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# SCIENTIFIC PREDICTION OF LIKELY AREAS FOR AGROCHEMICAL ORE PROSPECTING AND SURVEYING 1/

by

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Ministry for Chemical Industry USSR

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SUMMARY

# SCIENTIFIC PREDICTION OF LIKELY AREAS FOR AGROCHEMICAL ORE PROSPECTING AND SURVEYING[1/]

by

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Geological prospecting and surveying operations to find agrochemical ores are carried out on a large scale in the Soviet Union. The correct orientation and proper conduct of these operations is ensured by scientific prediction of likely districts, areas and sectors. The scientific basis for predicting the existence of agrochemical ore deposits is the determination of the geological laws governing their formation and location.

Agrochemical ores are minerals from which fertilizers are produced. The most important are apatites, phosphorites, potassium salts, and sulphur. Industrial deposits of agrochemical ores are represented by the following genetic types: apatites-magmatic, carbonatite, weathered, metamorphic; phosphorites - weathered, sedimentary; potassium salts - sedimentary; sulphur - volcanic and weathered.

Through study of agrochemical ore deposits and the regions in which they occur it has been possible to determine their extent - ore fields, belts, basins, and

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provinces. It has also been possible to establish the basic laws governing the regional structure, formation and location of agrochemical ore deposits (magmatogenic, tectonic, stratigraphic, facieslithological, mineralogico-geochemical, etc.) on the basis of which criteria for predicting such deposits have been worked out.

The geological bases for predicting and prospecting for deposits include magmatic, structuro-tectonic, stratigraphic, facies-lithological, formational, palaeographic, mineralogico-geochemical, and other factors. Signs of agrochemical ore deposits may be outcrops, aureoles areas of oxidation, and isotopic, geochemical, geomorphological, geophysical, and other indications.

In studying the laws governing ore deposit location and working out criteria for predicting deposits, use is also made of geological data accumulated by Soviet specialists in studying agrochemical ore deposits in other countries. The prediction criteria and methods which have been worked out can therefore also be recommended as a guide for ore deposit prospecting and surveying operations in the developing countries. The scientific prediction of agroochemical ore deposits takes concrete form in the preparation of prediction maps on different scales, showing areas with different degrees of probability of the existence of agrochemical ore deposits, which provide a reliable scientific basis for prospecting for new deposits.

The chemisation of agriculture in our country is progressing at a tremendous rate, calling for an accelerated growth of the production of mineral fertilizers, which in 1970 constituted 55,400,000 tons /arbitrary unit/ and in 1975, according to the Directives of the 24th Congress of the Communist Party of the Soviet Union, will total 90,000,000 tons.

The mineral fertilizer industry is developing on the basis of agronomical ore resources, as it is accepted to call mineral resources used in mineral fertilizer production. They include phosphate raw materials /apatites and phosphorites, potassium salts, calcareous rock for liming soil/ ores used for producing microfertilizers /boric, molibdenum, copper, etc./. And finally there are sulphur and sulphur-containing raw materials for obtaining great quantities of sulphuric acid used in the production of mineral fertilizers particularly phosphorous.

Prospecting and geological exploration work is being carried out to an ever-increasing extent in order to provide industry with resources of agronomical ores. It should be stated that in this respect Soviet geologists began from an almost completely barren plain, figuratively speaking. Deposits of potassium salts and apatites were altogether unknown. The knowledge of phosphorites and sulphur was limited only to very small deposits which were primitively extracted. Phosphorous fertilizers and sulphur were in the main exported.

Geological exploration work begun in the USSR resulted in the discovery of numerous very large deposits of agronomical ores such as the Khibini apatites, the Kara-Tau phosphorites, the Verkhnekamsk and Starobinsk potassium salt deposits, the Precarpathian sulphur-bearing basin, as well as a great many others.

The boundless expanses of our country and the rapidly increasing scope of prospecting and exploration work necessitated a substantiated trend of this work, which is ensured by the scientific prediction of perspective districts and areas.

Pre-prospecting prognostic explorations came to be an independent stage of geological work armed with specific methods. This work is carried out by permanently operating exploring parties. As a result of detailed geological studies of the country and the discovery of most of the easily detected surface deposits, and as prospecting work consequently became more complicated and cost-consuming, prognostic exploration work grew increasingly important.

Prognostic work on agronomical ores proved extremely fruitful and led to the discovery of many new areas, deposits and even entire basins. This considerably raised the effectivity of prospecting and exploration work. The aim of this report is to give knowledge of the practice, theoretical basis and methods of the scientific forecasting of perspective areas to be explored for deposits of certain types of agronomical ores - phosphorites, apatites and sulphur.

The prediction of perspective areas to be explored for deposits of agronomical ores, as well as other useful minerals, is scientifically based on the finding of the geological laws of their formation and location.

Discussed below are the laws that have concretely been established for deposits of phosphorites, apatites and sulphur, and the scientific criterion and methods of predicting deposits of these ores.

## Phosphorites

Of the world reserves of phosphate raw materials, which are roughly estimated at 32,000,000,000 tons $P_2O_5$, more than 95% are phosphorites. Numerous phosphorite deposits have been discovered in the USSR, including such large ones of world significance as the Kara-Tau phophorite basin.

Many areas of the USSR, in the European part of the Soviet Union and Central Asia, are highly perspective as phosphorite-bearing regions. These areas are being explored on an ever-increasing scale, such work requiring a scientifically-grounded trend, rational methods and greater effectivity.

All this, coupled with a rapidly growing demand for phosphate fertilizers, and, consequently, for raw material reserves used in producing them accounts for the fact that for a long time in the USSR much attention has been paid to prognostic work in the search for phosphorites. Considerable success has been achieved in this field, primarily because this work has been based on a profound theoretical study of the laws of the formation of phophorites.

It is known that the generally recognized chemogenic theory of phosphorite formation as a result of phosphate settling in shelf regions from rising deep sea water abounding in dissolved phosphorus was evolved in the Soviet Union by A.V. Kozakov.

The formational classification of phophorite deposits worked out by N.S. Shatsky and his detailed analysis of the geotectonic conditions of their formation constituted a significant contribution in the theory of phosphate geology. He distinguished three basic groups of phosphorite - bearing formations: volcano-siliceous, the main phosphorite deposit of which Skalistye Gori /Rocky Mountains, Kara-Tau/ originated under miogeosynclinal conditions; terrigenous-carbonate-platform-like /granulated phosphorites of Africa and the Middle East/ and glauconitic, that is platform-like, including septarium phosphorite deposits.

The outstanding lithologist N.M. Strakhov ascertained the appropriate climatic conditions under which phosphorites form and showed that the concentration of phosphorus in humid zones is attenuated and represented by lean septarian and shelly phosphorites, whereas under arid conditions the sedimentation of phosphorus compounds were intensive and characterised by the formation of prolific deposits of oolitic-microgranular massive /Rocky Mountains, Kara-Tau/ and granular /North Africa, Middle East/ phosphorites.

The works of B.M. Himmelfark, and particularly his fundamental work on the classification and laws of the disposition of phosphorites in the USSR, enjoy great popularity among geologists. His works generalise comprehensive material and the practice of the study of Soviet deposits and provide a theoretical basis of prognostic methods.

The theory of the evolution of phosphorite formation in the Earth's geological history which was evolved by N.A. Krasilnikova is of great theoretical importance for prognostic purposes. It showed that in Pre-Cambrian times phosphorite became deposited chemically as a result of volcanic phosphorus. Subsequent stages were marked by biochemogenic, in addition to chemogenic, sedimentation of phosphorus, and the depths of the ocean became more important as a source of phosphorus. The principal feature of the evolution of phosphorite formation was the transition from predominantly geosynclinal conditions to platform-like conditions with a considerable change of the types of phosphorites and phosphorite-bearing formations.

All these and many other essential theoretical elaborations made it possible to establish the following laws of the formation and disposition of phosphorites, which constituted a firm basis upon which reliable geological prerequisites for prognosticating and searching for them could be substantiated.

The stratigraphic correlation of large phosphate deposits on a planetary scale and in separate regions with a relatively small number of subdivisions of the geochronological column, to which belong:

The Proterozoic and the late Pre-Cambrian eras, including the sedimentary metamorphic deposits in China /Suyshun, Khaichow/, the recently explored deposits of Gamer-Kotri and others in India /Rajasthan/.

Lower and Middle Cambrian - Kara-Tau, Altai-Sayan region, the Khubsugal deposit /Mongolian People's Republic/, southern China, Maw Kok /Democratic Republic of Vietnam, Duchess and other deposits in Australia.

The Ordovician period - the Baltic Basin, the Siberian platform, Tennessee /USA/.

The Permian system - Rocky Mountains.

Upper Jurassic - lower Crustaceous - Vyatsko-Kamskoye, Yegoryevsk.

Upper Crustaceous - Aktyubinsk, deposits of the area of the European part of the USSR, deposits of Turkey, Syria, Jordan, Isreal, Saudi Arabia, United Arab Republic, Morocco.

Paleogene - Iraq, Syria, Tunisia, Algeria, Morocco, Western Sahora, Senegal.

Neogen - Florida, Peru.

The main phosphorite reserves /exceeding 90%/ are concentrated in only five stratigraphic subdivisions:
Paleogene - 45%, Upper Crustaceous - 18%, Cambrian - 12%, Permian - 10% and Neogene - 8%.

Thus the knowledge of the geological age of rock already makes it possible to estimate the perspectives of the presence of phosphorite and of prognosis for phosphorite prospecting.

Phosphorites are sea deposits, but they form only under very specific conditions of shelf stretching between a land coast and coastal riparian zone on the one hand and a deeper sea zone usually represented by carbonate sediments on the other.

The compiling of paleogeographical maps for the corresponding stratigraphic subdivisions with an indication of the above-mentioned zones and a specification of the character and depth of the basin where the sediment accumulates, the relief of its bottom, the direction of drift of terrigenic material, among many other things, makes it possible to lay out areas where phosphorite was most likely to form in the past.

The employment of paleographical prerequisites is a necessary and very important means of prognosticating phosphorites.

The relationship of phosphorite formation and certain climatic conditions should be considered as part of the paleogeographical law of the distribution of phosphorites, but also as being of self-sufficing importance. This relationship is particularly apparent in newly-formed mesokainozoic phosphorites of the platform type, the formation of which originated in broad epicontinental basins.

As mentioned above, the most intensive formation of phosphorite occurs in arid-climate zones, whereas this process is considerably attenuated under conditions of humid climate.

The application of this <u>paleoclimatic prerequisite</u> is of special importance in compiling prognostic maps of large regions and makes it possible to greatly narrow down the area where phosphorites are most likely to be found.

One of the most important prerequisites for prognostic and prospecting purposes in the natural relation of phosphorites with rocks specifically of lithological composition. Even on a planetary scale the three principal types of phosphorites - massive /"stratified"/, granular and septarian are related to three types of formations of moutain rock, namely, dolomite-siliceous, terrigenno -/-siliceous-/-carbonate and glauconitic.

However, <u>the lithographic law</u> of the location of phosphorites is also extremely evident within relatively limited areas and is a reliable prerequisite for forecasting and prospecting, as well as for delineating areas containing arenaceous, carbonate siliceous and other types of rock. This law makes it possible to mark out areas where phosphorites are most likely to be found and also to accurately predict the type of phosphorites that ce be expected, which consequently makes it possible to establish the geological and economic parameters of the forecasted deposit.

The formation and location of various types of phosphorites, excepting paleoclimatic, paleogeographical and other conditions already considered, are to a great extent determined by the geotectonic structure which directly influence the sedimentation regime.

Thus the geosynclinal regime is favourable to the thickest and most concentrated phosphate accumulation and the formation of prolific oolitic microgranular massive phosphorites of the Kara-Tau type which form in the external troughs of geosynclines of the so-called miogeosynclines. Forming in the internal sections of the geosynclines /eugeosynclines/, to which, for instance Siberian phosphorite deposits in the Altai-Sayan Region are confined, are massive phosphorites of a slightly different thin-crystalline type which do not render such concentrated accummulations as is the case with miogeosynclinal phosphorites.

Sedimentations under conditions of consolidated platforms are manifested by phosphorites of an essentially different type. They are thinner but usually extend over very broad areas. Particularly favourable are external slopes of ancient platforms on which extensive epicontinental basis existed over lengthy periods, which, under other favourable conditions, gave rise to sedimentation of enormous masses of granular-type phosphorites. The latter usually resulted in the formation of entire series of phosphorite beds intermittently manifested by not one, but several contiguous stratigraphic subdivisions. A vivid example of platform-like phosphorites of this kind are the deposits in North Africa, the Middle East, Florida, North and South Carolina, as well as many others. These phosphorite-bearing basins alone contain over 55% of the world's phosphorite reserves.

Poorer septarian phosphorites form under slightly different, however nonetheless platform-like geotectonic, conditions. They alse are characterized by great areal extent but are confined to an intraplatform-like structure, as to syneclise slopes, for example. In this case, the phosphorite-forming basins were of a more midland character and their shelves were not so broadly and directly connected with the world's ocean. The superimposition on these structural and geotectonic conditions of a humid climate, as was the case in the Jurassic-Cretaceous period on the Russian platform, resulted in a greatly slackened phosphorite formation and in the origin of widely spread but lean septarian phosphorites. To these belong the deposits in Vyatsko-Kamsk, Yegorevsk and Aktyubinsk, as well as a great many other deposits of this region.

The geotectonic movement of the lithosphere in the phosphorite-forming period brought about yet another geological law of particular importance to phosphorite forecasting, namely, the relation of phosphorites with the cessation of sedimentation and with transgressions. The intervals in sections of geological stratifications are quite clearly manifested, often being retained in the form of basal pebble-conglomeratic layers which constitute an important prospecting criterion and have many times led to the discovery of new deposits.

In this respect the discovery by N.A. Kresilnikova of the very first, Katangsk, phosphorite deposit in Siberia is exemplary.

In the initial period of phosphorite prospecting in Siberia, when absolutely no information was on hand as to where or in which deposits they were to be looked for, it was decided to use this criterion of connection between phosphorites and basal conglomerates and to revise collections made available by preceding expeditions. The upshot was that Ordovician conglomerates showing signs of phosphation were found among specimens in Leningrad. A search party sent to explore the area subsequently detected a widespread horizon of phosphorites.

In addition to the laws and prerequisites already discussed extensive use for phosphorite prospecting purposes is also made of minero-geochemical prospecting criteria, to which, belong phosphation dispersion haloes in bedrocks and the mantle of soil, the paragenetic association of phosphorites with manganese minerals and glauconite, heightened concentrations of vanadium, organic substances, etc. An important and widely used criterion is the commonly heightening radioactivity of phosphorites and certain other nuclear-geophysical properties inherent in them, making it possible to employ not only terrestrial radioactivation prospecting but also aerogeophysical methods allowing extensive areas to be taken in.

Proceeding from the foregoing laws of the formation and location of phosphorites and the geological, geochemical and geophysical prospecting criteria that follow therefrom, scientifically founded methods of forecasting phosphorite deposits, which have found concrete expression in the compiling of prognostic maps of different scales.

Prognostic maps are developed with the aid of an entire set of intermediary maps usually made up to estimate the possible content of phosphorite proceeding from individual or several closely related geological prognostic prerequisites.

Accordingly, paleotectonic, facio-lithological and paleogeographical maps are compiled for interesting stratigraphic subdivisions. Naturally, a prognostic map must be based on a geological map of the district, the scale of which is somewhat larger than that of the compiled prognostic map. A geological map, as a rule, is heavily dotted with all the phosphorite and minero-geochemical manifestations already known in the area. Reflected on such maps either separately are geophysical anomalies or other prognostic and assessment criteria.

Prognostic work is not confined only to the laboratory; it is always accompanied by field studies of the corresponding territory, during which a detailed study is made of sections of the most interesting deposits. Furthermore, additional material is collected to accurately define the tectonic lithological and and other distinctive features of the area.

A detailed analysis of all the collected geological data and compiled auxiliary maps is followed up by an assessment of the phosphorite-bearing perspectives of certain sections and elements of the prognosticated territory and the compiling of a resultant prognostic map. On it are outlined the areas, structures and certain suites and rock masses where phosphorite prospecting is possible. These elements vary in perspective degree and among them are found areas for prospecting work varying in detail.

Prospecting and exploration work /or detailed prospecting/ in the most perspective areas is recommended using a scale ranging from 1:10,000 to 1:50,000. This work is usually accompanied by geophysical work and drilling.

Perspective areas are recommended for prospecting using a scale ranging from 1:50,000 to 1:200,000 with a consequent transition in the most interesting areas to the type of prospecting and exploration work mentioned above.

Also indicated are probably perspective areas, a definite prognostic assessment of which cannot be made due to a lack of initial geological data. Prospecting and geological surveying work in such areas is usually recommended using a scale ranging from 1:100,000 to 1:200,000.

Prognostic maps also reflect non-perspective areas, the geological features of which clearly show that there is no possibility of detecting phosphorites there. Prognostic and prospecting work in such areas is discontinued. It should be noted that the indication of such areas entails great responsibility and therefore requires reliable substantiation.

Prognostic methods are of course constantly being developed and enriched. The store of equipment and assessment criteria is constantly being expanded and perfected. Engaged in this work are permanently operating research parties.

Small-scale areal prognostic maps have been developed covering all the territory and large regions of the Soviet Union. Many individual perspective areas have been subjected to medium-scope forecasting, and at the present time we have begun the most complicated form of prediction - the assessment of abyssal zones and the development of detailed large-scale prognostic maps.

We know of many instances when prognostic exploration work and scientific predictions have resulted in the discovery of corporeal deposits and separate veins. For example, this was how the Siberian platform-like granular-shelly deposits were discovered, however poor they may be. Forecasting resulted in the discovery of geosynclinal phosphorites in the Altai-Sayan Region and separate deposits within that area /Belkinsk, Tamalyk, etc./.

However, the main goal of forescasting does not lie in the immediate prediction and discovering of deposits. That is the aim of prospecting work which comes after forecasting work. What is most important is that proper trends, well-substantiated methods, orientation, the rational carrying out of prospecting work and its effectiveness totally depend on scientific pre-prospecting work theoretically grounded and reflected in practice in the form of maps.

## Apatites

As mentioned above, apatites constitute only 4-5% of the world's phosphate resources and therefore are of extremely little importance. That is why we have begun the search for them only very recently, when a planned increase of the production of mineral fertilizers, phosphorus in particular, demanded the mobilization of all possible sources of phosphatic raw materials. It is quite natural, therefore, that our theoretical basis of the laws of the origin and location of apatite deposits and the methods of forecasting them should be worked out in much lesser detail.

At present it is possible to distinguish two principal types of commercial deposits of apatite ores - magnetic, connected with nepheline-syenite intrusions, a unique example of which are our Khibini which contain 60% of the world's reserves of apatite ores, and, secondly, carbonatite, which is associated with the formation of ultrabasic alkaline rock. Apatization in carbonatite masses is ordinarily not high. The content in them of $P_2O_5$ rarely exceeds 6-8%, however secondary enrichment occurs in the near-surface belt of weathering, whereupon the concentration of apatite increases considerably.

Both nepheline-syenite intrusions and carbonatite masses are rather widespread; however apatite mineralisation is encountered only quite rarely in them. The main task of prediction, therefore, lies in determining geological criteria that would make it possible to concentrate prospecting work only on perspected masses.

Three types of alkaline rock intrusions are distinguished: granitoid-alkalic, ultrabasic-alkalic and gabbroid-alkalic. The most perspective for apatite is the last, or, to put it more precisely, it is a genetically connected but later-forming formation of so-called agpaite +/nepheline syenites.

Intrusions of this type are located in rigid platform-like structures alongside abyssal fracture zones, they have the appearance of central multi-stage intrusions of ring structure, being subvolcanoes. They are usually rounded, of concentric make-up and having an extensively developed ring structure. They have been made up by various types of alkaline rock oversaturated with alkalis, have an intensified content of phosphorus, titanium and strontium and are marked by a high content of nepheline and an agpaitic petrochemical characteristic. The accumulation of calcium and phosphorus takes place in the process

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+/ agpaite-nepheline syenites with a greater content of alkalis /$Na_2O+K_2O$/ than alumina /$Al_2O_3$/.

of magmatic differentiation with manifestations of their concentration in the final differentiate of the magmatic chamber. The most widespread among them are nepheline syenites differing in mineral composition and structure /khibinites, foyaites, lajaurites, ristschorrites/; most characteristic are feldspar-free rocks of the urtite-ijolite-melteigite series.

In Khibini, commercial apatite-nepheline ores are closely associated in time and space with the complex of feldspar-free ijolite-urtites.

The geochemical properties of alkaline rock are of great importance for prognosticating apatite deposits. For instance, the replacement of sodium in alkalis by potassium is accompanied by a drastic decrease of apatite concentration with the development of rock of the potassium line.

An alkaline massif was recently discovered in Northeast Pribaikalye, having many features in common with the one in Khibini /shape, dimensions, similar rock composition, etc./ and likely to contain apatite. However, a detailed study showed that its rock belonged to the potassium line and brought out the metasomatic nature of apatite manifestations, consequently indicating a very slim chance of finding commercial concentrations of apatite.

The established laws make it possible to outline the following criteria of prognosticating apatite-bearing massifs of the Khibini type.

1/ the structural and tectonic confinement to rigid platforms and shields and abyssal fracture zones in them;

2/ the connection with large central-type ultrabsic-alkalic ring intrusions and agpaite nepheline syenites; the presence of substabtial masses of ijolite-urite rock;

3/ minero-geochemical criteria of intensified concentrations in rocks of iron, titanium, calcium, sodium, fluorine, and minerals - sphene, titanomagnetite, diopide, etc;

distinct manifestations of the sodium line /Na > K/ in the alkaline complex.

Carbonatite massifs potentially containing apatite are also associated with the formation of ultrabasic alkaline rock represented by dunites, olivenites, pyroxenites, more rarely peridotites, as well as nephaline-pyroxenite rock /ijolite-melteigites/.

The majority of apatite-bearing deposits of this type are complex; apatite is associated with the ores of iron, rare metals and phlogopite. Distinguished accordingly are apatite-magnetitic, apatite-rare-metal and apatite-phlogopite ore deposits; Apatite is often contained in dolomite - calcite rocks of carbonatite massifs.

The greatest concentration of apatite in carbonatites is associated with magnetic mineralization /Kovdor deposit on the Kola Peninsula, Yessoy in Siberia, Lulekop in the UAR, Dorova in Southern Rhodesia, Yakupirang in Brazil, etc./. Therefore, intensified concentration of magnetice in carbonatite complexes are a reliable criterion of the presence of apatite mineralisation. Another sign of the presence of apatite is heightened phlogopitization and biotitization of ultrabasic-alkalic rock. An average content of $P_2O_5$ in apatite-bearing rock of carbonatite massifs ranges from 3-4% to 10-15%; a 6-7% content is the most frequent. At such concentrations apatite is obtained only in a complex with magnetite and rare-metal minerals.

Given favourable physiographical conditions in tropical climates and, much more rarely, in other climatic zones, apatite-bearing rock is intensely weathered, carbonates and other minerals are lixiviated and the rock disintegrates and becomes naturally enriched, at times several-fold with apatite as well as other ore components. At such deposits of the crust of weathering the content of $P_2O_5$ is 10-15%, and sometimes it is considerably higher. However, the reserves of such ores are usually limited, going up to several tens of millions of tons.

Ultrabasic-alkalic massifs and carbonatites with apatite-bearing rock usually lie alongside tectonic activated marginal zones of platforms, decidedly being confined to abyssal fracture; the massifs are characteristically of concentric zonal structure.

The mentioned laws of the structure and location of apatite magmatic and carbonatite deposits, although limited as yet, are used for developing prognostic maps to be later employed in apatite prospecting work.

## Sulphur

Many interesting results have been obtained from the study of the laws of the structure formation and location of virgin sulphur deposits, which has made it possible to work out prognostic methods and to accumulate prognostic experience.

A detailed geological investigation of Soviet sulphur deposits and a comparative study of those in foreign countries has shown that commercial sulphur deposits are represented by two genetic types - volcanic and infiltration-metasomatic.

The greatest concentration of volcanic sulphur are associated with the hydrothermo-metasomatic type of deposits, to which belong the largest deposits of Japan /Matsuo, Khorolets/, Tyakto and others in Chile, El-Vinagra in Columbia and a number of deposits in Kamchatka and on the Kuril Islands.

In some cases large accumulations of commercial importance form in crater lakes, on the floor of which sulphur-containing solutions and gases are intensively given off. The elemental sulphur which is also produced precipitates and is buried in the layers of lake mud, thus forming concentrations of up to 40-60% and over. The deposits of Telaga-Bodas and Kava-Putikh in Indonesia, which Soviet geologists have studied closely, belong to this type.

The volcanic deposits that are greatest in number belong to a type of sublimate forming in volcano craters, on their slopes and in the adjacent environs. The sulphur here is brought to the surface in the form of fumes or sulphurous gas and hydrogen sulphide and is separated by condensation or through the interaction of gases, with oxygen and with the surrounding rocks. Although the forming sulphur accumulations are often concentrated to a high degree /up to 80-90%/, they are always found in small quantities and are of use only for domestic extration.

Hydrothermo-matasomatic deposits of volcanic sulphur are the largest. They are of the greatest commercial interest and it has been namely this type on which prospecting work has been concentrated in recent years.

The most general geological prerequisite in prospecting volcanic sulphur deposits is their location in an area of young and modern volcanic activity and in areas where eruptive products of andesite and liparite composition accumulate.

One of the prospecting prerequisites is the availability of volcanoes, both active and extinct, which are clearly defined in relief. Volcanoes are often concentrated inside of large calderas, in which gaseous - hydrothermal activity is intensive in general. That is why calderas should be explored with particular thoroughness.

The formation of hydrothermo-metasomatic sulphur deposits is favoured by the accumulation of permeable loose pyroclastic rocks and by the presence of thin tuff or lava beds that can serve as a shield for gaseous-hydrothermal exhalations. In sulphur deposit-forming zones the rocks are intensively decomposed by sulphate solutions, resulting in the formation of secondary kaolins, opalites and other rocks of bright colors. The fields of such bleached rocks can be seen from afar and are good prospecting indications.

The above-mentioned laws of the location of volcanic sulphur deposits and prospecting criteria provide a sufficient basis for compiling prognostic maps which serve as a guide in prospecting work.

Exogenetic sulphur deposits are commercially much more important. They are genetically associated with sedimentary rocks An entire complex of the structure and location of the largest sulphur deposits has been established, which are of great importance as geological prerequisites for prospecting work.

The deposits of this group are always closely associated with strata of sulphate rocks either of primary or secondary sedimantary formation as in the case of cap rock sulphates of salt dome deposits. These sulphate-bearing strat are arranged nonuniformly in the geochronological column and is concentrated in the Permian, Jurassic and Neogene.

Sulphur ores, with few exceptions, are always carbonatite-calcite. The average sulphur content in rocks at all large deposits is constant - 23-25% /deposits of Precarpathia, Sicily, Iraq, the USA, Mexico/ and very close to its content in anhydrite - /23%/. The bulk of sulphur ore is 65-75% calcite /limestone/. What is more, it has been established that this limestone is not sedimentary rock, as supposed earlier, but that it formed as a result of chemical interaction between gas and oil hydrocarbons and sulphates which are transformed and metasomatically replaced by sulphur-calcite ore.

Objective proof of this is the lightened isotopic composition of calcite carbon of sulphur ores similar to the isotopic composition of the carbon of oils and combustible gases and differing greatly from heavier carbon which forms limestones of sea-sedimentary origin.

The formation of sulphur by regenerating sulphates is clearly confirmed also by the ratio of isotopes S32/34 of the most natural sulphur which is enriched by a light isotope $S^{32}$. This is conditioned by the kinetic effect . In the reaction of transforming and regenerating sulphates the "light" sulphur molecules participate faster than the molecules of a heavy isotope $S^{34}$. That is why in the product of the reaction - virgin sulphur - its "light" isotopes are accumulated.

The tectonic laws of the location of sulphur deposits are of great interest. They are confined to zones where elevations join with depressions and are concentrated in positive anticlinal and domed structures with a ruined vault., They are localized in their tectonically weakened parts - along dislocations with breaks in continuity, in jointly articulate parts and so on.

Sulphur deposits are always located in oil- and gas-bearing areas and contain definite accumulations of hydrocarbons, with which they are connected not only in space but genetically as well. Hydrogeochemical properties of sulphur deposits located in a zone of interaction of sulphate waters with depth brines carrying hydrocarbon compounds and hydrogen sulphide are characteristic.

The mentioned laws of the formation and location of sulphur deposits constitute a reliable theoretical basis for forecasting new deposits. However, in addition to these prerequisites, in developing prognostic maps a great number of prospecting indications are used, namely, outlets of sulphur-bearing rocks, dispersion haloes of sulphur - salt, gas, etc., geomorphological indications, a number of features of sulphur deposits fixed by geophysical methods, the complex of secondary mineral formations /potassium aluminum sulphate, gypsum, natural sulphuric acid, etc/ occuring in sulphur ore oxidation zones.

In addition to these geological indications, microbiological geobotanical and even topochemical indicaions are used.

The method of developing prognostic maps for vigin sulphur is basically the same as the method for phosphorites. A number of auxialiary maps are prepared for the development of the prognostic map, which are applicable to the basic type of exogenetic infiltration-metosomatic sulphur deposits.

First of all, a facio-lithological map is developed making it possible to delineate the range of sulphate-bearing strata with which sulphur deposits are genetically connected. In this way the possible presence of sulphur is determined on the map by lithological criteria. The possible presence of sulphate can be determined according to tectonic criteria on the basis of tectonic maps, establishing the structural elements favourable to sulphur formation.

A special map is developed of the manifestations and location of hydrocarbon deposits. An assessment of the possible presence of sulphur is made on this map, going by the gas-bearing conditions of the given territory.

A hydrogeochemical map is compiled indicating the range of various types of subterranean waters with a special indication of sulphate and hydrosulphuric waters. On it also is determined the possible presence of sulphur according to hydrochemical criteria.

One of the main auxiliary maps is the geological map of the area, on which are marked all the manifestations of sulphuric mineralization, as well as various minero-geochemical, geomorphological and other indications of the presence of sulphur.

Proceeding from the data of all these maps reflecting individual prognostic criteria, an overall map is drawn up of the geological conditions determining the possibility of the presence of sulphur. An analysis of these criteria and primarily the degree of their combination over the same territories makes it possible to bring out areas varying in perspective content of sulphur. These areas are usually delineated on a separate prognostic map showing areas of the various perspective categories: very perspective, perspective, probably perspective, low-perspective, sub-perspective and non-perspective. Prospecting and prospecting-geological-surveying work of respective degrees of detail are recommended in these areas.

The most substantial result of prognostic work in this field has been the scientific prediction of the Precarpathian sulphur-bearing basin, prior to the discovery of which not only a territory indicating widespread sulphur deposits was determined, but also the age and concrete Miocenic sulphur-bearing strata, which actually turned out to be a great store of very large sulphur deposits.

Continuing prognostic work in Precarpathia following the discovery of the first deposits in this area, we geologically found the continuation of a perspective stretch of sulphur-bearing deposits on neighbouring territories of southern Poland and eastern Rumania. A short time later Polish and Rumania geologists discovered sulphur deposits there. We shared with them our experience in prognostic, prospecting and exploration work in the search for sulphur. As is known, Polish geologists obtained most remarkable results in discovering sulphur deposits.

Precarpathian sulphur is by far not the only example of our scientific and technical cooperation with the fraternal socialist and developing countries in investigating and developing agronomical ore resources. Cooperation of this kind brought about very fruitful results with respect to apatite deposits in the Laokai district in the Democratic Republic of Vietnam, in discovering and investigating the Khubsugul phosphorite deposits in the Mongolian People's Republic, in detecting and closely investigating phosphorites in Siberia, the UAR and Iraq. In Iraq the world's largest sulphur deposit, Mishraq, was discovered with the assistance of Soviet geologists.

Such scientific and technical cooperation and joint geological research is also of great benefit to Soviet geologists, providing new geological data, helping to substantiate more deeply the laws of the formation and location of agronomical ore deposits and to perfect the methods of scientific prediction.

The current Symposium serves the purpose of developing such cooperation and exchanging knowledge. That is why we thought it of use to present this report, hoping that the worked out criteria methods and experience of scientific prediction of perspective areas of prospecting and exploring agronomical ore deposits can be recommended and utilised in the effective carrying out of prospecting and exploration work on the territory of other countries, in part those represented at this symposium.

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