralization would yield nonmag- netic concentrates with radically different variations in the abundances of these elements and in their partition between the types of concentrates. The most extreme partition is effected when both ferromagnetic and paramagnetic minerals are removed from the nonmagnetic concentrates.

Partition of the elements is also effected by a single processing stage after panning, such as removal only of the magnetite from the raw concentrate, or removal of the quartz, feldspar, and other low-density minerals. Removal of magnetite most affects the relative concentrations of Cr, Mo, Ni and V. Removal of the low density minerals depletes tenors in B, Ba, Be, and Sr unless high-density mineral containing these elements are present. The removal of the low-density minerals also raises the abundances of Fe, Ti, Mn, Cu, Nb, and Sn in the cleaned concentrate. To raise the abundances of Mg, Ca, Co, La, Pb, Sc, Y, and Zr in the concentrate, removal of both the magnetic and low-density fractions of the raw concentrates is necessary (Overstreet, Assegaff, Jambi, and others, 1983).

Use of highly processed nonmagnetic concentrates commonly defines localized, strongly mineralized areas more precisely than the raw or magnetic concentrates in which anomalous distributions of elements reflect broad areas of mineralization and aureoles in mineralized regions (Miller, 1983).

Common practice followed in recent investigations by the USGS of the regional distribution of mineralized areas and in evaluations of regional potential for ore deposits is to accompany geological and geophysical surveys with chemical and mineralogical analyses of nonmagnetic concentrates cleaned of minerals having low density and from which the ferromagnetic and paramagnetic fractions have been removed. The paramagnetic concentrates are also analyzed, but the ferromagnetic concentrate is considered to have too specialized a use to be analyzed routinely (Watts, Alminas, and others, 1978a, 1978b, 1978c; Watts, Hassemer, and others, 1978; Overstreet and Marsh, 1981; Miller, 1983).

Magnetic concentrates

The specialized-use ferromagnetic concentrates are the geochemical sample medium for which this review has been prepared. It is thought that some problems in exploration, such as the presence of the Pt-group elements, can be avoided, and blind deposits of base and precious metals in the Arabian Shield can be advantageously sought through use of this medium.

Generally, the most common mineral in the ferromagnetic concentrate is magnetite. Intergrowths of magnetite with many other paramagnetic and nonmagnetic minerals will raise the effective magnetic susceptibility enough for the intergrowths to appear in the ferromagnetic concentrates. Inclusions, some of submicroscopic size (Ramdohr, 1962; Garnik, 1979), can be common in magnetite, and their presence, like that of intergrown minerals, affects the results of chemical analyses, commonly toward the identification of anomalous elements. Secondary coatings of limonite and hematite may be present on detrital magnetite, which causes enrichment in coprecipitated elements. When detrital magnetite is lifted by hand magnet from the raw concentrate, various other paramagnetic and nonmagnetic grains may be mechanically trapped among the ferromagnetic grains. These accessory minerals can be largely, although not entirely, removed through several repetitions of the separation by hand magnet. However, no procedure in routine geochemical exploration can entirely free the ferromagnetic concentrate of these accessory minerals, the inclusions, or the intergrown minerals. Other ferromagnetic mineral will also be present; therefore, the ferromagnetic concentrate can seldom be regarded as a monomineralic fraction of magnetite. In recognition of the presence of mixed mineral grains, the ferromagnetic concentrate is usually referred to as a magnetic concentrate.

Simple methods for the recovery of a magnetic concentrate have been used in the field. The detrital magnetic minerals are lifted directly from alluvium with a shielded hand magnet without the panning of a concentrate (Callahan, 1975; Overstreet, 1978).

The use of magnetic concentrates as a geochemical sample medium is supported by many published studies on the characteristic suites of trace elements associated with ore-related or unrelated magnetite and other minerals likely to be present in the magnetic concentrate. Magnetite, pyrrhotite, pyrite, garnet, chromite, ilmenite, hematite, and limonite have received considerable study that has resulted in data that are useful in the evaluation of the trace-element geochemistry of the magnetic concentrate.

Composition

The composition of magnetite (Frietsch, 1970; Bocchi and Fabri, 1975) is of most interest for use in interpreting the results of geochemical surveys based on magnetic concentrates. The relation of its composition to geologic conditions of origin has been discussed by Wilson (1953), Fleischer (1965), Hamil and Nackowski (1971), Oshima (1971), Krylova and Galibin (1977), Hyman and others (1979), Pan and others (1980), Scheka and others (1980), and Swaddle and Oldmann (1980). Discussions of the genesis of individual elements or groups of elements in magnetite from different sources are of interest to explorationists. Some elements identified in magnetite are: gold (Korobynikov and Oleynikov, 1976), gold and platinum metals (Chyi and Crocket, (1976), chromium (Fominykh and Yarosh, 1977; Cawthorn and McCarthy, 1980), manganese and vanadium (Tugarinov and others, 1975; Bird and Klemic, 1976), rare-earth elements (Schock, 1979), tin (Sainsbury and others, 1970), titanium (Bayley, 1923; Fahey and Vlisidis, 1955; Basta and Grigis, 1969; Takahashi, 1976; Davis and others, 1978; Martin and others, 1979), uranium (Berezina and others, 1976; Pan and others, 1980), vanadium (Dunn and Day, 1937; Balsley, 1943; Neybergh and others, 1980), and zinc (Shibuya and Hirowatari, 1980). Magnetite may also be altered during weathering (Overstreet and others, 1963; Gilkes and others, 1979).

Extensive bibliographies on minor elements in pyrrhotite and pyrite were prepared in connection with geochemical investigations of massive sulfide deposits at Wadi Wassat in Saudi Arabia (Overstreet and others, 1978). These would be of use where pyrrhotite is among the ferromagnetic minerals in magnetic concentrates and pyrite, or limonite pseudomorphs after pyrite, are among the nonmagnetic minerals trapped in magnetic concentrates. Weathered cubes of pyrite clearly reflect their genetic connection with hydrothermal ore deposits through high contents of Ba, Co, Cu, Ni, Pb, and Zn in contrast to the low tenors of those element reported for limonite pseudomorphs after pyrite not genetically associated with mineralization (Bell and Hornig, 1970).

The trace-element composition of detrital garnets has been shown to reflect that of the source rocks and to vary in concert with different grades of regional metamorphism. Garnets have been identified as geochemical sinks for the rare-earth elements (Overstreet and others, 1970).

Chromium-rich diopside is one of the long-recognized indicator minerals for possibly diamondiferous kimberlite pipes (Fesq and others, 1976; Grey, 1976). Other long-known relations between the trace-element composition of heavy minerals that may be part of a magnetic concentrate through inherent magnetic character or association and their original sources are reported for ilmenite and rutile (Macdonald, 1971), zircon (Gottfried and others, 1956), native gold (Mertie, 1940; Antweiler and Campbell, 1977), and cassiterite (Meshcheyakov, 1967; Varlamoff, 1969; Kelly and Turneaure, 1970; Jeczmyk, 1971; Steveson and Taylor, 1973). Detrital platinum and inclusions of the Pt-group elements in magnetite and chromite may not show so clear a chemical relation to their source. The ratios of the Pt-group elements are variable in natural lodes (Mertie, 1976).

Variations in the trace-element composition of heavy minerals have long been recognized to affect the magnetic characteristics of the minerals (Murata and others, 1953, p. 300; Richartz, 1961, p. 54-56).

Influence of grain size on composition

When particular species of heavy minerals are handpicked from a concentrate for chemical analysis, as in the use of detrital limonite psedomorphs after pyrite (Bell and Hornig, 1970), some bias in composition may be introduced through the tendency to choose coarse grains because they are easy to separate. Bias in composition may be introduced by sieving. Differences in trace-element composition between coarse and fine grains of the same mineral species in the same concentrate have been noted for magnetite (Pan and others, 1980) and for monzonite (Overstreet and others, 1970).

An outstanding example of this chemical characteristic of detrital grains is the distribution of Pt-group elements in sized fractions of detrital magnetite from a platinum placer deposit at Goodnews Bay, Alaska, USA (Carlson, R. R., 1974, written commun.):

Grain size of detrital magnetite (mm)*	Abundances of Pt-group elements (ppm)				
	Pt	Pd	Rh	Ru	Ir
+1.68	0.07	0.025	0.007	-0.35	0.6
-1.68 +0.71	.45	.02	.008	-0.4	.4
-0.71 +0.35	50	.12	.2	-0.45	1.1
-0.35 +0.177	160	.6	.6	-0.4	2
-0.177+0.088	180	.4	.3	-0.6	3
-0.088	1,100	2	3.5	-1.7	35

*Samples collected in 1966 by J. B. Mertie, Jr., USGS, through the courtesy of Goodnews Bay Mining Company, and analyzed by R. R. Carlson and E. E. Cooley, USGS, in 1974.

An interpretation of these observations is that certain ranges in size for a given detrital mineral are derived from specific source rocks in a drainage underlain by several types of rocks. Knowledge that the composition of a detrital mineral may vary with grain size, and that where hydraulic factors are similar the grain-size distribution of specific minerals in the concentrate tends to vary by source rock, could actually be used to advantage in a geochemical survey. For example, in the Goodnews Bay area the material most strongly biased toward high values for the Pt-group elements is detrital magnetite with a grain size of -0.088 mm. That size fraction of the magnetic concentrate would be the preferred geochemical sample medium in further exploration for the platinum metals.

Interference from secondary minerals

The secondary oxides and hydrous oxides of iron and manganese that are components of stream sediments and concentrates in humid areas are not as common a constituent of alluvial concentrates in arid regions. Nevertheless, they are present and locally may be abundant. In arid regions, secondary carbonates also develop. These secondary minerals tend to form partial or complete coatings on detrital grains, or accumulate as cement that binds several heavy minerals in a cluster or attach fragments of secondary minerals to the heavy grains. Magnetite and other species in the ferromagnetic concentrates may be affected. The notable ability of the oxides and hydrous oxides of iron and manganese to scavenge Co, Ni, Cu, and Zn, and of the carbonates to scavenge Ba, Pb, and Sr, can result in false positive anomalies for these elements as well as identify true positive anomalies that might otherwise be overlooked (Erickson and Marranzino, 1960; Jenne, 1968; Chao and Theobald, 1976; Nowlan, 1976; Pan and others, 1980; Filipek and others, 1981; Robinson, 1981). In some geochemical surveys, advantage has been taken of the scavenging effect of these secondary mineals, and they have been either mechanically concentrated in the nonmagnetic fraction of raw concentrates or selectively extracted chemically to enhance the contrast between background and anomalous values for Ag, Au, Bi, Cu, Mo, W, and Zn in arid regions (Watts, Alminas, and others, 1978a, 1978b, 1978c; Watts, Hassemer, and others, 1978). Because of the generally low percentages of the essentially nonmagnetic secondary iron and manganese oxides and hydroxides in the ferromagnetic concentrates, this medium is the least satisfactory material when those secondary minerals are wanted in the geochemical sample medium. Secondary carbonates are lost in the heavy-liquid separations, except for particles attached to the magnetic heavy minerals; thus, the ferromagnetic concentrate is not a suitable medium where enrichment in these carbonates is wanted.

Secondary, low-temperature, authigenic magnetite is also known (Friedman, 1954), both as well-developed crystals and as earthy crusts. As noted by Chao and Theobald (1976), most of the literature on secondary iron oxides is from studies of soils, and indeed goethite and other iron oxides of secondary origin have been observed in the soils of Arabia (Aba-Husayn and others, 1980; Viani and others, 1983), but the presence of secondary magnetite was not specifically mentioned. Strong desiccation and dehydration in soils and wadi sediments in the arid environment may cause more hydrous oxides to form anhydrous oxides such as magnetite or hematite than has yet been recognized. If the grain size is in the range of the size of magnetite in the magnetic concentrates, identification of secondary authigenic magnetite as a component of the concentrate might be quite difficult. Such secondary authigenic magnetite could be expected to be enriched in base metals and other elements through scavenging, the effect of which could also be the delineation of false anomalies.

SUMMARY

Magnetic concentrates are one of several geochemical sample media exploted in anomaly-enhancement techniques developed for mineral exploration since the decade following World War II. The ferromagnetic fraction of raw concentrates has, however, been found to be less effective in general regional applications than either of the fractions of the raw concentrates magnetic at 0.6 amp or nonmagnetic at 0.6 amp. The ferromagnetic concentrate is a special-purpose medium, the effectiveness of which has not been thoroughly explored. Inasmuch as the principal mineral composing the ferromagnetic concentrate is magnetite, and a large literature reflects investigations of many elements in magnetite from diverse geologic sources, the results of the use of magnetic concentrates in geochemical exploration can be interpreted against a background of chemical mineralogy and classical geochemistry.

The ferromagnetic concentrate may be the most suitable geochemical sample medium for the Pt-group metals where native alloys of these elements are in micron-size particles that defy gravity concentration. In the search for titanium and vanadium in deposits of titaniferous magnetite, the ferromagnetic concentrate appears to be the best geochemical sample medium.

Applications of the ferromagnetic concentrate to the search for blind deposits of base and precious metals using pathfinder elements such as As, Bi, Cd, Hg, Sb, Se, Te, and Ti, in addition to the commonly determined elements Ag, Au, Co, Cu, Mo, Ni, Pb, and Zn have yet to be developed or to be tested against the paramagnetic and nonmagnetic concentrates.

DATA STORAGE

Data-File USGS-DF-04-43 was established for the storage of data used in this report. No entries were made to the Mineral Occurrence Documentation System (MODS) in connection with this report.

REFERENCES CITED

Alminas, H.V., and Mosier, E.L., 1976, Oxalic-acid leaching of rock, soil, and stream-sediment samples as an anomaly-accentuation technique: U.S. Geological Survey Open-file Report D76-466, 14p.

Altmann, J., and Serre-Ratsimandisa, R., 1970, Rare earths of monazites and geology of southern Madagascar, in United Nations, Proceedings of the Second Seminar on Geochemical Prospecting Methods and Techniques (With Special Reference to their Applicability in Tropic Humid Zones): Economic Commission for Asia and the Far East, Mineral Resources Development Series, no. 38, p. 115-126.

Andac, M., and Mucke, A., 1975, Die Paragenese der Schwermineralseifen suedlich von Troja (Westtuerkei) [The paragenesis of heavy-mineral placers south of Troja, western Turkey]: Maden Tetkik Arama Enstitutu [Mineral Resources Exploration Institute of Turkey] Bulletin 85, p. 150-152. [In German]

Anjaneyulu, B.J.N.S.R., 1953, Geology of the coastal strip from Vizagapatam to Pudimadaka with special reference to black sand concentrates: Geological, Mining, and Metallurgical Society of India, Quarterly Journal, v.25, no. 3, p. 89-98.

Antweiler, J.C., and Campbell, W.L., 1977, Application of gold analyses to mineral exploration in the United States: Journal of Geochemical Exploration, v.8, no. 1, p. 17-29.

Asad, S.A., 1970, The significance of hydraulic equivalence in transportation and deposition of heavy minerals in beach sands: Thesis, Department of Geological Sciences, McGill University, Montreal, Quebec, 175p.

Atkinson, W.J. 1983, Drainage sampling programmes for diamond deposits and other minerals in Western Australia: CRA Exploration Pty. Ltd. report presented 1 March 1983 at the Saudi Arabian Deputy Ministry for Mineral Resources Workshop on Geochemical Prospecting held February 26 - March 3, 1983, Jiddah, 1 p.

Bagdady, Abdulaziz, Whitlow, J.W., and Roberts, R.J., 1978, Placer gold deposits in the Mahd Adh Dhahab district, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 78-1074, 38 p.

Ball, L.C., 1905, Gold, platinum, tinstone, and monazite in the beach sands on the South Coast, Queensland: Queensland Geological Survey Publication 198, p. 5-19.

Balsley, J.R., 1943, V-bearing magnetite-ilmenite deposits near Lake Sanford, Essex County, New York: U.S. Geological Survey Bulletin 940D, p. 99-123.

Basta, E.Z., and Girgis, M., 1969, Petrological, mineralogical, and geochemical studies of the magnetite-ilmenite-apatite ore (nelsonite) from Kolmnab, South Eastern desert, U.A.R.: Egyptian Academy of Science Proceedings, v. 22, p. 47-157.

Bayley, W.S., 1923, The occurrence of rutile in titaniferous magnetites of North Carolina and East Tennessee: Economic Geology, v. 18, p. 382-392.

Beazley, A.W., 1950, Part 2, Physical and mineralogical composition, mineral descriptions, and origin of the heavy minerals, part 2 of Heavy mineral beach sands of southern Queensland: Proceedings of the Royal Society of Queensland, v. 61, no. 7, p. 59-104.

Behier, J., 1958, Determination pratique minèraux des concentrès de Madagascar: Malgache Service Gèologique, Documentation du Bureau Gèologique, no. 142, 5 p.

Bell, Henry, and Hornig, C.A., 1970, Use of iron-oxide pseudomorphs after pyrite in geochemical prospecting, in United Nations, Proceedings of the Second Seminar on Geochemical Prospecting Methods and Techniques (With Special Reference to their Applicability in Tropic Humid Zones): Economic Commission for Asia and the Far East, Mineral Resources Development Series, no. 38, p. 127-129.

Berezina, L.A., Berzina, I.G., Berman, I.B., and Chernysheva, L.V., 1976, Uran v magnetitakh iz ul'traosnovnykh-shchelochnykh porod i karabonatitov [Urnanium in magnetites from ultramafic-alkalic rocks and carbonatites]: Akademiya Nauk SSR, Isvestiya, Seriya Geologicheskaya, v. 2, p. 90-97, Moscow. [In Russian].

Berkman, D.A., 1975, Magnetite beach sand deposits of Southeast Papua: Australasian Institute of Mining and Metallurgy, Monograph Series 5, Economic geology of Australia and Papua New Guinea, 1, Metals, p. 1088-1092.

Besairie, Henri, 1933, Étude des alluvions: Bureau d'Études Gèologiques et Minières Coloniales, Comitè d' Etudes Minières pour la France d'Outre-Mer, La Chronique Des Mines Coloniales, v. 2, no. 17, p. 368-379. [In French].

———, 1953, Carte minière et des indices de Madagascar -- Notices explicatives: Madagascar Service Gèologique, Travaux 52, 154 p. [In French].

Beus, A.A., and Grigorian, S.V., 1977, Geochemical exploration methods for mineral deposits: Wilmette, Ill., Applied Publishing Ltd., 287 p.

Bird, M.L., and Klemic, Harry, 1976, Vanadium, manganese, chromium, magnesium, and aluminum in minerals of some magnetite-ilmenite deposits of the eastern Adirondacks: Geological Society of America, Abstracts with Programs, v. 8, no. 2, p. 134-135.

Bobriyevich, O.P., Golovko, M.M., Gritsik, V.V., Gritsik, Y.P., Druzhinin, L.N., Smirnov, G.I., Tarasyuk, O.N., Tarasyuk, L.P., and Yur'yeva, A.L., 1971, Rozshuki korinnikh ta rozsipnikh dzherel almazu na Ukrani z zastosuvannyam piropovoi ziomki [Exploration for source rocks and placerrs of diamonds in the Ukraine using pyrope as a guide]: Geologichniy Zhurnal Akademiya Nauk Ukrainskoy R.S.R., v. 31, no. 6, p. 83-90, Kiev. [In Ukrainian].

Bocchi, G., and Fabri, B., 1975, Applicazione della microanalisi al dosaggio degli elemente nele magnetiti; I, Elementi minori e tracce [Application of microanalysis to determine total elements in magnetites; I, Minor-element and trace-element analyses]: Mineralogica et Petrographica Acta, 20, p. 103-116, Instituto di Mineralogia e Petrografia dell'Universita di Bologna, Bologna, Italy [In Italian; English summary].

Boswell, P.G.H., 1933, On the mineralogy of sedimentary rocks; a series of essays and a bibliography: London, Thomas Murby and Co., 393p.

Boyle, R.W., 1968, Minor and trace element distribution in the heavy minerals of the rivers and streams of the Bathhurst-Jacquet River District, New Brunswick: Canada Geolgical Survey Paper 67-45, 9p.

Bradley, J.P., 1979, Heavy-mineral fingerprinting of gold-bearing gravels: Geological Society of America Abstracts with Programs, v. 11, no. 7, p. 392-393.

Bramlette, M.N., 1934, Heavy mineral studies on correlation of sands at Kettleman Hills, California: Bulletin of the American Association of Petroleum Geologists, v. 18, no. 12, p. 1559-1576.

Brammall, Alfred, 1928, Dartmoor detritals; a study in provenance: Proceedings of the Geologists' Association, v. 39, p. 28-48, London.

Brondi, A., Ferretti, O., and Anselmi, B., 1977, I minerali presenti nell' ambiente litoraneo; I, Ruolo fisiolografico; II, Tipi di placers italiani [Heavy minerals in a coastal environment; I, Physiographic features; II, Types of Italian placers]: Bollettino della Società Geologica Italiana, v. 96, no. 5-6, p. 665-678. [In Italian; English summary].

Brown, D.D., Bennett, G., and George, P.P., 1967, The source of alluvial kimberlite indicator minerals in the James Bay lowland: Ontario Department of Mines, Miscellaneous Paper 7, 35 p.

Brundin, N.H., 1969, Some experiences in heavy mineral prospecting, in Canney, F.C., Bloom, Harold, and Hansuld, J.A., eds., Proceedings of the International Geochemical Exploration Symposium, Golden, Colorado, April 17-20, 1968: Colorado School of Mines Quarterly, v. 64, no. 1, p. 89-94.

Brundin, N.H., and Bergstrom, J., 1977, Regional prospecting for ores based on heavy minerals in glacial till: Journal of Geochemical Exploration, v. 7, no. 1, p. 1-19.

Bugrov, V., 1974, Geochemical sampling techniques in the Eastern Desert of Egypt: Journal of Geochemical Exploration, v. 3, p. 167-175.

Bullard, F.M., 1942, Source of beach sand and river sands on Gulf Coast of Texas: Geological Society of Americal Bulletin, v. 53, no. 7, p. 1021-1044.

Butt, C.M.R., and Smith, R.E., 1980, Conceptual models in exploration geochemistry--Australia: Journal of Geochemical Exploration, v. 12, nos. 2/3, p. 89-365.

Callahan, J.E., 1974, A heavy-mineral based geochemical exploration program: Geological Society of America, Abstracts with Programs, v.6, no. 4, p.338.

_____, 1975, A rapid field method for extracting the magnetic fraction from stream sediments: Journal of Geochemical Exploration, v. 4, no. 2, p. 265-267.

_____, 1980, Heavy minerals in stream sediments from Churchill Falls, Labrador -- an aid in bedrock mapping: Canadian Journal of Earth Science, v. 17, no. 2, p. 244-253.

Canney, F.C., 1967, Hydrous manganeses-iron oxide scavenging -- its effect on stream sediment surveys: Geological Survey of Canada Paper 66-54, p. 267.

Carpenter, R.H., Robinson, G.D., and Hayes, W.B., 1978, Partitioning of manganese, iron, copper, zinc, lead, cobalt, and nickel in black coatings on stream boulders in the vicinity of the Magruder mine, Lincoln Co., Georgia: Journal of Geochemical Exploration, v. 10, p. 75-89.

Carroll, Dorothy, 1941, Heavy residues from some Upper Cretaceous sediments at Gingin, Western Australia: Journal of Sedimentary Petrology, v. 11, no. 2, p. 85-91.

Cawthorn, R.G., and McCarthy, T.S., 1980, Variations in Cr content of magnetite from the upper zone of the Bushveld Complex; evidence for heterogeneity and convection currents in magma chambers: Earth and Planetary Science Letters, v. 46, no. 3, p. 335-343.

Chao, T.T., and Theobald, P.K., Jr., 1976, The significance of secondary iron and manganese oxides in geochemical exploration: Economic Geology, v. 71, p. 1560-1569.

Chyi, L.L., and Crockett, J.H., 1976, Partition of platinum, palladium, iridium, and gold among coexisting minerals from the deep ore zone, Strathcona Mine, Sudbury, Ontario: Economic Geology, v. 71, no. 7, p. 1196-1205.

Cillik, I., 1977, Metodika a vysledky vyhladavania scheelitu v krystaliniku na strednom Slovensku [Methods and results of scheelite exploration in the crystalline rocks of central Slovakia]: Geologický Pruzkum, v. 19, no. 1, p. 9-12. [In Czech; English summary].

Clifton, H.E., Hunter, R.E., Swanson, F.J., and Phillips, R.L., 1969, Sample size and meaningful gold analysis: U.S. Geological Survey Professional Paper 625C, 17p.

Conradie, W.F., and Rabie, L.P., 1944, A petrographic investigation of the heavy residues associated with the alluvial cassiterite from Kuils River, Cape Province (South Africa): Annals of the University of Stellenbosch, v. 22, Section A, p. 105-134.

Cooley, E.F., Curry, K.J., and Carlson, R.R., 1976, Analysis for platinum-group metals and gold by fire-assay emission spectroscopy: Applied Spectroscopy, v. 30, no.1, p. 52-56.

Creitz, E., and McVay, T.N., 1949, Study of opaque minerals in Trail Ridge, Fla., dune sands: Transactions of the American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 181, p. 417-423.

Damodaran, S., 1976, Occurrences of heavy mineral sands in the eastern coastal parts of Kanyakumari and Tirunelveli districts of Tamil Nadu: Workshop on Coastal Sedimentaries of India, Madras; India, March 28-30, 1976, Oil and Natural Gas Commission of India, 25 p.

Danilchik, Walter, and Tahirkheli, R.A. Khan, 1959, An investigation of alluvial sands for uranium and minerals of economic importance; the Indus, Gilgit, Nagar and Hunza rivers, Gilgit Agency, West Pakistan: Pakistan Geological Survey Informaton Release 11, 14 p.

Davis, G.R., Ashworth, K.L., Ayers, P., Gochin, R.J., Thompson, E., and Abdulaziz, M., 1978, Report on chemcial analysis and magnetic separation tests of samples from Jabal Idsas, Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Open-file Report 666, 36p.

Day, D.T., 1905a, Black sands of the placer mines of the United States: U.S. 59th Congress, 1st sess., Senate Document 65, p. 8-15.

_________, 1905b, Second preliminary report on investigation of black sands: U.S. 59th Congress, 1st sess., Senate Document 65, p. 15-24.

_________, 1907, Black sands of the Pacific Coast: Franklin Institute Journal, v. 164, p. 141-153.

Day, D.T., and Richards, R.H., 1906a, Investigation of black sands from placer mines: U.S. Geological Survey Bulletin 285, p. 150-164.

_________, 1906b, Black sands of the Pacific slope: U.S. Geological Survey Mineral Resources of the United States 1905, p. 1175-1246.

de Grys, Ann, 1970, Copper and zinc in alluvial magnetites from central Ecuador: Economic Geology, v.65, no. 6, p. 714-717.

DeMent, J.A., 1945, Ultraviolet light in mineral prospecting: Mining Congress Journal, v. 31, no. 1, p. 23-27, 37, Washington, D.C..

Derby, O.A., 1889, On the occurrence of monazite as an accessory element in rocks: American Journal of Science, ser. 3, v. 37, no. 218, p. 109-113.

_________, 1891, On the separation and study of the heavy accessories of rocks: Proceedings of the Rochester Academy of Science, v. 1, brochure 2, p. 198-206, Rochester, N.Y.

__________, 1898, On the accessory elements of itacolumite, and the secondary enlargement of tourmaline: American Journal of Science, ser. 4, v. 5, no. 27, p. 187-192.

__________, 1902, On the occurrence of monazite in iron ore and graphite: American Journal of Science, ser. 4, v. 13, no. 75, p. 211-212.

Devismes, Pierre, 1979, Atlas photographique de minèraux d'alluvions: Bureau de Recherches Gèologiques et Minières, Mèmoire 95, 208p. [In French].

Dissanayake, C.B., and Nawaratne, S.W., 1981, The occurrence of gold in the gem beds of Sri Lanka: Economic Geology, v. 76, no. 3, p. 733-738.

duBray, E.A., 1981, Evaluation of geochemical sampling media in granitoid terrane of the southern Arabian Shield, Kingdom of Saudi Arabia : U.S. Geological Survey Open-File Report 81-1293, 8 p.

Dunn, J.A., and Dey, A.K., 1937, Vanadium-bearing titaniferous iron ores in Singhbhum and Mayurbhanj State, India: Transactions of the Mining and Geological Institute of India, v. 31, p. 117-194.

Dunstan, B., 1905, Monazite in Queensland: Queensland Geological Survey Publication 196, pt. 4, p. 11-16.

Dunstan, W.R., 1906, Reports on the mineral survey of Southern Nigeria for 1903-1904 and 1904-1905: Great Britain Colonial Office, Colonial Reports, Miscellaneous 33, Southern Nigeria, 33p.

__________, 1910, Report on the results of the mineral survey of Ceylon, 1906-7 and 1907-8: Great Britain Colonial Office, Colonial Reports, Miscellaneous 74, Ceylon, 70p.

El Shazly, E.M., Barakat, N., Eissa, E.A., Emara, H.H., Ali, I.S., Shaltout, S., and Sharaf, F.S., 1977, Geochemical exploration under extremely arid conditions: Journal of Geochemical Exploration, v. 8, p. 305-323.

Emberger, A., 1956 Produits utiles de l'Ankaizina, in Besairie, Henri, 1956, Rapport annuel du Service Gèologique pour 1956: [Madagascar] Direction Mines et Gèologie, Service Gèologique, p. 53-59. [In French].

Emery, K.O., and Noakes, L.C., 1968, Economic placer deposits of the continental shelf, in Hayakawa, Masami, ed., Mineral resources in Asian offshore areas: United Nations, Economic Commission for Asia and the Far East, Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas Technical Bulletin, v.1, p. 95-111.

Erickson, R.L., and Marranzino, A.P., 1960, Geochemical prospecting for copper in the Rocky Range, Beaver County, Utah, in Geological Survey Research 1960: U.S. Geological Survey Professional Paper 400-B, p. B98-B101.

Erickson, R.L., Mosier, E.L., and Viets, J.G., 1978, Generalized geologic and summary geochemical maps of the Rolla 1° x 2° quadrangle, Missouri: U.S. Geological Survey Miscellaneous Field Studies Map MF-1004A, scale 1:250,00.

Erickson, R.L, Mosier, E.L., Viets, J.G., and King, S.C., 1979, Generalized geologic and geochemical maps of the Cambrian Bonneterre Formation, Rolla 1° x 2° quadrangle, Missouri: U.S. Geological Survey Miscellaneous Field Studies Map MF-1004B, scale 1:250,000.

Esguerra, F.B., 1980, Chromite-magnetite bearing beach sand deposit along Kinalablaban, Surigao del Norte, in Geology and mineral resources of Surigao del Norte: Philippine Bureau of Mines and Geo-Sciences, Report of Investigations 102, p. 17-18.

Evans, P., Hayman, R.J., and Majeed, M.A., 1934, The grahpical representation of heavy-mineral analyses: Quarterly Journal of the Geological, Mining, and Metallurgical Society of India, v. 6, no. 2, p. 27-47.

Ewing, C.J.C., 1931, A comparison of the methods of heavy mineral separations: Geological Magazine, v. 68, p. 136-140, London.

Fahey, J., and Vlisidis, A., 1955, Thermometric and petrogenetic significance of titaniferous magnetite: American Journal of Science, v. 253, p. 497-533.

Fesq, H.W., Kable, E.J.D., and Gurney, J.J., 1976, The geochemistry of some selected South African kimberlites and associated heavy minerals: South African National Institute of Metallurgy Report, no. 1703, 33p.

Filipek, L.H., Chao, T.T., and Carpenter, R.H., 1981, Factors affecting the partitioning of Cu, Zn, and Pb in boulder coatings and stream sediments in the vicinity of a polymetallic sulfide deposit: Chemical Geology, v. 33, p. 45-64.

Fischer, R.P., and Fisher, F.S., 1968, Interpreting pan-concentrate analyses of stream sediments in geochemical exploration for gold: U.S. Geological Survey Circular 592, 9p.

Fitch, F.H., 1952, The geology and mineral resources of the neighborhood of Kuantan, Pahang: Malaya Geological Department Memoir, new ser., no. 6, 144p.

Fleischer, Michael, 1965, Composition of magnetite as related to type of occurrence, in Geological Survey Research 1965: U.S. Geological Survey Professional Paper 525-D, p. D82-D84.

Folinsbee, R.E., 1955, Archean monazite in beach concentrates, Yellowknife geologic province, Northwest Territories, Canada: Transactions of the Royal Society of Canada, 3d ser., v. 49, sec. 4, p. 7-24, Ottawa.

Fominykh, V.G., and Yarosh, P.Y., 1977, Chromium in Ural magnetite: Geochemistry International, v. 14, no. 5, p. 50-56.

Frantsesson, Y.V., 1974, Znacheniye melkikh almazov pri poiskakh korennykh mestorozhdeniy [The significance of minute diamonds for the exploration of diamonds in situ]: Razvedka i Okhrana Nedr, no. 3, p. 33-36, Moscow. [In Russian].

Freise, Ferdinand, 1910, Die Monazitvorkommen in Gebiete des oberen Muriahé-und Pombaflusses im Staate Minas Geraes, Brasilien [Monazite occurrences in the district of the upper Muriahé and Pomba Rivers, Minas Gerais State, Brazil]: Zeitschrift fur Berg-, Hutten - und Salinenwesen der preussish Staate, v. 58, B., p. 47-64. [In German].

Friedman, S.A., 1954, Low temperature authigenic magnetite: Economic Geology, v. 49, no. 1, p. 101-102.

Frietsch, Rudyard, 1970, Trace elements in magnetite and hematite mainly from northern Sweden: Sveriges Geologiska Undersokning Arsbok, v. 64, no. 3, ser. C, no. 646, 136p., Stockholm , Sweden.

Fujigaki, Shiyogo, and others, 1967, Adsorption of metal ions (Mn II, Cu II, Pb II, Zn II) on magnetite sand: Industrial Water, no. 108, p. 22-27. [In Japanese].

Gardner, D.E, 1955, Beach-sand heavy-mineral deposits of eastern Australia: Commonwealth of Australia Bureau of Mineral Resources, Geology and Geophysics Bulletin 28, 103p.

Gernik, V.V., 1979, Identification of submicroscopic inclusions in magnetic minerals: Doklady of the Academy of Sciences of the U.S.S.R., Earth Science Sections, v. 245, no. 1-6, p. 190-193. [Translation of Akademiya Nauk SSSR Doklady published by the American Geological Institute, Washington, D.C.].

Gilkes, R.J., Suddhiprakarn, A., and Cooke, G.W., 1979, Magnetite alteration in deeply weathered adamellite: Journal of Soil Science, v. 30, no. 2, p. 357-361, Oxford, England.

Gharaibeh, Riad, 1969, Geochemical exploration of Aqaba granite massif 1968-1969: The Hashemite Kingdom of Jordan, Natural Resources Authority, Mineral Resources Division Report, 33p.

Gleeson, C.F., Heavy mineral studies in the Klondike area, Yukon Territory: Geological Survey of Canada Bulletin 173, 63 p.

Gocht, W.R.A., 1976, Associated heavy minerals in alluvial tin deposits of South-East Asia: International Geological Congress Abstracts, Resumes 25, v.1, sect. 4, Mineral deposits, 4B, Surficial mineral deposits, p. 211-212.

Goni, J., 1966, Contribution à l'étude de la localization et de la distribution des éléments en traces dans les minéraux et les roches granitiques [Contribution to the study of the localization and distribution of trace elements in granitic rocks and minerals]: Bureau de Recherches Géologiques et Minières, Mémoire 45, 68p. [In French].

Gonzalez, Louis, 1967, Heavy-minerals reconnaissance in the Fatimah Formation near Jiddah, Saudi Arabia: U.S. Geological Survey Open-File Report (IR)SA-95.

Good, R.S., 1978, Correlation of stream-sediment mineralogy with geology, central Piedmont of Virginia, in Contributions to Virginia geology-III: Virginia Division of Mineral Resources Publication 7, p. 99-113.

Gottfried, David, Waring, C.L., and Worthing, H.W., 1956, Hafnium content, hafnium to zirconium ratio, and radioactivity of zircon from igneous rocks [abs.]: Geological Society of America Bulletin, v. 67, no. 12, pt. 2, p. 1700.

Granath, Goran, 1978, Heavy minerals from placer deposits in the county of Norrbotten, northern Sweden, and their provenance: Bulletin of the Geological Institutions of the University of Uppsala, new ser., v.7, p. 111-175.

______,1983, Trace elements in magnetites as pathfinders for base-metal deposits in Dalecarlia, Sweden: Bulletin of the Geological Institutions of the University of Uppsala, new ser., v. 9, p. 153-159.

Grey, D.R.C., 1976, The prospecting of the Mopipi area, north central Botswana, and associated Pleistocene studies, volume 1: Botswana Geological Survey Department, Open-file Report, 97p.

Griffith, S.V., 1960, Alluvial prospecting and mining (2d ed.): New York, Pergamon Press, 245p.

Griffitts, W.R., and Alminas, H.V., 1968, Geochemical evidence for possible concealed mineral deposits near the Monticello Box, northern Sierra Cuchillo, Socorro County, New Mexico: U.S. Geological Survey Circular 600, 12p.

Griffitts, W.R., and Cooley, E.F., 1978a, A beryllium-fluorite survey at Aguachile Mountain, Coahuila, Mexico: Journal of Geochemical Exploration, v. 9, no.2/3, p. 137-149.

_______, 1978b, Eolian dilution of silt samples from the Sheeprock Mountains, Tooele County, Utah: Journal of Geochemical Exploration, v.9, no. 2/3, p. 244-247.

Guigues, Jean, 1955, Le champ pegmatitique d'Ampandramaika - Malakialina [The pegamite field of Ampandramaika - Malakialina] in Besairie, Henri, Rapport annuel du Service Gèologique pour 1955 [Annual report of the Geological Service for 1955]: Madagascar Direction des Mines et Gèologie, p. 43-50. [In French].

Guigues, Jean, and Devismes, Pierre, 1969, La prospection minière à la battèe dans le Massif Armoricain [Mineral prospecting by panning in the Armoricain Massif]: Bureau de Recherches Gèologiques et Minières, Mèmoire 71, 171 p. [In French; English summmary].

Haile, N.S., 1954, The geology and mineral resources of the Strap and Sadong valleys, West Sarawak, including the Klingkang Range coal: British Territories in Borneo, Geological Survey Department, Memoir 1, 150p.

Hallenstein, C.P., Pederson, J.L., and Stendal, H., 1981, Exploration for scheeleite in East Greenland - a case study: Journal of Geochemical Exploration, v. 15, no. 1-3, p. 381-392.

Hamil, B.M., and Nackowski, M.P., 1971, Trace-element distribution in accessory magnetite from quartz monzonite intrusives and its relation to sulfide mineralization in the Basin and Range province of Utah and Nevada -- a preliminary report, in Boyle, R.W., ed. Geochemical exploration 1970: Canadian Institute of Mining and Metallurgy Special Volume 2, p. 331-333.

Harris, J.F., 1982, Sampling and analytical requirements for effective use of geochemistry in exploration for gold, in Levinson, A.A., ed., Precious metals in the northern Cordillera: Association of Exploration Geochemists, p. 53-67, Ontario.

Hassaan, M.M., and Al-Hawary, M.A., 1979, Geochemical orientation survey for manganese deposits in arid conditions, Eastern Desert, Egypt, in Watterson, J.R., and Theobald, P.K., eds., Geochemical exploration 1978: Proceedings of the Seventh International Geochemical Exploration Symposium, Golden, Colorado, Association of Exploration Geochemists, p. 93-101.

Hawkes, H.E., 1957, Principles of geochemical prospecting: U.S. Geological Survey Bulletin 1000-F, p. 225-355.

________, 1982, Exploration geochemistry bibliography to January 1981: The Association of Exploration Geochemists Special Volume Number 11, 388p.

Hawkes, H.E., and Webb, J.S., 1962, Geochemistry in mineral exploration: New York, Harper and Row, 415 p.

Hazelhoff - Roelfzema, B.H., and Tooms, J.S., 1969, Dispersion of cassiterite in the marine sediments of Western Mounts Bay, Cornwall: International Tin Council, Second Technical Conference on Tin, Bangkok, v.2, p. 489-516.

Hehuwat, F., 1976, The importance of geologic investigations of Quaternary deposits, in Proceedings of the Twelth Session of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas: United Nations, Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Tokyo, Japan, Aug. 8-22, 1975, Proceedings, E/CN. 11/L. 149, p. 161-164.

Herz, Norman, Vallentine, L.E., and Iberall, E.R., 1970, Rutile and ilmenite placer depostis, Roseland district, Nelson and Amherst Counties, Virginia: U.S. Geological Survey Bulletin 1312-F, 19p.

Hosking, K.F.G., and Rabelink, T.B.A., 1978, Galena-bearing grains from Lenggang stanniferous placers, Belitung, Indonesia, in Yeap, C.H., ed., A collection of papers on the geology of the Asean region: Geological Society of Malaysia Bulletion 10, p. 63-72.

Hummel, C.L., Mello, J.R., de, Sobrinho, M.L., and S. Cerqueiro, N.L., de, 1970, Geochemical prospecting in the Goias Project, central Brazil, through 1969, in United Nations, Proceedings of the Second Seminar on Geochemical Prospecting Methods and Techniques (With Special Reference to their Applicability in Tropic Humid Zones): Economic Commission for Asia and the Far East, Mineral Resources Development Series, no. 38, p. 131-134.

Hutton, C.O., 1940, The titaniferous iron sands of Patea, with an account of the heavy residues in the underlying sedimentary series: New Zealand Journal of Science and Technology, v. 21B, p. 190-205.

______, 1945, Vanadium in the Taranaki titaniferous iron ores: New Zealand Journal of Science and Technology, v. 27B, p. 15-16.

______, 1950, Studies of heavy detrital minerals: Geological Society of America Bulletin, v. 61, p. 635-716.

Hyman, M., Rowe, M.W., and Herndon, J.M., 1979, Magnetite heterogeneity among C1 chondrites: Geochemical Journal, v. 13, no. 1, p. 37-39, Nagoya University, Nagoya, Japan.

Iimori, Satoyasu, Yoshimura, Jun, and Hata, Shin, 1935, The occurrence and distribution of monazite sand along the Rivers Didoko and Seisenko, Korea: Bulletin of the Tokyo Institute of Physical and Chemical Research, v. 14, no. 5, p. 351-360. [In Japanese].

Illy, P., and Launey, P., 1955, Le granite Taourirt d'In Tounine et ses mineralizations [The Taourirt granite of In Tounine and its mineralization]: Algérie Bureau des Recherches Minières, Sciences, et Economique, Bulletin 3, p. 109-127. [In French].

Imbrie, J., and Van Andel, T.H., 1964, Vector analysis of heavy mineral data: Geological Society of America Bulletin, v. 75, no. 11, p. 1131-1155.

Inman, Douglas, 1949, Sorting of sediments in the light of fluid mechanics: Journal of Sedimentary Petrology, v. 19, p. 51-70.

Jack, R.L., 1928, Pigment minerals of South Australia: Geological Survey of South Australia Bulletin, no. 13, 70p.

Jeczmyk, Magdalena, 1971, Cassiterite and other heavy minerals in the alluvium of the Brusznik stream: Kwartalnik Geologiczny, Instytyt Geologicazny, v. 15, no. 3, p. 652-669, Warsaw, Poland.

Jenne, E.A., 1968, Controls on Mn, Fe, Co, Ni, Cu, and Zn concentrations in soils and water: the significant role of hydrous Mn and Fe oxides: Advances in Chemistry Series 73, p. 337-388.

Junner, N.R., 1943, The diamond deposits of the Gold Coast with notes on other diamond deposits in West Africa: Gold Coast Geological Survey Bulletin 12, 52p.

______, 1955, Discussion. The gold pan -- a neglected geological tool: Economic Geology, v. 50, p. 345 - 346.

Kahr, V.P., Overstreet, W.C., Whitlow, J.W., and Ankary, A.O., 1972, Reconnaissance geology of the Jabal Bitran quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report SA(IR)-124, 70p.

Kamal, O.A., Rasmy, A.H., and Bekir, R.K., 1980, Mineralogy of alluvial placer deposits of the central Eastern Desert, Egypt: Proceedings of the International Meetings held on the Occasion of the Fifth Conference on African Geology, October 6-11, 1979, p. 751-768, Cairo.

Kelly, W.C., and Turneaure, F.S., 1970, Mineralogy, paragenesis, and geothermometry of the tin and tungsten deposits of the eastern Andes, Bolivia: Economic Geology, v. 65, no. 6, p. 609-690.

Kesler, T.L, 1944, Correlation of some metamorphic rocks in the central Carolina Piedomont: Geological Society of America Bulletin, v. 55, no. 6, p. 755-782.

Keyser, U., 1972, The occurrence of diamonds along the coast between the Orange River estuary and the Port Nolloth Reserve: South Africa Department of Mines, Geological Survey Bulletin, no. 54, 23p., Pretoria.

Khmeleva, N.V., and Ivochkina, L.G., 1978, Osobennosti transporta chastits tyazhelykh mineralov ruslovym potokom [The transport of heavy mineral particles by river channel flow], in Makkaveyev, N.I., ed., Eksperimental'naya geomorfologiya [Experimental geomorphology]: Eksperimental'naya geomorfologiya, v. 3, p. 74-98. [In Russian].

Kitson, A.E., and Felton, W.J., 1930, Minerals of concentrates from stream-gravels, soils, and crushed rocks of the Gold Coast: Gold Coast Geological Survey Bulletin 6, 50p.

Korobeynikov, A.F., and Oleynikov, B.V., 1976, Zoloto v magnetitakh trappov, granitoidov, i kontaktovo-metasomaticheskikh obrazovaniy Sibiri [Gold in magnetite of trap rocks, granitoids, and contact-metamorphic rocks of Siberia]: Akademiya Nauk SSSR, Isvestia, Seriya Geologicheskaya, v. 1, p. 83-97, Moscow. [In Russian].

Krumbein, W.C., and Pettijohn, F.J., 1938, Manual of sedimentary petrography: New York, Appleton-Century-Crofts, Inc., 549p.

Krylova, M.D., and Galibin, V.A., 1977, Mineral-formation conditions indicated by geochemical features of accessory magnetite: Geochemistry International, v. 14, no. 5, p. 185-192.

Kuerzl, H., and Pohl, W., 1980, Regionale geochemische und Schwermineral-Prospektion [Regional geochemical and heavy-mineral prospecting]: Berg- und Huttenmannische Monatshefte 125, no. 12, p. 593-594. [In German].

Lahti, H.R., and Govett, G.J.S., 1981, Primary and secondary halos in weathered and oxidized rocks - an exploration study from Mykonos, Greece: Journal of Geochemical Exploration, v. 16, no. 1, p. 27-40.

Lampietti, M.J., and Sutherland, D., 1978, Prospecting for diamonds; some current aspects: Mining Magazine, v. 139, no. 2, p. 117-123.

Learned, R.E., Chao, T.T., and Sanzolone, R.F., 1981, The partitioning of copper among selected phases of geologic media of two porphyry copper districts, Puerto Rico: Journal of Geochemical Exploration, v. 15, p. 563-581.

Light, M.A., 1955, Diagnostic heavy minerals in the regolith of Massachusetts: Journal of Sedimentary Petrology, v. 25, no. 3, p. 216-221.

Lyon, R.J.P., and Tuddenham, W.M., 1959, Quantitative mineralogy as a guide in exploration: Mining Engineering, v. 11, no. 12, p. 1-5.

McCartney, W.D., and McLeod, C.R., 1965, Preliminary application of heavy mineral analyses to metallogeny of Carboniferous areas, Nova Scotia and New Brunswick: Canada Geological Survey Paper 64-29, 9p.

Macdonald, E.H., 1971, Detrital heavy mineral deposits in eastern Asia: United Nations, Economic Commission for Asia and the Far East, Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Technical Bulletin, v. 5, Special Volume - Detrital heavy minerals, p. 13-31.

McPherson, R.I., 1978, Geology of the Quaternary ilmenite-bearing coastal deposits at Westport, South Island, New Zealand: New Zealand Geological Survey Bulletin 87, 94 p.

Martin, Conrad, Roberts, R.J., and Stoeser, D.B., 1979, Titaniferous magnetite in the layered intrusive complex at Lakathah, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 79-1210, 36 p.

Mertie, J.B., Jr., 1940, Placer gold in Alaska: Journal of the Washington Academy of Sciences, v. 30, no. 3, p. 93-124.

______, 1954, The gold pan: a neglected geological tool: Economic Geology, v. 49, no. 6, p. 639-651.

______, 1979, Monazite in the granitic rocks of the southeastern Atlantic States -- an example of the use of heavy minerals in geologic exploration: U.S. Geological Survey Professional Paper 1094, 79p.

Meshcheryakov, S.S., 1967, A means of quantitative estimation of trace elements in cassiterite of various genetic types: Zapiski Vsesoyuznogo Mineralogicheskigr Obshchestva, v. 96, no. 4, p. 465-468, Leningrad.

Miller, W.R., 1983, A case history - mineral resources investigation of the Richfield, Utah, 1° x 2° quadrangle: U.S. Geological Survey Saudi Arabian Mission Report presented 1 March 1983 at the Saudi Arabian Deputy Ministry for Mineral Resources Workshop on Geochemical Prospecting held February 26-March 3, 1983, Jiddah, 1p.

Milner, H.B., 1952, Sedimentary petrography: London, Thomas Murby and Co., 666 p.

Minas Kuyumjian, R., and Ronan Bressan, S., 1976, Prospeccao atraves de sedimentos de drenagem em areas de rochas maficas-ultramaficas no Estado de Goias [Prospecting in fluvial sediments in areas with mafic-ultramafic rocks in Goias]: 29.0. Congresso Basileiro doe Geologia, Anais do Congresso, v. 29, no. 3, p. 105-112. [In Portuguese].

Moore, G.W., and Silver, E.A., 1968, Gold distribution on the sea floor off the Klamath Mountains, California: U.S. Geological Survey Circular 605, 9p.

Moore, J.R., 1979, Marine placers; exploration problems and sites for new discoveries, in Scolari, G., ed., Ressources minérales sous-marines, Orléans, France, October 23-37, 1978, Conference, p. 131-163.

Mosier, E.L. and Allcott, G.H., 1979, Geochemical evidence for thorium and associated elements in northern Sonora, Mexico, *in* Watterson, J.R., and Theobald, P.K., eds., Geochemical exploration 1978: Rexdale, Ontario, Association of Exploration Geochemists, p. 129-137.

Murata, K.J., Rose, H.J., Jr., and Carron, M.K., 1953, Systematic variations of rare earths in monazite: Geochimica et Cosmochimica Acta, v. 4, p. 292-300.

Nakagawa, H.M., 1975, Atomic absorption determination of silver, bismuth, cadmium, cobalt, copper, nickel, lead, and zinc in calcium- and iron-rich geologic materials, *in* Ward, F.N., ed., New and refined methods of trace analysis useful in geochemical exploration: U.S. Geological Survey Bulletin 1408, p. 85-96.

Neuerburg, G.J., Botinelly, Theodore, and Kulp, K.E., 1971, Prospecting significance of hypogene iron oxide distribution in the Montezuma district, central Colorado: Transactions of the Society of Mining Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers, v. 250, p. 97-101.

Newberg, D.W., 1967 Geochemcial implications of chrysocolla-bearing alluvial gravels: Economic Geology, v. 62, p. 932-956.

Neybergh, H., Laduron, D., Martin, H., and Verkaeren, J., 1980, The vanadiferous magnetite deposits of the Oursi Region, Upper-Volta: Economic Geology, v. 75, no. 7, p. 1042-1052.

Nowlan, G.A., 1976, Concretionary manganese-iron oxides in streams and their usefulness as a sample medium for geochemical prospecting: Journal of Geochemical Exploration, v. 6, p. 193-210.

Oenal, G., 1981, Die Bewertung von Schwermineralsanden aus der nordwestlichen Turkei [Estimate of the heavy-mineral content of sand in northwestern Turkey]: Erzmetall, v. 34, no. 7-8, p. 411-416. [In German].

Oshima, Osamu, 1971, Compositional variation of magnetite during the eruption and its bearing on the stage of crystallization of magma of Futatsu-dake, Haruna volcano: The Mineralogical Society of Japan, Mineralogical Journal, v. 6, no. 4, p. 249-263, Tokyo.

Ossenkopf, P., Erbe, C., and Zurlo, P., 1979, Methodische Ergebnisse von Schlichprospektionen [Methodical results of concentrate prospecting]: Zeitschrift fur Angewandte Geologie, v. 25, no. 11, p. 522-527. [In German; Russian summary].

Overstreet, W.C., 1962, A review of regional heavy-mineral reconnaissance and its applications in the southeastern Piedmont: Southeastern Geology, v. 3, no. 2, p. 133-173.

________, 1967, The geologic occurrence of monazite: U.S. Geological Survey Professional Paper 530, 327 p.

Overstreet, W.C., Assegaff, A.B., Jambi, M., Hussain, M.A., Selner, G.I., and Matzko, J.J., 1984, Reconnaissance geochemical exploration of the plutons of quartz monzonite and granite in the Jabal Lababa and Ar Rayth areas, southern Asir, Kingdom of Saudi Arabia: Saudi Arabian Deputy Ministry for Mineral Resources Open-File Report USGS-04-38, 132 p.; also, U.S. Geological Survey Open-File Report 85-8.

Overstreet, W.C., Harris, J.L., and Overstreet, E.F., 1970, Minor elements in detrital garnets, North Carolina and South Carolina, U.S.A., in United Nations, Proceedings of the Second Seminar on Geochemical Prospecting Methods and Techniques (With Special Reference to their Applicability in Tropical Humid Zones): Economic Commission for Asia and the Far East, Mineral Resources Development Series, no. 38, p. 136-142.

Overstreet, W.C., Hubert, A.E., Crenshaw, G.L. and Mosier, E.L., 1978, Petrogenic significance of minor elements in pyritic core from the Wadi Wassat massive sulfide deposit, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 78-863, 116 p.

Overstreet, W.C., Lovering, T.G., Rosenblum, Sam, and Day, G.W., 1978, Minor elements in magnetic concentrates from Alaska: U.S. Geological Survey Report USGS-GD-77-827, 596 p., available from U.S. Department of Commerce, National Technical Information Service, Springfield, Va., 22151, as Report PB-276638/AS.

Overstreet, W.C., and Marsh, S.P., 1981, Some concepts and techniques in geochemical exploration, in Skinner, B.J., ed., Seventy-fifth Anniversary Volume: Economic Geology Seventy-fifth Anniversary Volume, p. 775-805.

Overstreet, W.C., Warr, J.J., Jr., and White, A.M., 1970, Influence of grain size on percentages of ThO_2 and U_3O_8 in detrital monazite from North Carolina and South Carolina, in Geological Survey Research 1970: U.S. Geological Survey Professional Paper 700-D, p. D207-D216.

Overstreet, W.C., White, A.M., Whitlow, J.W., Theobald, P.K., Jr., Caldwell, D.W., and Cuppels, N.P., 1968, Fluvial monazite deposits in the southeastern United States: U.S. Geological Survey Professional Paper 568, 85p.

Overstreet, W.C., Yates, R.G., and Griffitts, W.R., 1963, Heavy minerals in the saprolite of the crystalline rocks of the Shelby quadrangle, North Carolina: U.S. Geological Survey Bulletin 1162-F, 31p.

Palma, J.J.C., 1979, Depositos de minerais pesados [Heavy-mineral deposits], in Amaral, C.A.B., ed., Recursos minerais da margem continental brasileira e das areas oceanicas adjacentes., (relatorio final) [Mineral resources of the Brazilian continental margin and adjacent oceanic area; (final report)]: Projecto REMAC (Reconhecimento Global Margem Contintal Brasileira), no. 10, p. 33-50. [In Portuguese; English summary].

Pan, K.-L., Overstreet, W.C., Robinson, Keith, Hubert, A.E., and Crenshaw, G.L., 1980, Equivalent uranium and selected minor elements in magnetic concentrates from the Candle quadrangle, Solomon quadrangle, and elsewhere in Alaska: U.S. Geological Survey Professional Paper 1135, 115p.

Pardee, J.T., and Park, C.F., Jr., 1948, Gold deposits of the southern Piedmont: U.S. Geological Survey Professional Paper 213, 156p.

Parfenoff, Alenandre, Pomerol, Charles, and Tourenq, Josette, 1970, Les mineraux en grains [Minerals in grains]: Paris, Masson et Cie, 578p. [In French].

Peele, Robert, and Church, J.A., 1941, Mining engineers' handbook: New York, John Wiley and Sons, Inc., 3d ed., p. 1-01 to 14-66, plus 63.

Philippines, Delegation of, 1978, Exploration of beach sand in the Philippines, in Proceedings of the Fifteenth Session of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Singapore, October 24-November 6, 1978: United Nations, Economic Commission for Asia and the Far East, Report, p. 223-233.

Piispanen, R., 1981, Heavy mineral compositions of lake placers in northern Finland: Geological Society of Finland Bulletin, v. 53, no. 1, p. 29-45.

Pisarski, J.B., 1968, Regional geochemical reconnaissance of beach sediments from the mouths of principle rivers in the British Solomon Islands Protectorate: United Nations Development Programme, Aerial Geophysical Surveys Project B.S.I.P. 1965-1968, Report.

Raeburn, C., and Milner, H.B., 1927, Alluvial prospecting: Thos. Murby and Sons, 478p., London.

Ramdohr, Paul, 1962, Erzmikroskopische untersuchungen an Magnetiten der Exhalationen im Valley of the 10,000 Smokes [Ore-microscopic investigations of magnetite from exhalations in the Valley of 10,000 Smokes]: Neues Jahrbuch fur Mineralogie Monatshefte, 1962, no. 3/4, p. 49-59. [In German; English summary].

Reimnitz, E., and Plafker, G., 1976, Marine gold placers along the Gulf of Alaska margin: U.S. Geological Survey Bulletin 1415, 14p.

Richardson, J.A., 1939, The geology and mineral resources of the neighborhood of Raub, Pahang, Federated Malay States, with an account of the Raub Australian gold mine: Singapore, Federated Malay States Geological Survey Department, 166p.

Richartz, W., 1961, Uber kristallchemische Untersuchungen und magnetische Aufbereitung von Monazit [On crystal chemical investigations and the magnetic separation of monazite]: Fortschritte der Mineralogie, v. 39, no. 1, p. 53-59, Stuttgart, Federal Republic of Germany. [In German].

Robinson, G.D., 1981, Absorption of Cu, Zn, and Pb near sulfide deposits by hydrous manganese-iron oxide coatings on stream alluvium: Chemical Geology, v. 33, p. 65-79.

Rosenblum, Sam, 1958, Magnetic susceptibilities of minerals in the Frantz isodynamic separator: American Mineralogist, v. 43, p. 170-173.

Ryall, W.R., and Taylor, G.F., 1981, Gossan evaluation manual for use in the Kingdom of Saudi Arabia: Kingdom of Saudi Arabia Deputy Ministry for Mineral Resources, Technical Record RF-TR-01-3, 146p., 36 pl.

Saigusa, M., and Tono, N., 1976 An unfavorabe effect of magnetite in stream sediments on geochemical prospecting: Kozan Chishitsu, v. 26, no. 1, p. 35-42.

Sainsbury, C.L., Hudson, T.L., Kachadoorian, Reuben, and Richards, Thomas, 1970, Geology, mineral deposits, and geochemical and radiometric anomalies, Serpentine Hot Springs area, Seward Peninsula, Alaska: U.S. Geological Survey Bulletin 1312-H, 19p.

Saks, S.Y., 1976, Principle of hydrodynamic equivalence of clastic particles: International Geology Review, American Geological Institute, v. 18, no. 5, p 541-544.

Sale, R.V., 1983, Regional drainage geochemical surveys conducted for tungsten in the southern Asir and north-central Shield, Saudi Arabia - with special reference to the pilot study in progress on the 1:250,000 - scale Halaban sheet: Riofinex Geological Mission Report presented 1 March 1983 at the Saudi Arabian Deputy Ministry for Mineral Resources Workshop on Geochemical Prospecting, held February 26-March 3, 1983, Jiddah, 15p.

Schmidt, R.G., and Asad, S.A., 1963, A reconnaissance survey of radioactive beach sand at Cox's Bazar: Pakistan Geological Survey Interim Geologic Report, IGR-3, 14p.

Schock, H.H., 1979, Distibution of rare-earth and other trace elements in magnetites: Chemical Geology, v. 26, no. 1-2, p. 119-133, Amsterdam, Netherlands.

Schumm, S.A., 1978, Experimental studies of fluvial placers, in, Miall, A.D., ed., Fluvial sedimentology: First International Symposium on Fluvial Sedimentology, Calgary, Alberta, Canada, October 20-22, 1977, Conference publication, 856p.

Scrivenor, J.B., 1911, Federated Malay States Geologist's annual report for the year 1910: Federated Malay States Government Gazette Supplement, p. 1-3, Kuala Lumpur.

Shcheka, S.A., Pyatkov, A.G., Vrzhosek, A.A., Levanshev, G.B., and Okgyabr'skiy, R.A., 1980, Paragenezisy milkroelementov magnetita [The paragenesis of trace elements in magnetite]: Izd. Nauka, 146 p. [In Russian].

Shen, J.T., 1956, Exploration of monazite and associated minerals in the province of Taiwan, China: International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955, Proceedings, v.6, p. 147-151.

Shibata, Yuji, and Kimura, Kenjiro, 1923, Analyses of fergusonite, naegite, and monazite, of Naegi, Mino Province, Part 1 of The chemical investigation of Japanese minerals containing rarer elements: Japanese Journal of Chemistry, Transactions and Abstracts, v. 2, no. 1, p. 1-6.

Shibuya, G., and Hirowatari, F., 1980, Mineralogical properties of Zn and Mn-bearing magnetite from Kawara-Sannotake, Fukuoka Prefecture, West Japan, in Mineralogy of manganese-bearing minerals: The Mineralogical Society of Japan Mineralogical Journal, v. 14, no. 3, p. 12-26. [In Japanese; English summary].

Sigov, A.P., 1939, Prospecing by heavy mineral studies [abstracted by H.E. Hawkes from Ural Scientific Research Institute Geology, Prospecting, and Economic Mineralogy, and Sverdlovsk Mining Institute Transactions, no. 4, 64p.]: U.S. Geological Survey Open-file report, 17p.

Smithson, Frank, 1930, The reliability of frequency-estimations of heavy mineral suites: Geological Magazine, v. 67, p. 134-136, London.

Staatz, M.H., 1947, Iron sand resources of Japan: Supreme Command Allied Powers, Natural Resources Section Report, no. 98, 30p., Tokyo.

Stendal, H., 1980, Distribution of metals and heavy minerals in drainage sediments in late Precambrian rocks of central East Greenland (72-74 degrees N.), in Vokes, F.M., and Reinsbakken, A., eds., Stratabound sulfides in the Caledonian-Applachian orogen, Trondheim, Norway, September 10-12, 1979: Norsk Geologisk Undersoknig Bulletin 57, no. 360, p. 99-111.

Stevenson, B.G., and Taylor, R.G., 1973, Trace element content of some cassiterites from eastern Australia: Proceedings of the Royal Society of Queensland, v. 84, p. 43-54, Brisbane, Queensland.

Stoeser, D.B., and Elliott, J.E., 1979, Post-orogenic peralkaline and calc-alkaline granites and associated mineralization of the Arabian Shield, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 79-1323, 42 p.

Sullivan, J.D., 1927, Heavy liquids for mineralogical analyses: U.S. Bureau of Mines, Technical Paper 381, 26p.

Sutherland, D.G., 1982, The transport and sorting of diamonds by fluvial and marine processes: Economic Geology, v. 77, p. 1613-1620.

Swaddle, T.W., and Oltmann, P., 1980, Kinetics of the magnetite-maghemite-hematite transformation with special reference to hydrothermal systems: Canadian Journal of Chemistry, v. 58, no. 17, p. 1763-1772.

Taggart, A.F., 1945, Handbook of mineral dressing, ores and industrial minerals: New York, John Wiley and Sons, Inc., p. 1-10 to 22-76 plus 47.

Takahashi, I., 1976, Geochemical investigations of titaniferous iron deposits in the Wadi Hayyan and Wadi Qabqab area north of Al Wajh, Kingdom of Saudi Arabia: Saudi Arabian Directorate General of Mineral Resources Technical Record TR-1976-13, 42p.

Tan, L.-P., and Yu, F.-S, 1968, Heavy-mineral reconnaissance for gold and copper deposits of the Chinkuashih area, Taiwan: Acta Geologica Taiwanica, Taiwan National University Science Reports, no. 12, p. 41-57.

Theobald, P.K., Jr., 1957, The gold pan as a quantitative geologic tool: U.S. Geological Survey Bulletin 1071-A, 54p.

________, 1970, Al Kushaymiyah as a target for a Colorado-type molybdenum deposit, southern Najd quadrangle, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report (IR)SA-120, 13 p.

________, 1983, Regional resource evaluation of a part of northern Sonora, Mexico: U.S. Geological Survey Saudi Arabian Mission Report presented 1 March 1983 at the Saudi Arabian Deputy Ministry for Mineral Resources Workshop on Geochemical Prospecting, February 26-March 2, 1983, Jiddah, 5p.

Theobald, P.K., Allcott, G.H., Flanigan, V.J., and Andreasen, G.E., 1975, Tungsten anomalies in the Uyaijah ring structure, Kushaymiyah igneous complex, Kingdom of Saudi Arabia: U.S. Geological Survey Open-File Report 75-657, 86 p.

Theobald, P.K., Jr., Overstreet, W.C., and Thompson, C.E., 1967, Minor elements in alluvial magnetite from the Inner Piedmont Belt, North and South Carolina: U.S. Geological Survey Professional Paper 554-A, 34p.

Theobald, P.K., Jr., and Thompson, C.E., 1959, Geochemical prospecting with heavy-mineral concentrates used to locate a tungsten deposit: U.S. Geological Survey Circular 411, 13p.

________, 1983, Regional wadi-sediment geochemistry in Saudi Arabia prior to 1983 *in* Woolf, D.L., ed., Geochemical workshop, Jiddah, 1402: Kingdom of Saudi Arabia Deputy Ministry for Mineral Resources, Open-file Report DM-OF-03-1, p. C1-C10.

Tugarinov, A.I., Il'in, N.P., and Mokhanti, R., 1975, Fractination of Mn and V between coexisting titanomagnetite and ilmenite and its significance in geothermometry: Geochemistry International, v. 11, no. 4, p. 706-717.

United Nations, 1970, Proceedings of the Second Seminar on Geochemical Prospecting Methods and Techniques (With Special Reference to their Applicability in Tropic Humid Zones): Economic Commission for Asia and the Far East, Mineral Resources Development Series, no. 38, 413p.

______, 1971, Special volume--detrital heavy minerals: Economic Commission for Asia and the Far East, Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas, Technical Bulletin, v. 5, 129p.

Varlamoff, Nicholas, 1969, The bearing of tin minerals and ores in the weathering zone and the possibility of geochemical exploration for tin: Colorado School of Mines Quarterly, v. 64, no. 1, p. 479-495.

Viani, B.E., Al-Mashhady, A.S., and Dixon, J.B., 1983, Mineralogy of Saudi Arabian soils: central alluvial basins: Soil Science Society of America Journal, v. 47, no. 1, p. 149-157.

Waters, A.E., Jr., 1934, Placer concentrates of the Rampart and Hot Springs districts: U.S. Geological Survey Bulletin 844-D, p.227-246.

Watts, K.C., Alminas, H.V., Nishi, J.M., and Crim, W.C., 1978a, Map showing anomalous tungsten and gold distribution in stream sediment concentrates, Hillsboro and San Lorenzo quadrangles exclusive of the Black Range Primitive Area, Sierra and Grant Countries, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-900I, scale 1:48,000.

________, 1978b, Map showing anomalous bismuth ditribution in stream sediment concentrates, Hillsboro and San Lorenzo quadrangles exclusive of the Black Range Primitive Area, Sierra and Grant Countries, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-900K, scale 1:48,000.

________, 1978c, Map showing anomalous lead distribution in stream sediment concentrates, Hillsboro and San Lorenzo quadrangles exclusive of the Black Range Primitive Area, Sierra and Grant Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-900J, scale 1:48,000.

Watts, K.C., Hassemer, J.R., Nishi, J.M., and Siems, D.F., 1978, Anomaly patterns for selected metals in heavy mineral concentrates and oxalic acid residues, Dwyer quadrangle, Grant and Luna Counties, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1027, scale 1:125,000.

Welch, B.K., 1959, The occurrence and paragenesis of the ores of titanium: Thesis, University of Durham, England, v.1, 257p. plus Appendix, v. 2, 211p. plus 59p. bibliography.

Wertime, T.A., 1973a, The beginning of metallurgy: a new look: Science, v. 182, no. 4115, p. 875-887.

______, 1973b, Pyrotechnology: man's industrial uses of fire: American Scientist, v. 61, no. 6, p. 670-681.

White, A.M., and Stromquist, A.A., 1970, Anomalous heavy minerals in the High Rock quadrangle, North Carolina, U.S.A., in United Nations, Proceedings of the Second Seminar on Geochemical Prospecting Methods and Techniques (With Special Reference to their Applicability in Tropical Humid Zones): Economic Commission for Asia and the Far East, Mineral Resources Development Series, no. 38, p. 163-164.

Whitlow, J.W., and D'Agostino, J.P., 1980, Mineral-resource assessment of the Charlotte 2-degrees quadrangle, North Carolina and South Carolina: U.S. Geological Survey Professional Paper 1175, p. 4-5.

Wilford, G.E., 1953, Progress report: British Territories in Borneo, Geological Survey Department, Annual Report 1952, p. 32-34.

Wilson, H.D.B., 1953, Geochemical control of chromium, vanadium, and titaniferous ore deposits: Transactions of the Canadian Institute of Mining and Metallurgy, Mining Society of Nova Scotia, v. 56, p. 9-12.

Woolf, D.L., 1983, Regional geochemical orientation studies of the Central Shield: Paper by Directorate General of Mineral Resources presented 1 March 1983 at the Saudi Arabian Deputy Ministry for Mineral Resources Workshop on Geochemical Prospecting held February 26 - March 3, 1983, Jiddah, 3p.

Yevdokimov, A.N., and Bagdasarov, E.A., 1982, Compositions and typical chemical features of pyrope garnets from kimberlites in the middle and lower Kuonam fields in Yakutia: International Geology Review, v. 24, no. 5, p. 548-558.

Yoho, Herbert, 1952, Provenance study of the heavy minerals in the streams of the gold belt portions of Lumpkin and White Counties, Georgia: Georgia Department of Mines, Mining, and Geology, Geological Survey Bulletin 60, p. 239-244 [1953].

Zantop, H., and Nespereira, J., 1979, Heavy-mineral panning techniques in the exploration for tin and tungsten in northwestern Spain, in Watterson, J.R., and Theobald, P.K., eds., Geochemical exploration 1978: Proceedings of the Seventh International Geochemical Exploration Symposium, Golden, Colorado, Association of Exploration Geochemists, p. 329-336.

Zenkovich, V.P., 1960, Study of the seashores of the Chinese People's Republic [translated by the U.S. Joint Publications Research Service from Izucheniye morskikh beregov KNR: Vestnik Akad. Nauk SSSR, 1959, v. 29, no. 9, p. 76-78]: International Geology Review 1960, v. 2, no. 4, p. 354-356.