Exploration Geochemistry for Uranium in India: Its Trends Hitherto and Suggestions for its Effective Applications

Preamble

Energy security is a major requirement for the development of any country. It is more so for India, in the context of its globalization and emerging economy, to have higher industrial growth and maintain the 'Gross Domestic Product' (GDP) of 8-10% per year in the coming years. For this to happen, the supply from energy resources should match the increasing energy-demand India, with power-generation of 700 TWh during 2006-07, is the 5th largest producer of electricity in the world and is amongst the top 10 countries producing electricity to a major extent by fossil-fuels of coal and oil-natural gas, with lesser by hydro and minor contribution by nuclear (-3%) and renewable resources like solar, wind, bio, tidal, and geothermal. In the current scenario of (a) the fast depletion of coal resources, (b) much of the oil-gas being imported at high cost, resulting in draining much of the Country's foreign exchange reserves, (c) less production from, coupled with uncertainty of, non-conventional resources due to various factors like climatic changes, area- and time-specific nature, and under-developed technology to harness their energy and (d) the necessity of reducing the emission of greenhouse gases (mainly CO₂, CH₄, and N₂O) that are causing global warming with disastrous consequences, nuclear energy, in spite of some radiation hazards, emerges as the most potential and dependable mode that requires very little quantity of fuel, viz. U and Th, [U 5000,000 Mega Joules (MJ)/kg], as compared to that of the fossil-fuels [coal 9-30 MJ/kg, crude oil 4S-46 MJ/kg, natural gas 39 MJ/m³], to generate power, besides it has relative merit in being clean with no emission of greenhouse gases. The nuclear industry, apart from its main objective of catering to the power generation, is also helping other fields like agriculture, health, defense, and some hi-tech industries. Keeping all these into consideration, the Govt of India envisages to step up the nuclear power generation to the tune of 20,000 MWe by the year 2020, and the Planning Commission projects 63,000 MWe nuclear capacity (out of the total 7,75,500 MWe) by the year 2031-32. For this to happen, the basic requirement is enough supply of nuclear fuels, preferably indigenous, and even by imports.

Taking into consideration the overall availability of less U- and abundant Th-resources in the Country, the 3-stage Nuclear Power Program, using natural U-, Pu-, and Th fuels sequentially, was envisaged by the great visionary, late Dr Homi J Bhabha. The Atomic Minerals Directorate for Exploration and Research (AMD) of the Dept of Atomic Energy, Govt of India was given the mandate to establish much of the required nuclear fuel resources for this program. During the last 58 yrs, AMD has identified 0.1 Million tonnes (Mt) of U₃O₈-resources and 0.9-1 Mt of ThO₂-resources in the country. It is exploring further to add much more to the resource-base of U, by adopting state-of-the-art methods of Exploration-Geology, -Geophysics and -Geochemistry. In this context, the present note deals with the use of different techniques of exploration geochemistry for U in India.

Introduction

Exploration geochemistry, together with geological- and geophysical-exploration, plays a crucial role in location and establishment of U-mineralization. AMD, with the exclusive mandate of exploration for U in India, has been carrying out geochemical surveys for U during the last 5 decades. As most of the surficial and near-surficial U-deposits in India have mostly been identified, multi-disciplined exploration efforts are intensified by AMD for locating hidden deposits to meet the ever growing demand for U. Since hidden U-deposits usually exhibit signatures of surficial/near-surficial geochemical-anomalies and aureoles, exploration geochemistry plays a critical role in bringing such deposits to light. Hence in this note, the geochemical methods of exploration adopted hitherto by AMD are briefly reviewed and some suggestions are advanced to make exploration geochemistry more effective in unraveling the yet to be discovered U-mineralization in the country.

Brief Account on Exploration Geochemistry, adopted hitherto by AMD

Scanning of AMD's publications shows that the geochemical surveys carried out by AMD hitherto, as briefly summarized below, are mostly of litho-, hydroy-, and atmo-geochemical, with very limited pedo-geochemical and geobotanical.

(a) Litho-(or petro)-Geochemical Surveys

These, with rock as the medium, generally form an integral part of reconnaissance exploration for U in all the areas identified as potential as well as in semi-detalled surveys in those areas with anomalously higher concentration of U, identified during reconnaissance surveys.

(b) Hydrogeochemical Surveys

These surveys, with surficial and ground/spring water as the medium, are next in both importance and intensity to the above. They include reconnaissance in larger areas and detailed in more focused areas like those earned out in parts of the Bhima Basin, Meghalaya, Andhra Pradesh, Rajasthan, and Haryana.

(c) Pedo-, Atmo-, and Bio-geochemical Surveys

These, compared to the above two, were carried out rarely, e.g., (I) pedo-geochemical with soil as medium like in the U-prospects of Bodal and Umra, (u) atomgeochemical, with Rn and He as medium, like in the Mikir Hills area, Assam, and (c) geobotanical in parts of the Hamirpur dist, Himachal Pradesh.

Furthermore, S-isotopic study of sulfides and mineral chemistry of both radioactive and associated non-radioactive ore/gangue minerals in many U-deposits/prospects such as those in the Singhbum Shear zone, Cuddapah- and Bhimu-Basins, and Meghalaya form an integral part of exploration geochemistry.

Suggestions for effective applications of Exploration Geochemistry

(a) Orientation or Pdot Surveys

It is always preferable to have an 'orientation survey' in a known mineral deposit(s) of the type being sought after and located in the

JOUR GEOL SOC INDIA, VOL 71, JUNE 2008
area(s) to be surveyed, before undertaking any type of geochemical survey, as the aim of the former is to provide, at the lowest cost, the technical information on which to base the latter. In an orientation survey, the following factors are to be optimized (i) optimum nature-size-character of samples, (n) best indicator elements, (m) efficacy of rock type, separated minerals, or types of material, weathering, alterations, and other variables on background and contrast of anomalies, (IV) shape, extent, homogeneity, and reproducibility of anomalies from a single site, (v) methods of sample preparation and analysis, and (vi) sources of contamination

(b) Lithogeochemical Surveys For proper planning of reconnaissance or detailed lithogeochemical surveys, a prior knowledge on important aspects of mineralization like type-classification of deposit sought, ore-forming processes, their patterns of both deep-seated origin and epigenetic anomalies in bedrock, major-minor-trace element haloes, and geochemical provinces and productive plutons is of much help. Furthermore, studies of Pb- and S-tsoptopes, and fluid inclusions in minerals of ores and rocks are important

(c) Hydrogeochemical Surveys. Apart from surface-, lake-, and ground-waters, drainage sediments (of spring/seepage areas, active streams, flood-plains, and lakes) can be the sampling medium. For efficient usage and interpretation of hydrogeochemical anomalies, knowledge on (1) mode of occurrence of elements in and factors affecting composition of the sampling media, (n) persistence of anomalies, (in) their time-vanations, and (iv) identification of anomalies not related to mineral deposits, is essential

(d) Pedogeochemical Surveys In these, either residual soil or transported overburden can be used, with the anomalies of the former being more reliable as ore guides. The sampling media can be weathered residuum, soils, cal-, sil-, and fenn-crete, till, sand, gravel, and glacial materials. These materials may be analyzed directly for the metal(s) explored for and its indicator elements, or alternatively samples of these can be panned and heavy (or sometimes light) concentrate can be subjected to mineralogical and/or chemical analysis, the latter is more effective. Knowledge of (i) weathering and soil formation in different regions for optimum planning of sampling and analysis, (n) separation of significant from non-significant anomalies, and (III) distinction between lateral and superjacent anomalies to avoid costly errors is essential for these surveys

(e) Biogeochemical- and Geobotanical Surveys. Biogeochemical method requires chemical analysis of plant organs like leaves, twigs, cones, wood, roots, and bark, whereas geobotanical method requires only visual observation of plant morphology like unusual size, deformities (e.g., abnormally shaped fruits, sterile apetalous forms, and stalked leaf rosette due to U-enrichment) or colours, and the distribution of plant species as a guide to buried ores, e.g., Astragalus species in Se-nch sandstone-type U-ores. Knowledge of ‘uptake of mineral matter by plants’ is of much help in these surveys that should become more regular, than hitherto, in geochemical exploration for U.

(f) Atmosgeochemical Surveys Use of Rn in soil-air and natural water is more efficient in locating buried U-mineralization than of He that is relatively of large amount in atmosphere and is more useful in locating fractures and other structurally weak zones, which have important bearing on concentration of U. Hence, surveys with these gases as media are to be resorted much in exploration for U.

(g) Luminescence Surveys Luminescence, though a physical property, is due to activator elements like U, Mn, Cr, Cu, Ag, and Eu, which are present as trace/minor constituents in minerals and rocks. Hence, surveys using the phenomena of fluorescence-phosphorescence, cathodoluminescence (CL), and thermoluminescence (TL) should be an integral part of exploration geochemistry, as they help in locating and predicting the unknown extensions of uramferous zones, e.g., on either side of the 6 km long Tunmalapalle-Giddankipalle belt, currently under exploitation by the Uranium Corporation of India Ltd., m the SW part of the Cuddapah Basin, and to separate the mineralized zones from barren ones. Such surveys should precede the costly drilling.

(h) Stable Isotope Geochemistry. Apart from S, studies on other important isotopes of H, O, and C of ores, rocks, and minerals should be routine, as they give critical information on hydrothermal U-deposits.

(i) Species Geochemistry. This, involving chemical analysis of different species of ore and gangue minerals and process-products of ore dressing operations, should be a part of exploration geochemistry. It helps in bringing to light the relative concentration of U in different minerals, its distribution, impurities, and its high-value co-/by-products like Au, Ag, Cu, Ni, V, and Mo, which could be recoverable during extraction of U from its ores, since as these have critical bearing on the cost-effective exploration/exploitation of U.

The above suggestions, when implemented together with appropriate techniques of exploration-geology and -geophysics, will help in rapidly discovering the hitherto hidden U-mineralization as also in reducing much the cost of exploitation of even low-grade deposits by recovering high-value metals as co-/by-products during extraction of U. Furthermore, establishment thus of substantial indigenous U-resources for use till the commercial operation of Th-technology will put India in a strong position so that there may not be any necessity to go in for discriminatory nuclear deals for nuclear fuel.

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Ultra High Temperature Metamorphism

Ultra-high temperature metamorphism (UHT) is the most thermally extreme type of crustal metamorphism with temperatures exceeding 900°C and even up to 110X. UHT metamorphism has now been documented from several high grade terrains based on mineral assemblage, texture, and experimental approach. David Kelsey (Gondwana Res., v 13, 2008, pp 1-29) presents a scholarly comprehensive review of the current status of our understanding of ultra-high temperature crustal metamorphism including (1) the history of