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Uranium Potential of Singhbhum Shear Zone, India: Future Prospects

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INTRODUCTION

The Singhbhum Shear Zone (SSZ), Jharkhand, India is one of the major uranium producing provinces of India, which hosts several uranium deposits. The SSZ uranium province has potential to host large tonnage of uranium resources besides metals like Cu, Ni, Mo, REE, Fe and Mg, etc. The proven uranium resource in the province as on July, 2017 is 64392tU3O8 (54604tU). The producing centres namely Jaduguda (from 1968), Bhatin (from 1986), Narwapahar (from 1995), Turamdih (from 2003), Bagjata (from 2008) and Mohuldih (from 2012) have been developed as underground mines and Banduhurang (from 2009) as open cast mine from this province. Recent conceptual work carried out by Atomic Minerals Directorate (AMD) based on new exploration strategies, has paved the way for resource addition in adjoining blocks of existing mining centres, thereby extending the life-span of the mines. Besides, conceptual exploration strategy has given encouraging results and has helped in identifying potential new zones. A few significant discoveries have come to light which are reorienting the exploration programme to enhance the resource base of SSZ from its present level to a much higher level. Present paper describes a few of them and plan for future exploration by AMD.

GEOLOGICAL SETTING

The SSZ is a 200km long arcuate belt of high strain characterized by multi-phase deformation, intense ductile shearing, multiple metasomatic features including imprints of sodic metasomatism and polymetallic mineralization [1]. It participated in the subsequent ductile deformations which obliterated a majority of earlier features [2]. The arcuate shaped SSZ involves various lithounits of Archaean to Neo-Proterozoic period. The oldest rocks representing ≥ 3.4 to 2.6 Ga period are Older Metamorphic Group (OMG), Older Metamorphic and Tonalite Gneiss (OMTG), unclassified mafic-ultramafic rocks occurring as enclaves within Singhbhum Granitoids, Banded Iron Formation (BIF) of Badampahar –Gorumahisani Belt, acid volcanics and ultramafic dykes of 2.6 Ga [3] which have suffered the SSZ related deformation especially along the arcuate belt. Probably uranium proto-ore was supplied from these Archaean lithologies and got concentrated in overlying Quartz-Pebble-Conglomerate (QPC), occurring at the base of Iron Ore Group (IOG) and also Dhanjori Group. The IOG comprises conglomerate, phyllites-shale-wacke, quartzite, Banded Magnetite Quartzite (BMQ), ultramafics, acid volcanics, tuffaceous units, grits, etc. Dhanjori Group comprises volcano-sedimentary sequence containing quartzite-conglomerate, mafic ultramafic flows and intrusives with tholeiitic (pillowed) basalt interlayered with tuffs (2.1 Ga) overlying the IOG. The rocks of Dhanjori Group are overlain by Singhbhum Group which comprises quartzite-conglomerate (oligomictic and polymictic), feldspathic schist, granite mylonite, sericite-quartz-schist, chlorite-quartz-schist (and their mineralogical variants), metabasic sills, mica schists and quartzites. The lower part of Singhbhum Group comprising the Chaibasa Formation represents a metasedimetary package in which non-diastrophic structures are preserved despite many deformational episodes. Deep to shallow marine turbidite, peri-tidal shallow, or even a totally fluvial depositional environment, have been proposed. Perhaps more than one environment coexisted in the region. The upper part of Singhbhum Group constitutes the Dhalbhum Formation comprising phyllites and ortho-quartzites have been interpreted as a meandering channel system [1]. Apart from the extensive Singhbhum Granite of different phases, several younger isolated granitic bodies are also exposed along the SSZ, such as Chakradharpur Granite (CKPG), Arkasani Granophyre (AG) and Soda Granite (SG) (now seen as feldspathic schists). Several younger mafic and ultramafic bodies have been emplaced all along the shear zone. These bodies vary in age, and therefore show repeated tapping of mantle during the process of shearing or even in post-shearing period.

The rocks of SSZ are characterized by compositional banding subparallel to major foliation. Large scale fold structures with sub horizontal to low plunging axes are seen on the northern side of SSZ. The shear zone is characterized by presence of small scale reclined folds, strong foliation as well as a strong set of downdip lineation of tectonic origin. Mylonites are commonly present in almost all rock types that are involved in shearing. These can be classified as L-S type tectonites [4]. Gentle warps along N-S axial planes mark a late deformation event postdating the shearing event. The shear zone rocks have been affected by progressive and retrogressive metamorphism. The grade is green schist in central part which has major uranium deposits. The chlorite-quartz schist and quartz-chlorite-schists are the major host rock for uranium and copper mineralization.

NATURE OF URANIUM MINERALISATION

The uranium mineralization is confined to the arcuate SSZ from Duarpuram in the west to Baharagora in the southeast. The arcuate shape is possibly due to the fact that Singhbhum Craton acted as buttress against stresses from NNE direction. The resultant structure is an anticlinorium of isoclinally folded rocks dipping consistently north and marked by a prominent shear zone with crushed and mylonitised rocks [5]. This has provided an ideal situation for mineralizing fluids to form shear controlled hydrothermally generated metamorphite type of deposits in addition to proto-ore and QPC environment. The metamorphite deposits occur as disseminations, impregnations and veins along shear planes within or affecting metamorphic rocks of various ages. These deposits are highly variable in size, resource and grade [6]. The deposits of Central Sector of SSZ (Narwapahar, Turamdih and Mohuldih) are peneconcordant, gradational strata bound and hosted in relatively lower metamorphic grade of rocks, whereas the deposits of eastern sector (Jaduguda, Bhatin, Bagjata and Kanyaluka) are discordant and vein-like associated with host rocks of relatively higher grade of metamorphism. Uranium mineralization is confined to Chaibasa-Dhanjori interface depending upon intensity of shear. In most of the cases mineralization is bottomed at the lowest unit of Chaibasa Group or upper part of Dhanjori metasediments. Quartz-sericite to sericite-quartz schists have been considered as the marker for bottom of uranium mineralization [7]. The uranium mineralization in SSZ is present in sheared low grade metamorphic rocks, viz., quartz-chlorite schist or quartz-biotite schist. However, it is absent in hornblende –(or actinolite) schist. This feature indicates that favourable rocks for U-mineralization are of green schist facies rather than epidote-amphibolite facies or rocks of ultrabasic composition (actinolite schist) [8]. Uranium mineralization is represented by uraninite, minor pitchblende, brannerite, U-Ti complex, which occurs in many instances in association with sulphide mineralization of chalcopyrite, minor bornite, chalcocite, covellite and molybdenite and oxides like magnetite, ilmenite, titano-magnetite, etc. The mineralogy is complex and the chemistry of the ores, particularly U and Cu, is greatly influenced by the host rock involved in shearing. Shear zone transgressing to Dhanjori Group (Jublatola) is richer in U, Cu, Ni, Mo [(±) Bi, Au, Ag, Te & Se], whereas in schists and quartzite of Chaibasa Formation it is poorer in above metals. Peneconcordance of ore bodies with host lithologies is seen in Chaibasa Formation [9].

CONCEPTS ON ORE GENESIS

Various modes of occurrence for uranium mineralization have been reported from SSZ. Titanium oxide-uranium oxide grain aggregates found in Jaduguda-Bhatin deposits are related to QPC-type of environment where primary and secondary brannerite have been reported [10]. Three generations of uraninite have been seen in SSZ in which last phase is post-sulphide mineralization. The refractory uranium bearing minerals (allanite, xenotime, monazite, sphene, etc) and uranium associated with apatite-magnetite veins are the product of pneumatolytic –hydrothermal metasomatism probably related to younger granitic phases referred earlier (AG and SG). The uraninite associated with feldspathic schist (˜SG) in Narwapahar-Turamdih sector has been correlated with metasomatic feldspathisation process and subsequent remobilization to form ore bodies [11]. On the basis of various observations, it was proposed that geochemical source of U was Singhbhum Granitoid, whereas the basic rocks of Dhanjori Group provided Cu, Ni and Mo for the formation of U-Cu deposits of SSZ [12]. Mahadevan [9] has concluded that U was enriched in Singhbhum Granite by partial melting of the upper mantle/ lower crust around 2900-3000 Ma. This continued till 1900Ma (Mayurbhanj and Nilgiri Granitoid) and 1420 Ma (SG). QPCs at the base of IOG and Dhanjori Group show evidence of detrital accumulation of uranium bearing minerals. These U-concentrations along with host rocks got folded into a major synclinal sequence prior to involvement in shearing episodes. Shearing episodes have further remobilised and reconstituted uranium mineralization concomitant with the early folding events, F1 and F2. The localization of U-Cu lodes with predominant platy minerals, particularly chlorite, is controlled by deformation and metamorphism of Chaibasa and Dhanjori rocks simultaneously. The younger granites namely CKPG, AG and SG along with younger basic units, formed by partial melting of lower crust –upper mantle interface generated geothermal gradient [9]. Mantle metasomatism or crustal contamination of upheaving melts cannot be ruled out in such cases, which would have generated diverse type of uranium mineralization hitherto not known. The chemical and structural characteristics of various uraninites differ from east to west and from north to south i.e. along and across the strike of the SSZ. The uraninite composition varies from UO2.31 to UO2.44 and cell dimension from 5.42 Å to 5.45 Å [11]. Larger cell dimension has been found in eastern and western part of the SSZ while it is comparatively smaller in Central Sector (Jaduguda).

URANIUM MINERALISATION-NEW CONCEPT/ ENVIRONMENT

(i) QPC Related U-Mineralisation: The potentiality of QPC as a paying horizon for U ± Au is yet to be established in Singhbhum Province. The QPC at the base of IOG and Dhanjori have been known from SSZ area. They have been involved in shearing episodes as well but retained their primary features in some shadow zones. Recent attempt by faster non-core drilling upto depth of 300m has provided insight to QPC-related horizons and their continuity in lenses. The exploration in western half of SSZ (Jamshedpur as centre) has resulted in identification of subsurface conglomerate bands with U-Th mixed anomalies at shallower level while uraniferous bands are found at deeper level (250-300m depth). Repeated nature of Th, U+Th and U-enriched bands at Gura and occurrence of intermittent yet significant QPC horizon over a considerable stretch of 35km along Udalkham-Manikbazar- Simulbera sector has strengthened the concept of exploration for QPC type of mineralization. Magnetite is predominant in these conglomerates and hematite is absent. Similarly, deformed uraniferous conglomerate of Jaduguda occurring above Dhanjori meta-basic/ basalt and its probable western continuity at Nimdih and further towards west at Chirugora, and its eastern continuity in Rakha mines, has generated interest to explore the whole belt where QPC is missing on surface. The concept is being tested with the help of huge non-core and core drilling programme of AMD.

(ii) Arkasani Granophyre Related U-Mineralisation: The SSZ bifurcates into two arms at Narwapahar and continues further westwards where Bangurdih-Gurulpada sector forms the southern segment of the shear while Sankadih-Galudih forms the northern shear plane of SSZ. The surface uranium occurrences defining an E-W trend along Banaykela, Gurulpada, Mahalimurup, Dhadkidih, Dugridih, Nilmohanpur, Ukri and Bijay areas are confined to southern shear while Sankadih, Saharbera, Sarmali and Tirildih are situated along northern segment. The northern shear has association of Arkasani Granophyre (AG) and Soda Granite (SG) as evidenced on outcrop level. Recent efforts in exploring the soil covered area between Sankadih and Galudih by non-core drilling has established uranium mineralization over a strike length of 360m upto depth of 120m in two series with grade ranging between 0.021 and 0.043%U3O8. Ground geophysics helped in identification of borehole location and understanding of target depths. This has established 800m strike length located west of main Sankadih ore block. The correlatable uraniferous mineralization is confined to Arkasani Granophyre / Feldspathic schist. The subsurface continuity in this unit has generated new concept to explore Arkasani Granophyre magmatic-hydrothermal related mineralization adjacent to SSZ.

The shear-controlled chlorite-biotite-quartz schist hosted uranium mineralization at Sankadih occurs near the contact of AG. Even schistose rocks occurring within the AG show presence of uranium [13]. This phase of uranium mineralization has been correlated with major episode of deposit formation in SSZ. The emplacement of AG and SG is syn- to post-major shearing phenomenon. The chalcopyrites developed in the schist show magmatic (+0.9 to + 1.4 δ34 S o/oo, n=2) and metamorphic (+2.6 to 3.4 δ34 So/oo, n=3) parentage, indicating later remobilisation under metamorphic conditions [13]. In other words, it is interpreted that AG has brought magmatic and metamorphic effects to shear zone rocks and probably supported in recycling of U-mineralisation in subsequent episodes. The concept developed has been tested. The investigations have resulted in encouraging values of uranium mineralisation related to AG.

(iii) Serpentinised Peridotite Hosted U-Fe-Mg-Cr-Ni-Mo-REE-C Mineralization: In pursuit of developing new concept and to satisfy our quest for knowledge a few boreholes were planned to extend beyond the quartz-chlorite and quartz-sericite-schist (marker for bottoming of uranium mineralization in SSZ) of Chaibasa Formation in Kudada-Turamdih area. The investigation recorded a new type of environment where polymetallic (U-Fe-Mg-Cr-Ni-Mo-REE-C) mineralization hosted by serpentinised peridotite has been established in four boreholes of Kudada (south of Turamdih Group of deposits). The corresponding surface mineralization has been located in the Kudada Protected Forest Area. The peridotite is emplaced at the interface of IOG and Chaibasa Formation, as Dhanjori Group of volcano-sedimentary rocks appear to be absent in this sector. The possibility of the peridotite to be representative of IOG or Dhanjori cannot be ruled out.

The host peridotite comprises relict olivine (after serpentinisation) and pyroxenes (after chloritisation) of 200-300 micron size. Presence of chromite and magnetite have been established. Uraninite (subhedral to anhedral) varying from a few microns to 600 microns are disseminated within the serpentinised peridotitic ground mass. Clustering of uraninite (˜ 3 grains) are common feature. Unit cell dimension of uraninite range from 5.4498 to 5.4650 Å (n=2) and matches well with other uraninite of SSZ showing high temperature of crystallization. XRD studies have confirmed uraninite and traces of beta-uranophane and monazite. Other ore minerals are magnetite, molybdenite, cobaltite (CoAsS), nickeline (NiAs), vaesite (NiS2), cerussite (PbCO3), pyrite, chalcopyrite and chamosite. Talc and fluorapatite occur as gangue [14]. Chemical analysis (n=10) of peridotite shows MgO (18-28%), FeO (3-17%), Fe2O3 (t) (2-23%), Cr (1623-3165ppm), Ni (221-1347ppm), Mo (<10-485ppm), Co (43-633ppm) and V (36-230ppm). REE (t) is enriched upto 1457ppm (n=5) when compared to non-mineralized host rock (558 ppm, n=4).

The geological environment for uranium mineralization intercepted in Kudada-Turamdih area is an unusual one and not reported from SSZ, and hence requires in-depth studies. Recent investigations have enhanced the potentiality of SSZ for a mega deposit hitherto unknown, developed due to work carried out recently.

(iv) Tirukocha Fault Related Exploration: The eastern part of SSZ records a few prominent faults related to brittle deformation as a post-shearing phenomenon. The Tirukocha Fault between Bhatin and Jaduguda, and Gohala Fault between Bagjata and Kanyaluka have affected the uranium mineralization. Both the faults have been represented in Total Magnetic Intensity (TMI) Image for central part of SSZ prepared by AMD. The integrated studies carried out based on geological mapping and collection of subsurface data from boreholes and underground Jaduguda mines, suggests its oblique slip nature. The surface manifestation of Tirukocha fault is identified by the clear displacement of the quartzite unit of Chaibasa Formation in Jaduguda by about 1km dextrally on plan. The level plan made on marker quartzite depicts a lateral displacement of about 1.07km with a vertical separation of 570m [15]. These measurements are significant understanding for exploration in Jaduguda-Tirukocha area where substantial tonnage is unexplored. The concept is tested and a few boreholes have picked up mineralization based on above understanding. Exploration so far indicates that richer grades are extending further east. This calls for meticulous planning in the east where the ore body and the fault plane make an intersection line plunging steeply towards northeast direction. Calculation of the intersection of the two planes indicates that intercepts of better grade (G) and thickness (T) values can be expected further eastward with each deeper series.

CONCLUSION

The sustained studies leading to the generation of additional geophysical, mineralogical, geochemical inputs have been integrated with new concepts on exploration, thereby developing an exploration strategy in SSZ for next five years. The strategy, inter alia, includes the concepts on:

(i) QPC related uranium mineralization.
(ii) Arkasani Granophyre related uranium mineralization.
(iii) Altered peridotite hosted polymetallic mineralization.
(iv) Mineralisation related to brittle tectonics along Tirukocha Fault.

Atomic Minerals Directorate for Exploration and Research (AMD) has already envisaged substantial coring and non-coring drilling to prove at least 15,000 t U_3O_8.

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