Soviet Geology: Achievements and Prospects

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This article is a broad review of some of the major advances in unravelling the geology of the U.S.S.R. that have taken place since 1937 when the International Geological Congress was last held in that country. Not only has much progress been made in geological science but there has also been a great increase in the reserves of mineral raw materials and a major intensification in mining. References are given to some of the important recent Russian literature.

Geological Coverage

The U.S.S.R. is unique in size, occupying an area of 22.4 million km² or 1/6th of the total area of all the continents. It contains a variety of large-scale geological structures (Nalivkin, 1973 – Ed.), including the ancient platforms of Eastern Europe and Siberia with the Baltic, Ukrainian, Aldan and Anabar shields, and it also encompasses extensive portions of the Uralo-Mongolian, Mediterranean and Pacific fold belts of Phanerozoic age (Fig. 2; see also Fig. 1 of Rundquist, this issue of Episodes – Ed.). Each of these megastructures can be subdivided into smaller regions distinguished by specific geological features, mineral assemblages, and geological history.

Much importance is attached in the U.S.S.R. to continuing regional geological, geophysical and geochemical studies (Figs. 1, 3). By 1940 only half of the country had been studied, mainly by small-scale geological surveys, but there is now complete coverage at a scale of 1:200 000. Some 30% of the Soviet Union has also been mapped to a scale of 1:50 000, including most of the major mining districts. Geological mapping follows a single, scientific and methodological approach that involves faunally characterized stratigraphic schemes, absolute age determinations, and the correlation of synchronous formations, igneous and metamorphic rocks.

Stratigraphy and Palaeontology

Much work has been done on correlating large stratigraphic subdivisions within geological regions and across the whole country (see Zhamoida, this issue of Episodes – Ed.). Unified working approaches to the subdivision of Archean, Proterozoic and Phanerozoic complexes have been used as the basis for national geological maps at 1:1 000 000 and 1:200 000 (Nalivkin, 1963–1982). However, additional palaeontological and biostratigraphic data are needed to successfully complete this program.

The application of a variety of methods has enabled the development of both regional and global stratigraphic schemes. The integrated use of palaeontology (especially micropalaeontology), and palaeomagnetic and absolute age data has made it possible to extend stratigraphic correlation from regional to sub-global levels (e.g. Spizharsky et al., 1983; see also Sokolov and Fedonkin, and Rozanov in this issue of Episodes – Ed.).

Mineralogy

Soviet geologists have been able to penetrate the hitherto

Figure 1: A geological survey party of the Ministry of Geology at work in the Kirghiz Republic.

inaccessible internal structure of minerals, thanks to advances in solid-state physics, physical and crystal chemistry, as well as to modern techniques involving the electron microscope, the electron microprobe, and X-ray structural, laser-optic and spectroscopic studies. Associations of minerals, their composition, structure and other properties provide valuable information on the physico-chemical conditions under which they formed or were subsequently changed. These data have been used, for example, to develop the theory of endogenetic, exogenetic and metamorphogenetic mineral and ore formations (Lazarenko, 1963; see also Smirnov, this issue of Episodes – Ed.).

The work of A.E. Fersman on the typomorphism of minerals, has given rise to new mineralogical approaches that increase the effectiveness of prospecting for and evaluation of mineral deposits, especially when combined with geochemical and geophysical methods (Yushkin, 1977). These techniques have been of great importance in the discovery and commercial development of many new deposits including Al (nepheline syenite and alunite), Be (genthelvite and bertrandite-phena-cite), B (datolite and danburite), Ta and Ni (microlite, rare-

Figure 2: Major structural divisions of the U.S.S.R., showing the location of seismic profiles and deep drillholes. 1 – shield areas; 2 – ancient platforms; 3 – young platforms; 4 – median massifs; 5 to 9 – fold systems (5 – Pre-Baikalian; 6 – Baikalian; 7 – Palaeozoic; 8 – Mesozoic; 9 – Cenozoic); 10 – volcanogenic belts; 11 – Deep (a) and Super-deep (b) wells; 12 – Deep seismic profiles (a – existing, b – planned).

earth plumbopyrochlore), Zr (baddeleyite) and non-metallic minerals such as zeolites, cryolite, brucite and wollastonite.

New methods of technological mineralogy have started to develop at the border between mineralogy and mineral processing. These techniques are intended to intensify the development and utilization of mineral deposits as progressively lower grades are being mined. Efforts are also being made to improve the recovery of all useful components, that is to devise a waste-free technology for mining. Finally, new ways of refining, altering and synthesizing minerals have been developed so that synthetic minerals like diamonds, gems and mica are now being produced on a commercial scale (Kalashnikov, 1980).

Petrography

The study of petrography and petrogenetic processes has been much advanced by the application of geophysical, geochemical and geomathematical methods, and through experimental studies of the thermodynamics of mineral-forming processes (Marakushev, 1979; see also Vistelius, 1980 – Ed.). Soviet and foreign petrographers have demonstrated clearly that the bulk of igneous rocks formed either from granitic magma formed in the crust, or from basaltic magma generated in the upper mantle. This conclusion has put an end to the long-standing debate on the nature of magma, and to the theory that all igneous rocks originated from a single parent magma. The works of Soviet volcanologists, particularly those dedicated to the study of active volcanoes of Kamchatka and the Kuril Islands are well known (Dunichev, 1983; see also Fedotov and Markhinin, 1983 – Ed.). Much data has been obtained about the production of ore elements in the process of volcanic eruptions.

Soviet petrographers have also drawn important conclusions concerning the history of igneous activity throughout geological time, from the primitive komatiite-basite magmatism

of Precambrian time to the strongly differentiated magmatism of the Phanerozoic, with its increase in the occurrence of calc-alkaline and alkaline series. Advances in modern planetology and the study of lunar rock specimens have also proved essential in understanding the early stages of the evolution of the Earth (see Barsukov and Basilevsky, 1983 – Ed.). It is assumed that at the first stages of its consolidation, the Earth's crust was similar to that observed today on the Moon.

The Soviet Union is largely composed of Precambrian metamorphic complexes, and the concept of metamorphic facies is thus of paramount importance. It has now been established that specific metamorphic rocks are formed only under specific PT conditions, and the stability ranges for individual minerals and mineral associations, metamorphic facies and subfacies have now been determined (Sobolev, 1972, 1974). Zoning has also been recognized from physico-chemical studies on metasomatic rocks formed under high PT conditions at the contacts between chemically heterogeneous rocks.

Lithology

Considerable progress has been made over the past 30 years in the field of lithology. One example is the development of the concept of a sedimentary formation as representing a natural rock association formed in specific climatic and tectonic environments, and containing a characteristic assemblage of minerals (Tseisler, 1977). More recently the concept of the formation has been extended by Siberian geoscientists to igneous, metamorphic rocks and related ore associations (Kuznetsov, 1964; Masaitis, 1979).

A classification scheme has been developed for ancient and modern sedimentation processes taking place in platform, geosynclinal and oceanic environments. The palaeogeographic and physico-chemical characteristics of each of these types have been established, as have the laws governing changes in composition and structure of sedimentary rocks at the diagenetic, epigenetic and early metamorphic stages. Important contributions also came from detailed studies of weathering processes under widely varying climatic conditions, and of the formation of mineral deposits (particularly placers of noble metals) associated with these processes (Perelman, 1972).

Figure 3: A helicopter is the best method for transportation over the vast Siberian territory.

Lithology was the first among the earth sciences used to investigate the irreversible evolution of geologic processes, as demonstrated by variations in the composition of the atmosphere (gases) and hydrosphere (salts), and by the development of the organic world of our planet. Global studies in this field have established a number of regular patterns in time that govern the distribution of sedimentary mineral deposits, and these concepts have also been extended to igneous and metamorphic facies and to ore deposits (Bogolepov and Zharkov, 1981).

Geophysics

Thanks to major improvements in theory, techniques, facilities and data processing systems, geophysics is now widely used in regional geological studies and at all stages in mineral and petroleum exploration. Geophysical methods have also become an effective tool for studying deep crustal layers and upper mantle, and shelves of seas and oceans.

New advances in the last decade include the development of a seismic exploration system, which is now the basic method used to detect potential oil and gas structures on land and offshore areas (Kunin, 1983). Airborne gravity and electromagnetic methods are increasingly used, as are geophysical techniques from space. Airborne gamma-spectrometric and a range of nuclear-physical methods (Petrosyan, 1981) have also proved to be highly effective in prospecting for different mineral deposits. Borehole geophysical measurements, which permit effective correlation between drill holes, reduced the need for so many holes during exploration work, especially when defining oil and gas pools (Dyakonov *et al.*, 1977).

Geo-, Bio- and Ecogeochemistry

In recent years geochemical prospecting methods have been greatly improved, and when used in combination with geophysical and geological approaches they have led to the discovery of many new deposits (Grigoryan, 1982). Concealed mineral deposits are searched for and evaluated by the use of primary and secondary lithochemical dispersion haloes of indicator elements. Work on the geochemical zoning of hydrothermal mineralization has led to a technique to estimate the erosional level of a given mineral deposit and to help identify zones of scattered ore mineralization. A method has been developed for prospecting for ore bodies buried under thick overburden using "sorption-salt dispersion haloes" of indicator elements. High-sensitivity atomic absorption field and laboratory devices have been designed, assisting in the development of a prospecting technique for buried sulphides using mercury gas dispersion haloes. Automated systems and programs of computer-based processing of geochemical data have been developed to assist in this work.

Figure 4: Overlooking the Naryn Valley in the seismically active Soviet Kirghizia. Nearby and distant hills are composed of gypsum-bearing Neogene sediments.

In the U.S.S.R. much importance is attached to the development of biogeochemistry, which deals with the processes of migration of chemical elements in the crust caused by the action of living matter. Likewise, geochemistry applied to the solution of environmental problems caused by the extravagant or harmful activities of man have led to the new study of ecological geochemistry or ecogeochemistry (Perelman, 1975; Glazovskaya, 1980).

Tectonics

Valuable data gathered during the study of the oldest geologic structures (Salop, 1983 – Ed.) have been used to reveal regular changes in the tectonic regimes of the Baltic, Ukrainian and Aldan shields, and to estimate the effect that the Precambrian basement had on the development of Phanerozoic mobile belts (Krats and Zapolnov, 1982).

It is now recognized that deep faults and a high degree of heterogeneity of the lithosphere play a significant role in the evolution of the planet (Puscharovksy, 1982). Studies of the tectonics (and metallogeny) of the basement of ancient mobile platforms, such as the Siberian craton and other massifs (e.g. Bureya, Khankai, Okhotsk and Omolon), have led to concepts about the processes of tectonic and igneous reactivation of structures stabilized earlier. Epochs of tectono-igneous reactivation coincided with periods of major crustal deformation during the transition between Archean and the Proterozoic, the early and late Proterozoic, the late Palaeozoic and early Mesozoic, and the late Mesozoic and Cenozoic.

Tectonics, as one of the major disciplines of geoscience, has served as a basis for the development of a well-substantiated global concept, which is bringing us closer to a fuller understanding of the structure and evolution of our planet (Sorokhtin, 1974; Zonenshain and Savostin, 1979; see also Artyushkov, 1984 – Ed.). Very popular is the plate tectonics concept based on the study of the ocean-floor structure by drilling and palaeomagnetic measurements. Plate tectonics, however, does not describe all tectonic processes of the geological past (see Dymkin and Puchkov, and Ruzhentsev and Trifonov, this issue of Episodes – Ed.). There is, for example, little doubt about the existence of independent vertical movement in the crust. These are caused by phase transitions at the Moho and Conrad discontinuities, by the rise to

the base of the lithosphere of hot low-density mantle material, by isostatic compensation and by other factors. These vertical movements are responsible for the block structural pattern of the continental and oceanic crusts (Artyushkov *et al.*, 1979). Many data on these and horizontal movements come from geodetic analyses on the ground and from satellites (Bulanzhe, 1981).

Advances in seismology have had a marked bearing on the field of tectonics (Fig. 4). Extensive data on seismic events within the U.S.S.R. and elsewhere have demonstrated a link between earthquake sources and zones of active deep faults. The expansion of seismic networks and geophysical polygons set up in active seismic areas of the country has permitted seismologists to work out a rather successful technique for long-term earthquake prediction, which has already been verified in a number of cases (Anon. 1982). A medium to short-term earthquake prediction technique is now being developed, based on types of movements along the deep faults.

Metallogeny

One of the important achievements of Soviet geoscience is the recognition of certain regular patterns in the formation and distribution of minerals (Shcheglov, 1980; see also Smirnov, and Rundquist, this issue of *Episodes* - Ed.). Formational analysis applied to metallogeny makes it possible to identify metalliferous associations (formations), and to determine the location of mineral deposits within these associations. This popular new approach to geological exploration permits us to single out and rank promising areas, and to provide a preliminary quantitative estimate of mineral reserves of both large and small areas.

Hydrogeology and Engineering Geology

Fundamental research in hydrogeology is aimed at revealing the laws governing the migration of ground water in the free-water exchange zone of the hydrosphere. This work contributes largely to the exploration for and estimation of the groundwater reserves, the prediction of water inflows into underground workings during mining, and the control of water-salt regimes on reclaimed lands (Kats and Shestakov, 1981). Work on the spatial variation in engineering properties of rocks assists hydrogeologists to define regional characteristics, to develop the theoretical basis for predicting exogenic processes, and to construct maps showing the predicted development of geodynamic processes to the year 2000 (Artyushkov, 1982; Sergeev, 1976-1978).

Mineral Resources

The U.S.S.R. possesses large reserves of oil and gas (see Meyerhoff, 1981, 1983 - Ed.), including one of the world's largest oil and gas provinces, that of West Siberia. This latter region has been rapidly developed, from an output of 200 tons of oil in 1964 to the present figures, which represent over 60% of the total volume of oil and 50% of the gas produced in the U.S.S.R. The largest oil and gas provinces within the Russian platform are represented by the Volga-Ural, Timan-Pechora and Caspian provinces. Large gas fields have been explored in the Amu-Darya region of Central Asia, and considerable oil and gas potential is associated with the Lena-Tunguska, Yenisei-Laptev and Lena-Vilyui provinces of East Siberia.

The Soviet Union is rich in reserves of bituminous and brown coal (Anon, 1962-1978). The major Donbas basin provides one-third of the Soviet production of coal, almost half of which is of coking quality. The Kuznetsk basin of West Siberia has become the largest source of high-quality power-generating and coking coals; coals from this basin are distinguished by their high quality and great variety in rank. The Kansk-Achinsk basin is unique in its large brown coal reserves and favourable mining conditions; the development of this basin is one of the most important energy goals of the

Figure 5: Drilling for groundwater in Central Asia.

U.S.S.R. Sizeable coal deposits have also been explored in the Pechora, Karaganda, Ekibastuz and South Yakutia basins, among others, and there are immense resources in the as yet poorly studied Tunguska and Lena basins of Siberia.

The supply of ferrous metals is well provided from mineral resources (Smirnov, 1974). Iron ore deposits of the Krivoi Rog basin in the Ukraine and of the Kursk Magnetic Anomaly area occupy leading positions both in identified reserves and production. Large iron deposits are also mined in the Urals and the Kola Peninsula, in Karelia, Kazakhstan, and West and East Siberia, and new districts are being explored in South Yakutia. The Soviet Union possesses considerable resources of manganese ores in the Ukraine, Georgia and central Kazakhstan, and chromium ores in northwest Kazakhstan.

Large reserves of non-ferrous metals have also been established. Copper deposits are being worked in Kazakhstan (cupriferous sandstones, Cu sulphide and Cu porphyry ores), Uzbekistan (Cu porphyry), the Urals (Cu sulphides), the area of the Baikal-Amur Railway (cupriferous sandstones) and together with Ni in the Norilsk district and the Kola Peninsula. Pb and Zn are mined in Rudnyi Altai and central Kazakhstan, Uzbekistan, Tadzhikistan, Transbaikalia, Azerbaijan and in the Krasnoyarsk region. Al comes from bauxites of the Urals, Timan, Kazakhstan, the Kursk Magnetic Anomaly area and the Arkhangelsk region as well as from nepheline-bearing rocks of the Kola Peninsula and West Siberia. There are also the alunite ores of Transcaucasia, W in the North Caucasus, Kazakhstan, Transbaikalia and Far East, Sn in the Far East and Kirgizia, and Mo in East Siberia, Kazakhstan and Armenia. The development of the diamond deposits of Yakutia represent a remarkable achievement (Anon, 1967).

Large reserves of raw fertilizer materials have been discovered in the world-famous apatite deposits of the Khibin group on the Kola Peninsula, in phosphorite deposits of Kazakhstan, central areas of the European part of the U.S.S.R. and Estonia, and in potash salts of the Perm area Byelorussia, Western Ukraine, Turkmenistan, and East Siberia.

Groundwater provides the water supply for some two-thirds of the towns in the U.S.S.R. (Fig. 5). More than two thousand deposits of fresh water and over 400 of thermal, mineral and technical waters have been discovered and are used for domestic and technical water supplies as well as for medicinal (balneological) purposes.

A Look at the Future

The program of economic and social development for the period from 1981 to 1990, which was adopted by the 26th Congress of the Communist Party of the Soviet Union, directs Soviet geologists to speed up their study of the country and to locate additional mineral reserves, primarily those of fuel and energy. The program lays out measures to discover new oil and gas deposits in West and East Siberia, in the European portion of the country, in Central Asia and Kazakhstan, as well as on the continental shelf. Mineral reserves will be expanded in the areas of existing mining centres, especially in the areas where territorial production complexes are located.

Exploration efforts will be intensified for rich and easily beneficiated ferrous and non-ferrous metals, coal, bituminous shale, raw materials for nuclear energy, building materials and mineral fertilizers, as well as for groundwater. Large mineral exploration programs will also be carried out on the continental shelf and in the oceans. Successful fulfillment of these tasks will require the rapid development and improvement of fundamental and applied research, primarily in the field of exploration and economic evaluation of mineral deposits. Experimental work is now underway to investigate the conditions of formation and migration of deep mineral deposits and hydrocarbons.

The large-scale prospecting programs planned for regions of unexposed mineral deposits demand first the preparation of large-scale geological maps to serve as a reliable base for exploration efforts. Preparation of a stratigraphic basis for these maps is a complex problem, for regional stratigraphical schemes must be, on the one hand, as detailed as possible reflecting local characteristics, while on the other hand, allowing for reliable correlation with stratigraphical subdivisions of other regions. Of particular importance is the

Figure 6: The Kola super-deep borehole.

Figure 7: The "Three Brothers," Kamchatka Peninsula

detailed stratigraphical subdivision of the Precambrian, which has considerable mineral potential.

Evolution of the material in the Earth's interior is considered to be a driving force for geological processes, determining thermodynamic regimes for sedimentation, igneous activity and metamorphism. This deep-seated regime also controls the material composition of the crust, its tectonic framework and the conditions under which mineral deposits are formed. For these reasons a systematic study of the deep crustal structure of the entire U.S.S.R. territory has been launched. A network of mutually linked geophysical profiles supported by deep and super-deep drill holes provides a key observation system for this study, backed up by data from satellites and airborne surveys (Fig. 2, and Kozlovsky, 1982a). The first of these drill holes, the Kola Super-deep (Fig. 6) has now reached a record depth of over 12 km (see Kozlovsky, 1982b - Ed.), and the second, the Saatly SG-1 Super-deep of the Southern Caucasus, is now at 8.5 km. Other deep and super-deep holes will be drilled in the West Siberian, Caspian and Dnieper-Donets oil and gas provinces, and also in the Urals, Noril'sk, Muruntaus and Krivoi Rog ore districts.

The search will continue for an optimum set of geological, geophysical and geochemical techniques for mineral exploration. Much work now is being directed towards the development of new geophysical prospecting equipment, using the latest achievements of mathematics, physics, automation, telemechanics and instrumentation, and cryogenic and micro-processor technology. Great emphasis is being placed on direct methods of prospecting, including three-dimensional seismic exploration surveys that utilize principles of holography. Powerful energy sources for deep crustal studies are being developed, such as magnetic hydrodynamic generators

(Volkov, 1983), and vibroseismic and laser systems. Updated telemetry systems using satellite communication links are being devised to improve the transmission of geophysical information.

In the field of exploratory drilling, efforts are being directed to the development of new and more effective rock-crushing techniques, to the optimization and automated control of technological processes by means of microprocessors and mechanization (robots and manipulators), and to the field management of drilling operations.

One of the current trends in research is the development of the scientific basis and technology for predicting changes in the geological environment brought about by human activity. This work is being carried out within the framework of an international project with Unesco and UNEP entitled "Protection of Lithosphere as Component of Environment." This includes a long-term integrated program on the "Scientific Basis and Development of Lithomonitoring of the U.S.S.R.," which is working out a unique system of estimation, prediction and control of changes in hydrogeological and geotechnical conditions resulting from industrial and other human activities. The problem of environmental protection is closely connected with the need to protect mineral resources, which are great but not unlimited, and whose rational utilization is becoming more and more vital today.

Further progress in geosciences will require, first, a thorough study of the outer part of the Earth, both on the surface and in depth, using the entire arsenal of scientific and technical facilities available; second, specialized experiments; and third, extensive generalizations of the accumulated data. Modern geology must not confine itself only to the qualitative characteristics of events and processes, but must produce quantitative estimates as well. In this way we can raise the study of the Earth's interior to new levels.

Finally, we in the Soviet Union are very pleased that the 27th Session of the International Geological Congress is being held in the U.S.S.R. in 1984. Foreign participants will have an

opportunity to acquaint themselves with the achievements of Soviet geology. Soviet geologists in turn will welcome an exchange of ideas and methods with their foreign colleagues. The scientific proceedings of the Congress will undoubtedly contribute to the development of a common view about the geological structure and evolution of the Earth.

Prof. Ye.A. Kozlovsky is Minister of Geology of the U.S.S.R., President of the Scientific Council on the "Investigation of the Earth's Interior and Super-deep Drilling," scientific leader of the international program on the "Protection of the Lithosphere as a Component of the Environment," and President of the Organizing Committee for the 1984 International Geological Congress. The author of over 200 scientific publications, he has studied for many years problems of the global mineral resources economic evaluation of mineral deposits, and the optimization and automatization of drilling technology.

Academician A.L. Yanshin is Vice-President of the Academy of Sciences, Chairman of its Earth Sciences Section and the Director of the Institute of Lithosphere. One of the senior geoscientists of the Soviet Union today, he is the recipient of many awards and honours. His main research concerns the tectonics of platform covers and recent marine basins, and the geological evolution of the crust.

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