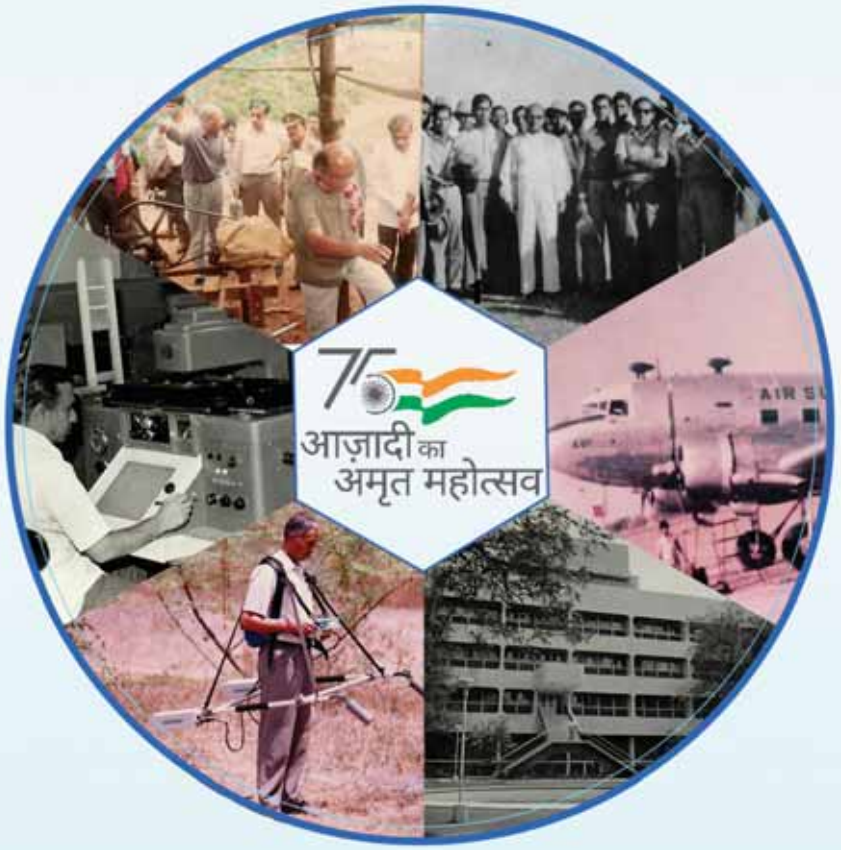
आज़ादी का अमृत महोत्सव

पखनि के सेवानिवृत वरिष्ठ वैज्ञानिकों की स्मृतियों की स्मारिका

Azadi ka Amrit Mahotsav

Souvenir on Reminiscences of Retired Senior Scientists of AMD



Editor-in-Chief

Dr. D.K. Sinha
Director, AMD

परमाणु खनिज अन्वेषण एवं अनुसंधान निदेशालय
ATOMIC MINERALS DIRECTORATE FOR EXPLORATION AND RESEARCH

परमाणु ऊर्जा विभाग DEPARTMENT OF ATOMIC ENERGY

अगस्त August, 2022 हैदराबाद Hyderabad

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Reminiscences of AMD Scientists

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NEW INDIA@75
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Atomic Minerals Directorate for Exploration and Research

Dr. D.K. Sinha
(Director, AMD)

PREAMBLE

Atomic Minerals Directorate for Exploration and Research (AMD), currently a leading geoscientific organization in the country, was created with 23 personnel in 1949 as Rare Minerals Survey Unit of Atomic Energy Commission soon after the country became independent. Since then, AMD has seen a steady growth and contributed significantly in establishing uranium, thorium, REEs and other rare metal deposits. Thanks to the visionary scientists including Dr. D.N. Wadia, doyen of Indian Geology, Dr. Homi Bhabha, father of atomic energy programme of the country, and the untiring efforts of our senior colleagues for laying strong foundation for AMD. Over the last 73 years since its inception, AMD has witnessed enormous growth both in terms of its technical capability and sophisticated instrumentation, which have paved the way for establishing economical deposits of atomic minerals. Today, the geoscientific world looks upon AMD for planning and exploration for atomic mineral resources.

At a time when the nation is celebrating "Azadi ka Amrit Mahotsav", to commemorate 75 glorious years of Independence, its history, people, culture and achievements, several programmes are being organised at AMD since August 15, 2021 in line with the directives received from DAE. A national seminar titled "MEFCI-2022" was conducted in collaboration with Geological Society of India, Bengaluru during 5-6 April 2022. "Atmanirbharta in Science", a webinar series of 10 invited lectures by eminent scientists of different specialities and decorated with Padma awards, was also organised. Public awareness programmes highlighting the peaceful uses of atomic energy and role of AMD in nuclear power programme of the country have been organised in a year long period. National level competitions in Essay writing and Science Quiz for school and college students were also conducted.

Today when we look back, we find that the contributions made by those who joined the Directorate in the initial years (1949-1979), when the techniques and machinery were rudimentary, are very significant. Their dedication and enthusiasm in establishing the facilities for airborne surveys, field work, drilling, laboratory investigations, data processing and even fabrication

Atomic Minerals Directorate for Exploration and Research

of sophisticated instruments including Mass Spectrometer is commendable. It is pertinent to mention these significant contributions, especially during the time when Atmanirbhar Bharat (self-reliant India) is a flagship programme of the Government of India.

In the true spirit of the Mahotsav, it was resolved to bring out a "Souvenir" comprising invited articles from former geoscientists of AMD, who have attained the age of 75 years and immensely contributed to the growth of the exploration and research for atomic minerals in the country. It gives me great pleasure to put it on record that we readily received positive responses from many former officers despite their ripe old age. As many as 28 senior scientists have contributed their wisdom in this volume. Some are purely technical and others are nuggets from their personal and professional life about on-foot surveys, tryst with destiny, accidental discoveries, personal losses, hardships, adventures, sixth sense notions, treacherous traverses, encounter with wildlife, value of money etc. The volume is filled with priceless anecdotes from successful geoscience professionals. I am sure this would become an interesting read for all, especially motivating for younger geoscientists of AMD.

I am highly indebted to all my seniors and also thankful to those who poured their heart out and also jotted down the roadmaps for the present generation for planning exploration activities in future. A few of them even shared rare photographs from their personal album which has made this memoir invaluable. While editing the souvenir care has been taken to retain the flavour of writing by the seniors.

This Souvenir contains valuable experiences of our former senior colleagues while they carried out exploration and research for atomic minerals. These will serve as a record of anecdotes for the present generation and posterity. I am sure that this memoir will connect the past, present and future of AMD. I also hope that this effort will be a befitting tribute to the hard work put in by our seniors on 75th anniversary of independence.

Dr. D.K. Sinha
(Director, AMD)

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Reminiscences of a uranium exploration geologist - exploration strategy and mid-course corrections

T.M. Mahadevan

(Former Director, Atomic Minerals Directorate for Exploration and Research)

Email: tmm154@gmail.com

Date of Birth: 15.04.1926 *Date of joining AMD: 12.09.1969* *Date of superannuation: 30.04.1987*

Shri T.M. Mahadevan obtained B.Sc. (Hons) from Presidency College, Madras and M.Sc. (by research) from Madras University. He joined Geological Survey of India in 1949 and served upto 1969. He joined AMD in 1969 and superannuated as Director, AMD in 1987 after one year of extension of service.

Shri Mahadevan is one of the renowned geoscientists of the country and has contributed immensely to the mineral development such as gold deposits of Wyanad, Beach Sand deposits of Kerala and several Uranium deposits. He is a recipient of several state and central awards. He has authored several books in Earth Sciences.

Post retirement he has been closely associated with Department of Science and Technology, New Delhi in pursuit of earth science projects dedicated to the Earth's Continental Interior. He has also served as a member of the AMD Council of Management.

Shri Mahadevan has artistry in violin and was a regular auditioned artist of the All India Radio.

This paper briefly outlines the broad framework of the exploration strategy that I had the opportunity to pursue in some eighteen years of my service in AMD from 1969 to 1987 and the changes in the exploration strategy that we had to implement, which resulted in identifying large uranium deposits. Some of these findings are unique and unparalleled among world class deposits.

I joined AMD in 1969, after some twenty years of service as a geologist in the Geological Survey of India. I retired after a year's extension in 1987. In the eighteen years of my service in AMD, I actively participated in evolving a new exploration strategy. Under the guidance of Shri K.K. Dar, the then Director, we commenced exploration in the Siwalik formations along the foothills of Himalayas. Dr. G.R. Udas took charge as Director in 1974. He further modified our approach to exploration. The key to this strategy was to diversify the exploration for uranium from one of a concentrated effort in the Singhbhum Thrust Belt (STB), with numerous deposits proved since 1949 (when the belt was discovered it was in Bihar, now Jharkhand), to other promising diverse areas. This strategy was also to use the limited men and material resources to seek other types of uranium deposits, so well-known from different parts of the world, such as the Phanerozoic sandstone-types of USA, France and other types. These new areas so chosen included large Precambrian terrains with Proterozoic sedimentary basins such as the Cuddapah, Kaladgi, Bhima and Vindhyans and the Phanerozoic basins of Gondwana, Mahadek and the Himalayas. In this new effort, we had many challenges that needed mid-course corrections to our exploration strategy, which then resulted in identifying new uranium deposits and opening up the potential of many new areas requiring intensive exploration. The new uranium deposits discovered include (i) the deposit at Domiasiat in Meghalaya in the Upper Cretaceous Mahadek sandstones, (ii) the Gogi deposit in the Proterozoic Bhima basin in Karnataka, (iii) the Tummalapalle deposit and its extensions in the western margin of Cuddapah basin, and (iv) Lambapur-Peddagattu and Chitrial in the northern fringes of the Srisailam sub-basin in the same Cuddapah-Kurnool basin.

The predominance of shallow enriched uranium outcrops

(i) The Siwaliks experience

The extensive belt of the Himalayan Siwalik Foreland, Tertiary basins raised high hopes,

when a window of U-rich vertebrate fossils' collections from the Siwalik formations in the geology museum of the Punjab University in Chandigarh revealed high concentrations of uranium. Subsequently, the discovery of high grade (>0.10% U_3O_8) uranium mineralization in Siwalik sandstone outcrops at Morni (Lat. 30°45'; Long. 76°16') in the Morni hills of Panchkula district in Haryana, located about 45 km from Chandigarh and 35 km from Panchkula, further strengthened our hopes. However, a few drill holes proved the Morni mineralization to be very shallow extending to not more than a few feet from the surface - a rootless mineralization. While this proved very disappointing, the Siwalik belt has still a high potential, as later continued exploration has proved mineralization down to a maximum of 700 m (Fig.1).

That many uranium-rich outcrops of fluvial sediments may be shallow is not a new experience, as revealed by the fact that the average reserves of some 3000 U-rich outcrops in the Colorado basin in USA is just one tonne.

(ii) Bodal-Bhandaritola experience

The Dongargarh uranium province in Rajnandgaon district, Chhattisgarh state is a promising belt of uranium mineralization hosted by volcano-sedimentary sequences with intrusive younger granites and granitic porphyry bodies. Uranium mineralization at Bodal was discovered in 1972-73 (Fig.2). It was then considered as important as the Jaduguda deposit in Sighbhum district, Jharkhand. Detailed exploration in Bodal, however, led to disappointments as it proved that the ore body extends only to the depths of 200 m and to nearly 400m in two sections of the ore body. The reserves estimated were, therefore, limited.

Structurally controlled uranium mineralization was found in Bhandaritola close to Bodal in 1976-77 along lineaments striking NNE-SSW to N-S along a contact of quartz-porphyry and the cataclasites of the Dongargarh Granite and amphibolite (sheared metabasalts akin to the Bodal rocks) country rocks. Initial samples analyzed 0.17% U_3O_8 offering much promise. But detailed exploration showed much lower grades extending down to hardly 5 m to

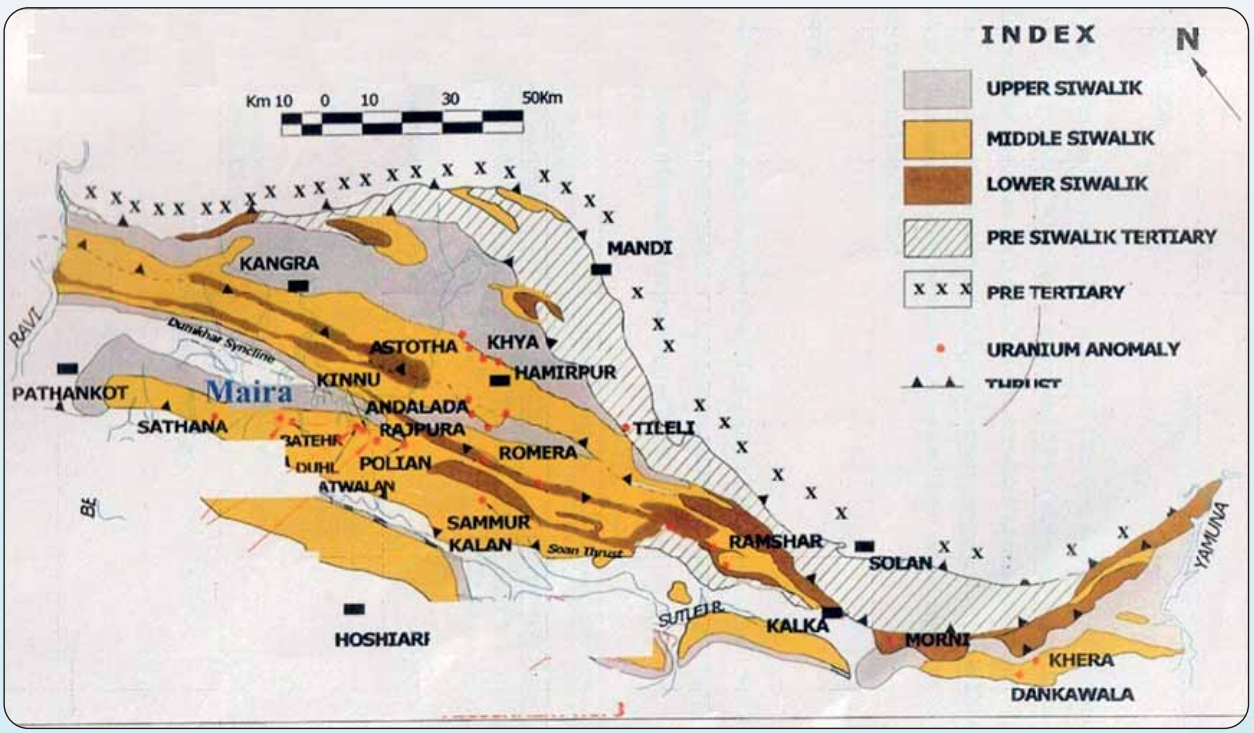

Fig.1. Geological map of Tertiary formations, Himachal Pradesh, Punjab and Haryana

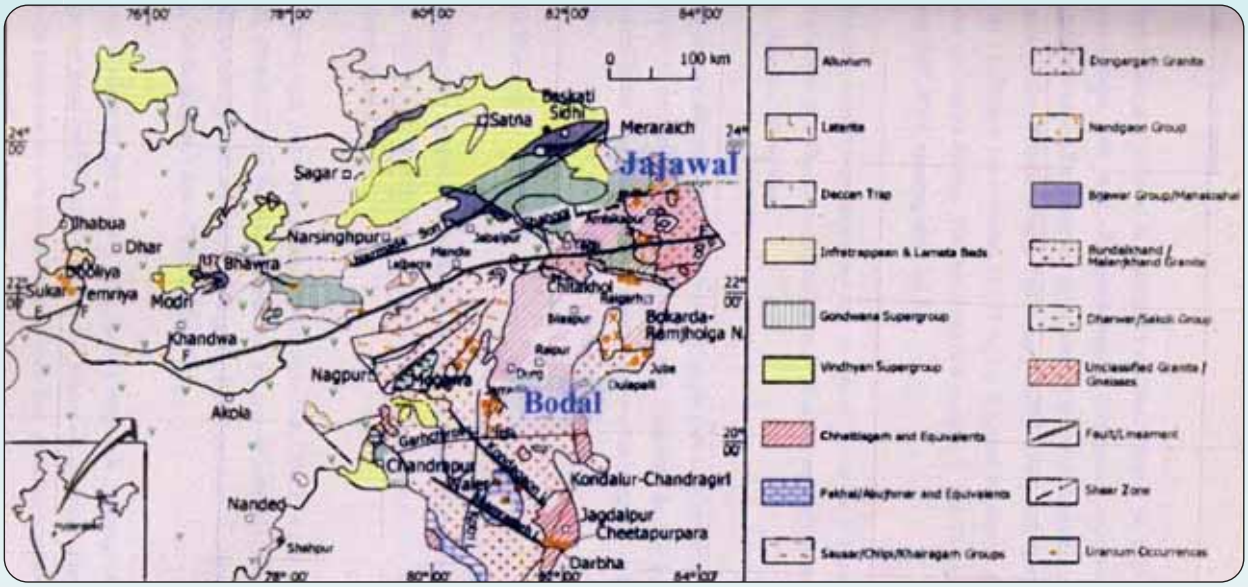

Fig.2. Geological map of the Dongargarh domain and Chhotanagpur Gneissic Complex.

280m along the strike length, limiting the reserves.

Limitation of some surface exploration methods

The Meghalaya plateau was for a long time clubbed to be a thorium province as a result of Jeep radiation surveys along motorable roads. However, detailed ground surveys along deep valleys identified U-mineralisation in the exposures of the upper Cretaceous Mahadek formations, in contrast to the overlying Tertiary beds that are thoriferous. Further exploration was extended to outcrops of Mahadek Formation and this led to discovery of rich U-deposits at Domiasiat renamed as Mawthabah-Wahkyn (Fig.3).

These limitations apply to also airborne-gamma ray spectrometric radiometric surveys. However, airborne EM methods have the promise of locating concealed sulphide bodies that may hold promise of U-concentrations due to the favourable reducing environment.

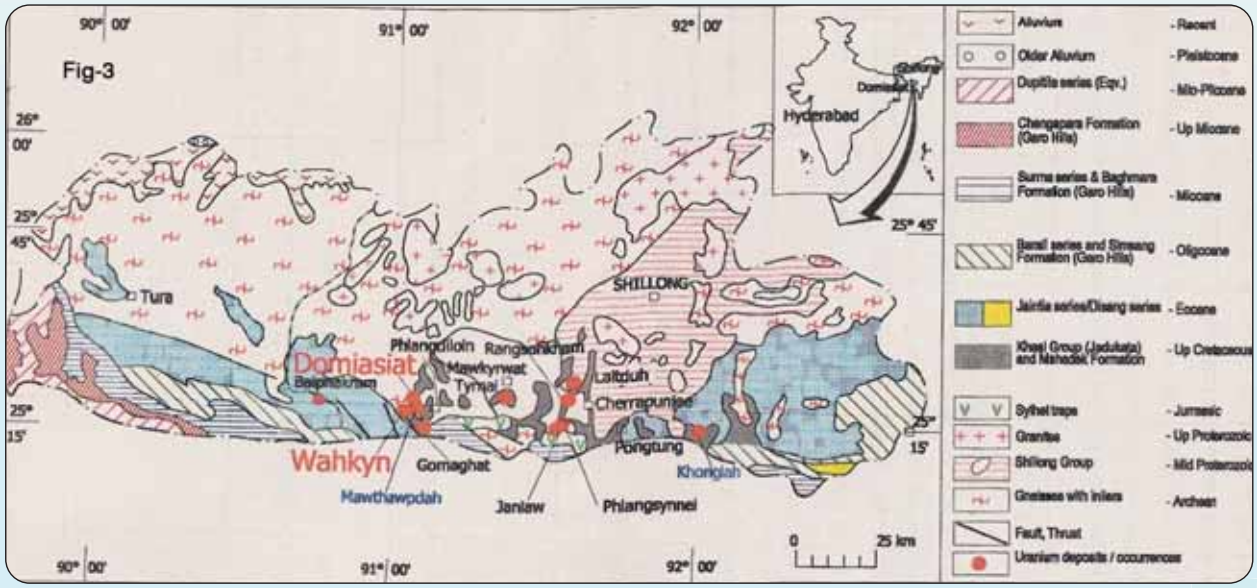

Fig. 3. Uranium mineralisation along southern fringes of Meghalaya plateau.

Limitations of ore grades and host-rocks (country rocks)

For several years our exploration targets were guided by ore grades above 0.04% U_3O_8 and ignored those below this grade. In 1987, just before I superannuated, we drilled some 10 boreholes along the southern fringes of the Cuddapah basin. As we encountered only mineralization of <0.04% U_3O_8 further drilling was discontinued, ignoring the possibilities of higher grades in rest of Cuddapah basins, for reasons outlined below. Exploration strategy at that time considered carbonate-phosphate sedimentary horizon as unfavourable for uranium mineralization both because of the paucity of uranium occurrence in carbonate belts among the world class deposits and low acid leachability of ores, even if found. So, no high priority was given to prospecting in the Cuddapah basin, where the host-rocks are largely carbonates. Subsequently, the whole scenario has undergone changes due to the discovery of uranium mineralization of high grade and thickness hosted by the brecciated Shahbad limestones at Gogi in the Proterozoic Bhima basin, based on favourable groundwater surveys (Fig.4). Detailed prospecting has revealed that the Gogi deposit hosts high grade ore bodies and with 2.5m thickness, in some places rising to higher values.

The encouraging results in Gogi led to further exploration along the fringes of the Cuddapah-Kurnool basins. This led to the identification

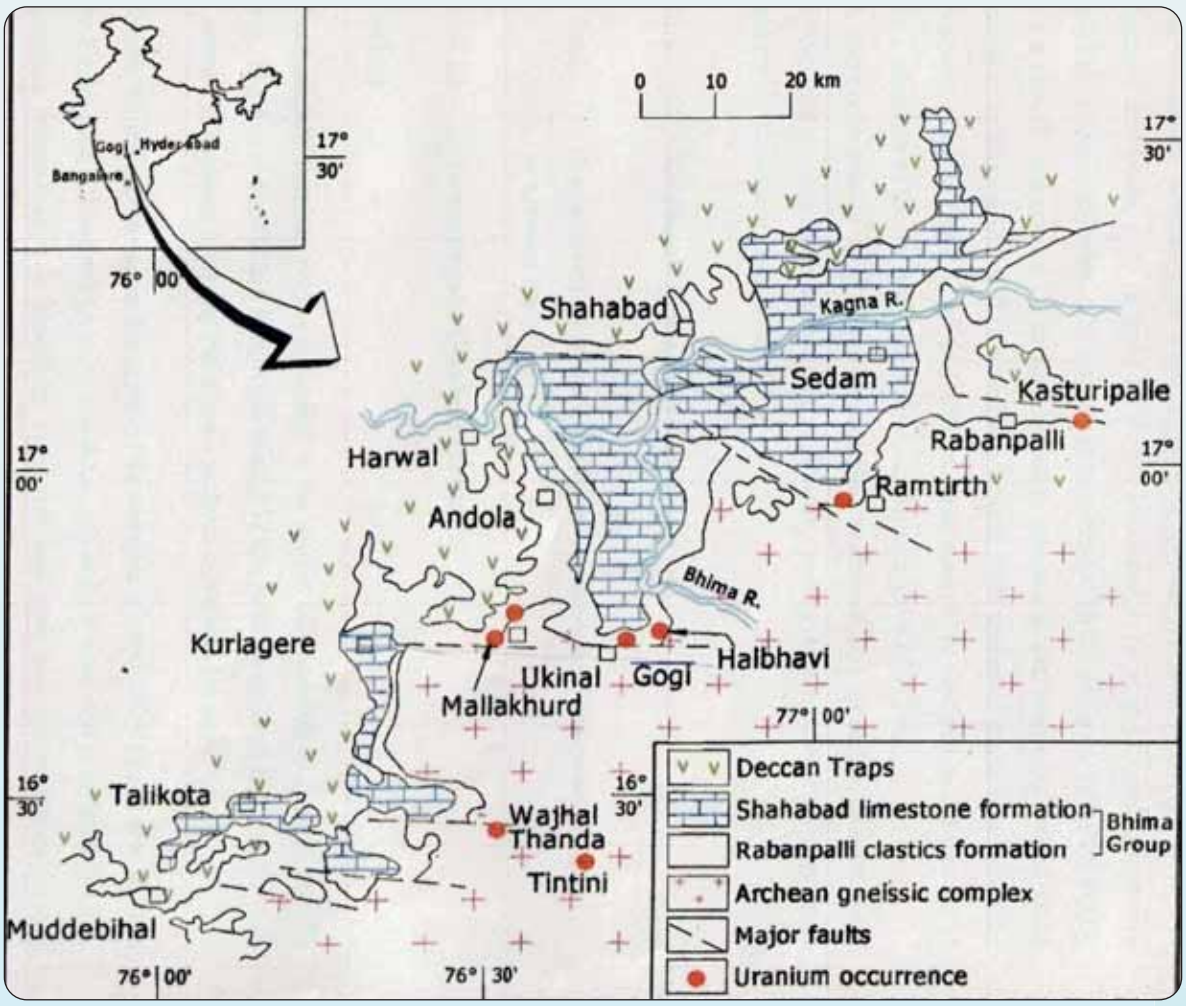

Fig. 4. Uranium mineralisation in the Bhima basin.

of uranium deposits hosted by carbonate–shale sequences at Tummalapalle and its extensions.

Detailed prospecting along the northern fringes of the Cuddapah basin in the islands of outliers along the northern fringes of Srisailam sub-basin led to identification of uranium deposits at Peddagattu, Lambapur and Chitrial (Fig.5). These discoveries opened up wide possibilities of finding uranium in the other Proterozoic basins, such as the Vindhyan basin, the largest Proterozoic sedimentary basin in India.

Leachability of Uranium ores

Uranium ores of Jaduguda and other mines around are highly acid leachable, generally over

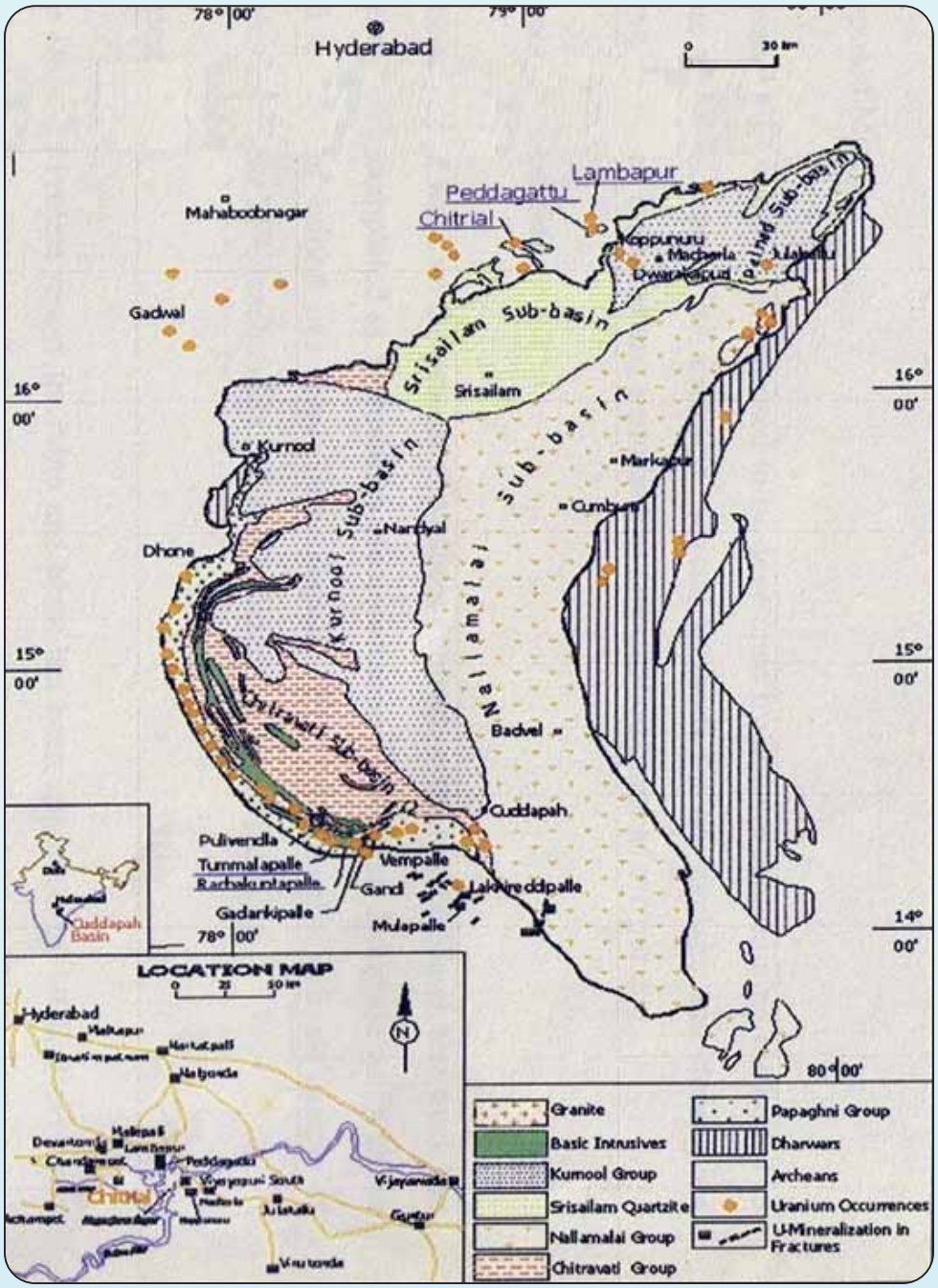

Fig. 5. Geological map of Cuddapah basin showing Lambapur-Peddagattu and Tummalapalle deposits

90%. In the case of carbonate-hosted ores as in Tummalapalle and its extensions, a pilot-scale test work on some 200 tonnes of mined ore at the Jaduguda Technology Demonstration Pilot Plant developed the Alkaline Pressure Leaching Technique. This new method provides a route that can help to develop uranium mineralization, if found in the carbonate horizons that dominate various Proterozoic provinces.

Concluding remarks

Our experience in uranium exploration has proved that exploration strategy is a continually evolving process and calls for broad outlook in choosing sites for exploration based on the geochemistry of uranium.

The unusually uranium-rich ore bodies discovered in Cigar Lake (>14% U) and in McArthur in Canada and the polymetallic deposits at Olympic Dam in south Australia in an iron-oxide breccia complex, all the three at depths of some 300 m, opens up possibilities of concealed ore bodies that may have no surface expression. These deposits are in regions of rich U-provinces hosting a large number of outcropping U-mineralization.

In India, therefore, the priority areas for search of concealed ore bodies are (i) the Singhbhum Thrust Belt (STB); (ii) the Aravalli-Delhi Precambrian terrain in Rajasthan; (iii) the Cuddapah and Bhima basins in south India, and (iv) the Chhotanagpur Gneissic complex and the Dongargarh U-province in Central India. A second order priority may be given to the several Proterozoic basins, where we are yet to find U-mineralization. Among the various tools we have used in exploration are groundwater surveys and radon emanometry. We can be benefitted by these conventional tools, especially when integrated with the large scale heliborne EM surveys.

In drafting this article, I have been helped greatly by Dr. Ajayakumar P., Assistant Professor in the Department of Marine Geology and Geophysics, CUSAT, Ernakulum. Dr. P. Krishnamurthy, who superannuated from AMD was good enough to go through this paper and made useful suggestions. Shri B.M. Swarankar, who also superannuated from AMD, helped by giving details of the exact geographical position of Morni mineralization in the Siwaliks. This article has been drafted mostly based on information available in my personal records and as such no references are presented. However, I am grateful to a large number of earth scientists in AMD who have generated all the basic information contained in this article.

Glimpses of the early decades of AMD

S.N. Virnave

(Former Regional Director, North Eastern Region, Shillong)

Email: satchitanandvirnave@gmail.com

Date of Birth: 01.01.1932 *Date of joining AMD: 20.12.1956* *Date of superannuation: 31.12.1991*

Dr. Sachchida Nand Virnave obtained M.Sc. from Patna University, Bihar and Ph.D. from Nagpur University, Nagpur. He joined AMD in 1956. He has served in several parts of the country in various capacities. He superannuated as Regional Director, AMD, North Eastern Region in December, 1991.

Dr. Virnave was deputed to France and Iraq and has authored three books besides several publications in journals. Post retirement he has served as Professor of Geology and Environmental Science in North Eastern Hill University, Kohima, Nagaland.

I feel profoundly humbled and honoured to be remembered by my adorable institution on the eve of "Azadi ka Amrit Mahotsav". It is an occasion of great celebration with rejoicing and jubilation on completion of 75 years of Independence. It is always with a feeling of nostalgia to reflect and recall its glorious achievements over the years as envisioned by our freedom fighters and founding fathers.

Science and technology played a pivotal role in the planned development of our country. The creation of the Department of the Atomic Energy (DAE), as one of the critical components of the technological thrust, resulted into a far-reaching consequences related to faster growth of science and technology in the country.

Atomic Minerals Division (AMD), earlier designated as Raw Materials Division (RMD), is a constituent unit of DAE, vested with the responsibility and commitment to deliver indigenous nuclear fuel material to support its envisioned programme of work. Accordingly, the seeds of AMD were planted that proliferated, bloomed and blossomed over the decades fulfilling its assigned roles. In this context, I am proud to say emphatically that this critical unit has stood the test of time in letter and spirit in discharging its obligation with resounding success. How this miracle has happened is a saga of human endeavour, its toils, trials and tribulation dictated with an innovative spirit.

I never looked back since the day I joined AMD, for me it turned out to be sacrosanct institution of learning, living with togetherness, inculcating the highest tradition of fellow feeling, camaraderie in a friendly environment of symbiosis, sharing each other's dreams and aspiration pursuing a common goal.

The unit started with a modest beginning, identifying certain target areas of uranium potential based on meagre and scanty geological information. The initial years were exclusively devoted to radiometric survey and search for uranium resources associated with base metal deposits in the Precambrian crystalline complex as an end product of magmatic differentiation associated with hydrothermal phase. Based on these promises, we concentrated in the Singhbhum Thrust Belt (STB) to explore its occurrences associated with the copper deposits of that area. On the same analogy, the other promising areas of exploration were identified centered around Khetri-Dariba copper belt of Rajasthan.

Apart from uranium, beryl investigation was also taken up simultaneously for its critical application in reactor technology. The well-known mica belts of Bihar (now Jharkhand), Rajasthan and Andhra Pradesh were the target areas of beryl

production associated with the pegmatitic belts. Besides these two main atomic minerals, the placer deposits of beach sands in the costal stretch of Thiruvananthapuram district, Kerala, were also under active investigation for evaluation of its thorium and zircon. The atomic minerals map of that period had only a few shades of interest with large area of the country looking barren that remained unexplored at that point of time.

In the prevailing scenario of that time, I wish to recall some interesting episodes of my professional tenure that left an everlasting impression on my mind. After joining the department in December, 1956 at New Delhi, I was sent to a training camp at Udaisagar, Udaipur district, Rajasthan, along with other new entrants. The well-organized training camp provided the opportunity to meet the doyens of Indian geology like Dr. D.N. Wadia, Dr. P.K Ghosh and other senior officers of the department. It was my dream come true to be in close company with those persons of great eminence and reputation. I vividly remember the first day of my field traverse under the guidance of Dr. P.K Ghosh, Mr. K.K Dar along with hosts of senior colleagues. The way Dr. Ghosh conducted the entire operation explaining the geological set-up vis-a-vis the environment of uranium mineralization in the black shales with the aid of neatly drawn geological sections was an enchanting learning experience of everlasting values for a beginner like me. His scholarly tutelage, leadership quality and the art of handling and grooming the youngster profoundly impressed me making him as my role model. At the end of exhaustive traverses he addressed the trainees with the following words of great geological significance. I quote, "Young men I want your legs to be stronger than your mind. Your physical stamina and healthy demeanour will facilitate you to scan and cover large areas and that's what I am interested at the moment". With these words of wisdom he parted our company assuring us to meet again.

Extending over a span of 35 years of my professional stint in the department, I have numerous reminiscences worth its salt to share with you but paucity of space prevents me to restrict to a few anecdotes of irresistible version that profoundly influenced my psyche and made me what I am today. It was a stroke of luck that placed me in the galaxy of highly qualified personas, who made a difference to my life with their qualitative contributions, friendly behaviour and adorable gesture. I pay my respects and regards to all those stalwarts, most of them are no more with us. In the long list of my mentors, I owe a deep debt of gratitude to Dr. G.R. Udas, former Director, AMD, who spotted me with corrective measures and chiseled out and shaped me according to his likings. He was my mentor, Guru, guide, friend and philosopher till he superannuated and that relationship continued even later on. He was a versatile genius with a multi-facet personality having a knack to venture out into unfamiliar terrain and take the risk and responsibility for any eventualities. No wonder, Dr. P.K. Ghosh picked him up to initiate the start-up of Jaduguda exploratory mining project, wherein he proved his mettle and competence to measure up to the expectation of his boss.

I wish to share one of his constructive comments that triggered my dormant potential to awake and arise to the demanding situation. In those days, I was conducting Radiation Jeep Survey and ground checking of the aerial anomalies spread over a vast area falling in parts of Gujarat, Rajasthan and Madhya Pradesh, for 3 consecutive field seasons. My boss Dr. Udas was not very pleased with the kind of assignments I was involved. I remember his caustic comments that changed the course of my life. I quote, "Virnave, look, a rolling stone gathers no moss. I want you to do something specific in the domain of uranium geology". I realized the gravity of his constructive suggestions that stimulated my imagination for concerted action. As per his considered opinion my assignment was changed to take-up radiometric reconnaissance survey, in parts of Satpura Gondwana, where he evinced keen interest by regular visits to the field areas, guiding, prompting and motivating me with the aid of published papers and journals that he brought from U.S. during his visit of the Colorado plateau hosting the sedimentary type of uranium deposits. He was instrumental in opening a new frontier in the strategy of uranium exploration

geology enkindling my curiosity with absorbing interest. His involvement with this project led to an evolution of an altogether novel culture of work combining the traditional approach with research orientation that ultimately culminated in the production of Ph.D. thesis under his supervision awarded by the University of Nagpur.

Bhawra uranium exploration project offered me yet another unique opportunity to get in touch with Dr. D.N. Wadia, Geological Advisor to the Govt. of India, AEC, our supremo. He camped along with his dignified and gracious lady, Madam Maher Wadia for seven days. It was a highly coveted and rewarding experience for me to take field traverses with him sharing his erudition, experience and profundity of everlasting value. It was amazing to watch his enthusiasm getting down into the trenches and examining the mineralized exposure with keen interest as an octogenarian, demonstrating his extraordinary passion for the subject that he loved throughout his life. Watching his stunning performance my mind flashed back to images of his outstanding contribution in identifying and defining the syntaxial bend structure of the north western Himalayan crystalline complex that distinguished him as one the pioneers of the Indian geology. Destiny brought me in his close contact to learn and enhance my knowledge of the subject. Reminiscence of that era tends to convince me that the older generation of geologists were endowed with far more insights and imagination to comprehend and discern the subtle and finer aspects of geology that is getting eroded in the digital era of dispensation. No doubt, modern science and technology has immensely contributed to the study and advancement of geology, yet it has limited scope of expansion without field work. On the other hand, field work offers you a vast space and scope to fathom into the mysterious domain of geology that conceals a lot of natural resources yet to be discovered.

In this context, it would not be out of place to share my personal opinion that may or may not be in conformity with the traditional concepts. As I perceive, the success story of human endeavour could be broadly classified into two distinct groups, one whose work shines for some time and then it fades away, while there is another group of victorious people, who leave a permanent legacy of everlasting value that stands out as a living monument of historic importance radiating beauty, charm, as a perennial fountain of joy and knowledge to inspire the coming generation. It would not be an exaggeration, if I place AMD's contribution in the latter group for its splendid achievement in enlarging the frontiers of uranium exploration geology. Today, it stands out on firm footing holding a colourful map of atomic mineral resources and its various establishments spread all over the geographical limits of the country

As mark of respect, I am proud to state that DAE has produced numerous well known personalities like Dr. Homi Jahangir Bhabha, Dr. Raja Ramana, Dr. D.N. Wadia along with many others whose glittering legacies will always be remembered by the grateful nation.

Lastly, but not the least, I wish to complement your untiring efforts and dedication in exploratory consolidation in promoting its legacies.

My contributions towards the progress of AMD

Late J.G. Jadhav

(Former Head, Meterial Management and Construction & Engineering Secrvices Groups)

Date of Birth: 12.06.1933 *Date of joining AMD: 24.12.1956* *Date of superannuation: 30.06.1993*

Shri J.G. Jadhav obtained M.Sc. (Electronics) from Institute of Science, Nagpur, Maharashtra. He joined AMD in 1956. He has worked in all parts of the country in various capacities. He superannuated as Scientific Officer-G and Head, Material Management and Engineering services in June 1993. He published several articles in national and international journals. He worked as IAEA expert in Zambia.

I joined AMD (Atomic Minerals Division), called RMD (Raw Materials Division) until 1958, in 1956 and worked there until I retired in 1993.

First, I was posted in the Udaipur field laboratory, where I received training in methods used for exploration of uranium and other radioactive minerals, and in instruments used for the detection and evaluation of uranium and thorium in samples from the field. Detection of radioactivity was done with radiation meters comprised G.M. counters, and circuits which used valve technology. Now NaI (Sodium Iodide) crystals are being used in place of G.M. counters and valves were replaced first by transistors and later by ICs.

Faster reconnaissance was done by jeep-borne and airborne radiometric surveys; else it was done on foot. In prospective areas, boreholes are drilled up to 1000 metre depth. The evaluation of uranium content at such depths required techniques to be developed in the Physics laboratory. For *insitu* evaluation, comparison with a standard simulating the deposit in the borehole was required. At the AMD laboratory, in Delhi, a pit of 36″ diameter and 3′ thickness was made. It was filled with a mix of crushed rock and uranium ore, which was a sample with a known content of uranium in equilibrium. This was the standard prepared by the pioneering physicists of AMD.

The density of the sample was less than the average density of rocks in the boreholes, also it was of limited dimensions and this entailed certain corrections. Later, it was proposed that another standard would be prepared with larger dimensions and with density closer to that of rocks. A new standard of 20′ height and 5′ diameter was prepared and located in the UCIL lab. The standard contained many layers of different grades separated by barren zones. The main layer's sample zone was 5′ diameter and 4′ height, containing a concrete mix of ½″ basalt, sand, cement, and uranium ore from Jaduguda mines. The uranium in the ore was in equilibrium. The standard is used for fixing the value of smaller secondary standards, which are carried to the field for evaluation of borehole logs. This was my first project under the guidance of late Shri N. Dayal, a pioneer in the AMD Physics Group.

Exploratory mining was carried out in Jaduguda. Uranium ore transported from the mines in tubs passed through scintillation arches, which were designed and fabricated to evaluate uranium.

After all this experience, I was posted in the Instrumentation Group at Hyderabad, where various instruments were designed and fabricated for use in the field by the scientists of AMD.

A high sensitivity gamma-ray spectrometer was designed for airborne surveys. The data was computerised for mapping. The Computer Group had developed a very sophisticated programme considering all the parameters such as altitude and temperature.

Along with the radioactivity, it was proposed to carry out surveys for magnetic field. A High Sensitivity Proton Precession Magnetometer was designed and installed in the survey aircraft. Prior to the installation, late Shri Chavan and myself worked for its design and completion for 12 hours a day for four months without any leave. Shri Chavan took the equipment to Chennai for installation. But on the first day a most unfortunate incident occurred. The aircraft crashed in Yedavali hills in Ongole district of Andhra Pradesh killing all five AMD scientists and three crew members. The next day I accompanied late Shri N.S. Bhalla (Group in-charge), to inspect the crashed aircraft. Everything was completely burnt only a mass of flesh remained. The remains were packed in wooden crates and brought to Hyderabad for cremation It was an appalling sight. That was the saddest incident in my life.

However, in the pursuit of scientific work the project had to continue. I completed the fabrication of the new magnetometer, which was installed in an aircraft and tested successfully. That was my second project.

Calibration Pads

The data collected in airborne gamma-ray spectrometric surveys needed a quantitative estimate, hence it needed to be compared with known sources. And so, it was proposed to construct a set of 'Calibration Pads' with a known quantity of radioactive material. A location near Nagpur airport was selected, so that the survey aircraft along with the instruments could be towed to the pads. The other consideration for choosing the area was the low radioactivity content in basaltic rock.

Five pads were constructed: (i) Uranium (ii) Thorium (iii) Potassium (iv) Barren (v) A mixture of uranium, thorium, and potassium, with a spacing of between pads. The pads were in the form of concrete of 12.5 metre diameter by meter thick. The concrete consisted of ½″ basaltic rock, chips, sand, cement, and measured quantity of uranium or thorium. Each pad had to be laid at a stretch so that there were no cracks. Hence, 10 concrete mixers were used simultaneously. Uniformity of the material was necessary. The pads were built to be strong enough to bear the weight of the aircraft.

Every year before starting, the survey unit is brought here for determination of the calibration factors. Thirty years later, the calibration pads are still being used. This was the third project completed by me under the guidance of late Shri Y. Lall.

I had the privilege of working as an International Atomic Energy Agency (IAEA) expert in Zambia for four months. The Government of Zambia was involved in the exploration of radioactive minerals, which required electronic instruments. Facilities for repairing of these instruments were to be set up. This included training Zambian personnel in (i) electronics engineering related to the servicing of radiometric survey and assay equipment; and (ii) organizing and operating such a laboratory. Seven personnel were trained by me in this period and I also helped them to repair a number of equipment. A well type NaI(Tl) crystal assay unit for determination of eU_3O_8 was set up and their servicing laboratory was organized. This was the fourth project.

Obituary

Mr. Chavan, who died young in the line of duty in AMD. AMD pays homage to him. May the departed soul rest in peace.

Shri J.G. Jadhav, former Head, MMG and C&ES Groups, subsequent to submitting this article, passed away at his home in Amaravati, Nagpur. AMD pays homage to him. May the departed soul rest in peace.

My views in brief on basic approach of field geologist in mineral exploration

S.K. Hansoti

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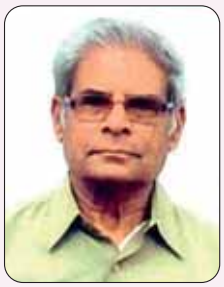
Date of Birth: 09.06.1936 *Date of joining AMD: 07.03.1960* *Date of superannuation: 30.06.1996*



Dr. S.K. Hansoti obtained M.Sc. from Karnataka University, Dharwad and Ph.D. from Nagpur University for the thesis on 'Structural and Geological controls of Uranium mineralisation in Sendur-Tatapani area, Balrampur district, Chhattisgarh'. He joined AMD in 1960. He has worked extensively in central and north eastern India. He superannuated as Deputy Regional Director, Central Region in June, 1996. He has published several research articles in journals of national and International repute.

Field geology requires keen observations of not only rocks but also soil, vegetation, drainage systems and morphology. Each one of the above is part of the earth's crust and stores history of that part or segment of the crust. It is the endeavour of a geologist to detect, decipher, imbibe, anlayse, investigate and interpret various characteristics of the above components of nature which form the crust of the earth. It is well known that nature reveals less and conceals more and therefore a geologist has to marshal all skills at his command to arrive at a plausible evolutionary history of the segment of the crust being investigated.

Before venturing into an exploration area, one should collect available information and data relevant to one's purpose. However, one should evaluate such data critically and determine its veracity in an unbiased way. Not all data/views mentioned in lectures, reports or publication are genuine and please do not get overawed by names of personalities. They are also humans and prone to have erroneous concepts. One may have to adapt an independent stand, which may be contrary to prevalent ideas/ concepts and may have to face censure. However, one should have courage of conviction.

In modern days, there are several sophisticated devices and analytical instruments, mathematical and statistical computations, remote sensing techniques, which help in enhancing geological information, data collection and interpretations. Interpretation of analytical data can be put to use in geochronological sequencing of events. Integration of such laboratory-derived data with data collected from field area facilitates propounding exploration models for minerals.

I, on my initiation as a field geologist, gradually developed skills of traverse mapping, recognition of geomorphological features, structural features using Survey of India toposheets, recognition of interrelationship of rock forming minerals under microscope, further aided and enhanced by referring to books and journals. Working in Himalayas helped augmenting some of the skills. At the same time, I learnt to recognize, various controls such as lithological or lithological contacts, structural, petrochemical and minerochemical in order to find / discover locations of such mineralisation elsewhere in an area and succeeded fairly.

I call upon the present day field geologists to blaze a trail starting with the national celebrations of "Azadi ka Amrit Mahotsav".

The saga of Rs. 1.25

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Shri S.P. Balakrishnan joined AMD in 1959. He has worked in several parts of the country in various capacities. He has been instrumental in the development of advanced analytical facilities in AMD and obtained intensive training in France (DC-AES) and Australia (ICP-AES). He was deputed to IGC, Washington for presenting a paper. He has edited 7 volumes of EARFAM (4-10). He has a passion for developing "Geostandards" by AMD. He superannuated as Head, Mineralogy-Petrology-Geochemistry Group in 1998.

Year: 1961. Place: Lakshettipet, Adilabad district, Andhra Pradesh (now Telangana).

I was camping in Lakshettipet, surveying the granites and the Gondwana sediments for uranium. In those days, we used to draw our salary through a cumbersome way. Every month, the pay bill was prepared by the individual and sent to the Accounts officer, AMD, New Delhi, who in turn, after due processing, would deposit the amount in our account in bank in Bombay (now Mumbai; in those days, a major part of Andhra Pradesh was under Western Circle with Bombay as Headquarters). The bank, following standing instructions, would send a specified amount in cash, in insured cover to our field address.

While expecting the salary amount, I received a rude shock - a letter from New Delhi, that my bill had not been received and that I should submit a duplicate bill, with explanation. The message was a bolt from the blue. It would take anywhere from 15 to 20 days to sort out the issue. I had 10 kg of atta, a bottle of jam, one kg of oil and one kg of tur dal. But there was no salt; I was planning to replenish my provisions after receiving money from the bank. My cash balance was as low as Rs.1.25 and I was scared to spend any amount, however small, even to buy salt; I started eating food without salt!!! I was totally in a dilemma!

Then I remembered that two of my colleagues were camping at a village, Peddapalli, 14 kilometers away from my camp. If I could somehow contact them, my conditions would improve. There was a skeletal bus service and the fare was 75 paise. I weighed the options and felt that if I had taken the bus and found that my colleagues had shifted to a new place, I would be in a soup. My cash balance would dip to a mere 50 paise!!!

Hence, I took the only alternative of walking the 14 km. It was scorching hot, but slowly and steadily I covered the distance. I reached the camp of my colleagues around 2.30 in the afternoon, totally exhausted, thirsty and ravenously hungry. To my delight, I not only could see my colleagues, but also food served on the table!! I recalled the famous words of the Mahatma - even God dare not appear in front of a hungry soul, except in the form of food!!

I borrowed Rs.25 from my colleagues and returned, satisfied, to my camp by bus. I have preserved the two coins - one rupee and 25 paise coins, as memento - to this day, over sixty years!!!!

A brief review on 'Contribution of spectrograph laboratories to geochemical exploration programmes of Atomic Minerals Directorate for Exploration and Research' is given hereunder.

Direct Current - Atomic Emission Spectrography (DC-AES) is a low cost multi-elemental analytical tool and has contributed significantly, the world over, to Geochemical Exploration programmes. Realising its potential, the first Spectrograph Laboratory was established in the Atomic Minerals Directorate for Exploration and Research (AMD) in 1962 at Headquarters, Hyderabad. The facility was enlarged, adding two more units in 1969.

The three spectrograph laboratories, over five decades, analysed thousands of samples of geological materials and produced significant qualitative, semi-quantitative, and quantitative data on selected trace elements viz. Be, Ce, La, Li, Nb, Th, Y and Zr - elements that have direct bearing in exploration for atomic minerals, and Ti, V, Cr, Co, Cu, Mo, Ni, Sn, Pb and Ga - elements that can be used to select or narrow down target areas.

The analytical methods in practice were frequently reviewed and procedures modified to increase reliability.

Most laboratories practicing Direct Current Arc Emission Spectrography around the world followed the method emulated by Barton et al. (1960) for the analysis of geological materials.

In order to overcome profound Matrix Effect, a pegmatite base is added to samples and standards. Mostly a series of synthetic standards, containing a known concentration of one or more elements, is used. Pure carbon/ graphite powder is added to control burning characteristics of the arc. Spectra are recorded on photographic plates. Net intensities are plotted against known values of elements and concentrations of the elements in samples are computed from working curves or from equations.

In 1960, only two natural geochemical reference materials were available i.e. G1 and W1, for checking the accuracy of the method in practice. These two were mixed with each other and diluted to get a series of control standards. Synthetic standards were extensively used.

Our experience over the years showed that these were not adequate and the method required refinement. A large number of natural standards (Table-1) were introduced to not only control the various parameters but also to evaluate a number of elements in the sample.

Table 1. International Rock, Soil (Natural) and Synthetic Standards

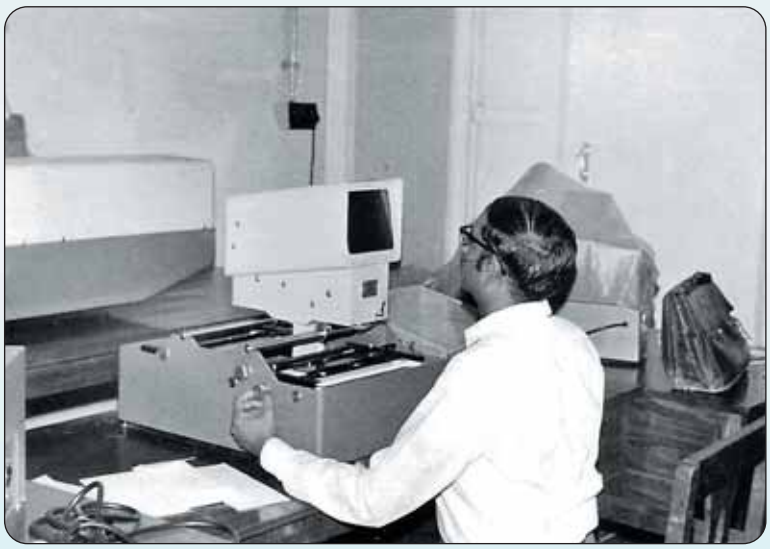
S. No.	Code	Rock Type	S. No.	Code	Rock Type
1.	G-2	Granite	14.	SY-3	Syenite
2.	GA	Granite	15.	ASK-1	Larvikite
3.	GH	Granite	16.	W-2	Diabase
4.	GS-N	Granite	17.	ASK-2	Schist
5.	GSP-1	Granodiorite	18.	SO-1	Soil
6.	DR-N	Diorite	19.	SO-2	Soil
7.	AGV-1	Andesite	20.	SO-3	Soil
8.	BCR-1	Basalt	21.	SSM-30	Synthetic Granite
9.	BR	Basalt	22.	SSM-29	Synthetic Granite
10.	MRG-1	Gabbro	23	SSM-28	Synthetic Granite
11.	DTS-1	Dunite	24.	SSM-27	Synthetic Granite
12.	PCC-1	Peridotite	25.	SSM-25	Synthetic Granite
13.	SY-2	Syenite	26.	SSM-23	Synthetic Granite

Each of the six Synthetic Granite standards contains 49 elements: Ag, Al, As, B, Ba, Be, Bi, Br, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, F, Fe, Ga, Ge, Hg, I, In, K, Li, Mn, Mo, Na, Nb, Na, Ni, P, Pd, Rb, Sb, Se, Si, Sn, Sr, Ta, Te, Th, Ti, Tl, U, V, W, Zn, and Zr, with concentration levels of SSM-30 (12.5 ppm), SSM-29 (25 ppm), SSM-28 (50 ppm), SSM-27 (100 ppm), SSM-25 (400 ppm), and SSM-23 (1600 ppm).

The accuracy of the method was statistically tested and found to be good. The details of the method in practice in our laboratories are available vide Balakrishnan et al., 1990 and Sankaran et al., 2008. It is evident that due to the use of natural standards, the matrix effect is minimized.

Keeping the height of the spectra at 1 mm and using electrodes with adapters paved the way for analysis of increased number of samples, thus bringing down the cost of analysis. The results of analysis of rocks, minerals and soil were published in leading journals and presented in national and international seminars and workshops.

Direct Current - Atomic Emission Spectrography (DC-AES) stands out as an excellent analytical tool in Geochemical Exploration for Atomic Minerals. The use of Natural / Geochemical / International reference standards provides an excellent media for quantitative estimation of a number of elements in varied geological materials, particularly for rocks, the method in practice in the Spectrograph Laboratories, AMD, is quite accurate and reliable.



Spectrograph laboratory

Down the memory lane - tale of an inquisitive uranium geologist

K.K. Dwivedy

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Dr. K.K. Dwivedy obtained M.Sc. from Indian Institute of Technology, Kharagpur and Ph.D. from Osmania University, Hyderabad. He joined AMD in 1959. He has a vast experience in mineral beneficiation including atomic minerals, for which he was honoured with "National Mineral Award-1996" by the Ministry of Mines. He superannuated in July, 1998 as Director, AMD. Post retirement he served as a Consultant in Andhra Pradesh Mineral Development Board. He has been a member of boards of UCIL and NFC during his tenure as Director, AMD.

Dr. Dwivedy has published more than 100 research articles in the journals of national and international repute. He has been the President, Indian Society of Applied Geochemists (ISAG) since 1997.

I joined AMD in October 1959 as Assistant Geologist along with forty-nine others as a part of the ambitious expansion programme of AMD to locate uranium deposits for the programmes of DAE.

A training camp was organized for the new entrants at Udaisagar in Udaipur district and comprehensive training was given in geology, geophysics, geochemistry, mining, surveying and related activities. There was a programme for field work from 7 am to 2 pm, followed by lunch, post-lunch lectures by specialists, volleyball and evening discussions and lectures. A report was to be submitted by each trainee, the next morning, before the day's field work.

Two months long training camp ended with a campfire on 31st December 1959 and the trainees were posted in different Regions of AMD as per the available vacancies while taking care the trainees' preferences.

I become a member of a three men group directly under the Circle Incharge and posted to work in the extension of Kalamagra area, Udaipur, where radiometric anomalies were located near the contact of black shale and silicified limestone.

In May 1960, the field season was extended by two months to quickly check airborne survey anomalies along Rajasthan - Gujarat border. In the unbearable heat of May-June, we used to work for 8 to 10 hrs daily to complete the assignments. Suddenly, we got the shocking news of the death of our beloved Director, Dr. P.K. Ghosh in an air accident near Chakrata. We closed the camp and returned to New Delhi Headquarters. Dr. Ghosh had taken some traverses with us in Udaisagar-Umra belt and guided us in taking field notes, making drawing of interesting features and taking photographs with our cameras, if we had any.

In 1960-61 field seasons, we were given independent survey assignments in Gwalior and adjacent districts of Morena. We used to shift camp every 10 days and move towards Morena. During surveys we came across tigers, bear and other wild animals. In the second week, I observed that my movements were being followed by one man and his accomplice. Deep in the jungle there was a dilapidated fort. I observed the same man driving a herd of cows towards the fort. Wherever I went, I felt that I was being followed. I shifted my camp in 8 days and camped in a school building. The teachers advised me not to proceed further ahead as the area was a hot centre for dacoits. I took traverses along available paths near the villages

and decided to proceed to Narmada valley next. I booked my tents and took the train to Barwaha via Khandwa and worked without being watched by the dacoits or their men. I had located small radioactive patches in quartz-silicate schist and the Morar sandstone. These turned out to be thoriferous.

While surveying in the Gondwana area, I came across huge fossilized log of a whole tree trunk but did not follow it up. It was later clarified as a tree fossil discovery by GSI, Geologists. Along Narmada River, there were many waterfalls, big and small, and people used to pick up saligram pieces and identify them. In the Mohua season, a wild bear came at night near my camp. They would climb the trees and fall down in intoxicated condition early in the morning and walk away.

In 1961-62 Field Season, I became a member of a field-party in Parvati Valley, Kulu Himalayas. As our tents arrived late we camped at Bhuntar Forest RH for 4 days, waiting for our tents. We utilised the time to meet the District Collector of Kulu and other revenue officials and moved around the Kulu mela, which attracts many tourists. By the end of October, we pitched our tent, near Shat village and planned to start work. But as a surprise, snowfall started on 30th October night and there was nearly 1 ft of snow. Next morning, it rained and snowed but cleared a bit by afternoon. Having stayed indoors whole day, we started out with GM counters and geological gadgets along Shat-Jari road. There was nearly one feet of snow on the road. I put my GM counter on, put it by the road side and eased myself. Suddenly my eyes fell on the counter needle. It was off the scale, I thought that the counter was malfunctioning, but when I broke the rock with my hammer I saw a dark vein with yellowish amber stain which was a vein of uraninite and secondary uranium minerals along a fracture in the quartzite. We traced the activity to the hill scarp, collected samples and proceeded to Jari FRH for night halt. The samples were sent to the Group Incharge with a message that we would meet him near Chhinjra village the next morning.

Next morning the hill face was scanned at approachable points and our delight heightened many fold for the discovery of the uranium occurrence of vein type for the first time in the Himalayas.

Heavy snowfall in subsequent days found us out of Chhinjra-Jari area and we shifted camp to Chakrata area in U.P. Himalayas. There we discovered fossiliferous phosphatic Krol-Tal exposures showing radioactivity.

By March-April, we shifted back to Chhinjra area and took up detailed mapping and sampling and collected bulk samples for beneficiation and extraction studies. In June-July 1962, our SG and GA visited the area and were happy to see the 80′ long uraninite vein, which was exposed in exploratory mining work.

The Chemical Engineering Group of DAE was keen to get bulk samples for extraction studies and was keen to produce as much uranium concentrate as possible for fuel elements of Test Reactor. We had planned to move to Headquarters before the season's snow fall, but our SG visited the area and pressurized us to expedite test pitting and mining work. Even I was denied leave to go for my marriage. My uncle contacted the GA and made him sanction my leave. The work was suspended in my absence and restarted with renewed vigour from April 1963.

In July 1963, Deputy Director General of GSI and a close friend of our SG visited the area and I was deputed to take him around the area and show interesting places. He enquired with our SG if I could be spared for 2 years on deputation to GSI. I still remember the words of my SG when he said, "he is my left hand in the Himalayas, he is my right hand in the Himalayas and he cannot be spared". He said that he had initially even denied 3 weeks leave to me for my marriage. This increased my confidence and made me work with renewed vigour.

In 1965-66, I availed one year study leave to complete my Master degree in Applied Geology. On return from leave, I was posted to Pokhri-Tunji area of U.P. Himalayas to supervise the work of new

recruits and plan and execute a drilling programme. The area was leech infested. Following repeated leech bites one of the young geologists sat down in his tent and wrote down a note resigning from the job. It was a tough task to make him change his mind. I worked from 8 am to 5 pm daily with those geologists to train them in all aspects of detailed mapping, borehole location and related jobs.

During the short recess period of 3 to 4 months, I used to work in the Petrology, Mineral Technology and Chemistry laboratories at AMD headquarters. I used to analyze my samples in the Chemistry lab, do ore microscopic study in the Petrology lab and beneficiation and leaching studies in the Mineral Technology (MT) lab.

At the beginning of 1970-71 field season, the Incharge of MT Laboratory influenced upon the Regional Director for my posting to the MT Lab. Since I had a very strong liking for field work, I requested the Regional Director to allow me to continue in the field for some more years. He invited me and my wife for dinner at his place and I could not decline. He told my wife that he was giving me Headquarters posting and that I was declining it. With her professional life as a doctor she was finding it difficult to manage the family with two children in my absence and she said that she would be happy and grateful to him if he did that. Thus, I became a laboratory man and was posted to the MT Group. As usual, I took up new assignment with total devotion and worked on leaching and ion-exchange work on Umra and Chhinjra ore.

The Chemistry Group of DAE found the phosphate-rich Umra limestone and phyllite ore difficult to treat. The phosphate-rich leach liquor was poisoning the ion-exchange resin. But by delicate control of pH and saturation of uranium, we accomplished more than 90% extraction from the ore. Still the DAE Chemical Engineering Group did not accept the result. We requested for sanction to set up a pilot plant at Umra to show the feasibility. Since it was a small sum, the Chemical Engineering Group agreed reluctantly to allow us to carry out the test. At one point, the discussions came to such a stage that the Chemical Engineering Group insisted that it will be a total loss. My MT Lab Incharge and I told Regional Director, AMD that we are sure to succeed and that if we failed the amount be deducted in installments from our salaries. Seeing level of confidence in us, the DAE Group agreed, the project was sanctioned and AMD produced the yellow cake needed for Zerlina Test Reactor.

Similarly, heap leaching was demonstrated by the MT group at Baginda in Kulu. Dr. Sarabhai, the than Chairman of DAE, visited the plant with his family, saw the yellow cake being produced and gave us the responsibility of producing as much as we could without contaminating the environment. AMD stood upto the promise.

In the meantime NFC needed niobium for fuel rod cladding with zirconium. They needed 10 tonnes of high grade Nb-Ta ore urgently but it was available at 10 times the market cost in International market. By that time AMD had a new Director and the MT group took up the challenge to produce the Nb-Ta concentrate. We had only about 2 tonnes of concentrate in our godowns so Lab experiments using fixed screen jigs and movable screen jigs were carried out and established the flow sheet for Nb-Ta recovery at faster pace. NFC started lifting Nb-Ta concentrate in installments and we provided the mineral concentrate as and when needed.

By-product recovery of uranium from copper tailing and low grade ores was taken up by bacterial leaching utilising *Thiobacillus feroxidans* on indigenous ore and also cultured and refined copper ores from Gangavalli River in the Western Ghat. The feasibility of the process was demonstrated in joint experiments with UCIL at Jaduguda. Bacterial leaching was demonstrated in joint experiments with Hindustan Copper Ltd. at Malanjkhand. Gold recovery from discarded tailings was demonstrated at Kolar Gold mines area.

Nitrate reduction in NFC waste liquor was demonstrated in tests at NFC Hyderabad and use of sludge to utilize the denitrifying bacteria was established.

Desulphurising bacteria were found to be useful in sulphate reduction and uranium precipitation. A number of uranium anomalies in Udaisagar were found to be related to bacterial action.

With the increase in demand for heavy rare earth minerals by DAE, AMD took up xenotime concentration at placers along river channels in Madhya Pradesh, Odisha and Bihar and sufficient quantity of xenotime concentrates was produced by setting up recovery plants in field areas.

Uranium bearing sandstones are a rich source of the metal. The ore is easily leachable. The process was demonstrated by setting up a plant at Domiasiat. Chairman DAE, senior officers from DAE, UCIL visited the plant. AERB Chairman too visited the area and got convinced that uranium can be extracted without contaminating the environment. While the project was to come up, some local issues delayed the project and it is yet to be taken up.

Starting as a uranium exploration geologist, I became a mineral technologist and then took up the responsibility of setting up the Western Regional Centre of AMD at Vadodara and gave a thrust to uranium and rare earth prospecting in that area. The work could not catch momentum due to shortage of drilling units.

The MT Group demonstrated in laboratory test the feasibility of uranium extraction from Tummalapalle dolomitic limestone by alkaline hot carbonate leaching. The repeated tests yielded 75-80% uranium leachability. Subsequently bulk tests were carried out by the mineral processing units of DAE and UCIL and the plant flow sheet was finalized.

As a Deputy Director, I gave a thrust to uranium exploration in Gondwana areas and followed it up as Director AMD. As a co-coordinator, I had successfully organized a training camp for 25 geologists in Kurnool area in 1984 and imparted training in similar lines as at Udaisagar in 1959.

With excellent laboratory facilities, modern drilling units, geophysical surveys, aerial surveys and collaboration with universities and other geological organisations, AMD is rocking ahead at a fast pace to add to the uranium and rare metal reserves of the Country.

Overruling the boss

Rajendra Singh

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Shri Rajendra Singh obtained M.Sc. (Geology) from Lucknow University, Lucknow, Uttar Pradesh. He joined AMD in 1959. He has worked in several parts of the country in various capacities. He was honoured with "National Mineral Award in 1991" by the Ministry of Mines for the discovery of the Domiasiat Uranium deposit. He superannuated as Additional Director (Operations-I), AMD in November, 1998.

Vein-type uranium occurrence located in Kasha area of Rampur Bushahr was second important discovery of uranium in Himachal Pradesh after those of Kulu. Field season in the Himalayan areas used to be closed by the end of October.

Radiation jeep survey was my assignment in parts of Mahasu district. Field season was about to close when I got a telegram from late Shri A.C. Saraswat, the then party Incharge, to the effect that Shri K.L. Bhola, S.M.G. is reaching Simla on October 25 by train. Send the jeep to bring him to Nogli and back to Simla after his visit to Kasha area and that I need not go to receive Mr. Bhola. Frankly speaking such messages at the fag-end of the field season have always been irritants. The visit meant a minimum 6 to 7 days programme. What am I going to do? The New Delhi office had booked new Jeep tyres to Simla and the R.R. was in my hands. I decided to get the old tyres replaced by the new ones before Mr. Bhola's visit. So, I shifted to a rest house in Koti about 25 km south of Simla. A day before Mr. Bhola came, I could collect the tyres and got them fitted to the jeep and booked the old tyres to New Delhi by train. As per the telegram, I was asked not to go to receive Mr. Bhola. Late Mr. Bhola was the senior most officer in AMD. He would certainly have come to know from the driver that I have sent the jeep. Not meeting him would not be decent on my part. I was in a fix. Finally, decided to receive Shri Bhola at Simla and get dropped at Theog enroute. I met Bhola Saheb at the Simla railway station and took him to the guest house which had been booked for his stay. This was my first meeting with him. I dropped him at the guest house, spent some time with him and returned to my camp. Next morning I met him at the hotel and accompanied him upto Theog and got dropped. Mr. Bhola continued his journey as per programme. While returning on the 6th day he met me at Theog and asked me if he could take the jeep upto Kalka instead of Simla. "Yes Sir, as you wish". He proceeded to Kalka by the jeep. The driver was asked by Saraswat Ji to report back at Nogli. Next day he came and we together travelled to New Delhi. He did not ask why I went to receive Bhola Saheb.

Another occasion when we overruled the orders happened in Shillong. Dr. H.N. Sethna, Chairman DAE, had come to Shillong to lay the foundation stone of the AMD complex. His lecture was organized at the State Library. After his lecture, he had a meeting with the Governor. We were asked to get back to office after the lecture and remain at our respective places.

We were categorically asked by late Shri A.V. Phadke, the then Director, AMD, not to come out of our rooms when the Chairman reaches after meeting the Governor. He will meet each one of you later. It so happened that because of the pilot car, Dr. Sethna came to office much earlier and the jeep in which late Phadke Ji and Duggal Ji were coming was delayed by the traffic. From our rooms Shri S.C. Verma and I were seeing that

Dr. Sethana has reached, but Mr. Phadke Ji and Mr. Duggal Ji are nowhere. We decided to go and receive the Chairman. We went down, received him and accompanied him to the Incharge's room. We spent nearly ten minutes talking to him, when late Phadke and Duggal came.

Occasions arise when one has to overrule the boss.

Bear and atta bag

Myself, B.M. Swarnkar and perhaps K.N. Tiwari had shifted to a place in Rupa Valley in Kinnaur at an altitude of about 8000 ft. We pitched our tents by the side of a small stream, which was a good source of water. The ground was gently sloping but good enough for us to pitch our tents. Tired as we were, after the dinner we slept in our tents. As usual, I kept the lantern on dim light in the rear part of the tent where boxes etc. are kept. Within an hour I was awakened by the tearing sound of my tent, as if someone has cut it to steal something in the rear. I raised the lantern light and shouted to convey that I am awake. It stopped for a while, only to disturb with the sound of the canister kept over the box. Now I started shouting at it with the stick hitting the sides of the tent all over. As there was no sound of any human being, I guessed that this was an animal and continued hitting the tent now and then for about an hour. I did not come out of the tent nor did I call my friends, sleeping in their tents nearby. After some time, it was all quiet and I too slept. On getting up in the morning the first thing I did was to look around my tent. To my surprise I found that my tent was cut about two feet with a sharp knife. It was exactly where a bag full of atta was kept. Then I called my friends and we could see the pug mark of bear. We went round other tents. Pug marks were seen around the kitchen tent also. Now we were sure it was a bear, which had come for the atta kept in my tent. In the apprehension that it will visit again at night, we all managed to sleep in my tent fully prepared to face the bear. We wrapped cloth in a stick and soaked it with kerosene, kept match box, torches and sticks handy, and an empty canister near the atta bag so that it makes sound no sooner the bear approaches. As expected the bear came and we lighted the 'mashal' and all of us came out shouting at it. We could see the bear running away down the stream. Tiwari threw the axe to hit it. Next morning we closed the camp and moved to a room of the H.P. Government Horticulture Department nearby.

My longest camp shift

It was my second field season i.e. 1961-62, in undivided Madhya Pradesh, now Chhattisgarh. AMD was in reconnaissance phase all over the Country except in the STB. Reconnaissance implied frequent camp shifts for the geologists. Our official baggage comprising of an awkward looking tehsildar, a double fly, a single fly tent and a necessary tent, a folding table and two chairs and a box. In addition, there was kitchen box with utensils, two buckets and a personal box containing my clothes. Put together the heavy baggage made camp shifts most headache. Normal camp shifts involved 8 to 10 km distance, which could be managed with bullock carts. In a party of 4 to 5 geologists, there used to be one jeep with trailer in the control of the party chief. I was camping at a small place called Tappa on the Nagpur-Kolkata Highway, not too far from the Maharashtra border. I had pitched tents on the grounds of the PWD guesthouse at Tappa. My next area was Saraipalli closer to Odisha border. I had to move to Saraipalli at a distance of nearly 270 km with the entire baggage by bus with a change over at Raipur. Looking to the distance involved it was imperative that I take the early morning bus. A day before the shifting, I talked to the bus driver to make sure that he allows the entire load. Many times the bus drivers refuse to accept such heavy loads. The driver of the bus agreed and asked me to reach the bus stop by 7.30 in the morning with tentages. I fixed a bullock cart fellow to come by 5.00 in the morning along with two more labourers. They came and the tents were unpitched and rolled up by 6.30 and loaded on the cart along with my personal baggage. With the cart load we reached the bus-stand in time. The bus came at 7.30 and everything was loaded. By 11 or so the bus reached Raipur bus-stand. On my request, the driver briefed his counterpart of the other bus that was to take me to Saraipalli. With the help of porters the tents etc. were loaded on

the Saraipalli bus. There was enough time for me and my personal servant, employed under the Field Establishment Allowance (FEA), to take lunch at the bus stand. The bus started after 12 noon, and by the time it reached Saraipalli, it was dark. Saraipalli bus-stand had no lights. With the help of porters, under torchlight, got everything unloaded from the bus. I had to go to the PWD guesthouse, which was nearly 3 km from the bus-stand. There was no way how to take the tents or to leave somewhere safe. I located a bullock cart near the bus-stand and requested the owner to take us to the PWD rest house. Initially, he was reluctant but with some persuasion, agreed to go. He was cooking his meal after the day's hard work. I had no alternative but to wait for him. After about an hour, he got everything loaded and we started towards the rest house. After about an hour we reached the rest house. Luckily the caretaker was present and he opened a room for me. The guesthouse too had no power. He helped in unloading of the baggage and placed in a corner in the outhouse. From 5 in the morning to 9 pm, it was a hectic day and the longest camp shift which is still vivid in my mind.

The Party Incharge based at Raipur knew about my camp shift but did not care to provide the jeep and trailer. Mind you the entire contingent expenses were borne by self and claimed through contingent bills, which used to take several months to clear. This was the AMD of those days.

Survey camp in Himalayas

Memorable years in AMD

Jagmer Singh

(Former Additional Director, Atomic Minerals Directorate for Exploration and Research)

Email: jagmersingh99@gmail.com

Date of Birth: 14.08.1939 *Date of joining AMD: 19.10.1959* *Date of superannuation: 31.08.1999*

Shri Jagmer Singh obtained M.Sc. (Geology) from Lucknow University, Lucknow, Uttar Pradesh. He joined AMD in 1959. He has served in several parts of the country in various capacities. His discovery of significant uranium mineralisation in Kasha-Kandi, Shimla district, Himachal Pradesh was honoured by the Department by granting him two advance increments. He was under deputation as Director, Geology and Mines, Government of Sikkim for 4 ½ years. He superannuated as Scientific Officer-H and Additional Director, AMD in August, 1999.

He is widely recognized for the identification and reporting of a new suite of potassic and per potassic syenite named "Sikkimite" from Sikkim. He has published more than 25 research articles in national journals of repute.

Created as the Rare Minerals Survey Unit (RMSU) on 29th July 1949, amongst the first of the units, by the Atomic Energy Commission, AMD (Atomic Minerals Division), now named as Atomic Minerals Directorate for Exploration and Research, has grown into one of the premier geoscientific organisations of the country.

As an important member of the DAE family, AMD is not only providing a distinctive variety to the strong and heterogenous conglomeration of the constituent units but also valuable support in the nuclear fuel cycle. At the Front End of the nuclear fuel cycle, AMD identifies and provides the vital fuel and mineral resources. Through the fuel cycle, responsibilities related to selection of sites for various departmental projects; environmental studies, airborne and ground radiation monitoring, etc. are shouldered to AMD. At the Rear End, geological input for site for Nuclear Reactor selection and repositories for nuclear waste disposal are also provided by AMD.

I joined AMD in October, 1959. There had not been any recruitment of geology graduates in the major organisations of the country viz., the GSI, ONGC, etc. for a couple of years, resulting in a considerable backlog of geology graduates awaiting employment. At that time, under the dynamic and visionary leadership of Dr. P.K. Ghosh, former Director, AMD, a major recruitment drive was initiated. Candidates from across the country, from leading Universities/Institutes, were in the fray. Doyens of Indian Geology, viz., Dr. D.N. Wadia, Dr. W.D. West, Dr. P.K.Ghosh, and a host of others made a selection of 50 Assistant Geologists.

All the freshly recruited geologists underwent a nearly 2-months rigorous training in all aspects of exploration and prospecting for uranium and other atomic minerals at Udaisagar in Udaipur district, Rajasthan. My first posting was with the Aerial Survey Party, then engaged in airborne scintillometer survey flights, from Nagpur base, in January 1960. Following initiation to activities connected with the survey flights, processing of data acquired during the flights, preparation of maps with radioactivity anomalies/higher background areas for onward transmission to field units for ground checking were carried out. Geological work in Jashpurnagar area of M.P. (now Chhattisgarh) for ground checking the aerial survey anomalies was also attended. Success was not far behind. We could locate several stretches of high order radioactivity, mainly associated with the Siri River sands, which in laboratory indicated significant values of monazite and xenotime. These occurrences were subsequently taken up for regular appraisal and recovery of xenotime bearing polymineral concentrate under the RMRE Group.

AMD's speedy march towards augmenting and modernising exploratory techniques came to a screechy halt with the sad demise of Dr. P.K. Ghosh, in an air crash at Chakrata (Uttarakhand), in June, 1960. He along with two senior scientists, Dr. A.S. Bhatnagar, Head, Physics Group and Shri N.S. Bhalla, were on a demonstration cum survey flight, with a foreign pilot, to assess the suitability of the aircraft, which was to be purchased for AMD's survey projects. Having just returned to Delhi for the first recess, I was required to accompany the relief team to Chakrata. There we met the local Army Commander, at the Military Hospital. He gave the first-hand account of the ill-fated flight. While sitting in the veranda of his bungalow he had observed the low flying aircraft heading towards the blind end of the narrow valley. Sensing untoward happening he had rushed the rescue team, which reached the crash site in time and brought the seriously injured to the Military Hospital. While Dr. Ghosh and the pilot succumbed to their injuries, other scientists recovered in due course of time.

Working in the Himachal Himalayas, from 1963 to 1967, I was credited with the discovery of Kasha-Kandi uranium occurrence at an average altitude of 8500 ft. above sea level, in 1964. It remains the largest vein-type uranium occurrence in the Himalayas. Reaching Kasha-Kandi then, involved a trek of nearly 40 km from the road head at Nogli and back breaking climb of nearly 5000 ft, from Jogni to cross the Buzudhar at 10,000 ft. Discovery was made in the company of a senior colleague late Shri R.L. Vaid. Department was benevolent enough to grant two advance increments of pay in recognition of the discovery.

Following the stint in the Himalayas, jeep borne scintillometer surveys, in parts of Rajasthan, in the late sixties, led me to a unique discovery of radioactivity in pegmatitic rock material, at Mewara Gujarwas, in Jhunjhnu district. Regional geological mapping by GSI, in subsequent years, established the occurrence to be the north-eastern extension of the famous 'albitite-line'.

On return from deputation abroad in 1977, I worked in Sikkim Himalayas for 3 years as a member of Eastern Region, AMD, and 4½ years, on deputation to the Govt. of Sikkim, to help to set up a department, to carry out geological studies. While in AMD, I was associated with the discovery of high-grade uranium mineralisation, as vein material, in the abandoned copper mines, worked by IBM, at Jagdum in South Sikkim area and was also associated with the identification of a rare potassic per-potassic syenite, now named as 'Sikkimite' (Jour. Geol. Soc. of India, vol.98, March 2022), in the Rangit tectonic window and its peripheral parts in South Sikkim.

I had the unique opportunity to visit the world-famous unconformity-related uranium deposit of Athabasca basin, Canada in 1987 and Australia in 1998, to participate in the Uranium Summit. In addition, visited the uranium deposits of Germany and France. Exploration strategy in the unconformity related deposits involved extensive application of geophysics, thorough geological mapping with adequate geochemical input, followed by large-scale drilling, mainly percussion, and limited core drilling. Adopted strategies indigenously led to considerable success in the peninsular shield areas.

Recounting the experience of working in the Himalayas, during the sixties, when hardly any vehicular support was available, transportation of camping paraphernalia was managed by public transport. With bulky tent packages, reporting much before time at the bus-stand was the key to success of ensuring travel. With the major luggage space atop the bus occupied by huge gunny packed tent bundles, always created hardship to fellow passengers. On one such trip from Shimla to Rampur Bushahr in H.P., on one of the sharp meandering roads, a precariously perched steel trunk of a village woman, got dislodged and rolled down the valley, several hundred feet. By the time it was recovered, it was a rounded steely mass. The curse and abuse of the owner were best ignored.

While working for ground checking of aerial survey anomalies, in the dacoit infested region

of Central India, in the mid-sixties, had a face to face encounter with a dacoit, locally addressed as 'Baghi'. In an attempt to mark my precise location, I got down in a dried-up river bed and was looking for an unused hunting lodge of the erstwhile rulers that was marked in the toposheet. Over period of time, the building had become the hideout of the 'Baghis'. Unknowingly, I had caused consternation amongst them. Suddenly a well-built man, with thick, menacing moustache, with a gun in hand, appeared on the river bed and started following me and the helpers. After some questioning about the ongoing activity, he issued a stern warning to quit, as our lives were at risk. First it took me time to figure out the developments and his identity, but then his threatening command to leave, left no doubt in my mind and no choice, but to abandon the mission.

Constraints of terrain or poor working conditions have never deterred the AMD scientists, from rising to the challenge and contributing to the overall success of the project. Several AMD scientists have won awards and recognition for their innovative work and discoveries in laboratory/ field. Recognition and reporting of 'Sikkimite', a new and rare suite of potassic-per potassic syenites from Sikkim, is one such example. Discovery and recovery of uranium from the (i) near the snow-clad environs of Kasha-Kandi in H.P., (ii) gorgeous, leech infested regions of Domiasiat, Meghalaya., (iii) uninhabitable, malaria-prone, high rainfall terrain of Wahkyn, Meghalaya, are all examples of AMD scientists' indomitable spirit to conquer the nature. For the discoveries in the afore stated areas, as well as in the Singhbhum (Jharkhand), Lambapur (A.P.), Gogi (Karnataka), and numerous other inaccessible regions, there is something more than the mere call of duty. The drive, the dynamism, the excellence, the positive attitude and the strong will to stand up to the adversities, are the hallmarks and essential traits of the AMD scientists. It is a heartening reality that there is no dearth of it in AMD.

I wish AMD continued excellence and success in all spheres of activity.

Dr. P.K. Ghosh, Director, AMD at Udaisagar Camp (1959).

My AMD diary

Subhas Chandra Verma
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Date of Birth: 10.08.1939 *Date of joining AMD: 05.03.1963* *Date of superannuation: 31.08.1999*

Shri S.C. Verma obtained M.Sc., A.I.S.M in Applied Geophysics from Indian School of Mines (ISM/IIT), Dhanbad, Jharkhand. He has served in various parts of the country in various capacities. He has served as a member of Council of Management of AMD during 1991-1999. He superannuated as Regional Director, Central Region in August, 1999.
Post superannuation he has served as member of Apex Exploration and Research Advisory Council of AMD during 2016-2021. Shri Verma has published several research articles in the journals of national and international repute. He was deputed to several countries like Vietnam and Vienna.

Prologue

It has been over five decades of eventful, enthusing, stimulating, often hazardous experience stretching beyond superannuation from government service. Some hard, even critical times for the family left alone. All this began fortuitously. I mean entry as an Asst. Geologist (SO/SB) followed by a long adventure beginning in the early developing years of Atomic Minerals Division (AMD). The advertisement required post-graduates in geology or graduates in mining engineering. An M.Sc., A.I.S.M. in Applied Geophysics, I ventured to apply, and was called for interview on 8th January 1963 in South Block, Central Secretariat, New Delhi. The committee was chaired by Dr. D.N. Wadia. He asked: "Where did you study Geology?" I replied I am self-taught, answered all his questions and was accepted as a geologist. Those were different days.

I joined AMD at New Delhi on 5th March 1963 and was straightaway posted to Singhbhum field area, already an established prime uranium belt by the work of V.R. Khedkar and Party (1950-51) and a hub of exploration activities. An excellent training ground in all facets of prevalent uranium exploration techniques, deposit development and evaluation up to exploratory mining stage. Domain knowledge, concepts, models, techniques and instruments were still rudimentary and evolving; just adequate for locating outcropping / near-surface occurrences. Privileged to work with AMD's pioneers as mentors and interaction with Indian Atomic Energy's leading lights like Dr. Homi Bhabha, Dr. Vikram Sarabhai and their illustrious successors, learning curve was sharp. Responsibilities entrusted early needing innovations, improvisations and instating new techniques spurred rapid professional growth and maturation. These followed multifarious testing assignments in other fields and areas, including study and analysis of geological and geophysical well-logging records of other organizations like Oil India Ltd. and ONGC in upper Assam. Association with work of other wings of the Department of Atomic Energy and membership in some of its important committees equipped me with a broader perspective in my job. The Department entrusted me with some sensitive assignments abroad (including one incognito); seemed daunting calling for summoning all skills, wits and alertness but accomplished with success beyond expectations (over three decades old, may no longer bear tag of confidentiality and shared safely).

I superannuated from AMD on 31st August 1999, with first-hand experience in wide-spectrum of atomic minerals and helium exploration and allied fields in diverse geological terrains. Functional levels covered solo pioneering assignments in different disciplines, resident geologist of exploratory uranium mine, co-ordination of large-scale detailed exploration activities in prime operational areas, project manager/agent and proforma owner of radioactive ore mines. Other responsibilities included Head, ore reserves

validation group, planning and setting up new centres / establishments and facilities of AMD as Regional Director, Eastern and Central Regions. As Member of AMD Council, since September 1991, I participated in formulation of its policies and programmes. There were emergencies calling for rapid response.

Odyssey begun in 1963 did not end with superannuation. I became re-associated with work programmes of AMD from 2016 onwards as Member of Apex Exploration Research Advisory Committee of Atomic Minerals Directorate for Exploration and Research. With the interregnum from year 2006 to 2014, proclivity and providence proffered opportunities to serve globally in advisory capacities in reputed private sector companies operating in different segments of uranium business chain. That is another story, beyond the scope of this article. But it broadened my perspective, gave deeper insight into important mineralisation models and concepts, formulating cost and effective exploration strategies, familiarisation with and optimal use of cutting-edge technology and evaluation of mineral assets for Joint Venture considerations and development investment. Career landmarks, lessons and reminiscences are encapsulated hereunder.

Initiation and Singhbhum Chapter (11 Years)

I reported at field headquarters in Sundernagar, 3 km from Tatanagar railway station and was assigned to work at Narwapahar, main hub of detailed exploration activity in Singhbhum Shear Zone (SSZ) after Jaduguda Mines Project (SSZ was then known as STB, short for Singhbhum Thrust Belt, following the geology by Dunn and Dey 1942). I was blessed with very considerate, caring seniors and colleagues. Mr. K.L. Bhola, Superintending Mining Geologist stationed in Delhi was overall Incharge of Singhbhum operations, Y.N. Rama Rao and C. Suri Sastry stationed at Sundernagar were Incharge for Narwapahar. A makeshift mud-hut at the edge of Hartoppa village provided with some locally made sal-wood tables and folding steel chairs served as the prospect office and stores for survey instruments and prospecting implements for digging pits and trenches. We were five geologists posted in a camp of tents. There was no vehicle. We walked 12 km up and 12 km down on a dirt track with our maps and field data to Sundernagar to discuss our work in field headquarters. We took it in our stride happily. Field Season was from 1st October to next 31st May. Prospect geologists got two months recess by rotation.

On the forenoon of 12th March 1963 my Kabulpal tent was pitched ~20 ft across from the office hut. Same afternoon as I sat working in the hut, a severe thunder squall struck uprooting my tent. As summer set in, snakes appeared. Three consecutive mornings, I found cobras sitting in the ante chamber of my tent, half of it covered with pebbles and a bucket of water placed for morning ablutions. Snakes choose cool spot! Old papers lay in other half of the ante chamber from where rustling sounds emanated at night, but I stayed in my camp cot till morning when help arrived. Taste of field life for starters!

By early 1963 at Narwapahar, a surface radioactive outcrop of 5,400 ft (divided in four blocks) had been established using GM counters. Geological mapping was in progress. Trenching and test-pitting all along the radioactive outcrop, with channel sampling and shielded-probe gamma ray logging, were in full swing. Exploratory drilling had begun and progressing fast with deployment of eight drilling units. At night, we went with an ultraviolet lamp to check the trenches for fluorescence from presence of any secondary uranium minerals. In addition, I did geological mapping of the westernmost Banadungri Block, study of depth of weathering/surface leaching of uranium and relationship of mineralisation with foliation in the host schist (weathering/leaching curve showed leached uranium values up to 40 m dept). Foliation dips in pits were 55°; refolding shallowed dip of orebody to 35°. Hot days during April onward out in field at 6 am, bare rocks, no shade! Other miscellaneous assignments (1965 and later) included short posting as Resident Geologist in Keruadungri exploratory mine and structural mapping of Turamdih North ridge and of Lotapahar hill (SSZ West).

By May 1963 two geologists resigned and left, the remaining two proceeded on recess on 1st June. Here I was, three months into my job, left alone for two months to manage a drilling campaign with eight drilling units. Monitoring their progress, checking drill cores with GM counter each morning, arranging for borehole gamma ray logging, planning and fixing next borehole sites. No surveyor, just two chainmen to assist and theodolites to do the work. Those were days when a slide rule, trigonometric and logarithmic tables were used for calculations. Geological logging of drill cores were done and recorded in daily drill log sheets. Other works included updating borehole location/ survey plans and subsurface correlation, miscellaneous jobs and multi-tasking. Good training and growth of one's potential! Two month recess in New Delhi Headquarters familiarised me with work of various laboratories there. Interaction with colleagues from other Regions gave glimpses of AMD's work elsewhere. Electrical resistivities of Narwapahar drill cores were determined in Physics laboratory.

I was back to Narwapahar in October. Preparatory work for exploratory mining with two inclines was in full swing. Twenty two million tonnes potential ore resource @ 0.054% eU_3O_8 grade had been projected. We four geologists jointly prepared a large-scale detailed geological-radiometric-borehole plan of Narwapahar on tracing cloth some 3 m long x 1 m wide as part of full-scale preparations for forthcoming visit of Dr. Homi Bhabha in December. Mr. Bhola came down from Delhi. All senior officers were there to review arrangements and decide who would brief Dr. Bhabha. Their choice settled on me, junior most officer, nine months in AMD.

Dr. Homi Bhabha at Narwapahar

Following visit to Jaduguda mine on 14th December 1963 forenoon, Dr. Bhabha accompanied by Dr. Alardice (Controller, Atomic Energy) and his entourage arrived in afternoon at Narwapahar. Seeing the office hut and crude furniture he asked: "Found this hut lying here? Can't you get some good Godrej furniture? Silence! I proceeded to fill him in with all vital details of the Narwapahar uranium deposit with the help of maps and sections. Next, we took him outside to show some uraniferous diamond-drill cores scanning them with a GM counter. He saw the ammeter attaining its maximum value in fluctuating steps and asked, 'Why is the needle drifting like this'? Is it an integrating meter? No one answered. I offered an explanation. "Sir, a capacitor in output stage is charging and discharging affecting movement of the needle". Dr. Bhabha nodded approval. After visit to drilling and mine sites he returned to the camp; I asked if he would care for a cup of tea. Folding steel chairs and table with tea tray were laid outside the canopy of my tent. Dr. Bhabha and Dr. Alardice sat down, poured their own cups, added milk and sugar and sat relaxed for over half-an-hour. Local tribal villagers gathered with their bows and arrows to see the illustrious scientist. Dr. Bhabha asked to show how far they could shoot. He placed an arrow on his forefinger to see if it was properly balanced. Rare occasion - father of India's atomic energy programme sitting relaxed outside my field tent, talking freely!!

Symposium on Uranium Exploration and Mining

Under the aegis of Jaduguda Mines Project, in November 1964, a symposium on 'Uranium Exploration and Mining in India' took place. I presented a research paper on 'Cross-folding in Singhbhum Thrust Belt' contained in the cyclostyled symposium volume (1965). The paper is based on a new rapid method of mapping crests and troughs of cross-folds by measuring variation in foliation dips along strike direction of the rocks and using differential calculus to determine their maxima and minima. Narwapahar and Tamadungri were field areas of the study. Narwapahar Main block occupies a crest with higher uranium grades, whereas Singridungri block occurs in a trough with relatively lower grades and migmatites intercepted at depth in boreholes.

Ground Geophysics

In addition to detailed geological and drilling exploration work, I was also given geophysical

assignments 1964 onwards. I carried out magnetic surveys at Narwapahar with an Askania Magnetic Field Balance, and later was a member of the geophysical party conducting electrical resistivity surveys, both profiling and depth sounding, with a Gish-Rooney apparatus. Spontaneous Potential surveys were done simultaneously. Geophysics helped in identifying marker horizons and in mapping structural features. Resistivity surveys identified cross-fold axes exhibiting fan-shaped pattern and oblique faults.

Borehole Camera and Borehole Geophysics

Challenging opportunity to innovate and introduce borehole geophysics in AMD fell in my lot. In 1962, two Eastman Kodak borehole directional survey cameras and a Volkswagen trailer-mounted borehole electro-logging system with a single moving electrode resistivity and SP measuring probe with one surface electrode, a temperature probe and a gamma-ray scintillation probe, had been imported from Germany. An analogue potentiometric strip-chart recorder with a console mounted on the trailer recorded the geophysical parameters. The trailer had a hydraulic motor driven winch with armoured electric cable for running the interchangeable probes. A 0.5 kW portable generator provided power for field operations. Recorder console with cobwebs lying rusted in veranda of Central Stores in Sundernagar, unused for over two years was damaged by seawater during unloading in Bombay. It had costed precious foreign exchange and audit observation was inevitable. Mr. Bhola asked me, if I could restore it and put in use. I accepted the responsibility in right earnestness with active support from Mr. Suri Sastry, and with assistance of one chainman set up a small laboratory and darkroom for this purpose.

Borehole Cameras: Both camera units were non-functional. Triple distilled kerosene damping fluid reportedly supplied in the angle units, was coloured yellowish, staining compass dial graduations; with fungus on camera lens and broken cross-hairs, the micro-film could not record. Clockwork operating cam light and film winding switches needed servicing and synchronising with surface stopwatch for depth-time control. Distilled fluid obtained by AMD earlier from Indian Institute of Petroleum, Dehradun did not meet requirements. Referenced and researched in National Metallurgical Laboratory's library, I gathered that kerosene had sulphur compound impurities (Mercaptans - decomposing in tropical heat, releasing sulphur) and comprised eleven fractions with different boiling points. There was a chemical laboratory of Jaduguda Mines Project (JMP) in Sundernagar. I requested permission of JMP General Manager to distill kerosene. Reaction: "No! No! You'll blow up my laboratory." But with help of laboratory Incharge B.N. Tikoo, fractional vacuum distillation unit for chemically purified kerosene free of mercaptans was set up. Lightest-boiling first 10% fraction of superior refractive index and transparency replaced the original yellowed fluid in the angle units. Compass dial fine graduations were repainted by hand and thinnest electric fuse wire fixed as cross-hairs. Fungus on camera lens was cleaned with acetone. I acquired a watchmaker's toolkit, opened and serviced the clockwork and rewired the cam switches controlling lighting and film winding motor. The borehole cameras became fully functional. All boreholes drilled by AMD in SSZ and some in Dhabi (MP) and in Sevattur (TN) between 1965 and 1973 were surveyed and deviation and drift calculated and plotted. A few boreholes of GSI in Giridih (Bihar), Khetri and Zawar Mines (Rajasthan) were also surveyed. Training in use of borehole camera was imparted to a few officers sent by GSI and MECL.

Borehole geophysics: The damaged imported borehole logging system needed extensive repairs, modifications and improvisation. I acquired necessary tools and a multi-meter. The recorder was opened up and its housing cleaned and spray-painted. Electrical circuitry short-circuited by seawater salt was washed clean with distilled water repeatedly; then dried by hot air-blower (hair-dryer borrowed from a Sikh physicist friend). Affected insulation was re-taped and damaged electrical/ electronic components replaced. Fine glass double bend capillary pens were needed for two moving ink carriages to record on the strip-chart. A chemical glassware stores provided services of

their glassblower to make four dozen capillary pens of which just six met the precise specifications.

The Volkswagen trailer-mounted logging system with oil-motor driven winch and recorder console supporting stanchion were shifted to another trailer attachable to AMD's field jeeps. This needed several modifications including fabrication and fixing of matching mountings and accessories. An equivalent Indian hydraulic fluid had to be found for replacing in the oil-motor. The petrol-engine-driven field power supply generator had a broken carburettor; improvisation was done by replacing it with a motorcycle's carburettor. Generator field-coils needed replacement of the selenium rectifiers; after much search a supplier in Bombay was located and the generator put in working order.

Finally, the borehole electro-logger was restored and put in use by early 1965. All boreholes drilled thereafter in SSZ by AMD were logged for electrical resistivity and S.P. The deepest were four >1200 m boreholes drilled at Jaduguda. The electro-logs proved useful in identifying litho-units, faults and fractures, sulphides and in correlation between boreholes. One afternoon, while I was logging borehole no. NRW/29 at Narwapahar, Dr. D.N. Wadia visited the drill site along with Mr. K.L. Bhola to witness the electro-logger in operation. Dr. Wadia asked me: "Where did you learn this"?

Winter School in NGRI, Hyderabad

I was one of three officers sponsored by AMD to attend a fifteen-day Winter School on Solid Earth Geophysics organised by NGRI, Hyderabad, in December 1968. The topics covered were Aerial Photography and Photogrammetry, Airborne EM Survey, Terrestrial Heat Flow, Terrestrial Xenology, Ground Geophysics Case Histories, etc.

Technical assistance to Superintending Mining Geologist (SMG)

In early 1969, Mr. Y.N. Rama Rao became the SMG with his office in Sundernagar. Apart from Singhbhum area, the Eastern Circle office in Calcutta and Bihar Mica Belt area came under the SMG. I was made his technical secretary. This was in addition to my existing borehole survey and electro-logging assignment. At that time there were twenty one surface and four underground drilling units, three exploratory mines and thirty-three field geologists working in Singhbhum alone. Managing the SMG office, co-ordinating and keeping track of all exploration activities, keeping all data, drawings and reports up-to-date and timely submission to New Delhi Headquarters office was an enormous task. AMD's central stores located in Sundernagar too came under the SMG. I continued as technical secretary till the suspension of exploration in Singhbhum towards early 1974.

Dr. Vikram Sarabhai in Singhbhum

Successor to Dr. Bhabha, Chairman AEC, Dr. Vikram Sarabhai visited Singhbhum in 1970. He had a group discussion with AMD geoscientists in the evening in SMG office compound at Sundernagar. Dr. Sarabhai visited my small Borehole Survey and Electro-logging laboratory and mused over the logging charts put up on display. He was instrumental in initiating action for transfer of ~21 acres Khasmahal land to AMD by writing to the Chief Secretary, Govt. of Bihar. AMD's Eastern Region Complex now stands on this land. I was closely involved in a joint survey and taking over of this land from the State Govt. Later in 1989-1990, I was associated with BARC's C&S Group and their Architecture Section in planning and design of the AMD Complex at Khasmahal.

Northeast Chapter (1974-81: ~8 Years)

Dual solo assignments for about first two years: 1. Jeep-borne scintillometer and geological reconnaissance surveys in Arunachal Pradesh, Assam, Manipur and Nagaland along with sampling of hot springs for helium; 2. Study of geophysical logs (particularly gamma ray and neutron logs) of all oil and gas wells drilled in Upper Assam by ONGC and Oil India Ltd. and sampling of gas for helium. Objective of study of well-logs was to assess favourability for uranium mineralisation in the Tertiary Shelf sediments. Though some long winding sand-bodies were observed in channels

cut in shales of Tipam Formation, no positive indication for uranium mineralisation was found.

I set up base camp in Sibsagar for visiting the ONGC's Nazira office and Oil India Ltd's Duliajan office to study their well logs. Temporary accommodation was arranged by a friend in ONGC till arrival of my camp equipment booked by road transport from Calcutta. There was a fish pond on other side of the road in front of this house. One day a near calamity struck my family. While I was away in the ONGC office, my two sons (aged ~3 and 6 years) slipped in to this pond and were almost drowned, when a passing college student jumped in and saved them.

In between study of well logs, other survey assignments were carried out. On the road in daytime, I often did not know where we would sleep that night. (At times my family, our dog included, accompanied). Once I reached Assam-Nagaland border check post, driving on a forest road, at mid-night, I slept on the office table of the Police Officer Incharge, who kindly cleared it for me.

At Hayuliang (Lohit district, Arunachal Pradesh), in the bed of Dalai River, a small highly radioactive boulder of mafic rock was found; it assayed ~1% ThO_2 with very little uranium. Apparently it had rolled down from up-thrusted Mishmi Hill crystallines in the northeast.

In December 1974, I was on way to Nagaland and Manipur to continue with Jeep-borne scintillometer surveys. I checked at the Post Office for my mail and found a two-page letter from my Circle Incharge at Calcutta. It informed me that good uranium mineralisation had been discovered in Cretaceous Mahadek Sandstone in deep gorges in Jaintia Hills (Meghalaya). The letter instructed to look for similar settings in the adjoining North Cachar Hills (Assam) and gave a detailed list of the streams and areas to be checked and samples to be collected. On return from Manipur, I proceeded to North Cachar Hills. I looked at the toposheets for lowest contours in the terrain there and saw that it was in a gorge of Dihangi River. I took a PWD boat from the ferry crossing point upstream and checked the bottom of the gorge, where Oligocene Barail Sandstone was exposed. The same formation was present at top of the gorge ~ 300 m above. The Barails were dipping gently at 5-7 degrees towards Disang-Naga Trust and the high Barail Range in the south. It was clear, there was no possibility of encountering any older exposed formation in that area. Acting on the detailed instructions would have been an exercise in futility. When I met Eastern Circle Incharge Mr. A.C. Saraswat at Guwahati couple of months later, I explained to him. He agreed and said: "Forget the instructions."

At the time, the available Survey of India toposheets were of 1920s. Landmarks had now shifted. Some roads/tracks shown were either non-existent or non-motorable. I was traversing across the Barail Range (~1600 m high) from Haflong in north to Silchar in the south. It was a treacherous drive. Crumbling Eocene Disang shales had almost obliterated the road. I did not meet a single vehicle during entire drive of over 8 hours. It was so narrow that turning back was not possible. The black Disang Shales recorded relatively higher radioactivity. The Miocene and younger sediments on the Cachar plains showed no significant radioactivity. The field jeep and its tyres were old; driver had little experience in driving on hill roads (mostly un-metalled). While returning from Dihang to district Headquarters town of Haflong 60 km away, jeep brakes failed on a downhill section; a loaded trailer attached. The driver panicked. I asked him to put the jeep in first gear to break speed and gently manoeuvre it till end of slope and bring it to rest on the hill flank. Getting help from Haflong is another story! Many more instances of mishaps on lonely roads!!

In 1975-77, I conducted exploratory drilling in Mahadek Sandstone at Pdengshakap (Jaintia Hills) and carried out magnetic survey with a Schmidt Torsion magnetometer to look for basement lows. On a Sunday morning in March 1976, a severe storm hit and my tent collapsed on me while I was still in my camp cot. Another time, I was returning in a pick-up van to camp 40 km from Jowai after bank and post-office work. Rain caused heavy

landslide blocking the narrow hill road with a high-standing wall of huge boulders and fallen trees. It was mid-afternoon. I had to make detour of ~200 km via Shillong. It was down the plateau to Dauki, then 15 km stretch of hardly identifiable dirt road along Indo-Bangladesh border and again ascending the plateau to reach camp, where my family was alone. It was midnight and pitch-dark when we reached Dauki and nearly strayed into Bangladesh. I realised it on seeing the barrier outside Bangladesh Rifles camp and retracted promptly.

Setting-up of Northeastern Circle Office in Shillong

Director Dr. Udas and Mr. Saraswat came on a visit to Pdengshakap in March 1976. There was discussion on bifurcation of Eastern Circle and setting up of a North-eastern Circle Office. Choice of location was Guwahati or Shillong, I said Shillong. Dr. Udas said: "Go find a place". In May, I got instructions to go to Shillong, find suitable office accommodation. I reached Calcutta with detailed proposal, and met Chief Secretary, Meghalaya Govt. who said there was no vacant Govt. office space, but if we liked any private building the Govt. could acquire it for us. Director, Mineral Resources, Meghalaya Govt., Mr. Lyngdoh, was known to me. He introduced me to owner of a large two-storey bungalow (Skyline View) in Mawlai, who readily agreed to give it on rent as assessed by CPWD. I got all necessary plans and documents ready and reached Calcutta, where Mr. Saraswat signed the proposal. I took it to Hyderabad and Director, AMD approved it.

On 14th October 1976, I came to Shillong from field camp along with a couple of watchmen and locks and took over the rented building from the owner. On 15th October, with borrowed office table, chair, typewriter and landline telephone from the landlord, AMD's Northeastern Circle Office (later a Region) was formally started. I informed the Circle Incharge at Calcutta over phone and men and material started moving from Calcutta to Shillong. Some office staff were recruited locally. Existing Chemistry laboratory at Guwahati moved to Shillong after the landlord constructed a new building.

Sung Valley Ultramafic-Alkaline-Carbonatite Complex

In 1977-78 radiometric survey, geological mapping and sampling of eluvial soil was done. Twenty two carbonatite bodies were mapped and auger-hole sampling up to 1 m depth in seven eluvium blocks showing high radioactivity was done. Significant minerals found were pyrochlore-microlite, phosphate, magnetite, vermiculite and baddeleyite. Two other geologists worked with me. It was observed that economic minerals were enriched in eluvium 10 times compared to host rock. Mineral reserve of 10,000 te pyrochlore along with 10-12% P_2O_5 in eluvium up to 1 m depth was estimated.

I was in field and my family in Shillong. My wife Achla fell critically ill with severe chest infection. She could not speak and was scarcely able to breathe. My two sons were having school examinations. A neighbour called a doctor, who took her in an ambulance, admitted her in the Civil Hospital and put her under oxygen. The neighbour also telephoned AMD office. Regional Director, Mr. Negi rushed a jeep to my camp 50 km away to bring me. I saw my wife in critical condition being administered 12 injections a day. Slowly, she recovered.

Geological and Radiometric Surveys

During 1978-81, surveys were conducted over large tracts in SE Jaintia Hills and NE Khasi Hills (Meghalaya) and in Mikir Hills (Karbi Anglong and Nagaon districts, Assam). Three other geologists formed my Party. Special attention was paid to the extension of Tyrsad-Barapani shear zone in Mikir Hills. It was a difficult period. Due to the Assam agitation, there was scarcity of fuel and kerosene. There was one condemned jeep for four officers. Yet, we managed a large number of camp shifts utilising private buses running empty one way on weekly rural market days. In an earlier survey (1975-76) done by me in Mikir Hills, jeep-borne survey recorded significant radioactivity over biotite granite 20 km north of Diphu. Follow-up radon emanometric survey in soil-covered area to the south also recorded higher radon values.

I had some hazardous encounters with wild life in Mikir Hills. Wading through shoulder-high grass, I nearly stepped on a python lying concealed; sensing a movement, jumped over it. Once walking on a hill track, I was about to step on a green snake (like a bamboo leaf). A colleague, Dr. Diwakar Singh walking behind, pulled me back by my shoulder in the nick of time. Another time, I faced the fury of a captured elephant. It was tied up in ropes on a truck trailer parked on a narrow road near a weekly rural bazaar. As I was walking past, it trumpeted furiously and gave a wild swipe with its trunk. Reflexively, I sat down and elephant's trunk barely grazed the hair on my head.

Radon Monitoring Station in Central Seismic Observatory (CSO), Shillong

CN film based radon measuring grid of cased deep auger-holes was set-up in CSO campus. Readings were regularly monitored and correlated with seismic activity recordings. This study was in pursuance of dilatational model of radon-based earthquake prediction.

I headed the first evaluation team for Domiasiat uranium deposit in Meghalaya in October 1991 and projected a potential reserve of 10,000 te U_3O_8, vindicated later by detailed exploration.

Eastern Region Chapter (1982-90: 9 Years)

On re-opening of AMD's work in Singhbhum, I was transferred to Calcutta in December 1981, and given charge of SSZ area. Mr. K.D. Agrawal, an old stalwart of SSZ was the Regional Director. The only other geologist familiar with earlier SSZ investigations was R.K. Gupta. Rest at Khasmahal (Tatanagar) were four newly-recruited geologists. More officers were posted later. Old records were lying in neglect and in garage of rented office building in Khasmahal. Most records were missing. Reconstructing old records was a mammoth task. Much valuable old data was lost. Closure of SSZ operations in 1973-74 took place at a time when AMD Headquarters in New Delhi itself was under shifting to Hyderabad. Stratigraphy of Dunn and Dey had been revised by Sarkar and Saha (1978). Focus was on known uranium areas, which could be developed and exploited soon.

For two years (1984-85) I conducted geological and radiometric surveys in Chhota Nagpur Granite-Gneissic Complex terrain in Palamau area. Exploratory drilling was done in extension of Jajawal Shear at Binda and Nagnaha; fractures filled with greenish alteration clay within granites recorded uraniferous mineralisation. Radioactivity declined in epidote-bearing granitoids. Surveys were conducted over gneisses - granites in Ranchi-Kolebira-Simdega tract. Radioactive heavy-mineral bearing sand was found in river near Kolebira.

In SSZ, subsurface exploration in Turamdih and Mohuldih prospects was pursued. Problems arising from on-going Jharkhand agitation and labour union had to be addressed. Ore reserve reports of Turamdih, Narwapahar, Garadih, Bhatin and Bagjata were finalised and deposits handed over to Uranium Corporation of India Ltd. (UCIL) after discussion and agreement in a joint AMD-UCIL committee.

Geostatistics was used in Bagjata for first time in SSZ. It led to higher estimate of 1000 te U_3O_8 @ 0.044% U_3O_8 average grade with natural cut-off at 0.025% U_3O_8 against previous estimate of 660 te U_3O_8 @ 0.046% U_3O_8 av. grade with cut-off at 0.030% U_3O_8. Exploratory mining began in Bagjata. I was Project Manager and Agent of the mine. I conducted the visit of Dr. Raja Ramanna, Chairman, AEC to Turamdih area in 1984.

In 1988, I made a presentation in DAE, Bombay on Turamdih group of U-deposits. Dr. M.R. Srinivasan, Chairman AEC, together with Addl. Secretary, Joint Secretary and Director (I&M) were present. With the help of a stratum contour plan based on data of 200 boreholes (displayed by Overhead Projector), I explained that the individual deposits were all unified in the subsurface at +75 m R.L. (surface R.L. being ~150 m). Present outcrop pattern resulted from structure and erosion. The gap between Central Keruadungri and Keruadungri ore bodies was a graben structure 100 m deep. It held richer uranium mineralisation of 0.5% U_3O_8 grade. Afterwards, Addl. Secretary, S. Rajagopal came

up to me and said: "No one told us these things before".

I was appointed Regional Director, Eastern Region in 1989. There were frequent interactions with and C&S Group engineers and plans of AMD Complex at Khasmahal were finalised; construction began in 1990.

Shri Atal Bihari Vajpayee led Official Language Implementation Committee of MPs - Inspection visit to Calcutta in January 1989

I made a presentation on work done in Hindi by AMD before the committee. Maps of Jaduguda area captioned in Devanagari script were shown. Copies of 'Smarika', first issue of science magazine of AMD in Hindi, were given to the MPs. Shri Vajpayee had read it before coming to the meeting. He was pleased and said to me (in Hindi): "You've done all this work? Some say Hindi cannot be used in science. Now I can tell them that if Atomic Energy Department can do it, why can't you?"

Dr. P.K. Iyengar, Chairman AEC at Jaduguda

I was invited by CMD, UCIL, to be present during a two-day visit of Dr. Iyengar to Jaduguda in October 1990. Director AMD, Mr. Ravi Kaul, was also present. There were visits to the mines and mill of UCIL and to its Mosabani copper tailings treatment plant. There were discussions on several issues at site and in the guest house. Dr. Iyengar inquired about the outcome of AMD's drilling in north of the Subarnarekha River to test for repetition of Jaduguda ore lode north of the river [model proposed earlier by two visiting COGEMA geologists from France with whom Shri K.K. Sinha and I had taken joint field traverses]. My 1989 report on work done in Vietnam and proposal for a Joint Venture was discussed by Dr. Iyengar with me. I conducted his visit to the Turamdih area.

Other DAE assignments in this period, internal and abroad are detailed in separate later sections.

Central Region [erstwhile Western Region] Chapter (1991-99: ~ 9 Years)

I took charge at Nagpur as Regional Director in January 1991 at a time when exploration activity in the Region had sharply declined due to closure of Bodal and Jajawal exploratory mines and reduction in number of drilling units. Immediate concern was to identify potential areas for exploration and effective utilisation of manpower and materials. Mining machinery was lying unutilised. New mining machinery in the supply line was diverted to Bodal stores following closure of Narwapahar mine. Qualified mining personnel were re-deployed in drilling and other jobs. Addl. Secretary, DAE, Mr. Afzalpurkar came on a visit and I discussed this issue with him. I suggested we could undertake small-scale mining and uranium recovery from thousands of tonnes of ore lying at the mine sites by heap leaching. There would be no additional capital expenditure. Mr. Afzalpurkar wrote to Director, AMD and also obtained approval of Chairman AEC. DAE issued a sanction of Rs.2.5 crores, even without a written proposal or request from AMD Headquarters. Jajawal mine was re-opened and a technology demonstration heap leaching plant set-up. Half-a-tonne of uranium yellow cake was recovered and sent to UCIL, Jaduguda.

Exploration was actively pursued in Jajawal extensions, Dongargarh-Kotri Belt, Khairagarh Basin, Chhattisgarh Basin, Abhujmar Basin, Satpura Gondwana Basin, Infra-trappeans, etc. Recovery operations of rare-earth concentrate from inland placers continued.

In December 1991, an armed Naxalite group surrounded AMD's Mogarra camp in Rajnandgaon district at night and kidnapped camp Incharge K. Ramesh Kumar and drilling Incharge N.S. Khan. Due to lack of communication facility, news reached me only next day afternoon at 2.30 pm. I rushed to the Police Control Room and contacted I.G. Anti-Naxalite Operations Mr. A.V. Krishnan, who was away in Gadchiroli. Then I rang up Mr. Afzalpurkar, Addl. Secretary, DAE to inform him. I informed AMD Headquarters, Hyderabad thereafter. By 6 pm, the State and Central Govts. had swung into action. The most difficult part for me was to go and inform the families of the kidnapped AMD officers. Maharashtra Legislative Assembly's winter session was ending in Nagpur. I got an appointment to meet the Maharashtra Chief

Minister Shri Sudhakar Rao Naik in his room in the Assembly building. He assured that Govt. would do everything necessary to get the kidnapped officers released. Prompt actions and efforts of all bore fruit and both officers were released safely after six days.

Construction work on the new Residential-Office-Laboratory complex in Civil Lines had begun by 1991. CPWD was the executing agency. Progress was closely monitored in monthly meetings with CPWD and C&S Group of BARC. Work was completed in 1996 and well equipped modern laboratories established.

A stores-godown complex was constructed at Wadi. Thousands of tonnes of pegmatite atomic minerals were shifted from Chhatarbar godown (Bihar) and stored in bins here. A 400 m long approach road was constructed over partly forest and partly private land after necessary permission and acquisition and clearing of encroachments.

Dr. R. Chidambaram, Chairman AEC at Nagpur

Dr. Chidambaram first visited AMD Nagpur office in 1994. It was in an old Bungalow acquired from CPWD. He saw the Complex under construction and had general discussions with us. I mentioned the 1989 Vietnam report. On return to Bombay he called a meeting where I was present. When he opened the relevant file there was a pending request from the Vietnamese Govt. forwarded by the Indian Embassy in Hanoi, requesting DAE to send a delegation of experts in uranium to Vietnam.

Dr. Chidambaram visited AMD CR office for a second time in 1998 soon after the Nuclear Test at Pokhran. He met all the AMD scientists in the conference hall and narrated details about the event. Earlier when he was with me in my room, I requested him to sit in the RD's chair. He sat in it and joked: "Shall I take over"? I said to him, "Sir, this chair is too small for you".

Assignments Abroad

IAEA, Vienna: Was deputed to IAEA, Vienna in December 1988, to participate in a 4-day Advisory Group Meeting on 'Uranium exploration planning and practice'. The Group comprised experts from six countries. The report of the Group is contained in IAEA-TECDOC-583 (February 1991). IAEA wanted India to conduct a training programme for geoscientists from member countries in the Asia-Pacific region. Accordingly AMD conducted a training programme in 1991 in which I was one of the trainers.

Deputation to Vietnam (March-April 1989): I headed a 4-member delegation of experts from AMD to study the potential for uranium mineralisation in selected areas of Vietnam. The visit was part of follow up of the Protocol signed at Hanoi on 14.08.1988 between Prof. Nguyen Dinh Tu, member state council, S.R. Vietnam and Director Vietnam National Atomic Energy Institute (VINATOM) and Dr. M.R. Srinivasan, Chairman Atomic Energy Commission of India. Other members of the delegation were R.K. Gupta, J.C. Nagabhushna and K.K. Achar. I was a 2-week visit. Before departure for Vietnam, studied all available geological information of that region. French geologist La Fontaine's book 'The Geology of Indo-China' was particularly useful. In fact, I already had a mental picture of the most geologically favourable area for uranium there even before departure from Bombay. A ground check of the place later proved my hunch to be correct.

On arrival in Hanoi, we were met by our counterparts from VINATOM. Then we met the second secretary in the Indian Embassy. Next day (Sunday 26.03.1989) we visited the mausoleum of the great Vietnamese leader Ho Chi Minh and saw his embalmed body in a glass casket. Next two days we had technical discussions with the Vietnamese scientists on work done by them in uranium exploration. We also met Director, VINATOM. We left for field areas on 29th March 1989 and drove south 1000 km along the Pacific coast to reach uraniferous graphite-biotite-amphibole schist drilling area of TienHyiep and TienAn in Da Nang province on 1st April. (Along the way we witnessed the ravages left behind by the Vietnam war and saw many historical places). The fertile uraniferous area, yielding 0.02% to 0.022% U_3O_8 in boreholes formed part of the Paleoproterozoic Kontum Massif

exposed south of the Nong Son sub-basin. The coal-bearing sub-basin was part of a much larger volcano-sedimentary SavannaKhet (SwarnaKshetra) basin extending from Laos in the west in to Vietnam. The basin holds a 5 km thick pile of sediments and volcanics. To the north of Nong Son sub-basin, Tertiary granites with higher uranium content were exposed. Earlier, a visiting senior AMD officer had advised the Vietnamese to explore the granites.

But as a result of prior study, my target was right in the middle of the Nong Son sub-basin 70 km to the NW of the graphitic area being drilled. It was a NW-SE running basement ridge, which had dissected the elliptical sub-basin into two displaced halves. The area had earlier been mined for its Jurassic coal by the Americans and Germans. They found anomalous uranium content in the coal ash but did not pursue further. I asked our Vietnamese hosts to take me to that area. On 2nd April we reached KheDienne area. First spot on the ground, where we placed our scintillometer we got off-scale reading, which continued all around. The next day we continued our survey in the same area, which exposed highly radioactive Triassic sandstone all along a road-cutting covering a large area. My teammates collected samples and noted all field details. I asked our Vietnamese counterparts to move their drilling units to this area. First major uranium discovery in Vietnam had been made (confirmed in first five boreholes drilled showing correlatable uranium band with 0.5% U_3O_8 av. grade). News of the discovery reached highest Govt. levels in Da Nang and Hanoi very fast. On the way back we were invited to meet the Governor of Da Nang Province.

We reached Hanoi on 6th April. On 7th we met the Indian Ambassador and other embassy officers. Events moved swiftly thereafter. We had discussions with the Vietnamese side, which were keen on a bi-lateral agreement. I had no mandate or authority to sign any agreement (I was an SF grade officer). I said let us first submit a joint proposal for this to our respective governments for consideration.

We were scheduled to have a meeting with the Director, VINATOM and Dy. Director General of Geology and other Vietnamese officers in the presence of the Second Secretary, Embassy of India, at 11.00 am, on 8th April. That morning I had to draft the proposal for a joint venture. I thought it is appropriate to get the draft vetted by the Indian embassy before the scheduled meeting. I woke up that morning at 5 am with severe diarrhoea and the task of drafting the proposal loomed over me. Mr. Harsh Vardhan Shringla, Head of Chancery in the Indian Embassy (currently Mr. Shringla is India's Foreign Secretary) was to come at 10 am. My homeopathic medicine kit came in handy. By 8 am things were under check and I crafted the proposal with all necessary terms and conditions for a bilateral agreement. At 10 am Mr. Shringla came, read the draft and said 'fine' without changing a word. He informed me that the "Vietnamese Govt. is giving very high importance to AMD delegation and Gen. Vo Nguyen Giap, Vice Premier, Vietnam, wants to meet us next day morning; the Ambassador H.E. J.C. Sharma will accompany you after breakfast at his place". He also invited us for dinner that evening. Mr. Shringla was a very generous and pleasant host. Gen. Giap was the legendary Vietnamese Military General who had defeated the American forces at the historic battle of Dien Bien Phu in 1976. He was also the minister Incharge of science and technology. On 9th April we had breakfast and an informal but useful conversation took place at the Indian Ambassador's residence, where Mr. Shringla was also present. Then we all proceeded to the State Guest House for the meeting with Gen. Giap.

Gen. Vo Nguyen Giap did an unexpected honour of receiving me personally in the Portico and leading me by the hand to the dais in the meeting hall which was full. We were the only two on the dais with a senior scientist of VINATOM standing behind acting as interpreter. The meeting lasted for about 30 minutes. Gen. Giap kept patting my hand thanking me for finding uranium for them. The Indian Ambassador sitting in the front row was prompting me (in Hindi) to invite Gen. Giap to India, for which I really had no authority. After the meeting, Gen. Giap again came to the Portico to see me off.

That same evening at 9 p.m. at a banquet, we and our Vietnamese counterparts, signed a Proposal for

Vietnam and India to conclude an agreement in the field of uranium exploration and exploitation.

Next morning 10th April, I and my team left Hanoi at 7 am by flight for Bangkok. We were pleasantly surprised to find Gen. Giap on the same flight. He along with his interpreter walked from the front of the aircraft to the rear, where we were seated. I stood up and he informed me that his Govt. had approved the Proposal signed by us the previous night. Fast overnight work. He said: "I am going to New Delhi and will speak to Rajiv Gandhi". At Bangkok, I parted company with my team mates as I had another assigned task waiting for me in Thailand. My teammates continued their journey to Hyderabad via Bombay.

Task in Thailand: Some NRIs had informed Chairman AEC of India that a shipload of uranium ore had gone from Thailand to a neighbouring country of India. I was asked to stop over in Thailand on way back from Vietnam to check unofficially. I took three days casual leave. The mining property belonged to a family member of someone high-up in Thailand. I was flown 500 km south of Bangkok and taken another 200 km by road to reach the deposit area. I took samples and collected the necessary information. On return to India, briefed Chairman, AEC and handed over my hand written report to him.

Follow-up on Vietnam Assignment: After study and assay of samples, a classified report was prepared setting out all details for the Proposed Joint Venture with Vietnam. A copy of the report was carried by me from Hyderabad to Bombay on 9th July 1989 and handed over to Dy. Secretary (External Relations), DAE. I understand that the Proposal was approved in the AEC meeting held in New Delhi a week later.

There were follow ups and several meetings called in 1992 and 1994 by successive Chairmen in which I was present.

Other DAE Assignments

1. Co-opted Member, Nuclear Power Profile Up-dating Committee [constituted in July 1988]
2. Member, DAE's Internal Working Group for 9th 5-Year Plan (I&M Sector)
3. Member, Safety Review Committee for Operating Plants of UCIL [constituted by Atomic Energy Regulatory Board in August 1988]
4. Member, Safety Review Committee for Projects of UCIL [constituted by AERB in August 1990]
5. Member, AMD Council [September 1991 to August 1999]
6. Member, Apex Exploration Research Advisory Committee for AMD [November 2016 to July 2021].

Epilogue

My tenure in AMD is an Odyssey to be remembered. I had the privilege and pleasure of working with more than three generations of scientists and staff in the Atomic Minerals Directorate for Exploration and Research (AMD). I have seen and been part of its growth for over five decades and witnessed changing geological philosophies, emerging technological aids and exploration methodology. More than that, it is the human experience gained and shared with colleagues of all ages. There is something to be learned from each and everyone and from the working environment. Problems encountered are only an opportunity to recognize and develop one's own potential in finding solutions. Job satisfaction is the ultimate reward.

Growing 38 years with the Department of Atomic Energy

Radha R. Das

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Date of Birth: 15.05.1940 *Date of joining AMD: 05.10.1962* *Date of superannuation: 31.05.2000*

Dr. Radha R. Das obtained M.Sc. (Chemistry) from University College, Trivandrum, Ph.D. from Bombay University, Bombay, and completed Post-Doctoral work in Cornell University, Ithaca, UNY, USA. She joined Atomic Energy Establishment Trombay (AEET) BARC in 1962 and later transferred to AMD in 1980.

She has vast experience in Mineral Technology and Chemistry laboratories and has published several research articles in national and international journals of repute. She superannuated as Associate Director, Chemistry Group, AMD in May, 2000.

In the late fifties, many of us, who were degree students in Physics and Chemistry, were inspired by the news of the setting up of a Research Establishment and research reactors, in Bombay, for developing nuclear energy. Therefore, the award of a merit scholarship from the Department of Atomic Energy (DAE), during my M.Sc. course, at the University College, Trivandrum, and the scope thereby of joining the DAE, after the completion of M.Sc. degree, meant a dream come true. I joined the Chemistry Division of the Atomic Energy Establishment Trombay (later named as Bhabaha Atomic Research Centre) in 1962. Looking back to the seemingly short 38 years arouses pride, a sense of belonging, and achievement.

The seeds of all chemistry-based research, essential in the nuclear fuel cycle and those related to the nuclear power programme, were sown by Dr. Jagdish Shankar, the first Head of Chemistry Division. During early sixties, the activities in Chemistry Division centered on three main areas (i) the preparation of pure materials required for the nuclear and electronic industry, (ii) the applied and fundamental aspects of radiation chemistry, and (iii) the studies in the solid state on the structure and properties of fuel and cladding materials. I was given assignments in the "preparation of pure materials" (PPM) section.

The assigned responsibility was to develop a process flowsheet for the preparation of high purity indium by solvent extraction, ion exchange and electrolytic procedures and the characterizations of products for specified impurities. The objective of the study was to investigate and understand the mechanism of reactions in the metal-EDTA systems, their compositions, interactions and their stability. The "most modern instrument" at the "PPM Section" of Chemistry Division was a Beckman DU Spectrophotometer, and I used it along with a stopwatch, to follow the reactions of metal ions with EDTA - which was a novel ligand then, and this reagent almost revolutionised the separation chemistry of the rare earth elements and transuranium elements.

The need for and the sensitive awareness of engaging in scientific research was a major objective of the scientists working in the Division. There was the right environment for doing research, though the necessary equipments and facilities were meagre. The youngsters were provided with less burden of routine work and they were trained for challenging assignments so that the individual was left with enough time and energy for advanced study in research, and developmental work, a philosophy that was followed in AEET for the human resource development. Two important components, in the development of several areas of research that were initiated under the leadership of Dr. Jagdish Shankar, were (i) the application of "Scientific Method" to gain knowledge on a

"system of interest", and (ii) the application of the scientific capability so developed to benefit the nuclear programme.

Being a DAE scholar for M.Sc. studentship, I was permitted to register for Ph.D. within 6 months of my joining AEET. Working with Dr. Jagdish Shankar, for a Ph.D. degree was a very rewarding experience. With his standing among scientists, he could attract eminent scientists to the Division from U.K., Europe, and the U.S. Dr. Shankar never hesitated to introduce these visitors to his young colleagues, particularly his students. He used to offer opportunities for students and young colleagues to interact with them and the discussions with such accomplished scientists are one of the most memorable ones even now.

The policy of AEET, to offer opportunities for talented scientists, for studies in National Laboratories and Universities abroad took me to Cornell University, Ithaca, New York. My two-year period at Cornell, during 1968-70, provided opportunities of interactions with several renowned chemists like Malfred Eigen, Raold Hoffman, Gordon Hammes, Harold Sherage and Robert Plane. Switching over from the field of purely inorganic and physical chemistry of the metal-EDTA complexes to the inorganic, bio-inorganic and biophysical chemistry of porphyrins and metallophyrins, and studying their reaction kinetics of microsecond durations, using modern techniques like temperature-jump and stopped flow methods, was a beautiful experience. Porphyrins and metalloporphyrins are of immense importance in both chemistry and in biology. Professionally, it was during that period of the stay at Cornell that I experienced the joy and excitement of working in a frontier area of science, and realized the fascinations of unraveling a problem by the use of several equipments that are required to solve a major problem. Much later in the 1990s the geochemical characterization of the uraniferous sandstone ore of Domiasiat, using different techniques, has been one of the fruitful results of this realization and experience.

Dr. Karkhanawala, who took over as Head, Chemistry Division in 1972, reiterated the importance of providing opportunities to work in the frontier areas of chemistry and wanted to create a "Centre of Excellence" in studies of "fast reactions" in the Chemistry Division. This centre for fast reactions (as he used to refer), was to carry out fundamental research of "world class" in the areas of flash photolysis, pulse radiolysis, and temperature jump relaxations. This required the development and use of highly sophisticated techniques and equipments of this type were not available then in the country. They were to be either imported or to be made. This responsibility fell on many of us, Dr. Jai Pal Mittal, Dr. P.N. Murthy, and several others, who by early seventies, had returned from abroad after receiving special training in fast reactions. For much of the work, we had to design, and fabricate by ourselves the equipments needed and demonstrate their applications in a variety of disciplines viz. inorganic and physical chemistry, as well as bio-inorganic, biophysics and nuclear related studies. The team consisted of electronic engineers also; and such type of 'team work', ultimately encouraged to generate professional scientists with wide spectrum of knowledge and experience! The efforts of designing and fabricating the equipments encouraged our interactions through inter-laboratory and inter-institutional collaborations.

The necessity of shifting to Hyderabad, brought me in 1980, to the environment of the Atomic Minerals Directorate, the oldest Division of the Department that explores and evaluates minerals, required for materials in the nuclear energy industry. There was support from Dr. K.M.N. Rao, the then Head, Chemistry Division; from TSC, BARC, and from the then Director, AMD, Dr. G.R. Udas for this transfer. I was to carry out investigations on the leaching characteristics and the recovery of uranium from the ore of Bodal area. The assignments changed. A goethite and clay containing uraniferous sandstone type of deposit was discovered, in late seventies at Gomaghat, Khasi hills, Meghalaya. AMD had initiated, under an IAEA research contract, a programme (1977-78) "on the study of factors controlling the formation of sandstone type uranium deposits in India". The period of my shifting to AMD, almost

coincided with these two developments. I initiated studies in the separation for the associated fine particulates (viz. clay, hydroxyoxides of iron, and organic matter) from sandstone ores, in their characterizations by different techniques and in the uranium sorption at the solid-solution interfaces, in order to gain insight into the depositional environments of uranium mineralization. The properties of these particulates are the manifestations of their chemical compositions and structure (both shape and the internal architecture). The switch over to the chemistry of rocks, ores, minerals, their architecture, and sociology and their characterizations, from the frontiers of porphyrins, and metal-enzyme fast reactions, was worth trying. I remembered that Dr. Shankar, while organising the work, of the chemistry programme, at 'Kenilworth', began, by the analysis of ores and minerals.

The term clay has a dual meaning. It is used both as a rock term and as a particle size term. As a rock, the clay minerals are essentially hydrous aluminium silicates. Iron, alkalies and alkaline earths are also present with these. With water, it develops plasticity. As a particulate, these are mostly fine than about 2μ in size. The hydrous oxides of iron are of different composition and structure. The organic matter in ore, are of different compositions, maturity and properties. In my learning the chemistry and the architecture of clay, rocks, ores and minerals, and in my carrying out the investigations, I owe much to Dr. K.M.V. Jayaram (the then overall I/C of Chemistry and Mineral Technology Laboratories), for the support received to create certain facilities and infrastructure within the mineral technology laboratories for such investigations; to Dr. K.K. Dwivedy (then I/C, MT Laboratory) for the appropriate samples, and to Shri T.M. Ramachar (then I/C Nb-Ta Investigations), for the patience towards my innumerable questions. Shri B.N. Tikoo (then I/C Chemistry Group) taught me how to break the knots in geological materials, prior to their analysis.

The first results of the investigations on "Uranium Sorption on Clays" were presented at the International Symposium on Particulate Science and Technology, held at IIT, Madras in December 1982. They were well received. It was fun to respond to the questions raised, particularly by a few Japanese Scientists, who had similar interests. I felt a confidence, of being on the right track! Several years later even after assuming the responsibility as the Incharge of the Chemistry laboratory, my interests in the reactions of uranium and other metal ions at the solid-liquid interface, and in the investigations on the structure - reaction - property relationships of fine particulates separated from different uraniferous ore continued along with the service, analyses of geological samples and the research related to it. Opportunities were many and participation was challenging. [An exercise that I enjoyed was the writing of an article for Nuclear India, and Paramanu, to trace the evolution, growth, development and achievements of the Directorate in the 50th year of AMD, 1999 in the form of an interview with Director, AMD.] The discussions with colleagues were quite interesting and educative; each one had a story to tell. I realized that writing 'History' of an institution was indeed challenging and enjoyable!

The spirit of comradeship and of team work, irrespective of the hierarchy of the personnel is reflected in every activity of this Directorate, from exploration to the evaluation of the mineral resources. One realizes that the field operations and the laboratory activities are inextricably woven together, and the great beauty of such an activity is more visible, when one is part of it.

There were 'predictable crises', as in any facets of life; there were 'passages and trials'; there were questions which remained unresolved; but there were "challenges, support and good will" throughout. Finally, there is a feeling of triumph in the endeavour, and a sense of belonging to the department. The easy passages to different situations and assignments, I attribute to the training in basic and developmental research that I received in the Chemistry Division, at the Cadell Road Laboratories of AEET, where it began in 1962.

Reminiscences of thirty years journey through AMD/DAE

N.L. Durg

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Date of Birth: 20.06.1940 *Date of joining AMD: 30.05.1970* *Date of superannuation: 30.06.2000*

Shri N. L. Durg obtained M.Sc. (Geology) from Karnataka University, Dharwad, Karnataka. Prior to joining AMD in 1970, he had carried out research project on Manganese deposits of Potoli-Nagari of North Karnataka. He has worked in several parts of the country. He superannuated as Scientific Officer-F and Incharge, Petrology Laboratory, Southern Region in June, 2000. He has published six research articles in various journals of repute.

I joined AMD in May 1970 at Beach Sand Investigations cell at Trivandrum, Kerala. We, a group of 11 young geologists, were given the task of evaluating beach sand for the heavy mineral content in Neendakara-Kayamkulam coast of Quilon district, Kerala and Chatrapur-Gopalpur coast of Ganjam district, Odisha under the guidance of Dr. G. Prabhakar Rao and along with our seniors like S/Shri D.N. Ramarao, Subba Rao, K.B. Rao, and M.K. Rajgopal. We were going to field in batches and others were working in Labs. We collected samples at a grid pattern of 100 meters along the berm line and across till the coastal sands exist, and every 5 meters depth till the bedrock comes using Conrad Banka Drill, where four persons used to stand on platform for thrusting and another four persons use to rotate the platform. This resulted in a very huge quantity of samples to be treated at labs. So by trial and error it was decided to group 16 samples to make one composite sample considering other factors of distribution of heavies both in horizontal and vertical directions. In the lab, representative samples of 100 gm were treated with dilute HCl to remove the calcareous material, then sieved through 40-200 mesh to segregate size distribution of the sand grains, subjected to electromagnetic separation to separate magnetic minerals like ilmenite and non-magnetic minerals like rutile, monazite, zircon, sillimanite, kyanite etc. These fractions were further subjected to bromoform heavy media separation. Then they were subjected to microscopic study by counting at least 700-800 grains per slide mounted with glycerine / clove oil for easy differentiation and identification of sillimanite and zircon. Then the number of grains and their specific gravity and the weight of the fraction used to be calculated, the percentage of each mineral in the sample after computing all fractions, and then the total percentage of each mineral was calculated taking into account of sample in the block of the coast. Thus, finally evaluating each heavy mineral in the entire coastal area including the depth-wise distribution. This was done under a crash programme and we were able to evaluate the total heavy mineral contents in both Kerala coast and Odisha coast in a period of three years. Based on our work IREL set up heavy mineral separation plants at both Kerala and Odisha coasts. We were facing a lot of cyclones in the Odisha coast. I got the opportunity to work on both Kerala and Odisha coasts.

I had the opportunity to work in Precambrian conglomerates of Parsad of Udaipur district, Rajasthan, where I was able to locate primary uranium mineralization in conglomerates under the supervision of Dr. D.S. Sharma, Shri Rajendra Singh and under the guidance of Shri G.R. Narayandas, who was then Regional Director of Northern Region. During the early part of investigations one day myself and Dr. D.S. Sharma went for field work on a long traverse and by late afternoon there was heavy downpour and we returned to camp almost after dark and when we reached the camp, I was shocked to find my wife

sitting on the camp cot with three year old son and one year old daughter as my Kabulpal tent was under knee-deep water and we had to wait whole night like that as it took water to recede by almost sunrise.

I also got the opportunity to work in Bijawars of Mardeora of Sagar district, Madhya Pradesh. While working in that area, myself and Shri Ajit Pande had to face a peculiar situation. When we were descending the hill, all the people working in the fields at lower level ran away. When we called them in the camp, they told us that they had mistaken us for the officials for forceful family planning operations as that was the period of mass family planning operations.

I also worked in the Siwaliks of Kangra district of Himachal Pradesh under the supervision of Shri Ravi Kaul. I was able to locate Cb-Ta mineralisation at Taskola pegmatite near Paota of Kothputali in parts of Jaipur district, Rajasthan. During this period, I had to face a peculiar situation. I had shifted to a small village near Paota and kept my tentages and other materials in a small room provided by village Sarpanch. I was spending the night in a guest house nearby with a plan to shift finally next morning. At about 2 am in the night, the Sarpanch along with some more persons came and woke me up informing me that a thief had broken the lock of the room, where I had kept our materials and they have locked up the thief. So I went to the village and was shocked to find that entire village was there and police were interrogating the thief who was nearly 60 years old. That day I saw how the police mercilessly beat the so called thief, hanging him upside down and beating with cane and lathi. But to my astonishment the thief did not utter a word. Finally, I was asked by the inspector to lodge a complaint in the morning. I had no option as it was demanded by Sarpanch. After nearly two years, I was to appear before the Hon'ble Judge, who asked me to identify the person who was in the court room. I looked around and identified him. Hon'ble Judge asked how sure I was. I told him as a geologist I am able to locate the exact point from where I collected the rock sample even after decade what to talk about humans. Hon'ble Judge smiled.

I also worked in pegmatites of Sangwa-Tiloli of Bhilwara district. While working in the Neem ka Thana area myself and Shri B.N. Khazanchi were mistaken for spies by the villagers and the Police inspector came to arrest us. We could convince the inspector by showing our credentials.

I was very happy to locate primary uranium mineralisation in the Siwaliks of Danaur area of Nainital district of U.P. During these investigations, S/Shri Pannerselvam, R.S. Yadav, S. Zakaulla, R.D. Deshmukh were my party members and Dr. S.N. Virnave was our leader, under the supervision of Shri Saraswat. In this area, which is the extension of Corbet National park, tigers and elephants were our usual companions and myself and my young children have got the opportunity to see freely roaming tigers and huge tuskers within 5-10 meters. It was a very pleasant time to be with nature in those thick forests.

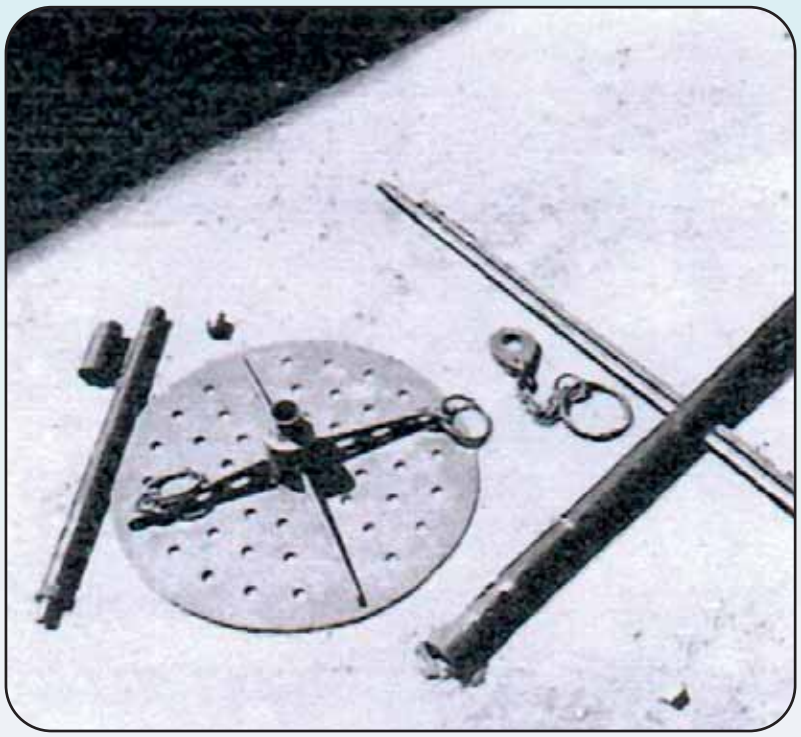
I was asked to set up Sedimentary and Petrology laboratories at New Delhi, NR from a scratch and was able to get all the instruments and equipments through the kind help of Shri Saraswat and the then Director Shri T.M. Mahadevan, who was kind enough to get the same equipments for all Regional labs based on the indents I had prepared.

I was able to locate primary uranium mineralisation in the Kaladgi sandstones near Nidgundi-Aalmatti area of Bijapur district of Karnataka which opened the Kaladgi investigations after a gap of few decades. Dr. R. Gajapati Rao and Shri U.P. Sharma also worked with me in this endeavour.

I had the privilege of assisting Chairmans of DAE Dr. Raja Ramanna, Dr. P.K. Iyengar, Dr. Brahmanda Reddy during their meetings with the then PM, and also during AEC meetings at Parliament and at Defence offices.

I laid down my office on 30.06.2000 as Incharge of Petrology laboratory of Southern Region, Bangalore. I express my heartfelt gratitude to Atomic Minerals Directorate for Exploration and Research in particular and DAE, Government of India in general for giving me and my family an opportunity to see the country from Kanyakumari

to Himalayas and to know the people across the country and different cultures. I wish AMD a successful period ahead to fulfill the responsibility that has been given by the GoI for welfare of the people and country.



Conrad Banka drill.

Shri K.K. Dar, the then Director visited Gopalpur camp along with Dr. G.P. Rao, Shri Subbarao, Shri K.B. Rao, Shri P.K. Hansda, Shri V.P. Saxena, Shri N.L. Durg, Shri S.K. Saxena, Dr. Dhirendra Kumar and Mrs. Kumar.

Face to face with divine grace in Higher Himalaya: a reminiscence

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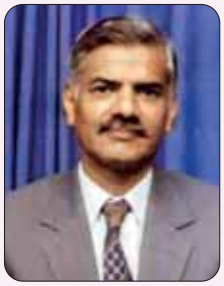
Date of Birth: 24.12.1940 *Date of joining AMD: 27.07.1966* *Date of superannuation: 31.12.2000*



Shri Bal Mukund Swarnkar obtained M.Sc. from Rajasthan University, Udaipur, Rajasthan. He joined AMD in 1966. Prior to joining AMD he served as Lecturer in geology in Dharam Samaj College in Aligarh, Uttar Pradesh. He has contributed in several parts of the country in various capacities. He superannuated as Scientific Officer-G and Regional Director, Northern Region, New Delhi.

It was during 1966-67 field season, I was staying in a tent pitched on a small hill terrace at Village Kandi of Kandi-Kasha-Pat area, Shimla district, Himachal Pradesh. Shri H.S. Mehta being with his wife and their 3 years old child, Bawa, were staying in a nearby house. We were there in those shelters since the month of May, 1967 onwards.

On a Sunday morning during August, 1967, we were having our breakfast. Suddenly an intuition came to my mind that the giant quartzite block, lying uphill, behind my tent is likely to roll down and would fall over my tent. I immediately told Shri Mehta about my intuition. He and his wife were surprised to hear and expressed that probably I was not liking their company so with this pretext I wanted to shift away from them. We discussed this for about 5 to 10 minutes and finished our breakfast. Again, in the afternoon, during lunch hours, the same thought came repeatedly in my mind and this time I told them that I should close down my camp and shift from there immediately. On hearing this, with tears in her eyes, Mrs. Mehta asked me whether I was unhappy with their company or their behaviour. I assured her that this was not the case, but only because of the fear of the possibility of the stone rolling down. We finished our lunch and did not discuss it further.

In the afternoon, around 4.30 pm. the landlord of Shri Mehta's house, Shri Hari Das came there. Shri Mehta narrated to him about my 'haunting thought'. Immediately, Shri Hari Das came to me along with Shri Mehta and told me that "Sir, this house was constructed by my father and I have been seeing this stone lying there for decades and decades. I am already nearly 50 years old, but this rock has not moved even an inch. So, why are you worried?" I did not discuss anymore and Shri Hari Das also went back.

Again, in the evening around 6 to 6.30 pm. the same thought haunted me and I decided to convey this to Shri Jagmer Singh sir, who was camping nearly 3 km away. I just scribbled on a small piece of paper that the giant rock is likely to fall over my tent and that I wanted to shift immediately and asked for his kind advice. Shri Jagmer Singh sir, in turn, sent 4-5 persons with the instruction that I should immediately close my camp and shift to his camp. I unpitched the tentages, kept some items in the house of Shri Mehta and moved to Shri Jagmer Singh's camp around 9.30 pm with essential items.

Next day morning, when I was taking traverse along with Shri Jagmer Singh sir, we passed through Shri Mehta's camp, where I was camping till the previous day. To my horror, I was shocked to see that the giant rock had really rolled down and fallen on the ground, where I had been staying for the last so many months. A look at the site made me shiver and breathless with perspiration on my whole body. Probably the giant rock had fallen during the night just after my shifting the camp. Had I continued camping there that particular night I would have been crushed to pulp. The Almighty had thus given me a rebirth on the particular day.

In my humble opinion, this spine-chilling incident may be termed as a "face-to-face with divine grace". The divinity was expressed in the form of timely advice, guidance and instructions by Shri Jagmer Singh sir, who actually emerged as "the divine messenger". Since then, we consider and respect him as our "God Father"!

Field photographs of Kandi-Kasha-Pat area, Shimla district, Himachal Pradesh.

Field camp Kandi area, Shimla (photo by Shri B.M. Swarnkar, 1967.)

Another view of Kandi area, Shimla (photo by Shri B.M. Swarnkar, 1967.)

Highlights of the exploration, research and discoveries with experience in AMD from September 28, 1964 upto July 31, 2001

Arun Kumar Bhattacharya

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Date of Birth: 05.07.1941 *Date of joining AMD: 28.09.1964* *Date of superannuation: 31.07.2001*

Dr. Arun Kumar Bhattacharya obtained M.Sc. from Banaras Hindu University, Varanasi, Uttar Pradesh, and Ph.D. from Delhi University. He joined AMD in 1964. He has served in several parts of the country in various capacities. He received the Platinum medal for the best paper published in the Journal of Geology, Kolkata. He superannuated as Scientific Officer-G and Regional Director, Central Region in July, 2001. He has published several research articles in several national and international journals of repute.

Mobile belts, cratons, and Proterozoic basins in Eastern, North-eastern, Central India, Himalayan Main Central Thrust (MCT) zones from Himachal in the west upto Nagaland-Mizoram in the east encompassing Bhutan Himalayas and some cover sediments were the targets I investigated during my 37 years tenure in AMD.

STB-East (Singhbhum Shear Zone, SSZ) [Sept. 1964 - Nov. 1967]

Surda-Pathargora-Mosaboni-Bagjata-Gohala-Kanyaluka-Purandungri tract: [apatite-magnetite bearing schists/granular rock]

Uranium mineralization at Surda-Pathargora tract was commonly found in the schist/granular rocks containing less apatite (modal distribution ~8% or less) with conspicuous association of iron oxides and albite along with variable proportions of biotite, chlorite, sericite, quartz (2 generations), tourmaline, epidote, and pyrite.

Fine streaks (10 cm x 10 mm) of dark, cryptocrystalline mylonite (trap shorten, example being at Surda granulite hill) are found frequently associated with the host rocks. The radioactivity due to uranium was found particularly associated with feeble or non-magnetic portions of the iron oxides namely martite/maghemite and not the highly magnetic magnetite fraction. Reflected light, petrographic study (carried out by me during recess at ER, Kolkata) revealed two phases of remobilized uranium mineralization.

I located two float boulders of radioactive (high U value analyzed) metabasic rocks around Duma Pahar, south of Dhobani; but in situ outcrop could not be traced with limited efforts since it was the belief of the generation that basic rocks do not host radioactivity.

Borehole cores of limestones (personal communication with Shri K.D. Agrawal), massive ultramafic/mafic rocks, apatite-magnetite, conglomerate, quartzites have been intercepted during drilling as isolated enclaves within schistose/granular rocks in Roam Siddheshwar and Kendadih areas. These geological signatures were ignored then, since they were not recording radioactivity. These are the designated signatures of olistoliths and olistostromes, which occur along with metamorphosed terrigenous and volcaniclastic sedimentary mélange of ferruginous, phosphatic mud assemblage documenting imbrication, convolute beddings, slump sediments, ripple-drift lamination along with colour banding structures. Overall, this observation reflects the style of sedimentary deposition on slope under severe perturbation of the basement within intracratonic structural basins (rhombochasm).

At Bagjata, the mineralized host-rock rich in biotite and chlorite at surface gets transformed into sericite-rich schist at depth as recorded in the mineralized borehole cores. Fluorite (suggested as introduced by hot brines and convection of the super-heated ascending fluids) is frequently associated with the host rocks. The collisional tectonics developed thrust zones paired with periodic lags (normal

faults) giving rise to the present status of the SSZ. [Lags were missed by geologists since they were overbiased with preconceived idea of thrust and reverse faults.]

At Purandungri, the mineralization shifts from the apatite-magnetite bearing schists on surface towards the footwall side at depth in association with the iron oxides having less magnetic martite-maghemite association as recorded in the borehole core study. It is quite likely to find few more concealed mineralized bodies of uranium mineralization at depth which could be intercepted on the hanging-wall sides associated with lags in Bagjata, Kanyaluka, and Purandungri.

The above view is substantiated by the interception of occasional high value (~0.10 % eU_3O_8) at around ~1000 m depth from time to time, while conducting gamma-ray logging of deep boreholes by our physicists (S/Shri N. Dayal, J. Jadhav, O. Jhingran, Bansal, Hari Shankar and few others) in Mosabani and Badia areas.

The process of crustal shortening during the collisional tectonic regime transposed the original bedding into schistosity planes (S0=S1). These planes were reactivated as shears pronouncing reverse faults (thrust) paired with periodic lags (normal faults) giving rise to the present status of the SSZ.

Selenium enrichment (study organized by Shri H. M. Verma at Ghatshila core library) has been recorded particularly in sulphide-rich portions of both radioactive and non-radioactive borehole core samples from STB East and STB West. This confirms the signature of the low temperature, sedimentary parentage of uranium as well as copper.

The 'soda granite' is a 'tonalite-trondhjemite' clan of granitic basement rocks forming parts of the Singhbhum craton. Repeatedly flushed (by deep-seated fluids of brines and super-heated steam) and transformed bodies of schistose soda granite, which got tectonically transported in the shallower levels due to structural slicing of the basement (example at Kanyaluka along the foot wall zone) as result of the reactivation of the basement faults.

Uranium zone also contains Y and Th in the form of xenotime and monazite respectively at Kanyaluka North, besides some clusters of thorium-bearing placer sands in certain locations north of Pathargora, north of Purnapani Nala and Badia. These must have been eroded from the surface of the basement rocks and left behind as fossil sands by the running waters. In view of the above signatures, as discussed in aforesaid paragraphs, the SSZ is postulated comparable to the IOCG type of activation and mineralization.

Uranium in migmatites at Sonbhadra, Uttar Pradesh and Indarwa near Kodarma, Jharkhand within Chhotanagpur Granite Gneiss Complex (CGGC) [1969-1071 & 1987-1996]

Na-feldspar-bearing, pegmatoid leucosome mobilizates (PLM) out of the ultra-metamorphosed ensialic sediments host uranium deposits at Naktu, and many other locations including the widespread leucogranite at Bijpur in Sonbhadra.

NTPC's Bijpur thermal power plant has been built over the mineralized horizons. Besides, large part of the mineralized terrain extends underneath the Rihand dam reservoir. The above uranium mineralization occurs in proximity to partially melted, partially metamorphosed/unmetamorphosed or untransformed arkose preserving fabric relict such as Bouma sequence of turbidite and seismite sedimentary structures representing thermo-tectono-metamorphic 'shadow zones'. This is an 'enigmatic occurrence' within highly mobilized collisional tectonites, which escaped the effects of thermal, tectonic and metamorphic transformations.

At Indarwa, a saddle reef structure hosts uranium mineralization within amphibolite restites (inclusions of uraninite in amphibole) and K-feldspar bearing leucosomes as component of metatexite-migmatites. The mineralized zone occupies the northern limb of a regionally huge synclinorium having emplacement of Nirupahar phacolith of potassic, S-type diatexite-granite in the fold core of the synclinorium (A.K. Bhattacharya & S.R. Rajderkar, 1969-70).

Following the U discovery at Indarwa, many more uranium anomalies were located in the terrain at several locations as a result of radiometric and biogeochemical (leaf, stems, and roots of shrubs, which produce kattha used for chewing betel leaf) surveys (D.V. Katre & A.N. Basu, 1968-1969).

I discovered high value (~ 5.0 % U_3O_8) of uranium occurrence hosted by calc-silicate rock within the Proterozoic schists at Dupu, Siang district, Arunachal Pradesh (A.K. Bhattacharya, 1986-87).

The first uranium anomaly in Arunachal Pradesh was discovered at 'Pampuly' by Shri D.V. Katre and Shri T.K. Mukhopadhyay (1969-70).

I also discovered ~150 km long belt of non-pegmatitic source of beryllium hosted by leucogranites and vein /reef quartz inclusive of monomineralic beryl rocks in the Central Bhutan Himalaya near Tongsa as well as clusters of pegmatitic beryl (including giant sized crystals) deposit at Chirang (Shri A.P. Roy) in foothill Bhutan.

Working Condition & incidents

Geiger Muller Counters were only available to us for radiometric survey. Scintillometer and Beta counters were made available in late 1970s. Until 1969, the then SG (Shri K.K. Dar) and SMG (Shri K.L. Bhola) were only authorized (by GA) to select just few samples for chemical analysis with the sole objectivity of corroboration of the radiometrically analyzed uranium values.

I used bullock (buffalos) cart for camp shifting in Keonjhar-Mayurbhanj areas in Orissa in 1967-68 and used Public Buses in Himachal Himalayas in1975-76.

Living in tents was becoming unsafe in 1970s. So, we used to find some rented hutment/house in villages at our own expenses until early 1980s.

We used to submit hand written reports excluding few fortunate who had portable type writers inherited from parents. The only means of communication was through hand written post-office mails sealed under cream coloured envelop inscribed with "ON INDIA GOVERNMENT SERVICE" posted with service stamps.

The computer was introduced in AMD as late as 1990 that too for the operation in technical section to begin with. GPS system and satellite /mobile phones were not invented in those days. We had to depend upon toposheet and brunton compass for navigation. We used to carry with us some preventive medicines and first-aid items at own expenses living life in the wilderness under 'God's mercy'.

A wild elephant uprooted my tents and ransacked my Pathargora camp on a freezing-cold mid-night of Jan.13/14, 1965, while I was sleeping inside. I escaped with severe injuries all over my body and got a second life after receiving medical treatment two days later at the Mosabani Mines Hospital with the help of my boss Shri V.G. Shirke. Thereafter, I was nick named as 'Hathi Bhattacharya'. Headquarters (New Delhi) questioned me: "knowing fully well the area is infested with wild animals, what precautionary measures had you taken before camping, and why the government will not ask for compensation for the torn tents (one discarded and used, and two other small new tents)"?

On a rainy mid-night while returning to Kanyaluka camp, three of us (Shri E.U. Khan, myself and driver Shri Kuldeep Singh) got stuck at Sankh Nala because one tyre of the wheel got swept away while crossing the flooded stream under heavy rains. The jack could not be used on the wet mud to change the tire. So, I ventured and lifted the jeep with both hands and held it for about a minute while the driver and Khan opened the rim and replaced it quickly with stepney. After this incident my colleagues made a joke, 'GA will not sanction jack anymore and shall ask to use Bhattacharya now onwards in place of jack'.

Untold Truth

Dr. G.R. Udas, as a mining geologist demonstrated to us (B.Sc. students' field tour) short-hole drilling by holding the drill machine upon his shoulder at the underground drive in Jaduguda U Mines (1959-60).

As the case history goes, thorium anomalies were the source of radioactivity in Meghalaya sediments but for one, namely 'Kingdong sandstone' in Jaintia Hills, which analyzed high value of eU_3O_8 (having negligible thorium) with low value of U_3O_8 with the remark (Shri S.R. Rajderkar 1956?) "Uranium leached out and moved away leaving daughter products revealing high radioactivity".

Shri A.C. Saraswat (RD-ER) picked up this point as the justification for the proposal of renewing survey and exploration for uranium in the sandstones of Meghalaya to counter headquarters' argument of 'thorium anomalies and land-locked basins'. Thereafter, we discovered and established the existence of leachable (labile) uranium at several locations within granites and the metasediments in the Precambrian basement rocks, which served the provenance as well as the precursor to the Cretaceous

-Tertiary sedimentary cover in southern Meghalaya. This was followed by the Director's (Shri K.K. Dar) approval of the assignment to renew the survey and exploration for uranium in the sedimentary cover in southern Meghalaya close to East Pakistan (presently Bangladesh) border. AMD teams were actively working near the border (around Dowki) within the bombing and shelling range during the 1971 war with Pakistan just before the emergence of Bangladesh.

Renewed surveys resulted into several discoveries of Uranium (free from thorium) mineralization by a team of geoscientists led by Shri. S.R. Rajderkar (1972 to late 1970s) opening with the occurrence at Pynursla plateau associated with clay balls rimmed with carbonaceous material hosted by sandstones grading into the underlying basal conglomerates (Diwakar Singh & A.K. Bhattacharya, 1972-73).

As a member of the first 'Igneous & metamorphic evaluation team' in 1974, I studied the abandoned Umra uranium occurrence and found the folds having the axes plunging oblique (by about 70°) to the strike of the axial planes (handwritten report/ diary, 1974). This observation was re-considered and modified while renewing uranium exploration at Umra in late 1980s.

Trails of Vindhyan sediments have been located overlying the basement crystallines in Sidhi and Mirzapur districts of Madhya Pradesh and Uttar Pradesh respectively with halos of hydro-geochemical anomalies at Barhgaon. In addition, the reported Vindhyan promontories extending underneath thin cover of Gangetic alluvium in Mirzapur-Varanasi tract recorded high uranium values in well waters (including Kharikuawan, Varanasi city, G. Chowdhary, BHU, Geol. Soc. Ind., 1993?) in Babadpur-Varanasi tract (Shri D. Saxena 1994-95). This mapping record indicates that the Vindhyan basin in geological past was extending further south from the present boundary limited by Son River valley. The above sites of Vindhyan outliers and the locations of hydro-geochemical anomalies could be considered for re-evaluation for probability of Vindhyan sediment-related unconformity type of uranium mineralization.

I found that Gogi uranium mineralization (one week field study note submitted 1998?) occurs in terrigenous sediments interlayered and graded with volcanogenic mudstones and volcaniclastic sediments preserving telltale signatures of volcanic bombs, olistoliths and olistostromes. Keeping this observation as unbiased the exploration results could be relooked upon and re-evaluated regarding the characteristics of the host-rock for better correlation and appreciation of the status of the uranium deposit.

Some suggestions to derive better results under 'U' exploration strategy

Besides the concept of 'shear zone & hydrothermal mineralization' we might also apply the understanding of other models of uranium mineralization globally established so far while exploring both Precambrian as well as Phanerozoic targets. While dealing with the Proterozoic mobile belts the basement-cover relationship must be studied and evaluated considering the globally established fact that the structural slices of the Archeozoic basement got elevated, complexed with the overlying metasediments during the processes of crustal shortening under collisional tectonics.

I submitted a report (handwritten, 1976) to the Director (Dr. G.R. Udas) identifying targets favourable for uranium exploration (with justification) in a few selected North and East African countries based upon detailed study of available literature.

In personal capacity, I worked in several African countries for multi-metals such as gold, platinum, base metals (Cu, Pb, Zn,), cobalt, REE, iron, tin-tungsten and manganese including working for vein-type and unconformity-type of uranium mineralization in Uganda, Kenya, Ethiopia, Tanzania, Malawi, Ivory coast, Burkina Faso, Ghana, Liberia and Sierra Leone. Ubendian/Usagaran mobile belts, and Mozambique metamorphic belt, in East Africa and the Birimian greenstone belts in West Africa and the Mesozoic greenstone belt in Alaska, USA were the main targets. I explored, during post-superannuation period, from 2005 up to 2017.

My reminiscence and reinterpretation of the eastern part of Singhbhum Shear Zone (erstwhile STB), Jharkhand (Period: 1964-1967)

The reinterpretation is restricted to the targets in Jharkhand (erstwhile Bihar) encompassing shear zones (SSZ) extending from Bhatin Mines in the west and east of Jaduguda, through Roam-Siddheshwar-Rakha-Kendadih-Surda-Pathargora-Dhobani-Mosabani-Badia-Bagjata-Gohala-Kanyaluka-Bhalki-Purandungri-Kjejurdari in the east (erstwhile STB-East) and brief work in Keonjhar, Orissa.

This tract had been explored and observations recorded in the period from Sep. 1964 upto Oct. 1967 and May 1989. Myself and my batch-mate Shri Ehsan Ullah Khan were born (Sept-1964) together in AMD and reported to Shri S.N. Singh, the Mines Manager cum Mining Geologist In charge, at Bhatin Mines, after a brief orientation at Sundernagar (near Tatanagar), the STB-head office by the then boss Shri Y.N. Rama Rao.

Shri Singh had trained both of us, how to carry out the underground mapping at Bhatin Mines with plotting of the mandatory features like variable lithologic contacts, faults and fractures, alterations, and visible significant metallic or nonmetallic minerals, if any, in both adit as well as in drive followed by 'Plain Table' mapping on surface across the radioactive outcrops around the mines. AMD Scientists, Shri K. Krishnanunni (Ex-Director General, GSI) and Shri Prakash K. Shrivastava (presently a professional Mining Geologist in Australia), one-year seniors were also associated with us while carrying out Plain Table mapping guiding how to trace the limits of the outcrops of the radioactive zone and map. This was my first assignment after joining AMD followed by posting at Pathargora and later in 1967 at Kanyaluka prospect, where I learned mapping using theodolite from Shri R.V. Viswanath.

One day Shri Krishnanunni accompanied us and helped both Khan and me opening bank account at State Bank of India, Jamshedpur by crediting Rs. 100/- to each account on our behalf and he never accepted the repay in his lifetime from either of us. I do acknowledge the friendly gesture of Shri Krishnanunni throughout my life. The face value of Rupees One hundred in 1964, I guess would be equivalent to Rupees One hundred thousand at present time.

In course of underground mapping, we located disseminated blue (ink color) metallic mineral (which we suspected as molybdenite) accumulations here and there associated with the 'granular rock' (host-rock containing uranium ores). Shri Singh revisited the location in the drive and confirmed it as molybdenite. He reported this discovery officially to SMG (Shri K.L. Bhola), who in turn reported this to Dr. D.N. Wadia, GA. Later, it became one of the value addition metals in the Bhatin Mines. The molybdenite occurrence was already reported from Jaduguda Mines in past. However, this instance of discovery in Bhatin Mines generated additional interest, which was followed up by profuse discovery and recovery of Mo in Jaduguda Uranium Mines. The rest has been the history.

After the training, I was posted at Pathargora to commence radiometric survey under the guidance of Shri V.G. Shirke, who was camping near Mosabani copper mines and Shri E.U. Khan was posted to Kanyaluka to work under the guidance of Shri G.H. Sahasrabudhe. In first week of December 1964, I was transported in a truck along with an old Kabulpal tent (used by Jhandu Ram the truck driver) with name painted on it and two new small (Schouldari) tents and an old Necessary Tent. Three casual laborers who accompanied the truck helped in erecting the tents in jungle in the outskirts of the village opposite IISCO Pathargora phosphate mining quarters. I was left alone in the tent to spend the night to begin independent professional life the next morning.

My newly married wife who just joined me in the camp after couple of days had to leave for Kolkata on Jan 11th 1965 to attend to registration of a land property. I saw her off in Kolkata bound Ranchi-Howrah express train at Ghatshila station in the mid-night and returned to camp walking 20 km

along with another man (Sharma) an employee of the Pathargora phosphate mines. I carried out field work on 12th and 13th Jan. as usual. The manager of the phosphate mines, Mr. Banerjee, asked me to accompany him to spend 3 holidays of Makar Sankranti (Jan.13, 14, & 15) in Tatanagar. But I declined and preferred to continue at the camp. I spread my mattresses, rugs, and pillows in the sun for the whole day and put them back inside the tent in the evening. My FEA (helper) man, Kalo Zena made one bed which was used by my wife and dumped the rest on the other bed which, usually I used for sleeping.

Kalo and the night patrolling labourer both left for home in the afternoon to celebrate 'TUSHU PARAB' (Makar Sankranti) the most important festival among Santhal tribes. They began drinking, dancing and merry making throughout 13/14 evening till next morning. Thus, I was left alone in the tent miserably missing my wife who had to suddenly leave for home.

On 13th around mid-night (~11.30 pm) I woke up from sleep hearing some odd sound, like breaking of crockeries, from my kitchen tent. While lying on the bed inside, I saw my tent shacking vigorously as if someone is pulling the ropes. In the process my tent fell apart opposite my bed placing me uncovered under the sky in freezing cold. I got up in shock with a hit on my back by an uprooted wooden peg and sat over the cot clamping it with both hands. I looked around and found my camp ransacked. Before I could figure out the reason, to my surprise, I discovered an elephant with wounded right knee approaching me slowly limping. Suddenly, it stopped very close to my cot over which I was sitting placing my feet on the ground. I found myself placed between its two long tusks passed by my body and strong pillar like legs and the trunk near my feet. To my good luck it did not lift its trunk and I too did not move my head or body. It was blowing air over the ground around my feet moving the end part of its trunk, guess to avoid ants. I was feeling very uncomfortable with air blows. After standing for nearly 10 seconds or so it back stepped a few meters and started etching its head against a branch of Kendu tree situated in front of me at about 5-6 meters away near the barbed wire fence (which I borrowed from the private mine owner and fenced the camp boundary).

However, it again came charging towards me but passed by my cot and started uprooting again the kitchen tent located behind my living tent, which was standing with the support of one pole after it was damaged initially. Now, I got the opportunity and jumped from my bed and fell on the ground and with another leap crossed over the fence. In the process, I got a deep cut below my hip and fell on the ground over some rubble. As a result, I injured my knees and found my right heels welled and damaged with blood clot. Both shins got severely damaged with deep cuts and wounds. Soil and sand got stuck over the bleeding shin.

I pulled up courage and stood up from the fall and started climbing towards the hillock opposite camp, but I noticed the elephant was chasing me from behind. I jumped into an old test pit and tried to hide inside. The elephant followed me up and stood by the edge of the pit. It was making trumpeting sound with the trunk and beating gigantic ears, which was sounding like bursting crackers. I could see only its forehead and eyes while squatting inside. I presumed and noticed it got very angry for not intercepting 'the moving man (me)'.

While in anger, it was thumping the ground with its huge feet, which led to severe vibration of the ground causing fall of soil and rubbles over my head and body inside the pit. It stood there for about 20 seconds, but I was feeling as if it was 20 years passed by. I cursed myself for hiding in the pit which could turn out to be suicidal!

But to my good luck it moved away from the pit and went back to the camp site and started throwing my belongings including crockeries, books, chairs, and utensils. All grocery items including wheat flour, rice, spices, cooking oil, kerosene oil got spilled over the ground and got mixed up and spoiled. I could hear again the breaking sound of the crockeries while sitting inside the pit. Then, I decided to escape from this location as soon as possible. I climbed up on to the ground and crawled down the hillock putting my chest on the earth

surface and sustained cuts and wounds on the chest and limbs in doing so. On reaching the plain ground, I ran immediately through the foot track joining the unbridled road leading to Pathargora village. I could see the lighting fire and hearing the music and sounds of beating drum. I knew that the folks would be celebrating the festive night with merry making.

While running, I saw on the midway some light coming out through a partly opened door of a mining quarter. I bumped into the room and found the same gentleman (Mishra), who walked back from Ghatshila along with me two nights earlier. I was breathing very fast. I took little time to become normal and narrated the incident. Immediately, both of us came out and again climbed the hillock and threw stones towards the camp site thinking we can drive it away. We noticed the elephant was pulling the barbed wire all around the fence. While doing so it fell over the small bath tent and pulled it up putting over its head like a vale and ran into the forest with poles, pegs and ropes dangling all around its body.

We both came back on the road and saw two men (night watchmen on duty guarding the apatite stacks at the loading site situated next to my camp) approaching the mines quarters. Recognizing Mishra standing on road, they stopped and expressed their concern for the geologist's safety. They could not see me, though I was standing nearby but under the shadow of a tree. They asked Mishra for extending help to rescue the geologist, who might be still breathing after suffering from the elephant attack. Actually, they saw the rogue elephant 'standing over the bed' around the uprooted tent before running away from the duty spot. Listening to their concern, I came forward and they became happy to see me. One of them embraced me while congratulating for being alive after the incident. But he could not separate himself from my body because thick blood clots all over my shirt glued to his cloth. I too realized then that I was bleeding all over my body.

Thereafter, I started feeling pain all through my body and gradually falling unconscious with passing time. One person got me fresh clothes from my partly damaged tin box, which was kept underneath the bed I was sleeping over (that was my wife's bed I was using that night). Later, I discovered that my bed was broken into pieces by the elephant. Mishra gave some first aid by cleaning my wounds with antiseptic (Dettol). By this time the news of elephant attack spread like wild fire in the village. The villagers gradually assembled around my camp with the intension of safeguarding me and the camp.

I scribbled over a small piece of paper to Shri Shirke seeking medical assistance before I fell unconscious. By early morning, I was almost frozen. Kalicharan, my head labourer biked down to Mosabani and delivered the chit to Shirke before dawn. He had a jeep, which he drove immediately and came to Pathargora and located me resting inside Mishra's room. He lifted me and helped sit over the jeep, and drove me down to Mosabani Mines Hospital, where I was operated upon my heel and put several stitches all over my limbs and body. I was made to sleep under medication throughout two days and nights.

Meanwhile, Shirke sent a telegram informing Sr. Boss, Mr. Rama Rao stating, "Elephant attacked camp; Bhattacharya escaped; Come soon". The delivered telegram read "---- Bhattacharya Expired (instead of escaped)". I got up after two days of rest and asked Shirke not to inform my wife. However, Shirke already sent a telegraphic message to my father-in-law before I could wake up. The same afternoon Mr. and Mrs. Rama Rao drove down to Mosabani Camp almost crying and asked to see my body. So, the error in the telegraphic message was immediately explained to them and both were brought down to the hospital near my bed. They consoled me expressing their sympathy and happiness after finding me alive.

A week later I resumed my survey work in the same area living in a small dilapidated broken thatched hut (located nearby previous camp), which I got repaired in my personal capacity.

Uranium Mineralization at Pathargora

At Pathargora, the host-rock containing uranium mineralization is biotite-chlorite schist having variable proportions of apatite and iron oxides complex in addition to two phases of quartz, albite, biotite, chlorite, sericite, tourmaline, fluorite, garnet,

pyrite, and epidote. It is termed as mica schist/ granular rock. Schistosity is not pronounced at most parts of the area, but it shows granular texture often merging with the schistosity throughout the shear zone in STB East. In view of this it was given the name of granular rock by AMD for exploration purpose only.

Classical 'apatite-magnetite (A-M)' assemblage occurs in lenses of different sizes, bands, veins as well as disseminated lumps and unassorted clusters within the above-mentioned host-rocks. Noticeable radioactivity is recorded when apatite distribution ranges around 8% or less in modal proportion (modal analysis) in the host-rock along with iron oxide complex with conspicuous association of albite. However, rest of the albite-rich locations do not record radioactivity unless it fulfills the other two factors mentioned above. There are fine streaks (tens of cm long and tens of mm thick) of cryptocrystalline, dark colored mylonite (trap-shotten?) here and there associated with the schistosity planes of the host rocks particularly near Surda granulite hill.

Laboratory experiments show the following:

Examination of the separated fractions of the mineralized apatite-magnetite bearing schist/ granular rock has been conducted for its magnetic property and radioactivity. The fraction of the iron oxide complex rich in magnetite was found strongly magnetic but poorly radioactive, whereas the remaining portion of the iron oxide fraction rich in martite-maghemite found feebly magnetic or non-magnetic but strongly radioactive. The apatite fraction out of the above matrix does not record any noticeable radioactivity and found to be non-magnetic. The separated chlorite-rich mica mineral fraction shows low radioactivity yet comparably, more than the above-mentioned strongly magnetic portions rich in magnetite. The above study indicates that the radioactivity due to uranium mineralization goes with the non-magnetic fraction of the iron oxide complex associated with the host rocks containing apatite around 8.0% or less and albite. Sericitization is more pronounced as we proceed from Bhatin eastwards up to Kanyaluka and again becomes rich in biotite and chlorite with subordinate sericite in the areas further east of Kanyaluka in Purandungri-Khejurdhari tract.

In 1964, after the end of the International Geological Congress (IGC), Prof. Arribas of Spain and Dr. Gabbleman of USA visited the abandoned phosphate mines at Pathargora. It was noticed that the chlorite-rich concave side of the lenticular pockets showed glossy-shining (as if brushed with colourless plastic paint) surface wherever it was exposed after the removal of the apatite magnetite lenses from the pocket. The reason of shining could not be understood at that point of time. Two decades later (1984), I discussed this point with Dr. N.K. Rao of ODS (a doctorate on Singhbhum uranium deposits). He opined that it could be the emplacement of PGE group of elements on the paleo-surfaces prior to or simultaneous to the emplacement of apatite-magnetite. In continuation he informed that 'the paleosol surface of Dhanjori conglomerate from the ore zone at Jaduguda Mines analyzed very high values of PGE'.

The metasedimentary assemblages including Dhanjori and Singhbhum Groups of rocks show the signatures of retrograde metamorphism into the chlorite zone of the green schist facies all through STB-East. Copper sulphide ores at Dhobani mines are hosted by the metamorphosed mafic/altered ultramafic rocks showing both massive as well as schistose structure, which is in the southeast of Pathargora copper mines where the sulphide ores are hosted by apatite-magnetite-bearing, chlorite-rich schist and granular rock.

Pathargora-Dhobani range merges further southwards with the hill chain occupied with mica schists, granular rock, basaltic meta-tuffs/mafic rocks extending further south occupying higher mountain chain covered with thick forest, locally called Duma Pahar. Two small floats of rolled boulders of basaltic meta-tuffs recoded radioactivity at Duma Pahar hill flank in a 3rd order periodic dry stream. It looked like same as the radioactive meta-basic schistose rock that was discovered much later in1980s at Jublatola. Outcrops of these radioactive boulders could not be traced after limited input and effort was suspended since seniors assigned lowest priority to such mafic rock targets.

Underground Channel sampling in Surda copper mines

I identified few bands of radioactivity due to uranium, extending up to few unit meters in the footwall copper lode zone in the underground level (~150 m depth) at Surda copper mines, by carrying out channel sampling and radiometric assay. Petrographic study including reflected light microscopy conducted during recess at Eastern Region, Kolkata on the samples collected from this zone revealed the following inference:

Two phases of uranium mineralization were noted in association with copper sulphide deposit at Surda mines. First phase - uraninite occurs as inclusion within sulphide mineral, or it occurs at the intergranular boundaries of the sulphides or encircled by the sulphide mineral assemblage. Second phase - copper sulphide ore mineral (mainly chalcopyrite) occurs as inclusion within uraninite. That indicates phase-2 uranium was introduced into the system as the remobilized one out of the first phase of uranium simultaneous to the introduction of the copper sulphide mineralization. I did not submit these findings because in those days the Headquarters, New Delhi never encouraged any laboratory work done by a field geologist. The only priority was to 'identify radioactivity' in the assigned targets in rocks, soil or sand.

Deep-seated uranium mineralization

Our AMD physicists (S/Shri Mr. N. Dayal, O.G. Jhingran, Bansal, Hari Shankar, and a few others) routinely detected radioactive spots including high values around 0.10% eU_3O_8 by routine gamma ray borehole logging in several deep boreholes (some >1000 m deep) drilled by Hindustan Copper Company around Mosabani and further southeast around Badia Mines including the intervening area between these two mines. This observation indicates chance of intercepting uranium mineralization at deeper level (already found uranium in deeper level at Jaduguda mines as well as copper mineralization as deep as in 36th level (information as on 1965-66) in Mosabani mines. I suggest the probability of intercepting uranium zone in association with the 'lags' (= Normal Fault zone) at deeper levels as the downthrown counterpart of the footwall ore zone. Thus, it could be visualized that the footwall ores on the surface that pinches out in the third dimension at shallow depths, say around 400±100 m, might be picked up again at depth as concealed ores with shift towards the hangwall side. It is quite likely to find few concealed mineralized bodies associated with lags on the hangwall sides having no surface manifestation in all three areas suggested hereunder.

This could be examined by drilling a couple of deeper series inclined boreholes on the hangwall side at locations say by further 600-750 m plan distance away from the foot wall zones as visualized in Kanyaluka-Bhalki, Bagjata, and Purandungri. This is a positive suggestion for study and reexamination of the mineralized shear zones associated with lags, if any. At Bagjata, there is good amount of fluorite association along with the ore horizon as well as the rest of the host-rock. It is indicative of good flow of brines during the deposition of the sediments, followed by diagenesis and metamorphism and remobilization through convecting super-heated hydrotherms at different phases of the geological processes, which developed the present geological transact.

At Purandungri, the mineralized zone shifts from the apatite-magnetite-bearing host-rock on surface to the less magnetic (martite-maghemite) zone on the footwall side as we go deeper in the third dimension. This is reflected in the borehole cores of the shallow boreholes drilled at Purandungri (1967).

Occurrence of olistoliths and olistostromes

The areas extending from east of Jaduguda up to Surda-Pathargora through Roam-Rakha-Siddheshwar and Kendadih.

Borehole cores of limestone (personal communication with Shri K.D. Agrawal, 1977), massive mafic rocks, apatite-magnetite, conglomerate have been intercepted as isolated foreign bodies within schists/granular rocks during drilling under uranium exploration while penetrating the mineralized host-rocks in Roam-Siddheshwar-Rakha mines and Kendadih areas.

These signatures are the evidence of high energy sedimentation recording the signatures of turbidite with Bouma sequence and seismites reflecting the style of deposition as olistoliths and olistostromes. These are associated with bed forms such as imbrication, slump sediments, convolute bedding, cross-bedding, ripple-drift laminations, and color banding structures. It signifies sedimentation of chaotic mass of heterogeneous materials deposited in slopes of the deep intracratonic, structural basins under severe perturbation of the basement translated through the pre-existing basement faults.

It is visualized that the volume of the terrigenous and volcano-sediments was maximized with ferruginous mud mélange and dissemination of apatite and lumps of apatite-magnetite clusters in this sector. Conspicuous occurrence of the above mentioned olistostromes of heterogeneous compositions including apatite-magnetite are also demarcated in the present sector. The origin of apatite is debatable particularly in the absence of igneous intrusions. It is visualized that the continental weathering and riverine discharges and the volcanic gases including hydrogen fluoride could be the important sources, which delivered both particulate and dissolved phosphates in the basin of sedimentation. The occurrence of lumps of apatite-magnetite olistostrom indicates its pre-existence in the provenance prior to deposition of the sediments. More evidences supporting the above observation could be observed in this tract.

Outcrop of bizarre shaped Dhanjori conglomerate grading into the schist around Bhatin mines possibly belongs to the clastic olistostrome origin. Outcrops of huge floats of boulders of kyanite-granulite studded with pockets and veins of lazulite resting on the ground over weathered apatite-magnetite bearing schists at Gohala could be considered of olistostrome origin. It is suggested that originally uranium, and copper were syngenetic which have been remobilized at different stages in more than one geological processes starting from the formation of deep intracratonic, continental, structural basin - the rhombochasm within the Singhbhum craton followed by sedimentation.

The metasedimentary assemblages including the windows (inliers) of the associated soda granite bodies forming SSZ were subjected to several types of thermal, tectonic, and metamorphic transformations giving rise to schists grading into granular rocks, quartzites and meta-tuffs/basics. The beddings (S0) including imbrications were transposed into schistosity planes (S0=S1), which were affected in later phases of coaxial cross-folding and fold interference with the development of S2 and S3 cleavages. The S1 planes were reactivated as shears pronouncing reverse faults (thrust) paired with periodic lags (normal faults) giving rise to the present status of the SSZ. Many hardrock geologists have mapped the ripple-drift laminated beddings as crenulation cleavage (S3) and the bends associated with it as pucker b-lineation (L2). This aspect can be reexamined at selected locations to revise the basic concept for application into renewed uranium exploration.

Soda granite

The elongated 'soda granite' is outcropping close to the ore horizon in Kanyaluka main block right within the transition zone between silicified biotite-chlorite-albite-sericite schist and the garnetiferous mica schist on the footwall side. In my opinion, it is one of the 'tonalite-trondhjemite' clans of oldest basement-granite rocks belonging to the Singhbhum craton. This part came into being in the present space as tectonically elevated body emplaced juxtaposed overlying metasedimentary host-rocks due to structural slicing and crustal shortening during reactivation under collisional tectonics.

The shear zone rocks along with the soda granites were subjected to repeated flushing over multiple times by the deep-seated, hot brines as well as convecting super-heated steam within the prism under the reactivation regime. Fluorite and tourmaline along with the mobilized uranium and copper occurring in association of other granular and platy minerals as discussed above could be the contribution of the brines and super-heated steams. The flushed soda granite could have introduced albite into the host-rocks which is suggestive of partial feldspathization due to metasomatic transformation.

Selenium Enrichment

A set of selected radioactive as well non-radioactive borehole (drilled by AMD) cores from the hangwall and footwall zones were collected from the Core Library, which was situated at Ghatshila and subjected to multi-elemental analysis including selenium. The sampled areas represented the entire STB-East and STB-West including the copper mines areas around Mosabani, Surda, Badia and all AMD prospects namely Kanyaluka, Khejurdari, Bagjata, Bhatin, Narwapahar, Roam-Rakha and several prospects explored in the STB-West. It was noticed that the core samples analyzed high values of selenium particularly containing copper sulphides both within radioactive and non-radioactive zones.

The AMD scientist Shri H.M. Verma [personal communication] as Incharge of the Core Library had organized this R&D work. He was denied any further work in this direction with the remark: "AMD has to focus on uranium-related information and not selenium". The Chief Engineer of the Electrolysis Plant of Hindustan Copper Co. [located near Ghatshila at Maubhandar] somehow came to know about this information of high-valued selenium association with copper sulphide ores. Thereafter, Hindustan Copper Co. commenced extracting pure selenium out of the ores along with the extraction of copper through electrolysis. Selenium became another value addition (pure metal 'selenium' of Hindustan Copper Co.) in addition to copper.

The association of enriched selenium could be applied and postulated as a sure signature of the sedimentary origin of copper and the associated uranium along with iron oxides are suggestive of being initially deposited as low temperature high energy sediments. However, there are many other additional signatures recorded in SSZ rocks by various geologists supporting the characteristic sedimentary origin of uranium as well as copper and phosphates. This information negates the possibility of any kind of magmatic intrusion generated hydrothermal system in SSZ. There are main signatures of the mineralized zones:

- Apatite-magnetite (A-M) phosphate, uranium, and copper (sulphide) mineralized zones.
- Apatite-magnetite (A-M) load, irrespective of uranium association, runs generally on the footwall side throughout the width of the shear zone in most part of STB-East with the following variations.
- At Bhatin, A-M repeats on the hangwall side also in the form of granular rock in addition to its presence in the footwalls.
- At Jaduguda, it is not present as a separate zone, but conspicuously associated with U-mineralization as well as non-radioactive zones in the form of granular rock.

Further east of Jaduguda in Roam-Rakha - Siddeshwar -Kasidih-Somaidih-Chirudih and at Pathargora, the A-M occures as pronounced phosphate-ore zone mostly on the footwall side of the U-zone. It also reappears as narrow mineralized phosphate zones on the hangwall side further east of Pathargora. A-M zone displays its presence in the hangwall side of the copper mineralization at Surda, Pathargora tract. The uranium mineralization zone merges with the A-M zone in this sector. A classic example being uranium bearing 'granulite hill' situated in the west of Pathargora and east of Surda. Further eastwards, the A-M zone becomes sporadic in areas around Dhobani, Mosabani and Badia copper mines. The copper enrichment is maximum in tenor and grade in this sector in the entire STB. A-M zones gradually appear in conspicuous association with the uranium mineralization at Bagjata, Gohala and Northern part of Kanyaluka. Copper mineralization is insignificant in this sector. Further east of Kanyaluka the A-M appears as wider and repetitive zones conspicuously in Purandungri and Khejurdari (Dhantuppa). Here the A-M is invariably associated with uranium mineralization with missing identity of copper mineralization.

Uranium zone also contains Y and Th in the form of xenotime and monazite respectively at Kanyaluka north, besides some clusters of thorium bearing placer sands in certain locations further north by about

1500 m away in the hangwall side of Pathargora mineralization and in the north of Purnapani Nala and Badia mines. These sands must have been derived out of erosion of the surface rocks exposed to weathering agencies and transported through the running waters and left behind as fossil sands by the meandering Subarnarekha River and its tributaries. In view of the above signatures as discussed above the SSZ is postulated comparable to the IOCG type of activation and mineralization.

Keonjhar-Orissa

I also discovered (1967-68) radioactive monazite-bearing river placer sand in the meandered bed of a 4th order stream at village Mankerbera draining the Precambrian granite-gneiss complex making the periphery of Orissa craton in Keonjhar. After exploration it may turn out to become another 'Siri River' type of Rare Earth placer deposit.

Various uranium mineralization and deposits of India - a study

Diwakar Singh

(Former Deputy Regional Director, North Eastern Region, Shillong)

Date of Birth: 04.07.1941 *Date of joining AMD: 15.06.1970* *Date of superannuation: 31.07.2001*

Dr. Diwakar Singh obtained M.Sc. (Geology) from Guwahati University, Guwahati, Assam and Ph.D. for the thesis on "Geology of Vindhyans and Son valley, Mirzapur district" from Banaras Hindu University, Varanasi, Uttar Pradesh. He joined AMD in 1970 and has worked in several parts of the country in various capacities. He superannuated as Deputy Regional Director, North Eastern Region in 2001. He has published many research articles in the journals of repute.

I would like to share some of my experiences in the field of geology and in research on uranium mineralization in various parts of India. As a geologist, my first posting was in the eastern coast of Orissa for evaluating the various minerals in the coastal sand. While studying the separated heavy minerals, I observed that simply counting the heavy minerals to assess the percentage of various minerals (grain counting) is not enough in East coast deposits as done in the coastal deposits in Kerala. This is because, in Kerala coast the heavy minerals are equidimensional and derived from Tertiary sediments (Verkalla beds). However, in the Eastern coast the sediments are first cycle heavies, derived from Precambrian rocks, that have retained their original shape and size. The heavies in East coast are therefore, inequidimensional and were considered as length and breadth divided by two for area counting. After convincing my colleagues, it reduced the number of sieves resulting in less consumption of bromoform. It was tallied with chemical analysis, which was also appreciated by an Australian geologist, who visited the Berhampore office. This made me more confident towards my personal view to understand geology of the area to further generate genetic models.

My first posting for uranium investigations was at Gomaghat in East Khasi Hills, Meghalaya. Here, the investigation was going on to explore the uraniferous coaly chunks spread in thick (90 m) pile of Cretaceous Lower Mahadek conglomerate over the Precambrian granite basement and Jurassic Sylhet Traps. Two E-W parallel faults created a trough fault. Sedimentation and turbulence deposited glauconitic sandstone over conglomerate, which could cross the southern ridge of the fault. Drilling in Tarangblog and Pdengshakap areas indicated radioactivity in few boreholes, but without correlatable band. My second posting was at Gomaghat south of Jadukata River in West Khasi hills district.

Before examining the uranium mineralization, let us know the development of Mahadek Formation (Upper Cretaceous). It started as fluvial sediments for a short period, where the algal matter was distributed in some places, and coaly matter as reducing agent. This is overlain by oxidized purple Upper Mahadek due to sudden development of trough fault as in East Khasi Hills, having a thickness of nearly 90 m in Gomaghat. Due to oxidized Mahadek sediments, the soluble hexavalent uranium moved downward and preciptated in the lower part of fluvial channel, where the sandstone show reducing condition (sandstone with coaly matter). Drilling done in Gomaghat area did not show satisfactory uranium concentration.

With the ongoing investigations in the northern part of Plateau region, significant radioactivity was located at Satiknala, north of Gomaghat also designated as Mahadak sediments. Drilling, here also did not reveal desired uranium mineralisation. As you look north of Gomaghat i.e., northern portion of trough fault, Sylhet Traps (Jurassic) are overlain by reduced thick sediments of Jadukata

Formation (Early Cretaceous) embedded with carbonized woody fragments along with a resinate mineral (gum product, a resin), a product of pine trees in hot and dry climate.

In fact all the uranium deposits in Plateau area overlying the fertile granite are hosted by Jadukata sediments, which have lots of carbonaceous traces and stromatolite. The mineralization is retained by sediments deposited in low-lying areas or within depression in the basement. The process of uranium mineralization is by syn-diagenetic process or calcrete mode i.e. upwelling of mineralizing solution accumulated in these two underlying basement series rocks. Jadukata sediments already had carbonized algal matters, which acted as reducing agent and deposited uranium in stratified form which is also proved by drilling. In calcretes, the upwelling uraniferous hexavalent uranium is captured during their formation in hot arid climate. Since I have visited Tiniang & Kulang drilling areas, I have seen the granites exposed at the bank of Jadukata River and these deposits are within the depression in the granitic basement.

In the Himalayan foothills of NW states, survey/ exploration were going on along with drilling in Hamirpur district of Himachal Pradesh, and it reached upto mining stage at Andalada. We could succeed to get appreciable uranium mineralization at depth but due to some problem, mining activity was stopped. I studied the Sibbal Nala section, where upwelling water deposited secondary uranium. When the stagnancy stage was seen in the nala section, it was suggested that after diverting nala by making wall, the mining activities could be initiated.

Let us know depositional environment and various factors involved for uranium mineralization in Siwalik belt of NW Himalayan foothills. The Siwalik sedimentation as Lower Siwalik before Teritary orogeny created a wide shallow trough at foothills. The rivers flowing north originated from Indian plateau deposited deltaic sediments. The deposits show alteration of silt and sandy sediments. The colour difference as reddish brown fine siltstone and grey sandstone can be clearly demarcated. The orogenic pulses caused E-W slump faults from Jammu & Kashmir upto Uttar Pradesh along Himalayan foothills. Thus, these faults (upto 400 km referred in various literature) became suitable conduits for uranium, expelled above due to compaction, and upcoming hydrocarbon gases. This soluble uranium got deposited along a narrow fence, as observed by high spotty uranium concentration (up 0.2 % eU_3O_8). This zone can be marked by convolute folding and red chilling spot. This type of hydrocarbon gases are still coming up as seen at Jwala Devi temple as burning flames on the western bank of Satluj river in Himachal Pradesh. Drilling by ONGC to search for reserves of hydrocarbon gases could not prove fruitful.

Drilling undertaken by AMD on western bank of Beas River in Jammu & Kashmir could not prove depth wise concentration inspite of high uranium values recorded on surface samples.

The Middle Siwalik gray sandstones began to deposit, after peneplanation of basin, as fluvial sediments in a braided river system in semiarid climtae in several water logged areas. This also caused luxuriant growth of algal matter, which after burial got carbonized. The seasonal variation brought such carbonized zones at different levels causing reducing environment as seen by gray colouration in entire thickness of Middle Siwalik. The Upper Siwalik began with deposition of conglomerates. Further, the orogeny created folds and faults. The carbonaceous matter got filtered through porous zones within the sandstone and logged as perched bodies as seen at Khya and various localities in Hamirpur district. The drilling operation in Khya area did not show any depth continuation. At Andalada, south of Hamirpur, the drilling revealed continuation of appreciable uranium mineralization dip wise. The mining activities also indicated good mineralization depth wise, but due to legal problems the mining activity was stopped. The investigation went further at Jawar area, where core sample analyzed upto 0.4 % eU_3O_8 upto 12 m, but further could not be drilled down dip due to pebble conglomerat as over burden. Similarly, the drilling activity further east along the contact of Upper Siwalik

with the Middle Siwalik has faced the same drilling problem. So from the study of various areas in the Middle Siwalk exploration, it is found that U-mineralisation must have brought the stagnancy just below the permanent water table, where further migration is not possible.

Here, I have to mention about the Colarado uranium mineralization which has long down dip migration and accretion called roll type of uranium mineralization.

Uranium mineralization along the fault zones

First we must understand that any U-mineralization needs a conduit to form a deposit. The lithological conduits are already mentioned. Similarly, fault zone is also equally important. It has been seen that normal fault in the fertile granite or black shale may not provide a deposit for which the conduits must have periodically tectonic pulses for downward migration & concentration. The reducing agents are carbonaceous matter, if present in host-rock overlying black shales or the fault is created in basic host-rock as seen in Proterozoic rocks, where the reducing environment was created by ferrous iron.

Let us take a simple example of Cuddapah, which I have visited as team member. The Cuddapah rocks are earlier folded suggesting an orogenic event. It is also to analyze, how the mineralization took place in the overlying host-rock. The provenance areas had higher elevation to provide sediment by river originating from them to the depositional basins. During non-depositional period, chemical precipitation provided the rocks such as limestone / dolomite and shale, which were deposited as fine sediments with algal activity to provide carbonaceous matter after burial. Even the carbonate may provide algal stromatolite. In Cuddapah area, the Nallamalai orogeny created slip faults as seen in Tummlapalle area. Uranium was leached by acidic solution provided by silicic and phosphoric acids during hot arid climate. The dip slip faults could not provide a better conduit because the host rock was chemically sensitive. The reducing carbonaceous matter is provided by overlying black shale and ingrown stromatolite and algal matter.

The uranium mineralization in Himalayan Kashapat area is hosted by basic rock conduits where uranium was reduced by ferrous iron. Similarly, in the STB uranium deposits, frequent orogenic pulses created complexity.

Other anomalous environments

After studying various types of uranium mineralization in different parts of India, I could generate genetic models to search U-mineralization, in different geological settings as discussed. The desert of Rajasthan is suitable for calcrete type mineralization as indicated by water sampling and radon counting. Geophysical survey may help in locating depression suitable for deposition.

Similarly, the Vindhyan rocks having the fertile granite basement may be another future target for search of uranium.

I must thank the Director, Atomic Minerals Division for remembering me after 22 years of retirement. I also thank Shri Dheeraj Pande, a co-member of my team during field survey in Siwaliks, for going through this manuscript.

Fifty years of heavy mineral exploration in India

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Shri S. Krishnan obtained graduation from Annamalai University, Tamil Nadu. He joined AMD in 1967. He has worked in various parts of the country including Beach Sand and Offshore Investigations along the eastern and western coasts of India. He superannuated as Head, Beach Sand and Offshore Investigations Group in August, 2001.

Indian mineral sand industry in general and its exploration and evaluation in particular has come a long way since Schomberg, a German National, discovered monazite in 1909 in the beach sands of erstwhile Travencore State. India is today rightly placed high on the ilmenite and monazite map of the world.

The journey to achieve this was arduous, and every one had to sweat it out in burning hot sand and humid weather. Be it east or west coast or the interior dunes of Tamil Nadu, the rigors and regimentation never changed. It was a dawn to dusk schedule, everyday all through the season. In the laboratory, it was a sort of musical chair and scramble for microscope to complete the sample work before one could proceed on leave.

Beach Sand and Off-shore Investigation Group (BSOI) and its predecessors by other names had a true roller coaster ride throughout the 50 years of its existence. There were times when officers were especially selected and appointed for the crash programmes and at times there was just a token presence catering to day to day work.

The entry of AMD in mineral sands exploration brought along with it systematic exploration and evaluation, which until then was to identify an ore body, mine the rich pockets and if it pays, continue or abandon. Adoption of scientific methods by the Group was responsible for delineation and quantification of heavy mineral reserves of Manavalakurichi and Chavara deposits on the southwestern and western coasts and discovery of Chatrapur sand deposit on the east coast. On completion of crash programme in these deposits and armed with the knowledge gained therein, exploration and evaluation was extended to other parts of Indian coasts.

The surveys helped in identification and delineation of large tracts of potential heavy mineral deposits both along east and west coasts of India. Apart from the shoreline deposits, large spans of reddened dunes of eolian origin, 'Teri Sand', were identified as potential heavy mineral hosts, in parts of Tamil Nadu. Today, the seven major Teri sand deposits contribute bulk of the heavy minerals and ilmenite reserves and resources of the state.

The initial exploration efforts had brought to light ilmenite reserves of 146 million tonnes with other associated economic heavy minerals by 1984. The figure kept accruing over the years. In the olden days the search for placer / heavy mineral was considered as a simple matter of panning. Today, it is a multi-disciplinary activity embracing remote sensing, coastal geomorphology, geophysics, geochemistry, sedimentology, mineral engineering, palaeo-climatology, coastal dynamics and environment.

The technological advancement in mining and milling processes of late seventies caused a revolution in exploration and evaluation and profusely influenced the mineral sand industry in all its spheres. The open-pit mining was replaced by efficient deep drilling, mechanized dredging.

The Conrad Bunka, a manually operated percussion drill unit of varied diameter, was replaced by a partly mechanized Vibro-core and/or dormer drill unit. These helped in the augmentation of our drilling capacity from 9 m per day/per unit in early seventies to 35 m to 40 m per day/per unit, apart from reducing the overall drilling cost. A fully mechanized mounted drill unit, reverse circulatory drill is planned for mineral sand exploration.

The new approach has paid rich dividends and helped in location of palaeo, fossil and off-shore mineral sand deposits in many parts of the world. In India, a number of large heavy mineral deposits viz. Bhavanapadu, Kalingapatnam, Srikurmam and Kakinada deposits on the east coast, eastern extensions of Chavara deposit on the west coast with its depth persistence to 16 m and Teri sand deposits were discovered.

New methods of exploration and evaluation required many new parameters and vast data inputs to achieve optimum mineral recovery. This brought in new analytical processes and procedures that were further accelerated by the availability of modern analytical instruments. A number of modern techniques are available for mineral identification and estimation that have been used at different times. Various methods using physical and optical properties for determination of mineralogy are in vogue. Important among them are Electron Micro Probe, Image analysis system, X-ray diffraction and X-ray fluorescence. These techniques are precise, accurate and be cost effective in the long run.

In times ahead, detailed studies on coastal evolution and ecological balance, origin and genesis of the heavy mineral deposits and environmental studies will have to be carried out for better understanding of the deposits and maintaining the ecological balance.

Having covered most part of the productive coast of Indian sub-continent, the future exploration strategy has to be thought about. Exploration could also be centered around the palaeo-strand lines and beach ridges in various delta zones on the east coast that have given encouraging results in the recent years. Significant heavy mineral concentration akin to beach deposits and within exploitable zones in the continental shelf off Andhra Pradesh, Orissa and Kerala could also form future target areas.

I laid down the office on August 31, 2001, with a heavy heart and deep sense of contentment. The heavy heart is because of the long association of over 31 years with officers and staff, who were more of friends and well wishers than colleagues. The relationship developed, the days and months spent in the field, the raging tempers and the cooling counsel that were part of the life in and out of camp and office will be cherished by me forever. The contentment is because of the enormous reserves of individual heavy minerals proved over the years both from the shoreline and inland eolian deposits that has made the country self-sufficient and self-reliant in these minerals.

My own AMD

R.P. Sinha

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Date of Birth: 11.03.1942 *Date of joining AMD: 23.09.1964* *Date of superannuation: 31.03.2002*

Shri Rajendra Prasad Sinha obtained M.Sc. (Geology) from Patna University, Bihar. He joined AMD in 1964. He has worked in different pegmatite belts of India. He has contributed immensely in fabrication and development of Mobile Field units for collection of columbite-tantalite. He has added new field equipments for xenotime collection from riverine placers. The columbite-tantalite bearing pegmatite deposit in Pandikimal, Jharsuguda district, Odisha, discoverd by him, is still under production. He has developed the Drilling Group by adding new modern drilling rigs and borehole survey cameras. As Head Drilling Group, he initiated contract drilling operations by private drilling operators with DTH rigs. He superannuated as Scientific Officer-G and Head, Drilling and RMRE Investigations in March 2002.

My journey in AMD started from Narwapahar Uranium prospect on 23.09.1964 and ended at Hyderabad Headquarters on 31.03.2002. The 38 years of eventful story of my association with AMD in field operations as well as in laboratory cannot be put in just few lines.

I joined AMD in formative years of young AMD and had a proud privilege to work with 10 Directors including Dr. D.N. Wadia. In my subsequent years in the Division, I got the opportunity to work at Singhbhum Thrust Belt, where I understood various aspects of uranium exploration, starting from radiometric survey, drilling and mining. Singhbhum Thrust Belt, known as STB, is the best place for training of the young and new geologists, the place where I also got the opportunity to commence my career. Later, I was associated with Mineral Technology, Rare Metals and Rare Earths Investigations and Drilling Group. Mostly, I was part of many challenging assignments like (i) Leaching of Bhatin Uranium ore in the year 1971; (ii) Survey, exploration and production of Nb-Ta minerals from pegmatite and rare earth minerals – xenotime, from riverine placers.

I worked in three pegmatite belts of India as well as tin and tantalum bearing pegmatite at Bastar and Chhattisgarh. Pandikimal in Jharsuguda district of Odisha was discovered in the fag-end of my survey career and it is still in production.

In the year 1973, there was an increased demand from NFC for Nb-Ta ore. Subsequently, AMD formulated a new strategy of survey and exploration for Nb-Ta in pegmatite and non-pegmatitic sources. Accordingly, the production of columbite-tantalite in pegmatitic gravel by mechanised plant was taken up in Bihar, Karnataka, Madhya Pradesh and Odisha.

In July 1999, the Golden Jubilee year of AMD, a special publication on Rare Metals and Rare Earths pegmatites of India, edited by Sri T. M. Mahadevan and Dr. R. Dhana Raju, was a landmark and unique contribution of RMRE Group.

In 1998, late Shri D.C. Banarjee, erstwhile Director, AMD, also entrusted me with the responsibility of Drilling Group. Drilling is the most necessary tool for mineral exploration and deposit evaluation. I had added 10 latest drilling machines and a new borehole survey camera, to the existing infrastructure to increase drilling output.

A manual was published for the inspection of various drilling equipments under my guidance by drilling officers and was distributed to other geological organizations like GSI, MECL, NMDC and State Geology Department. The manual was appreciated by GSI and MECL.

I had the opportunity to attend many national and international seminars and symposium in connection with rare earths and rare metals, which enriched my knowledge.

I had created a team of young geologists and trained them in all aspects of exploration and production of rare metal and rare earth minerals. This helped in transferring my experience and knowledge to them, for future use of Department.

India is celebrating its 75th year of independence. The government has decided to celebrate this great event as "Azadi ka Amrit Mahotsav" from 15th August 2021 to 15th August 2022. It is my privilege to celebrate my 80th birthday (11.03.1942), during this year. I cherish my association with AMD forever.

Long live AMD.

Looking down the memory lane

Dr. G.R. Udhas interacting with other geoscientists in a Nala section

My journey in AMD

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Shri V.N. Dwivedi obtained M.Sc. (Chemistry) from Udaipur University, Udaipur, Rajasthan. He joined AMD in 1970. He has worked in various Chemistry Laboratories of AMD. He superannuated as Scientific Officer-F and Incharge, Chemistry Laboratory, Central Region in September, 2002.

I joined AMD in the year 1970 at Bangalore after completion of my post-graduation at Udaipur University. Initially I was called as 'Zinc Man' because of my previous working experience at Hindustan Zinc Limited, which produces zinc metal from its ore. I had great pleasure to work with AMD for more than 32 years at different chemistry laboratories located at Bangalore, Hyderabad, New Delhi, Shillong and Nagpur. During my journey, I was mostly involved in analysis of hydro-geochemical samples for major cations and anions, different rock samples for whole rock analysis; determination of uranium by both classical and instrumental analytical techniques; mineral samples such as beryl, barite etc. for major elemental analysis.

As a coordinator, I was also involved in the deployment of mobile geochemical laboratory at different field areas of Northeastern Region, Central Region for quick analytical feedback to geochemists for identification of concealed uranium deposits. I got the opportunity for commissioning of first Atomic Absorption Spectrometer (AAS) at Chemistry laboratory, New Delhi which facilitated the determination of trace elements and enhanced the analytical output of the laboratory exponentially.

As an Incharge of Chemistry Laboratory, Nagpur, I took the responsibility of guiding chemists as well as organizing technical discussions through questionnaire for enhancement of their scientific temperament.

As an experienced chemist in the field of classical methods of chemical analysis, the challenging task was to maintain healthy competition among the chemists having exposure to instrumental methods of chemical analysis. In this respect, I learned a lot from late Shri B.N. Tikoo in scientific knowledge as well as in personal life, being a neighbour to him.

Be Active and Be Alert! I have given an equal importance to spiritual activity along with scientific temperament and followed two sutras given by my guru. The two sutras are (1) HOPE (Harnessing of Personal Efforts) for gaining; and (2) 'Be Alert' is where no harm by self or others, which tells the way of life one should live.

During working, I came across several occasions which were overcome by implementing 'Addition by Subtraction' that involves addition or gain of knowledge by subtracting negative approach.

I take this opportunity to request the AMD management for providing opportunity to analytical chemists for exposure in the field of exploration and exploitation and mining of atomic minerals.

Since the creation of AMD as 'Rare Minerals Survey Unit' in the year of 1949, it involved in exploration of atomic minerals for successful implementation of three-stage nuclear power programme which makes India self reliant (Atma Nirbhar) in atomic mineral resources.

I take this opportunity to wish AMD all success and growth to newer heights.

Reminiscences, contributions and suggestions from my 30 years of service in Atomic Minerals Directorate for Exploration and Research

R. Dhana Raju

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Dr. Dhana Raju obtained M.Sc. (Geology) and Ph.D. from Andhra University, Visakhapatnam, Andhra Pradesh. He joined AMD in 1973. He has been the recipient of the: (i) Geological, Mining and Metallurgical Society's Medal - 1974; (ii) National Mineral Award (Mineral Exploration) of the Govt. of India - 2002; (iii) S. Narayanaswamy Award in Economic Geology - 2002 by the Geological Society of India, Bengaluru; (iv) Prof. P.R.J. Naidu Gold Medal - 2003 by the Mineralogical Society of India, Mysore; (v) Bharat Excellence Award -2011 by the Friendship Forum of India, New Delhi; (vi) International Biographical Centre's (IBC, Cambridge, England) 'Leading Scientists of the World-2012' and IBC's Man of the Year (World Leader of the Sciences) for 2018; and (vii) International Scientist Award on Engineering, Science and Medicine, and the Lifetime Achievement Award by the VDGOOD Professional Association, India - February, 2021. He has published 174 articles/papers in the national and international journals.

He superannuated as Associate Director in December , 2002.

My reminiscences, contributions, and suggestions from my service in the Atomic Minerals Directorate for Exploration and Research (AMD) during the period 13.04.1973-31.12.2002, are briefly presented in this communication.

Reminiscences and Contributions

(i) Transition from Academic to Professional Service: I had started my professional service in AMD from April 13,1973 by reporting to late Dr. K.B. Rao, the then OIC-BSOI, Berhampur, Odisha, after my nearly 10 years academic work in the Department of Geology, Andhra University, Visakhapatnam, during which period I got my M.Sc. (1965, as a student of late Prof. C.S. Pitchamuthu), Ph.D. (in 1970, under the guidance of late Prof. J.S.R. Krishna Rao), fellowships of UGC and CSIR, and CSIR-Pool Officer post, besides 11 publications. After getting trained in the BSOI, I worked on the survey-drilling-sampling-mineral-analysis-resource evaluation of beach sand heavy minerals (ilmenite, rutile, zircon, garnet, sillimanite, monazite etc.) in the coastal mineral sand deposits of Odisha and Andhra Pradesh, besides measuring sea-level changes for 1year in a part of the Gopalpur coast.

Contributions: (a) Bringing to light notable BSM resources in the dune/beach sand deposit of Nizampatnam with positive correlation of the content of magnetite with that of total heavy minerals, ilmenite and pyriboles; (b) Demonstrating the minimum number of mineral grains as 200 and 300, respectively, in each of the 7 magnetic/non-magnetic fractions of sand samples for resource evolution of BSM deposits; (c) arriving at net marine accretion/regression in 1 year at Gopalpur (a, b and c, respectively, with late M/s. B.K. Setty/D.N. Rama Rao/A.S. Siddique); and (d) mineral analysis of ~20 mineral sand samples (12-14 fractions in each) per month.

(ii) Work in the Andaman Islands (1975-78): With late Shri B.S. Negi and Shri T.N. Parthasarathy as Incharges, I have carried out radiometric survey in parts of a few Andaman islands viz. South/Middle/North Andaman, Baratang, Havelock and Neil.

Contributions: (a) Reporting the Tertiary layered complex in the Chauldari area, South Andaman island comprising rocks of the anorthositic suite and serpentinized garnet-peridotite, containing pyrrhotite, pentlandite (first time reported), along with the other already known sulphides and oxides; (b) Petrography of the ophiolite suite of rocks (with late Mr. Negi); (c) Helium-bearing (13-180 ppm) gas from the mud-volcanoes of the Andaman Islands (Baratang and North Andaman Islands); and (d) reporting ultrafine 'platinum' from an altered basalt, permeated by serpentine (with late Mr. S.N. Aurora).

(iii) Transfer from Field Investigations to the Headquarters Petrology Lab., Hyderabad (1979-89): Due to my severe heart-problem and consequent hospitalization in Calcutta during the 1978 recess, late Mr. A.C. Saraswat, the then OIC, Eastern Region immensely helped me and my family, for which I have life-long gratitude to him. On his recommendation, late Dr. G.R. Udas, the then Director transferred me to the Petrology Lab., Headquarters, where I got acquainted with the petrographical investigations from late Mr. B.N.V. Raju, I/c and other colleagues (late M/s. S.G. Vasudeva, S.N. Aurora and K. Suryanarayana, and Dr. Dipica Mookheerjee).

Contributions: (a) Petrographical characterization of the uranium ores from different types of U-occurrences/ prospects/ deposits, e.g., Tummalapalle, A.P.; Pdengshakap-Gomaghat-Domiasat, Meghalaya; Jublatola-Turamdih-Narwapahar-Mohuldih in the Singhbhum shear zone, Jharkhand etc., of diverse geological domains in India; (b) Introduction of polished thin-sections for simultaneous microscopic study under transmitted and reflected light; (c) Imparted training in 'Petrographic studies on 'Radioactive Ores' to a few petrologists and trainee scientists of AMD, and a few scientists from Vietnam, Sudan and Cuba (under Exchange Programmes); (d) Established the usefulness of the technique of Natural Thermo-Luminescence (NTL) on whole-rocks and ores for delineation of U-/Rare Metal-mineralized zones and classification of different metamorphic rock types in a suite from Jublatola (collaboration work with the AMD's TL group); (e) Demonstrated a quick technique, using dentist's micro-drill attached to a microscope, to obtain different generations of pure minerals from rocks and ores for isotopic analysis; (f) Reported for the first time rare ultra-potassic alkali syenite from parts of South Sikkim (with Mr. H.M. Varma and Sikkim party officers), cancrinite, tinguaite, sodalite-phonolite, ferrorhyolite and K-rich trachyte from Nongcharam-Darugiri area in the East Garo Hills district, Meghalaya (collected by Garo Hills party officers), and a fossil-placer, 'Radioactive Cyrtolite-bearing Hematitic Ironstone', with sp. gr. of 4.66 (with Arunachal Pradesh party officers); (g) Renovation-work of AMD's Museum in Hyderabad; and (h) prepared some display boards for the AMD's exhibitions in academic institutes, as part of Public Awareness Programme.

(iv) Work in the Southern Region (SR), Bangalore (1989-98): As the In-charge of Petrology Lab., SR, guided and supervised 5 officers in their petrographic studies on the (a) U-ores/rocks from the SW-, S- and W-parts of both within and in the environs of the Cuddapah basin, including the world-class, rare, large-tonnage, low-grade Si-P-impure dolostone-hosted U-deposit in the Tummalapalle-Giddankivaripalle stretch in Andhra Pradesh, and Gogi U-deposit, Karnataka; (b) RMRE prospects/ occurrences in Tamil Nadu; (c) estimation of minerals in Beach Sand samples from Kerala; and (d) fluid-inclusion studies and S-/C-/O-isotopes. As the Deputy Regional Director, SR from July 1996 to May, 1998, supervised the works of the technical, administrative, accounts, security, engineering & CHSS in SR and assisted Regional Director.

(v) Work as the Head and Associate Director, MPG Group, Hyderabad (May, 1998-Dec. 2002): On transfer from the SR to the AMD Headquarters, first as the 'Head, Mineralogy-Petrology-Geochemistry' (MPG) Group up to Sept. 1999 and then as the Group's Associate Director, supervised and guided (a) The technical and administrative work of the officers and staff in 15 laboratories of the Petrology, X-ray diffraction, Spectrograph, WDXRFS, EMP and Biogeochemistry at both the Headquarters and Regional Centres; (b) Introduced the "Image Analysis System" as an accessory to transmitted-reflected light microscope and (c) Proposed WDXRFS-based rapid, non-toxic and accurate determination of valuable heavy minerals in mineral sands (with officers of Petrology and XRF Labs); (d) Drafted and published AMD's brochure, "Those Who Search – Find" and (e) Edited (along with other co-editors) AMD's EARFAM v.12, 13 and 14.

Brief account of experiences during my formative years in AMD

(i) Participated, as one of the AMD's five trainee-officers - along with Shri Veerabhaskar, Shri D.B. Sen, Shri A.K. Pande and Shri Shah, nominated by late Dr. G.R. Udas, the then Director, together with 10 participants from a few other Asian countries, in the IAEA's field-/laboratory-oriented 2-month Training Course on "U-Th Prospecting and Ore Evaluation", conducted by AMD during Nov.-Dec., 1974, in its

different operating areas, which helped us to get comprehensive training in exploration for atomic minerals. As instructed by Dr. Udas, I had reviewed all the lecture-notes of trainers and submitted my reports to him; (ii) From late Mr. Negi, learnt different aspects of the field-work during traverses mainly along nalas and on outcrops of the ophiolite suite of rocks in the Andaman Islands; (iii) From late Mr. S.N. Aurora, learnt the measurement of quantitative parameters (% R, VHN) of ore minerals in reflected light microscopy; (iv) Visualized by late Mr. A.C. Saraswat, the then Director, participated in 3 working-groups comprising field-/laboratory-based geologists for jointly investigating potential uraniferous areas in Meghalaya and Arunachal Pradesh and drafted their reports; mentored the officer & staff of Petrology Lab., NER; (v) On my two foreign visits in 1988, viz. China (for presentation of a paper at an International Symposium and chairing one of the sessions, followed by field-visit) and France (1-month long studies visits to COGEMA Petrology Lab. at Razes on diverse types of U-ores and other plants and laboratories of CREGU and CRPG).

Laboratory Facilities under the MPG Group, available during my tenure in AMD

(i) Petrology Laboratory: (a) Rock/slab/drill-core cutting, preparation of thin-/polished thin-sections and polished slabs for microscopic study under trinocular/binocular transmitted and reflected light for petrographic characterization of rock and ore samples, including rock-nomenclature, and doubly polished ~ 0.5 mm thick sections for fluid-inclusion study, besides preparation of specimens for museum; (b) Sieving, magnetic separation and mechanical analysis of sand samples for sedimentological studies; (c) Radioluxography (RLX) and Cellulose Nitrate (CN) film study to locate radioactive minerals in thin/polished-thin sections and polished slabs and relative radioactivity of different U/Th minerals; (d) Chromogram study for determining leachable/refractory nature of radioactive minerals; (e) Staining for feldspars and carbonate minerals; (f) Dentist's micro-drill for obtaining pure mineral-powders of ore and gangue minerals from polished slabs for stable- and radio-isotopic studies; (g) Modal analysis of rock/ore samples by point counting; (h) Mineral separation using heavy liquids and isodynamic separator; (i) Determination of percentage reflectivity (% R) and micro-hardness (VHN) of ore minerals under reflected light microscopy; (j) Studies on textures of gangue and ore minerals, including replacements, overgrowths, zoning etc., and weathering and alteration index of rocks; (k) Photo-micro/macro-graphy; (l) Studies using Image Analysis System (IAS); (m) Ascertaining suitability and grouping of rock samples for geochronological study; (n) Determining the nature, roundness, angularity etc., of synthetic diamonds for their suitability for diamond-drilling; and (o) Cathodoluminescence (CL) study.

(ii) X-ray Diffraction (XRD) Laboratory: (a) Mineral separation using heavy liquids and isodynamic separator; (b) Obtaining X-ray diffraction patterns of ore and gangue minerals; (c) Identification of ore (primary and secondary) minerals of U, Th, Nb-Ta, REEs, including oxides, sulphides etc., by comparing their X-ray data with that of international standards; (d) Calculation of unit-cell dimensions of the identified minerals; (e) Determination of triclinicity of feldspars and Anorthite content of plagioclase; (f) Determination of clay minerals; and (g) Confirmation of the identified ore minerals by microscopic study.

(iii) DC-Arc Emission Spectrograph Laboratory: (a) Powdering of rock/mineral samples; (b) Mineral separation using heavy liquids and isodynamic separator; (c) Qualitative scan for identification of elements in powders of rocks and ore/gangue minerals; and (d) Semi-quantitative and quantitative estimation of elements in the powders of rocks and ore/gangue minerals.

(iv) WDXRFS Laboratory: (a) Ultrafine powdering of rock and mineral samples and making their pellets; (b) Qualitative scan on the pellets of rocks and ore/gangue minerals to know the relative concentration of elements; and (c) Whole-rock analysis in terms of the major, minor and trace elements/oxides on the pellets of rock/ore/gangue mineral samples and comparing their data with that of the appropriate geo-standards.

(v) Electron Micro Probe (EMP) Laboratory: (a) Preparation of carbon-coated polished mounts/thin sections of rock/ore samples for the EMP study; (b) Microscopic study of the prepared samples to know the ore and gangue minerals, their textures, alterations

etc., and delineation of ore/gangue minerals of interest for their EMP-based analysis; (c) Back Scattered Electron (BSE) and X-ray imaging for identification of ore and gangue minerals in the delineated areas and also for observing relative concentration of elements at different points in them; (d) Ore/gangue mineral analysis at different points in the delineated areas for major, minor and trace element contents, using appropriate spectrometers, crystals and standards; and (e) Estimation of the chemical ages of U-Th minerals, based on their contents of U, Th and Pb.

(vi) Bio-geochemistry Laboratory: Bio-leaching experiments on U and associated metals in U-ores to probe their degree of leachability under different experimental conditions, etc.

Experiences while carrying out exploration/ analysis etc.

(i) Starting of the fluid-inclusion study in the Petrology Laboratories at Hyderabad and Bangalore, after getting trained by Prof. C. Srikantappa of the University of Mysore; and (ii) Collaborative R&D work with (a) BARC, for the first time, on the Electron Micro Probe (EMP) determinations of U-Th-Pb in U-ores from different deposits/prospects in India and calculation of their chemical ages, with initiation by Mr. T.M. Mahadevan, the then Deputy Director; (b) IGCAR for the determination of platinum in a rare REE-Th-Zr-Ti-rich tremolite-actinolite rock from Vattalakki, Kerala; and (c) NPL, Ahmedabad for the oxygen and carbon isotopic studies on the U-ore samples from Tummalapalle, as per the suggestions of late Dr. S. Viswanathan, the then Director; and publishing papers together with the concerned officers of the above organizations on the results of the above studies.

Others: (i) Guided 7 officers of AMD for their PhDs; (ii) Adjudicator for a few PhD theses in Geology of the Andhra and Osmania Universities; (iii) Recipient of the 'Geological, Mining and Metallurgical Society of India, Calcutta for the "best paper" (1974) and 'National Mineral and S. Narayanaswamy Awards' (2002); (iv) Former Member, DST's 'Deep Continental Studies' (DCS) Committee'; (v) Former Member, Research Advisory Committee (RAC), Wadia Institute of Himalayan Geology, Dehradun; (vi) Resource Person of the GSI's Training Institute, Hyderabad; (vii) Published 92 papers during 1973-2002 (details available on ResearchGate); (viii) Reviewer of 'Research Papers' for 9 Journals; (ix) Delivered 34 presentations and 17 invited-lecturers at different university-departments and academia meetings.

Suggestions for Present Generation of Geoscientists in AMD

(i) Geoscientists joining AMD, after their present 1 year training, should be exposed for the next 10 years to field terrains hosting diverse types of radioactive deposits/prospects as well as different laboratories so as to enable them to understand the entire gamut of AMD's exploration methodology; (ii) During this 10-years period, each geoscientist's interest and expertise in one or two specific branches of geo-exploration should be identified and an opportunity be given to pursue the same afterwards, which helps in maximum contribution to AMD's programmes with interest and dedication and thus, beneficial to both the individual and to AMD; (iii) For important prospects, working-groups comprising both the field and related laboratory geoscientists should collectively work and prepare comprehensive joint reports that will be useful to plan further exploration for their possible conversion into deposits; (iv) CL study on radioactive and carbonate minerals is to be undertaken, after getting trained in a CL-lab; and (v) Value-addition should be included in the final reports of a deposit by identifying and quantifying high-value metals associated with U, as it helps to plan appropriate mineral processing for their extraction along with U.

I sincerely thank for the help, support and encouragement given to me by former Directors and all former colleagues in AMD. Thanks are also due to Dr. D.K. Sinha, Director, AMD, for inviting me to contribute a write-up for the AMD's special volume to be released, commemorating the 75 years of India's Independence under the Azadi ka Amrit Mahotsav of the Government of India.

Golden reminiscences in AMD

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Date of Birth: 01.06.1943 *Date of joining AMD: 31.07.1965* *Date of superannuation: 31.05.2003*

Shri R. Sreehari obtained M.Sc. (Nuclear Physics and Electronics) from Andhra University, Vishakhapatnam, Andhra Pradesh and completed one year training in BARC Training School (8th batch) in 1965. He joined AMD in 1965. He superannuated as Associate Director, Physics Group in May 2003. He received the National Mineral Award by the Ministry of Mines, Government of India for the year 1998 with cash award and a Golden shield. He has published 10 papers in national journals.

I joined AMD at New Delhi on 31st July 1965 from BARC 8th Batch Training School (then AEET) with M.Sc. degree (Nuclear Physics and Electronics) from Andhra University, A.P. I was transferred to Khashmahal Physics laboratory, Jamshedpur in October 1965 and was assigned the borehole drill-core assay for $\%eU_3O_8$ for each 6″ piece of various sizes of BX, HX and NX size core samples from boreholes. The work was routine, therefore I wanted to return to AEET. I wrote an inland letter to Dr. Raja Ramanna, Chairman, AEET stating that the work does not require one year Orientation Course imparting high-standard training in mathematics, reactor engineering, nuclear engineering, solid-state physics and electronics. At the outset he appreciated my apprehension, but wrote on the same letter with a brief note stating that "People have given their lives for the Country and the work could be made interesting by reading a book on 'Probability, Random Variables, and Stochastic Processes' by Anthanasios Papoulis". I took that advice positively.

Late Prof. Dr. D.N. Wadia, Geological Advisor to Government of India visited Khashmahal assisted by his wife during 1966. An employee complained that he did not get the promotion. Dr. Wadia interrogated whether he was getting increments? That person told affirmatively. Dr. Wadia told that the Government was pleased then with him. Promotions do come automatically with dedication as seniors do observe. One can make the given opportunity a grand success by contributing the might. AMD is unique.

During 1950s Physics Group, AMD, had fabricated the first gamma-ray borehole logging system using valves and Geiger Muller (GM) counter for use at Jaduguda mines for the first time for $\%eU_3O_8$ measurement. A bulky Counting Rate Meter (CRM) with a heavy 9V battery housed in a pressure-cooker type container having rubber gasket for moisture-proof for the electronics and a big micro-ammeter for readings corresponding to radioactivity was used. With the availability of transistors, the electronic circuitry became lighter with less power drain facilitating the use of lighter batteries and micro-ammeters. AMD became the only organisation making CRMs for internal use. Shielded probe trench checking for reconnaissance surveys and mine face checking became easier with those lighter CRMs.

Another borehole logging system using GM counter was developed with transistor based high voltage (1000V DC) generation in the logging probe with counting circuitry drawing battery power from surface CRM through a long wire cable. One junior officer asked me in 1966 at Turamdih, how the micro-ammeter recording was correlated to radioactivity. One had to use $\%eU_3O_8$ standard before the borehole/ shielded probe logging was taken up to obtain calibration constant every time. It ($\%eU_3O_8$) does not mean necessarily uranium, but it could be from thorium and/or potassium. Sample analysis only gives true picture about $\%U_3O_8$ content. No natural material that is exactly UO_2 has been found, although some approach $UO_{2.2}$. Naturally U^{4+} is oxidized to U^{6+} (uranyl ion) to a varying extent. As U^{4+} ion is replaced by the smaller U^{6+} ion, extra O ions enter to occupy the interstitial positions. The limit of oxidation

extends to at least $(U^{4+},U^{6+})O_{2.67}$. Hence $(UO_{2.67})$ x $3=U_3O_8$ concept is used.

A borehole of 300m, drilled by Geological Survey of India (GSI) at Turamdih, was the first borehole for AMD for radiometric logging. On a Ganesh pooja day till late in the evening the borehole logging was done by me without any pooja as the radioactivity was continuous along the borehole with <100 to 300 ppm with sporadic high activity which is typical to Turamdih deposit. I had worked for radiometric estimation of core samples for $\%eU_3O_8$, $\%U_3O_8$, $\%ThO_2$ and %K at the Khashmahal Physics laboratory.

I also worked at uranium mines at Narwapahar and Bhatin and at Surda copper mines in East Singhbhum district. At Surda mines, copper is associated with uranium. I was deputed for logging the footwall and hangwall probe holes for $\%eU_3O_8$ in the abandoned 10th level of this mines, where radon and water-filled levels existed without ventilation and water pump facility. From 5th level, I had to go to the 10th level sitting in a trolley, with a helper, hoisted by wire rope in an incline where head clearance was bare minimum. I had completed the work, in a record time, which was pending for many years. I was the Resident Physicist at Bhatin mines during 1975-76 for mine face checking and also footwall and hangwall probe hole logging for $\%eU_3O_8$, by going down on a ladder into the mines, for further rock blasting on the mine face to follow the ore body.

A continuous scintillation gamma ray logging system for estimation of $\%eU_3O_8$ by computation of area under the curve (A) and grade-thickness (GxT) products along the borehole was developed and calibrated in a model borehole with different grades constructed by Physics Group at Jaduguda mines. That logging system with the motorized winch was used in the field areas for uranium exploration programme of AMD. A deep borehole (>1000 m) logging system with the motorized winch was used copiously at Bhatin fault zone and other areas in Singhbhum Thrust Belt.

I was transferred to Instrumentation Group, AMD, Hyderabad, during 1976. During 1975-76, AMD in association with National Remote Sensing Agency (NRSA) was using Beaver aircraft with less floor area with an Airborne Gamma Ray Spectrometer (AGRS) system using scintillation detector volume of 4166cc, 6-channel-analogue recorder and digital magnetic tape recorder (under testing) and a 35-mm strip-film camera. There was major thrust on airborne survey instrumentation when AMD had quoted for Iran airborne surveys. The digital Data Acquisition System (DAS) was to be made in AMD. The foundation stone was laid for 'Make in India', although Iran surveys did not take place. Integrated Circuits (ICs) were tested at that time with a grounded metal wrist belt to avoid static electricity. A single IC was being procured with a sanction at a time.

The design, development and fabrication of the first high sensitivity AGRS system based on Transistor-Transistor Logic (TTL) Integrated Circuits (ICs), in association with late Sri K.B Ingreji, late Sri Narendra Dayal as In-charge, Instrumentation Group and late Sri N.S. Bhalla as Head, Physics Group, was taken up on a top priority basis. Many hours were spent engrossed in fabrication and testing the circuit modules in a rented space/furniture at 3rd floor of Chandralok Complex, Sarojini Devi road, Secunderabad. When the DAS was being tested, Sri Narendra Dayal one day sat up to 11 pm and went home after offering Jilebi and tea. We were continuing the testing. At 2 am next day, the DAS started functioning with the designed specifications. A faulty new 10 micro-farad capacitor in the IC oscillator circuit of DAS was identified for the malfunction. That was the 'Greatest Happy Day' as an instrumentation person when the DAS was functioning for the first time. That AGRS system was fully tested by me when Sri K.B. Ingreji fell sick. I had exhibited the system at 64th Science Congress held at Bhubaneswar during the end of 1976. Prime Minister, late Smt. Indira Gandhi, visited the stall with AGRS system and spent considerable time complementing the indigenous efforts made by AMD. Late Sri J.N. Gupta, In-charge, Geochronology Group, also exhibited the Mass Spectrometer of 6/12″ radius of curvature fabricated by AMD.

Indigenously built AGRS system installed in the Dakota aircraft of Air Survey Company, Calcutta crashed on 4th April 1977 at Kavali, Prakasham district, Andhra Pradesh, when airborne survey

operations were being conducted by AMD from Bangalore airbase with late Sri B. Krishnamurthy as In-charge, Airborne Survey operations. On that fateful day, 5 young and dynamic officers of AMD, S/ Shri Prahlada Rao and Asoka Joshi from Geology; K. Viswanathan and Chouhan from Geophysics; Menon from Instrumentation and Wing Commander, Goel and his co-pilot, Sardarji lost their lives. Incidentally, myself and late Shri S.C. Mathur from Physics Group were in the aircraft, on 3rd April 1977, at the same area where heavy clouds with drizzle were seen. The aircraft had to pass through a narrow space between two hill peaks to reach the survey area. On that day we returned to base camp as radiometric surveys did not yield proper results on wet soil. Sri J.G Jadhav from Instrumentation Group went to my residence at Srinagar Colony to inform my family that probably I was not in the air crash as news was flashing on radio sets. Communication gap existed at that time due to lack of telephones /mobile phones. Whenever the aircraft returned to airport after surveys, then only we used to know that all was well. On that day when aircraft did not return to airport, alarm was raised and scientists at the base camp went by road to Kavali to find that there was a big fire-ball in between the two hill peaks covered with clouds. The human remains and aircraft parts were strewn over a kilometer area. High strength aluminum racks fitted with instruments became globules with the intense heat. That was the second air crash in AMD's exploration history. The first air crash took place on 19.06.1960 in a test flight in which Dr. P.K. Ghosh, Director, AMD, died and late Sri N.S. Bhalla, In-charge, Instrumentation Group, New Delhi, escaped with a head injury with deep dent on his skull.

Our consistent efforts resulted in the fabrication of another AGRS system with TTL ICs with advanced features. This AGRS system was exhibited to International Atomic Energy Agency (IAEA) delegates at India International Trade Fair-79 (IITF-79) at New Delhi. Late Sri N.S. Bhalla told me to bring back that delicate AGRS system with scintillation detector packages to Hyderabad. We approached the General Manager (GM) of Railways, New Delhi to give permission to carry the AGRS system by train to Hyderabad. As the equipment weighed about 850 kg, he refused to give permission as the maximum limit was 200 kg. Myself and late Sri N.B. Mathur with big moustache told the GM, Railways, to give the refusal in writing so that he may be held responsible for any possible damage to the Government equipment. Fearing the consequences, GM Railways gave permission. When AP Express train reached the platform at New Delhi railway station, the luggage van was already fully loaded with vegetables and other luggage. After looking at the permission of GM Railways, porters removed the vegetable bags and loaded the AGRS system and stuffed the vegetable bags in between the aluminum racks and thus the equipment reached Hyderabad safely. At the time of need, we have to be tough in rendering the Government duties.

Physics Group, AMD, had constructed 5 gamma ray calibration pads for calibration of AGRS system and scintillometers at Nagpur Civil Airport, which is the only calibration facility in South-East Asia. The calibration pad concentrations are (i) U: 10.9 ppm; (ii) U: 21.7 ppm; (iii) Th: 34.8 ppm; (iv) K: 5.4% and (v) a mixed pad for U, Th and K to obtain Compton scatter coefficients for use in airborne survey data analysis. The effective high sensitivities achieved at low altitude (120m) for identification of geophysical haloes for 50000cc volume of scintillation detector for 4pi geometry (terrestrial radiation) are 1ppm in the presence of 4 ppm of U, 2ppm in the presence of 8 ppm of Th, and 0.2% in the presence of 1% of K. For better counting statistics 8200cc volume of scintillation detector for 2pi geometry (extra-terrestrial radiation: cosmic, aircraft background and radon in the air) was used with bottom shielded with 2.5 cm thick lead. In the later design that 2pi geometry scintillation detector was placed on the 10 cm thick scintillation detector of 4 pi geometry to dispense with the lead shield getting the same high sensitivities during air borne surveys. The calibration pads were used for the calibration of AGRS system of AMD and also for GSI with their imported AGRS system. Natural test strips at Devarakonda, Nalgonda district, Andhra Pradesh, and another at Malharbadi, Bhandara district, Maharashtra were also used to test the AGRS systems. Mandatory morning testing of AGRS system, in the aircraft at the survey air bases,

before survey flights, with U, Th, K and Cesium-137 standards was done. The digital print outs were verified daily in the evening after surveys to release the aircraft for next day's survey.

One day GSI, Bangalore brought their imported SCINTREX AGRS system to Hyderabad stating that the sensitivities of their equipment have gone down and they could not find the reason. After testing, it was found that in one of the detector packages the high voltage circuit was dysfunctional. It was rectified and GSI could obtain the desired sensitivities on Nagpur Calibration Pads.

Another compact high sensitivity AGRS system was designed, developed and fabricated based on Complementary Symmetry Metal Oxide on Semiconductor (CMOS) logic DAS system for installation in the Dakota aircraft with reduced volume, weight and power drain on the 28 V DC supply of the aircraft. These high sensitivity TTL and CMOS AGRS systems were flown over different parts of country at low altitude (120m) covering 4.58 lakh line km for geological mapping for AMD, hydrocarbon exploration for ONGC and environmental monitoring over nuclear sites for NPCIL. These systems were maintained at various airbases during the airborne surveys. When airborne surveys were being conducted from Madurai, one day the U channel was not recorded in the DAS, and expensive operations were grounded. I had to fly to Madurai specially and rectified the problem within short time. At Bhopal airbase, when AGRS system was being tested in the aircraft at 6 am with a 28 V DC battery cart, smoke was suddenly emanating from the battery contact wires below the aircraft which I had rectified. Battery contacts do develop resistance when heavy power is drawn and becomes hot. As Dakota aircraft is no longer available and import of such an AGRS system for a smaller aircraft is cost prohibitive, I took up the responsibility of the design and development of hardware/software for a PC-AGRS system in which latitude and longitude data from Global Positioning System (GPS) and Multi-Channel Analysers (MCAs) having 256 and 64 channels with fast Analog to Digital Conversion (ADC) and First-in-First-Out (FIFO) Random Access Memory (RAM) were recorded. The new PC-AGRS system with reduced volume, weight and power drain was fabricated and calibrated on Nagpur Calibration Pads. That system was installed in a B-200 aircraft to obtain the data on total activity, U, Th, K, total magnetic field and altitude parameters for recording on the hard disk of a Notebook PC /Portable Hard Disk (PHD) instead of bulky magnetic tapes used earlier. That PC-AGRS system was the first of its kind in our country. That endeavour avoided the necessity of import of technology resulting in considerable foreign exchange savings to the Department. That PC-AGRS system was flown over various areas in our country at low altitude for about 30000-line km with excellent results. At Kalvakurti, Mahbubnagar district, Telangana, I also went for airborne survey anomaly identification. There was a high anomaly in the airborne surveys in that area which was not traceable on ground with a scintillometer. After grid line space reduction, a big boulder with high radiation was identified for that anomaly. It was a high thorium containing boulder. I took up with that rich experience for the design, fabrication and calibration of (i) a Notebook PC-based gamma ray spectral borehole logging systems for in-situ ppm level radioactivity measurements using 1x4″ scintillation detector. That system was the first of its kind in our country with a MCA-256 in the logging probe sending digital signals through the wire cable to a Notebook PC on the surface displaying the gamma-ray spectrum and concentrations on the 'Liquid Crystal Display' of the PC. The system was calibrated on 3 Primary Standards at AMD Headquarters, Hyderabad having U: 715 ppm, Th: 745 ppm and K: 4.9% obtaining sensitivities for the radio elements; (ii) a scintillation gamma-ray logging system, using ¾x2″ scintillation detector for ppm-level radioactivity measurements was calibrated on Primary Standards which was used for lithological studies. The logging probe for high activity measurement at Gogi Uranium deposit, Yadgir district was redesigned with a lead shield on the GM counter and recalibrated; (iii) Bulk Uranium Ore Analysers (BUOA) using microcontroller was designed for using at UCIL-Jaduguda and Narwapahar mines, both on the surface and underground levels. The grade of the run of the mine ore brought in with 25 tonne dumpers was computed in-situ and displayed on coloured Light Emitting Diode (LED)

lamps for dump at grade-wise sites; (iv) Moisture-proof CRMs for UCIL at Jaduguda and Narwapahar mines; and (v) Audio-visual Scintillometers, differential spectrometers and radon monitoring systems. Radon on Activated Charcoal (ROAC) and Solid-State Nuclear Tract Detectors (SSNTD) were used to detect radon. Spectrometers were used for Jeep borne surveys to find the $\%eU_3O_8$ along the motorable roads.

Instrumental Neutron Activation Analysis (INAA) system, in a low background room at Headquarters using high purity Germanium co-axial semiconductor detector with an 8K PC-MCA, was used for estimation of elemental concentrations. For geochronological studies on rocks and minerals by Rb-Sr, Sm-Nd and U-Pb methods using fully automated PC based 6-collector Thermal Ionisation Mass Spectrometer-VG354E was procured from VG Isotopes Ltd., UK. I was deputed for training in the system electronics and late Sri J.N. Gupta for operation of that system for a month during 1984 at Winsford, Cheshire, UK. We both visited Institute of Geological Sciences at London and Department of Geology at Oxford University, where similar VG354E were under operation. After a decade of its operation, there was a smoke in the VG 354 system. I was called upon to rectify the problem. On examination it was found that the 10 Ampere supply circuit in the system was burnt. A suitable power supply was designed, fabricated and commissioned into the system.

In 1970s, I went to Kanyaluka drilling camp at Singhbhum district for stock verification. I had to cross the Sankh-nala rivulet by boat. While I was returning, the boat at the rivulet got over loaded and capsized. Locals saved us. That was a scary incident in my life. One day Sri V.K. Bansal did not return to Khashmahal after borehole logging at Kanyaluka. Late Sri Narendra Dayal, Sri J.G. Jadhav, and myself reached Kanyaluka camp along the forest route by an open Jeep at 1 am next day to find that he was asleep in the camp as the driver informed him that the battery of the jeep was getting overcharged. Sri Bansal believed him. We found that the battery charging was normal. He returned in the same jeep.

I wish to remember the following founder-fathers of Physics Group, AMD since its inception - Head, Physics Group: S/Sri late Dr. A.S. Bhatanagar, N.S. Bhalla, Narendra Dayal and S.C. Mathur, Deputy Director (Physics): Late Shri S.G. Tewari; Associate Director: late Sri J.N. Gupta and Sri B.S. Atal; In-charge, Instrumentation Group: S/Sri late Sri K.S. Rao and K.B. Ingreji, In-charge, Khasmahal Physics laboratory: S/Sri late Dr. Lajpath Rai and Yudhishtar Lall. I am grateful to all Directors of AMD including Dr. K.K. Dwivedy and late Sri D.C. Banerjee for their excellent support during my tenure. I became Associate Director (AD), Physics Group on 3 April 1999 and SO-H on 1 August 2000. A 10 milli-Curie Cesium-137 source, procured during 1960s by Physics Group from Isotopes Division, AEET for density logging with a heavy lead shield, was returned to BRIT, Mumbai by me as it was no longer in use. A batch of 10 physicists were recruited by open competition and posted at Regional Physics laboratories and Headquarters, Hyderabad. An 'Orientation Course for Physicists (T-25)' was conducted by me from 10-25 June 2002 for selected Physicists from Regions and Headquarters. 5 lectures by senior scientists from BARC/AERB and 18 more lectures by officers from AMD were arranged. Towards these contributions in the field of physics/geophysics, 'NATIONAL MINERAL AWARD FOR 1998' was conferred upon me on 13th January 2000 at Asoka Hotel, New Delhi, by Prof. Rita Verma, Minister of State for Mines and Minerals, Government of India, with a cash award and a golden shield embossed 'TOWARDS THAT BRILLANT GOAL'. I retired from active service on 31st May 2003.

A small write-up on some of my experiences and reminiscences of AMD

T.A. Dattanarayana
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Date of Birth: 30.10.1943 *Date of joining AMD: 20.10.1971* *Date of superannuation: 31.10.2003*

Shri T.A. Dattanarayana obtained M.Sc. (Geology) from Mysore University, Mysore, Karnataka. He joined AMD in 1971. He has contributed immensely in the Airborne Survey and Remote Sensing Group of AMD, besides working in various parts of the country. He superannuated as Scientific Officer-G and Deputy Regional Director, Souther Region, Bengaluru in October, 2003. He has published about 20 papers in national and international journals.

I Joined AMD on 20.10.1971 at Southern Circle, Bangalore under Mr. H. Nandi, OIC. I worked as Assistant Geologist, Department of Mines and Geology, Government of Karnataka for a brief period, before joining AMD. I was posted to field areas of Mahabubnagar district, Andhra Pradesh (now in Telangana), under Mr. S.R. Tatachar, party In-charge and within a week we proceeded to field to take-up geochemical soil sampling in 300 sq.km area. Later Mr. S.Q. Hoda also joined AMD and he also joined my camp. It was a unique and wonderful experience that year as we had to shift our camps by bullock carts and finally close our camps and shift our tentages to railway station by bullock carts only.

To my surprise, just within a year in October 1972, I was transferred to Beach Sand and Offshore Investigations (BSOI), Trivandrum under Dr. G.P. Rao, OIC. I was assigned work along Tamilnadu coast. Mr. K.K. Dar, Director, AMD, visited 2-3 times at Manavalakurichi Camp.

Just after 3 years, in September 1975, I was transferred to New Delhi, Northern Circle (longest distance). When I received the transfer order by telegram, I was on earned leave at Bangalore, as my wife had come for confinement. In the telegram it was strictly mentioned that my earned leave has been cancelled and Director Dr. G.R. Udas desired that I must report at Delhi on 1st October 1975. Unfortunately, I could not be with my wife when my first son was born. As I was posted at Ghateshwar-Rohil area, Sikar district Rajasthan, I could see my son only after 7 months during recess period.

One of the memorable experiences I would like to mention here that I was given an assignment of investigation in the quartz-pebble conglomerates (QPC) in Aravallis of Udaipur, Rajasthan in the year 1976-77. Dr. D.S. Sharma was our party In-charge. I was camping at a village Chanavda with my wife and 1½ years old son in a tent. One day Dr. D.S. Sharma and Mr. H.R. Nagaraj came to my camp at around 3.00 pm and wanted to take a traverse. We parked our vehicle at one place and started our traverse. Around 5.00 pm our field guide informed us that it is not safe to continue and return to camp. He was very familiar of those forest areas. But Dr. Sharma insisted on continuing the traverse. However, the field guide left for camp, leaving us to our fate. After some time, it was pitch dark and we lost our track roaming in the forest. In the meantime all the three of us got separated and after some time we joined again. Finally, around 1.30-2.00 am in the midnight, we could come to camp dead tired. As my wife was alone with the baby, she got scared. We had to rush our field guide with some villagers with torches to fetch our driver who was waiting alone in the forest. We cannot forget this episode.

Between 1975 and 1983, I got great opportunities to work in various geological environments in Rajasthan, Madhya Pradesh, Uttar Pradesh and Himachal Pradesh. I could locate good radioactivity

at Rohil hills, Ghateshwar and at Andalada, Hamirpur district, Himachal Pradesh. I got good opportunity to work under M/s A.C. Saraswat, G.R. Narayan Das, N.K. Duggal, Dr. D.S. Sharma, Ravi Kaul, Rajendra Singh, B.M. Swarankar and others.

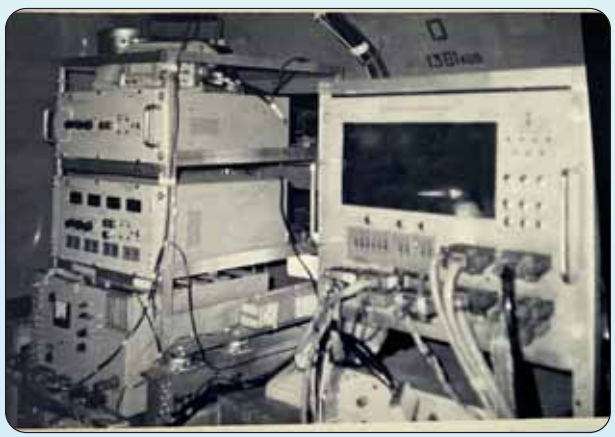
In the year 1982, I underwent training for four months at the Indian Institute of Remote sensing, Dehradun and in the year 1983 on the advice of Shri A.C. Saraswat and Mr. B. Krishna Moorthy, Incharge, ASRS group, I was inducted into Aerial Survey and Remote Sensing (ASRS) group at New Delhi. I was given additional assignment of Liaison work with DGCA, Survey of India and Ministry of Defence in connection with obtaining necessary permits for airborne surveys and procurement of toposheets and aerial photographs. I was also participating in the aerial surveys from different airbases.

In the year 1989, I was transferred to ASRS group, Hyderabad. During my 12 years of stay at Hyderabad, apart from carrying out surveys for our own exploration over different parts of India from different air bases, we have also done low altitude airborne radiometric surveys for ONGC and NRSA on contract basis over very large areas. Some of the favourable areas delineated by us have helped them in their further exploration. For the first time, we have also carried out surveys over MAPS and RAPS to monitor radiation level at various heights over the reactors. This survey has greatly helped the BARC officials in designing their own aerial survey equipments for their future activities.

One memorable incident is worth mentioning while carrying out airborne surveys over Western Ghats from Goa, Navy base. One day while on survey area, suddenly very thick clouds unexpectedly covered the entire area. Pilots immediately contacted nearby air base at Belgaum – Air Force base and requested for emergency landing. Permission was granted and we could land our Dakota Aircraft. After situation improved, we returned to Goa base. At Headquarters, Hyderabad, we got excellent co-operation from S/Shri. S.N. Singh, S.N. Kak, Jagmer Sing, K.K. Dwivedi, D.C. Banerjee and also from members of Physics Group, Geophysics Group and Data processing Group. Without their fullest support, we could not have achieved the desired results.

In the year 2001, I was transferred to Bengaluru, Southern Region. Here, I got very good opportunity to work and guide in different field areas. I retired on 31st October 2003 from active service after serving for nearly 32 years.

From day one of my joining to till the date of my retirement, I thoroughly enjoyed every moment of my journey with fullest co-operation of my seniors and other colleagues. We rarely see such a wonderful atmosphere and brotherhood in any other Government organizations. Wishing AMD to reach to greater heights, and with more discoveries many more tonnages of uranium in the years to come.



Inner view of Dakota Aircraft

My golden years in AMD: scripted by providence through eminent Directors and seniors

P. Krishnamurthy

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Date of Birth: 29.12.1943 *Date of joining AMD: 15.11.1975* *Date of superannuation: 31.12.2003*

Dr. P. Krishnamurthy obtained M.Sc. (Geology) from M.V.M. College, Bhopal, Madhya Pradesh and Ph.D. for the thesis on "Petrological and chemical studies of Deccan trap lavas from western India" from Edinburgh University, Scotland, United Kingdom. Prior to joining AMD, he carried out research in Sagar University. He joined AMD in 1975. He has been the recipient of the Common Wealth Scholarship, UK (1970-1974) and was a Visiting Scientist to the US (Scripps Institute of Oceanography, La Jolla, San Diego in 1984) and USSR (1989 and 1990) under the Indo-US and Indo-USSR programmes on the Deccan and Siberian Traps. He was awarded the Prof. M. R. Srinivasa Rao award for 2002 for outstanding contributions to Igneous Petrology, especially on Deccan Basalts and Carbonatites of India from the Geological Society of India, Bangalore in 2002. He has published 62 articles/papers in national and international journals. He superannuated as Regional Director, Eastern Region, Jamshedpur in December, 2003.

It is a very momentous opportunity to look back at the golden years that I served in AMD from 1975 to 2003 on the occasion of India's 'Amrit Mahotsav', celebrating 75 years of India's Independence.

Joining AMD, a special start

After my return to India in 1974, I served as a CSIR Pool Officer at the Department of Applied Geology, Sagar. I had applied for an SO/SB post in AMD sometime in July. AMD had called for an interview in August, 1975. After completing the interview, I had requested the Interview Committee to protect my grade (SO/SC) of the Pool Officer. CSIR, as I came to know later, also had stressed the point with DAE, so as to encourage Scientists returning to India with suitable positions. DAE and AMD had graciously agreed to my request and I was given the SC-grade, with a basic of Rs. 780/- in the 700-40-1100 scale. Thus my joining AMD on 15th November, 1975 had an interesting background.

Off to Kala Pani, the Andaman Islands as it was known: Radiometric Survey and Helium Investigations in Andaman Islands (FSP 1975-76)

After reaching Port Blair, in December, 1975, I was received by Dr. Dhana Raju, who was part of the Special Investigations. I met Shri B.S. Negi, Officer-in-Charge. He gave my assignments in the South Andaman, largely consisting of radiometric surveys in the ophiolite-melange with flysch-facies sediments with some acid intrusives, which were checked for radioactivity both jointly with other members of the team as well as independent traverses.

Collection of Helium from the mud volcanoes of the Baratong Island, Middle Andaman's, was my first independent assignment.

For want of camping site, I had to request the local school Headmaster, Shri Chatterjee, for some space in the local school. It was Saraswathi Pooja time and the school was full with students comprising both Bengali and Tamil speaking students, their parents being refugees from Burma and Ceylon (Sri Lanka) settled in Andamans. Helium was collected by water-displacement method in inverted jerrycanes of 2 liter capacity. The low values of He (0.1 ppm or less) abundances indicated that leak-proof, stainless containers were needed to obtain true results.

Laboratory Postings (Petrology, Spectroscopy and XRD Lab (1976-78)

After brief postings in Petrology under Dr. T.K. Bhattacharya and under Dr. A.V. Sankaran in the Spectroscopy laboratory in 1976, I was posted in the XRD Laboratory under Shri Nagaraj Rao for two years. Specialized in powder diffraction studies of radioactive rocks after mineral separations using heavy liquids. Confirmation of native Pt in an Andaman Is. ophiolite using Deby-Schairerer camera after hand picking Pt from a polished thin section and comparing it with Pt wire powder was a noteworthy finding.

Geological mapping of the Carbonatite-alkaline complex, Sung Valley, Meghalaya, January, 1978

Dr. G.R. Udas, then Director, sent me for detailed mapping of the complex, which led to a new geological map of the oval shaped complex comprising dunite, peridotite, pyroxenite, ijolite, fenites and carbonatite cone-sheets with soils rich in pyrochlore (Nb), magnetite, and apatite. Interactions with Shri S.C. Varma and Shri D.K. Sharma, who were evaluating the Nb potential of the complex, also took place.

Field Posting (1978-1986) at Bodal prospect

I was transferred to the then Western Region at Nagpur and posted at the Bodal Prospect to carry out detailed mapping (1:2000 scale), exploratory drilling, reserve estimation, underground mapping in the drive besides other assignments in the Prospect along with Shri R.M. Sinha, Dr. Anjan Chaki, Shri P.S. Parihar, Dr. A.K. Rai (all became Directors of AMD during 2002 to 2017), Shri S.P. Sharma and others under Shri V.V. Rao. A field Museum of Geology was established and numerous Officers of AMD and University students were trained by our team in the prospect.

XRF and EMP Laboratory works (1987-2000)

I was transferred back to Hyderabad and took charge of the XRF Lab. in 1987-88 and EMP Lab. in 1994. Major XRF support was provided to flow-sheet development and recovery of xenotime and monazite from Siri-Deo River, besides analytical support. EMP Lab was put to over 12 hours of analytical schedule and that led to substantial increase in analytical support to numerous field investigations besides micro-probe analyses of numerous atomic minerals.

Publication Group and activities

Shri T.M. Mahadevan (Director, 1986-87) initiated AMD's publication in collaboration with the Geological Society in 1987. AMD's own publication, EARFAM, got launched in 1988 under the guidance of Dr. S. Viswanathan, when Shri A.C. Saraswat was the Director. The inaugural issue was released by Dr. M.R. Srinivasan, then Chairman of AEC. Myself and Shri S.P. Balakrishnan, then OIC, Spec. Lab., were fully involved in the Editorial and copy-editing of the issue besides others. Publication assignments of EARFAM (1988-2000) were continued under Dr. Viswanathan (1988-1993) and later under Shri Rajendra Singh (1994-2000).

Transfer to AMD, Eastern Region, Jamshedpur (2000-2003)

I took over as Deputy Regional Director under Shri A.K. Bagchi in November 2000 and became Regional Director in 2002 and retired in December 2003. During the period, the Khasmahal office-cum Residential complex was developed with new plantations, Football/Cricket ground with whole-hearted participation of the Residents of all ranks, besides sinking new bore wells with UCIL's assistance. The Homi Bhaba Seminar Hall was inaugurated by Dr. Anil Kakodkar in October 2003.

Other Assignments

Supervised and guided five Officers of AMD (Dr/S: H.Q. Hoda, Rajiv Bidwai, Chanchal Sarbanja, U.K. Pandey and Veena Krishna) towards their Ph.D (Osmania University, Hyderabad, 1993-2002). Participation in International Projects (Indo-US, 1984-1988) and Indo-USSR (1989-1991) on the Deccan and Siberian Traps with visits to US (with visits to Scripps Institure, San Diego, USA) and the then USSR (visits to Moscow Irkutz, Novosibirisk and Norilsk).

I also worked as a member of the Program Advisory Committee member DST (1997-2000) and guiding research activities in Universities by way of work in selection Committees of DST.

I served as a member in the AEC, Chairman appointed Committee on **'Optimum Utilization of UCIL's Resources'** (1993-1996) with visits to UCIL.

The Grand Finale

AMD's interactions with UCIL under Shri Ramendra Gupta, CMD during 2000 to 2003, were very cordial. These included conducting Training Programmes for AMD Officers and drilling at Rakha area. In addition, speedy-exploratory drilling under Shri M.K. Varma (which led to the first-time introduction of incentives to highly-productive drilling) for mine-slope stability studies and other support during the commissioning of the open cast mine at Banduhurang and the Turamdih Mill that was commissioned in October, 2003 by Dr. Anil Kakodkar, then Chairman, AEC. As a sequel, my services were requested for by CMD, UCIL for five years as a full-time consultant to them from March 2004 to March 2008 to develop the Management Training Centre of UCIL at Narwapahar, which was successfully completed. One of the highlights was the conducting of an IAEA conference by both AMD-UCIL in 2006 at Narwapahar, Training Centre.

AMD-Geological Society of India (GSI), Bangalore Training Programmes (2015-1019) on Rare Metals and Rare Earth (RMRE)

In order to develop human resources pertaining to RMRE in Indian Universities (faculty and research students), Training Programmes during 2015 (Bangalore), 2017 (Thiruvananthapuram) and Jodhpur (2019) were conducted jointly by the Society and AMD. The association has climaxed during the Amrit Mahotsav with the recently concluded National Seminar on **'Seventy Five Years of Mineral Exploration in India' and the Special August Issue of the JGSI, 2022** containing the contributions that have been critically scrutinized and edited.

The tryst with AMD that started in 1975 is continuing. I wish the AMD team all success in all their endeavours of National service.

Camping at Wemberly Ganj, Andaman Is. January, 1976

P. Krishnamurthy explaining the radioactivity in a sample to Dr. M.R. Srinivasan, Chairman, AEC during a visit to AMD on Founders Day, 1989, Hyderabad . Dr. Balrama Murthy, Chief Executive, NFC is also seen along with others.

Planning for FSP 2002-2003 at Jamshedpur, AMD.

Visit to Kunjar Basin Uranium investigations, 2003

Exploratory drilling at the Kunjar Basin, 2003.

Inauguration of the Cricket-cum-Football ground at Khasmahal. Members of the revised ore-reserve estimate committee of Turamdih group of deposits in 2003 are also seen.

Participants in AMD-Geological Society of India training programme on 'Rare Metals and Rare Earths' organised at Bengaluru.

Reminiscences of my experience in the search for uranium in Meghalaya and southern Peninsular India

D. Veerabhaskar

(Former Regional Director, South Central Region, Hyderabad)

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Date of Birth: 01.07.1944 *Date of joining AMD: 23.02.1973* *Date of superannuation: 30.06.2004*

Shri D. Veerabhaskar obtained M.Sc. (Geology) from Sri Venkateswara University, Andhra Pradesh. He joined AMD in 1973. He has worked in several parts of the country in various capacities. He superannuated as Scientific Officer-G and Regional Director, South Central Region in June, 2004. He has published nine articles in national and international journals.

The Prologue

Nostalgic memories of my early years in Atomic Minerals Division (AMD) are unforgettable episodes of my life. As a young geologist carrying big hopes of a great career in AMD, I reported at the then Eastern Circle in Calcutta in February, 1973. No sooner did I settle down in my new post, namely Scientific Officer-SC, than I was packed off to Meghalaya by Shri A.C. Saraswat, the then Officer-in-Charge at the Eastern Circle, for my first field assignment. The assignment was 'Investigation for Uranium in the Upper Cretaceous - Tertiary sediments of Meghalaya'. Collecting my field equipment, I took off for Guwahati by train. Next day, I reached Shillong from Guwahati by State Transport bus. I started shivering at Shillong (a hill station located 6000 ft. above MSL) because I never experienced that kind of cold climate back in my home state. I met Shri A.K. Singh, another young geologist like me at Shillong, who helped me in buying some warm clothing. From Shillong, we together moved to our first field camp at Dawki on the southern foothills of Meghalaya plateau. I reported to Shri S.R. Rajderkar, our Group Incharge, who was already camping at Dawki and guiding the exploration in the Cretaceous-Tertiary sediments in the southern parts of Meghalaya. Thus started my geologist's career and life in AMD.

Exploration for Uranium in Meghalaya

In the early seventies great stress had been given for the exploration of 'Sandstone-type Uranium Deposits' following the discovery of huge uranium deposits in the Mesozoic sandstones of Colorado Plateau in the United States. Meghalaya was selected based on similar favourable geological criteria for the development of Sandstone-type Uranium Deposits in the Upper Cretaceous-Tertiary sediments.

Meghalaya plateau is composed of granite gneisses and Shillong Group of metasediments of Early Proterozoic age intruded by Late Proterozoic Mylliem Granite (~750 Ma), Anek Granite and pegmatite. Over this basement are deposited Upper Cretaceous Mahadek conglomerates, sandstones and Langpar sandstone, which in turn are overlain unconformably by a thick blanket of Tertiary sediments namely, Cherra Sandstone, thin coaliferous black shales and limestones successively. These sediments with gentle southerly dip are well exposed along the southern part of the plateau.

Earlier reconnaissance surveys in Meghalaya in the 1960s had yielded some thorium anomalies. Systematic surveys targeting Upper Cretaceous sediments were started from 1972-73 onwards and the first uranium anomaly was recorded by the author in February, 1974 in Lower Mahadek sandstone in Umryngka River section near Tarangblang village, about 10 km northeast of Dawki in Jaintia Hills. Uranium mineralisation was recorded over a stretch of about 60 m in a grey sandstone bed above

a thick conglomerate zone. The host sandstone is medium to coarse grained and grey coloured with streaks of black carbonaceous matter. Samples from this zone analysed from 0.05% upto 1% of U_3O_8 (chem.), while one coalified wood sample from the zone analysed >10% U_3O_8! This stunning report from Jaintia Hills gave a big boost to AMD and Shri A.C. Saraswat, our boss at Calcutta, immediately wrote a letter asking for a brief report on the occurrence and thoroughly examining the entire area for its lateral extensions. The discovery gave a great impetus for AMD for taking up intensive exploration of Mahadek Formation not only in Jaintia Hills but also in Khasi and Garo Hills towards west. In the subsequent year similar uranium mineralisation was found in another river section in Jaintia Hills near Pdengshakap, about 5 km NW of Umryngka. Reconnaitory drilling was carried out both at Umryngka and Pdengshakap to explore the extensions of mineralised zone at depth, but it did not yield encouraging results.

In the meantime, a new circle office was opened by AMD at Shillong in October, 1976 to facilitate exploration activities in the North-Eastern Region of India covering all the seven NE states. Thus, those of us who were already engaged in survey and exploration in Meghalaya, Assam and Arunachal Pradesh, were *en bloc* shifted to Shillong. Communication and interaction between the circle office and field camps became faster and smoother.

Surveys were later extended to the western parts of Khasi Hills all along the southern slope of Meghalaya plateau, where Mahadek Formation is well developed. Gomaghat uranium occurrence came to light in the field season 1976-77 and it was located by Dr. Mir Azam Ali, along the Jadukata River section, about 2 km west of Ranikor village. Uranium mineralisation is hosted by dark grey coloured medium to coarse arkosic sandstone, overlying a thick basal conglomerate. The host sandstone is in turn overlain by a thick pile of purple sandstone, which represents the upper Mahadek Formation. The mineralised zone was traced for more than 3 km in the river section and its adjacent area. Subsurface drilling proved the continuity of mineralisation at depth in Gomaghat area. Encouraged by these results, sustained efforts were made in subsequent years to scan the area in the upstream portions of Jadukata river and its tributaries in the plateau region further north. As a result, rich mineralised zone was located around Phlangdiloin and then subsequently at Domiasiat. Detailed subsurface drilling in both these areas proved large tonnage rich grade uranium deposits in Mahadek Sandstone. More reserves will come to light from this area if and when exploration continues. This is the historical perspective of uranium exploration in Meghalaya.

Uranium exploration history in Meghalaya is a textbook case of mineral exploration starting from selection of the area based on the concept of 'Sandstone-type U-deposits', followed by field reconnaissance surveys, identification and delineation of target zones for detailed investigations, drilling and finally proving and establishing large tonnage rich grade uranium deposits at Phlangdiloin and Domiasiat. The time span covered is nearly three decades from early 1970s to late 1990s. The trials and tribulations we experienced as young geologists while working in Meghalaya should be a lesson for the present generation of young geoscientists. Meghalaya is a tough mountainous terrain with thick forests, awe-inspiring deep river gorges, and endless winding roads and what not. Rocky outcrops are very few and found in limited road cuttings and steep river sections. With such limitations, there is no other option for the geologist except venturing into the river sections in search of Mahadek Formation, the main target. That was how the author was able to locate the first uranium anomaly in Mahadek sandstone in Umryngka River section near Tarangblang in Jaintia Hills. This occurrence once and for all firmly established the high favourability of Mahadek Formation for uranium mineralisation and inspired us for intensive exploration of Mahadeks throughout Meghalaya plateau. The final results of these efforts are there for everyone to see. An important attribute for an exploration geologist is sincerity in one's effort and abundant positive attitude and success is sure to follow. This is the author's experience and his advice to the present generation of young geoscientists.

Uranium Exploration in the Proterozoic Basins of Southern Peninsular India

Southern Peninsular India was another important area where the author had the opportunity to work for the greater part of his career in AMD. Till 1970s, Southern Peninsular India was dismissed as 'Thorium Province' with huge deposits of monazite in the beach placers all along the Southern seaboard. In the initial days, search for uranium was confined to granitic pegmatites and leucogranites (Kullampatti), pegmatites (Nellore) and conglomerates in parts of Andhra Pradesh, Karnataka and Tamil Nadu. In 1975, uranium mineralisation was reported for the first time in Late Archaen-Early Proterozoic 'Chikmagalur (quartz-pebble) Conglomerate' while checking the cores of a GSI borehole drilled for gold at Kalasapura in Chikmagaluru district of Karnataka. Gold-uranium association is well documented in Early Proterozoic quartz-pebble conglomerates in Witwatersrand, South Africa, and Elliot Lake and Agnew Lake in Canada. Following this discovery, AMD carried out extensive surveys for uranium in 'Chikmagalur (quartz-pebble) Conglomerate' in parts of Chikmagaluru, Udupi, Shimoga and Uttarakannada districts of Karnataka along the Western Ghats from Walkunji in south upto Arbail in north, including some exploratory drilling at places like Kalasapura, Walkunji and Arbail. Though uranium mineralisation was recorded in all these areas, its economic viability was not encouraging. Moreover, the entire Western Ghats is now declared ecologically sensitive.

Exploration in Cuddapah Basin

The concept of 'Unconformity-Related Uranium Deposits' in Proterozoic basins gained momentum in late 1970s and 80's following the discovery of rich uranium deposits in Late Proterozoic Athabasca basin in Canada. The Cuddapah basin (Middle to Late Proterozoic), thus became the first target of uranium exploration in Southern Peninsular India. Extensive surveys were taken up both along the southern and eastern margins of the Cuddapah basin in Cuddapah and Nellore districts in Andhra Pradesh (A.P.). The first breakthrough was achieved along the eastern margin at Kasturigattu, near Somasila in Nellore district by the author and Shri M. Thimmaiah in the year 1984. Uranium mineralisation with grades from 0.03 to 0.1% U_3O_8 was found associated with schistose granite close to the unconformity with the overlying Nallamalai quartzite of the Cuddapah Supergroup. It was traced over an extent of nearly 500 m, beyond which it was found covered by soil and dense vegetation. Extension surveys towards north and south of Kasturigattu showed some low grade uranium concentration in schistose rock in discontinuous patches. Further investigations in this area were abandoned because of environmental restrictions. However, the author is of the opinion that this part of the eastern margin of Cuddapah basin still holds great potential and deserves a second look.

In the meantime, surveys were undertaken around Tummalapalle, near Pulivendula in Cuddapah district, along the southern fringes of the Cuddapah basin following the reporting of radioactivity in the Vempalle Limestone Formation by GSI in 1985. Detailed surveys carried out by AMD brought to light significant uranium mineralisation in dolostone near Tummalapalle Village in the year 1986. Dr. A.V. Jeyagopal and late Shri M. Vasudeva Rao were the pioneers in this effort. Stratigraphically Vempalle Limestone Formation overlies the basal Gulcheru Quartzite Formation of Cuddapah Supergroup. Archaean granite and gneiss and Dharwarian schists form the basement rocks. Uranium mineralisation is hosted by dolostone at the base of the Vempalle Formation and found characteristically stratabound with extensions both in the strike and dip directions. Its lateral strike-ward continuity was traced intermittently over an extent of 60 km both towards east and west of Tummalapalle, with significant mineralisation being found near Rachakuntapalle, Giddankivaripalle and Bakkanagaripalle in the east and Kannampalle in the west. The dip-ward extension was established for more than a kilometre depth vertically by subsequent exploratory drilling. The mineralised carbonate rock comprises alternative thin bands of light grey dolomite-rich carbonate and medium to dark-grey

ultrafine collophane with coarse detritus of quartz, feldspar and some sulphides. Ultrafine granules of pitchblende and coffinite were identified along with pyrite and minor organic matter by petrographic studies. The fertile basement granitic rocks on the basin margin are the source rocks for uranium in the dolostone. These granitic rocks are also extensively fractured with some fracture zones running over a few kilometres and extending into the basin beneath the Gulcheru Quartzite Formation. Some of these fracture zones were also found radioactive and explored by drilling. But nothing significant came out of it.

Exploration and evaluation drilling was taken up in Vempalle Limestone at Tummalapalle and Rachakuntapalle blocks around 1988 and the author was associated with the subsurface exploration work in the initial phases of the Project. It became clear in the initial stages itself that the orebody continued to show constant thickness as well as grade in the down-dip direction and the mineralised zone was found persisting even beyond one kilometre depth (vertical), thus indicating the huge potential of the ore reserves in the area.

The main challenge for AMD in those days was 'how to extract uranium from these limestones'. In fact, in the very beginning, when the discovery of uranium mineralisation associated with limestone at Tummalapalle was announced, the then Director, AMD, Dr. T.M. Mahadevan in an open meeting at Southern Region, Bangalore, pronounced, "Walk off the area, if it is associated with limestone; it is unviable and a very costly proposition to extract uranium from limestone". It was, of course, a very innocuous statement. Had we walked off the area, we would have missed Tummalapalle deposit forever. Dr. Mahadevan did not literally mean to abandon the area. It was just his initial reaction or off-the-cuff remark. It was only a challenge he threw at us. The challenge of extraction of uranium from Tummalapalle dolostone was taken by Southern Region, AMD. The main players in this were late Shri M. Vasudeva Rao, the then Cuddapah Project Incharge and late Shri K.M. Muniyappa, the Mineral Technologist at the Mineral Technology (M.T.) Lab., Southern Region, Bangalore. The author is the direct witness how Shri Vasudeva Rao used to spend lot of time in M.T. Lab, discussing with Shri Muniyappa about improving the leachability through 'alkali-carbonate' route. Acid leaching was ruled out in view of the excessive consumption of acid, besides damaging the environment. Pressure leaching experiment with sodium carbonate and sodium bicarbonate at different temperatures and pressures was taken up and leachability upto about 70% was gradually achieved. Various oxidizing agents like potassium permanganate and iron carbonate were also tried at different P&T conditions to improve leachability. These experiments were later taken over by M.T. Lab., Hyderabad, seeing the initial success of M.T. Lab at Bangalore. It is now established that alkali-carbonate leachability of Tummalapalle ore is in excess of 80% and economically viable.

Tummalapalle deposit is being mined and latest subsurface exploration has proved ore reserves in excess of 2 lakh tons of U_3O_8. It is now the largest uranium deposit in India. What a gratification for the old geologists who were associated with the Tummalapalle exploration to see it unfold from its baby-looks to a giant mineral deposit, having surpassed two lakh tons of U_3O_8 ores in its belly and more is coming out as the days passed! No award could give us more satisfaction and happiness!

Exploration in Bhima and Kaladgi Basins

In the 1990s, other Proterozoic basins like Kaladgi basin and Bhima basin became the next targets of uranium exploration in Southern Peninsular India. Initial success was seen in Bhima basin with the discovery of Gogi anomaly in Yadgir district of Karnataka by Dr. Achyut Pandit and his team in 1995-96. While tracing the unconformity contact zone between the basement granite and Bhima (Shahabad) Limestone in the outskirts of Gogi village, the first U-anomaly was located over a small outcrop of limestone. Picking the signal, a nearby drinking water borewell was radiometrically logged, which confirmed the presence of a high radioactive zone at depth. Subsequent investigations in the area, both surface and subsurface indicated that uranium mineralisation is mainly associated

with fractured and brecciated Bhima (Shahabad) Limestone immediately overlying the basement granite. An east-west trending Gogi-Kurlagere fault cuts the basin along its southern margin. A NE-SW trending cross-fault cuts the main Gogi fault at Gogi village and the fracture zone developed along the younger cross fault hosts rich grade uranium mineralisation between Gogi and Kanchankayi villages. Extensions of mineralisation both towards west and east of Gogi were traced around Halbhavi and Hulkal, besides Kanchankayi. Experimental mining was subsequently started at Gogi to study the configuration of the ore body and its behaviour at depth. Latest ore reserves proved from the area in Bhima basin, as known from AMD sources, are in excess of 7000 tons of U_3O_8. (The author was not associated with uranium investigations in Bhima basin at any stage but visited the area on the invitation of Dr. Achyut Pandit and made notes during the visit).

Uranium investigations were also simultaneously initiated in Kaladgi basin in late 1990s. No significant breakthrough was achieved in the initial years and only some isolated anomalies associated with basement granite were recorded in the eastern part of the basin around Bagalkot and Badami. However, in the western part of the basin first uranium anomaly was recorded in a 'gossan-type' outcrop of Badami Sandstone near Deshnur village, in Belgaum district of Karnataka in 2000-01 by Dr. Gajapathi Rao and Dr. Sukanta Dey team led by the author. Detailed surface investigations followed by exploratory drilling at Deshnur indicated encouraging mineralisation at depth associated with a NE-SW fault in Badami arenite. Further extension surveys in this sector brought to light Gujanal anomaly about 15 km NW of Deshnur as known from AMD sources, where highly encouraging mineralisation was intercepted at depth in Badami conglomeratic sandstone, by subsurface drilling. In both these areas, subsurface exploration is reported to be continuing and simultaneously ore reserve estimations are also being carried out. Kaladgi basin holds great promise and exploratory efforts need to be continued to identify more potential zones in Badami Sandstone in the western as well as eastern parts of the basin, wherever it directly overlies basement granitic rocks and subsequently cut by faults and fractures.

Exploration in Srisailam Sub-basin

The author had a brief opportunity to guide uranium exploration in Srisailam sub-basin in north Cuddapah basin in A.P., while he was heading the South Central Region at Hyderabad. Typical unconformity-related uranium mineralisation occurs at the base of Srisailam arkosic sandstone/ quartzite close to granite basement and more often than not the mineralisation extends into the granite across the unconformity. The basement granite underlying the Srisailam Formation is a fertile granite with several uranium anomalies recorded earlier [eg., Veeraboyanapalli, etc.] along the northern peripheries of the basin in Nalgonda district. While sizeable uranium reserves had already been established at Lambapur and Peddagattu in Nalgonda district, evaluation drilling was in progress at Koppunuru in Palnad sub-basin in Guntur district, A.P., and at Chitrial outlier, south of Devarkonda and SW of Peddagattu in Nalgonda district, Telangana. In both these areas, evaluation of the reserves and further exploration in the extension areas are reported to be in progress. It is heartening to know that uranium ore reserves of >18,000 tons of U_3O_8 have already been proved in all these areas in Srisailam sub-basin. The challenge in Cuddapah basin, now, is to explore and identify potential sectors in the younger 'Kurnool Group' especially in Palnad sub-basin, where it immediately overlies the Srisailam quartzite. It holds great promise for uranium mineralisation. The younger generation has to take up this challenge. Who knows! Another Tummalapalle might be lurking there!

The Epilogue

The three Proterozoic basins of Southern Peninsular India, namely the Cuddapah basin, the Kaladgi basin and the Bhima basin have richly contributed to the uranium inventory for the country's nuclear power programme, the Cuddapah basin contributing the lion's share. Once upon a time Southern Peninsular India was dismissed as 'Thorium Province'; but no more. It is a proven 'Uranium Province' now. What a great turn around! And what a great satisfaction

for all the geologists who immensely contributed in this great effort! It is a great feeling to the author for being one among them.

'Hunt for an elephant in an elephant country' is an old adage. The Proterozoic basins should now be the prime targets for uranium exploration. Continuing the investigations in the present basins, other Proterozoic basins such as Chattisgarh, Indravati, Gwalior, Bijawar and Vindhyan basins should become AMD's immediate target for exploration in order to augment the country's uranium resources.

Notes on geological and radiometric observations in Archaean-Proterozoic terrains of India - review summary

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Shri Ravi Kant Nagar obtained M.Sc. (Geology) from Jammu and Kashmir University, Jammu and Kashmir. He joined AMD in 1967. He superannuated as Scientific Officer-G and Regional Director, Northern Region in October, 2004. He has published 12 articles/papers in national and international journals.

During the period of more than three and a half decade, in Atomic Minerals Directorate for Exploration & Research (AMD) from 1967 to 2004, I worked initially for exploration and production of beryl, columbite-tantalite and lithium minerals in Rajasthan Mica Belt and identified beryl and Cb-Ta bearing pegmatite belts in parts of

(a) Ajmer-Bhilwara-Dungarpur and

(b) Jharool-Oghna-Koliari, Udaipur district.

In the following years, I had the opportunity to work with senior AMD officers in various geological environments of the country and carried out investigation in the field of uranium geology and exploration vis-a-vis evaluation of uranium resources, and other atomic minerals.

My geological and radiometric investigations were primarily confined to Archaean Proterozoic terrains of India covering Aravallis of Rajasthan, Vindhyans, Bundelkhand Craton of Central India, Singhbhum Craton of East India, Dalma Syncline, Simlipal Basin and Kolihan sedimentary basin of Odisha and along the Main Central Thrust of the Himalayas.

Systematic geological, geochemical, geophysical and radiometric surveys were carried out in the aforesaid terrain and the data was supplemented with interpretations from the Landsat imageries and aerial photographs. Significant belts hosting uranium minerals associated with base metals were also identified for exploration.

Extensive exploration activities were carried out in the thermal field of Bakreshwar and Tantloi, Birbhum district of West Bengal and Dumka district of Jharkhand respectively, for the assessment of helium gas resource potential. Geological, geophysical, geochemical surveys were carried out and established the litho-tectonic control responsible for the emergence of hot springs. Radon and helium investigations were carried out in soil and ground water around the hot springs followed by exploratory drilling to demarcate the thermal field vis-a-vis its helium potential. The work was carried out in collaboration with Indian association for the Cultivation of Science (IACS) and VECC, Kolkata in 1978-1980. Two shallow boreholes were drilled by AMD at Tantloi for the estimation of rate of helium gas flow and its concentration. In the Bakreshwar-Tantloi thermal field, it is inferred that the hot springs are enriched in helium and may serve as potential and indigenous source of helium.

The following is the review summary of observation made during the course of geological and radiometric investigation in Archaean-Proterozoic belts with particular reference to the Aravalli mountain belt of Rajasthan and Archaean Basement Complex (sheared granites & basic rocks) of Bakreshwar-Tantloi in which the hot springs are located.

1. Rampura-Agucha (Pb-Zn) - Udaipur (Cu-U) - Zawar (Pb-Zn-Ag) metallogenic province: Mineralisation is structurally controlled by Archaean-Proterozoic unconformity and hosted by Archaean/gneissic complex as well as Aravalli metasediments e.g. calc-silicates, impure limestone, carbonaceous phyllites in Rajasthan.

Kala Magra, Udaisagar lake, Umra are the type areas of uranium mineralisation, in parts of Tonk and Udaipur district.

2. Khetri (Cu-U-Mo) - Khandela (Cu-Mo) copper belt: Structurally controlled by shears and fractures in Delhi metasediments along Khetri lineament. Calc-quartzites, impure limestone, albitites / albitised metasediments and carbonaceous rocks are the typical hosts. Types and areas of uranium mineralisation are

(a) Kolhon - Chand Mari Block

(b) Babai-Papurna-Siswali (albitised metasediments) and

(c) Rohil-Ghateshwar-Diara-albitised Delhi metasediments (Jhunjhunu and Sikar district, Rajasthan)

3. Babai - Papurna - Sior - Dhancholi-Albitite zone, (albitite line), Jhunjhunu district, Rajasthan.

4.Mahendargarh-Papurna-Babai-Ajmer albitite line (170 km approx.): Typical hosts are albitised schists, sheared quartzite and albitised metasediments explored by shallow drilling in the early seventies at Siswali, Jhunjhunu district, Rajasthan. Cu-U-association has been established in bore holes at shallow levels at Siswali near Papurna.

5. Pegmatite belts in the Aravallies:

(a) Ajmer-Bhilwara mica mining centres,

(b) Jharol-Ogna Som, Ajmer, Bhilwara and Udaipur district, Rajasthan have been explored in the past for recovery of beryl, columbite-tantalite and lithium and pitchblende.

A 30km long thermal field trending NW-SE was demarcated by geological and geophysical surveys between Bakreshwar and Tantloi, Birbhum district of West Bengal. Thermal springs have come up along the NW-SE fault zone between Bakreshwar and Tantloi. Helium gas appears to be escaping/ continuously from the hot springs through fractures/shears. The thermal field holds promises for helium recovery. Extraction of helium gas on large scale is desirable as the gas is continuously escaping to the atmosphere.

Based upon my experience and observations the following suggestions are made to strengthen the growth of exploration and research in the promising uraniferous belts.

1. Archaean-Proterozoic Unconformity

(i) Kharbar-Prasad area, Udaipur district, Rajasthan

Uranium mineralisation was recorded below and above the unconformity in basement quartz-biotite schist ± quartz veins and the unconformably overlying Aravalli conglomerates ± metabasics. Primary and secondary uranium mineralisation has been recorded at three different locales along the unconformity. The area warrants further exploration along the unconformity.

(ii) Umra uranium deposit

The deposit is hosted by Aravalli metasediments away from the unconformity between B.G.C. and Aravallis. High grade uranium mineralisation was located in Grid-3 along the fault zone which disappears further north and re-appears northeast of Umra railway station. The fault zone along the phosphatic limestone, exposed in the Maton hill with its eastern contact, shows pulverized rocks all along the hill. The NE shear near Umra has already been drilled during 1989-1990 with appreciable uranium results. Investigation along the Grid-3 fault and its possible extension towards NE is suggested. It may be recalled that mining activity was closed in 1962.

(iii) Khan Mogra locality

Old copper workings located about 2 to 3 km to the east of Umra Grid-1 was examined in 1974. Feeble radioactivity was recorded in the calc-phyllite and impure limestone. Few boreholes were drilled between Umra Grid-1 and Khan Mogra in mid 1980s with encouraging uranium values in calc-silicate and carbon phyllites. Radiometric investigations are suggested around Khan Mogra as this area is soil covered.

2. Maonda-Babai-Siswali Area

Shallow drilling was taken up in Siswali area in 1971-73. Uranium mineralisation was recorded in albitised calc-silicate rock, calc-quartzite, quartz-biotite schists at shallow depths. The area is soil covered. Deep drilling is suggested in the area.

Journey 36

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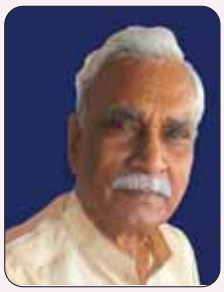

Shri Arjun Prasad obtained Diploma in Mechanical Engineering from Polytechnic College, Gaya. Prior to joining AMD he served in TELCO (Tata Engineering and Locomotive Company) and Bihar state Irrigation Department.
Shri Prasad joined AMD in July 1969 as mechanic and migrated to scientific cadre as a Scientific Assistant-C. He has worked in Central, Eastern, North Eastern, Southern and South Central Regions. He superannuated as Scientific Officer-F and Incharge, Drilling Operations, Central Region in January 2006.

My eventful journey of almost 36 years in AMD began on 17th July 1969, after completion of Diploma in Mechanical Engineering in the year 1966 from Gaya, Bihar. After initial few years working with Telco (Tata Engineering and Locomotive Company) and Bihar State Irrigation department (on *ad hoc* basis), joining a Central Government Department brought cheer to me and all my family members. My journey in AMD which started as a Mechanic and ended as Scientific Officer-F is the greatest achievement one can have in life. One cannot ask for more achievement in professional carrier along with the love and affection bestowed on me throughout these years.

The wheel of my journey started rolling on 17th July 1969 at Bhatin prospecting area of Jamshedpur, erstwhile Bihar, now Jharkhand and completed a full circle at Central Region, Nagpur on 31st January 2006. The initial 8 years of life as Mechanic in AMD gave me ample opportunity to learn every intricacy of drilling rig operation, maintenance - repairing and overhauling of prime movers/IC engines at various geological as well as geographical domains of India including Narwapahar, Sevattur, Kalsapura and Bhaura (till 1977).

Being a mechanic, my main job was to maintain/ repair and upkeep all the machines of my camp at site. During my entire carrier in AMD, I got chance to overhaul 20 engines in various Regions. One such repairing has long lasting imprint on my mind. I remember an unfortunate incident that happened in Bhaura during April 1973, when I was repairing a petrol-driven Mahindra pick-up van at camp. This kind of pick-up van used to have closed cabin and open trolly at back. After overhauling the engine, time was to test the engine running performance. Since all the petrol was drained from petrol tank, so we decided to use make-shift tank with pipe connected to carburettor. As I started the engine, due to vibration of engine, petrol from the temporary tank splashed all over the cabin and caught fire. I was trapped in front cabin of van, which was totally engulfed in fire. The first thing that happened instantly was that I closed my eyes and tried to open the door with handle, which I could not locate in hurry. Subsequently, with lot of difficulty, I could manage to jump out of cabin through window panel. People watching from out-side immediately made all efforts to put-off the fire. It was time when terylene and gabardine was in fashion and unfortunately, I was wearing a terylene shirt, which melted like plastic and stuck all over my body. My colleagues immediately rushed me to nearest hospital located at Padhar (a missionary hospital 20 km north of Betul town), where I received best treatment and best support from my friends which made me to recover in a very short time. This reminded me of a forecast made by my friend (a palmist by hobby) during my small tenure in State Government, “Arjun, you will have a life-

threatening accident before 30 years in your life, and if you survive you will have bright future and long life". Everything is fresh in my mind like it is yesterday's affair, but lot of water has flowed.

My subsequent transfer to Bodal in 1977 really made lot of positivity in life and career. AMD announced for the 1st time to recruitment of Scientific Assistant-C for Mechanical Engineers and I got through it and thereafter there was no looking back. As 1st time drilling unit Incharge, an assignment of drilling 927 m deep borehole in Bodal was a real challenge. The entire crew along with rig LT-1000 achieved it using combination of conventional and wireline drilling. Sometimes it used to take whole day to achieve only 3 meters of progress and rest of the day hoisting the drill rods from greater depths. I was privileged to be 1st operator to operate DEL-500 rig which was 1st truck mounted drilling machine procured by AMD in 1976. I continued my journey in Central Region till 1983 and worked in Bodal-Bhandaritola-Darbha field areas. In 1983, I was transferred to Eastern Region, where my tenure in various field areas was filled with thrill and achievements. Here, I worked from 1983 to 1991 with postings at Turamdih, Kanyaluka, Jublatola and Nimdih field area. During my camping at Turamdih, I was assigned a special assignment at Kanyaluka to drill a borehole of 600m depth in a duration of 30 days. It so happened that unit Incharge of rig GD 42 S(1) was on long leave and the same machine was to drill a borehole of 600 m in Kanyaluka. The location of borehole was such that, owner of land wanted to vacate the space by middle of June (rainy season) to sow paddy. I was called from my camp Turamdih by my boss Mr. Chaudhuri at Khasmahal office and he asked that "Arjun, we have to drill a borehole of 600m and we have only 30 days to complete. Can you do it?" It was difficult for me to complete this job being posted in Turamdih. So I requested him to provide all support and give me free hand too. I was shifted temporarily to Kanyaluka. Leaving my family in Turamdih, I could achieve the desired drilling progress of 597 m within 30 days and it was stopped because it had reached the desired depth and touched the marker horizon. I requested for 3 m more to drill so that I could make a record figure of 600 m. But that was time when every meter counted. That was the time when a drilling unit generally used to have target of 1000 m/year. This not only gave me a moral boost but also lot of appreciation by my senior colleagues. In the subsequent year, another challenging assignment was entrusted upon me to drill a vertical borehole of about 500 m at Jaduguda mine for sand stowing which was completed successfully. Due to different kind of rocks present in Jaduguda, it was almost impossible to drill a vertical hole without deviation. My posting and stay during 1988 at camp Kanyaluka witnessed an unprecedented event. On a Sunday morning, supporters of Jharkhand agitation attacked the camp and burnt government vehicles and machines. The mob also attacked my house, where they manhandled me and damaged my household belongings using axe. There was huge personal loss and mental agony which continued for months together.

During my posting in Southern Region from 1991 to 1993 at Giddankivaripalli, I got an opportunity to work in India's biggest uranium deposit and from 1993 to 1996 at Lambapur - India's first unconformity-related uranium deposit. My subsequent transfer to Shillong in 1997 and posting till 2001 was real challenge to work in hostile conditions of NER. It was toughest to work in field areas of Kulang, where reaching from Headquarters, Shillong itself was a challenge. 160 km of journey from Shillong to field area used to take not less than 12 hours, which includes transporting of jeep/truck on boat to cross Jadukata River. I still remember my 1st journey to Kulang camp from Shillong along with Resident Geologist, Shri Rakesh Sharma when our jeep was attacked by miscreants and they emptied our purse. But the huge money meant for prospecting allowance was saved, as it was kept in government envelope, which they thought as official documents. My journey in AMD ended on 31st January 2006 at Nagpur, where I served for 5 years as Drilling Incharge. There drilling in the north-eastern part of Chhattisgarh basin was a challenge for all my fellow colleagues. Drilling operation was being carried out on the top of the hill at Chitakhol-Renkhol area. Generally, it used to take 1-2 hours to reach drill site on top of the hill.

The entire 36 years of service in AMD is full of achievements and memories. I always found my seniors from drilling and geology supporting at every step of professional carrier. As drilling engineer, it is heart-warming to know that AMD is drilling almost 3 lakh meters in a single year which we could never imagine even in our dream. I find myself lucky to be part of this journey and to work in Bodal, STB, Tummalapalle, Lambapur-Peddagattu, Wahkhyn-Kulang areas, which are like a dream for others to work in such uranium deposits of our country.

Arjun Prasad operating DL-500 truck-mounted rig

My experience and reminiscences of working in AMD

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Shri Bhishma Kumar obtained M.Sc. (Physics) from Bhagalpur University, Bihar. He joined AMD in 1970. He superannuated as Scientific Officer-G and Incharge, Atomic Mineral Data Centre in January, 2006. He has published six articles/papers in national journals.

With utmost fondness, I remember the day in February 1970, when I joined AMD at National Physical Lab. (NPL), New Delhi. It did not take much time for me to realize the potential and importance of work and culture being developed to achieve the goal for which AMD was created. I had a meeting with Dr. A.S. Bhatnagar, the legendary Head, Physics Group who welcomed me and gave a golden mantra, "You are here to serve our Nation and achieve self-reliance in power production, particularly atomic power". The ambitious goal of AMD was made clear to me. I felt my importance and came out of his room supercharged with an ambition to learn the science and technology behind uranium exploration. This zeal remained within me and never subsided. Even now I enjoy the idea and the flame of learning refuses to extinguish.

The work culture in AMD is unique. Even young entrants are treated equally. I found the atmosphere at NPL very relaxed and conducive to learning. In a couple of months, I became conversant with various radiometric techniques employed for uranium exploration. After three months, I was transferred to Khasmahal Physics lab at Jamshedpur to be trained in the nitty-gritty of field assignments to be followed during field assignments beginning from October 1970 onwards.

I would like to divide my 36 years of experiences in AMD in three broad phases.

Initial eight years - a consolidation period in uranium exploration using various techniques of radiometric survey.

During this period, I was posted at five Headquarters viz. Delhi, Jamshedpur, Ranchi, Shillong and Hyderabad. I also underwent field assignments at Arunachal Pradesh then known as NEFA, Bhutan, Daltonganj in Bihar and Dongargarh in Chhattisgarh etc. Apart from various assignments, this period helped me to visit large parts of eastern and central India. During this period, I also got an opportunity to work with a whole spectrum of scientists, who were the backbone of AMD. I worked with eminent geologists like Shri A.C. Saraswat and Dr. D.V. Katre during radiation jeep survey in NEFA area, Shri D.S. Sharma and Dr. G.R. Udas in Kolarghat operation, Shri H. Nandi and Shri D.C. Banerjee at Ranchi in Nb-Ta survey, and Shri B.S. Negi and Dr. Mir Azam Ali at Shillong and Gomaghat. Working in field areas opened my horizon about the typical way AMD has been involved in achieving its goal.

Isotope excited portable XRF analyzer for finding concentration of elements niobium (Nb), tantalum (Ta) and tin (Sn).

In 1978, IAEA gifted a machine manufactured by Columbia Scientific Industries. This machine, which is a typical example of energy dispersive XRF, was capable of knocking off K or L-shell electrons of elements in question using properly mounted radioisotopes. The resulting K or L-shell X-rays were isolated using a pair of balanced filters. X-ray signals were subsequently sensed by a thin NaI crystal-photomultiplier assembly and proper electronics to give counts proportional

to concentration of elements. During the 1978-79 field-season, a new group was created called 'On site geochemical measurement of niobium, tantalum and tin using portable isotope excited XRF analyzer'.

I was transferred from Shillong to Hyderabad to work on this machine. This assignment was quite challenging as the use of radioisotopes for exploration under field conditions were unique not only for AMD, but in India as well. Shri Satish Mathur was In-charge of the group. I had an interesting and fruitful interaction with Shri N.S. Bhalla, Head, Physics Group, Dr. S. Viswanathan of wavelength dispersive XRF Lab., Dr. K.K. Dwivedi, then In-charge of Mineral Technology lab. and Shri S.R. Sivananda of the same lab. It took us almost two years to prepare a library of standards of different rock formations. Hundreds of standards were prepared for calibration of the system. There was extensive support provided in preparing standards by chemical labs of AMD and BARC. Radioisotopes were supplied by BARC to replace original isotopes of low half-life. Mounting of isotopes was critical for achieving proper excitation of samples. An analytical procedure involving matrix absorption correction was developed enabling a sensitivity of 0.30% niobium, 1% tantalum, and 0.50% tin.

This instrument was extensively used in exploration for niobium, tantalum and tin in the Bastar district of Madhya Pradesh. Shri R.P. Sinha was Resident Geologist for exploration activities. On-site elemental analysis of more than thousands of samples in a short period of five months led to the delineation of the new Nb-Ta-Sn-rich ore horizon. This work was presented at 4th Indian Geological Congress and published in Current Trends in Geology (Vol. 7, pp 323-332; Today & Tomorrow's Printers & Publisher, New Delhi).

Third phase of my work started with posting in the computer group in 1982, where I remained till my retirement 24 years later in January 2006. It was a fairly long period. I would like to divide this period into two distinct parts, 3A and 3B.

(3A) Initially, I was associated with the development of a suite of computer software for processing airborne gamma-ray data to measure ground concentration of U, Th and K. This type of measurement is done by using large volume of sodium iodide crystal (50 L) kept on aircraft platform flown at a height of 400 ft. intercepting high energy terrestrial gamma-ray (2.62 & 1.76 MeV) for Th and U. What a phenomenal change for me from my work on low energy X-ray (<100 KeV) to high energy gamma rays. AMD has been working on such a wide spectrum of energy and this was a thrilling experience for me to be associated with such unique assignments. At least a dozen computer programmes were developed.

It is not necessary to discuss the work of data processing here as the work has been extensively covered in research papers published in different volumes of EARFAM by us. It may not be out of context to mention that the work of data processing was appreciated by IAEA and a number of training programmes were organized in AMD for international scientists. I look back with satisfaction that such remarkable achievement goes to the credit of AMD.

Airborne gamma ray surveys was also conducted for ONGC to delineate oil bearing horizons. AMD also conducted surveys over reactor sites to map radioactive plume and its possible migratory pattern due to wind. Such study is necessary for the safety of people living near the reactor site.

(3B) Computer Group was created in the late seventies, primarily for processing airborne survey data for uranium exploration. During the late eighties, demand for computers among scientists in general picked up as its usefulness for organizing personal data, internet browsing and email etc. were recognized. Computer Group played a vital role in helping the computerization process in AMD by organizing a series of training programmes for geoscientists not only in Hyderabad but at other locations, in which I was personally involved. With the increase in computers, a local area network (LAN) was set up. Demand for the internet as well as LAN resulted in computer security issues. In the meantime, DAE was also rapidly pursuing

a Satellite based network, named ANUNET to connect all its units. As a coordinator of ANUNET, I attended a series of meetings in Mumbai and also at IGCAR Kalpakkam & CAT Indore. The idea was to disseminate library data, organize online meetings and interviews to save time and scarce resources.

Organizations like AMD collect data from field operations at great cost. Data is subsequently refined and analyzed to find out new uranium resources. Life cycle of data does not end here. They need to be archived safely and re-evaluated in future under new scientific understanding. Security of archived data, therefore, is of utmost importance. All databases were protected by installing a firewall to track unauthorized access and kill such requests in real-time. I am proud that AMD has taken such precautionary steps whenever it was needed.

Last but not the least, the arrival of the new century at the close of the 20th century was greeted with suspicion in the computer world. The old practice of allocating only two digits for the year field was a serious issue. In this scheme, the year field for '1999' was represented as '99'. Therefore, the year 2000 would have appeared as '00'. This was known as the Y2K (year 2000) problem. It is well known that none of the software installed on a computer would have functioned if the year field was wrong. AMD took great care to protect its computer and data resources. We upgraded all the old computers and changed programmes to take care of likely issues. As a coordinator of the Y2K project, I spent almost a sleepless night on 31st December 1999. AMD had three networks in operation then. They were (1) LAN connecting each computer, (2) Internet enabled network, and (3) ANUNET connecting all DAE units. Any malfunction of a single computer might have resulted in network failure. To our great satisfaction there was no failure. We reported this to a centralized monitoring team in Mumbai. Similarly, all units of DAE were on alert. We successfully passed over possible calamity without any issue.

With great satisfaction, I look back to the period when we worked as dedicated soldiers of a great scientific organization like AMD. Its evolution is amazing. Now as a retired scientist, I am happy to see AMD progressing very fast and ready to meet its obligation to DAE and our nation. I wish AMD a great future in days to come.

Role of geophysics in AMD

Shankar Mishra
(Former Incharge, Exploration Geophysics Group)

Date of Birth: 24.02.1946 *Date of joining AMD: 16.02.1970* *Date of superannuation: 28.02.2006*

Shri Shankar Mishra obtained M.Sc. (Physics) from Bihar University, Muzzaffarpur, Bihar. He joined AMD in 1970. He superannuated as Incharge, Exploration Geophysics Group in February 2006.

Radioactivity of the uranium-bearing minerals is a very important property, solely over which most of AMD exploration programme depends. However, its applicability is confined only to shallow deposits having surficial signatures. The size and concentration of the uranium deposits is usually such that they cannot produce detectable non-radiometric, i.e., magnetic, gravity, resistivity, induced polarization and conductivity, geophysical anomalies. But the world's richest and the largest uranium deposits in Canada and Australia having virtually no surface indications were discovered by geophysical techniques.

AMD having probed the favourable near surface environs with its continued intense exploration activities, it is now exigent to evolve and adopt an effective exploration strategy to search for concealed high grade and large tonnage uranium deposits, which are commercially exploitable. India is endowed with three giant Proterozoic basins, viz., Cuddapah, Chhattisgarh and Vindhyan and a number of smaller basins like Bhima, scattered around the country. The basement - sediment unconformity of these basins is thought to be favorable for uranium mineralization. Exploratory test drilling in prospective geological environs may be an idealistic approach, but in the absence of surface shows and subsurface geological data, it is very expensive and impractical. The non-radiometric geophysical techniques can probe greater depth and provide very important clues on the geological set up, nature of unconformity, presence of conducting bodies, structural dislocations and a number of other features that have relevance for locating uranium mineralization. In the context of significant role played by exploration geophysics in discoveries of concealed uranium deposits in Athabasca and other Proterozoic basins worldwide, suitable comprehensive geophysical strategy for probing deeper parts of these basins with an intent of mapping favourable structures and other controls of mineralization in highly desirable.

Aeromagnetic data provides the structural framework of the region and zones favourable for mineralization and the electromagnetic (EM) data helps in identifying conductive zones possibly associated with uranium mineralization. Ground EM surveys capable of penetrating the depth upto 1 km provide valuable clues on the mineralization associated with uranium ore. Supplementary information on the marker conductor obtained by resistivity, induced polarization and potential field (gravity, magnetic) measurements help in locating faults, shear zones, fracture zones and basement configuration underlying sedimentary basin having potential for uranium mineralization. Borehole geophysics is applied at a later stage for finer demarcation of the zones with uranium mineralization.

It is desirable to apply suitable combination of geophysical methods as the application of a single method may not yield the desired information or resolution. Availability of nano-technology and PC-based high-speed computation have resulted in the development of the state-of-the-art equipments capable of recording subtle signatures of deep

seated mineralized zone ranging from a few meters to a few kilometers. AMD has acquired one latest such geophysical equipment called "Multifunction Transmitter Receiver system". This system consists of high power transmitter (30 kW) and 10 channel receiver capable of acquiring all geophysical electrical parameters, like controlled source audio frequency magneto telluric (CSAMT), time and frequency domain EM, time and frequency domain induced polarization and spectral IP. In frequency domain mode, the transmitter has frequency range from 0.06 Hz to 8192 Hz in 54 steps. The receiver is microprocessor controlled with 10 input channels for simultaneous measurement equipped with real time calibration, automatic gain and SP control, bad sample rejection, on-site editing, notch filters, and stacking capability. Data is stored in RAM and can be transferred later to a field computer for processing and interpretation. The unique feature of this system is that it has the capability to measure CSAMT parameters apart from the other conventional EM and IP measurements. In CSAMT method, a high power transmitter is used to energize the ground to overcome the problem of weak signal encountered in Audio Magnetotelluric and Magnetotelluric surveys. The greatest advantage for this method is that it generates stronger and coherent signal, better signal to noise ratio, and is a rapid and less costly survey. The parameters measured are magnitudes and relative phases of both parallel electric field and orthogonal magnetic field at a specified frequency. The apparent resistivity and phase differences are calculated using standard "Cagniard" equation. The electric field and magnetic field measurement is more diagnostic for resistive and conductive targets respectively; hence this method gives the complete resistivity and conductivity structures of the subsurface. In CSAMT survey, the distance between transmitter and receiver locations is a constraint. This distance should be greater than 3 times the skin depth so that plane wave assumption is valid and "Cagniard" equation can be used. This method will be more suitable in geological environs, where overburden is conductive in nature.

There are several advantages of this method over other EM methods. The effective depth of penetration in CSAMT is not a function of the received dipole length or the distance between transmitter and receiver. The effective depth of detection therefore depends upon the frequency and may be several hundred meters to kilometers, depending upon the characteristics of conductor at depth. It offers excellent lateral resolution, dependent only upon the length of the received dipole, independent of the transmitter and receiver distance. The length of the receiver dipole can be adjusted to the size of the target, with no loss in depth of penetration. The topographic relation between transmitter and receiver is not an important factor since the measured value is normalized at the receiver. This fact makes CSAMT particularly useful in mountainous or remote regions. The location of a large loop transmitter for time and frequency domain EM is often critical to anomaly response. CSAMT, on the other hand, is much more independent of transmitter location with reasonable large distance between transmitter and receiver. Intervening conductors between them do not affect the relative phase shift and amplitude ratio between E and H fields. The parameters are controlled by local resistivity around measuring point and each station is essentially a point sounding. Fewer receiver dipole measurements are required to represent an anomaly in CSAMT method, whereas in other EM and resistivity methods, to obtain satisfactory anomaly shape information, the measurements have to be performed on either side of the anomaly. Wide frequency range from 0.06 to 8192 Hz in 54 steps provides very shallow to very deep soundings, thus making the interpretation more effective. Ten channel provided in the receiver will yield high productivity through simultaneous multi-station measurements.

I am sure, with the induction of this system in the Group, my dedicated colleagues will be able to support the exploration programme for concealed uranium deposits at greater depth.

Some fond memories

D.B. Sen

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Date of Birth:09.04.1946 *Date of joining AMD: 19.01.1973* *Date of superannuation: 30.04.2006*

Shri D.B. Sen obtained M.Sc. (Applied Geology) from Peoples Friendship University, Moscow, Russia. He joined AMD in 1973. He superannuated as Additional Director (Operations-I) in April 2006. He has published 16 articles/papers in national and international journals.

A group of geoscientists were recruited in 1973 to boost the country's atomic minerals inventory, while news was afloat that the AMD Headquarters would be shifted from New Delhi to Hyderabad in near future. I was lucky to be one of them. At that time, mineable, proven uranium reserves were located only in the Singhbhum Thrust Belt (STB) although quite a few uranium-bearing areas of various magnitudes were known in many parts of the country. I was posted in the then Western Circle, now Central Region, with Headquarters at Nagpur.

Life in AMD was full of challenges, thrill, adventure, and joy. Let me share some of my most cherishable and fond memories in AMD.

Two days after joining, I was sent to the field area in Rajnandgaon district, then in Madhya Pradesh. After a couple of days of preliminary introduction in the techniques of radiometric survey and related activities in the Udrichhapar camp near Dongargarh, my field party Incharge, Shri D.S. Sharma, took me to Ambagarh Chowki, taught me how to pitch a tent and the very next day he went away, with a strict instruction that I must shift my camp every ten days. Not to mention, I was supposed to arrange the shifting with the available local resources, which were nothing but bullock carts. My life in AMD started thus.

As a beginner's luck would have it, within 40 days of joining AMD, I was fortunate to discover a significant uranium anomaly near Bodal village, south of the Seonath River. The host rock was very unusual, appeared to be an amphibolite rock, which comprised mainly of quartz, hornblende and biotite. At that time, the perception was that basic rocks were low in priority as a normal host for uranium mineralisation. As the surveys were taken only on foot, I used to check each and every rock that came on my route. Hence, the uranium anomaly in a basic-looking rock was rather a sensation. Unconventional approach at times brings success!

Another satisfactory moment was when in the late 1980s, we set up a uranium heap-leaching plant at 3000 m height near Kandi village, Himachal Pradesh. Everything was shifted from Seri Camp, on head load over about 20 km and crossing two ridges. It was a challenge well met by all my colleagues of the then Project Rampur Window. Credits for accomplishing such a herculean task go in equal measure to the Mineral Technology Laboratory of the Northern Region, AMD.

While on the Himalayas, another moment of immense satisfaction was the discovery of an angular unconformity between the Manikaran Quartzite and Green Bed Formation near Dharmoar village in Chhinjra area, Parvati Valley. This unconformity was duly recognized by the GSI and was cited in one of the publications on the Himachal Himalaya.

Another memory that I would cherish forever is proving of significant tonnage of uranium in Wahkyn area in a record time since the discovery of high-grade mineralisation there. This was

achieved by developing infrastructural facilities in a most inhospitable, malaria-infested terrain in Meghalaya, without any roads or any other camping facilities. As there was no village nearby, the name Wahkyn was coined by my colleagues, the area being the confluence of Wahblei and Kynshie rivers. Initially, some of my dare-devil colleagues were camping on the sandy island at the confluence, always a threat of washing away of the camp being there. All rock faces were checked, cleaned, and logged by shielded-probe on a make-shift raft or by moving across waist-deep water. It was an adventure in real sense of it. A geologist's job is really a thrilling one!

Similarly, the foot tracks on both banks of the Wahblei River and across the Plu nala were widened manually for enabling shifting of drilling rigs and other machinery. Though elephants were often crossing the Wahblei River in our areas of activity, our workers took the challenge and shifted the rigs in record time before onset of monsoon. Despite the threat of cerebral malaria and terrain constraint, our drilling officers and staff achieved the targets on time. They did a commendable job!

Indeed, AMD is such an organization that gives an opportunity to fulfill one's heart's desire of leading an eventful professional life.

Geomicrobiology – its significance in Uranium ore beneficiation

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The aim of this article is to increase awareness, among fellow scientists, of some of the important roles that certain types of microbes have played and are playing as geological agents in the ore forming processes.

Microbes and the evolution of the Earth in the Precambrian

It seems certain that since the early Precambrian, the activity of microbes has had an impact on the evolution of the Earth's surface, including the upper most lithosphere and the hydrosphere. Microbial activity has also had an impact on the composition of the atmosphere. It is now generally accepted that bacteria of various kinds were the only form of life on earth during the Precambrian, from about 4 billion years ago, when cellular life is thought to have originated, to about 2 billion years ago. The evidence for the existence of the earliest life rests mainly on carbon isotope data from the banded iron formation and on the discovery of prokaryotic micro-fossils and the earliest eukaryotic fossils and megascopic algae. The earliest microfossils were recognized as remains of bacterial microbes because their shapes appear similar to those of currently living bacteria. Because of this resemblance, it has been inferred that these ancient microbes must have had a complexity in cellular structure and function close to that of their modern counterparts and that they evolved from primitive ancestors existing hundreds of millions of years earlier. Micro-organisms must have evolved with an ability to conserve energy from sunlight (phototrophy) and from the oxidation or reduction of certain inorganic elements that can exist in more than one oxidation states (chemo-lithotrophy). At the same time, phototrophs and lithotrophs learned to form reduced (organic) carbon from CO_2. The emergence of oxygenic photosynthesizing microbes (cyanobacteria formerly called blue-green algae), which reduced CO_2 with H_2O by a light driven reaction, $H_2O + CO_2 \rightarrow (CH_2O) + O_2$. By inferring that early Precambrian microbes were bacterial, it is implied that they possessed a prokaryotic cell organization. Typical prokaryotic cells are delimited by a wall or cell envelope overlying a cell membrane that encloses the cell interior. These cells contain their genetic information encoded in DNA.

Geological processes affected by microbes

Rock and mineral weathering is one process in which microbes very often play an important role by promoting mineral diagenesis and dissolution. In some instances, their weathering action may be due to the formation of metabolic products, especially when the microbes live in a film on the surface of rock or mineral. In other instances, their weathering action may be the result of oxidative or reductive attack of appropriately reactive mineral constituents (e.g., Fe, Mn, sulphide, sulphate) or a rock or mineral. All types of igneous and sedimentary rocks are susceptible to microbial weathering including siliceous and calcareous rocks.

Rock weathering by metabolic products of microbes

Some microbes excrete chemical agents that corrode the rock through chemical interaction or by oxidizing or reducing a rock component that leads to minerals diagenesis or dissolution. These chemical agents may include the inorganic acids like HNO_3 and H_2SO_4 and organic acids such as citric, oxalic and gluconic acids produced mainly by fungi and formic, acetic, lactic, pyruvic, succinic, 2-ketogluconic acid produced by bacteria. Microbes that cause rock weathering by excretion of corrosive agents often grow on the surface of the rock in the form of a biofilm or colony. Microbial weathering of rocks is involved in deterioration of natural building stone or concrete and stone sculptures. Limestone and sandstone are especially susceptible to this action.

Mobilization of metals in metal sulphides (biomining)

The chemical reaction in weathering of rocks and minerals by microbial metabolic products does not usually involve direct microbial catalysis. However, some weathering processes involving redox reactions may be directly catalyzed by microbes. An example is the mobilisation of metals from metal sulphides, which is now termed as 'biomining' and is now being practiced commercially for the extraction of metals like copper, uranium, nickel, molybdenum, cobalt and gold from lean grade ores.

The enthusiasm of the microbiologists working on the development of the 'biomining' techniques is matched by a need in the minerals industry to find alternatives to conventional methods of mining, ore processing and waste water treatments. The need arises from recent trends in the industry due to (a) continued depletion of high grade mineral resources, (b) the resulting tendency for mining to be extended deeper underground, (c) the growing awareness of environmental issues, (d) burning of sulphur-rich fossil fuels, and (e) the rising cost of high amount of energy required in the conventional recovery methods.

Nowadays, bioleaching occupies an increasingly important place among the available mining technologies. It is a promising technology with an economical alternative for treating specific mineral ores. A number of large-scale bioleaching operations are located in developing countries, which have significant mineral reserves and mining constitutes one of their main sources of income. Another advantage of adopting this technology may be of its simplicity and low capital cost requirements.

Hydrometallurgical extraction (leaching) of copper from ore and the precipitation of copper from the resultant solutions by treatment with metallic iron (cementation process) is an ancient technology. The Chinese practiced a form of this technology as far back as 100-200 BC. The practice of copper leaching and cementation was refined through the centuries and has continued to the present day. In 1951, Colmer, Temple and Hinkle reported the involvement of bacteria in the oxidation of pyrite inclusions of bituminous coal and identified this bacteria a *Thiobacillus ferrooxidans.*

In the early 1960s, uranium mine operators found that the mine waters were acidic in nature and also contained soluble uranium. *Thiobacillus ferrooxidans* was also found to be present in these mine waters. This confirmed the active catalytic role of this iron oxidizer in solubilisation of uranium from the ores. A lot of study on morphology and physiology of *Thiobacillus ferrooxidans* has been carried out over the years and different strains have been identified. Other bacterial species of *Lepto spirillum* and thermophilic *Sulpholobus sp*. have also been studied and used for leaching of metals from sulphide ores.

The principal bacteria, which play the most important role in solubilising sulphidic minerals at moderate temperatures are species of the genus *Thiobacillus*. Most species are mesophilic, acid tolerant and acidophilic. Some grow best at pH 2 and may grow even at 0.5 pH. *Thiobacillus* are chemo-lithoautotrophs, which means that carbon

dioxide is the only source of carbon and they derive their energy from chemical transformation of inorganic matter or ferrous iron available in pyrite in ores. All Thiobacilli oxidise sulphur or sulphur compounds to sulphate or sulphuric acid.

Thiobacillus ferrooxidans can oxidise hydrogen sulphide, thiosulphate, polythionates or elemental sulphur. They produce hydrogen ions thereby lowering the pH of medium, often below pH 2, in some cases even below pH 1. In addition to the oxidation of sulphur and sulphur compounds, *Thiobacillus ferrooxidans* is able to oxidize ferrous to ferric ion and so derive its energy from this exergonic reaction, owing to its ability to oxidise ferrous ion to ferric ion (ferric sulphate), which is the principal agent of ore leaching at moderate temperature.

During the oxidation reactions, sulphuric acid and ferrous sulphate are regenerated. Sulphuric acid generated maintains the acidic pH of the leaching solution. Further addition of sulphuric acid is avoided. Ferrous sulphate is required as the energy source for growth of *Thiobacillus ferrooxidans.*

Bacterial leaching of ores has been applied on a large-scale for many years almost solely to leach copper and uranium ores. In the past few years, this has been carried out in many countries like Canada, USA, Mexico, Australia, India, USSR, Turkey, Yugoslavia, Romania, Hungary, Spain and some other countries.

Dump / Heap Leaching

The most common applied method is based on percolation of leach solutions on the big ore dumps set up on impermeable ground usually valleys. The ore size has to be such that leach liquor could percolate through the heap or dump and air may enter from the sides.

The leach liquor is sprayed on the top of the dumps / heaps by sprinklers or flooding of ponds. At the bottom liquor is collected in a reservoir from which it is pumped back on top of the dump after adjusting pH and nutrients in the liquor. The metals can be recovered from leach liquor using cementation or ion exchange process and the barren solution can be recycled.

In the uranium industry, there were several applications of biologically mediated heap leaching. At Dension Mines in Elliot lake, Ontario, an underground heap leaching method was successfully developed, eventually contributing almost a quarter of mine production. Uranium was leached by acidic ferric solution produced by bacterial oxidation of pyrite present in the ore. About 800,000kg of uranium alone was produced during 1987 and 1988.

In-situ Leaching

In this technique the ore is not moved from its geological setting with the advantage that excavating costs can be saved. But difficulties arise if the ore body is impermeable or if there are only a few channels through which the leach liquor would pass without percolating through the whole ore body. In such cases the ore body has to be cracked by explosions, because it is necessary to collect the leach liquor after it has passed through the ore body. Unsuitable sitting may lead to escape of large quantities of leach solution underground which may pollute the ground water.

In-situ leaching was developed in 1960 in the former Soviet Union as well as in central and eastern Europe. Commercial in-situ leach uranium mining in the U.S.A. began in mid-1970. The first commercial in-situ leaching was upgraded at Utah Construction and Mining Corporation at their Shirley Basin mine at Wyoming. Both acid and alkaline leach had been adopted. Other countries which have adopted this technique are Germany, Bulgaria, Ukraine, Uzbekistan and China.

The leaching solution (acid or alkali) containing oxidants that can mobilize uranium are injected into the ore zone below the water table. The leaching solutions are pumped up to the surface from production well, where the uranium is recovered by ion-exchange method and further processed. *Thiobacillus ferrooxidans* culture can

be mixed with the acidic solutions in place of chemical oxidants to enhance the oxidation rates of the reactions, which could be a useful tool for enhancing the uranium leachability. Experimental studies need to be carried out at laboratory stage before applying on industrial scale.

Tank Leaching

While biological heap leaching has been practiced for a long time, agitated tank bioleaching is more recent and largely been restricted to gold ores. Biox ® process from Gold fields, GFL, Mining services at their Fairview plant in South Africa was started in 1986, its first commercial scale operation to process 10 tonnes per day (tpd) of arsenopyrite concentrate. Subsequently, it was scaled upto 40 tpd and 1000 tpd (Ashanti gold fields, Sansu Project in Ghana, 1995). Other companies like Bach Tech Environmental (Australia) now based in Toronto (Canada) and Mintek (South Africa) have formed a joint venture to market this technology. The only commercial application of tank bioleach process in the North American Gold Industry is at Tonkin springs in Nevada, U.S.A.

New Developments

Biotechnology in mining is now going for a big leap forward by using new bacterial cultures, mixed cultures of thermophiles, which are active at more than 50°C in slurries in agitated tanks. Early laboratory testing of processes using extreme thermophiles have indicted recoveries of about 94 to 99%. Heap leaching will continue to be the choice of low grade ores and tailings specially treating low grade uranium deposits of India and tailings from mill, while tank bioleaching technology would be useful for leaching gold, copper and other base metal ores. Developing countries should increase their efforts in research and development in bioleaching technology as they have comparative advantage over conventional leaching technology.

Atomic Minerals Directorate for Exploration and Research has carried out isolation and identification of microorganisms from the uraniferous ore samples of various uranium deposits of the country. Some of the species of *Thiobacillus ferrooxidans* were used for extraction of uranium from ores and some of the fungal species were tested for biosorption of uranium and Radium-226 from the uranium mill effluents. The work on these studies over a period of more than 35 years was published in national and international Journals / IAEA TECDOCS.

Photographs on the cover pages

All the photographs utilised in the cover pages are from the archive of Planning & Management Services Group, AMD, Hyderabad