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Full Length Research Paper

Low grade metamorphosed sandstone-type uranium deposit, Wadi Sikait, South Eastern Desert, Egypt

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Wadi Sikait (WNW-ESE) is one of the most famous emerald sites in the world, since Pharonic times. The exposed rocks are ophiolitic mélange (consists of mafic-ultramafic fragments set in metapelites matrix), metamorphosed sandstones, gabbros, granites and post-granite dykes (lamprophyres) and veins (quartz). The metamorphosed sandstone (MSS) rocks (vary from greywacke to arkosic in composition) outcrop at Wadi Sikait at two locations. The first MSS outcrop (Sikait-1) is located west the upstream of W. Sikait highly tectonized, elongated in NW-SE (1.8 km in length) and thinning in NE-SW (100-400 m in width) forming float-boat-like shape and intruded by fertile porphyritic granite (15 ppm eU) and lamprophyre dykes (vary in thickness from 0.5 to 2 m and up to 1.4 km in length). The second MSS outcrop (Sikait 2), is located at the bending of Wadi Sikait covering a small area (0.5 km) and intruded also by the fertile porphyritic granites. The MSS rocks cut by two generation of quartz veins; a) barren quartz veins (E-W, N-S and NNE-SSW) cross-cut the foliation planes of MSS and b) mineralized quartz veins (NE-SW)-bearing visible mineralization (wolframite, cassiterite and xenotime) and varies from 1-2 m in width and extends for 15 m in length parallel to the foliation planes. The MSS rocks show relics of primary bedding, banding and obvious foliation in NW-SE with angel of dip 35°/SW. The common alteration products are represented by kaolinitization, flouritization, hematitization, chloritization and manganese dendrites. The alterations are associated with visible greenish yellow U- minerals in Sikait-1. The results of the spectrometric survey were achieved in the form of 1:1,000 scale radiometric maps (K%, eU, eTh, U-mobility) for the first outcrop (Sikait 1). The chemical U content (60 to 480 ppm) is more than the equivalent U content (15 - 100 ppm), this result support the youngest age (less than one million years) for U-mineralization. The emplacement of both of lamprophyre dykes and porphyritic granites may be played an important role as a heat source, which lead to U-mobilization from hot granites, transported (along deep faults, foliation planes and banding) and redeposit in MSS rocks under suitable conditions.

Key words: Sandstone, lamprophyre, U-minerals, Sikait.

INTRODUCTION

Sandstone uranium deposits are characterized by medium to coarse-grained sandstones deposited in a continental fluvial or marginal marine sedimentary environment. Uranium precipitated under reducing conditions caused by a variety of reducing agents within the sandstone includes, carbonaceous materials (detrital plant debris, amorphous humate, marine algae), sulfides (pyrite, H_2S), hydrocarbons (petroleum), and interbedded basic volcanics with abundant ferromagnesian minerals (e.g. chlorite). Sandstone deposits constitute about 18% of world uranium resources. Ore bodies of this type are commonly low to medium grade (0.05 - 0.4% U_3O_8). The United States has large resources in sandstone deposits and most of its uranium production has been from these deposits, recently by in situ leach (ISL) mining. Other large sandstone deposits occur in Texas, Colorado Plateau, Niger, Kazakhstan, Pakistan, Uzbekistan, Gabon (Franceville Basin), and South Africa (Karoo Basin).

Wadi Sikait is one of the famous emerald sites in the

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World, since Pharonic times where Sikait temples were constructed. It is located about 95 km SW of Marsa Alam town in the south Eastern Desert of Egypt (between latitude 24° 37` 16`` to 24° 38` N and longitude 34° 46` to 34° 46` 35`` E). It strikes WNW-ESE and far about 1.5 km from W. Abu Rusheid (NW-SE trend). Abu Rusheid cataclastic rocks are highly sheared, foliated and cut by N-S and E-W shear zones. Lamprophyre dykes were emplaced along the shear zones bearing U, REEs, Zn, and Cu (Ibrahim et al., 2006 and 2007a, b, c and d). This paper records for the first time new occurrence of metamorphosed sandstone type uranium deposits at Wadi Sikait, South Eastern Desert, Egypt. Detailed geologic and spectrometric maps were carried out.

Geologic setting

Detailed geologic maps for the metamorphosed sandstone site at W. Sikait were constructed (Figures 2 and 3) on the base of a grid pattern 25 × 25 m. The exposed rocks are arranged as follows: 1) ophiolitic mélange (consists of mafic-ultramafic fragments set in metapelites matrix); 2) metamorphosed sandstones; 3) gabbros, 4) granitic rocks (porphyritic biotite granites and mylonitic biotite granites) and 5) post-granite dykes (lamprophyres) and veins (quartz). The ophiolitic mélange are fine- to medium-grained, grayish green in color, and occur mainly on the eastern side of W. Sikait. The ophiolitic mélange is characterized by tectonically mixed fragments and blocks of mafic-ultramafic rocks within fine to coarse-grained matrix. It composed mainly of mélange matrix (mainly schists) that encloses abundant fragments of meta-peridotites, meta-pyroxenites and meta-gabbros of variable sizes and dimensions (Saleh, 1997; Assaf et al., 2000).

The mafic-ultramafic fragments mostly highly serpentinized and in many places transformed into talc-carbonate rocks which are creamy in colors. The fragments occur in various sizes, reaching big slabs or mountainous size. The matrixes are highly foliated and featured by the frequent presence of folds of meso-dimension and boudinaged quartz and pegmatite lenses extending parallel to the foliation planes. The matrixes are represented by wide varieties of highly folded and sheared schists (talc, quartzo-feldspathic, garnet-mica, tourmaline-garnetiferous-biotite, graphite and sillimanite schist). Bedding, foliation, bounding, mineral lineation, minor- and micro-folding are observed in the matrixes. Foliation is mostly parallel to the bedding and marked by elongated chlorite, mica and quartz grains.

The metamorphosed sandstone rocks are fine-grained, white in color, highly sheared, banded, less foliated and cross-cut by lamprophyre dykes (NW-SE, N-S and E-W) and quartz veins (NNW-SSE, NNE–SSW and E-W). The metamorphosed sandstone rocks crop out in W. Sikait at two locations. The first outcrop (Sikait-1) is located west the upstream of W. Sikait (Figure 1), whereas the second outcrop (Sikait-2) is located at the bending of W. Sikait (Figure 2). The metamorphosed sandstone rocks are consisted of recrystallized and tightly interlocking grains of quartz. The origin of metamorphosed sandstone rocks is sandstones which have been subjected to heat with or without pressure, as a result of contact with a body of molten rock or, more usually, by deep burial due to earth movements, and all traces of the original sediments are erased.

Sikait-1

Sikait-1 covers a relatively larger area than the second exposure, with low to medium peaks, highly tectonized, elongated in NW-SE (2 km in length and thinning layering in NE-SW (150-500 m in width) forming float-boat-like shape and intruded by fertile porphyritic granite (20 ppm eU) and lamprophyre dykes. The metamorphosed sandstone rocks are traversed by three sets of strike-slip faults (Figure 2) trending NW-SE, NNW-SSE and NNE-SSW and one set of dip-slip fault trending ENE-WSW. These faults control the shape and setting of metamorphosed sandstone rocks, where the maximum elongation of metamorphosed sandstone is controlled by NW-SE sinisteral strike- slip fault set. The metamorphosed sandstones are range in color from pale white to milky white, generally uniform in texture and composed of fused quartz grain. The rock shows relics of primary bedding, banding and obvious foliation in NW-SE with angel of dip 35°/SW. It has granular appearance on the weathered surface with common vugs (boxworks) filled with secondary mineralization but along a broken surface the quartz grains are usually splited.

The fractures are usually open spaced, filled with secondary uranium and molybdenite. The common alteration products are represented by hematitization and manganese dendrites. Semi-angular to elongated rock fragments (mainly metagabbros in composition) are enclosed in metamorphosed sandstones, manifesting the greywacke composition. Lamprophyre dykes were emplaced relatively in NW-SE, N-S and E-W trends cutting both metamorphosed sandstones and porphyritic granites. The trend of lamprophyre dykes is concordant with the main structural trends that control setting of the metamorphosed sandstones. These dykes are altered, fine-grained, black grey in color, discontinuous and vary in thickness from 0.5 to 2 m and up to 1.4 km in length.

Sikait 2

Sikait 2 covers a small area (0.5 km), forming low terrain (500 m above sea level) and intruded by the granites (Figure 3). Some scattered goethite and yellow limonite

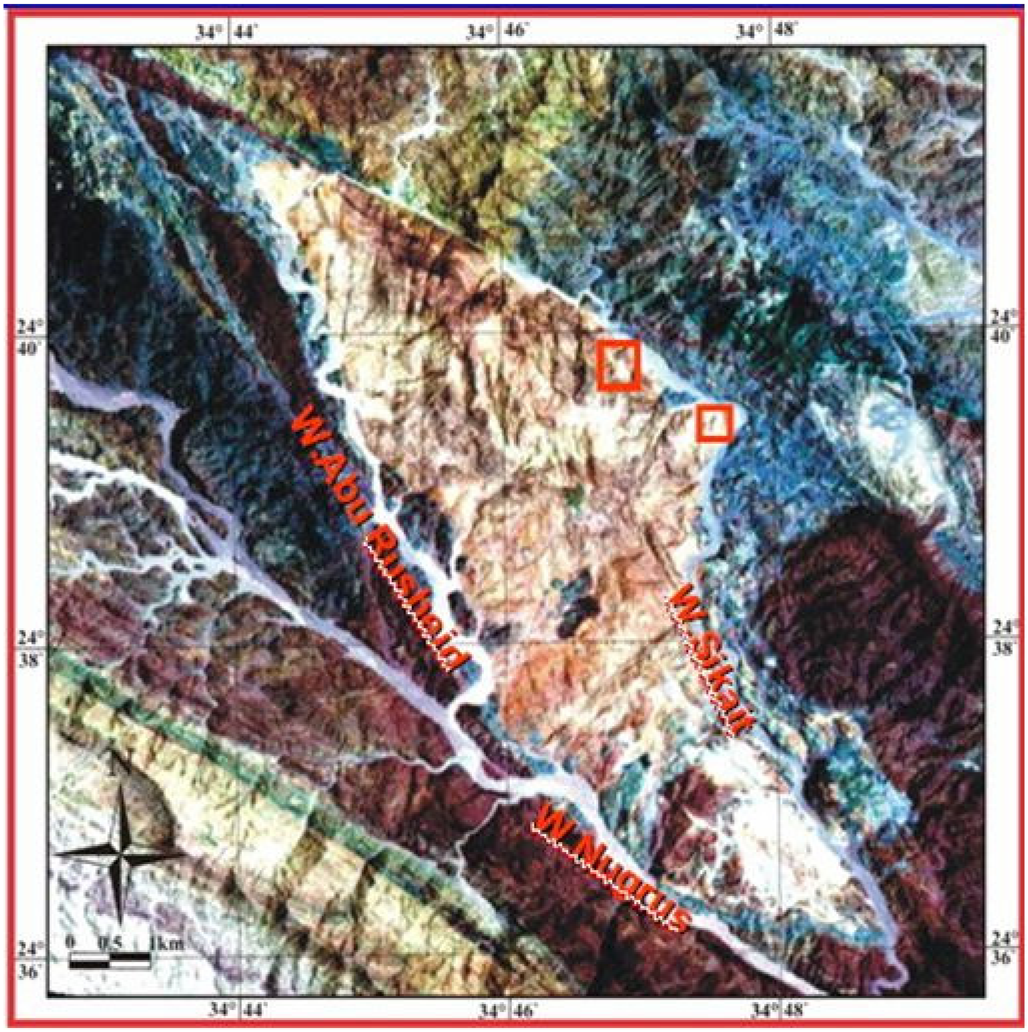

Figure 1. False color composite map (TM-image) showing the location of metamorphosed sandstone at Wadi Sikait.

after sulfide crystals are observed on the weathered surface of the rocks. The metamorphosed sandstones are whitish in color, sheared, foliated (NE-SW) and cut by two types of quartz veins: A) Barren quartz veins (E-W, N-S and NNE-SSW) dislocated by N-S strike slip faults and cross-cut the foliation planes of metamorphosed sandstones and B) quartz vein (NE-SW)-bearing mineralization (wolframite, cassiterite and xenotime) visible by naked eyes. It varies from 1 - 2 m in width and extends for 15 m in length parallel to the foliation planes. Microscopically, the metamorphosed sandstone rocks are fine to medium-grained of whitish grey in color and vary from greywacke to arkosic in composition.

Greywacke

This is mainly composed of quartz, plagioclase and k-feldspar. Garnet, fluorite, zircon and allanite are accessories while the secondary products are represented by chlorite and sericite. Quartz (66% in volume) occurs in two generations; the first one is euhedral in shape, showing undulated extension, corroded in plagioclase, whereas the second is squeezed between primary minerals filling the plagioclase fractures and may be formed related to the structure affected in the area. Plagioclase mainly albite (An7-10) in composition represented 32% in volume of the rock. Albite occurs as subhedral to anhedral crystals, cracked, highly deformed twining and partially sericitized. K-feldspars are represented by microcline, orthoclase and orthoclase microperthite phenocrysts (Figure 4a) in various proportions. They are normally coarse-grained and oriented with their long axes parallel to the foliation planes. The feldspars in general are subjected to different degrees of kaolinization. Biotite forms subhedral flakes and partly altered to chlorite along their cleavage planes.

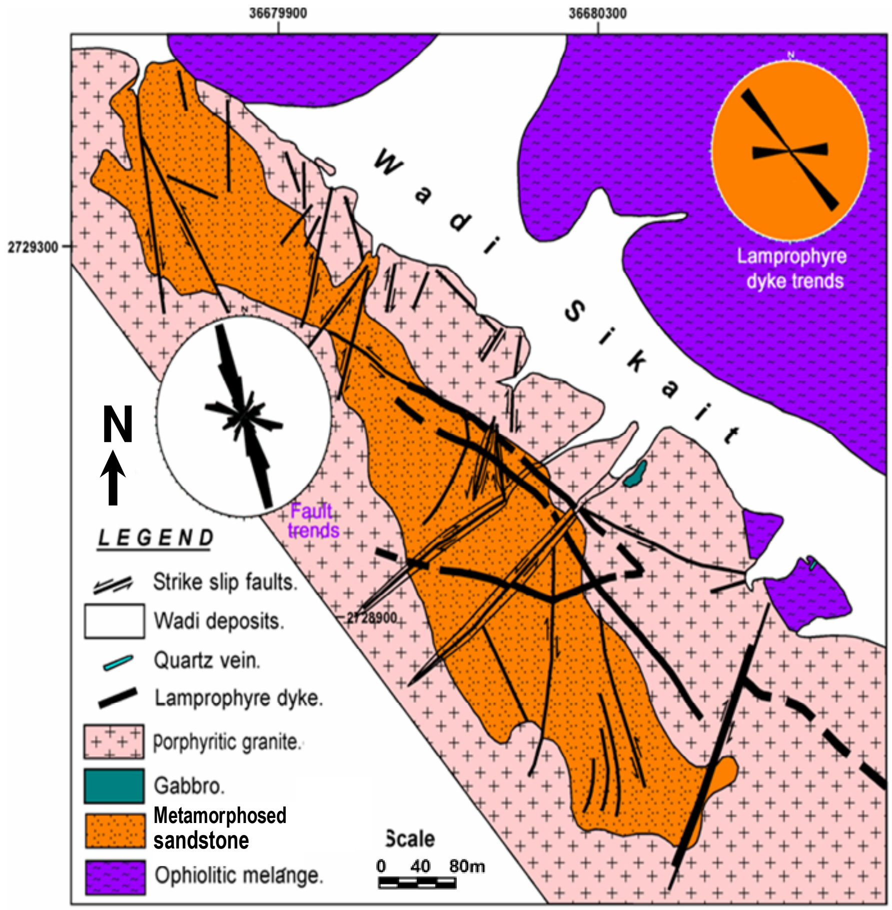

Figure 2. Geologic map of W. Sikait-1, South Eastern Desert, Egypt. Metamorphosed sandstone at Wadi Sikait.

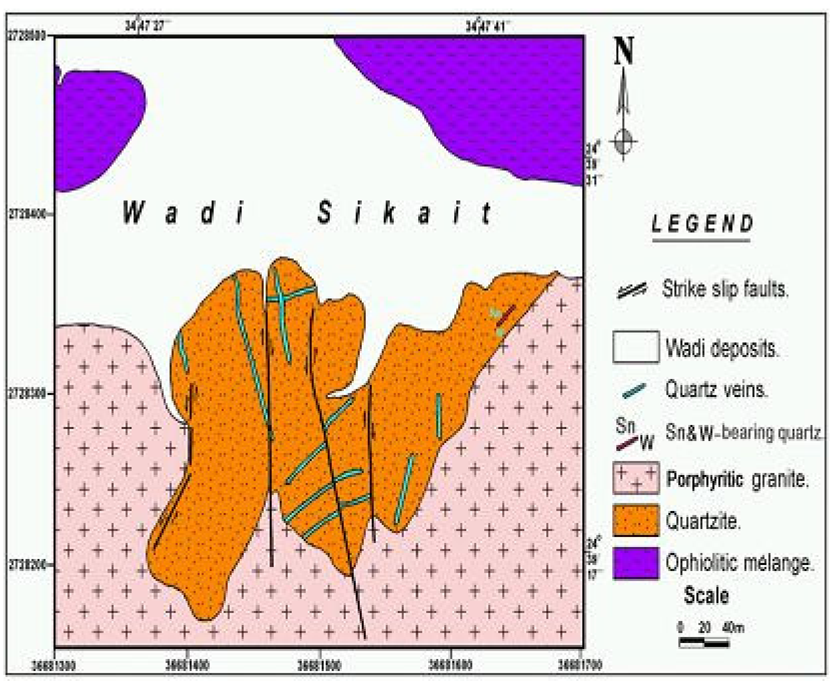

Figure 3. Geologic map of W. Sikait-2, South Eastern Desert, Egypt.

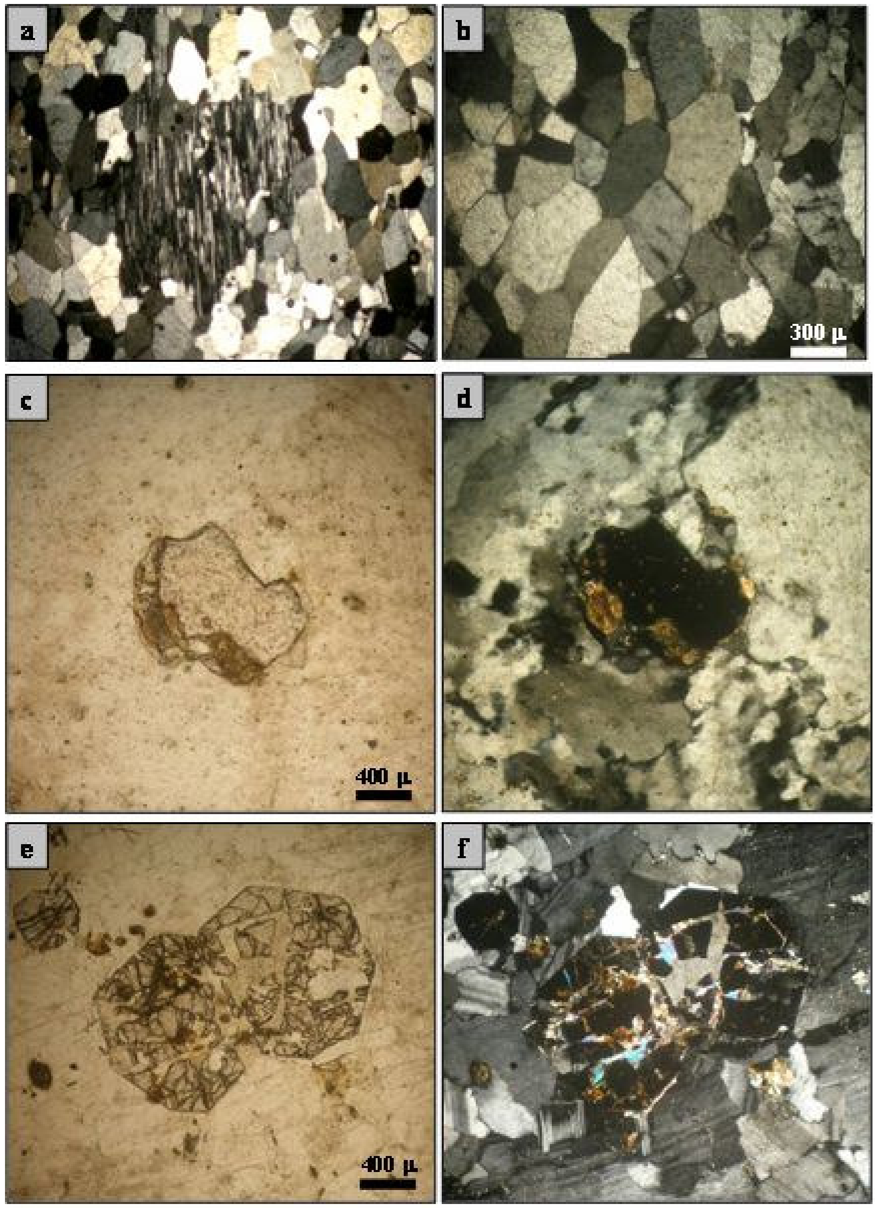

Figure 4. (a) View showing perthite phenocryst in greywacke, Wadi Sikait, (C.N. X20). (b) Photomicrograph showing triple junction in arkoses. Sikait, (C.N. X20). (c & d) Photomicrograph of fluorite in greywacke, P.L. (e & f) Photomicrograph of garnet in greywacke, P.L.

The rocks show gneissic texture (Figure 4b).

Muscovite

This occurs as aggregates associated with biotite and arranged either as parallel or oblique to the foliation planes and absorb thin films of iron oxides along their cleavage planes. Chlorite occurs as few subhedral to anhedral flakes reaching up to 0.3 × 0.7 mm in dimensions. Chlorite associate with thin streaks of opaque. Zircon found as short anhedral prismatic crystals. Allanite occurs as subhedral to anhedral crystals between the spaces of primary minerals. Fluorite occurs as considerable amount, filling the space between plagioclase and quartz or included in plagioclase (Figure 3c, d). Some crystals show radiation in basal section. Garnet occurs as short prismatic crystals (Figure 4e, f). Arkoses are mainly composed of quartz and feldspars. Accessories are represented by opaques, zircon and allanite, while sericite is the secondary mineral. Quartz (about 80 in volume) occurs as polygonal shape, triple junction and sometimes showing undulated extinction due to the effected of strain. Feldspars (about 18% in volume) are represented by albite (15% in volume) and perthite (4% in volume). The albite crystals occur as subhedral to anhedral, highly cracked and corroded /or contains quartz crystals. Some crystals of albite taking preferred orientation. The perthite crystals occur as anhedral string type cracked and eroticized. Opaques are rare and occur as skeletal shape. Zircon found as short anhedral prismatic crystals. Allanite occurs as subhedral to anhedral crystals between the interspaces of primary minerals. Wolframite found as subhedral to anhedral crystals between the interspaces of quartz.

Porphyritic granites

This are coarse to very coarse-grained, with K-feldspar crystals up to 2 cm in length, grey to white pinkish in color and composed mainly of quartz, plagioclase, feldspars and biotite. It is marked by well and a sharp contacts, sheared and hematitization. Elongated xenoliths of metamorphosed sandstone are recorded within porphyritic granites. The porphyritic orthoclase perthite crystals form allotriomophic plates showing preferred orientation parallel to the general direction of elongation of the biotite flakes. The rocks show mylonitic texture at their contact with ophiolitic mélange. The rock cuts by lamprophyres dikes which strike N50º W-S 50º E and dips 65º due to NE. Reddish, brecciated and highly deformed barren quartz veins (N 40° E–S 40° W) cut also the porphyritic granites. Microscopically, it is composed mainly of porphyritic potash feldspars, quartz, plagioclase and biotite. Opaques, zircon, apatite and allanite are accessories. The secondary minerals are muscovite, chlorite, sericite and kaolinite. Potash feldspar are represented by orthoclase-perthite and microcline-perthite of patchy to string perthite and relatively altered to kaolinite. The quartz occurs as medium to coarse-grained, highly cracked and show undulose extinction due to the stress effects. Plagioclases occur as subhedral tabular forms of medium-grained. Biotite occurs as brown to dark brown flakes arranged with their longest axes in a preferred orientation. The flakes show alteration to chlorite and muscovite. Opaques are rare and occur as subhedral forms and as skeletal forms. Allanite found as subhedral prismatic crystal associated with biotite. Zircon occurs as very minute crystal associated with biotite. Apatite occurs as long prismatic crystals enclosed with feldspars.

GAMMA RAY SPECTROMETRY

Spectrometric prospecting

In situ gamma ray spectrometry measurements were carried out using a GS-512 spectrometer with a 7.62 × 7.62 cm^2 sodium iodide (Thalium) [NaI (Ti)] crystal detector. Before field measurements, the spectrometer is calibrated on concrete pads containing known concentrations of K, U and Th. This calibration provides the stripping ratios and sensitivities required for correcting the measured K, eU and eTh. The term ‘equivalent’ or its abbreviation ‘e’ is used to indicate that equilibrium is assumed between the radioactive daughter isotopes monitored by the spectrometer, and their respective parent isotope. Gamma rays emitted by ^{214}Bi at 1.76 MeV were measured for ^{238}U and gamma rays emitted by ^{208}Ti at 2.614 MeV were measured for ^{232}Th within the spectrometer to automatically maintain system gain stability. In the case of high uranium concentration zones, a barium source is used. To improve results, the background radiation is measured over a large body of water.

Radiometrical investigation

The results of the survey were achieved in the form of 1:1,000 scale radiometric maps (Total-Count, K%, eU, eTh, eTh/eU, U-mobility and eTh/K) for the two locations; Sikait-1

Total-count contour map

Matching between the total radiometric contour map with geologic map shows that different two rock types differ in radioactivity. These two rock types can be discriminated under two radioactive levels according to the range and averages of the radioactivity. At Sikait-1, the first radiometric level (≤50 Ur) associated with porphyritic granites. The second radioactivity level (55 to 115 Ur) associated with metamorphosed sandstones (Figure 5)

Potassium % contour map

At Sikait-1, the comparison between potassium % contour map and the geological map (Figure 1) indicates that the low level of potassium % contour line values (≤4K%) associated with porphyritic granites whereas, metamorphosed sandstones show the higher level of potassium % (range from 4 - 11K%). The highest contour lines of potassium % within metamorphosed sandstone rocks are controlling by Na^- and K^- metasomatism as well as by the main structure trends at Sikait-1 (Figure 6).

Equivalent U-contour map

At Sikait-1, matching the equivalent uranium contour map with geologic map reveals that two levels of radioactivity. The first level has the lower value (≤15 ppm eU) and

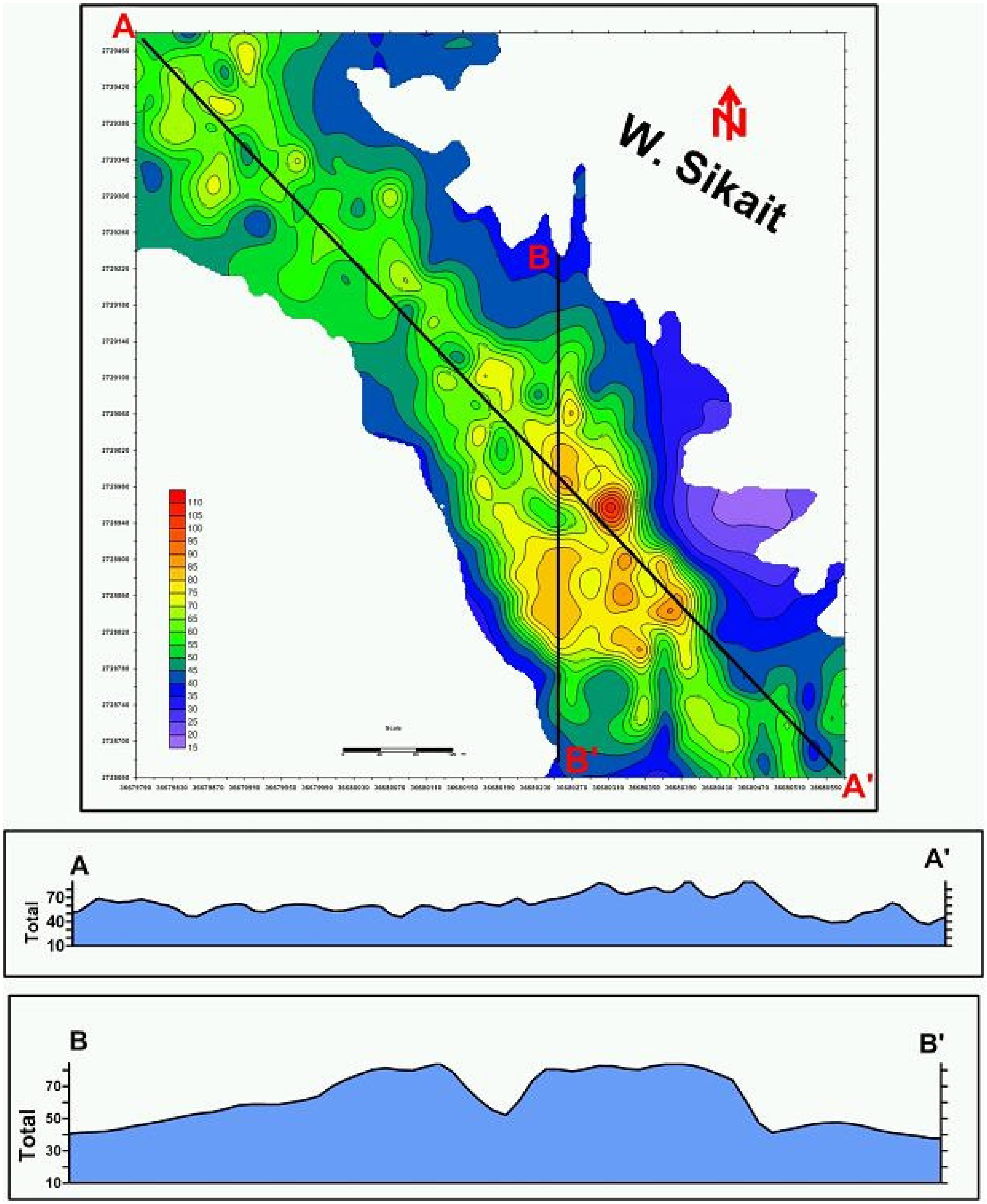

Figure 5. Total-count radiometric contour map for Sikait-1.

coincides with porphyritic granites with no specific trend. The second level ranges in the intensity from 15 to 85 ppm eU and associated with metamorphosed sandstones (Figure 7). The abnormal eU contents in metamorphosed sandstones were relating to high Na^- and K^- metasomatism. The eU anomalies also reflect visible secondary U-remobilization (mainly uranophane, autunite and kasolite after Ibrahim et al., 2009) along the

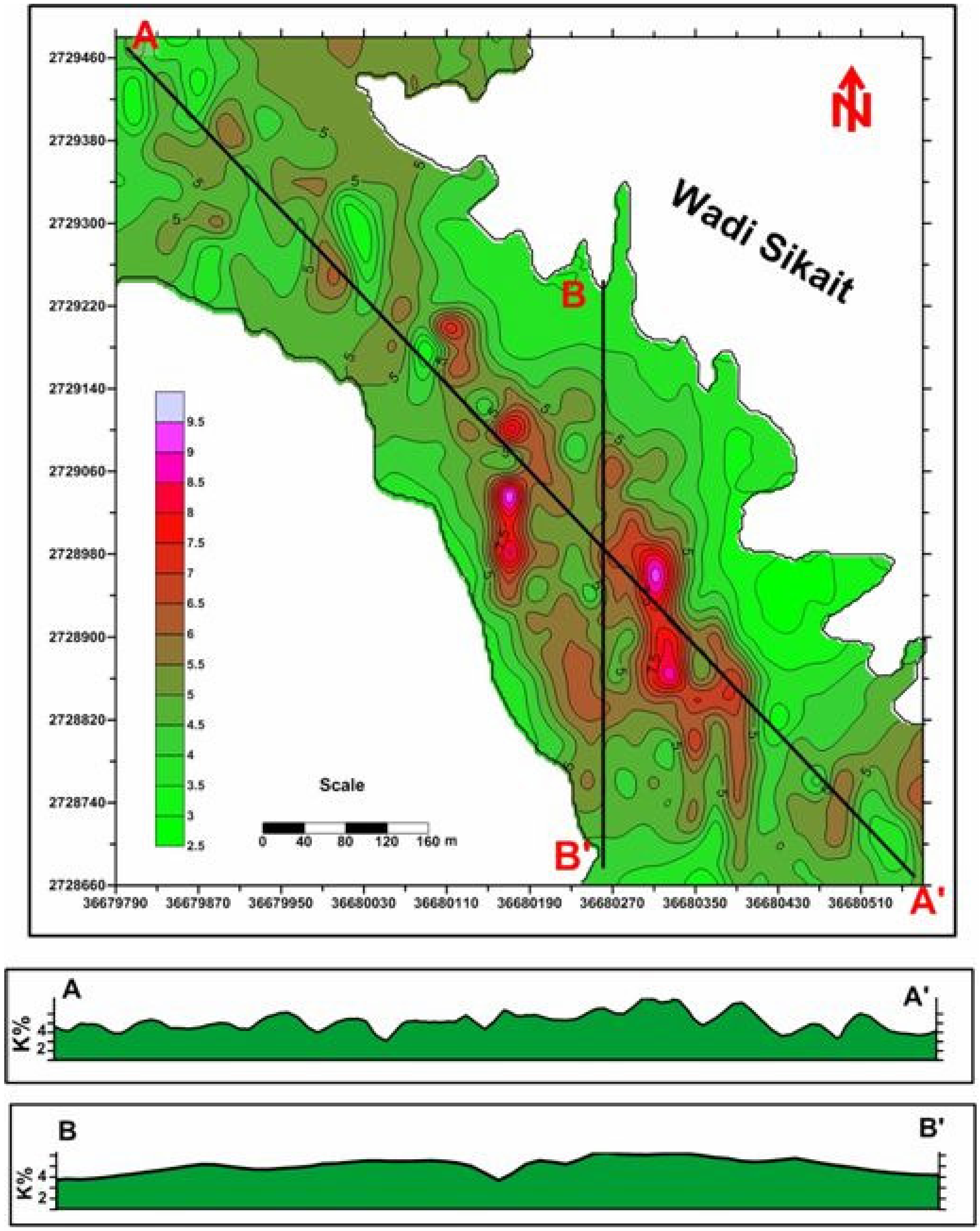

Figure 6. Potassium % contour map for Sikait-1.

structural trends (NW-SE, N-S and E-W) in Sikait-1.The tectonic trends act as good traps for U-rich fluids or U-ores.

Equivalent Th-contour map

Correlation between equivalent Th-contour map (Figure 8) and geologic map of Sikait-1 (Figure 1) indicates two levels of eTh-contents. The first level has the lower value of eTh-content (≤ 40 ppm eTh) and coincides with porphyritic granites, whereas the second level ranges from 40 to 85 ppm eTh and associated with metamorphosed sandstones in Sikait-1.

eTh/eU ratio contour map

eTh/eU ratio depends mainly on the mobile element (uranium) so, this ratio is important for uranium exploration because it determines the most promising areas for uranium migration and accumulation. Uranium

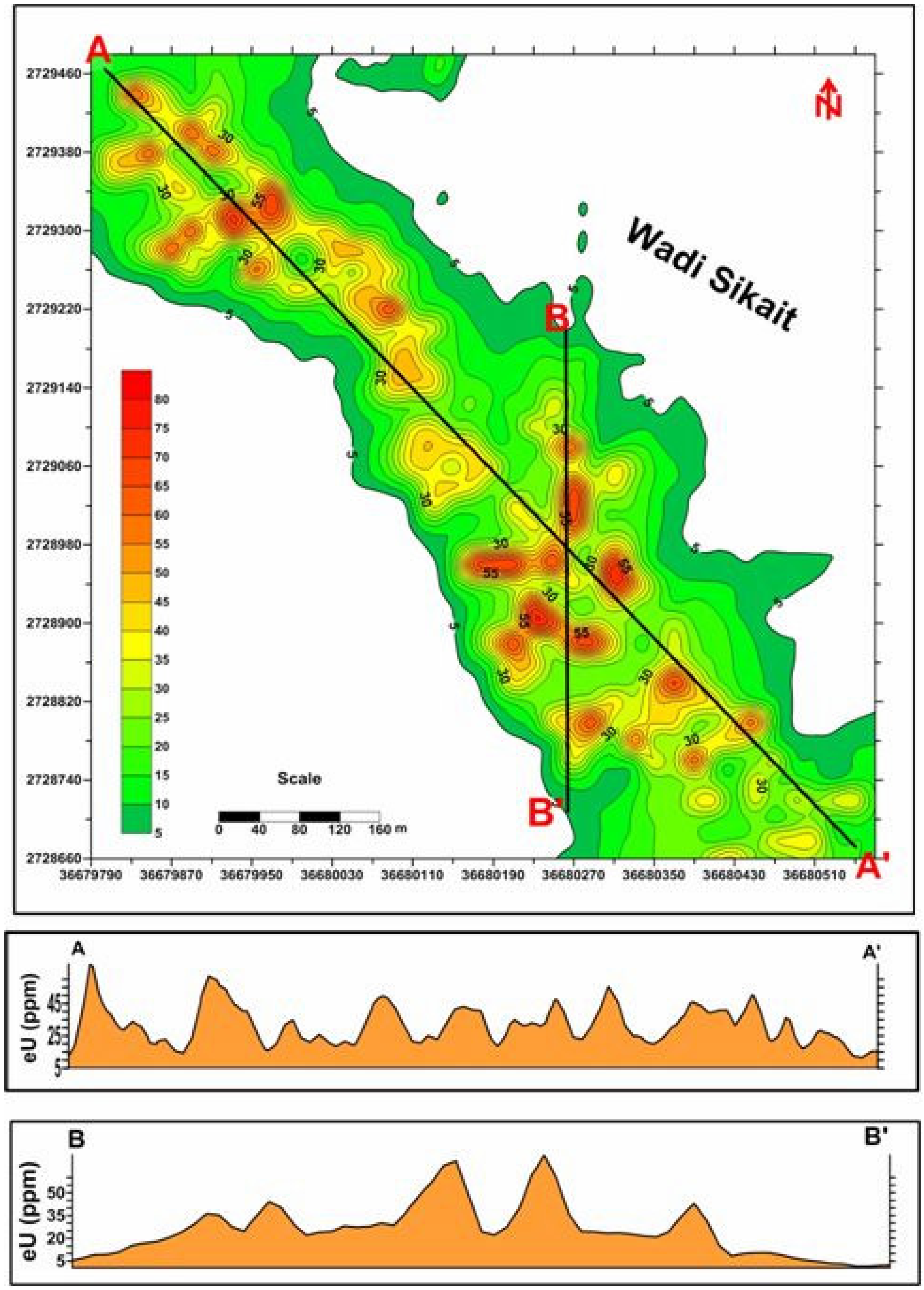

Figure 7. Equivalent uranium contour map for Sikait-1.

enrichment can be indicated by the ratio decrease lower than 3.0, while uranium leaching out can be indicated by its increasing above 3.0. The eTh/eU contour maps (Figure 9) confirms the presence of low eTh / eU ratio zones in metamorphosed sandstones (0.5 - 1.5), reflecting increased uranium contents superimposed on nearly constant thorium content. The high eTh/eU ratios (3.5 - 7) coincide with the porphyritic granites reflecting uranium migration toward metamorphosed sandstones.

Chemical U-contour map

At Sikait-1, matching the chemical uranium contour map with geologic map reveals that two levels of radioactivity. The first level has the lower value (≤ 280 ppm U) and coincides with NE side of metamorphosed sandstones towards W. Sikait. The second level ranges from 280 to 480 ppm U and close contact with fertile porphyritic granites (Figure 10). The abnormal U contents in

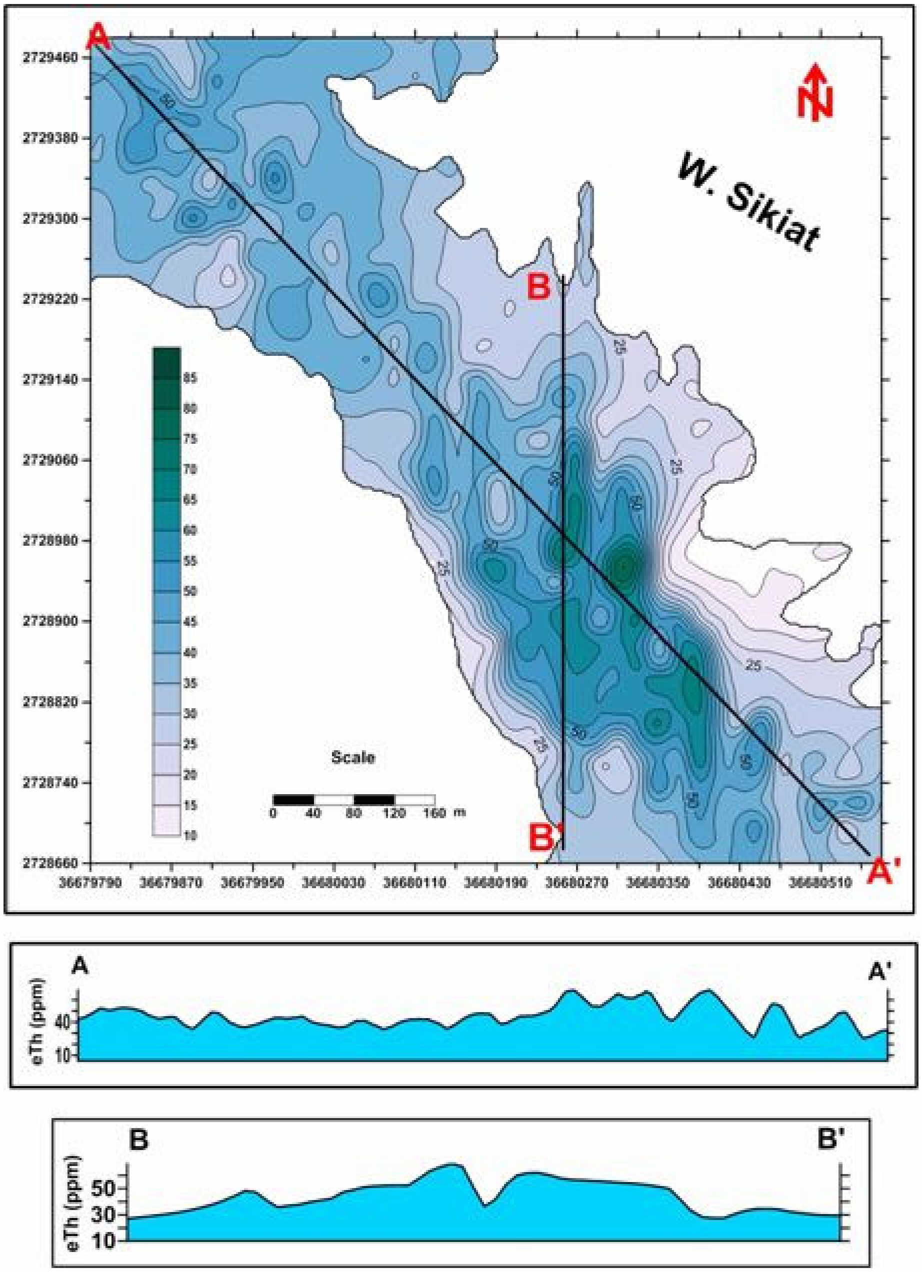

Figure 8. Equivalent thorium contour map for Sikait-1.

metamorphosed sandstones were relating to high shearing, tectonic and mobilization. The chemical U content is five times equivalent U content, whereas the chemical U content ranges between 60 to 480 ppm, while the equivalent U ranges between 15 to 85 ppm. This conclusion support the youngest age (less than million years) for U mineralization.

U-mobility [eU-(eTh/3.5)] contour map

The U migration map is interested in calculating the uranium mobilization. The migration of uranium depends on different agents for liberation, transportation, channel way and reduction environment to change soluble (U+6) to insoluble (U+4) state. It is calculated the difference between eU now and the theoretical value (Th in ppm /3.5) to give the leaching values of uranium. If this value is positive (+ve) it mean that the uranium leaching in and if it negative (-ve) this mean leaching out. The U-mobility map (Figure 11) shows the probable trends of uranium fixation. According to the mobilization maps, the metamorphosed sandstone rocks show positive contours range from 5-55 and from 2-34 in Sikait-1 and Sikait-2

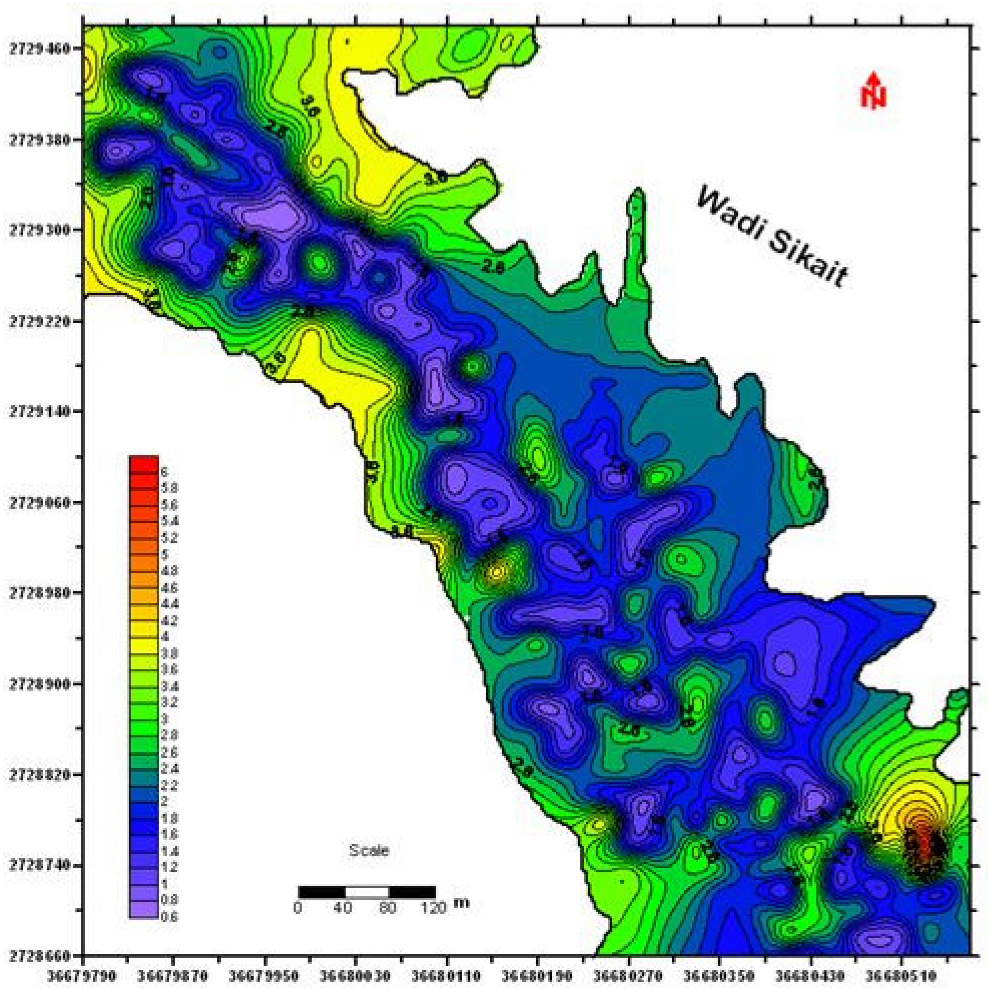

Figure 9. eTh/eU ratio contour map for Sikait-1.

respectively.

Most of the migrated uranium comes from porphyritic granites, whereas it shows negative contours. Uranium mobilization can be traced with directions trending from the negative anomalies to the high positive ones as shown in (Figure 10). The mobilization contour map shows negative ones distributed along the porphyritic granites. In contrast, positive contours are concentrated in the metamorphosed sandstone rocks. Lamprophyre dykes and the emplacement of hot porphyritic granites could be played an important role as a heat source, which lead to U-mobilization from porphyritic granites and transported (along deep faults, foliation planes and banding) and redeposited in metamorphosed sandstone rocks under suitable conditions.

Conclusions

Wadi Sikait area is one of the most promising areas in the Eastern Desert of Egypt. It is highly tectonized and covered by ophiolitic mélange, metamorphosed sandstones, gabbros and porphyritic granites. The metamorphosed sandstone (20 million Mt. above W. Sikait level) represents the target for uranium and associated minerals. It extends NW-SE for about 2.0 km in length and ranges from 100 - 400 m in width. The uranium minerals include uranophane, beta-uranophane, kasolite and autunite, and they are affected by some factors:

1. The presence of mineralizing source represented in our opinion by both cataclastics (west the mapped area) and hot contact granitic rocks (20 ppm eU).
2. The hydrothermal solutions play a major role in dissolution, transportation and deposition of minerals (e.g. wolframite, U-minerals, fluorite, ilsemnite and uraniferous xenotime).
3. The good open fracture system which is represented by shearing, foliation, and bedding acts as good pathways for the solutions.
4. The mobilization of migrated uranium from the hot

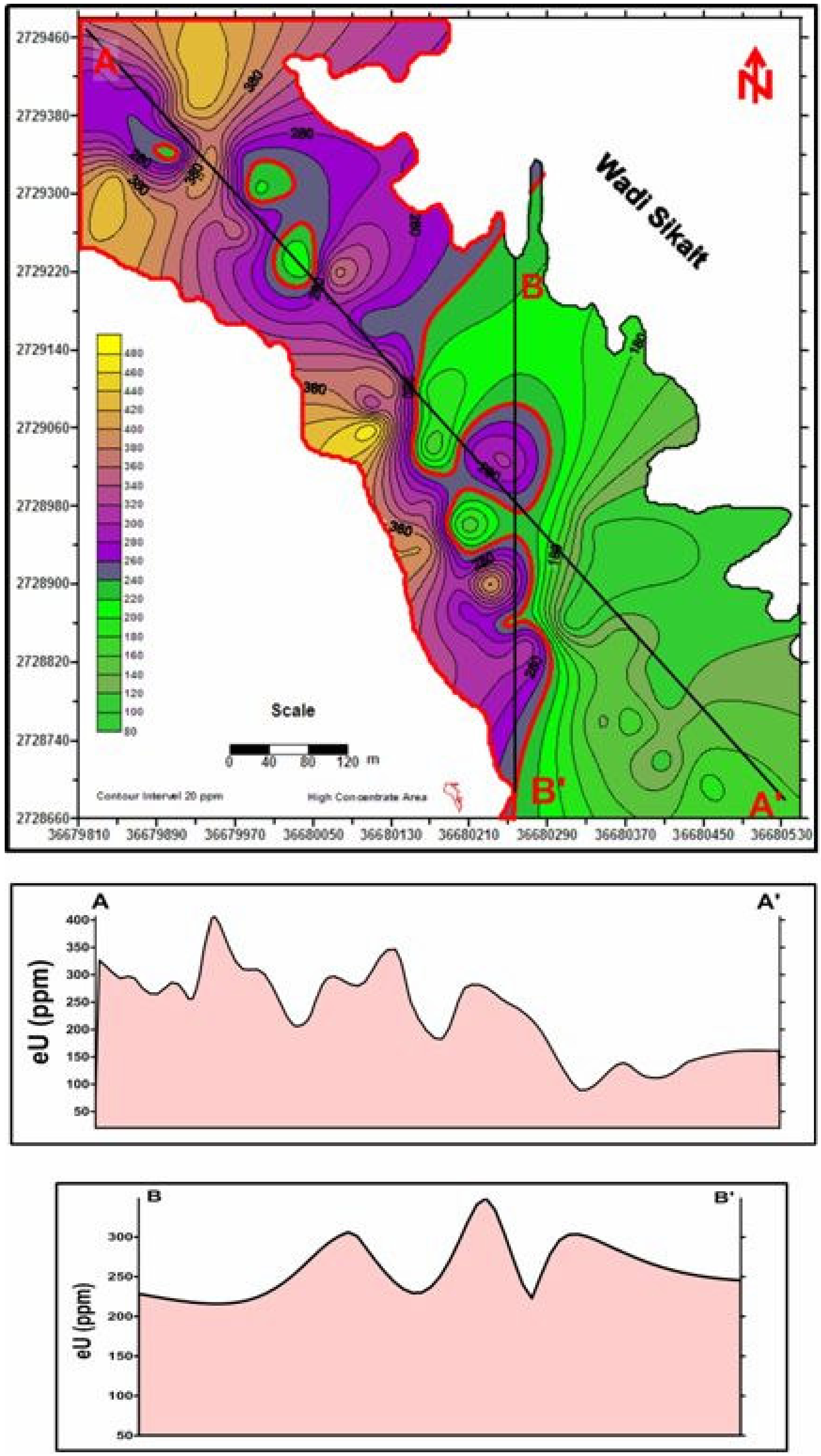

Figure 10. Chemical uranium contour map for Sikait-1.

uraniferous porphyritic granite towards metamorphosed sandstone is due to the heat of metamorphism, emplacement of both lamprophyre dykes and granites.

5. The effect of post depositional (diagenesis) and alteration processes (sodic, potassic and flouritization) respectively.

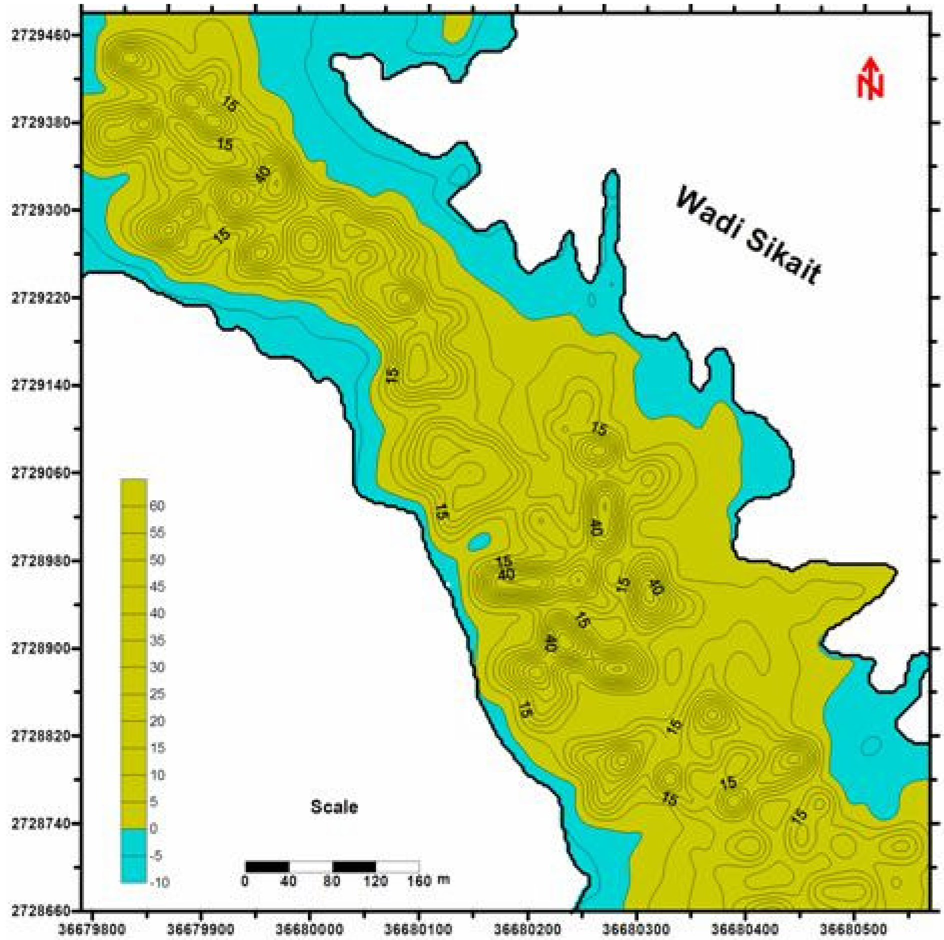

Figure 11. The U-mobility (eU-(eTh/3.5) contour maps of Sikait-1.

6. The presence of reducing condition (sulfides).

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