URANIUM POTENTIAL OF THE SINGHBHUM SHEAR ZONE, INDIA: FUTURE PROSPECTS

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1. INTRODUCTION

The Singhbhum Shear Zone (SSZ), Jharkhand, India, hosts several uranium deposits and is one of the major uranium producing provinces of India. The SSZ uranium province has the potential to host significant uranium resources in addition to metals such as Cu, Ni, Mo, REE, Fe and Mg. Proven uranium resources in the province as of July 2017 were 64,392 tU₃O₈ (54,604 tU). 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 an open pit. Recent conceptual work carried out by the Atomic Minerals Directorate for Exploration and Research based on new exploration strategies, has paved the way for additional resources to be located in the adjoining blocks of the existing mining centres, thereby extending the lifespan of the mines. The conceptual exploration strategy has also given encouraging results and has helped to identify new potential zones. Some significant recent discoveries are reorienting the exploration programme to enhance the resource base of the SSZ significantly. The present paper describes some of the results and the plan for future exploration by Atomic Minerals Directorate, India.

2. GEOLOGICAL SETTING

The SSZ is a 200 km long arcuate belt of high strain characterized by multi-phase deformation, intense ductile shearing and multiple metasomatic features, including imprints of sodic metasomatism and polymetallic mineralization [1]. It was subjected to subsequent ductile deformations which obliterated a majority of the earlier features [2]. The arcuate shaped SSZ involves various Archaean–Neoproterozoic lithological units. The oldest rocks (≥3.4–2.6 Ga) are represented by the older metamorphic group, the older metamorphic and tonalite gneiss, unclassified mafic–ultramafic rocks occurring as enclaves within Singhbhum granitoids, banded iron formation of the Badampahar–Gorumahisani Belt, acid volcanics and ultramafic dykes of 2.6 Ga [3] which have also suffered the SSZ related deformation, especially along the arcuate belt. Uranium protore-oxy was probably supplied from these Archaean lithologies and was concentrated in the overlying quartz pebble conglomerate (QPC), occurring at the base of the iron ore group (IOG) and also the Dhanjori Group. The IOG comprises conglomerate, phyllite–shale–wacke, quartzite, banded magnetite quartzite, ultramafics, acid volcanics, tuffaceous units, grits, etc. The Dhanjori Group comprises a volcano-sedimentary sequence containing quartzite–conglomerate, mafic ultramafic flows and intrusives with tholeiitic (pillow) basalts interlayered with tuffs (2.1 Ga) overlying the IOG. Rocks of the Dhanjori Group are overlain by the Singhbhum Group which comprises quartzite–conglomerate (oligomicitic and polymeric), 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 metasedimentary package in which sedimentary structures are preserved despite many deformational episodes. Deep to shallow marine turbidite and shallow peri-tidal to fluvial depositional environments have been proposed. Perhaps more than one environment coexisted in the region. The upper part of the Singhbhum Group is the Dhalbhum Formation, comprising phyllites and ortho-quartzites which have been interpreted as a meandering channel system [1]. Apart from the extensive Singhbhum granite which comprises different phases, several younger isolated granitic bodies are also exposed along the SSZ, such as Chakradharpur granite, Arkasani Granophyre and Soda Granite (now interpreted as originally feldspathic schists). Several younger mafic and ultramafic
bodies have been emplaced along the shear zone. These bodies vary in age and therefore show repeated opening of the mantle during the process of shearing or even in the post-shearing period.

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

3. NATURE OF URANIUM MINERALIZATION

The uranium mineralization is confined to the arcuate SSZ from Duarpuram in the west to Baharagora in the south-east. The arcuate shape is possibly due to the fact that the Singhbhum Craton acted as a barrier against stresses from the NNE. The resultant structure is an anticlinorium of isoclinally folded rocks dipping consistently north and marked by a prominent shear zone with crushed and mylonitized rocks [5]. This has provided an ideal situation for mineralizing fluids to form shear controlled, hydrothermally generated metamorphite type deposits in addition to proto-ore and QPC environments. The metamorphite deposits occur as disseminations, impregnations and veins along shear planes within or affecting metamorphic rocks of various age. These deposits are highly variable in size, resource and grade [6]. Deposits of the central sector of the SSZ (Narwapahar, Turamdih and Mohuldih) are peneconcordant, , stratabound and hosted in relatively lower metamorphic grade rocks, whereas the deposits of the eastern sector (Jaduguda, Bhatin, Bagiata and Kanyaluka) are discordant and vein-like and associated with host rocks of a relatively higher grade of metamorphism. Uranium mineralization is confined at the Chaibasa–Dhanjori contact and is dependent on the intensity of the shear. In most cases, mineralization is present at the base of the lowest unit of the Chaibasa Group or in the upper level of the Dhanjori metasediments. Sericite–quartz schist has been considered as a marker at the base of uranium mineralization [7]. The mineralization in the SSZ is present in sheared low grade metamorphic rocks, i.e. quartz–chlorite schist or quartz–biotite schist. However, it is absent in hornblende (or actinolite) schist. This feature indicates that favourable host rocks for U mineralization are of greenschist 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 complexes, which occur in many instances in association with sulphide mineralization comprising chalcopyrite, minor bornite, chalcocite, covellite, molybdenite and oxides such as magnetite, ilmenite, titanomagnetite, etc. The mineralogy is complex and the chemistry of the ores, particularly U and Cu ores, is greatly influenced by the host rock involved in shearing. The shear zone, when affecting the Dhanjori Group (Jublatola), is richer in U, Cu, Ni, Mo (± Bi, Au, Ag, Te, Se), whereas when in schists and quartzite of the Chaibasa Formation it is poorer in these metals. The peneconcordance of the orebodies with the host lithologies is seen in the Chaibasa Formation [9].

4. CONCEPTS ON ORE GENESIS

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

5. **URANIUM MINERALIZATION–NEW CONCEPT/ENVIRONMENT**

5.1. **QPC-related U mineralization**

The potentiality of the QPC as an economic horizon for U ± Au is yet to be established in Singhbhum Province. The QPC at the base of IOG and Dhanjori are present in the SSZ area. They have been involved in shearing episodes as well but their primary features have been preserved in some shadow zones. Recent non-core drilling up to a depth of 300 m has provided insight into QPC-related horizons and indicated their spatial continuity in lenses. Exploration in the western half of the SSZ (Jamshedpur as centre) has resulted in the identification of subsurface conglomerate bands with U–Th mixed anomalies (placer type) at shallow levels while uraniferous bands are found at deeper levels (250–300 m). The repeated nature of Th, U+Th and U-enriched layers at Gura and the occurrence of intermittent yet significant QPC horizons over a considerable length (35 km) of the Udalkham–Manikbazar–Simulbera sector has strengthened the concept of exploration for QPC type mineralization. Magnetite is predominant in these conglomerates and haematite is absent. Similarly, deformed uraniferous conglomerates of Jaduguda occurring above the Dhanjori metabasic/basalt and its probable western continuity at Nimdih and further west towards Chirugora, and its eastern extension to Rakha mines, has generated interest in exploring the whole belt where QPC has no surface expression. The concept is being tested by Atomic Minerals Directorate through comprehensive non-core and core drilling programmes.

5.2. **A rkasani Granophyre-related U mineralization**

The SSZ bifurcates into two arms at Narwapahar and continues further westwards where the Bangurdih–Gurulpada sector forms the southern segment of the shear while Sankadih–Galudih forms the northern shear plane of the SSZ. The surface uranium occurrences, defining an E–W trend along Banaykela, Gurulpada, Mahalimurup, Dhakkidih, Dugridih, Nilmohanpur, Ukri and Bijay areas, are confined to the southern shear while Sankadih, Saharbera, Sarmali and Tirildih are situated along the northern segment. The Arkasani Granophyre and the Soda Granite are associated within the northern shear as evidenced by outcrops. Recent efforts to explore the soil covered area between Sankadih and Galudih by non-core drilling has discovered uranium mineralization over a strike length of 360 m and up to a depth of 120 m in two drilling profiles with grades in the range 0.021–0.043% U3O8. Ground geophysics has helped to define planned borehole
location and depth of the targets. A potential area with an 800-m strike length is located west of the main Sankadih ore block. The uraniferous mineralization that can be correlated is confined to the Arkasani Granophyre/feldspathic schist. The subsurface continuity in this unit has generated a new concept, namely, to explore the Arkasani Granophyre magmatic–hydrothermal mineralization adjacent to the SSZ.

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

5.3. Serpentinitized peridotite hosted U–Fe–Mg–Cr–Ni–Mo–REE–C mineralization

In order to develop new concepts and to get more information, a few boreholes were planned to extend below the quartz–chlorite and quartz–sericite schist (marker for the base of uranium mineralization in the SSZ) of the Chaibasa Formation in the Kudada–Turamdih area. The investigation discovered a new type of environment where polymetallic (U–Fe–Mg–Cr–Ni–Mo–REE–C) mineralization hosted by serpentinitized peridotite was established in four boreholes of the Kudada area, south of the 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 the IOG and the Chaibasa Formation, as the Dhanjori Group of volcano-sedimentary rocks appear to be absent in this sector. The possibility that the peridotite belonging to IOG or Dhanjori need further study, however present knowledge place it in IOG as it intrudes quartzites of IOG.

The host peridotite comprises relict olivine (after serpentinitization) and pyroxenes (after chloritization) of 200–300 μm in size. Also, the presence of chromite and magnetite has been established. Uraninites (subhedral to anhedral) varying from a few μm to 600 μm are disseminated within the serpentinitized peridotitic groundmass. Uraninite clusters (~3 grains) is a common feature. The unit cell dimension of uraninite ranges from 5.4498 to 5.4650 Å (n = 2) and corresponds well with that of other uraninites in the SSZ, indicating a high temperature of crystallization. XRD studies have confirmed the presence of uraninite and of beta-uranophane and monazite traces. Other metalliferous minerals are magnetite, molybdenite, cobaltite (CoAsS), nickel (NiAs), vanesite (NiS2), cerussite (PbCO3), pyrite, chalcopyrite and chamosite. Talc and fluorapatite occur as gangue [14]. Chemical analysis (n = 10) of peridotites gives the following values: MgO (18–28%), FeO (3–17%), Fe2O3 (t) (2–23%), Cr (1623–3165 ppm), Ni (221–1347 ppm), Mo (<10–485 ppm), Co (43–633 ppm) and V (36–230 ppm). REE (t) is enriched up to 1457 ppm (n = 5) when compared with non-mineralized host rock (558 ppm, n = 4).

The geological environment for the uranium mineralization intercepted in the Kudada–Turamdih area is an unusual one and has not been reported in the SSZ, and hence requires detailed study. Recent investigations have enhanced the potential of the SSZ with respect to the hosting of a large deposit.

5.4. Tirukocha Fault-related exploration

The eastern part of the SSZ records a few prominent faults related to brittle deformation as a post-shearing phenomenon. The Tirukocha Fault between Bhatin and Jaduguda, and the Gohala Fault between Bagjata and Kanyaluka have affected the uranium mineralization. Both faults have been identified by total magnetic intensity imaging in the central part of the SSZ. The integrated studies carried out are based on geological
mapping and the collection of subsurface data from boreholes and from the underground Jaduguda mines suggests its oblique slip nature. The surface manifestation of the Tirukocha Fault is identified by the clear displacement of the quartzite unit of the Chaibasa Formation in Jaduguda by about 1 km dextrally on plan. The level plan made on marker quartzite depicts a lateral displacement of about 1.07 km with a vertical separation of 570 m [15]. These measurements are significant and aid both geological understanding and also exploration in the Jaduguda–Tirukocha region where substantial areas remain unexplored. The concept is tested and a few boreholes have identified mineralization based on the above understanding. Exploration so far indicates that richer grades are extending further east. This will necessitate meticulous planning in the east where the orebody and the fault plane make an intersection line plunging steeply towards the north-east. Calculation of the intersection of the two planes indicates that intercepts of better grade and thickness values can be expected further eastwards with each deeper series.

6. CONCLUSION

Comprehensive studies on the SSZ have generated additional geophysical, mineralogical and geochemical data. They have been integrated to provide new concepts and develop an exploration strategy to be applied to the SSZ over the next five years. The exploration strategy will focus on four types of mineralization:

1) QPC-related uranium mineralization;
2) Arkasani Granophyre-related uranium mineralization;
3) Altered peridotite hosted polymetallic mineralization;
4) Mineralization related to brittle tectonics along the Tirukocha Fault.

Atomic Minerals Directorate for Exploration and Research has planned substantial coring and non-coring drilling to prove the existence of at least 15 000 tU3O8 as an additional resource from these new concepts.

REFERENCES


