

International Symposium on Uranium Raw Material for the Nuclear Fuel Cycle: Exploration, Mining, Production, Supply and Demand, Economics and Environmental Issues (URAM-2018)



Contribution ID: 138

Type: ORAL

GENESIS OF SANDSTONE TYPE URANIUM DEPOSIT IN DHOK PATHAN FORMATION, SIWALIK GROUP OF TRANS-INDUS SALT RANGE (SURGHAR RANGE), PAKISTAN

Thursday, June 28, 2018 9:20 AM (20 minutes)

Abstract

The Surghar Range (Trans Indus Salt Range) is a part of Himalayan Fold & Thrust Belt of Pakistan. The 5300 meters thick Siwalik rocks represent molasse type clastic sediments of fresh water nature. The Siwalik Group in Pakistan is divided into three subgroups: upper, middle and lower according to the lithological characters. The Middle Siwaliks Dhok Pathan Formation varies in thickness from 807 –1540m typically represents cyclic alternation of fluvial fining upward rhythm.

Detailed petrographic and geochemical study of surface and sub-surface core samples led to the characterization of the formation of uranium ore body and allowed to propose a metallogenic model. Scanning electron microscope (SEM) observations evidenced that a significant amount of uranium is precipitated in interstitial spaces, on and along grain boundaries in the reduced zone mainly as micro to nano crystals of UO_2 & $USiO_4$ as well as adsorbed on clay minerals in amorphous form. The uranium mineralization corresponds to synsedimentary / diagenetic concentrations which has been redistributed and remobilized due to successive phases of Himalayan Tectonics. The ore body has attained the present horizontal position, 15 –25m below present day water table. The sandstone depositional model and geochemical data suggest that the source of uranium mineralization was contained within the sediments.

Introduction

The NW Himalayan foreland Fold and Thrust belt formed by progressive south directed folding and overthrusting of slices of Indian Plate crust during the ongoing collision between India and Eurasia [1]. Following the onset of collision along the Main Mantle Thrust and its lateral equivalents during Latest Cretaceous to Early Tertiary [2], thrusting generally progressed southward with time. Most of the youngest thrusting has occurred along the frontal thrust system in the Salt Range in the east and the Trans Indus Ranges in the west. The Surghar –Shinghar Range (SSR) of the outer Himalayas represents the eastern end of the Trans-Indus Salt ranges of North Pakistan [3]. The range exhibits east-west structural trend along the southern margin of the Kohat Plateau and changes to north-south trend along the eastern flank of the Bannu Basin. The SSR forms asymmetrical, over-folded anticlinal structure plunging to the south near the Kurram River, with Permian strata exposed in the core, overlain by Mesozoic and Palaeogene rocks [4]. The western limb of the range is well exposed (present study area), while its eastern limb is deeply eroded exposing older formations. The end of marine sedimentation in SSR is marked by the deposition of fluvial rock units of Siwalik Group. The Neogene-Quaternary Siwalik Group preserved in the Himalayan foreland basin have been extensively documented along the Himalayan arc from Pakistan to Nepal, providing valuable information on mountain building in space and time, past organization of drainage networks, and paleoclimate [5].

Geologically, the Siwaliks represent molasse type clastic sediments of fresh water nature. These sediments had been accumulated in a foreland basin of the Himalaya during the third and most intense phase of deformation during the middle Miocene to Pleistocene. The Siwalik Group sediments are one of the most comprehensively studied fluvial sequences in the world. They comprise mudstones, sandstones, and coarsely bedded

conglomerates deposited at times when the region was a colossal basin during Middle Miocene to Upper Pleistocene. Rivers flowing southwards from the Greater Himalayas, resulting in extensive multi-ordered drainage systems, deposited these sediments. Following this deposition, the sediments were uplifted through intense tectonic regimes (commencing in Upper Miocene times), subsequently resulting in a unique topographical entity - the Siwalik Hills or the Siwaliks [6].

The Siwalik Group in Pakistan can be clearly divided, according to the lithological characters, into the usual three subgroups: Lower, Middle and Upper, and further into their formation scale lithostratigraphic units. The Lower Siwaliks (Kamlial and Chinji Formations) consist of a sequence of sandstone-mudstone couplets with a marked dominance of the mudstones over the sandstones. The Middle Siwaliks (Nagri and Dhok Pathan Formations) are dominantly arenaceous, consisting of multistoried coarse to fine grained (generally medium grained), light grey, bluish grey massive sandstones with subordinate representation of siltstones, mudstones and clays. The Upper Siwalik (Soan Formation) is mainly conglomeratic in nature. These sedimentary deposits are 5300 meters thick in this area. Thickness of the Dhok Pathan Formation varies from 807 to 1540 meters and represents alternate fining upward sedimentary rhythms of shale, siltstone and sandstone units [7]. The Dhok Pathan Formation of this area has assigned an age ranging from 7.5 - 2.5 Ma based on the magnetostratigraphy studies [8]. The Dhok Pathan Formation is hosting a small scale tabular sandstone type uranium deposit named as Qubul Khel Uranium Deposit after a small nearby village located in the southern part of SSR.

The present contribution is aimed to understand the genesis of this uranium deposit and to propose a metallogenic model.

Methods and Results

- i. A comprehensive geological map has been prepared with the help of high resolution satellite data, selective traversing of the area and ArcGIS 10.2 software.
- ii. Detailed sedimentological and lithofacies analyses of different sandstone and mudstone units of Dhok Pathan Formation resulted in the identification of seven distinct lithofacies (Gt, St, Sh, Ss, Sl, Fm, and Fl) which had been deposited under traction current, low and upper flow regime conditions by sand dominated large river. Paleocurrent studies indicated 210° direction of paleoflow with a braided stream pattern.
- iii. The XRD and SEM analyses of different sandstone and mudstone units (38 samples) reveal that kaolinite, smectite (montmorillonite & saponite), illite, vermiculite, and chlorite (clinocllore & chamosite) are the main clay mineral suits present in the Dhok Pathan Formation. The morphology of clay mineral suits is indicative as weathering products or the contribution from source areas. The sandstones units are classified as lithic arkose to feldspathic lith arenite based on petrographic studies.
- iv. Organic rich samples were analyzed for carbon isotopes that characterized type III kerogen mainly derived from terrestrial plants.
- v. The analyses at serial number iii & iv were carried out at State key laboratory, Breeding Base of Nuclear Resources and Environment, East China University of Technology (ECUT), Nanchang, China.
- vi. To understand the geochemical variations 28 surface and sub-surface drill core samples were analyzed for 42 elemental analyses on XRF and LA-ICP-MS at Beijing Research Institute of Uranium Geology (BRIUG). Analyses show a range SiO₂ 55.2 –68.35%, Al₂O₃ 12.54 –14.59%, Fe₂O₃(total) 3.07 –6.03%, MgO 1.8 –4.03%, CaO 5.08 –7.86, Na₂O 2.35 –2.61%, K₂O 1.51 –2.91%, MnO 0.06 –0.96%, TiO₂ 0.36 –0.67%, P₂O₅ 0.078 –0.159%, U 0.0001 –0.16%, Th 0.0007 –0.0012%, Pb 0.001 –0.002%, V 0.006 –0.015%.

Discussion and Conclusions

The Qubul khel uranium deposit developed in the basal part of host sandstone belonging to the upper part of Dhok Pathan Formation of Middle Siwalik Group. The host sandstone is about 100 –400m thick with occasional grit and calcified, concordant sandstone lenses of varied size. The host sandstone dips 21 –38° SW with the strike varying from N26°W to EW. The sandstone is friable to weakly cemented, generally medium grained and light grey to bluish grey on fresh surface. The mineral assemblage includes quartz 26 - 30%, feldspar 14 –16%, igno-metamorphic rock fragments 12 –21%, micas 6 –7%, amphibole 2%, clay minerals 2 –18%, calcite 8 –12% and magnetite, hematite/limonite, tourmaline and garnet as accessories. The ore body is of irregular tape like configuration; it has a NW-SE length of some 200 m, a thickness commonly from 2 to 15 m averaging 6.5 m, persists over a depth interval from 68 to 118 m below the surface, and averages 0.053% U [9].

The study of the Qubul Khel uranium deposit evidenced that a significant amount of uranium is precipitated in interstitial spaces, on and along grain boundaries in the reduced zone below the present day water table mainly as pitchblende (UO₂) micro to nano crystals which also occur as cluster of micro fine globules. Minor amount of coffinite (USiO₄) occur as pore fillings and coating along grain boundaries and a considerable amount is still present as adsorbed on clay minerals and earthy iron oxide in amorphous form. Uranium mineralization does not show any preferred affinity for any sedimentary, textural or structural feature of the host sandstone however adsorption on clay minerals, organic matter and iron oxide are common. Detrital uraninite and its alteration products such as schoepite, metaschoepite, carnotite and uranophane are typical uranium mineralization for oxidized environments.

Studies of nature and evolution of organic matter indicate type III kerogen which is inherited from land plants

as coaly phytoclasts, thermally immature and devoid of any free hydrocarbon. Two different morphological types of pyrite are characterized (i) framboidal pyrite in replacement of organic matter and (ii) idiomorphic pyrite which may have been crystallized during diagenesis.

The Qabul Khel uranium deposit is thought to have evolved through multiple reworking by infiltration. Continual leaching and migration of uranium to its present position occurred during successive tectonic activity and related fluctuation of the water table in response to Himalayan tectonism. U precipitation was caused by permeability barriers combined with upward migrating hydrocarbons, which are considered to have provided the required reductants [9].

The careful investigations led to understand the plausible uranium concentration processes. Uranium was first concentrated in the basin at synsedimentary stage which may have been reduced directly or shortly after the first step of adsorption on clay mineral surfaces and organic matter, as UO₂ micro to nano crystals disseminated in the host sandstone. Uranium reduction probably happened during early diagenetic processes within the reduced depositional environment. The uranium concentration processes were gradually upgraded within the depositional environment or in the host sediment which were interacting with the surface water involved in on-going sedimentation. At diagenetic stage uranium may be liberated from organic matter during its replacement by pyrite or by desorption from clay minerals. The presence of framboidal pyrite in replacement of organic matter and the occurrence of phosphorous-rich uranium minerals most likely reflect the metabolic activity of sulfate reducing bacteria [10]. Microorganism activity may have occurred during diagenetic evolution of the host-sediments and is most likely responsible for iron sulfidization and possibly uranium reduction, H₂S produced by bacteria being a strong reductant [11]. After burial of the host sediments, Himalayan tectonic events may have caused groundwater movements and thus in situ and local redistribution and remobilization of uranium characterized by recrystallization of pitchblende and coffinite.

The Qubul Khel uranium deposit experienced three main stages of uranium concentration processes : (i) a synsedimentary / early diagenetic stage concentrating uranium in reduced environment, possibly most if not all the uranium stock present in the deposit has been brought; (ii) a late diagenetic stage with formation of different morphologies of pyrite followed by a nearly in situ uranium mineralization; and (iii) finally, the uranium mineralization of Qubul Khel uranium deposit was redistributed and remobilized during the successive upheaval of Himalayan tectonics and the ore body attains the present position 15 –25m below present day water table. The organic matter, framboidal & idiomorphic pyrite are the main reductants involved in the uranium concentration processes. The system is devoid of any free hydrocarbon as was previously thought that permeability barriers combined with upward migrating hydrocarbons have provided required reductants [9].

The presence of detrital uraninite grains and its alteration products are evident that the source of uranium mineralization was within the sediments. The contribution of other uranium bearing detrital minerals like zircon, monazite, uranothorite is limited as these behave as refractory minerals and have not released their uranium.

Acknowledgment

The authors would like to thank M/s Abdul Majid Azhar, Khalid Pervaiz, and Muhammad Ahsan Amin for critically reviewing and improving the manuscript. We also would like to thank the PAEC & CNNC, for providing facilities to carry out this research at East China University of Technology (ECUT), Nanchang, China as part of Ph.D studies. Special thanks to IAEA for providing funding and facilities for presentation & publication of this article. The authors acknowledge the support of Qazi Mujeeb ur Rehman, Dr. Imtiaz Ahmed, Muhammad Abbas Qureshi, Saira Imtiaz, Imran Asghar, Muhammad Naeem Iqbal, Ghulam Shabbir Khan Faridi, Ghulam Rasool, and Asif Imran.

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Session Classification: Applied Geology and Geometallurgy of Uranium and Associated Metals

Track Classification: Track 3. Applied geology and geometallurgy of uranium and associated metals