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SELECTED RUSSIAN PAPERS ON GEOCHEMICAL PROSPECTING FOR ORES

TRANSLATED BY
V. P. SOKOLOFF AND H. E. HAWKES

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary
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W. E. Wrather, Director

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SELECTED RUSSIAN PAPERS ON GEOCHEMICAL PROSPECTING FOR ORES

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CONTENTS

IELD SPECTROANALYTICAL LABORATORY FOR SERVICING PROSPECTING PARTIES

E. A. Ratsbaum

Translated by V. P. Sokoloff

From Razvedka Nedr, vol. 10, no. 1, pp. 38-41, 1939.

Ratsbaum, E. A., Field spectroanalytical laboratory for servicing prospecting parties: Razvedka Nedr, vol. 10, no. 1, pp. 38-41, 1939. Translated by V. P. Sokoloff.

Ratsbaum, E. A., Polevaia spektroanaliticheskaia laboratoriia dlia obsluzhivaniia poiskovykh partii: Razvedka Nedr, vyp. 10, no. 1, st. 38-41, 1939.

Spectrographic analysis has been applied successfully in the field since 1935. Its economic usefulness and the feasibility of its field application may be regarded as established.

Two types of such laboratories may be mentioned:

(1) Stationary laboratories, in proximity to industrial centers and to sources of electrical power. Such stations may be used for servicing the needs of field parties operating in a large area.

(2) Field laboratories with their own power sources set up for temporary use, frequently in poorly accessible regions.

Organization of a mobile laboratory mounted in a truck is entirely feasible. Field practice of spectrography offers examples of such mobile laboratories. For example, the Khapcheranga laboratory is an example of the first type, and the laboratory on the Turkmenistan range of the second. Absence of suitable spectrographic apparatus so far has been the main obstacle in the development of such laboratories. Examples of such laboratories described in the literature have been equipped with miscellaneous equipment not especially designed for the purpose. At the present time, however, we have a specially designed and tested ultraviolet spectrograph of the universal type (produced by the L.O.M.Z. plant and, in part, by the State Optical Institute), and a field spectrograph of simplified design. Both spectrographs have spectra of the same length (170 mm) and are entirely equivalent in this respect.

The following list of equipment and supplies for field use is intended for a mobile laboratory of the second type. The list can be used also for laboratories of the first type, in which case the "power plant" section may be deleted. This list is based on personal experience with mobile laboratories in the Turkestan Expedition in 1936.

. Equipment and supplies required for field spectrographic laboratory -- Continued

Item No.	Description	Quantity	Remarks
	1. Power plant		
1	Gasoline motor, 6 hp, 220 rpm, of the Kiev plant	1	If bulky samples (more than 100 g) are to be handled, an electric motor is required to operate the roll mill and disc mill. See also items under 4.
2	Generator, d-c or a-c, 110-120 v, 1800-2000 rpm, 2-3 kw, 15-20 amp	1	
3	Ammeter, a-c or d-c, 20-30 amp	1	
4	Voltmeter, d-c or a-c, 150-250 v	2	
5	Rheostat, 6-7 amp, 7-10 ohms	1	
6	Switch, bipolar, 25 amp	1	
7	Cut-out with fuses	2	If an a-c generator is used, all apparatus should be suited for alterating current.
8	Lamps, 40-60 v	3	
9	Gasoline	2 tons	
10	Lubricating oil	0.2 ton	
11	Drive belt	10 m	
12	Bolts, for mounting machine on support	10	
13	Paste, for lubrication of belts	1 kg	
14	Wrenches, assorted	5	
	2. Spectrographic apparatus		
1	Spectrograph, sylvin ultraviolet, stationary, code G.O.I.[1] (see translator's remarks at end of paper), I.S.P.–4; field code G.O.I., I.S.P.–6, of the L.O.M.Z. plant, with a quartz condenser and universal support	1	
2	Riders ("reiterov")	2	
3	Ammeter, 20-30 amp, d-c or a-c	1	Depending on the kind of generator (a-c or d-c)
4	Voltmeter, 150-250 v, d-c or a-c	1	
5	Rheostats, 6-7 amp, 7-10 ohms	6	
6	Switch, bipolar, 25 amp	1	

Equipment and supplies required for field spectrographic laboratory -- Continued

Item No.	Description	Quantity	Remarks
	3. Electrical equipment[2]		
1	"Gupper's"[3] wire, 1½ kw	150 m	
2	Cord, illuminating	50 m	
3	Switches	2	
4	Tape, insulating	0.5 "ko"[4]	
5	Sockets, electrical	3	
6	Tubing, rubber 1 cm diameter	4 m	
7	Electric lamps, 40-60 w	5	
8	Multiple plugs, with branches	2	
9	Insulators, porcelain	50	
10	Kudinov carbons, "Extra," 9-12 mm diameter	2000	
	4. Laboratory equipment		
1	Thermometer, chemical, 100° C	1	
2	Balance, horn	1	
3	Weights, porcelain	1 set	
4	Weights, milligram	1 set	
5	Hot plate	1	
6	Pan, enameled	1	
7	Bucket, galvanized iron	1	
8	Cup, enameled	1	
9	Pans, enameled, for quartering	2	
10	Tablespoon, aluminum	1	
11	Mortar, agate, with pestle	1	Rollers and a disc mill are essential for large samples (more than 100 g). Small samples can be pulverized in a steel mortar.
12	Stands, wooden (test tube) for carbons	4	
13	Watch, pocket, with second hand	1	
14	Lens, preparation, with a table for examination of spectrograms	1	
15	Funnels, enameled	2	
16	Meterstick, steel, portable	1	
17	Diamond, for cutting photoplates	1	
18	Furniture (tables, shelves, stools) built in place		

Equipment and supplies required for field spectrographic laboratory -- Continued

Item No.	Description	Quantity	Remarks
	5. Tools		
1	Hammer	1	
2	Screw drivers, miscellaneous	2	
3	Knives, table	1	
4	Hack saw with blades	1	
5	Plane	1	
6	Hatchet	1	
7	Drill bits, assorted	3	
8	Files,[5] assorted	2	
9	Pincers, assorted	2	
10	Tongs, large	1	
11	Files,[5] assorted	5	
12	Drill, American, hand, with chuck for drilling carbons	1	
13	Vise, medium	1	
14	Drill bits, for 2-mm carbons	20	
15	Scissors	1	
16	Pliers	1	
	6. Reagents		
1	Tin chloride, mono- or tetravalent	0.2 kg	These reagents are required for the determination of Sn, Cr, Ni, Co, Zn, Pb, Bi, Mo, W, and V.
2	Potassium bichromate	0.2 kg	
3	Nickel sulfate	0.2 kg	
4	Cobalt nitrate	0.2 kg	
5	Zinc oxide	0.2 kg	
6	Lead chloride	0.2 kg	
7	Bismuth nitrate	0.2 kg	
8	Ammonium molybdate	0.2 kg	
9	Tungstic acid or potassium tungstate	0.2 kg	
10	Vanadium oxide	0.2 kg	

Equipment and supplies required for field spectrographic laboratory -- Continued

Item No.	Description	Quantity	Remarks
	7. Photographic materials		
1	Film, for the F.E.D.	100 rolls	For the field inst.
2	Photoplates, orthochrome, sensitivity 100 ND or better, diapositive, sensitivity 2, 13x18	20 doz.	For the stationary G.O.I. spectrograph only.
3	Cylinders, graduated, 100-200 cc	2	
4	Desensitizer, "Irsa," N.I.K.F.I.	30	
5	Trays, enameled, 13 x 18 [cm]	6	
6	Hyposulfite	5 "ko"[4]	
7	Sulfite, crystalline, anhydrous	8 "ko"	
8	Paraamidophenol	0.5 "ko"	
9	Hydroquinone	0.5 "ko"	
10	Soda, crystalline, anhydrous	2 "ko"	
11	Potassium bromide	0.1 "ko"	
12	Acetic acid	1 "ko"	
13	Alum, aluminopotassium	0.2 "ko"	
14	Cotton, hygroscopic	0.5 "ko"	
15	Lantern, red, photographic	1	
	8. Additional supplies for spectrographic analysis		
1	Kaiser's [7] tables of principal lines	1	
2	Tables of the arc spectrum of iron	1	
3	Filippov, A.N., "Spectrographic Analysis"	1 book	
4	Reference tables for spectrographic analysis	1 book	
5	A manual of mineralogy	1	
6	Goggles, blue	1	
	9. Other supplies		
1	Nails, assorted	2 "ko" [4]	
2	Hooks, door	1	
3	Padlocks	2	
4	Geologist's kit, field	1	
5	Cloth, black (satin, moleskin)	20 m	
6	Towels	2	
7	Stationery, etc., and notebooks for the analytical log		

Translator's remarks

[1] G.O.I. - State Optical Institute

[2] "Electromaterials"

[3] Could be "Hooper," "Huper," etc. Russian "G" is used in the transliteration of English of German "H"; Russian "U" for "U," "OO," "OU," and some others.

[4] I do not know what dimensions or units "ko" stands for.

[5] "Perka" (item 8) is a file with a semicircular fluted back; "napil'nik" (item 11) is a triangular or flat file.

[6] Could be "Kiser," "Keiser," "Kaizer," etc.

WATER ANALYSIS AS A MEANS OF PROSPECTING FOR METALLIC ORE DEPOSITS

E. A. Sergeev

Translated by H. E. Hawkes

From Razvedka Nedr, vol. 12, no. 2, pp. 51-55, 1946.

Sergeev, E. A., Water analysis as a means of prospecting for metallic ore deposits: Razvedka Nedr, vol. 12, no. 2, pp. 51-55, 1946. Translated by H. E. Hawkes.

Sergeev, E. A., Issledovanie vod kak sredstvo poiskov polimetallicheskikh mestorozhdenii: Razvedka Nedr, vyp. 12, no. 2, st. 51-55, 1946.

Many mineral deposits formed under one set of geologic conditions are in their present environment commonly undergoing oxidation, solution, mechanical disintegration and transport, breakdown of the primary minerals, and migration of the ore metals.

This process, which is primarily one of disintegration, may entail the simultaneous formation of new concentrations of valuable minerals. However, for the vast majority of ores the earth's surface may be regarded as the "field of dispersion" of ore minerals.

The field of dispersion is made up of areas of normal dispersion, local "halos of dispersion" immediately adjoining the mineral deposit, and "trains of dispersion" which develop out of the halos where the weathering products of the ore enter the surface drainage. The movement of material within the field of dispersion is sometimes accompanied by the formation of secondary concentrations of minerals precipitated by mechanical or chemical processes. However, the main trend is towards dispersion rather than concentration.

In recent years, specialized methods of geophysical prospecting have been developed for the location of dispersion halos of mineral deposits.

Alluvial methods of prospecting for certain types of ore are essentially the observation of dispersion trains consisting of heavy, resistant minerals such as cassiterite, wolframite, gold, and platinum.

Unfortunately, this highly effective method can be used only for a relatively small group of minerals. Copper, polymetal, and nickel deposits are not included in this group, and for them no analogous system of exploration exists. There is no fundamental reason, however, why a somewhat similar method could not be developed for the latter metals based on the observation of dispersion trains of soluble material. The geochemical nature of these elements provides a sound basis for such a method. The theory is as follows: vadose water percolating through the zone of saturation comes in contact with the oxidizing mineral deposit and is enriched in the soluble products of weathering. This water is eventually discharged into the open watercourses which drain the area. If the drainage pattern is sufficiently well developed -- that is, if each of its elements coincides with a small drainage basin -- then we may expect to find a detectable concentration of ore metals dissolved in the water. By analyzing stream water, proceeding systematically from the mouth of the stream to the source, we may find the origin of the metal-bearing waters.

Until recently, the tediousness and inadequate sensitivity of the analytical methods have constituted an insuperable obstacle to the development of such a method of exploration.

In 1941 A. A. Reznikov, research hydrochemist of VSEGEI (All-Union Geological Institute), proposed an original method of water analysis for a certain group of heavy metals (Cu, Zn, Cd, Pb, Co). This method is characterized both by high sensitivity and by relative simplicity.

The essence of this method consists of the extraction of the above cations from a large volume of water by a reagent dissolved in a small volume of carbon tetrachloride. Under laboratory conditions the sensitivity is sufficient to detect 1 x 10^{-6} percent heavy metals.

Using this analytical method, the present author in 1941 investigated surface waters in a few areas of polymetallic mineralization. Some of the resulting data as applied to the question under discussion deserve attention. The results of field observations of dispersion trains are described below for two polymetallic deposits of the Altai -- the Zavodin and Berezov deposits.

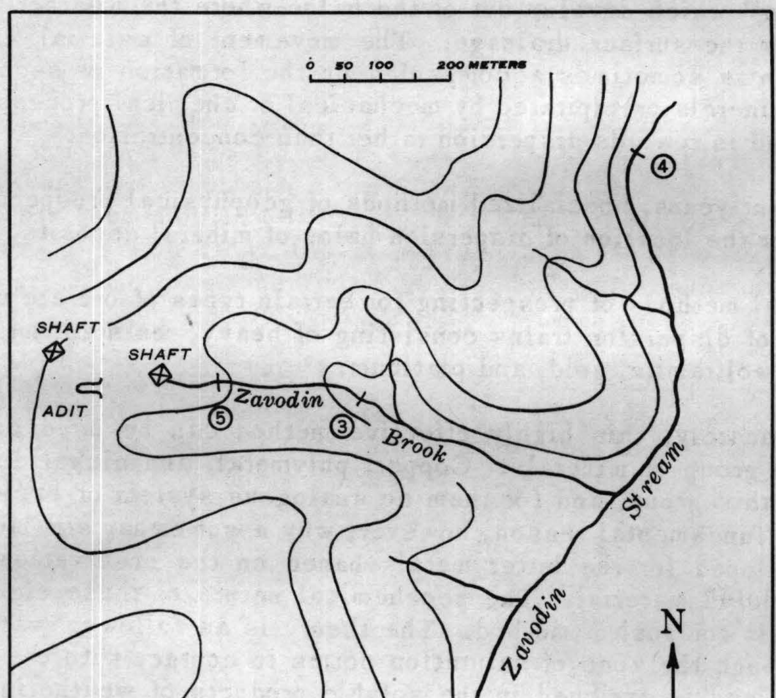


Figure 1. Sketch showing location of anomalies near the Zavodin deposit

At the Zavodin deposit the data are few and may be expressed completely by five points of anomalous metal content in the streams which flow through the area (see table 1).

Table 1

Results of stream water analysis of the Zavodin area

No.	Sample locality	Composition, mg/1		
		pH	Cu	Me [1]
1	Bukhtarma river	7.0-7.2	0.004	>0.02
2	Mouth of Zavodin stream	7.0-7.2	0.002	0.07
3	Brook draining the mine area near its discharge into Zavodin brook	6.8	0.026	1.5
4	Upper part of Zavodin stream	7.0-7.2	0.008	0.03
5	Brook draining the mine area at its source	6.8	0.022	2.85

[1] "Me" indicates heavy metals.

An analysis of the data of table 1 for the significance of the metal concentrations at the sample localities brings to light a definite conformity: the water at the mouth of Zavodin stream is more than three times as rich in heavy metals as the water of the Bukhtarma river. In the middle part of the Zavodin stream, the concentration of heavy metals increases to 70-100 times, and 150-200 times, that at its source. At the same time in the upper part of Zavodin stream the total metal content falls almost to normal (0.03 mg/1). The figures for copper are less spectacular.

Geological interpretation of the above data is unequivocal, as the indications clearly show the source of the metal-bearing water in the area of mining activity. Furthermore, the area is interesting because of the higher metal content of sample 4 found in the main stream.

Somewhat more significant results were obtained in the investigation of the metal content of Berezov stream, which drains a mining district of the same name.

Figures for total metal content of stream waters are presented in table 2. Column 1 of the table shows the sample numbers arranged in the order in which they were collected. Column 2 gives the number of the sample cluster, at most of which three samples were collected: one taken upstream from the mouth of the tributary, one downstream from the tributary, and one at the mouth of the tributary itself, designated by "u," "d," and "t," respectively.

Table 2

Total metal content of Berezov stream water

Sample number	Sample cluster number	Index	Heavy metals mg/1 x 1000
1	1	u	10
2		d	20
3		t	(50)-60
4	2	u	50-60
5		d	50-60
6		t	10
7	3	u	60
8		d	60
9		t	10
10	4	u	100-110
11		d	80-(90)
12		t	30-40
13	5	u	110
14		d	80
15		t	30
16	6	u	130
17		d	120
18		t	50
20	7	d	160
21		t	110
22	8	u	20
25		t	1290
26	9	u	30
27		d	20
28		t	30-40
29	10	d	20
30		t	20-30
31	11	u	20
32		t	10
33	12	u	20
34		t	80

The first cluster (the discharge of Berezov brook into Krasnoyark stream) shows a minimum concentration of metal in the Krasnoyark stream above the mouth of Berezov brook (sample no. 1). Further, we observe a sharp increase in the metal content of the water of the main stream below the junction of Berezov brook (sample no. 2). This jump in metal content is the effect of the admixture of salts from the waters of Berezov brook, which contains more than five times the minimum metal concentration (sample no. 3).

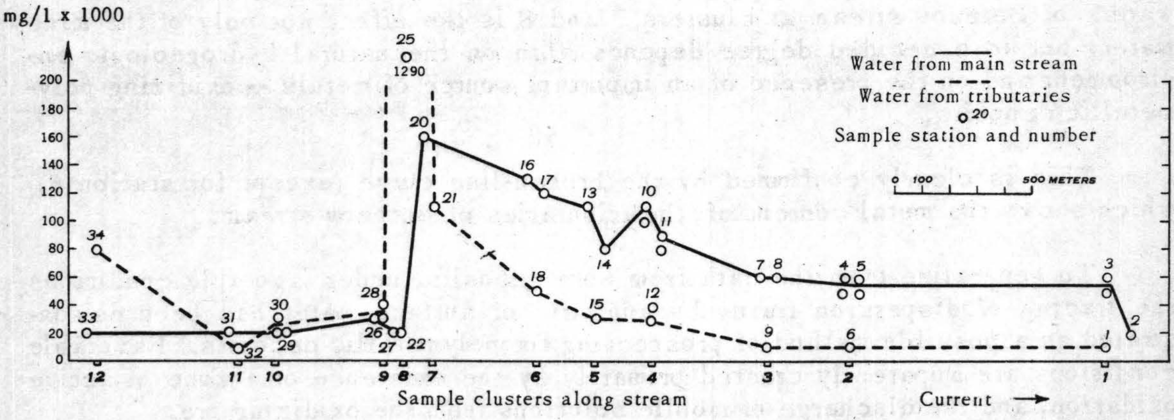


Figure 2. Graph of variations of total heavy metal content in Berezov Brook

Other variations in the concentration of metals along the brook are shown in figure 2. In the graph in figure 2, concentration in mg/1 x 1000 is plotted on the ordinate axis, and distance of a scale of 1:10,000 measured from a point in the upper part of the brook is plotted on the abscissa. The solid line shows the metal concentration in the water of Berezov stream, and the broken line shows the metal content of the tributaries. The maximum concentration observed in clusters 7, 8, 9 coincides with the location of the mineralization.

A more detailed analysis of the data leads to the following conclusions:

Cluster no. 8 is at the mouth of a tributary fed in part by shaft water, which contains 1290 mg/1 metals. This causes an increment in the metal content of Berezov stream at this place, which gradually diminishes towards its mouth.

The solid-line curve shows apparently that it does not have great value for prospecting purposes, and attention should be focused on the broken-line curve for a further appraisal of the situation. Actually, clusters 12, 10, 9, 7, 6, 5, 4, where the tributaries contain no mine water, all have a significantly high metal content. These streams are for the most part of small size (some tens of meters long), and come from springs presumably fed by artesian water.

The interrelation of soil water and artesian water has been established by hydrogeological surveys of the region.

From this it follows that cessation of pumping of mine water will cause more artesian water to be discharged into the tributaries, or in other words more soluble weathering products will be contributed to Berezov stream.

We may conclude that the presence of a maximum metal content in the waters of Berezov stream at clusters 7 and 8 is the effect not only of the mine water, but to a decided degree depends also on the natural hydrogeologic environment and on the presence of an important source of metals -- oxidizing polymetallic deposits.

This is clearly confirmed by the broken-line curve (except for station 8), which shows the metal content of the tributaries of Berezov stream.

To generalize from the data from both deposits, under favorable conditions the tracing of dispersion trains by analysis of surface water has been demonstrated as a possible method of prospecting for polymetallic deposits. Favorable conditions are apparently created primarily by the existence of a zone of active oxidation, and the discharge of mobile solutions from the oxidizing ore.

Dissected topography and a well-developed drainage pattern appear to be essential, as well as a hydrogeologic environment where the artesian water is fed by soil water.

The proposed method of prospecting should take its place in our geological survey work alongside of alluvial prospecting. This experiment shows the need for further investigation of techniques, and also methods of field analysis.

A NEW LUMINOSCOPE FOR FIELD USE

E. A. Sergeev

Translated by V. P. Sokoloff

From Razvedka Nedr, vol. 12, no. 5, pp. 41-42, 1946.

Sergeev, E. A., A new luminoscope for field use: Razvedka Nedr, vol. 12, no. 5, pp. 41-42, 1946. Translated by V. P. Sokoloff.

Sergeev, E. A., Novyi polevoi luminoskop: Razvedka Nedr, vyp. 12, no. 5, st. 41-42, 1946.

A new luminoscope for field use was constructed at the All-Union Institute for Geophysical Exploration (V.I.R.G.), for locating sources of the rare metals by their dispersion halos.

The apparatus makes it possible to examine unconsolidated materials in situ, directly in the field. The luminoscope (see figure) consists of a cylindrical jacket, 1, covered with a lid, 2. The junction between the lid and the jacket is movable but is impervious to light. Illuminator, 3, and "viewer," 4, are fastened rigidly to the lid. In the field the luminoscope is placed directly on an area of residual soil stripped of humus.

A small spot of the ground (about 40 mm in diameter), covered by the jacket, is exposed to ultraviolet light. The optical system allows a fourfold magnification of the irradiated spot. The objective may be adjusted to give a 25-fold magnification. The movable junction between the jacket and the lid permits free shifting of the beam and an examination of the entire area covered by the jacket (about 3 sq. decimeters).

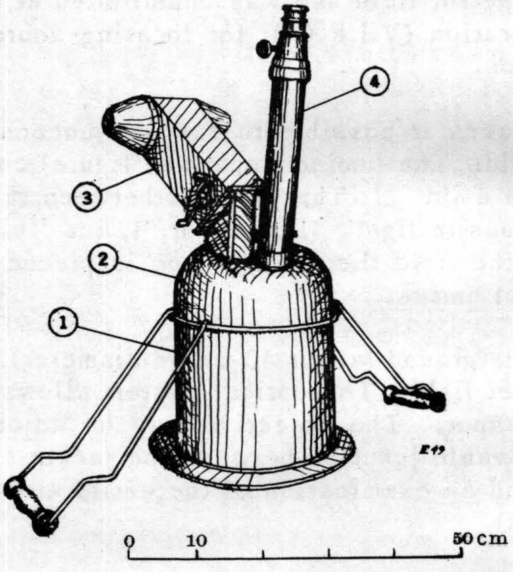
A quartz-mercury lamp, the high-pressure model PRK-4, is used as a source of ultraviolet light. The illuminating mechanism is changeable: in one case, it consists of a quartz monochromator with a wide slit; in another, the common type of illuminator is used, with an ultraviolet light filter and a quartz condenser. The illustration shows the quartz monochromator type. Each illuminator is intended for the corresponding group of minerals luminescent either in the long-wave or in the short-wave part of the ultraviolet. The luminoscope weighs 7 kg. and has a height of about 70 cm.

The lamp is fed by means of a hand-operated alternator mounted on a tripod. The PRK-4 lamp uses 3 to 4 watts. The weight of the entire rig is about 25 kg. It should be possible to reduce this weight roughly to one half the present weight by modifying the construction.

The second variety of the illuminator is fed by 12-volt batteries through a vibration oscillator. Power fed to the lamp and weight of the rig are the same as for the hand-operated alternator.

Laboratory studies indicated that the luminescence of a large number of minerals can be observed in this manner and that these minerals are detectable in small amounts. For example, the presence of less than 0.05 percent of scheelite is definitely demonstrable in fragmented rock materials.

The apparatus is being tested in the field.



Sketch of luminoscope from original photograph

GEOCHEMICAL METHOD OF PROSPECTING FOR ORE DEPOSITS

By E. A. Sergeev

Translated from Russian by V. P. Sokoloff

From Materials of the Soviet Union Geological Institute, Geophysics, Fascicle 9-10, pp. 3-55, 1941.

CONTENTS

CONTENTS --Continued.

Sergeev, E. A., Senior Scientific Associate, Geochemical method of prospecting for ore deposits: Materials of the Soviet Union Geological Institute, Geophysics, Fascicle 9-10, pp. 3-55, 1941. Translated by V. P. Sokoloff.

Sergeev, E. A., St. Nauchnyi sotrudnik,[1] * Fiziko-khimicheskii metod[2] poiskov rudnykh zalezhei: Materialy Vsesoiuznogo Nauchno-Issledovalel'skogo Geologicheskogo Instituta, Geofizika, sbornik 9-10, st. 3-55, 1941.

TRANSLATOR'S FOREWORD

Because of the idiomatic phraseology of the original article, together with the abundance of rather inadequately defined new concepts, it has been difficult to render a translation that is both accurate and clear. The translator's aim throughout was to translate meaning rather than words, and wherever possible idiom for idiom. This approach has led occasionally to reconstruction of sentences, changes in tense and mood of verbs, substitutions, expansion or contraction, and various other expedients. Most of these apparent departures are noted and commented upon in Translator's Remarks at the end of the translation. Transliteration of Russian characters follows the convention of the Library of Congress, except for the omission of diacritical marks.

The translation has been edited and checked with the original by H. E. Hawkes. Elizabeth L. Zimmerman assisted in preparation of the diagrams.

V. P. Sokoloff

INTRODUCTION

The present article is an attempt at a systematic discussion of the principles of a new prospecting method. The method originated recently within the geophysical group of V.S.E.G.E.I.[3] (formerly Ts.N.I.G.R.I.[4]), and is still in the process of development.[5]

An increasing number of prospecting organizations employing geochemical methods and a complete absence of any manuals on the subject are the principal reasons for publication of this discussion. The necessity for a critical appraisal of the method, moreover, has become sufficiently manifest by this time, as a guide in further development of the method and for its application in industry.

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* Numbered footnotes refer to Translator's Remarks at the end of the translation.

Our problem proved to be more difficult than anticipated, as may be seen from the following considerations:

The method was developed chiefly for the sake of practical problems of the moment. Evolution of individual components of the method was devoid at times of any rational foundation. Such deficiencies could not be compensated easily without special studies the organization of which would have been extremely difficult. Thus certain very important problems can be presented here only schematically. This is the case specially in the chapter dealing with applications of the method to prospecting in the field. In the majority of the field reports, the geologic background of the geochemical method is insufficiently developed, and details of the investigational work are understood and presented[6] entirely inadequately.

Despite the consequent defects of the work, the author hopes that the attempt at generalization here offered to the reader may be of some practical use and may serve as a certain basis of further development of the theory of the geochemical method. The author acknowledges gratefully the valuable aid of L. D. Bersudskii, Engineer-Geologist, and especially of S. D. Miller, Engineer.

I. Origin of the Method

Prospecting for new ore bodies in areas of already known mineralization is highly important in the development of mineral resources. Concrete prospecting indications of the mineral in question must be established in the very first stage of the reconnaissance. Examination of outcrops, among other things, is regarded as the most reliable prospecting method. However, in areas where recent formations blanket the rock, rather expensive operations may be required in order to locate the ore.[7] Development of prospecting geophysics, a specialized field of general prospecting and reconnaissance, has been a major attainment.[8] Geophysical methods afford a basis for our judgment regarding the nature of the physical fields of objects concealed by intervening materials from our direct observation. These methods proved to be decisive in prospecting for certain specific kinds of minerals (oil) and contain every promise of further growth and expansion. Nevertheless, outcrops of ore continue to remain the most reliable prospecting guide. On close examination, this fact may be appreciated in full. A certain fundamental deficiency of the entire group of prospecting methods may become apparent also by the following considerations:[9]

The whole complex of prospecting indications based on geologic premises and on geophysical data belongs, with rare exceptions, to a kind of indirect or circumstantial evidence, the unique interpretation of which has, at best, a varying degree of probability. Application of more than one geophysical method to one and the same prospecting problem is explained, in part, by the above considerations. Under favorable conditions, indirect indications of several different kinds tend to increase the probability of unique interpretations. The same reasons help to explain the constant tendency of workers in the prospecting-geologic service to be on the lookout for new procedures whereby direct indications of an ore body may be obtained. Hence the development of relatively unusual prospecting methods. For example, for elements associated with heavy and weathering-resistant minerals (cassiterite, wolframite, chromite, gold, platinum, etc.), alluvial methods of prospecting have been in use.* Simple elutriation or washing or a fairly detailed mineralogic analysis of surficial deposits was employed in the course of the reconnaissance. It was possible, with the analytical data for a guide, gradually to come nearer the placer deposit or the primary ore body. Fairly recently, in the United States (White, 1922)[11] a new method of prospecting for copper was proposed which came to be known as the cuprometric survey. The survey consists of a macroscopic (or a blow-pipe) examination of rock in place and of detritus[12] in the area of prospecting. Areas of intense mineralization are shown by copper isograds,[13] against a general background of disseminated mineralization. This method was applied, in the USSR, at Kounrad.

It can be easily seen that the basis of these and of certain other methods is relatively simple: detection of indications of mineralization in surficial materials and a subsequent localization of the ore body.

Economic and technical possibilities of this group of known methods are rather limited. These methods are unable to meet the standards of prospecting geophysics. For example, the best technically developed method in question is limited to the group of heavy and stable minerals, is limited moreover by a certain minimum size of the grains, permitting identification of the minerals. In other words, the method is not universal.

Interest in a uniform and a widely applicable method of establishing, by direct evidence, the presence of mineralization became especially acute in the practice of prospecting geophysics in the course of its relatively recent industrial development.

An immediate cause of this interest was in the difficulties faced by geophysics in certain prospecting problems (tin, polymetallic deposits) and, correspondingly, occasionally unfavorable results of the geophysical methods. The problem of establishing the cause of the anomalies (owing to the ore or to some other properties of the area) by methods less expensive than drilling[14] persistently presented itself in the field practice. Beginning in 1932, the problem of the economic significance[15] of geophysical anomalies demanded the attention of geophysicists. In 1932, V. A. Sokolov proposed the gasometric method of prospecting for deposits of oil. At about the same time, a group within Ts.N.I.G.R.I.

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* In USSR first applied in 1927 by the former geological committee.[10]

proposed the ionic method, in prospecting for sulfide deposits, as well as certain other methods (32), (33).[*] These procedures, having been tested in the laboratory and in the field, are now beginning to be recognized by industry. Methods developed to suit specific problems, differing only in the choice of the indicators, are acquiring specific designations. At the present time they may be considered in a single category, namely, geochemical methods.[16]

II. Dispersion [17]

Upper horizons of the lithosphere, accessible to direct observation where they crop out at the surface, constitute, as we know, a zone not exceeding 15 to 20 kilometers in thickness. This zone is composed, to the extent of 95 percent, of acid granite-diorite silicate rock. The average chemical composition of this part[18] of the earth's crust is expressed by the well-known numbers of Clarke. The Clarke numbers for the economically important metals are shown in table 1, column 1. Column 2 contains examples of the orders of magnitude of concentrations of such metals in economically valuable deposits. Column 3 shows the ratio of these two magnitudes. The ratio shown indicates roughly the extent of concentration of the valuable metals in economic deposits, with reference to the metal content of the country rock. In cases where the country rock is sedimentary, the ratios tend to be as a rule higher than the ones shown in the table. Moreover, for tin, tungsten, molybdenum, and a number of other elements not detected in the rock,[†] by Clarke's analytical procedures, the ratios are likewise higher than shown in the table. The ratios for these latter elements shown in the table were calculated on the basis of the known world reserves of the element in question.

Striking differences between the average amounts of the metals in the earth's crust and the amounts found locally as economic deposits are not due to accidents but are expressions of the characteristic behavior of the substance in the cyclic development of the earth's crust.

The cyclic nature of the geologic processes, as we know, is one of the guiding principles of modern geology. Vernadskii (3) regards the development of the earth's crust as characterized by a closed cycle of matter, that is, by the cyclic migration of substance within the confines of more than one geosphere.[‡]

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[*] Figures in parenthesis refer to literature cited under bibliography.

[†] Presence of determinable amounts of these elements in the rock may be considered as an established fact, in our time.

[‡] The incomplete reversibility of the cycle determines the forward development of the crust. As a certain proportion of the substance falls out of the cycle, fresh mineral masses are drawn into the same cycle.

Table 1.[19] Concentration of elements in their economic deposits in relation to their concentrations in the earth's crust:[20]

Element	K (percent in earth's crust, according to Clarke)	P_n (percent in economic deposits)	P:K
Aluminum	8.080	10x*	< 10
Iron	5.080	10x	~ 10
Magnesium	2.090	10x	~ 100
Phosphorus	0.157	~ 10	10 to 100
Manganese	0.124	10x	~ 100
Sulfur	0.080	10x	~ 100
Chromium	0.068	10x	~ 100
Vanadium	0.041	1x	~ 100
Nickel	0.031	1 to 10	~ 100
Copper	0.010	~ 10	~ 1000
Zinc	0.004	~ 10	~ 1000
Lead	0.002	~ 10	1000 to 10,000
Cobalt	0.003	1 to 10	~ 1000
Boron	0.001	~ 10	~ 10,000
Molybdenum	0.0001x	~ 10	~ 10,000
Tin	0.0001x	1 to 5	~ 10,000
Arsenic	0.0001x	5 to 10	10,000 to 100,000
Antimony	0.00001x	5 to 10	~ 100,000
Cadmium	0.00001x	0.5 to 1	10,000 to 100,000
Mercury	0.00001x	1 to 5	~ 100,000
Silver	0.000001x	0.0001	100 to 1000
Bismuth	0.000001x	~ 1	~ 1,000,000
Gold	0.0000001x	0.0001	~ 1000

* x is a factor between 1 and 10.

Without any further discussion, let us consider a graphic diagram of the basic cycle (8) shown in figure 1. There can be no doubt as to the fundamental principle of the cycle or the reality of its individual phases. It may be remarked also that the closed cycle presupposes, in its second phase, an assimilation of the sediments by the magmatic melts.

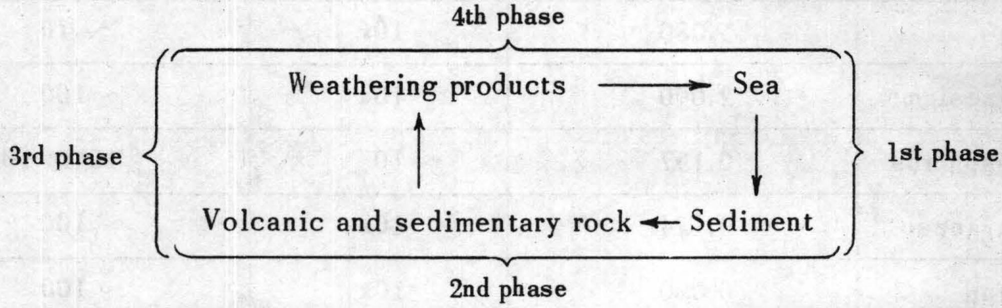

Figure 1. Weathering cycle (according to Vernadski)

The above concept, though it has met with no objections in principle, still remains entirely undeveloped quantitatively. Different chemical elements behave differently in the basic cycle. For example, a significant group of the elements, recognized in geochemistry, is distinguished by cyclicity of its compounds produced in the course of migrations. The latter phenomenon is accompanied by regular changes in concentrations. This particular group of elements is characterized by the development of geochemical anomalies[21] resulting, under certain conditions, in the formation of economically valuable deposits.

The non-ore group, as we know, develops economic deposits partly in the first phase of the basic cycle (fig. 1). A large group of ore deposits is the result of magmatic activities as the magma penetrates the periphery of the earth's crust (the second phase of the basic cycle). Finally a significant development of zones of accumulation is observed in weathering, in the third phase of the basic cycle. This same phase may be accompanied, in the first and second groups, by an extinction of their deposits. The latter becomes especially manifest in the fourth phase of the basic cycle for all deposits previously formed.

Phenomena responsible for lowering the concentrations of metals in the enriched zones, leading eventually to disappearance of the geochemical anomalies, may be designated here collectively as dispersion processes.[*] The corresponding period of time may be referred to as the dispersion phase.[22]

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[*] The term "dispersion process" lacks relation and correspondence to the "state of dispersion," in the geochemical sense. "The state of dispersion," geochemically, is characteristic of a certain group of the elements, as we know, that is so distinguished from the cyclic elements. The inconvenience of such confusion of terms is self-evident. The established usage of the term, however, constitutes our justification for its present use.

In this connection it is important to recognize the periodicity in the sequence of processes of concentration and dispersion.

Enrichment processes, i.e., the ore-formation or mineralization, have been regarded for a long time as problems of high priority that have been developed in detail consistent with the present state of our knowledge. The complementary part of the cycle, however, the dissipation of the accumulated elements (here designated as the dispersion) has been studied only insofar as one was dealing with two mutually transcending aspects of one and the same phenomenon. Abundant factual data on the phase of dispersion in recent years has begun to attract the attention of investigators dealing with some specific problems. Certain regularities in the dispersion process need be noted in relation to the problem here discussed. Any change in the physical or chemical state of matter in nature's laboratory, particularly changes in the process of accumulation and dispersion, is regarded as tending to regulate the equilibrium in the changing physicochemical environment.

A deposit at a certain level in the lithosphere, in the course of a certain geologic period, while approaching spatially the zone of weathering, continues to exist approximately in the same kind of physicochemical environment. This period of time may be regarded as a phase of retarded development of the system. In any event, processes operating during this period, in the majority of cases, do not affect the deposit, in the sense of not affecting the localized zone of the accumulation of the valuable element.

At a certain later time, the deposit is subjected to the action of weathering agents, entering thereby a new phase of its development. Dissipation of the previously accumulated groups of elements is conditioned by this new phase. Alongside the major trend, there develop locally prominent cycles leading to secondary enrichment by chemical or by mechanical means of parts of the deposit, although the deposit as a whole is undergoing a dissipation in the course of the fourth (dispersion) phase of the basic cycle. Local secondary cyclicity, subordinated to the dissipation phase of the basic cycle, is characterized merely by periodic changes in the concentration of elements, with individual exceptions, in the general directional course of the migration of substances.

The process has many forms whose common feature is the interaction between the anomaly and the environment. The space wherein the process is developing extends away from the productive body. Physical properties of such space are not the same as those of the surrounding space. The former is here designated as the *field of dispersion.* Depending on mineralogic composition of the mineralized zone and on other conditions, the field of dispersion may be characterized by different parameters. For example, the thermal dispersion field may develop, in a favorable environment, where liberation or adsorption of heat may be due to certain minerals contained in the deposit. The presence of thermal fields had been established experimentally. This principle, however, has not been applied in prospecting, on account of insufficient experimental work. The exothermic oxidation reactions in the zone of weathering of certain sulfide deposits give rise to certain kinds of electrical fields, on account of the peculiar nature of the minerals. A study of these fields has a wide application in prospecting geophysics, by the method known as the "natural potential field."

The most common case of dispersion is the field developed by enrichment of the environment in substances characteristic of the given deposit, particularly the valuable element in question. The designation *geochemical dispersion field* here adopted has a wider significance than the area of the process limited by the condition stated above. The concept of the geochemical dispersion field, however, combines the following salient features of the process:

(a) The fundamental phenomenon of dispersion.
(b) Indications as to the type of dispersion and its causes.

These two concepts, considered simultaneously, are sufficient to delimit the topic under discussion.

The dispersion halo is concrete expression of the physicochemical (geochemical) dispersion field. It may be regarded as a certain zone, consisting chiefly of loose materials,[23] embracing a series of geochemical anomalies[24] ranging in value from the highest in the ore body to the lowest in the country rock. As already stated, local cycles of transformation, resulting in periodic local temporary accumulations of the characteristic and, in individual cases, economically valuable elements, may develop and do develop within the limits of the dispersion phase of the basic cycle. The chain-like series of variations in concentrations, away from the ore body, regardless of its genetic type, leading through the halo of its dispersion, through the multiform transportation paths, toward the state of the ultimate dispersion in the great cycle of the ocean, may be visualized as developing in both time and space.[25] This generalized concept affords recognition of still another specific type of dispersion field: The spatial element of the field connecting the halo of dispersion of one local phase with the zone of concentration of the subsequent local phase. This spatial element we shall designate as the train of dispersion.[26] If, in the definition of the dispersion halo, the gradual character of the concentration trends were emphasized, the train of dispersion is to be characterized, in this respect, by significant variations. The spatial relation of the train of dispersion to its source, the halo, and, accordingly, to the ore body, should be less apparent therefore to the observer. In field practice, the occasional lack of connection between the dispersion train and the deposit gave rise to the concept of the *false halo of dispersion*,[27] owing its origin to secondary processes including activities of man unrelated to the primary dispersion of the deposit.

Thus three successive stages of the process peculiar to the local phase[28] were established:

1. The accumulation phase, wherein the deposit is formed, under favorable environmental conditions.
2. The halo of dispersion.
3. The train of dispersion.

However, the process will not always develop in accordance with the above scheme. Depending on the mineral composition of the deposit and on other features of geologic and petrologic environment, the process may assume a variety of forms. Certain simple examples of regularity of the development of dispersion halos are considered in the following discussions.

III. Geochemical dispersion halos[29]

1. Gaseous Halo

Gaseous or gas-containing deposits are rather distinct from the others in the nature of their dispersion halos. The peculiar character of the gaseous halos and our relatively better knowledge of them permit us to consider them before the others. Gaseous deposits generally constitute masses of gas trapped in geologically favorable structures under impermeable layers. Depending on depth, the gas is under pressures exceeding atmospheric pressure. The latter causes a migration of the gas in the direction of lower pressures, that is, as a rule, toward the surface. This is accepted, by common consent, to be the fundamental dispersion process, the intensity of which depends on the permeability of the entire mass of materials covering the deposit, all other things being the same. Passage of the gas through materials having pores of subcapillary dimensions must obey the laws of diffusion. Materials through which diffusion takes place are termed "impermeable." These include wet clays, water-bearing sands, and others. Limestone, sandstone, and similar rock are characterized chiefly by the capillary pores, and the passage of gas in this case conforms to the law of effusion:

$$V = KP \div d^{1/2}$$

where V is the rate of effusion,
P is the pressure of gas, and
d is the density of gas.[30]

In reality, the passage of gas through rock combines both diffusion and effusion. The calculations may be carried out in accordance with the empirically established law of Darcy (single-component gas).

$$K = \frac{mQL}{A(P_1 - P_2)}$$

where Q is the rate of passage of the gas, in cubic centimeters per second,
K is permeability, in Darcy's units,
A is cross-section area, in square centimeters,
L is length of path, in centimeters,
P_1 and P_2 are pressure, in atmospheres, and
m is viscosity coefficient, in poises.

For a simple case, where the deposit is associated with the regularly formed dome and the covering rock is entirely uniform in its properties, it is reasonable to assume that, along the path of migration of gas, its concentration will vary as the square of distance from the source. The concentration curve in the profile through the dispersion halo near the surface will have a regular form (35), as shown in figure 2.

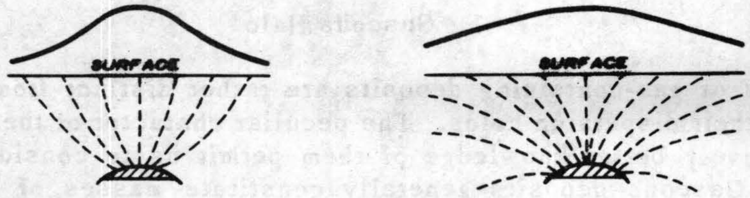

Figure 2. Distribution of gas near daylight surface; graphs for gases of different density (according to Sokolov)

On the basis of these assumptions, V. A. Sokolov (35) and, in a somewhat different form, P. L. Antonov (1) proposed methods of estimating concentrations of gas near the surface. Solution of the complementary problem, determination of depth of the source and outlining contours of the deposit, on the basis of the above calculations, yielded results coinciding with those obtained by both methods. Application of mathematical analysis, however, has so far only a limited usefulness, inasmuch as the actual character of the gaseous halo is influenced by all of the multiform structural elements, diversity of composition, barometric and thermal fluctuations, meteorological and biochemical factors. The greatest disturbance in the normal dispersion of the deposit takes place where the pores of the overlying mass are sufficiently large to permit a free passage of gas to the surface, whereby a more or less potent stream of gas is formed. The same may be caused by fissures. In such case, the gradual regularity is not observed in the concentrations of the gas, and the phenomenon must be classified as a dispersion train.

Selective adsorption of gases by rock is highly significant in the utilization of gaseous halos. Such extremely complex and relatively uninvestigated phenomena are apparently not limited to sorption but are accompanied, particularly for the hydrocarbons, by chemical changes in the gas. Prospecting significance of the adsorption zones so developed in solid materials has recently attracted the interest of American investigators (44).[31]

2. Halos of Mechanical Dispersion

Let us assume that the valuable element of the deposit is stable, as a chemical compound, in the zone of weathering. The valuable element in question will be subject then only to changes in its physical state or in its distribution with respect to the surrounding materials, the vein minerals and the country rock, while participating in all successive transformations of the ore body in the weathering environment.

Development of a halo of such kind (halo of mechanical dispersion) is determined fundamentally by two processes. First, the outcrop is subjected to a continuous physical destruction and the valuable minerals enter the eluvium directly. Second, a continuous removal of loose (deluvial) materials may be taking place. When both phenomena are operating simultaneously, which is most commonly the case, there develops between them a kind of dynamic equilibrium. The partially weathered and fragmented material of the deposit and of the country rock becomes subject to translocation, with subsequent increments of fresh mineral masses in the above processes. As a consequence, the outcrop of the deposit is buried under loose materials of recent origin and of varying thickness. The dispersion halo develops within these loose materials.

In the normal development of eluvium-deluvium, it is possible to observe, in excavations, a certain orderliness in the structure of the detritus layer. Massive country rock grades through visibly fissured layers into a definitely fragmented zone. The volume of fissures is small in comparison with massive fragments still preserving their original spatial relationship. The fissures are filled commonly with fine friable materials, partly derived apparently from the upper horizons. Nearer the surface may be observed a gradual diminution of the size of fragments, without any definite boundaries, down to the size of fine friable materials. Mutual position of the fragments is so altered, under the circumstances, that their peculiar orientation, typical of the lower layers, disappears. Directly in the subsoil layer, the principal material of the formation will be loose sand-clay mixtures, with more or less uniformly distributed small rubble.

Certain features of the translocation of the loose formations of the above types need be noted. It is known that the detritus moves downslope with a certain low velocity. (Where the slope exceeds 35° to 45°, the angle of repose, there develops a rapid downslope movement of the loose materials. Such cases are not considered here.) The most likely commonly accepted causes responsible for the movement of deluvium are:

1. Periodic moistening and the effect of atmospheric precipitation diminishing mutual cohesion of the particles (in extreme cases leading to water-wash).

2. Temperature fluctuations, diurnal and annual, causing periodic contraction and expansion of the mass, especially if they are associated with the formation of ice, and also conducive to disturbance in cohesion of individual particles.

Individual particles, as their cohesion with the others is weakened, may be transposed a certain distance away from the surrounding particles, determined by distribution of the latter. The sum total of individual movements constitutes movement of the entire mass. Figure 3 is a typical cross-section showing creep structure[32] in surface materials (sketch from nature). The curved form of the fractures gives an idea of the distribution of relative velocities of the movement by horizons. The surficial layer of deluvium moves with the greatest velocity; the velocity of movement decreases with depth to zero at the surface of the undecomposed rock. As a general picture of the distribution of velocities, in conjunction with the previously noted features of cohesion between detrital particles, the movement of deluvium may be likened to that of a liquid with a high coefficient of friction. This similarity is also preserved in a still different aspect. Let us consider the probable character of movement of an individual deluvial layer near the surface. Let us assume, for the sake of simplicity, that the particles are of the same order of magnitude and shape. The structure of the layer under consideration may be represented conventionally as a layer of spheres (fig. 4). Assuming that particles of two kinds, "a" and "b," are uniformly distributed in every n-th row and that the proportion of the "a" particles per unit length of every row increases from left to right. As a layer is moved in the direction "V," every particle is transposed to the extent of "delta S," an element of path equal to the diameter of the particle. It is necessary also to assume that the direction of the individual transposition does not coincide exactly with the general direction "V" and has a component normal to "V."

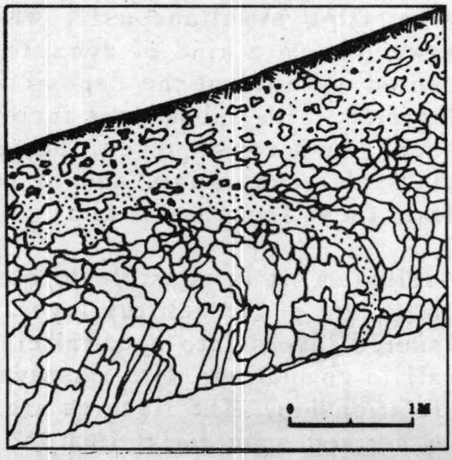

Figure 3. Creep structure;
section through soil

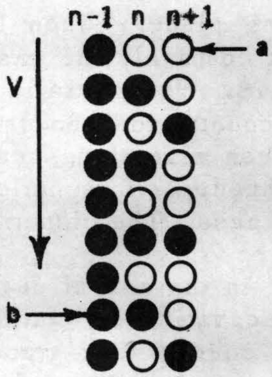

Figure 4

If the number of particles in the row is large, in a given period of time sufficient for the transposal of every particle, the normal components of movement will be distributed in accordance with the law of probability. The numbers of particles capable of entering the adjoining rows, to the left and to the right, will be equal. It may be maintained that the number of "a" spheres per linear distance "delta Q," in every n-th row, will be proportional to the differences between the number of "a" spheres in the examined and in the adjoining layers. The magnitude "delta Q," in its dependence on one of the adjoining rows, [33] may be expressed as follows:[34]

$$\text{delta } Q = KS\ (c_n - c_{n+1})\ T \div L$$

where c_n and c_{n+1} are numbers of "a" particles per unit length of "n" and "$n+1$" rows respectively,
S is length of a part of the row,
L is distance between "n" and "$n+1$" rows, and
T is number of periods of transposition of the entire layer.

It can be easily seen that this equation resembles the well-known Fick's law of diffusion of a substance into a medium:[35]

$$dm = -\text{delta } S\ \frac{ds}{dx}\ dt$$

The first equation shows that the intensity of the phenomenon is indirectly dependent on the number of the periods of transposition per unit time or, correspondingly, on the velocity of movement of this or that layer. Therefore, in comparing translocations of the particles in the direction normal to the general direction of the movement of deluvium, to the process of diffusion, it is necessary to conclude that K, corresponding to the coefficient of diffusion, varies, depending on the distribution of velocities of the movement of detritus by horizons, from zero, in proximity to the bedrock, to its maximum in a horizon near the surface. In this connection, any calculations would be unsound, of course, inasmuch as the diagram upon which the conclusion is based does not reflect the complexity of actual conditions. Nevertheless, the suggested orderliness in the movement of particles, on the first approximation, serves to explain the field observations and indicates ways of describing this phenomenon qualitatively.

The foregoing discussion makes it possible to indicate the forms of spatial distribution of concentrations of the element undergoing dispersion, against the background development of the eluvial-deluvial blanket. Let us imagine the deposit as a vertical column (stock). Let us assume that the relief is flat and that there is no marked creep of the detritus. It is necessary nevertheless to assume a continuous mutual translocation of particles of the detritus, caused by the volume changes (in consequence of removal of a part of the material as solutions), movement of atmospheric precipitation, and temperature fluctuations. The most probable direction of translocation of the particles is vertical, downward. This translocation should be accompanied, from the foregoing reasoning, by a "diffuse" dispersion, in horizontal directions, with the maximum effect in the zone of the longest paths traversed by the particles vertically.

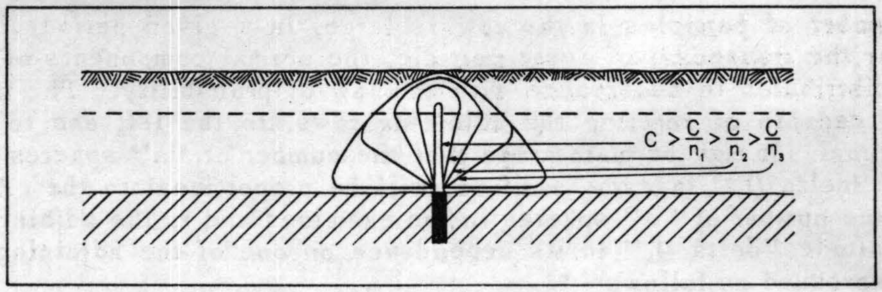

Figure 5. Section through dispersion halo of an ore body in flat relief

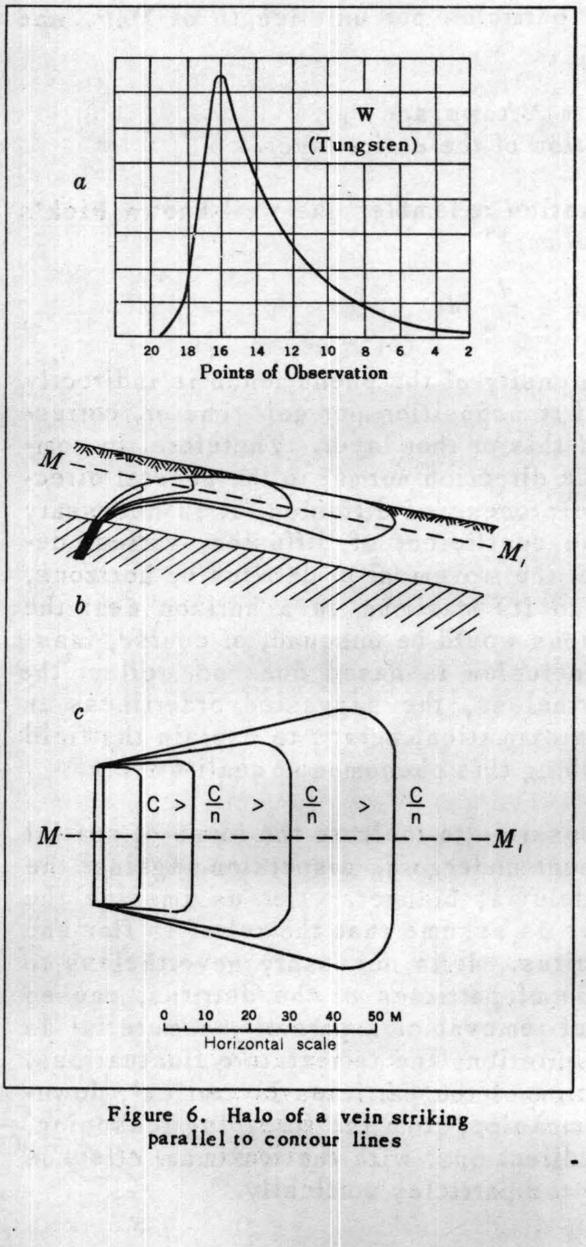

Figure 6. Halo of a vein striking parallel to contour lines

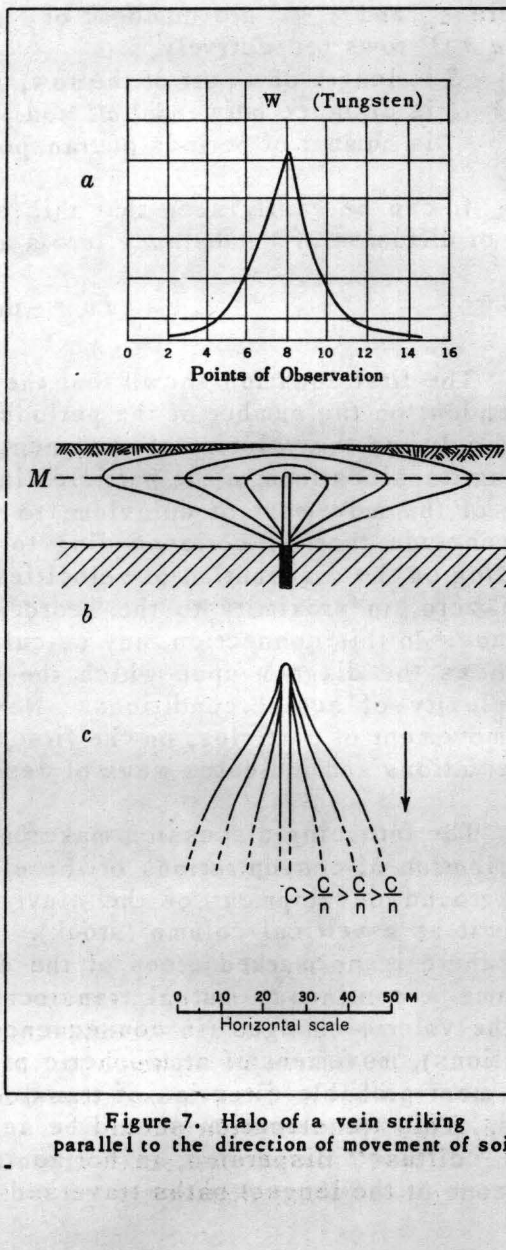

Figure 7. Halo of a vein striking parallel to the direction of movement of soil

In cross-section, this phenomenon may be represented by isograd concentration curves, as in figure 5, where a diagrammatic representation of the halo of an ore stock is given in a cross-section through the deluvium. The representation is in the form of contours delineating areas of different concentrations of the indicator element in the dispersion field.

A downslope creep of deluvial cover[36] takes place in the majority of cases. If the creep is sufficiently pronounced, it may play a decisive part in the formation of dispersion halos. Depending on the distribution of velocities of the movement of deluvium in depth (fig. 3), there will be a displacement of the upper horizons with respect to the lower.* Vertical displacement of the fine components of the deposit will have a subordinate significance. Cross section of the halo, as outlined by the isograds, will correspond to figure 6b.

The second important consequence of the detrital creep will be the lateral dispersion effect. As the length of the paths traversed by a given layer of deluvium increases, there should be a corresponding increase in dispersion at right angles to the principal direction of the movement. The maximum lateral dispersion effect will be observed apparently in the upper horizons of deluvium.

Outcrops of the vein type of deposits may be regarded as a continuous line of stocks in the direction of the vein, and the halo of a vein deposit as the sum of halos of its components.

Two cases may be encountered:

1. The vein extends in the direction of deluvial creep. Without any special proof, it may be assumed that the form of the halo, in its vertical cross-section perpendicular to the vein, will appear as in figure 7b. Figure 7c represents a map of the halo and figure 7a – the concentration diagram in profile $M\text{-}M_1$. The diagram 7a is constructed on the basis of field tests at a tungsten deposit. A similar orderliness in the concentration trends is confirmed by a large number of field observations at tin deposits.

Sections through the halo of a tin vein, shown in figure 8 (the "Water-Divide" Vein, Khapcheranga deposit), exemplify the phenomenon under consideration. In this case, it must be added that in the plane of the section there is a slight, 6° to 8°, westward slope. This fact, together with the character of the veins, is manifested in the asymmetry of the halo, that is, in strengthening of the halo's left side.

2. Vein extends parallel to the contours. A vertical cross section of the halo perpendicular to the vein is shown in figure 6b; figure 6c is the plan view of the halo; figure 6a is the diagram of concentrations in profile $M\text{-}M_1$ (as observed for tungsten).

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* A conformity of the buried relief with the surface is assumed, in this discussion, for area of the buried outcrop.

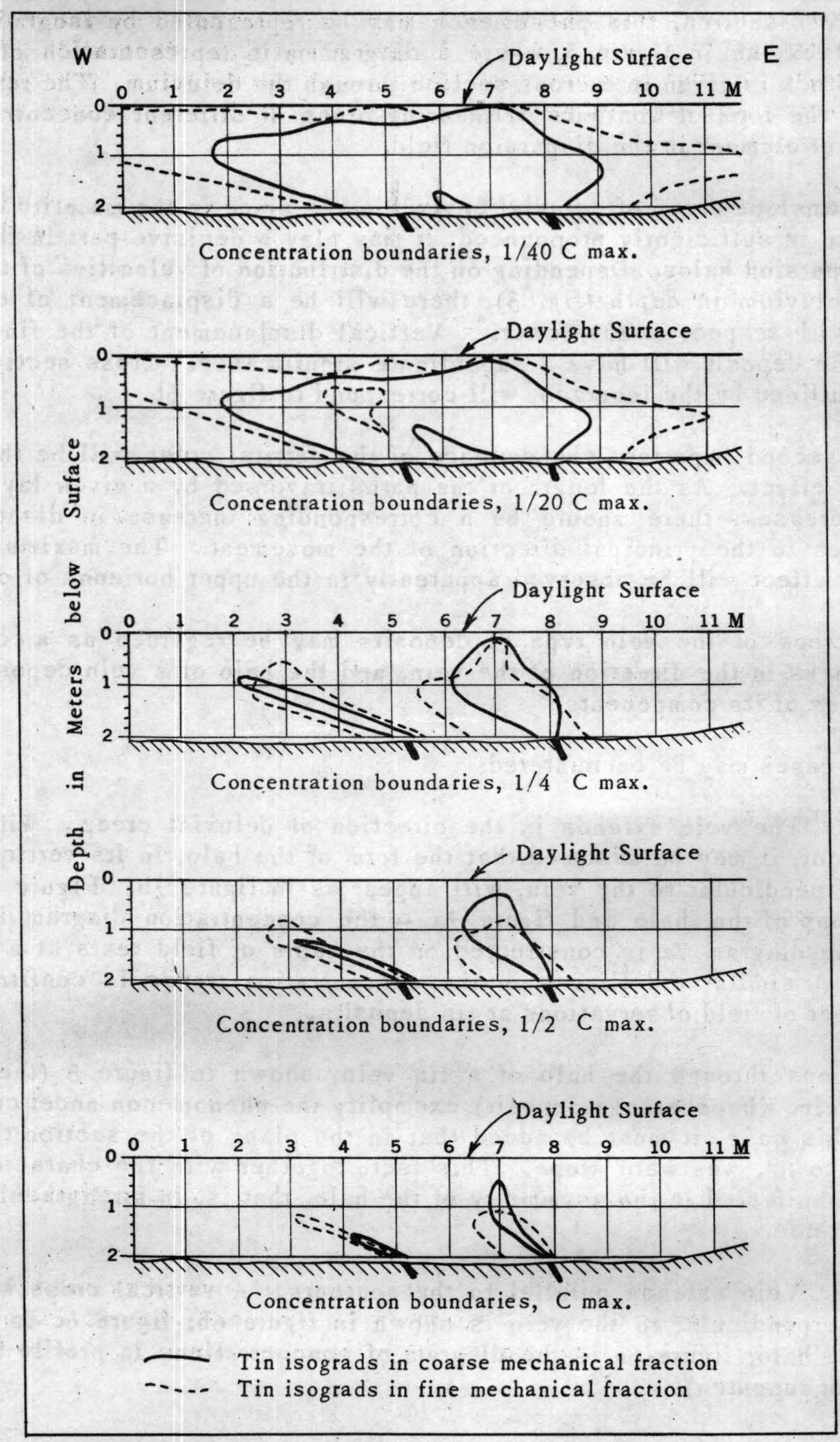

Figure 8. Development of dispersion halo of a tin-bearing vein; section along ditch

All other possible positions of vein deposits with respect to relief will produce intermediate forms of halos which can be easily surmised by combining elements of the examples described above. Halos of complex forms of ore bodies or of the "nest" type of mineralization, however, will be less definite. Accumulation of thick (thicker than 2 to 3 meters) deluvial materials is also conducive to distortion of the elementary forms of halos of the type described, as shown, for example, in figure 9.

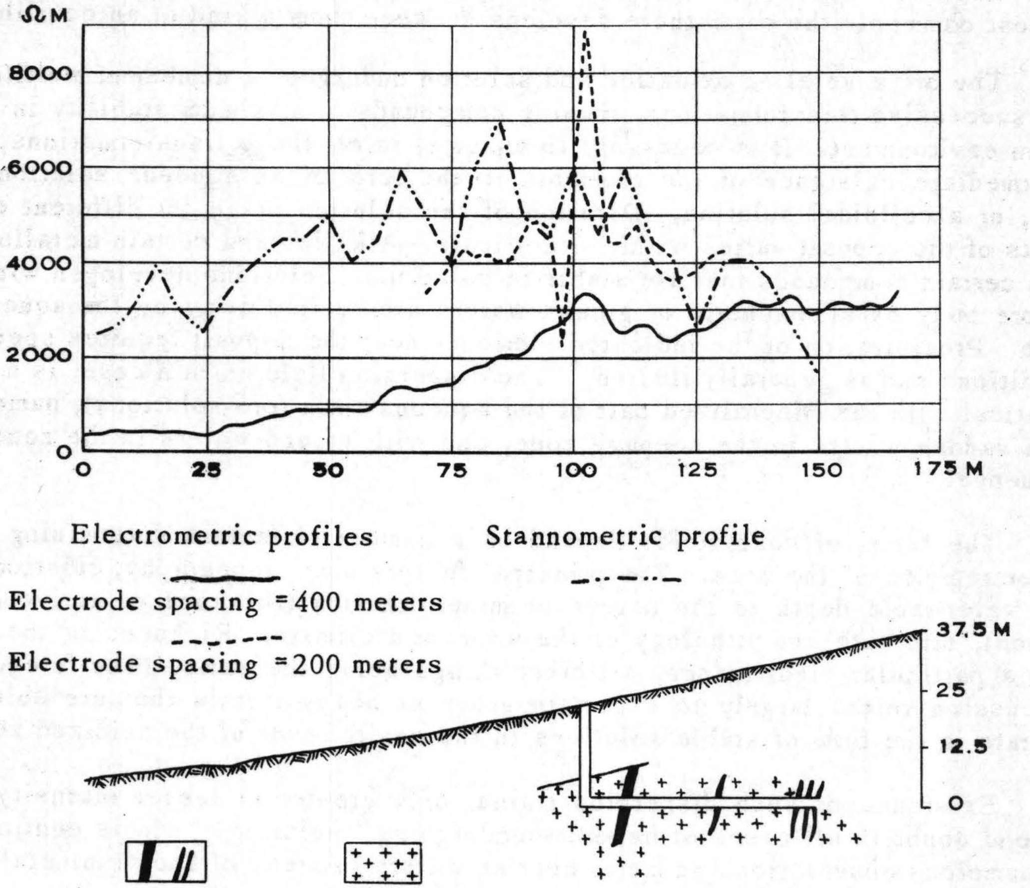

Figure 9. Electrometric and stannometric investigations in an area of tin mineralization

On entrance of the movable material into the sphere of action of perennial aqueous streams, there develops the second type of dispersion field, previously designated as the train of dispersion. This process may be accompanied by local accumulations and the development of placer deposits. Study of placer deposits is a matter of long standing and is considered in the corresponding literature.

3. Saline and Complex Halos

Development of dispersion fields by minerals chemically unstable in the oxidized zone takes place in a most complicated way. Under the influence of water, oxygen of the air, and other weathering agents, the primary minerals of the deposit undergo various chemical alterations, being subject chiefly to oxidation and even to a simple solution. Oxidation proceeds generally more rapidly than the mechanical destruction of the deposit. When both are operative, which is most commonly the case, there develops between them a kind of an equilibrium.

The ore mineral on oxidation and solution undergoes a number of multiform and successive transformations, forming compounds of maximum stability in the given environment. It is necessary to assume, in all these transformations, an intermediate existence of the elements in the form of an aqueous solution, a salt, or a colloidal solution. Duration of the solution stage for different elements of the deposit varies within wide limits. Alkalies and certain metalloids form certain compounds that are stable in solutions. Solutions developed within an ore body by atmospheric or ground waters are carried away by the aqueous train. Precipitation of the indicated elements near the deposit requires special conditions and is generally limited.* The dispersion field, in this case, is made identical with the mineralized part of the aqueous train (ore solutions), namely, with vadose waters in the seepage zone, and with ground waters in the zone of effluence.

The forms of such fields depend on a number of factors determining the water regimen of the area. The principal factors are: topography, relation of the water-table depth to the source of mineralization (the zone of active oxidation), structure and lithology of the area, and climate. Richness of the ore has a particular significance, all other things being the same. The foregoing discussion refers largely to a certain group of heavy metals that are able to migrate in the form of stable solutions in the environment of the oxidized zone.

Existence of such dispersion trains, of a greater or lesser intensity, is beyond doubt in all cases of deposits undergoing "solution" and is confirmed by numerous observations on metal-bearing waters in areas of known mineralization.

Concentration of valuable or characteristic elements in mine waters may attain considerable magnitudes in direct proximity to the ore. Thus, according to Emmons (47), the average sulfate content of the mine waters of copper deposits, in 18 samples, excluding the high extremes, is 1820 g/t^{37} (several hundredths normal), and concentrations of zinc and copper locally may be of the same magnitude. Among the numerous known examples, the nickel-bearing waters of shallow reservoirs may be cited, in prospecting areas of nickel deposits associated with peridotites, in the vicinity of Kalgachikha village, Lake Onega Region, as established by a geophysical field party of Ts.N.I.G.R.I.

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* For example, the products in question may be re-deposited, under favorable conditions, in the nearest water reservoir, entering thereby a new state of development of the saline dispersion field.

Passage of mineralized solutions through rock is accompanied by an extension of the zone of mineralization (the dispersion train). Studies by A. F. Lebedev (13) of movement of solutions in soils permit establishment of the following premises:

Salts do not move in soils at a moisture content below the maximum hygroscopicity. Active movement of salts takes place in the presence of pellicular or of gravitational moisture. Salts move in accordance with the concentration gradient, but their movement does not coincide necessarily with the direction of the movement of moisture. According to Polynov (22), (23), (24), migration of easily soluble salts takes the form of an upward movement of the mineralized moisture, following the capillaries of the soil, or of the water films moistening the surface of the soil particles. The latter process is regarded as essentially limitless. Its cessation is understandable only in places where a dynamic equilibrium has been established with the surface evaporation. The orderly relationships established by pedologists may undoubtedly also be applied to the phenomena of dispersion on account of similarity between the physical environments.

The second important phenomenon, not related directly to the chemical nature of the element, is the physicochemical binding adsorption of the solutions by colloids and by dispersed material. The latter are well developed in the weathering zone in the form of various silica gels, aluminosilicates, hydroxides of iron, manganese, and others. Without discussing the substance of these processes, as developed by K. K. Gedroiz (6) in his doctrine of the adsorbing capacity of soils, we may consider only certain fundamental principles. The chief objects of the fixation are the positively adsorbed components (cations) of the soluble salts. Quantitatively, as we know, the process is expressed roughly by the adsorption isotherm:

$$x \div m = KC^{1/n}$$

where x is weight of adsorbed substance,
m is mass of adsorbent,
K and n are constants, peculiar to the two materials, and
C is equilibrium constant.

The process is reversible, which accounts for the possibility of removal of the adsorbed substance by leaching, either with a pure solvent or with a solution containing cations with the greater energy of adsorption. These phenomena, in reference to the heavy metals (Cu, Zn, Ni, etc.) in dispersed natural systems (clays), have had little study. Investigations of the All-Union Institute of Fire-Resistant and Acid-Resistant Materials (V.I.O.K.) dealing with adsorption of inorganic acid and alkali solutions by clays give an approximate idea as to the orders of magnitude of $x \div m$. For various home refractory clays and $0.01N$ solutions of acids and salts, this value ranges from 0.03 to 0.3, in other words, attains large magnitudes (4).

Incomplete studies by our group gave approximately the same order of magnitude for the adsorption capacity of clays, in reference to Cu^{++}, Zn^{++}, and Ni^{++}. According to S. S. Smirnov (34, p. 37), the process in question may attain large dimensions, giving rise locally to high concentrations of the adsorbed materials.

A significant group of economic deposits is characterized by minerals whose valuable elements are able to form stable new compounds in the oxidation zone, on interaction with solutions enriched with bicarbonates, phosphates, etc., salts, and gases. These reactions take place within the saline dispersion field. Depending on the chemical nature of the element and on the mineralogic environment, distance of the zone of deposition from the original source of the metals may vary within wide limits.* For example, in the case of lead, the sequence of successive transformations, sulfide-sulfate-carbonate, is not related apparently to any significant translocations in soluble form. The dispersion field of lead, nevertheless, in the main is developed in a manner analogous to the mechanical dispersion. Copper deposits occupy an intermediate position in this respect. Deposits of zinc most commonly produce a saline field. In evaluating the probabilities of the existence of an intense saline field related directly to the deposit, i.e., of a dispersion halo, it is necessary to consider leaching processes. In arid regions or in parts of oxidized zones inadequately supplied with water, noticeable enrichments of the saline halo should be expected, up to the separation of the solid phase. Where oxidation resulting in solution is taking place in horizons in which erosion is also operating, the environment is favorable for accumulation. On the other hand, in regions of abundant annual rainfall or where erosion is far ahead of oxidation-solution processes, the environment cannot be regarded as favorable for the development and fixation of a saline dispersion halo.

As an example, it may be pointed out that the presence of a zinc dispersion halo could not be demonstrated in the Zyrianovskaia group of zinc-lead deposits, characterized by a thick, well-developed oxidized zone, but that definite halos of lead (fig. 10) were demonstrable near the surface (16). The same kind of results was obtained at the Sinanchin polymetallic deposit. The Esaulov deposit, Nagolnyi Range, which was practically devoid of a leached zone (its thickness locally was 1 to 2 meters), possessed clearly defined zinc halos, as well as lead halos. Figure 11 is a profile diagram across ore-bearing slates, showing a very clear relationship.

It should be noted that the term "saline halo," as here employed, is a genetic concept rather than a state of matter peculiar to the phase.

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* In discussing development of the dispersion fields of polymetallic deposits, we are not considering the secondary sulfide enrichment phenomena. It may be remarked that the secondary enrichment of sulfides is an excellent example of a locally significant cyclic migration.

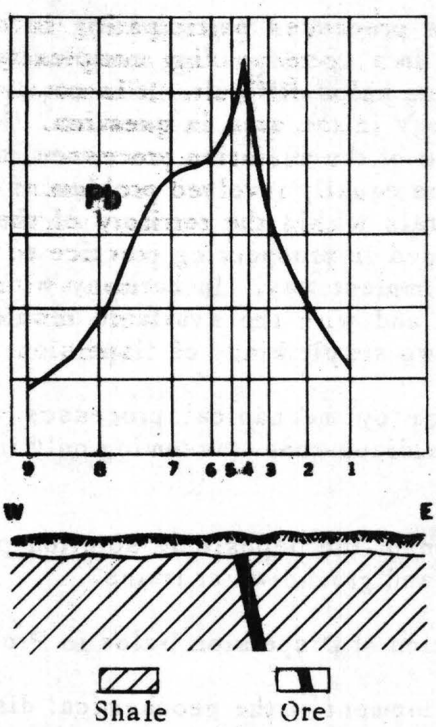

Figure 10. Profile of concentrations of lead in dispersion halo of lead-zinc deposit. Grekhov Mine, Altai

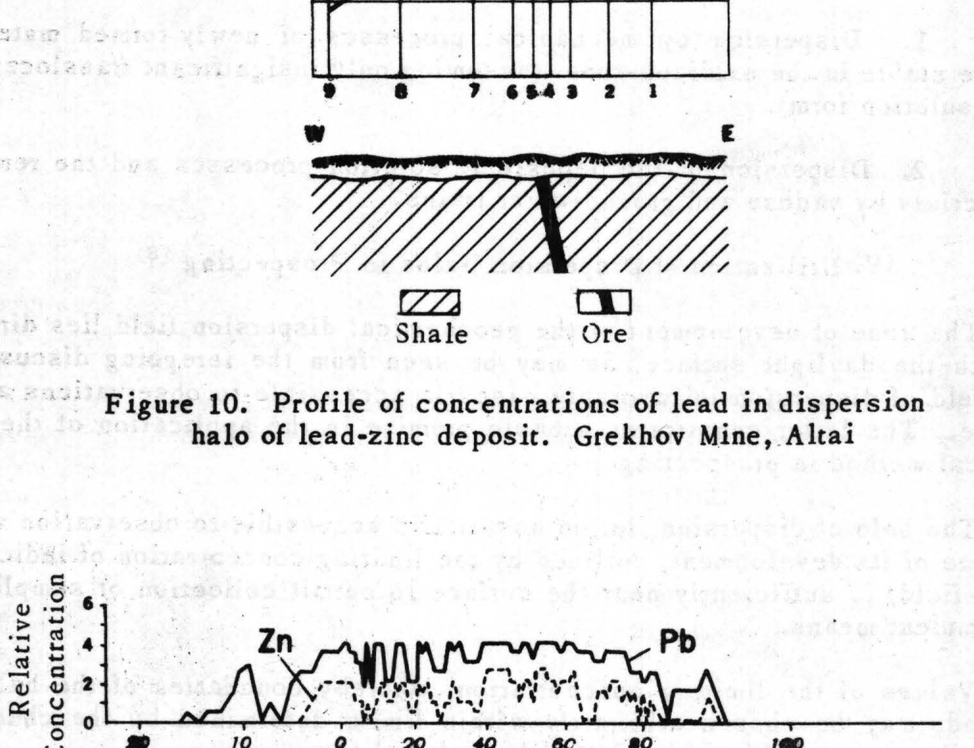

Figure 11. Indication profile of an ore-bearing zone. Esaulov deposit, Nagol'ni Range

The multitudinous processes participating in the development of fields of such type, reflected in a corresponding complexity of the dispersion halos, make the study of saline halos difficult. It is not always possible to evaluate the elements of hydrology in the area in question. It is extremely difficult to appraise the development of the migration processes, the absorption of solutions by rock materials, and the equally involved problem of the development of newly formed secondary minerals within the territory of the saline train. For these reasons it is recommended in prospecting practice to analyse the dispersion of such deposits in the simplest way. In harmony with the sum total of the environmental conditions and with the available results, we should choose the more likely one of the two simple kinds of dispersion:

1. Dispersion by mechanical processes of newly formed materials that are stable in the oxidized zone (assuming only insignificant translocations in the solution form).

2. Dispersion of the deposit by solution processes and the removal of materials by vadose and ground-water trains.

IV. Utilization of Dispersion Halos in Prospecting[38]

The zone of development of the geochemical dispersion field lies directly beneath the daylight surface, as may be seen from the foregoing discussion. The field of dispersion in favorable cases is accessible to observations at the surface. The latter constitutes a basic premise in the application of the geochemical method in prospecting.

The halo of dispersion, let us assume, is accessible to observation where the zone of its development, outlined by the limiting concentration of indicators of the field, is sufficiently near the surface to permit collection of samples by the simplest means.

Values of the limiting concentration, whereby boundaries of the halo are outlined, may be chosen arbitrarily within limits determined by the character of the dispersion field and by the analytical techniques.

Proximity of the halo to the daylight surface depends on the specific conditions of the development of the dispersion field as well as on the type of halo.

Simple mechanical dispersion halos may be divided into two groups, on the basis of their genetic relationship to the surficial deposit.

1. Simultaneous weathering of the deposit and of the country rock, leading to the formation of residual soil. This type of halo, which may be termed syngenetic, crops out most commonly near the surface and is accessible to observation. The capping of such a halo in relatively level relief, by loose

materials from the higher slopes, may occur mechanically. It is reasonable to assume (see "mechanical dispersion") that transposition of the detritus resulting in its accumulation at the base of the slope (the local basis of denudation) takes place chiefly at the expense of the relatively thin surficial layer.

It follows, therefore (fig. 12), that there should exist a certain zone "C," a boundary, between points "A" and "B" on the slope, with the following characteristics:

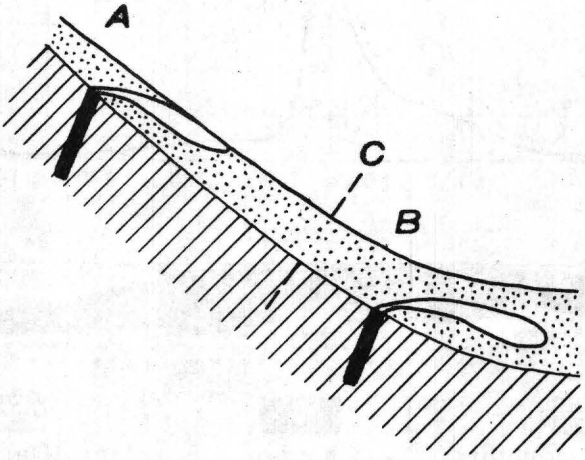

Figure 12. Capping of halo by loose materials

Movement of the upper layers of the loose material in the area above "C" must be assumed to take place freely without any hindrance or accumulation. The area below "C" is characterized by a gradual increase in thickness of the loose material.

If the ore body is in position "A," at a relatively great distance from the trough, the halo, as shown by experience, may be regarded as cropping out at the surface. In the second case, where the ore is in position "B," the halo is entirely covered by masses of loose material of varying thickness. The halo, in such manner, is rendered less accessible to observation. Localization of the boundary line "C" and determination of the principles of movement of the concealing materials constitute an important field problem which awaits solution.

2. In case of concealment of the mechanical dispersion halo by materials of distant origin (fluviatile, lacustrine, glacial, and marine sediments), observations near the daylight surface are rendered even more difficult, as we are dealing then with a "buried halo."

There may be doubt as to the existence of buried halos. Omitting details because of insufficient factual data, we may refer to R. S. Zaidina, engineer, who established in the Mugodzhar chromite deposit the existence of geochemical anomalies of chromium in Cretaceous deposits overlying a pre-Cretaceous dunite-peridotite laccolith. Figure 13 gives the results in graphic form.

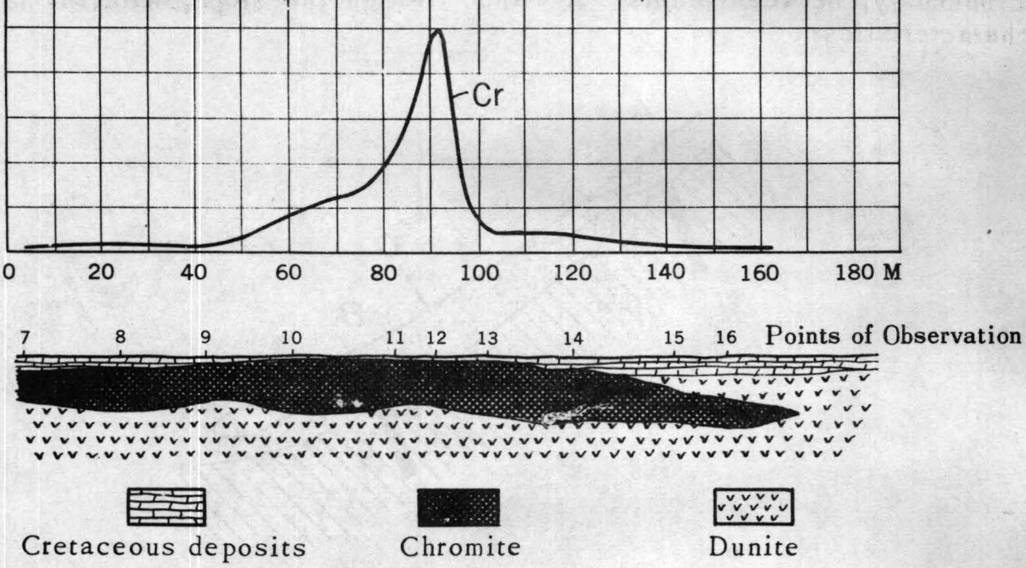

Figure 13. Profile of halo of a chromite deposit

Halos of saline and complex fields of dispersion, as distinct from the mechanical type, may take the form of "superimposed halos," developed as a result of the migration of solutions into deposits overlying the syngenetic halo. The theoretical possibility of such formations was indicated previously. The well-known salinization of soils, in full analogy to the superimposed halo, gives further support to this view. The superimposed halo, nevertheless, is very rare in nature, as it requires an uncommon combination of favorable conditions, namely:

(a) A sufficiently abundant source of the salts.
(b) A hot and dry climate.
(c) A structure of the overlying deposits favorable for the rise of moisture films.

An original approach to the investigation of saline fields of dispersion is indicated in the utilization of the well-known phenomenon of the assimilation by plants of heavy metals in the soil solution. Individual observations in this direction were made as early as 1934 by Ts.N.I.G.R.I.*

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* Sochevanov, N. N. "Otchet Bliavinskoi Geofizicheskoi Partii za 1934 g."

Recently Swedish geologists (Niels Brundin and Sven Palmquist) have been investigating leaves of trees in their search for rare metals.

A systematic study of this problem is highly desirable in the immediate future. If the metals of dilute soil solutions are truly accumulated by the plants, this latter type of investigation may become practical in prospecting.

As previously discussed, the daylight surface constitutes the natural boundary of halos of gaseous deposits, or, more exactly, the gas-exchange horizon between soil, air, and atmosphere. The commonly accepted thickness of this horizon is of the order of magnitude of 3 meters, within the practical limits of gasometric mapping.

Summarizing the above considerations, it is necessary to conclude that the accessibility of halos for observation at the daylight surface (with the exception of gaseous halos) is limited to areas of development of eluvial-deluvial deposits, although locally it may be possible also to observe superimposed and buried halos.

It follows, from the very statement of the problem of the dispersion field, that there can be no mechanical halo of dispersion in the case of blind ore bodies.

Caution is required, however, in appraising such conditions because of our conventional methods of indicating boundaries between ore and country rock. (It is well known that the concept of an ore body includes a whole complex of other concepts.)

Absence of a well-defined boundary between the commercial part of the deposit and the country rock is characteristic of a significant group of primary deposits. This is also characteristic of a group of purely magmatic deposits. Deposits related to the pneumatolitic phase may be characterized by deep impregnation, with respect to the valuable metal, from a filled fissure. Even in the case of definitely banded veins, in places a significant penetration of the metallic elements into the country rock may be observed. Thus it becomes possible to assume, in certain cases, the existence of a so-called "genetic halo" of the deposit, a zone of concentrations intermediate between the ore body and the country rock.

The genetic halo may be equally responsible in the development of the halo of dispersion, expanding thereby our powers of observation to include blind ore bodies. As an example of such possibilities, we may cite the work of Riley (26) who investigated the zonation of a silver-lead ore body at Sierra Mojada, Coahuila, Mexico. Riley has made a comprehensive study of alterations outside the ore body. He was able to identify certain chemical substances and separate elements whose quantitative content in the sample was determined by position

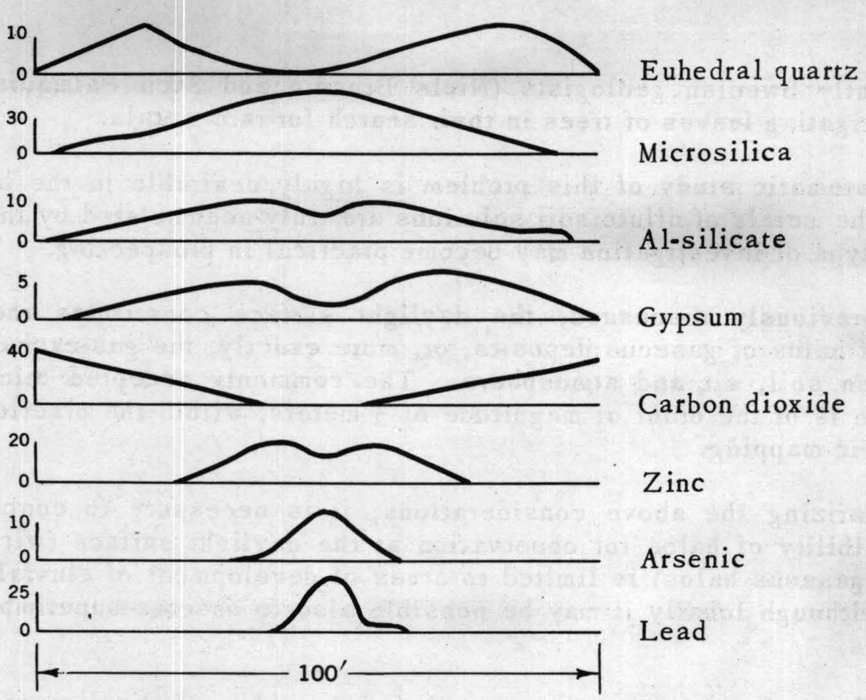

Figure 14. Typical diagram of zoning around oxidized silver-lead ore body. Sierra Mojada, Coahuila, Mexico

of the sampling point with respect to the ore body. Figure 14 gives the results of his study in a somewhat idealized form which, of course, does not affect the substance of the case. The self-explanatory diagram needs no discussion, except for pointing out the possibility of a characteristic genetic halo, as suggested by a varied group of indices, including minerals of the contact zone.

Riley's results are highly significant in considering the wide development of metamorphic zones accompanying a large number of ore deposits. These zones are known to be characterized by introduction of substances and of mineralogic peculiarities unlike those of the country rock. Elucidation of these facts in the study of dispersion halos may prove to be of utmost significance in reconnaissance and prospecting.

Choice of the indicator element for a particular halo is part of our general problem. There are certain advantages in the choice of the economically valuable element as the indicator, whereby the test results acquire a direct prospecting significance. In some cases, however, the prospecting problem may be solved more advantageously by selecting some paragenetic associate as the indicator. For example, in certain tin deposits (Sinanchin, Vanchin), the choice is determined by the higher content of lead than of tin both in the ore bodies and in their halos.

We may refer, in this connection, to one of the diagrams (fig. 15) prepared by the Sinanchin field party of Ts.N.I.G.R.I. In other cases, paragenetic associates were similarly employed, depending on conditions of development of halos and on the testing techniques. For example, in considering suitability of geochemical methods in prospecting for certain arsenic-gold bodies, it developed that arsenic should be taken as the index for the dispersion field. In prospecting for sulfide deposits, experiments show that sulfates could be used successfully as indicators alongside the direct indicators (Cu, Pb, Zn). One of the numerous diagrams for the lead-zinc ore bodies in Buurdu, North Kirgiziia, is here considered (fig. 16). The tests were made by specially prepared electrodes whose emf depended on concentration of sulfate in the upper horizons of the soil. A departure from the use of direct indicators in individual cases should be regarded as an expansion of the possibilities of the geochemical method.

In every individual case these examples recommend a clear statement of the problem of a rational selection of the indicator for the halo, depending on the entire complex of the field conditions. This problem, and certain others, may well constitute the subject of experimental work in areas of known mineralization.

V. Problems and Methods of Field Work*

The first step in a geochemical prospecting survey is the investigation of surficial materials, waters, exploratory mine workings, etc., in search of evidence for a dispersion field of the deposit (i.e., of geochemical anomalies[40]). Detailed studies are aimed to locate the halo proper and to determine its form. The latter is accomplished by establishing concentration gradients of the indicator (element) in a surficial horizon. Both problems are solved in practice by sampling surficial formations on a systematic grid and by determining concentrations of the indicator in every sample.

In the second state of prospecting – an economic appraisal of the area[41] – the geochemical method has so far not been applied. It is unlikely, however, that it could have any peculiarity in selecting the observation points that would distinguish it from well-known methods of alluvial prospecting (stream bottoms, springs, depressions).

Deposits undergoing saline dispersion should obviously be studied chiefly through a systematic observation of ground waters and springs as well as of solid surficial materials which may have retained traces of the dispersed component. The method may be employed concurrently for chemical tests of rocks in geologic surveys.

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* Gasometric survey is not considered in this chapter. Its methods are being applied to prospecting for oil (and, in part, coal). The literature on gasometric survey is extensive in the form of generalized monographs as well as of numerous magazine articles. Gasometric survey so far has not been applied in prospecting for other economic raw materials: combustible gases, helium, etc. (excluding the emanation measurements). Possibilities of extending the method to include ores appear relatively remote[39] and require experimental studies in any case. This chapter is limited to our experience with saline and the mechanical halos.

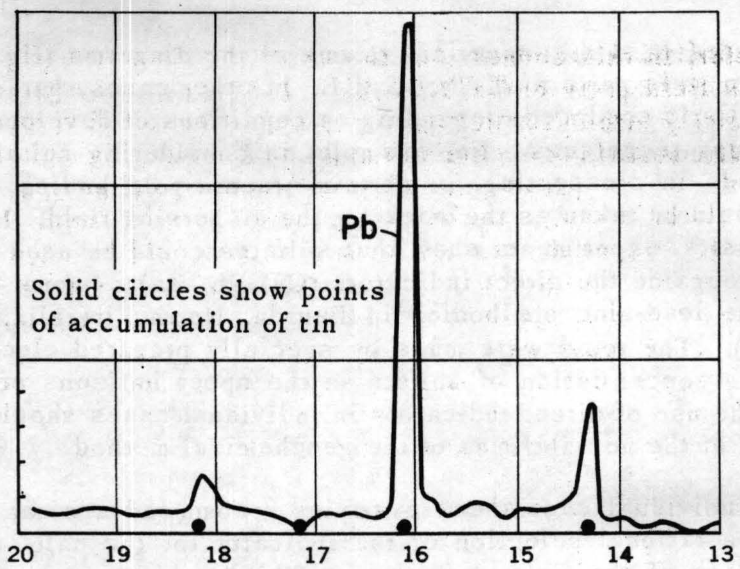

Figure 15. Concentrations of tin and lead in profile of halo of a polymetalic tin deposit

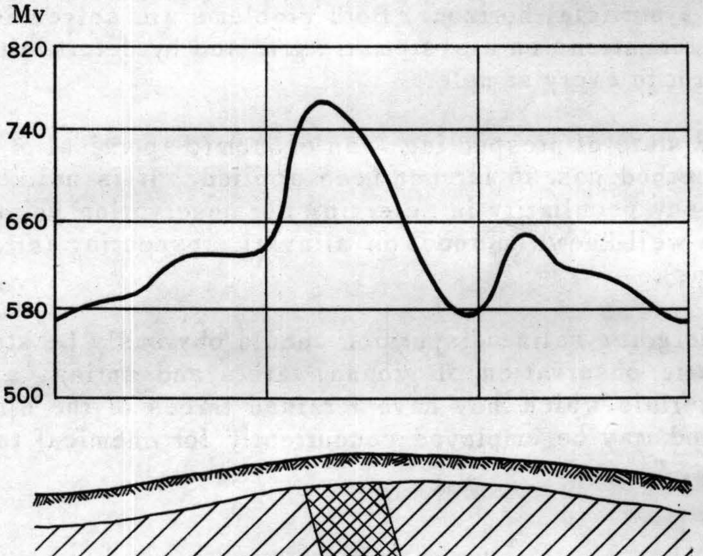

Figure 16. Indication profile of a dispersion halo by the electrode polarization method. Lead-zinc deposit, Buurdu, North Kirgiziia

This discussion is limited to consideration of the method as a component of an integrated geologic survey. Decisions as to the exact plan of work in every case are left to the investigator.

Peculiarities of the method may be learned most readily by direct experience in detailed prospecting for primary ore bodies. The practical application of geochemical methods is discussed below.

1. Distribution and Type of Profiles

The sampling grid should be as widely spaced as practicable, for economic reasons. This requirement is limited by the necessity of "fixation" of the halo by a certain small number (not fewer than two) of geochemical anomalies, as shown by the indicator. In planning the grid, one should lay out profile lines normal to the probable extension of the anomalies (ore bodies), as is common practice with geophysical methods. These considerations permit certain minimum distances between the profiles determined by the minimum size of economically important deposits. Such a profile arrangement is most profitable economically.

Valuable technical instructions with a discussion of the characteristics of dispersion halos have been given by Flerov (41), (42), in discussing alluvial prospecting for tin. From the viewpoint of the geochemical method, these instructions acquire the following significance: the profile rule, where applied at right angles to the presumed extension of the anomaly, must take into account the following regular features of the dispersion:

1. A downslope development of the halo; field observations at tin and tungsten deposits (27), (42) indicates a 40- to 60-meter extension, and longer.

2. Lateral dispersion magnifying size of the outcrop by 15 to 20 meters, and more.

In other words, one must consider both size of the deposit and size of the halo. The latter may be appreciable in certain conditions. Orientation of the profile lines in relation to the halos has an obvious advantage, as the latter are invariably dependent on the visible relief. The above figures referring to the areal development of the halos are emphatically empirical. They depend on a multitude of factors: the degree of slope, intensity of the deluvial creep, structure, etc. Extent of lateral dispersion depends on the length of path traversed, chemical stability of the primary mineral or of the newly formed oxidation zone, etc. In ascertaining the dimensions of the halos, the selected limiting concentration of the indicator has a decisive significance. In order to recognize the weaker manifestations of the halos, it is necessary to standardize the testing technique for the least and limiting concentrations of the indicator. The latter is determined by the expression:

$$C_{\mathrm{lim}}\big| = C_0 + \text{delta } C^*$$

where C_0 is the concentration of the indicator in the country rock[42] and delta C is the absolute accuracy of the test.

It follows, from the above considerations, that where the extent of the deposit is not known or where the deposits are isometric, the geochemical profiles should be taken in the direction normal to the direction of the deluvial creep, i.e., along the contour of the slope. The first prospecting profile should be established most advantageously in the zone of maximum dispersion, that is, near the foot of the slope but still within the confines of the exposed halo. Distance between points along the profile line should be generally one half of the sum of (a) + (b) where

(a) is the lateral distance across the dispersion halo, and

(b) is the probable thickness of the deposit itself, characteristic of the given area.

An average spacing of 5 to 10 meters may be accepted, with suitable deviations, even in reconnaissance studies of unprospected areas.

Subsequent profiles are taken higher on the slope, parallel to the first profile. Distance between the first and the next profile should be chosen reasonably to be somewhat smaller than the longitudinal downslope extent of the halo[43] peculiar to the area. In the absence of the required data, for 20° to 25° slopes, a distance of 40 to 50 meters may be accepted tentatively in the beginning of the survey.[44]

As soon as the characteristics of the deposit are ascertained, i.e., depth and shape, thickness, type of movement of the overburden, etc., methods of surveying the area may be placed on a systematic basis.

Direction and spacing of detailed profiles are determined entirely by the nature of the anomaly and by the desired degree of detail. Detailed directions in this regard are unnecessary and probably impossible because of variety of field conditions.

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* $C_0 = 0$ most commonly. If so, "delta C" markedly exceeds "C_0" and "C_{lim}" is very close to "delta C", the latter acquiring the meaning of the sensitivity. By virtue of this, the sensitivity of the test becomes decisive, in the sense of increasing the range of the method. Quantitative accuracy of the method, as shown by experience, may be very low, sufficient merely on the first approximation, to give an approximate idea as to the order of magnitude.

One additional remark, from the previously cited work of Flerov, may be here adduced for practical reasons. A homogeneous development of the dispersion halo may be assumed in establishing the geochemical profiles only provided the overburden does not exceed 3 to 4 meters in thickness. Delineation of the halo in Flerov's usage "geometrization" becomes difficult for a greater thickness.

2. Sampling Horizon

As the number of test points on the prospecting grid or along the profiles is to be maintained at a minimum, the sampling should be conducted in horizons of maximum development of the halo (in the sense of its areal extent). The latter condition is encountered generally in the upper deluvial layers (figures 6, 7, and 8). In practice, sampling is conducted in the horizon[45] directly beneath the vegetative cover, preferably under the soil because the soil is enriched with products of the biosphere (on account of the obvious weakening[46] of the halo in the soil layer).

There may be exceptions to the above generalization where limiting concentrations of the dispersion halo lie outside the upper horizon of the detritus, in consequence of the following:

(a) Differentiation by gravity, causing a migration of the specific mineral into lower horizons.

(b) In a saline halo, removal of the indicator from the upper horizons by leaching.

(c) Where the halo is buried under later deluvium (and other kinds of concealed halos).

In all such cases, it is necessary to know the thickness of the weakened layers or of the concealing materials. Ascertainment of these factors is a part of the orientation work that precedes prospecting in the field.

Continuous sampling is also feasible in relatively thin deluvium through the entire section of the loose formations. This method guards against possibilities of missing the halo, as may be the case in sampling of one particular horizon only. Weakening of the sample and the relative complexity of operations must be considered, however, where the overburden is fairly thick (thicker than 0.5 to 1 meter).

Detailed studies require supplementary sampling in at least one lower horizon to define more accurately the shape of the halo. These tests, with due consideration for the environmental factors and for the auxiliary geophysical data, form a basis for prospecting conclusions.

Where the groundwater table is not far below the surface, sampling of waters should be conducted from open reservoirs or from test holes.

3. Kind and Quantity of Sample

It follows from field experience with tin and, in part, with tungsten and chromium (15), (17), that samples collected in the part of halo nearest the deposit may be divided tentatively into the following mechanical fractions:

(a) Smaller than 1 mm.
(b) 5 mm and coarser.

The content of the valuable element is approximately the same in both. In places, however, the coarser fraction contains somewhat more of the valuable element. Lean samples (a remote or the train part of the halo) have a lower content of the valuable element (down to zero) in the coarser fraction, although its concentration is stable in the finer fraction. It may be concluded that dispersion takes place chiefly at the expense of the finer materials. This conclusion is in harmony with our concept of the mechanism of the process and is confirmed by field observations (fig. 8). Remembering that halos of saline genesis are characterized by secondary compounds less directly related to the massive rock, the advantages of observing the halos in the fine deluvial fraction become evident. Such samples provide a reliable expression of the dispersion halo in its largest spatial development.

In the absence of sufficiently fine material, the coarser material could be sampled with suitable changes in the size of the aliquots.

By the well-known equation of Desmondes and Halferdale, the amount of a properly collected sample is:

$$q = Kd^a,$$

where q is the weight of the sample, in kilograms,[47]

d is the average diameter of particles, in millimeters, and

K and a are coefficients determined by uniformity of distribution of the valuable element in the sample.

This relationship is true, with the evident assumption that the dispersion halo may be characterized by any mechanical fraction of the material comminuted and intermixed by natural processes.

The upper deluvial horizons containing the dispersion halo may be classified as "fairly uniform" test materials. Assuming, according to Pozharitskii, $K = 0.06$ and $a = 1.7$, we shall obtain the weight of sample: 60 grams for 1-mm particles and 20 grams for 0.5-mm particles. In practice the fine "fry"[48] is sampled, containing particles of all diameters not exceeding 1 to 2 mm, about 200 grams. If an enrichment of the sample is desired by panning, the weight of sample is increased to 400-500 grams.

Comparisons of percent of tin in a customary sample and in a sample 20 to 30 times as large showed that the order of concentrations of tin, established spectrographically, is the same.

Repeated collection of samples of the standard weight shows, by the range scale of the adopted spectrographic method, that percent of tin at a given sampling point has a constant value (25).

These facts attest the correctness of our approach to the dispersion halo studies as well as of the original testing methods, for materials with a fairly uniform distribution of metallic concentrations.

In the presence of a surmised genetic halo[49] or in dealing with coarsely fragmented deluvium only, it is permissible to sample the unweathered rock itself. Field experience at the Chibukhlin deposit testifies to the fact that a certain orderly picture may be so obtained, showing distribution of the indicator element, even with the aid of relatively small samples (400 to 500 grams). Figure 17 shows distribution of nickel in unweathered rock near the above deposit.

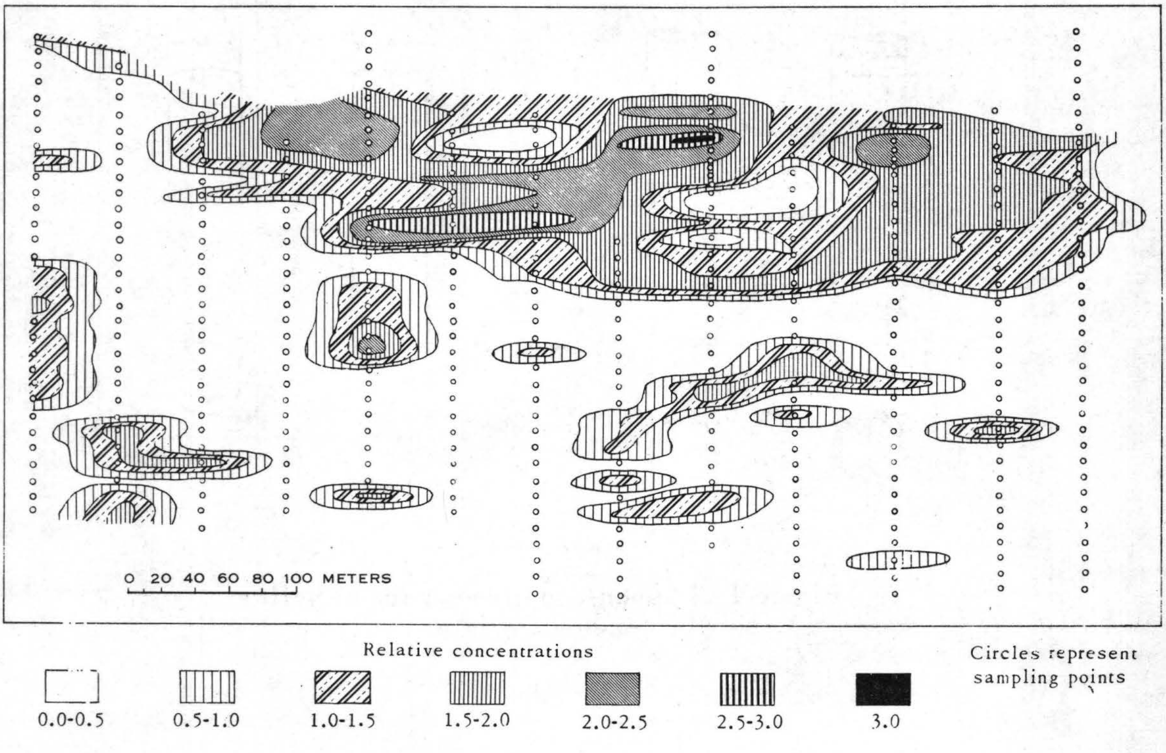

Figure 17. Concentrations of nickel, as indicated by spot tests. Chibukhlin Deposit

4. Sampling

The sampling depth rarely exceeds 0.5 meter for basic reconnaissance profiles. Sampling at this depth is best performed from the dug hole by means of a pick (with one end flat and the other sharp). Sampling from dug holes becomes difficult at greater depths. A set of tools, consisting of a crowbar and a spoon, shown in figure 18,* can be employed successfully for depths from 0.5 to 1.5 meters. The crowbar is driven by a hammer to the desired depth, while being turned at the same time by a wrench. The rotation of the crowbar helps its penetration past the coarser detritus. Samples are collected from the hole so made, by the spoon.

The operations are conducted by a team of two laborers and one collector, on a sampling grid of minimum spacing of 50 meters. Participation of the collector, who is also logging the samples, is required also for the technical supervision of the work.

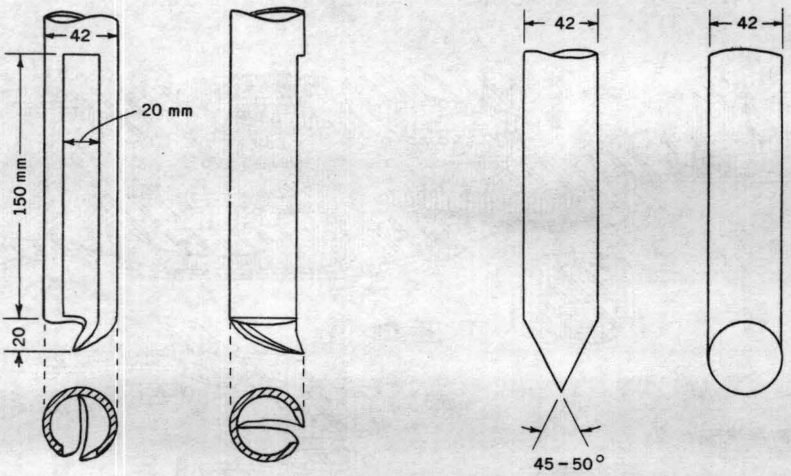
Front and profile views

Figure 18. Spoon and crowbar for sampling loose materials

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* The spoon can be easily made from a discarded Krelium and Wirt drill pipe.[50] The crowbar is best made of a whole steel rod.

5. Analysis

Preparation of samples for analysis consists of the following:

(1) Drying (if required).
(2) Screening.
(3) Reduction in bulk.
(4) Grinding of the reduced sample.

The technique of these simple operations needs no discussion here. We will consider only the significance of the various operations in chemical prospecting jobs. A preliminary panning has been applied successfully in several cases. In experience with the stannometric survey in the Arctic (27), the tin content of sample could be increased 20-50 fold, depending on the mineral composition of the vein.* If the material of the sample is dispersed as clay, enrichment by panning is ineffective.

Reduction in bulk, that is, separation of the aliquot for analysis, has not been standardized in prospecting practice. The reduction procedures are determined empirically in locating and ascertaining the dispersion halos. For economic reasons, with some exceptions, there is a tendency toward utmost simplicity in this operation. The problem in question should be developed experimentally in the immediate future in harmony with the needs of specific field problems in dispersion halo studies, and in harmony with the accuracy of the adopted analytical procedures. In the light of acquired experience, one may be guided by the following:

If the sample consists of fairly fine materials, it should be passed through a sieve with 1- to 2-mm openings and reduced to 10-15 grams without further grinding. If coarser materials predominate, the sample should be ground to pass the sieve, and then mixed with the fine fraction prior to the reduction in bulk.

The bulk, reduced to 10-15 grams, is pulverized to about 150- to 200-mesh size. In practice, such degree of fineness is ascertained by touch; absence of grit makes the pulverization satisfactory.

A preliminary grinding may be performed in a disc mill without the necessity of cleaning the inner surface of the sleeve after each grinding† 51 (if not, the economic advantage would be lost).

Pulverized samples are sealed in paper envelopes and transmitted for analysis.

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* Enrichment of the sample increases sensitivity of the field test, which is especially important in the first stage of prospecting.

† Cleaning of the receptacle is mandatory, of course, after every sample.

VI. Rapid Analysis[52]

The specifications required of rapid analytical techniques are determined by the technical and economic aspects of the geochemical method in the field. The basic requirements are:

1. High sensitivity and rapidity of operations.
2. Together with its high sensitivity, the method must be distinguished from the majority of common analytical procedures by its cheapness, which is a prerequisite for large-scale investigations.

These requirements determine the rigid limits within which the choice of procedure must be made. The choice is possible at all only because the simplest prospecting problems do not require so far any great accuracy in determining concentrations (of the metals) or any absolute significance of the determined magnitudes. It must be remembered that only a qualitative picture of concentration gradients in the dispersion field is desired. Among other desirable features of a method may be mentioned:

(a) Automatic recording, conducive to a greater reliability of the results,

(b) Universal applicability,

(c) A maximum simplicity and portability of the apparatus (especially in remote and sparsely inhabited regions).

The fundamental requirements of sensitivity, rapidity, and cheapness are characteristic of modern methods of physicochemical analysis that have been developed and recognized widely during the last decades, particularly the spectrographic method.

Along with qualitative spectrographic analysis, it is possible to utilize essentially qualitative chemical procedures to which a certain semi-quantitative significance may be imparted. The cuprometric survey (28) may serve as an illustration, where quantitative indications are given by the length of the colored flame on the basis of the well-known blow-pipe test for copper. The plumbometric survey, proposed by Ts.N.I.G.R.I. in 1936 and applied successfully at the Vanchin tin deposit, may be cited also, together with some others. The well-known qualitative reaction, precipitation of lead as sulfide in an alkaline solution, is utilized therein; and the quantitative indications are made nephelometrically, by comparison of weighed precipitation in the test solution with the standards. The method is highly sensitive, simple, and entirely reliable in its quantitative indications. In addition, a series of spot tests may be mentioned, and will be discussed later. All this indicates that, as the need of detection of this or that element arises in connection with the geochemical prospecting problems, a positive answer becomes feasible (occasionally even in harmony with some local feature) by utilization of the vast chemical analytical experience of modern technology. A systematic accumulation of experience and a critical adaptation of procedures already developed should produce an integrated series of semi-quantitative analytical methods applicable specifically to prospecting problems. Such an integrated series should be characterized and distinguished from existing ones, as for example blow-pipe methods, by high sensitivity and semi-quantitative significance – the prerequisite of field observations – as well as by a large-scale productivity (i.e., simplicity of operation). Analytical procedures, presently to be described, may be regarded as the first experiment of the kind in answer to practical needs.

1. Spectrographic Analysis

Spectrographic analysis occupies a place of pre-eminence among the rapid methods on account of its obvious merits. An outstanding and highly commendable feature of the method is the possibility of analysis without any kind of chemical pretreatment of the sample (panning, separation of sediments, etc.). A very large group of elements can be determined by the simplest spectrographic means. The method becomes universal accordingly and only slightly dependent on the mineral and chemical forms of the elements determined.

Spectrographic analysis, as we know, at the present time is in the state of intensive development and of technical improvement. So far only the simplest kind of spectrography based on the presence of the lines and on their density has been employed in geochemical prospecting work. This is far from perfection. Simplicity of operations, on the other hand, satisfies the basic requirements of sensitivity, cheapness, objectivity, and reliable recording. Discussion and description of spectrographic techniques is not our purpose here. It may be sufficient merely to comment on certain critical points in the procedure.[*]

So far we have employed chiefly spectrographs for the ultraviolet part of the spectrum.

Trade marks of home instruments:

1. Ultraviolet spectrograph, 13x18, U.S.P.-1; L.O.M.Z.
2. Universal "stillometer"[53] N.I.I.F., M.G.U. (for visible part of spectrum).

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[*] The reader interested in the details of spectrography may be referred to the numerous manuals of recent origin: (12), (60), (56), (61).[31]

Excitation of the spectrum is obtained by combustion of the sample in an arc of direct or alternating electrical current with carbon electrodes (sample in the cavity in the lower carbon).

Spectra of samples, under constant conditions (of excitation, exposure, etc.) are photographed on a film which, after the usual treatment, is interpreted by comparison with standard tables.

A number of tables are presented here, showing the lines of tin, tungsten, molybdenum, lead, nickel, arsenic, and antimony obtained with instruments of different kinds.

Table 2. [54] Lines of tin shown by the sylvin spectrograph of National Optical Institute (type U.S.P. – 1)

(Constant conditions. Carbons "extra," 10-mm diameter; diameter of cavity in the positive electrode 2.7 mm; depth of cavity 6 mm; "orthochrome" films, sensitivity 200 by H. D. Exposure 30 sec.; current 6 to 7 amp.)

% Tin	Lines
0.01	2429 and 2863 well marked; 3034 conspicuous against the background of banded structure
0.05	2286 poorly expressed; weak 2334 apparent; a weak but distinct 2421
0.1	Trace of 2317; trace of 2571; weakly expressed 2546
0.2	Trace of 2495 and 2785
0.3	A weak but distinct 2850; 2495 and 2785 become clear
0.5	2408 appears; 2913 appears clearly
1.0	Distinct 2232 appears; distinct 3142; trace of 2268
3.0	2268 outstanding; 2455 highly distinct; 3218 appears
10.0	Diffuse 2558 appears

Table 3.[54] Lines of tin shown by a field spectrograph, autocollimation type, constructed by National Optical Institute. (Model No. 1, 1936) (Constant conditions. Photographs on the negative perforated film, for the F.E.D. "Isopanchrome," sensitivity 700; current 8 amp; exposure 60 sec. "Extra" carbons, 10-mm diam. Diam. of cavity 2.7 mm; depth of cavity 6 mm. Films immersed into desensitizer IRSA-NIKFI for 1-2 minutes before developing.)

% Tin	Lines
0.05	2429 distinct; trace of 2421
0.1	2421 distinct; traces of 2334 and 2571
0.3	Weak 2317 appears; trace of 2495.
0.5	Weak but noticeable 2495
1.0	Weak 2785 appears
3.0	Weak but well noticeable 2381; trace of 2408.
10.0	2408 becomes clear; trace of 2268; weak 2558; fairly distinct 2455.

Table 4.[54] Lines of lead shown by G.O.I.[55] sylvin spectrograph (type U.S.P.-1)

(Constant conditions: "Extra" carbons, 10 mm diam. Diameter of cavity, in the positive electrode, 2.4 mm; depth 4 mm. "Orthochrome" films; sensitivity 200 by H. D.[56] Exposure 30 sec.; current 6 to 7 amp.)

% Pb	Lines
0.01	3639.58, 3683.47, and 4057.07 present and distinct
0.05	Very weak 2476.39 appears
0.1	2476.39 becomes quite distinct
0.3	Weak 2577.28 and 2446.20 appear; 2393.81, quite distinct
1.0	Weak 2443.86 and 2401 appear; a wide diffuse 2246.90
3	2411.75 distinct; weak diffuse 2237.42; weak 2332.47
5	2697.5 quite distinct; a weak shadow of wide diffuse 2650.5
10	Diffuse 2253.9 appears
20	2388.8 clear, quite distinct

Table 5.[54] Lines of lead shown by quartz spectrograph made by Adam Hilger (London) (E 316)

(Constant conditions. "Extra" carbons, 10 mm diam. Diam. of cavity in the positive electrode 2.4 mm; depth 4 mm. "Orthochrome" films, sensitivity 200 by H. D. Exposure 30 sec.; current 6 to 7 amp.)

% Pb	Lines
0.01	3639.58 distinct
0.05	2476.39 very weak
0.1	Trace of 2393.81
0.3	2577.28 weak but noticeable against the banded structure of the background; 2446.20 and 2443.86 weak and thin; 2246.90 barely perceptible, as a shadow
0.5	2411.75 weak, diffuse 2401.95 distinct; 3683.47 distinct but diffuse
1.0	2237.42 distinct
3.9	2399.60 quite distinct; very weak shadow of 2253.9
10.0	2697.5 distinct, conspicuous against the banded-structure background; 2657 distinct and thin; 2650.5 quite distinct, as a wide diffuse shadow; 2426.64 clearly distinct against the banded background; 2388.8 clear; 2332.47 very clear. 3220.54 and 3240 visible

Note: This table is adapted for a simultaneous estimation of tin, by the same film.

Table 6.[54] Lines of molybdenum shown by quartz spectrograph made by Adam Hilger (London)

(Constant conditions. "Extra" carbons, 12 mm diam. Diam. of cavity in positive electrode 2.8 mm, depth 4 mm. "Photocolor" films, orthochromatic, sensitivity 200 by H. D. Exposure 30 sec.; current 6 amp.)

% Mo	Lines
< 0.01	3158.2 quite distinct
0.01	3132.6 fairly distinct against the banded background; 3170.3 quite distinct; 3194.0 weak but clear
0.05	3112.1 of a slightly greater intensity than lines of the adjoining banded structure; 3208.9 weak
0.1	3358.1 quite distinct; 2655.0 very weak; 2641.0 very weak but distinct; 3456.4 weak
0.2	3327.3 very weak; 3290.8 weak but distinct; hints of 3094.7 and 3085.6; 3013.8 very weak; hints of 2816.2 and 2775.4; very weak but noticeable 2649.4; trace of 2664 and 2848; 2978.3 and 2891.0 weak but distinct; hint of 2785.0
0.5	Appearance of clear 2954.6 and 2944.8
1.0	3307.1 weak but distinct; hint of 2849.4; 2827.7 weak but clear; 2751.4 weak but quite distinct; 2701.0 weak; 2567.0 very weak, poorly visible against the banded structure
3.0	2572.3 distinct and clear

Table 7. [54] Tungsten lines, as shown by quartz spectrograph made by Adam Hilger (London) (E 316)

(Constant conditions. "Extra" carbons, diam. 12 mm. Diam. of cavity in the positive electrode 2.8 mm; depth 4 mm. "Photocolor" films, orthochromatic, sensitivity 200 by H. D. Exposure 45 sec.; current 10 amp.)

% W	Lines
0.05	4008.8 distinct; 2896.4 weak
0.1	2656.5 very weak but separate from the surrounding bands; traces of 2935.0 and 2879.4
0.2	Trace of 2744-2774.5 couple; very weak 2792.7, almost blending with the surrounding banded structure on the left; 2405.6 noticeable; 2547.1 weak but distinct; very weak but distinct 2724.5; weak 2831.4; trace of 2866.0; weak 2935.0; weak but distinct 2947.3; trace of 2633.1; very weak 2979.9; trace of 2818.1
0.3	2504.7 weak but distinct; trace of 2561.5; weak 2691.4; 2856.0 and 2911.0 appear
0.5	Trace of 2415.7
1.0	Weak 3176.7 and 2662.2 appear; weak but distinct 2964.5; trace of 2473.1
3.0	2473.1 becomes distinct; 2435.0 distinct; 2431.0 well visible; distinct 2456.5; 2480.1 and 2572.3 appear; 3108.1-3108.9 well visible; weak 3373.9 appears
10.0	Very weak 2720.0 appears

Table 8. [54] Nickel lines as shown by sylvin spectrograph of the National Optical Institute (type U.S.P. – 1)

(Constant conditions. "Extra" carbons, diam. 10 mm. Diameter of cavity in the positive electrode 2.7 mm: depth 3.4 mm; "Photocolor" films, orthochromatic, sensitivity 200 by H. D. Exposure 30 sec.; current 8 amp.)

% Ni	Lines	
	Distinct	Weak
0.01	2311; 2315.5; 2320; 2345.5; 2419; 2992.5; 3057.6; 3318	3081
0.05	2317; 3002.5; 3064.6; 3081; 3222; 3225; 3365; 3493	
0.1	2424; 2821.5; 3114	
0.2	2410; 2321	2388; 2414; 2441; 2984
0.3	2357	2316; 2347 2415
0.5	2316; 2415	2865.5
1.0	2441	

Table 9. [57] Arsenic lines as shown by quartz spectrograph made by Adam Hilger (London) (E 316)

(Constant conditions. Current 10 amp; exposure 60 sec. Photographed in the cathode layer. Graphite electrodes. Diam. of cavity 2 mm; depth 4 mm. Weight of sample 15 to 20 mg.)

% As	Lines
0.01	2349.8 of the same intensity as the adjoining banded lines, on the long side; 2288.1 weaker than the shorter neighboring line of the molecular spectrum
0.03	2349.8 slightly more intense than the adjoining banded lines, on the long side; 2288.1 of the same intensity as the shorter banded neighboring line
0.1	2288.1 more intense than the neighboring short banded line; trace of 2860.4
0.3	2860.4 visible but weak
1.0	2456.5 weakly separated from structures on the short side; weak 2492.9; very weak 2898.7; trace of 2381.2
3.0	2381.2 weak but quite distinct; 3032.8 barely visible
10.0	3032.8 well seen; 2991 barely visible between the Fe lines

Notes: 2288 of As may be used only in the absence of Cd 2288;

3032.8 of As coincides with 3032.8 of Sn; the latter does not interfere with the determination of arsenic if the tin content is less than 0.2%.

2898.7 of As is masked by 2898.7 of Bi if bismuth content is high.

Table 10.[57] Antimony lines as shown by quartz spectrograph made by Adam Hilger (London) (E 316)

(Constant conditions. Current 10 amp; exposure 60 sec. Photographed in the cathode layer; graphite electrodes. Diam. of cavity 2 mm; depth of cavity 4 mm. Weight of sample 15 to 20 mg.)

% Sb	Lines
0.01	2311.0 visible; weak against the background
0.03	2311.0 entirely visible
0.1	2877.9 barely visible
0.3	2877.9 fairly intense; 2670.6 barely visible against the background, on the long side; 3267.5 equal in intensity to the neighboring line on the long side
1.0	Traces of 2445.5, 2306.5 and 2574.1
3.0	2445.5 fairly definite; 2306.5 weak but noticeable; 2574.1 weak but distinct; 2682.7 more intense than lines to the left and to the right; trace of 2426.4
10.0	2422 barely noticeable; 2426.4 weakly noticeable; 2383.6 distinct

Notes: 2877.9 may interfere with the 2877.4 of titanium.

2670.6 may interfere with the 2670 of zinc, in presence of about 10% Zn.

3267.5 of Sb should be used with great care, as it coincides with the intense 3267.7 of V and is poorly separated from 3268.2 of Fe.

2574.1 of Sb is close to the very intense 2575.1 of Al and also coincides with the weak 2574.4 of Fe.

2422 of Sb may be used only if the tin content of sample is less than 0.1% (2421).

2426.4 may be interfered with by the 2426.6 of Pb, if lead content is high.

All wave lengths in the tables are shown in angstrom units.

The spectrograms are interpreted by locating the required lines and observing their intensity. For this, special forms are required. Lines of the element sought are first located systematically, first in the line-rich standard spectrum and then in the spectrum of the test materials. Depending on presence or absence of the line in the spectrum of the sample, notes are made, in appropriate graphs of the report form. Presence of a distinct line is indicated by a plus sign, absence by a minus sign. It is convenient also to employ designations "weak" and "trace." An example of such record is given in table 12.*

Spectrographic analysis of rock materials for boron could not be reported in the regular form, on account of the poverty of the emission spectrum with respect to the characteristic lines of the element. For small amounts of boron, from 0.01 to 0.5 percent, the simplest kind of spectrographic comparison is employed, with the aid of the boron doublet, 2497.53 and 2498.48. For higher amounts of boron, 0.3 to 10 percent, there is the method of the homologous pairs of boron and copper spectra. The lines of boron and copper utilized in the selection of homologous pairs are given in table 11.

Table 11. [58] Homologous copper-boron pairs

Wave Length		Conditions
B	Cu	
2090.25	2105.1 2112.0	Copper electrodes; 6-amp current; 30-sec. exposure. Film should be sensitive in the ultraviolet region of the spectrum.
2089.59	2117 2123 2126.0 2130.7 2135.9 2138.5 2140.7	

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* The example corresponds to determinations of tin, in the stannometric survey, by the field spectrograph of the auto-collimation type constructed by G.O.I.

Table 12. [58] Sample check list of spectrographic lines calibrated with standards prepared from local materials

Sample	0.05%		0.1%		0.3%	0.5%	1.0%	3.0%		10.0%			Interval in the Sn-content. %
No.	2429	2421	2334	2571	2317	2496	2785	2381	2408	2268	2558	2455	
1	0	0	0	0	0	0	0	0	0	0	0	0	Not detected
2	+	0	0	0	0	0	0	0	0	0	0	0	<0.05
3	+	tr.	0	0	0	0	0	0	0	0	0	0	~0.05
4	+	+	tr.	0	0	0	0	0	0	0	0	0	0.05 to (0.1)
5	+	+	tr.	tr.	0	0	0	0	0	0	0	0	0.05 to 0.1, av.
6	+	+	+	+	wk.	tr.	0	0	0	0	0	0	0.5
7	+	+	+	+	+	0	0	0	0	0	0	0	0.5 to 1.0
8	+	+	+	+	+	+	wk.	0	0	0	0	0	(0.3) to 1.0
9	+	+	+	+	+	+	+	wk.	tr.	0	0	0	~3.0
10	+	+	+	+	+	+	+	+	tr.	tr.	0	0	(3.0) to 10.0
11	+	+	+	+	+	+	+	+	+	+	+	+	>10.0

Standards used in preparing the table are made from rock barren of the element sought, i.e., metal-free, in proportions characteristic of the given deposit of the mineral. The barren rock is selected, of composition corresponding to the average composition of the country rock of the deposit and the mineral gangue of the deposit itself. As stated above, the selection is influenced by the effect of composition of the sample on excitation of the spectrum, as expressed in intensification of certain lines and in weakening of the others. Verification of the table with the aid of standards made of local materials (table 12) is mandatory, especially if the problem requires accuracy exceeding the needs of the usual metallometric survey.*

The master table of the appearance of lines may prove to be of no value in individual cases, even in the metallometric survey. This was actually the case in an experimental field project on chromium. Here the use of the master table, calibrated against materials alien to the area in question, gave unreliable results with reference to the true concentrations of the element.

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* Geochemical studies of dispersion halos by determining concentrations of the indicator element (metal) are known, in field practice, as the metallometric survey.

Improved spectrographic methods for field use (in examination of materials without any chemical pretreatment), such as different procedures of quantitative appraisal (11), (14), (25), different combustion methods* (12), (30), a full utilization of the photographic advantages of the cathode layer, etc., are timely and highly desirable. Of equal interest is the possibility of wide application of the universal "stilometer,"[59] which measures the spectral lines photometrically.

All other analytical procedures used in the field require a transfer of the constituent sought from the sample to a solution. Such procedures are convenient in studies of the halos containing minerals unstable in the weathering zone. The latter, as we know, tend to form hydrates, carbonates, and oxides that are relatively soluble in dilute acids.

In the field, economic reasons make it impossible to ascertain completeness of the elutriation or extraction, especially as one may be dealing with concentrations on the borderline of sensitivity of the reactions. This limitation, however, should not influence the qualitative distribution of the indicator element in the dispersion field, provided that a constancy of the test conditions is observed, with respect to C, the extraction coefficient (determined by the proportion of the extracted element with respect to its total content in the sample), and B, the dilution coefficient (determined as the ratio of the volume of solution to the weight of the sample). If A is the observed concentration of the indicator element in the extract, its proportion in the sample is determined by the expression:

$$Q = AB \div C = kA$$

Constancy of coefficients C and B must be assured by careful observance of the procedure rules. A laboratory study of variability of C under standard conditions (boiling in dilute acids for definite periods of time) shows constancy in the orders of magnitudes for comparable minerals of copper, zinc, and other metals. Depending on type of compound (mineral), susceptibility to leaching varies, attaining unity (100 percent) for carbonates, lower values for sulfides, and 0.1 to 0.2 percent for the silicate group of minerals (17). Scattered determinations of C are desirable in the field practice to ascertain its constancy and as a check on the method. Effect of deviations and of unforeseen variables, unavoidable in the field, rarely exceeds the limits of the accepted crudely quantitative gradations.

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* The author developed recently a method of exciting the spectra of rock materials in a voltaic arc, with application of a magnetic blower. The principal advantages are: possibility of "burning" an unlimited bulk of sample; local examination of drill cores without grinding; relative simplicity and reliability of the excitation.

Practical field problems – outlining of the halo and locating the zone of maximum geochemical anomalies – may be solved effectively by a group of the so-called wet methods. A comparison between the wet methods and the spectrographic results is given in figure 19.

The wet methods are marked by simplicity, high sensitivity, and the light apparatus required. These are their advantages. Their disadvantages, in comparison with the spectrographic method, are chiefly as follows: [59]

(a) A narrow range of applicability of any one of the methods. Every method is suited for determining only one or sometimes two elements. Hence the multiplicity of testing procedures requires special skills of the operator in every case.

(b) A subjective appraisal of the analysis (absence of objective documentation).

Not considering the systematic procedural description of separate methods already presented in detail in the manual of geophysical methods (38), let us present now their general characteristics by groups together with a statement of principles underlying some individual methods.

2. Spot Tests [60]

A new branch of analytical chemistry, spot analysis, is applied to the study of dispersion fields. Many spot reactions are characterized by their group selectivity. In a number of tests, one particular element is indicated, regardless of the presence of others. A qualitative indication of the element sought is generally a colored drop or a spot on a filter paper. Reactions described in the literature (39), with certain modifications chiefly to make them useful in the quantitative appraisal, have been used successfully in prospecting. The quantitative estimation is generally made by comparing intensities of the color effects with standard colored spots. Dilution of the test solution to the limits of sensitivity of the reaction, in various modified forms, is rarely resorted to. The quantitative estimation, as a rule, is expressed with the aid of conventional scales.

The following reagents for a group of non-ferrous metals were made a part of the prospecting practice: dithizone, hydrogen rubeanic acid, and dimethylaminobenzylidinerhodanine.* Sensitivity of these reagents and kinds of colors produced are shown in table 13.

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* The author, in 1936, secured the originator's certificate for this method.

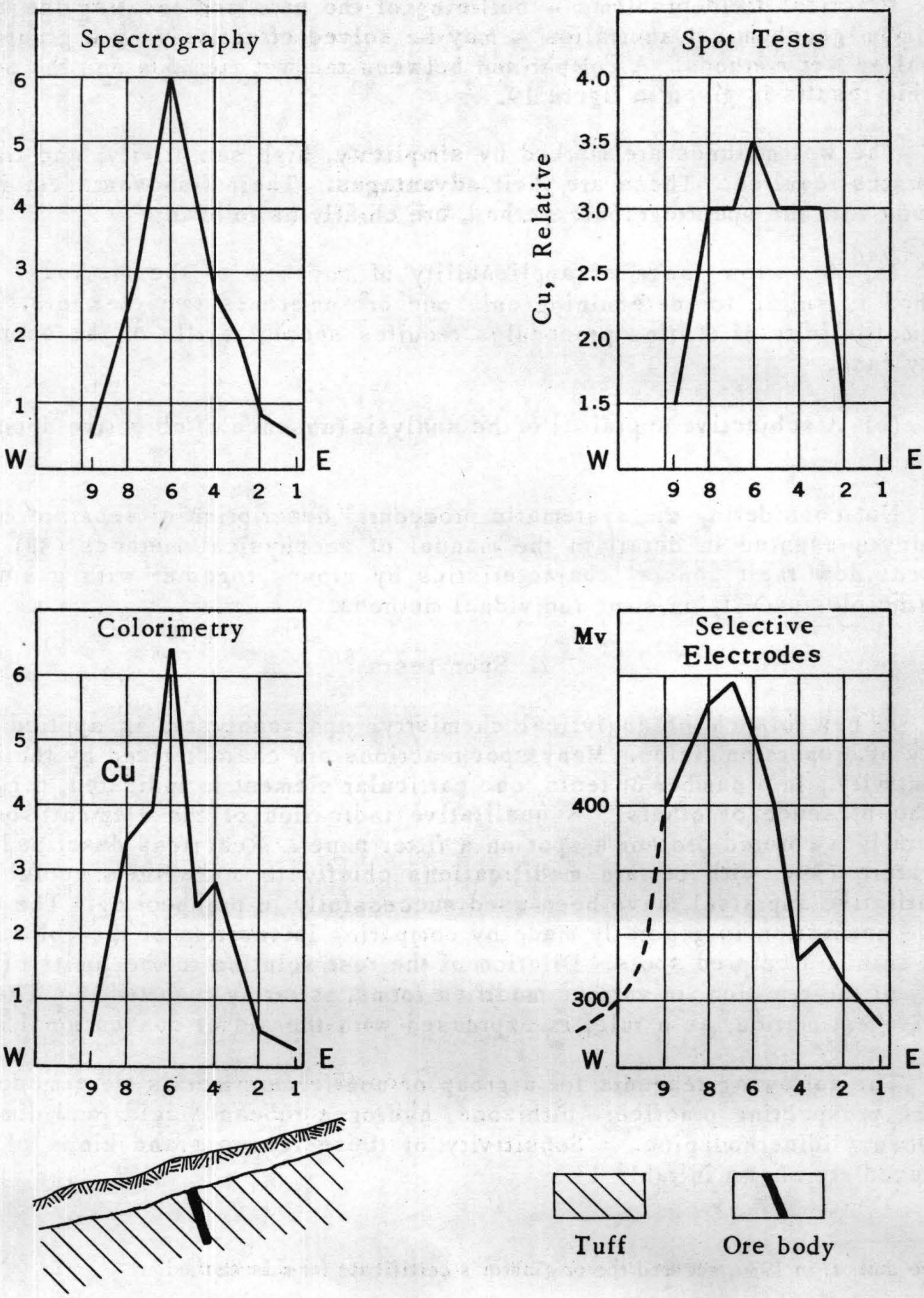

Figure 19. Indication profiles for halo of a copper deposit, as shown by different methods. Alexander Mine, Altai

Table 13.[61] Sensitivity of reagents employed in spot tests and corresponding colors

Reagent		Elements					
		Cu	Ag	Zn	Pb	Ni	Co
Dimethyl-aminobenzylidene-rhodanine	Color	Red sediment	Red X	Red XX	Red XX	None	None
	Sensitivity	0.0004%	0.001%	0.005%	0.008%	–	–
Hydrogen rubeanic acid	Color	Gray-green	Buff[62] brown	None	None	Blue	Buff brown
	Sensitivity	0.0004%	0.01%	–	–	0.00008%	0.0008%
Dithizone	Color	Gray green	Red violet	Raspberry red	Brick red	None	None
	Sensitivity	0.0004%	0.001%	0.00005%	0.008%	–	–

Notes: (a) The table represents pure solutions of salts of the metals.

(b) Fe and others produce no color effects but, if present in large amounts, lower the sensitivity of reactions.

(c) X means in an acid solution.

(d) XX no color in acid solutions or in the presence of a crystal of sodium sulfite.

Various procedures of detection were used at different times as aids in specific prospecting problems. These procedures were based on well-known analytical reactions. In addition to the previously described method for lead, semiquantitative procedures were developed for boron, arsenic, molybdenum, manganese, and tin. The quinalizarine reaction (32) was used in the detection of boron; arsenic was determined as silver arsenate (18), etc.

One cc of ground sample is treated for 30 minutes with 3 to 4 cc of strong hydrochloric acid; 0.5 g chemically pure zinc is then placed in the crucible. After 2 or 3 hours the liquid is tested for tin. For this purpose, the lower end of a test tube filled with water is immersed in the crucible. After the contents of the crucible are mixed, the wet lower end of the test tube is introduced into the reducing cone of flame of a Bartel burner. A typically blue-colored flame envelopes the test tube. The area covered by the flame is proportional to the tin content of the sample. A quantitative estimation of tin is made by comparison with standard solutions. Table 14 shows comparisons between results of the above method and of the chemical analysis of a "coded"[63] series of samples from one of the localities.

Table 14.[61] Comparison between flame tests for tin and chemical analyses

Method	Percent tin												
Flame tests	0.01	0.01	0.1	0.1	0.1	0.1	0.1 to 0.5	0.1 to 1.0	More than 0.1	More than 1.0	1.0 to 3.0	1.0 to 3.0	0.1 to 0.5
Chemical	0.02	0.04	0.07	0.08	0.1	0.16	0.22	0.33	0.36	1.28	2.47	3.74	0.44

Mass examination permits a high productivity for the testing part of the work.

To complete the review, two other methods should be mentioned: The electrode potential and the polarographic method which, for various reasons, were not tested on a large scale in the field. The electrode potential method was described in 1935, as the ionic method (33). Special metallic surfaces, the so-called selective electrodes, are placed in contact with an aqueous solution or moist weathered rock. Potentials so developed depend on concentrations of certain ions. The principle of the method is not new and was applied, in various modifications, by agricultural physicists[64] in rapid measurements of soil acidity.

Among a number of suitable selective electrodes, the Ts.N.I.G.R.I. laboratory has developed and tested in the field the so-called platinum-lead-peroxide electrodes. These electrodes indicate sulfuric acid in neutral sulfate solutions.[65] Potentials developed by the electrodes in reference to the calomel half-element may be expressed by the equation:

$$E = 1.34 + 0.023 \log (H^{+})^{4} (SO_{4}^{--})$$

Figure 16, earlier in the text, shows a profile of observations obtained by the means of such electrodes for materials over a lead-zinc ore body. In recent years the method was applied with intermittent success in a number of field projects.

Certain fundamental defects, expressed chiefly in a significant inertia of the readings, do not recommend it for industrial use at the present time pending refinements of the method.

The polarographic method (5), (16). The rather complex physical aspects of the method cannot be conveniently discussed here. It may be stated briefly that polarographic analysis utilizes the electrochemical ionic discharge phenomena at the mercury drop electrode (cathode). The instrument, the polarograph, records automatically the curve of electrolysis (current, tension) producing thereby, so to speak, an electrochemical spectrum of the test solution. In general, examination of the polarogram provides a basis for judgment as to the qualitative and quantitative composition of the solution. Polarographic analysis is similar to spectrographic analysis in many respects except that its productivity is lower. The lowering of productivity is due chiefly to the necessity of chemical pretreatment of the sample as well as to relatively complicated apparatus and operational techniques. A simplification of the method is required to suit the demand for rapid field analysis which, incidentally, is one of the research topics being developed by the Laboratory of Physico-Chemical Methods of Ts.N.I.G.R.I. Replacement of the commonly used mercury drop electrode by electrodes made of solid metal, now under study, is of particular interest in this connection.

As indicated, a positive solution of this problem, together with the high sensitivity, reliability, and possibility of automatic recording of results, may give a definitive and an irreplaceable role to the polarograph in the relatively new and uninvestigated field of its application to the aqueous dispersion train in mineralized areas.

VII. Productivity

The following tables illustrate production standards developed by the geophysical group, Ts.N.I.G.R.I., in 1938. The standards are based on the results for 1936, 1937, and a part of 1938.

1. Sampling

Samples are taken with a pick, to a depth of 0.5 meter. A crowbar and a spoon, designed by the geophysical group of Ts.N.I.G.R.I. in 1938, are used for depths from 0.5 to 1 meter.

Table 15. Sampling; productivity standards for metallometric surveys, per team of two laborers and one supervisor per 8-hour working day

Depth	Number of sampling points
Less than 0.3 meter (or from side of trench)	135
0.3 m to 0.5 m	85
0.5 m to 0.7 m	60
0.7 m to 1.0 m	40

The above standards are intended for a 10x40 meter grid, in an area of fairly flat relief, and for loose and fine surficial materials. The standards are lowered, by 25 percent, in extreme cases, in unfavorable topographic environment and in the presence of dense vegetation. They may be lowered also by 20 percent in sticky soils as well as in the presence of coarsely fragmented materials. Increases in the intervals between sampling points or of distance between the profiles may lower the standards to 10 percent.[66] Selection of samples is made on a prepared grid.

2. Preparation of Samples

Depending on kind and structure of materials sampled, different procedures may be employed in preparing samples for analysis.

Procedure 1. Sample is screened, particles coarser than 2 mm discarded, and on reduction in bulk is pulverized to about 200-mesh fineness.

Procedure 2. Sample is crushed to about 0.5-mm grain size, reduced in bulk, and pulverized to about 200-mesh fineness.

Table 16. Preparation of sample; productivity standards per man-day[61]

Operation	Number of Samples
Screening and reduction in bulk	120
Grinding and reduction in bulk*	70
Pulverization of reduced sample (5 g to 10 g) to 200-mesh fineness	60
Concentration of 400 g sample to about 20 g–5 g by panning	60 to 100

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* The standard may be reduced to 35 percent for particularly hard materials.

3. Analysis

(a) Spectrographic determinations (based on experience with tin and tungsten).

Table 17. Spectrographic analysis; productivity standards in number of samples per man per 8-hour working day

Operation	For a stationary sylvin spectrograph G.O.I. (U.S.P. – 1)	For a field spectrograph G.O.I. 1936 model (autocollimation)
Preparation of spectrograms and their logging (without interpretation)	140	100
Charging carbons	180	180
Cleaning and drilling carbons	180	180

Standards for the charging and cleaning operations presuppose manual work with a file and a drill.

(b) Spot tests and other wet methods.

Table 18. Wet methods; productivity standards per team consisting of one operator and one laborer, per 8-hour working day

Method	Number of Samples
Drop analysis for either one of Cu, Ni, Co, Ag	80
Nephelometric	80

In cases where the final extracts are used for determination of more than one of the metallic constituents, the above-shown standards are reduced by 20 percent (as regards the number of samples) for every additional element.

The standards presuppose performance of all necessary operations in accordance with the technical manual, beginning with preparation of weighed aliquots and ending with logging of the samples and of the analytical results.

The cost of one sampling point, including the overhead due to travel expenses of the team, based on the spectrographic productivity standards, is between 6 and 7 rubles and is somewhat higher for the wet methods.

VIII. Applications of Geochemical Method

1. Integrated Utilization of the Method

Field experience and the very nature of our subject indicate the necessity of geochemical investigations in reasonable and complete coordination with geologic, geophysical, and mine exploration studies, either as an auxiliary or as a guiding method. Discussion of the entire integrated group of reconnaissance-prospecting methods, including the geochemical, is outside the scope of the present paper.* It is sufficient here to formulate some generalized and fairly evident propositions.

I. In an integrated geologic survey, discovery of the components of the dispersion field, together with indications of their intensity (not accessible to the unaided eye) may well become a decisive element in the investigation, liberating the prospector from the necessity of collecting samples of doubtful value in the area. Experiments of this character by Ts.N.I.G.R.I. in 1938 were given a favorable appraisal.

II. The geochemical method offers greater possibilities in the solution of special problems related to metallization of an area than the petrographic-mineralogic method, as it embraces a larger group of the valuable elements.

III. In detailed prospecting in an area with detailed geologic coverage, field experience in coordination with the geophysical methods shows that:

1. Geochemical methods may be useful in evaluating anomalies established by the geophysical methods, particularly by the electrometric and magnetometric surveys.

2. Geochemical methods serve to establish anomalies in metalliferous zones of the prospected area, with subsequent detailed localization of the outcrops by other geophysical means or by trenching. Actual coordination of the methods is determined, in every case, by specific environmental conditions and by the genetic features of the deposit.

2. Interpretation of Results and Possible Prospecting Conclusions

Direct results of the tests, that is, concentration values of the dispersion field indicator, are mapped together with reasonably complete orohydrographic data. Depending on the scale of the investigation, the geochemical anomalies may be shown by dots, profile curves, or isograds. The results are evaluated against the background of the entire complex of prospecting indications for the given area, with due consideration for the genesis of the deposit and for the

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* This problem is considered, in part, in the monograph of M. V. Iuneev, L. D. Bersudskii, and G. L. Padalka, on application of geophysical methods to prospecting for tin.

degree of regularity in the development of the field and of the halo of dispersion. Omitting the relationship previously discussed, it is necessary to emphasize the usual lack of correspondence between the peak of the accumulation values of the indicator in the upper horizons of loose materials and the location of buried outcrops. A maximum displacement for the mechanical dispersion halos, as previously shown in a vein deposit, will be in the environment shown in figure 6. The extent of displacement, as observed in a number of areas, may attain tens of meters (27), (42). Position of buried outcrops, on the basis of the peak, may be determined only approximately. Only the direction in which the buried outcrops should be sought may be determined with certainty. The intensity of the displacement and the extent of dislocation of the halo may be surmised from the gently descending branch of the asymetric profile curve. Supplementary sampling of the lower horizons, guided by the profile of the anomaly, may clarify the relationships. The horizontal profile[67] [*] may yield apparently exact locations of buried outcrops. In geophysical practice, where the outcrops are located commonly by other geophysical methods, regularities in the displacement of the halo must not be overlooked. The same applies to the converse problem: establishment of metallization of a geophysical anomaly.

Conclusions that may be drawn from geochemical prospecting data may now be enumerated:

1. A surmise regarding general metallization of a plat or of an area.
2. A surmise regarding metallization of a plat within a geophysical anomaly.
3. A surmise regarding the extent of buried outcrops or of the ore-bearing zone.
4. In favorable environment, a direct location of buried outcrops.
5. A concept as to the relative economic value of the upper part of the deposit which served as the parent material of the dispersion halo.[†]
6. Components of the dispersion field, ascertained in the course of prospecting, provide additional orientation for further prospecting.

Moreover, the geochemical method sometimes may yield results that may rather suddenly introduce radical changes into the economic evaluation of the area as, for example, the discovery of nickel in concentrations of the same order of magnitude as copper, in the Chibukhlin copper deposit (21).[31]

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[*] The necessity of a narrower spacing of samples taken in the vertical profile should not be overlooked.

[†] It is understood that rigorous account should be taken of the geologic-petrologic environment and of the conditions that led to the formation of the halo.

The geochemical method, in addition to its direct utilization as a first-hand study of the dispersion fields, may be employed successfully and economically in secondary problems more or less related to prospecting. For example, an estimate of the content of valuable metals in cores, tailings, mineralogic-petrographic samples, etc., may be made by the same testing procedures.

This reduces the expense that would be required otherwise in quantitative analysis, by excluding definitely barren or very lean samples. In this connection it must be emphasized that geochemical methods have no claims whatsoever in competition with more reliable quantitative analyses. It would be erroneous, of course, to overlook the possibilities of rational combinations of the components of different methods. Thus a combination of spectrographic analysis with panning of the sample for tin may make it possible to trace dispersion fields of tin in concentrations of 0.00001 percent in the sample.

3. Field Projects

This report is based on experimental and industrial data of integrated geophysical field parties of Ts.N.I.G.R.I. obtained in four years (1935 to 1939).*

The geochemical method was utilized recently by a number of other prospecting organizations, including the All-Union Arctic Institute (V.A.I.), the Union Nickel-Tin Reconnaissance, and regional geologic offices. The results obtained by these organizations were made available in the discussion of the present problems.

The majority of field reports, as stated in the Introduction, are deficient for a number of reasons, from the viewpoint of the modern requirements of the geochemical method. Verification of geophysical anomalies by exploratory mining is not included in the program of the geophysical parties for obvious reasons. The geophysical group of Ts.N.I.G.R.I., with individual exceptions, on fulfillment of its contract obligations would lose its contact with the industrial operation and would receive no information on further explorations. Tangible results of the field projects consisted therefore chiefly of the geophysical anomalies and of the appropriate recommendations.

The geochemical method is somewhat better placed in this regard inasmuch as its results consisted of:

1. Demonstration of the presence of ore in a given area, without any detailed study of the dispersion halo proper.

2. Establishment of the presence of halos accompanied by a degree of localization of the outcrop[68] on the basis of electrometric and magnetometric

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* From 1932 to 1935 scattered observations were made by individual geophysical parties, with the aim of demonstrating the existence of dispersion halos.

prospecting. The industrial significance of the first type of result is obvious. The second type of result, as distinct from other geophysical methods, yields unique indications of the presence of metallization. The next stage of prospecting may consist of an appraisal of economic significance of the mineralization causing the observed halo.

It is evident from the above considerations that trenching and excavation in the area may be reduced to a reasonable minimum with the aid of intelligently conducted geochemical investigations. In areas characterized by complex structures and by weak electric and magnetic geophysical fields, the geochemical method has a pre-eminent significance, as compared with other geophysical methods. In such cases, its economic usefulness is already evident, as it offers possibilities of solving prospecting problems formerly not accessible to geophysics.

With due consideration to the above, we should examine now the following list of field projects, together with a brief account of their peculiarities and results.

1. Khapcheranga, 1935. Supervisor A. P. Solovov. Object of prospecting: tin-bearing veins of the quartz-cassiterite and sulfide-cassiterite type. Indicator of the dispersion field: tin. Method: spectrographic analysis. Some 3000 tests, made in one season. The investigations had experimental-productional aspects. The principal methodologic result was a proof of accessibility of the dispersion halo of the main tin ore bodies, to observation by the simplest spectrographic techniques. Economic results: discovery of "spectral"* vein by its dispersion halo.

In the area of one anomaly established by the same investigation, the economically valuable Vodorazdelnaia ("water divide") vein was discovered in 1938. A stationary spectrographic laboratory established by the expedition was employed in subsequent years for rapid determinations of tin in a variety of materials, particularly in sludges from drill holes.

2. Sherlovaia Mountain, 1935. Supervisor A. P. Solovov. A small amount of work, about 400 determinations, by methods developed in the Khapcheranga project, indicated the suitability of the metallometric survey in prospecting problems and demonstrated the extent of mineralization with respect to tin in a number of areas.

3. Buurdu, North Kirgiziia, 1935. Supervisor I. S. Sidorov. A lead-zinc deposit. An extensive rich[69] ore body. Study of the sulfate solutions by the electrode polarization method. Positive results in outlining the halo, as shown in figure 16.

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[*] Detailed study showed that stannite is the principal tin mineral in the spectral vein.

4. Zyrianovskaia group, Altai, 1936. Supervisor S. D. Miller (16). Experimental observations on dispersion halos of polymetallic deposits. A number of methods applied: polarographic, spot tests, potentiometric, spectrographic, in the study of the dispersed complex (Pb, Cu, Zn). Methodologic results, in the main, are reflected in the present paper. See also figures 10, 19.

5. Nagol'nyi Range, 1936. Supervision S. B. Fridman and E. A. Maiorova (43). Experimental observations on dispersion halos of polymetallic deposits. Analysis by the wet methods: spot tests for zinc, lead, and copper. More than 2000 tests.

Proof of the existence of dispersion halos at such deposits, which are particularly difficult for the application of geophysical methods, may be regarded as the principal result of the project. See figure 11.

6. Inder Boron Deposit, 1936. Supervisor A. M. Vinogradov (15). Spectrographic determinations of boron. Approximately 12,000 determinations. It was shown that the ore bodies lying in boron-bearing clays directly beneath the alluvium possess dispersion halos. A borometric survey, however, on account of its insufficient precision, received no adequate economic evaluation. *

7. Smirnov Deposit, 1936. Supervisors M. V. Iuneev and R. S. Zaidina. Standard stannometric survey. 4,200 determinations. Results: establishment of the presence of tin in parts of the Smirnov mine area and in the adjoining plats: Rtutnyi, Ildikan, Bezymiannyi, and Sernyi.

8. Kalba-Narym Area, 1936. Supervisor A. P. Solovov. A small stannometric study (about 400 observations). Results: presence of tin established in a number of places.

9. Badam-bai, 1936. Supervisor I. S. Sidorov. A lead-zinc deposit characterized by a thick oxidized zone. Laboratory analysis for lead chiefly by the polarographic method. Enrichment zones established against the background of a contaminated ore field.

10. Sinanchin Tin Deposit, 1936. Supervisor L. D. Bersudskii (2). Polymetallic tin-bearing veins of sulfide-cassiterite type and rather complex geologic structure. Production problems, with about 5,000 determinations. As a result of an integrated geophysical study (electrometric and magnetometric prospecting), with metallometric applications,

(a) Presence of tin was demonstrated, in a number of new plats;

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* V.S.E.G.E.I., in 1939, conducted geophysical studies at the Inder deposit (B. A. Poklad - field party chief). Preliminary reports indicate a complete vindication of the geochemical method, not merely in controlling the reconnaissance results but also as the means of prospecting in areas not covered by trenching and drilling.

(b) Two new ore-bearing veins were traced (Sedlovinnaia and Perevalnaia);

(c) Usefulness of lead as the indicator element was established.

11. Dzhidin Tungsten Deposit, 1937. Supervisor A. M. Vinogradov. The deposit is of the vein type with complex geologic structure. Tungsten and molybdenum were used as the indicators in the spectrographic analysis. 4,700 determinations. Metallometric survey was the guiding method in the investigation with supplementary electrometric indications. Results: A large number of anomalies established, with well-defined forms of tungsten and molybdenum dispersion halos. Verification of a small number of the anomalies proved the ore-bearing character of the veins in their upper layers in 70 percent of the cases.

12. Chibukhlin Copper Deposit, 1937. Supervisors B. A. Poklad and E. A. Maiorova. Disseminated metallization in tuff-porphyrite rock. Spot tests for copper and nickel (the latter element "discovered" here by the geochemical method). About 2,000 determinations. The project should be appraised as a successful application of the method to halos of the genetic type. Well-defined localized geochemical anomalies of Cu and Ni were obtained. An example of the survey shown in figure 17.

13. Achisai Deposit, 1937. Supervisor I. S. Sidorov. A dispersion halo, outlined with the aid of polarographic determination of lead, corresponding to an electrometrically established anomaly.

14. Prospecting Plat Piaia-Vara, Karelo-Finnish S.S.R., 1937. Supervisor V. N. Shushkevich. Absence of the dispersion halo is shown in glacial lake deposits overlying a molybdenum-bearing quartz vein.

15. Vanchin Tin Deposit, 1937. Supervisor L. D. Bersudskii. Tin-bearing sulfide-cassiterite veins. Production problems, involving about 2,000 determinations were approached by (1) Spectrographic determinations of Pb and Sn; (2) Nephelometric determination of Pb. Suitability of Pb as the indicator was shown. Results of the integrated prospecting (including magnetometric and electrometric studies):

(a) The vein under investigation was traced in a new direction.

(b) Metallization established for a number of areas.

(c) A new ore fissure discovered.

16. Khapcheranga, 1938. Supervisor L. D. Bersudskii (6). Stannometric, and plumbometric survey involving 5,000 determinations. Results:

(a) Series of anomalies established in a number of new prospecting plats.

(b) A check on the central field gave identical results with the data obtained by trenching in demonstrating presence of the ore.

(c) Certain essential problems relating to the shape of the halos and field techniques were clarified.

17. Prospecting plat in vicinity of Kalgachikha village (Lake Onega Region), 1937. Supervisor A. I. Katskov. Object: nickel ores in peridotite. Spot tests employed in the investigation of fragmented materials of landslides in the prospecting area. Genetic obscurity and the coarse size of the material make it difficult to evaluate the map of nickel isograds. Presence of nickel in water reservoirs in the peridotite area was established by the party.

18. Chromite Deposits of Mugodzhar Region, 1938. Supervisor R. S. Zaidina. Experimental chromometric survey to test suitability of the method; spectrographic analysis, in the visible part of the spectrum; 800 determinations. The main result is discovery of rich dispersion halos over the ore bodies. Existence of a peculiar halo in the contact between the crystalline rock and the overlying chalk is also of interest; extent of the halo within the chalk – up to 1 meter. Figure 13 shows the diagram of the halo over the chromite deposit overlain by the chalk, up to 2 meters thick.

19. Nagol'nyi Range, 1938. Supervisor E. A. Tkachenko. Problem: participation in the integrated geological reconnaissance in the area. Volume of work: about 6,000 determinations. A group of metals, chiefly lead, examined spectrographically and nephelometrically. Preliminary data serve to elucidate the ore-bearing character of the prospected plats.

20. Beginning in 1936, the All-Union Arctic Institute has been conducting reconnaissance-prospecting studies for ores, with application of the geochemical method (as a part of integrated geophysical reconnaissance). Available data indicate positive results (27).

IX. Conclusions

1. The geochemical prospecting method was developed empirically to satisfy the needs of geophysical reconnaissance in ascertaining direct evidence of mineralization in the field.

2. Geologic background of the method may be indicated by the following scheme:
   (a) An ore body within the weathering zone enters the *dispersion phase*[70] of the basic cycle of matter in the earth's crust and develops a *field of geochemical dispersion.*

(b) The field of geochemical dispersion, extending away from the ore body into surrounding materials, develops in three successive stages: *the dispersion halo* of the ore body; *the dispersion train;* and the secondary accumulation, with respect to the element in question.

3. The dispersion halo and the dispersion train may be accessible to observation at the surface. Their study may become the means of establishing the presence of geochemical anomalies for the element in question. This is the substance of the geochemical method.

4. The above possibilities are contingent upon the accessibility of the materials to be observed or tested. The latter depends on a number of factors peculiar to the ore body itself and to its geologic environment. Correct choice of the indicator element is essential, as well as sensitivity of the testing method.

5. Application of modern analytical techniques, particularly spectrographic analysis and spot tests, are indicated by the field environment in which the geochemical method is utilized. These methods are rapid, inexpensive, sensitive, and universal; they afford the means of study of the dispersion of a large group of economically important elements.

6. Semiquantitative determinations of the element sought (or of some other element or substance serving as *the indicator* of the dispersion field) in surficial materials constitute the field application of the method. The field work comprises two stages:

(a) Sampling on a grid pattern; the grid is based on a working hypothesis as to the mechanisms responsible for the development of the dispersion field in question.

(b) Testing of the samples by the simplest spectrographic or analytical techniques.

Field testing procedures have been developed so far to include the following elements: Sn, W, Mo, Cu, Pb, Zn, Ni, Co, B, As, Sb, Cr, Mn.

7. Field data obtained by the geochemical method, in conjunction with geologic and geophysical data, are instrumental in the solution of the following problems:

(a) Nature or kind of mineralization – areas insufficiently investigated geologically.

(b) Location of buried outcrops, in detailed prospecting.

(c) In appraising exploration work, as a guide to further investigations.

8. The geochemical method has been employed so far chiefly in conjunction with geophysical prospecting for primary deposits of tin, tungsten, molybdenum, and other metals. Locally, the geochemical method served as a guide for the entire investigation.

9. The present discussion of the principles of the geochemical method is the first systematic and fairly broad treatment of the problem. The results should be conducive to a proper application of the method in industry to facilitate a rapid and inexpensive solution of prospecting problems. The results should be conducive also to further development of the method, expansion of the prospecting program, increase of knowledge of new kinds of dispersion, improvement of testing procedures, and further growth of the industrial possibilities of the method.

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Translator's remarks:

The larger part of the bibliographic list has been translated in the same order and form as appears in the original, except that titles have been translated. An asterisk (*) before the author's name indicates that the reference has been checked, and page numbers added. Some of the items refer to Russian translations of European or American papers and texts, and where these could be identified, the correct non-Russian author and title are given. The dates assigned to such translations apparently refer to the date of issue of the translation rather than the date of the original. "O.N.T.I." stands for the United Scientific and Technical Publishing House. This was superseded by the "G.O.N.T.I." or National Scientific and Technical Publishing House.

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(45) Sheibe, G., Khimicheskii spektral'nyi analyz (Spectrochemical analysis): O.N.T.I., 1938.

(46) Emmons, W. H., Vvedenie v uchenie o rudnykh mestorozhdeniiakh (Introduction to theory of ore deposits): Gosizdat, 1925. (Probably a translation of: Principles of economic geology, McGraw-Hill, 1918.)

(47) Emmons, W. H., Vtorichnoe obogashchenie rudnykh mestorozhdenii (The enrichment of ore deposits): O.N.T.I., 1935. (Probably a translation of U. S. Geol. Survey Bull. 625, 1917.)

(48) *Hoffmann, Malvin G., Advance in exploration by soil analysis methods: Oil and Gas Journal, vol. 37, no. 44, pp. 23-24, 115, March 16, 1939.

(49) *Penck, Walther, Die morphologische Analyse: J. Englehorn, Stuttgart, 1924.

Translator's Remarks

[1] "Starshii nauchnyi sotrudnik" appears to be an equivalent of the U. S. Civil Service Commission rating of P-5 or P-6.

[2] "Fiziko-khimicheskii," in reference to the prospecting method developed by Sergeev's group, is translated by me as "geochemical." The two designations appear to be equivalent in the usage of their respective originators. It may be remarked that in Sergeev's method there is some chemistry, a small amount of physics, but very little physical chemistry. The use of "physicochemical," however, is not wholly offensive to the Russian reader.

[3] V.S.E.G.E.I., Vssoiuznyi Nauchno-Issledovatel' skii Geologicheskii Institut, "the All-Union scientific-investigational geologic institute" or the National Institute of Geologic Research. The English equivalent appearing on the cover of the magazine is "The Soviet Union Geological Institute (V.S.E.G.E.I.)."

[4] Ts.N.I.G.R.I., the predecessor of V.S.E.G.E.I., is "Tsentral'nyi Nauchno-Issledovatel' skii Geologichesko-Razvedochnyi Institut," literally translated as "The central scientific-investigational geologic-prospecting institute."

[5] I have divided this long introductory sentence of the original into two.

[6] "Understood and presented" is my poor rendition of "osveshchaiutsia," "are illumined."

[7] The sentence is an extrapolation of the rather terse original.

[8] Extrapolation of the terse original has led, in this case, to a slight distortion of the sense, which I could not avoid.

[9] The long sentence of the original is simplified with changes in construction. The page-long single paragraph of the original was split, in translation, into four parts dividing also some of the involved passages into simpler sentences.

[10] The old geological committee appears to have resembled, in its organization and functions, the U. S. Geological Survey.

[11] Probably refers to White, C. H., Prospecting for disseminated copper by a study of leached croppings: Eng. Min. Jour. Press, vol. 117, pp. 483-488, 1924.

[12] "Eluvium," translated as "loose materials."

[13] "Isokupriki" for "copper isograds."

[14] "Gornorazvedochnye raboty," "exploratory mining works."

[15] "Rudnost'," "ore'ness."

[16] "Physico-chemical" in the original.

[17] In the original "Dispersion of deposits of valuable elements," "Rasseianie mestorozhdenii tsennykh elementov."

[18] "poias," belt.

[19] Title supplied by me; the original has none.

[20] The ratios of P:K are expressed as 10^n (ten to the n-th) in the original.

[21] "Geochemical anomalies" is used by me in suitable places throughout the translation; the original has "unusually high concentrations," "abnormally high," and similar expressions.

[22] "Dispersion" is "dispersiia" throughout the original. The author's misgivings, stated in his accompanying footnote, could be avoided perhaps in the English usage by substituting "dissipation" for "dispersion," reserving the latter term for what may be called the basic phenomenon of geochemistry.

[23] "Eluvium-deluvium" in the original. This expression is translated as "overburden," "loose materials," or "soil materials," as distinct from "soil." Elsewhere the eluvium-deluvium is used untranslated.

[24] In the original, "extension of concentrations of the characteristic component of the deposit in accordance with the simplest regularity." This 16-word expression (8 words in Russian) I translate as "geochemical anomalies."

[25] This 55-word sentence (37 words in Russian) is translated, by way of an example, rather closely except that I placed the subject at the beginning. In the original the subject is in the middle of the sentence.

[26] "Potok rasseianiia," lit. "stream of dispersion."

[27] A "pseudo-halo" is leptologically not quite the same as "false halo" but sounds better to me.

[28] The author means probably "the local phase of the great cycle."

[29] "Formation of the halo of the field of physicochemical dispersion." I translate Sergeev's "physicochemical" as "geochemical" only in reference to the field methods used.

[30] "K," unexplained, is apparently the inevitable "constant."

[31] Apparently a mistaken reference.

[32] Literally "fractures of sliding."

[33] This discussion makes use of both "row," "riad," and "layer," "sloi" in such a manner as to make me wonder whether these two terms, in the author's usage, are interchangeable.

[34] In this and in the following equations, I replaced the Greek letters by their names and the division bar by ÷.

[35] Presumably t =time.

[36] "Deluvial cover," or "deluvium" in this case, means really "the overburden." There is no reason for us, however, to reject the Russian terms "deluvium," "eluvium," and "eluvium-deluvium." They could be reserved for use in geochemical prospecting.

[37] "g/t" means "grams per ton" or parts per million. The "hundredths normal" sulfate, i.e., tens of e.p.m. is very common in semi-arid climates and not all exceptional as the author (and possibly Emmons) seem to believe. See "South Coastal Basin Survey," Calif. Div. Water Res. Bul. 40A and the USDA Western Irrigation papers.

[38] Original "accessibility (not feasibility) of utilization of halo of dispersion in prospecting."

[39] "Relatively remote" is "menee perspektivny," "have less of the perspective."

[40] "Geochemical anomalies"; in the original: "points of anomalous significances of concentrations of the indicator of the field of dispersion." A succession of genetives is neither good nor bad Russian; it is soporific English.

[41] "Economic appraisal"; in the original: "elucidation of metallization."

[42] "The blank," in our usage.

[43] "Longitudinal downslope extent of the halo." In the original: "characteristic for the region magnitude of the development of the halo in the direction of downward removal of the detritus" (20 words for 10 words of the original).

[44] In other words, a (40 to 50) meter by (5 to 10) meter grid.

[45] "Horizon," here and elsewhere in the paper, is used in a loose sense and is not the same as "horizon" of pedologists.

[46] "Razubozhenie," poorly rendered as "weakening," is a highly expressive colloquial term.

[47] The original has "kilometers," the second major misprint; the article, on the whole, is remarkably error-free.

[48] "Sypuchka," friable material, colloquially.

[49] That is, a halo in the country rock.

[50] "Shtanga" as "drill pipe ' may be inaccurate.

[51] I.e., the mill is not cleaned between the successive grindings.

[52] Original: "methods of express-analyses"; the picturesque original expression is sacrificed again.

[53] This is apparently an instrument similar to the Adam Hilger "Steeloscope" used for sorting scrap metal.

[54] Original contains notation "(53)" at beginning of title of table. This may be an erroneous bibliographic reference.

[55] "National Optical Institute." "Gosudarstvennyi" is not quite "national" nor is it "State" or "government." In the modern Russian usage, the term in question, despite the etymological and other differences, had acquired the meaning of "national."

[56] I do not know the significance of these recurring initials.

[57] Original contains notation "(26)" at beginning of title of table.

[58] The original has no title.

[59] See note 54. The Hilger Steeloscope does not measure the spectrum photometrically and the "stilometer" mentioned here may be a different instrument than the "Stillometer" mentioned previously.

"Disadvantages"; in the original "a weaker technical armament."

[60] Original: "Methods of drop indication."

[61] No title in the original.

[62] "Buryi" is a somewhat indefinite color, in Russian usage.

[63] "Ciphered" in the original; apparently, the analyst was tested, as well as the method.

[64] A strangely obsolete application.

[65] A neutral solution should not contain any ionized acid.

[66] "Do 10%," i. e., down to 10%

[67] "The horizontal profile" means a lateral distribution of geochemical anomalies in a section.

[68] Original: "establishment of halos with a greater or lesser degree of localization of the outcrop of the ore body."

[69] "Moshchnyi" is "powerful"; my translation is inexact.

[70] The italics are mine, throughout the "Conclusions".

Note: A dictionary-minded reader of Russian may be confused occasionally by words seemingly identical with English words but having a restricted meaning, in some professional languages. Examples of such *occasionally restricted* meaning, drawn from Sergeev's paper may serve to illustrate the point:

Russian	English equivalent
Instruktsiia, instruction	Manual (of operating procedures) or a prescribed procedure.
Fondy, funds	Files (office records)
Element, element	Component
Kompleks, complex (adjective)	Integrated
Partiia, party	Team (also a naval technical school)
Kontrol, control	Verification, checking (also auditing).

IONIC METHOD OF GEOPHYSICAL PROSPECTING

E. A. Sergeev and A. P. Solovov

Translated and abstracted by H. E. Hawkes

From Central Geological and Prospecting Institute, Geophysics, Fascicle 3, pp. 1-10, 1937.

Sergeev, E. A., and Solovov, A. P., Ionic method of geophysical prospecting, Materials of the Central Geological and Prospecting Institute, Geophysics, Fascicle 3, pp. 1-10, 1937. Translated and abstracted by H. E. Hawkes.

Sergeev, E. A. i Solovov, A. P., Ionnyi metod geofizicheskikh poiskov: Materialy, Geofizika, TsNIGRI, Sbornik 3, st. 1-10, 1937.

1. Introduction and 2. Physicochemical Basis of the Method with Respect to Geology

(Abstract)

The author discusses the need for new prospecting methods, and describes the research work of the Central Geological and Prospecting Institute (TsNIGRI) on developing methods. He outlines the process of dispersion of material in the soil from the weathering of ore deposits, and the formation of halos of dispersion. He points out that mine waters contain sulfate, and that soils near oxidizing ores also should contain sulfate carried in ionic form in the soil moisture.

3. Method of Electrochemical Surveying for Salt Halos

(Translation)

The salt-halo method is based on the following considerations:

It is a well-known fact that the electrical conductivity of most minerals is conditioned by the presence of capillary moisture, and is hence dominantly electrolytic. Thus the contact of an electrode with the soil is effectively a metal-electrolyte cell, with all the physicochemical properties of such a cell. The potential at such an interface is a function of the character of the electrode and of the composition of the electrolyte. In conventional natural potential surveys, an attempt is made to eliminate this effect by using nonpolarizing electrodes. However, measurement of electrode potentials may be useful in prospecting if the material of the electrodes is specially selected for the purpose of reacting with specific soluble components of the soil. The method of electrometric determination of soil acidity (pH) has been well developed by soil science. However, that is essentially different from our method of distinguishing different soil components by using selective electrodes.

The theoretical possibility of this type of electrode arises from the following well-known facts. In aqueous salt solutions, the number of dissociated molecules in the solution and the concentration of the resulting ions is given by the equation:

$$\frac{(C_A)^m \ (C_K)^n}{C_M} = K \tag{1}$$

where C_A is the concentration of anions,
C_K is the concentration of cations,
C_M is the concentration of undissociated molecules, and
K is a constant depending on the characteristics of the electrolyte.

Furthermore it is known that any metal when immersed in a solution of its salt acquires an electrical potential (P) with respect to the solution according to the following relationship:

$$P = P_0 - \frac{RT}{nF} \ln \ C_K \tag{2}$$

(Presumably R is the gas constant, T is the absolute temperature, n is valence, and F is Faraday constant. H.E.H.)

From this it is apparent that the potential of a metallic electrode is a function depending on equation (1) of the concentration of metallic salts. Thus for each soluble salt we theoretically have a corresponding series of selective electrodes. Practically, however, the situation is more complex, as we now know of only a few electrodes whose potential is a simple function of the concentration. These are well-known electrodes that have been checked by precise measurements.

Laboratory research in the Geophysical Section of TsNIGRI has been conducted on the use of such electrodes for the ions that characterize the zone of oxidation of ore deposits; that is, for the sulfate ion and free sulfuric acid.

First, the lead sulfate electrode may be used in the system:

$$\mathrm{Pb} \big| \ \mathrm{PbSO_4} \ \big| \ \text{Unknown solution}$$

Second is the platinum-lead electrode in the system:

$$\mathrm{Pt} \ \big| \ \mathrm{PbO_2} \ \big| \ \text{Unknown solution}$$

It is apparent that the construction of these electrodes is somewhat more complex than the conventional metallic electrode. In principle the lead sulfate electrode consists of the metal immersed in a solution (with precipitate) of its slightly soluble salt.

The potential of this electrode resulting from the reaction $\mathrm{Pb} \rightleftharpoons \mathrm{Pb}^{++} + 2e$ according to equation (2) conforms with the following formula

$$P_N = P_0 + \frac{RT}{2F} \ln (\mathrm{Pb}^{++}) \tag{3}$$

(Pb^{++}) is the concentration of lead ions forming from the sulfate according to the formula

$$PbSO_4 \rightleftharpoons Pb^{++} + SO_4^{--}$$

The dissociation process follows the rule

$$(Pb^{++}) \times (SO_4^{--}) = S = 1 \times 10^{-8}$$

or

$$(Pb^{++}) = \frac{1 \times 10^{-8}}{(SO_4^{--})}$$

Inserting this in equation (3), we have

$$P_N = P_0 + \frac{RT}{2F} \ln S - \frac{RT}{2F} \ln (SO_4^{--}) = K - 0.029 \log (SO_4^{--})$$

This last equation shows that, in general, the potential of the lead sulfate electrode depends on the sulfate-ion concentration of the solution in question.

We have computed the emf of electrodes coupled with the conventional calomel saturated half-element. Using the last equation, and keeping in mind the known quantities:

P_K = Potential of the calomel half-element in hydrogen = + 0.250 v

P_0 = Normal potential of the lead electrode = –0.130 v

$\frac{RT}{2F}$ = 0.029, when logs to the base 10 are used.

The emf is

$$\begin{aligned} E &= P_N - P_K \\ &= -0.130 + 0.029 \log 10^{-8} - 0.029 \log (SO_4^{--}) - 0.250 \\ &= -0.612 - 0.029 \log (SO_4^{--}) \end{aligned}$$

With this formula, we can construct curves relating emf to sulfate-ion concentration in the solution.

The lead sulfate electrode is prepared by immersing an anode of metallic lead in a solution of sulfuric acid together with a little nitric acid. For certain kinds of work, the coating of lead sulfate thus formed is sufficiently durable and thick. The potential electrode in a solution of alkaline sulfate gives a curve

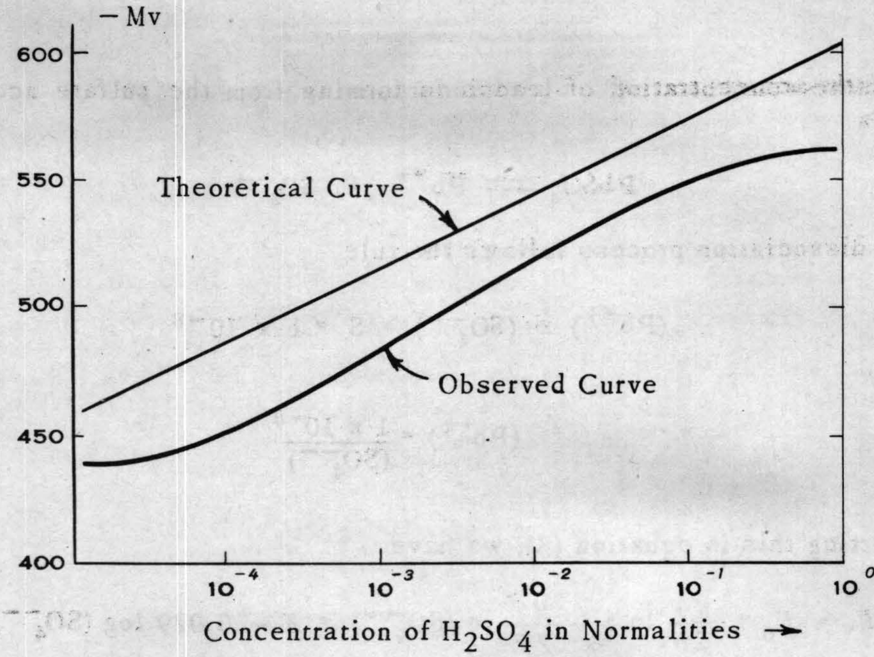


Figure 1

which conforms sufficiently closely to the theoretical curve. Figure 1 is a laboratory curve showing the potential in a solution of neutral potassium sulfate. The straight line in the same graph is the theoretical curve.

The second type -- the Pt PbO_2 electrode -- is of the same type as the electrodes used for determining oxidation-reduction potential. In principle it consists of a noble metal immersed in a solution containing ions of the same metal in different states of oxidation (Pb^{++} and Pb^{++++}).

If *Ox* is the concentration of the oxidized phase and *Red* the reduced phase, we have the equation of Peters

$$P = P_0 + \frac{RT}{nF} \ln \frac{Ox}{Red}$$

In our set-up, these two phases are formed by the partial solution of lead peroxide in sulfuric acid, according to the reactions:

$$PbO_2 + 2H_2SO_4 \rightarrow Pb(SO_4)_2 + 2H_2O \qquad (4)$$

$$PbO_2 + H_2SO_4 + 2H^+ + 2e \rightarrow PbSO_4 + 2H_2O \qquad (5)$$

The basic electrode reaction is:

$$Pb^{++++} + 2e \rightarrow Pb^{++}$$

The potential at the electrode, according to Peters' formula is

$$P = P_0 + \frac{RT}{2F} \ln \frac{(Pb^{++++})}{(Pb^{++})} \qquad (6)$$

The logarithm of the ratio $\frac{(Pb^{++++})}{(Pb^{++})}$ which is a function of the electrode potential, depends on the sulfuric acid concentration, as follows. For processes following equation (4), (PbO_2) = const. and (H_2O) = const., so that by the law of mass action

$$\frac{(H_2SO_4)^2}{Pb(SO_4)_2} = K_1$$

and furthermore

$$\frac{(H_2SO_4)}{(H^+)^2(SO_4^{--})} = K_2 \qquad \frac{(Pb(SO_4)_2)}{(Pb^{++++})(SO_4^{--})} = K_3$$

Therefore

$$\frac{(H_2SO_4)^2}{Pb(SO_4)_2} = \frac{K_2{}^2(H^+)^4}{K_3(Pb^{++++})} = \frac{K_4(H^+)^4}{(Pb^{++++})} = K_1 \qquad (7)$$

Furthermore, lead sulfate forming according to equation (5) dissociates:

$$(Pb^{++})\ (SO_4^{--}) = K_5 \qquad (8)$$

From equations (7) and (8) it follows that

$$\frac{(Pb^{++++})}{(Pb^{++})} = \frac{(H^+)^4(SO_4^{--})\,K_4}{K_1\,K_5} = K_6\ (H^+)^4(SO_4^{--})$$

Introducing equation (6) for the potential electrode, we have

$$\begin{aligned} P &= P_0 + 0.029 \log K_6\ (H^+)^4(SO_4^{--}) \\ &= K_7 + 0.029 \log (H^+)^4(SO_4^{--}) \end{aligned}$$

Thus the potential of the platinum-lead electrode depends on the fourth power of the concentration of hydrogen ions of free sulfuric acid and the first power of the concentration of the sulfate anions in sulfate solution.

This provides a basis for interpretation of the selectivity of this electrode in sulfuric acid solutions, with sufficient accuracy for our purposes.

The emf of our electrode paired with the saturated calomel electrode for sulfuric acid solutions is

$$E = +\ 1.34 + 0.029 \log (H^+)^4(SO_4^{--})$$

The electrode is prepared by immersing a platinum anode in a solution of lead nitrate. In this treatment the platinum is coated with a reddish-black deposit of lead peroxide. Fig. 2 shows a curve of potential as a function of sulfuric acid concentration. The straight line on the same graph is the theoretical curve.

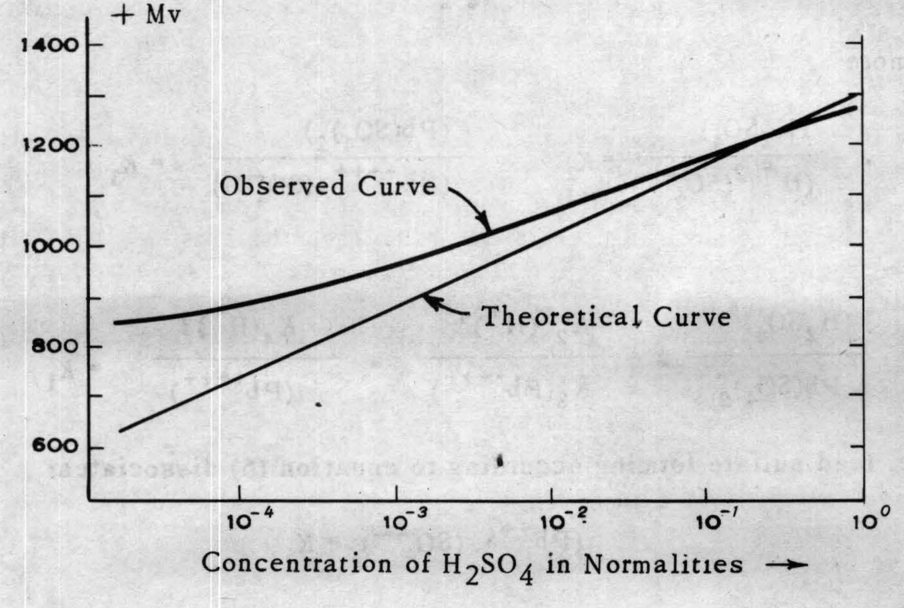


Figure 2

In the laboratory experiments, the potential of this electrode was apparently not affected by the presence of cations of alkali metals, alkaline earths, and such ions as Cu, Fe, and Zn.

It should be mentioned that our computed formulas for the potential of the electrodes will not serve to determine the absolute values of the concentration of ions, but only show the conformity of the experimental observations with the theoretical principles.

4. Field Methods

(Translation)

Beginning in 1932 numerous experiments have been conducted in the field on potential electrode measurements to determine the concentration of oxidation products of sulfide ore deposits.

In the Altai in 1932, N. N. Sochevanov obtained the first encouraging results. The investigation was subsequently repeated by P. F. Rodionov (Central Urals, 1933), N. I. Sofronov (Southern Karelia, 1934), and N. N. Sochevanov (Southern Urals, 1934); but their surveys were not sufficiently systematic, and their electrodes gave them somewhat erratic results. The results of this field work, apart from its promising character, could not serve as a basis for any definite conclusions.

However, the small amount of field work done up to the present time and the results of laboratory work do provide a basis for outlining the methods of field procedure.

Ion concentrations are observed in soil solutions at individual points along a profile normal to the strike of the ore deposit. The potential of the polarizing electrode is measured by a simplified potentiometer by comparison with a normal calomel (or other nonpolarizing) electrode placed in the surface soil at the observation station. In the areas where the water table is low, the second active electrode may be placed in a small bore hole deep enough to reach a moisture-bearing layer. In the absence of such conditions, the active electrode may be placed in simple contact with moist soil, at a depth sufficient to eliminate the effect of the humus layer.

Field data may be presented graphically, with distances on the abscissa and potential values on the ordinate. Depending on the characteristics of the region, the electrode potentials, which indicate the ion concentration, may be interpreted in terms of sulfide mineralization.

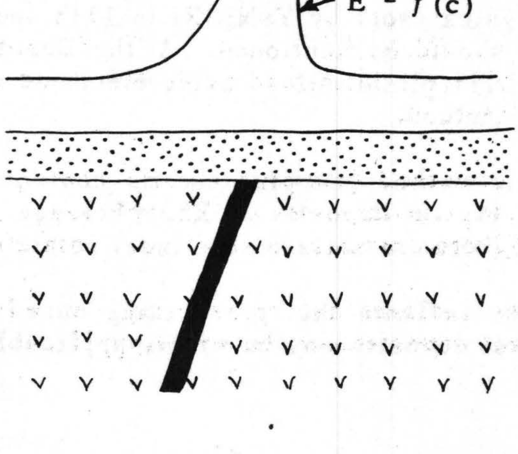


Figure 3

Fig. 3 shows an idealized curve of electrode potentials as a function of the concentration of oxidation products of sulfide ores.

For checking such anomalies, a consideration of drainage conditions and mode of occurrence of the ore deposits is necessary.

It should be mentioned that very favorable conditions for such observations may exist at depth below the water table. Under some conditions, a common difficulty might be excessive dryness of the soil, so that conditions of ionic equilibrium would not prevail. In such cases, the soil in the hole may be moistened. The resulting dilution apparently lies within permissible limits, so that the general constancy of conditions is maintained. Under particularly unfavorable conditions, a sample of soil slightly moistened in a small vessel may be subjected to electrometric tests.

This method may be useful as a check on anomalies obtained by other geophysical methods. First, it may be possible to classify natural potential anomalies according to whether they represent indications of carbonaceous slates or are evidence of pyritic mineralization. The ion method may also be used independently, in conjunction with other prospecting methods, on zinc and polymetal deposits, where the unfavorable electrical constants of sphalerite make conventional electrical methods inapplicable.

5. Conclusions

(Abstract)

Oxidizing ore deposits cast a halo of weathering products in the residual soil. Such halos may be identified visually, spectrographically, chemically, or electrometrically, and hence serve as a guide in locating buried ore.

Author's Addendum

(Translation)

Pertinent geophysical work by TsNIGRI in 1935 and completed before publication of this paper should be mentioned. At the Buurdu polymetal (lead-zinc) deposit in Northern Kirgiz, platinum-lead oxide electrode measurements confirmed the validity of the ion method.

The stannometric method (mapping the tin content of residual soils) was successfully used at the tin deposits of Khapcheranga (Eastern Zabaikal) and the borometric method (boron in soils) at the Inder borate deposits.

These successes indicate that prospecting based on the search for dispersion halos of mineral deposits may be widely applicable.

ON A PHYSICOCHEMICAL METHOD OF PROSPECTING FOR MOLYBDENUM IN THE SEMIDESERT CLIMATE OF THE NORTHERN LAKE BALKHASH AREA

N. I. Tikhomirov and S. D. Miller

Translated by H. E. Hawkes

From Razvedka Nedr, vol. 12, no. 2, pp. 34-39, 1946.

Tikhomirov, N. I., and Miller, S. D., On a physicochemical method of prospecting for molybdenum in the semidesert climate of the northern Lake Balkhash area, Razvedka Nedr, vol. 12, no. 2, pp. 34-39, 1946. Translated by H. E. Hawkes.

Tikhomirov, N. I., i Miller, S. D., O fiziko-khimicheskom metode poiskov molibdena v usloviyakh polupustynnogo klimata Severnogo Pribalkhash'ya: Razvedka Nedr, vyp. 12, no. 2, st. 34-39, 1946.

The flat relief of the northern Lake Balkhash area, grading into low hills, together with the lack of outcrops owing to the cover of wind- and water-borne material which almost completely obscures the pre-Quaternary rocks, makes prospecting extremely difficult. Thus, the absence of ore deposits is not assured by negative results of geological observations based on the usual visual methods.

This situation applies in general to all valuable minerals. In prospecting for molybdenum the difficulties are greater because of the leaching of molybdenite in the zone of oxidation, as may be observed for example in the eastern Kounrad tungsten-molybdenum area. Small fragments of quartz on the present surface may show no evidence of mineralization, or at best only traces of ore minerals which could easily be overlooked.

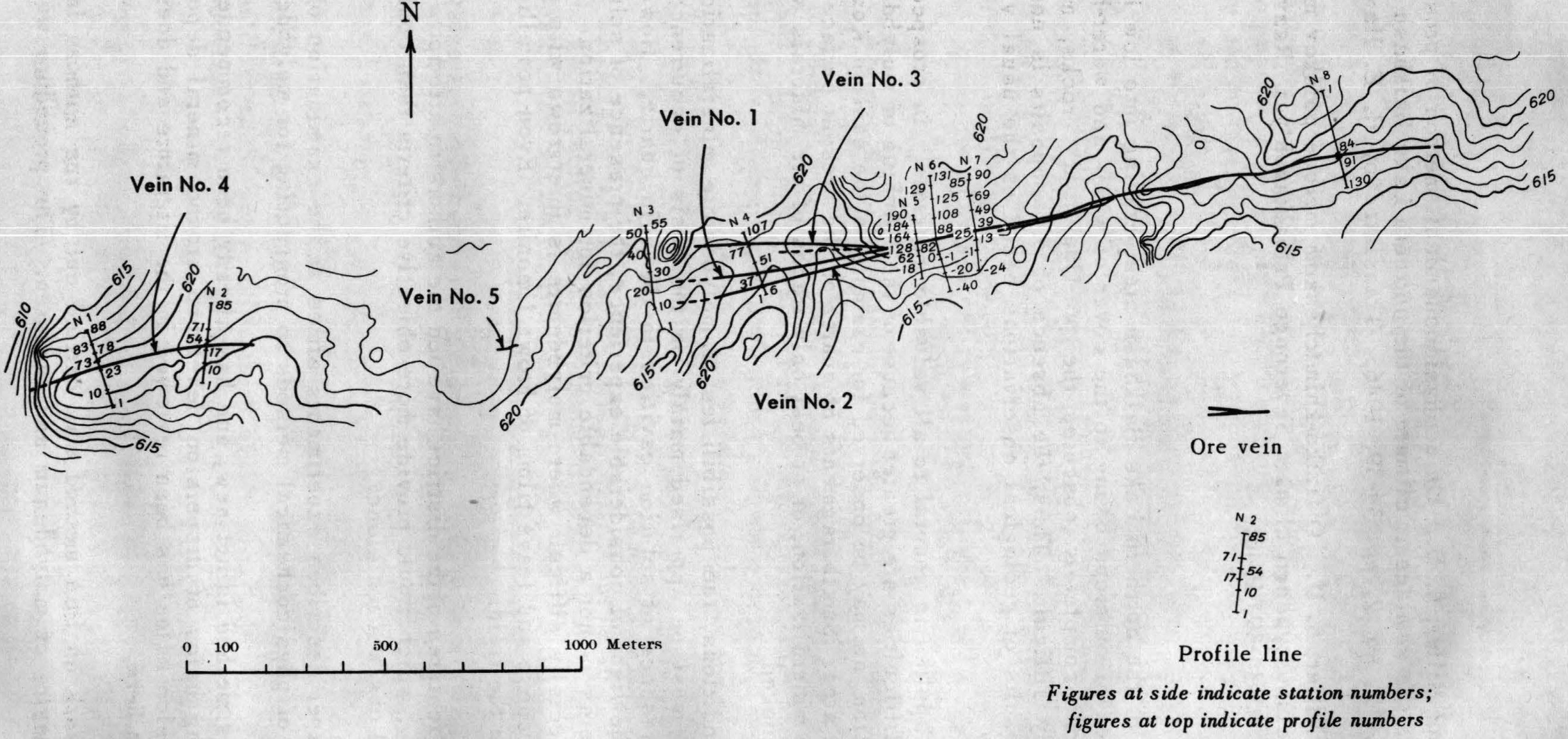
Under such conditions, the possibilities of molybdenite mineralization in vein quartz material must be appraised mainly on the basis of occurrences of powellite and the presence of solution cavities in the vein quartz. However, even interpreted in the light of considerable experience, the presence of solution cavities in quartz veins is not a dependable criterion for mineralization. Such interpretation is especially difficult where molybdenite is intergrown with other sulfides, which decompose and leave films of brown limonite. Even powellite is difficult to identify in the field.

These peculiar features of the district have led the authors to attempt a new method of prospecting, which would provide more objective criteria than could be derived from personal observation alone.

The present paper describes experiments aimed at the examination of the possible application of physicochemical methods to prospecting for molybdenum.

In principle this method is not new, and has already been recommended as a method for locating halos of dispersion developed around mineral deposits. The theory of dispersion halos has been reviewed in the literature and does not need to be dwelt upon here.

Experimental work on this method was carried out by the authors in the eastern Kounrad deposits of molybdenum and tungsten. The procedure was as follows:



Figures at side indicate station numbers; figures at top indicate profile numbers

Figure 1. Plan showing location of profiles for experimental metallometric survey at the east Kounrad tungsten-molybdenum deposit

Across the strike of the main ore vein eight profiles were laid out, following in most places exploratory trenches (figure 1).

Samples of surface material about 200 grams in weight were taken at intervals along the profiles. The sample interval was from 2 to 5 meters, with a closer spacing of 0.5 meter where the profile intersects the veins. The closer spacing near the veins was for the purpose of observing the maximum metal concentration in the halo and the amount of displacement of the peak relative to the veins.

Two profiles, nos. 1 and 2, intersect vein no. 4, which contains primarily wolframite with only minor amounts of molybdenite. One profile (no. 3) was laid out to the west of the main mineralized area, at a place where the ore body, pitching west-northwest, does not come to the surface. Profile no. 4 lies farther east, where vein no. 1 has branched out to form a cluster of veins. In the central, most richly mineralized part of the area, three profiles were run (nos. 5, 6, and 7) at a distance of 50 to 100 meters from each other. The last profile (no. 8) was run across the eastern part of the deposit, to intersect the poorly mineralized eastern extension of vein no. 1.

The surface material which was sampled is the weathering product of biotite granite country rock as well as the vein material itself. The thickness of the overburden varies from 10-20 to 60-80 centimeters, and is composed of fine granitic rubble together with larger fragments and sandy clay material. The size and quantity of fragments of ore material increased with proximity to the ore body.

Samples were collected at the surface, immediately under the thin layer of humus. The fine material in the sample was selected by screening with a sieve with openings 0.8 mm in diameter. After sieving, the sample was quartered down to 10-15 grams, and ground in a porcelain mortar to a size corresponding to 150-200 mesh, as judged by feel. Samples prepared in this manner were placed in paper capsules and submitted for spectrographic analysis.

The spectral analysis was carried out with an ultraviolet spectrograph of the firm of A. Hilger (model E-316, length of spectrum 25 cm). The spectrum was excited by a carbon electric arc using a current of 8 to 9 amperes. The spectrogram was read by comparing the line density with a similarly prepared spectrogram of a standard sample.

The results of semiquantitative analysis for molybdenum and tungsten in the samples are given graphically in figure 2 for each of the eight profiles. In addition, a map is presented (figure 3) showing iso-concentrations of molybdenum in the central part of the area covered by profiles 5, 6, 7.

Analysis of these data and comparison with data from exploratory work at the deposits leads to the following conclusions:

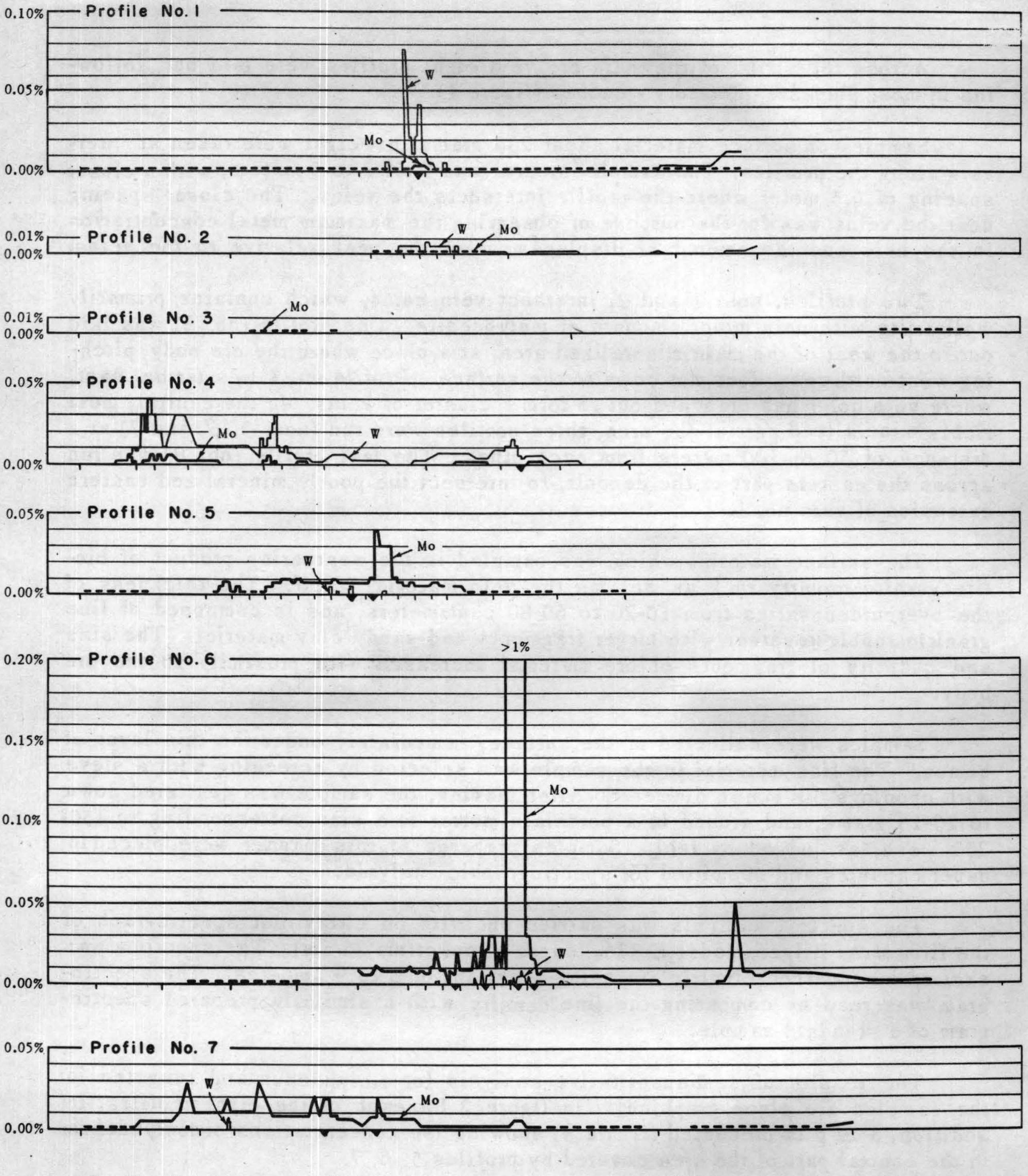


Figure 2. Graph of profiles of experimental metallometric surveys at the East Kounrad tungsten-molybdenum deposits

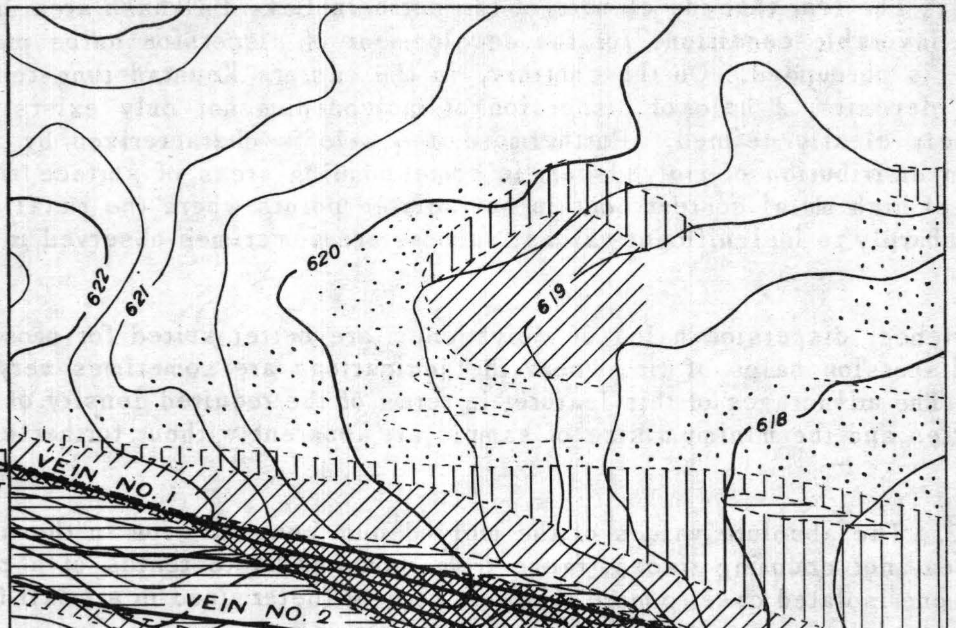


Figure 3. Sketch of the dispersion halo of molybdenum east of shaft No. 2 (after drawing by N. I. Tikhomirov)

1. The fear that the climate of the northern Lake Balkhash area does not create favorable conditions for the development of dispersion halos of molybdenum is unfounded. On the contrary, in the eastern Kounrad tungsten-molybdenum deposits, a halo of dispersion of molybdenum not only exists, but is extremely clearly defined. Furthermore, the halo is characterized by a fairly uniform distribution of molybdenum in corresponding areas of surface material. Areas of high metal content contain no isolated points where the metal content drops sharply to insignificant values, such as are sometimes observed in surveys for tin.

Hence, dispersion halos of molybdenum are better suited for prospecting than dispersion halos of tin, where the indications are sometimes very capricious. The advantages of this feature, in terms of the required density of sample localities and the minimum size of sample, are apparent without further explanation.

2. The absolute values of the molybdenum concentration in the halos of the area, not counting traces, range from thousandths to tenths of a percent, and in one isolated case to more than one percent (determined in a small fraction of the sample).

3. An unquestionable correspondence was observed between the character of the halo and the metal content of the vein below the zone of leaching; in other words, the richest and widest halos correspond with the rich part of the veins.

Thus along vein no. 4, where the molybdenum content is low and tungsten predominates, the width of the molybdenum halo is only 20 to 30 meters, and the molybdenum content is in the order of thousandths of a percent. Along the economic parts of vein no. 1 with its branches, the width of the molybdenum halo reaches 70 to 120 meters, and if concentrations below 0.001 percent are included, the width of the halo will be still greater. Also, the molybdenum concentrations in the halo near the ore body are expressed in hundredths and tenths of a percent (see fig. 3). Over the eastern non-economic parts of vein no. 1, in which the molybdenum content of the vein below the zone of leaching does not exceed hundredths of a percent as observed in test pits and drill holes, a dispersion halo is lacking except as indicated by traces.

4. The epicenters of molybdenum halos in the economic parts of the vein are richer in molybdenum than the oxidized zone of the vein itself. Instead of a "halo of dispersion" we have here a "halo of concentration," even though the general trend of the process is towards dispersion.

5. Wolframite, which is scattered through the ore, also forms dispersion halos. The concentrations of tungsten in the halo, as with molybdenum, correspond with the tungsten content of the ore, although the tungsten halo is narrower (20-30 meters) and the metal content usually is in the order of thousandths of a percent, even along vein no. 4 where the tungsten content approaches 0.1 percent.

6. The regular and smooth lateral variation in the molybdenum content of the halos indicates that the method of sample preparation was sufficiently accurate and that the original size of sample (200 grams) was adequate.

These are the principal results of the investigation. Results of the experiment indicate that spectrometric surveys of metals are possible and suitable for prospecting work, even in molybdenum districts like the east Kounrad where intensive leaching has taken place near the surface. It is also concluded that leaching does not inhibit the formation of molybdenum halos, but in fact contributes to them (provided the halo can be nourished in part from solutions ascending from the zone of oxidation).

However, because of their high cost, regional spectrometric metal surveys are not applicable to large areas which are being investigated by exploration geologists on scales of 1:100,000, 1:50,000, and even 1:25,000. The application of the method will be possible only where new deposits are being sought within known ore fields, or in the vicinity of known deposits where structural or other indications are favorable for continuations of known veins or the occurrence of new veins.

Surveys by these methods may be recommended for large areas where sampling of the surface material over the veins may be substituted for sampling of the vein material itself.

This method was used successfully by the Kazakh Geological Administration (Kazgeolupravlenie) in prospecting for molybdenum in the Lake Balkhash (Pribalkhash) area. The small size of the veins where these experiments were conducted does not detract from the general effectiveness of the method.

The method is recommended for other regions and for prospecting for valuable metals in general.[1]

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[1] Ed.: During the past few years exploratory surveys for molybdenum on the basis of spectrographic analysis have already been used successfully by geophysical parties in eastern Siberia sent out by the State Geological Committee (Geolupravlenie Komitet) for Geologic Affairs and the Trust for Exploration of Western Siberian Non-ferrous Metals (Zapsibtsvetmetrazvedka).