Use of Remote Sensing and Gamma Ray Spectrometric Data for Elucidating Radioactive Mineralized Zones, Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt

By Abdelmohsen G. Nady, Reda E. El Arafy, Mohammad G. Al-Ibiary, Maysa M. Nabeh & Samah S. Abdeen

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Keywords: airborne gamma-ray spectrometry, landsat 8 operational land imager (OLI), hydrothermally altered rocks, argillic, phyllic, band ratios, principal component analysis (PCA).

GJSFR-H Classification: FOR Code: 040699

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Use of Remote Sensing and Gamma Ray Spectrometric Data for Elucidating Radioactive Mineralized Zones, Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt

Abdelmohsen G. Nady α, Reda E. El Arafy α, Mohammad G. Al-Ibiary α, Maysa M. Nabeh α & Samah S. Abdeen ¥

Abstract: Wadi Jararah-Wadi Kharit is considered a large area located in the southeastern desert of Egypt with approximately 38,000 Km2 coverage extensions. The geologic outcrops of the area show a wide range of stratigraphic rock units from Precambrian to Quaternary. The detection of lithologic surface coverage units and their relationships to the high-radioactivity zones and its characterizations are the main tasks of this article. An integration between airborne Gamma-ray spectrometric data and Landsat 8 Operational Land Imager (OLI) satellite image has been used to determine and highlight the main radioactive zones covering the entire area of investigation; in addition, to the relationship between airborne radioactive detected zones and their different kinds of related geologic alterations. The radioelement concentration values of the equivalent Uranium (eU), equivalent Thorium (eTh), and Potassium (K) successively discriminated several distinctive radioactive zones over Wadi Jararah-Wadi Kharit area. Fifteen main groups of statistically significant (anomalous) zones have been distinguished and show localities that represent uraniferous anomalous zones which could considered as a possible target of interest for ground follow-up investigation. Most hydrothermally altered rocks are readily grouped into two primary facies; the argillic and phyllic facies, these facies and other related alterations have been mapped using a familiar remote sensing image processing technique, on Landsat 8 OLI data; such as band ratios and Principal component analysis (PCA). By computing band ratios and feature-oriented PCA technique substantial improvement has been achieved in mapping the alteration zones enhanced through both processing. In addition to the new discriminated radioactive zones in the study area; this study shows that satellite image processing can distinguish more similar classes than airborne Gamma-ray spectrometric data, while the better availability and spatial coverage makes the Landsat 8 OLI sensor more suitable for large-area lithologic mapping related to radioactivity.

Keywords: airborne gamma-ray spectrometry, landsat 8 operational land imager (OLI), hydrothermally altered rocks, argillic, phyllic, band ratios, principal component analysis (PCA).

I. Introduction

Wadi Jararah-Wadi Kharit area is a part of the South Eastern Desert of Egypt (East Aswan area) and located between latitudes 23°00’ & 25°00’N, and longitudes 33°00’ & 35°00’E and occupies an area Approximately 38,000 Km2 (Fig.1). The area is characterized by a variety of igneous, metamorphic and sedimentary rocks ranging in age from Precambrian to the Quaternary ages.

Two types of remotely sensed data are used these are: Airborne Gamma-ray spectrometry & Landsat 8 (Operational Land Imager) OLI. Airborne gamma-ray spectrometry (AGRS) is a passive remote sensing technique that measures the naturally emitted gamma radiation emitted from three radioelements i.e., potassium, uranium, and thorium, residing in soils and rocks located within the upper 30 cm of the earth’s surface (Dickson, 2004; Chiozzi et al., 1998). The gamma-ray spectrometric measurements give qualitative and quantitative determination of the individual radiation elements in the rocks and soils, and assist considerably in the search for uranium ores and therefore are of great importance to mineral exploration in general and geological i.e., lithological and structural mapping, in particular especially in regions where the geology is complicated, or the access is difficult. However, it must be note that it is a surface mapping method and cannot provide information about the underlying formations if their compositions are not reflect in the surface materials (Gharieb et al. 2004). In airborne gamma ray spectra, the photo peaks are the primary information about the geological and geophysical state of soil and rocks (Eugene, 2016). Darnley and Ford (1989) show that, in many situations, gamma-ray spectrometry is probably more useful than any other single airborne geophysical or remote sensing technique in providing information directly interpretable regarding surface geology. The interpretation of radioelement distribution requires a thorough understanding of the rock types, vegetation, soil cover extent and alteration and enrichment processes.

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Due to the wide variation in the radioelements concentration in each rock type, no global classification is possible and this is the key in the geologic mapping.

On 4 February 2013, Landsat-8 was launched from Vandenberg Air Force Base in California. It is an American Earth observation satellite and the eighth satellite in the Landsat program. Landsat-8 joins Landsat-7 on-orbit, providing increased coverage of the Earth's surface. It is carrying a two-sensor payload, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). These two instruments collect image data for nine visible, near-infrared, shortwave infrared bands and two longwave thermal bands. They have a high signal to noise (SNR) radiometer performance, enabling 12-bit quantization of data allowing for more bits for better land-cover characterization. Landsat-8 provides moderate-resolution imagery, from 15 meters to 100 meters of Earth's surface and Polar Regions (A. Ariza, 2013). Landsat-8 data have been distributed to the general public on a nondiscriminatory basis at no cost to the user. The data can be easily downloaded from the (http://earthexplorer.usgs.gov) and (http://glovis.usgs.gov/) online linkages.

In the current study, the authors used the OLI image to map hydrothermal alteration zones in the study area. Hydrothermal alteration is defined as the reflection of a response of preexisting rock-forming minerals to physical and chemical conditions different than those, under which they originally formed, especially by the action of hydrothermal fluids (Arunachalam et al., 2014) with a possible temperature of 500°C to 50°C.

Previous studies explained the fact that certain minerals associated with hydrothermal processes, such as iron-bearing minerals (e.g., goethite, hematite, jarosite, and limonite) and hydroxyl-bearing or clay minerals (e.g., kaolinite and K-micas) show diagnostic spectral features that allow their remote identification. Landsat 8 OLI data have been used by many authors for determining hydrothermal alteration areas e.g., (AB Pour & A Ali, 2014; M. Arunachalam et al., 2014; M. W. Mwaniki et al., 2015; AB Pour & M Hashim, 2015; F Masoumi et al, 2017; N Jain et al, 2018; H Aryanmehr et al, 2018; L Han et al, 2018).

This study aims at integrating airborne Gamma-ray spectrometry and OLI data for determining the tie relationship between airborne radioactive zones and different kind of alterations at areas which surveyed using the airborne and attempt to explore new radioactive zones that didn’t survey using the airborne.

![Figure 1: Location map of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.](image-url)
a) Geologic setting

The area of investigation is a part of the Pan African Arabian–Nubian Shield that was discussed by many workers. Topographically, the study area is mountainously characterized by moderate relief with high granitic hills generally extending several kilometers and form several peaks of relatively high elevation than the other rocks. Stratigraphically, it is comprises of foreland sediments (Nubian Sandstone Formation) represented by the Cretaceous and Tertiary Formations as well as Quaternary deposits filling wadis and their streams plus the enormous plains which located between high lands, these sedimentary rocks overlying Precambrian rocks. These varieties of rocks are exposing within a geological map of the area (Fig.2) (Conoco, 1987). Precambrian rocks cover the northeastern and southern parts of the study area and comprise a ring complex, meta-volcanic, meta-sediments, (meta-gabbro)-(meta-diorite) complex, ophiolites, gneisses, and calc-alkaline granites (older and younger). Upper Cretaceous volcanic (wadi Natash volcanic) and trachyte plugs cover the northeastern part of the area (Hashad et al., 1982). Meanwhile, the upper Cretaceous sedimentary rocks cover most of the southern parts and the northwestern parts of the study area, which are represented by the Abu Aggag, Timsah, Umm Barmil, Dakhla, Taref, Duwi, and Quseir Formations. Tertiary rocks represented by Pliocene Deposits which located as spots in the northwestern parts of the study area. In the southeastern and northeastern parts of the study area, leucocratic and melanocratic medium to high grade metamorphic rocks are observe. E. El Shazly & Kris, 1973 Indicated that, the area east Aswan is covered by well exposed basement-metamorphic rocks of Precambrian age, overlain with foreland sediments and volcanic, represented by Nubian sandstone and Wadi Natash volcanic of Cretaceous age. Structurally, the investigated area subjected to different tectonic movements giving rise to some complex structures and it dissected by various types of faults and joints, which are either concomitant with wadis (dry valleys) and drainage lines or cutting through country rocks (Fig.3).

![Geologic Map of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt](image-url)
These faults are extracted manually from (Conoco & EGPC, 1987) and mainly trend in the NE-SW, NW-SE, NNW-SSE, NNE-SSW, WNW-ESE, and ENE-WSW directions, as well as some minor faults trending in the N-S and E-W directions.

II. Data and Methods

a) Airborne Radiometric data

Wadi Jararah-Wadi Kharit area was included in the airborne gamma-ray spectrometric survey conducted by Aero Service Division, Western Geophysical Company of America, in 1984 over a large segment of the central and southern Eastern Desert, Egypt (Aero-Service 1984). The survey was flown along a set of parallel traverse flight lines oriented in an NE-SW direction, at 1.5 km spacing, while tie lines were flown NW-SE at 10 km intervals and 120-m terrain clearance. A high-sensitivity 256-channel airborne gamma-ray spectrometer was used to carry out the gamma-ray spectrometric survey (Aero-Service 1984). The obtained airborne gamma-ray spectrometric data were compiled and presented in the form of contoured maps of scale 1:50000.

b) Landsat-8 data

The study area is covered by four cloud-free level 1T (terrain corrected) Landsat-8 images namely, LC81730432017109LGN00 (path/row 173/43), LC81730442017109LGN00 (path/row 173/44), LC81740432017116LGN00 (path/row 174/43) and LC81740442017116LGN00 (path/row 174/44) that downloaded from the US Geological Survey Earth Resources Observation and Science Center (http://earthexplorer.usgs.gov) in TIFF format. Scenes (Path 173 Raw (43 and 44) and Path 174 Raw (43 and 44)) acquired on 19 and 26 April 2017, respectively, spatial resolution of approximate scene size 170 km north-south by 185 km east-west.

c) Data Analysis

- Preprocessing for aero-spectrometric data: The collected gamma-ray measurements was: 1) corrected for background radiation resulting from cosmic rays and aircraft contamination, variations caused by changes in aircraft altitude relative to ground and Compton scattered gamma-rays in potassium and uranium energy windows, then compiled and finally displayed in the form of contour maps (Aero Service report, 1984). These maps show the apparent surface concentrations of radioelement Potassium (K in %), equivalent Uranium (eU in ppm), equivalent Thorium (eTh in ppm) and Total count Total counts were measured in count per second (cps) and then converted into micro Roentgen per hour (μR/h). 2) geo-referencing the map sheets for each element to UTM (Universal Traverse Mercator) system this process was necessary to achieve compatibility with Landsat 8 images and to ensure the coincidence between the different layers that could extracted from both types of data. 3) Gridding each element using minimum curvature tool. The preprocessing steps for aero-spectrometric data prepared using Oasis Montaj 8.3 package software.
The preprocessing and processing steps for aero-spectrometric data prepared using Oasis Montaj 8.3 package software and for Landsat-8 image using the ENVI (Environment for Visualizing Images) version 5.1 Software and Arc-GIS10.5 software package.

### III. Result and Discussion

**a) Airborne Spectrometry**

**i. Description of aero-spectrometric data**

The aero-spectrometric images provide views of the overall patterns of elements and usually contain patterns related to various lithologies. The collected data involve the total count (TC), equivalent uranium (eU), equivalent thorium (eTh) and potassium concentration (K %) used to construct four image maps. Data values are multiplied by 10 to facilitate presentation and relative variation of the gamma radiation.

**ii. Aero-spectrometric maps**

- **TC map**

  The TC map (Fig. 4) shows three radiometric levels, high, intermediate and low. The high level indicates values exceeding 60 μR/ h (from red to magenta). This level is observed over granitic rocks (especially younger granites), Duwi formation, Quseir formation Metamorphic rocks, Ring complex, and Natash volcanic. The intermediate level ranges from 40.4 to 60 μR/ h (from green to yellow) and is associated mainly with Cretaceous formations (Um Barmil, Timsah, Abu Aggag, Taref, and small parts in Quseir formations) and small parts in Meta-sediments, Meta-volcanic, Meta-gabbro, undifferentiated Quaternary deposits, Pliocene deposits, and Wadi deposits. The low level is less than 40.4 μR/ h (from deep blue to green) and extends over Undifferentiated Quaternary deposits, Dakhla formation, Wadi deposits, Abu Aggag Formation, and small parts in Timsah formation, Um Barmil formation, Meta-sediments, older granite, and Meta-volcanic.

- **eU map**

  The eU map (Fig. 5) can be classified into three levels; the first level expands up to 30.6 ppm (from red to magenta) and is associated with younger granites, ring complex, Duwi Fm, Quseir Fm, Um Barmil Fm, and Timsah Fm. The intermediate level ranges from 10 to 17 ppm (from green to yellow) and is associated mainly with undifferentiated Quaternary deposits, older granites with small parts in Meta-sediments, Meta-volcanic, Timsah Fm, Um Barmil Fm, Quseir Fm, Abu Aggag Fm, and Metamorphic rocks. The low levels with values less than 10 ppm extend over metasediments, Abu Aggag formation, Um Barmil formation, Metavolcanics with small parts in older granites, undifferentiated metamorphic rocks, and meta-gabbro.

- **eTh map**

  The eTh map (Fig. 6) can be divided into three levels. The first level increases up to 108 ppm and is associated with younger granites, ring complexes, Duwi Fm, Quseir Fm with small parts in Um Barmil Fm, Timsah Fm, Metamorphic rocks, and Natash volcanic. The second level ranges from 37 to 58 ppm and is restricted over the undifferentiated Quaternary deposits, Wadi deposits, Abu Aggag Fm, meta-sediments, Dakhla Fm, Pliocene deposits, Meta-volcanic, Older granites...
Fm, Pliocene deposits, Meta-volcanic, Older granites with small parts in Um Barmil Fm, Timsah Fm, Metamorphic rocks, and Quseir Fm. The low level decreases to less than 37 ppm, which is mostly associated with Abu Aggag Fm, Um Barmil Fm, Meta-sediments, Meta-volcanic, Meta-gabbro, and some older granite.

- **K% map**

  The K map (Fig. 7) indicates that Abu Aggag formation and Um Barmil formation with small parts in Taref formation, Quseir formation, and undifferentiated Quaternary deposits represent the low level (less than 3 %); while the intermediate level ranges from 3 to 10 %, which is connected with Quseir formation, Timsah formation, Um Barmil formation, Meta-sediments, Meta-volcanic with some parts in Abu Aggag formation, and Wadi deposits. The high level (up to 28 %) is associated with younger granites, metamorphic rocks, ring complex, meta-sediments, and meta-volcanic.

![Figure 6: Colored Image Map of Eth In Ppm of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt. (Data Value * 10).](image1)

**Figure 6:** Colored Image Map of Eth In Ppm of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt. (Data Value * 10).

![Figure 7: Colored Image Map of K% of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt. (Data Value * 10).](image2)

**Figure 7:** Colored Image Map of K% of Wadi Jararah-Wadi Kharit Area, South Eastern Desert, Egypt. (Data Value * 10).

- **Ternary (Composite) Images**

  Ternary maps are color composite images generated by modulating the red, green and blue in proportion to the radioelement concentration values of the K, eTh, eU and their ratio grids. Since particular rock types often have distinctive ratios of the three radioactive elements, the ternary maps of these ratios are a useful geological and mineral exploration tool for discriminating the zones of consistent lithology and contacts between contrasting lithologies (Duval 1983). Four composite color image maps were prepared as follows:

  1. Radioelements composite image map K, eTh and eU (Fig.8).
  2. Equivalent uranium composite image map eU, eU/eTh and eU/K (Fig.9).
  3. Equivalent thorium composite image map eTh, eTh/eU and eTh/K (Fig.10).
  4. Potassium composite image map K, K/eTh, K/eU (Fig.11).

- **Radioelement composite image map**

  Different rock types have different characteristic concentrations of radioelements, potassium, uranium and thorium. Therefore, concentrations calculated from gamma-ray spectrometric data can be used to identify zones of consistent lithology and contacts between constraining lithologies. The three radioelements composite image map (Fig.8) of the study area shows the variations occurring in the three radioelements concentrations, which mainly reflect lithologic variations. This map is a three-element display of equivalent uranium (ppm), equivalent thorium (ppm) and potassium (%). The colors at each point inside the triangle represent different ratios of the radioelements, according to the color differences on the absolute three radioelements composite image map. The eU, eTh and K% images emphasize the radioelement and high light areas, where the particular radioelement has relatively higher concentrations.

  It was noticed that the higher light zones are correlated with granite rocks, Ring complexes, and metamorphic rocks, which are normally characterized by their strong radio-spectrometric responses and
elemental differences. The characteristic radioelement ratios are visible on the ternary radioelements map (Fig.8). Consequently, they can be easily discriminated from the surrounding rock units with spatial correlation to zones of anomalously high K, eU and eTh levels (areas in white color) are illustrates as yellow polygons (Fig.8), as occurred in the Southern (like G. Abu Maru, G. Hadayid, G. Uqab El Nugum), Central (like Sikhat Al Jallalah, Rawad El Kabsh, Khushaybat Umm Safi, G. Dihmit, G. Abu Gihan, G. Ghurab Al Atshan, G. Ghurab Ar Rayan, Homor Akarim, and G. Nikeiba) and Eastern part of Northeastern portions (like Urf Abu Hamam) of the study area. These high radioactive zones (bright or white zones) are illustrated in Table 1. The blue polygon in refers to the highest uranium concentrations which associated with Duwi (phosphate) formation.

 Meanwhile, the ternary (three radioelements) composite image map shows black areas of weak radioelement contents as indicative to the low radioactive rocks as Abu Aggag Fm, Um Barmil Fm, Meta-volcanic with some Meta-sediments and Meta-gabbro. These dark zones are recorded at most of the Southern (like W. el Quffa, G. Hareigal, Qarn el Ties, G. Abu Hashim, G. Tarbtie, G. Abraq, and G. Kalat) parts of the study area as well as small parts in the Northeastern portions (like W. Beizih and W. Sha'it).

**Table 1: Summary of Radioactive Zones of the study area**

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Radioactive Zone</th>
<th>Rock Type</th>
<th>Situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>G.Abu Marw</td>
<td>Younger Granite</td>
<td>SW</td>
</tr>
<tr>
<td>B</td>
<td>G.Uqab El Nugum</td>
<td>Younger Granite</td>
<td>SE</td>
</tr>
<tr>
<td>C</td>
<td>G. Umm Naqa</td>
<td>Younger Granite</td>
<td>SW</td>
</tr>
<tr>
<td>D</td>
<td>G. Ghadir ib</td>
<td>Younger Granite</td>
<td>SW</td>
</tr>
<tr>
<td>E</td>
<td>G.Dihmit</td>
<td>Younger Granite</td>
<td>SW</td>
</tr>
<tr>
<td>F</td>
<td>Sikhat Al Jallalah</td>
<td>Younger Granite</td>
<td>SW</td>
</tr>
<tr>
<td>G</td>
<td>Rawad El Kabsh</td>
<td>Ring Complex</td>
<td>SW</td>
</tr>
<tr>
<td>H</td>
<td>Khushaybat Umm Safi</td>
<td>Younger Granite</td>
<td>S Central</td>
</tr>
<tr>
<td>I</td>
<td>G.Nikeiba</td>
<td>Younger Granite</td>
<td>SE</td>
</tr>
<tr>
<td>J</td>
<td>G. Ghurab Al Atshan</td>
<td>Younger Granite</td>
<td>NE</td>
</tr>
<tr>
<td>K</td>
<td>G. Ghurab Ar Rayan</td>
<td>Younger Granite</td>
<td>NE</td>
</tr>
<tr>
<td>L</td>
<td>Homor Akarim</td>
<td>Younger Granite</td>
<td>NE</td>
</tr>
<tr>
<td>M</td>
<td>G.Abu Gihan</td>
<td>Younger Granite</td>
<td>NE</td>
</tr>
<tr>
<td>N</td>
<td>Urf Abu Hamam area</td>
<td>Younger Granite</td>
<td>NE</td>
</tr>
<tr>
<td>O</td>
<td>Natash Volcanics</td>
<td>Natash Volcanics</td>
<td>NE</td>
</tr>
</tbody>
</table>

- **eU Composite image map**

  The uranium composite image (Fig.9) combines eU (in red) with the ratios of $\text{eU/eTh}$ (in green) and $\text{eU/K}$ (in blue). The relative concentration of uranium concerning both potassium and thorium is an important diagnostic factor in the recognition of the possible uranium deposits (IAEA, 1988). The uranium composite image also reflects lithological differences and could be useful in geologic mapping problems (Duval, 1983). Therefore; this map could assist in identifying the anomalous zones (bright areas on the image) of the enriched uranium concentration.

  It was noticed that the high Uranium concentration (bright color) in $\text{eU}$, $\text{eU/eTh}$ and $\text{eU/K}$ ternary map are spatially correlated with Dakhla Fm, Duwi Fm, younger granites, Ring complexes and some dispersed spots in Wadi deposits. The dark areas (low uranium values) are mainly associated with the meta-sediments, Meta-volcanic, meta-gabbro with small parts in undifferentiated Quaternary deposits and older granites.
Figure 8: False colored Radioelements Ternary image of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

Figure 9: False colored Equivalent Uranium Ternary Image of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

• **eTh Ternary Image**

  The thorium composite image (Fig.10) combines eTh (in red), eTh/eU (in green) and eTh/K (in blue). This image emphasizes the relative distribution of thorium and highlights areas of thorium enrichment. The blue and pale blue color on this image is a good pointer to parts of Abu Aggag Fm, Wadi deposits, undifferentiated Quaternary deposits, Taref Fm and small parts in Um Barmil Fm, which indicates that these areas are having high eTh/K concentrations. The pale magenta color is associated with Timsah Fm, Um Barmil Fm, and Quseir Fm, which indicates that these areas are having high eTh and eTh/K concentration. The pale green color is mainly related to meta-sediments with some older granite and undifferentiated Quaternary deposits, which indicates that these areas are having high eTh/eU concentrations. The pale red and the yellowish red color is mainly associated with younger granite and ring complexes, which means that these areas are having high eTh and eTh/eU concentrations. It was noted that the dark parts (low relative thorium values) are mainly associated with the Meta-volcanic, older granites with some parts in meta-sediments. There are some dispersed bright spots in the central part of the study area trending NW-SE and associated with Wadi deposits with some parts in Um Barmil, Timsah, and Quseir Formations.

• **K Ternary Image**

  The potassium composite image map (Fig.11) combines K (in red) with K/eTh (in green) and K/eU (in blue). This image shows the overall spatial distribution of relative potassium concentrations. The bright zones (high values) are well correlated with the younger granites, ring complex, metamorphic rocks, and metasediments, which recorded at the southern, central and central part of the Eastern parts of the study area as well as some spots in the Northeastern and Western parts. The Pale blue color is mainly associated with Meta-sediments, Meta-volcanic, some older granite, and Um Barmil Fm, which means that these areas are having high K/eTh and K/eU concentrations. The dark zones on this image (low relative potassium values) are associated with Abu Aggag, Timsah, Taref, and Um Barmil Formations and located at most of the rest of the study area.
c) Location of relatively high uraniferous concentration

A large portion of the gamma-ray spectrometric interpretation aims essentially at identifying areas of real relative uranium enrichment and eliminating any false or misleading anomalies. This will allow the uraniferous provinces to be defined so that more detailed prospecting methods can be applied to the most promising area, which could be favorable sites for potential economic radioactive mineral deposits or associated non-radioactive metallic mineralization (Saunders and Potts, 1976). There are several methods of statistical data analysis to identify and outline such potential uraniferous provinces.

According to Potts, 1976, the value equal \( X+3S \) in each rock unit for \( eU \), \( eU/eTh \) and \( eU/K \) variables (Table 2) was considered the threshold value which determines the occurrence of anomalous values.

This technique is based on the fact that 99% of all measurements in any normal frequency distribution should fall within the range of (±) three standard deviations from arithmetic means \( (X±3S) \), which approximate the background. All values that occurred beyond this range are regarded as statistically significant (A. G. N. Gharieb and Gouda, 2007). Figure 12 shows the interpreted point anomaly map of the study area, which possesses values exceeding \( X+3S \) for \( eU \), \( eU/eTh \), and \( eU/K \) variables. Eight groups of statistically significant (anomalous) points can be distinguished on this map. Localities represent uraniferous anomalous zones which could be considered as a probable target of interest for ground follow-up investigation. These zones make sure and coincidence with the extractive radioactive zones from radionuclear ternary image (Fig.8).

**Table 2: Uraniferous anomalous distribution**

<table>
<thead>
<tr>
<th>Rock Units</th>
<th>Variables</th>
<th>Statistical Parameters</th>
<th>Rock Units</th>
<th>Variables</th>
<th>Statistical Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Older Granite (gα)</td>
<td>( eU(ppm) )</td>
<td>72.83</td>
<td>Umm Barmil Formation (Kub)</td>
<td>( eU(ppm) )</td>
<td>47.03</td>
</tr>
<tr>
<td></td>
<td>( eU/eTh )</td>
<td>0.88</td>
<td></td>
<td>( eU/eTh )</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>( eU/k )</td>
<td>4.95</td>
<td></td>
<td>( eU/k )</td>
<td>9.59</td>
</tr>
<tr>
<td>Weathered Older Granite (gαw)</td>
<td>( eU(ppm) )</td>
<td>41.53</td>
<td>Dakhla Formation (Kud)</td>
<td>( eU(ppm) )</td>
<td>76.22</td>
</tr>
<tr>
<td></td>
<td>( eU/eTh )</td>
<td>0.48</td>
<td></td>
<td>( eU/eTh )</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>( eU/k )</td>
<td>2.39</td>
<td></td>
<td>( eU/k )</td>
<td>15.34</td>
</tr>
<tr>
<td>Younger Granite (gβ)</td>
<td>( eU(ppm) )</td>
<td>69.02</td>
<td>Quseir Formation (Kuq)</td>
<td>( eU(ppm) )</td>
<td>49.82</td>
</tr>
<tr>
<td></td>
<td>( eU/eTh )</td>
<td>0.59</td>
<td></td>
<td>( eU/eTh )</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>( eU/k )</td>
<td>3.18</td>
<td></td>
<td>( eU/k )</td>
<td>10.17</td>
</tr>
</tbody>
</table>
Zone 1: uraniferous anomalous are concentrated in Dokhan volcanic, Natash volcanic, and granitic rocks which associated with Urf Abu Hamam area (radioactive zone) at the northeastern corner and trending NE-SW.

Zone 2: uraniferous anomalous concentrated in Duwi Fm, Dakhla Fm, and Pliocene deposited which associated with G. Al Maghraby and east G. Al Maghraby (the highest uranium concentration) at the northwestern part of the study area and trending E-W.

Zone 3: anomalies of eU only are concentrated in older granite rock which associated with, G. Abu Gihan (radioactive zone) at the northwestern part of the study area and trending NW-SE.

Zone 4: anomalies of eU and eU/K are focused in Natash volcanics and granitic rocks which associated with, Homor Akarim, Natash volcanics, G. Ghurab Ar Rayan, and G. Ghurab Al Atshan (radioactive zones) at the northeastern part of the study area and trending NE-SW.

Zone 5: anomalies of eU and eU/K are focused in younger granite rocks which associated with G. Nikeiba (radioactive zone) at the southeastern part of the study area and trending E-W.

Zone 6: anomalies mainly of eU and some eU/K are concentrated in younger granite rocks which associated with G. Dihmit (radioactive zone) at the southwestern part of the study area and trending E-W.

Zone 7: uraniferous anomalous are concentrated in granite rocks, ring complex, meta-gabbro, metavolcanic, and Abu Aggag Fm which associated with G. Abu Maru and G. Umm Naqa at the southwestern corner of the study area and trending NW-SE.

Zone 8: uraniferous anomalous are concentrated in granite rocks, Abu Aggag Fm, Timsah Fm, Umm Barmil Fm, and quaternary deposits which associated with G. Uqab El Nugum (radioactive zone), G. Kalat, G. Amreit, and G. Abraq at the southeastern corner of the study area and trending NW-SE.
Figure 12: Spatial distribution of uraniferous concentration of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

d) **Landsat-8 Images**

i. **Band Ratios**

Band ratio is a multispectral image processing method that includes the division of one spectral band by another. This division results in the ratio of spectral reflectance measured in another spectral band. Identical surface materials can give different brightness values because of the topographic slope and aspect, shadows or seasonal changes in sunlight illumination angle and intensity. These variances affect the viewer’s interpretations and may lead to misguided results. Here the author used various bands of Landsat 8 satellite imagery for band ratio which related to airborne radioactive zones. Band ratio’s such as b6/b7, b6/b5….and so on, are used to discriminate hydrothermal alteration and its relation with airborne radioactive zones.

Tested different kinds of band ratios that show a different kind of alterations such as:

1. Hydroxyl-bearing minerals (clay minerals) alteration showed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.13) as:
   a) G. Uqab El Nugum. b) G. Umm Naqa. c) G. Dihmit. d) G. Ghurab Al Atshan. e) G. Ghurab Ar Rayan and f) Horor Akarim area.

2. Sericitization alteration showed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.14) as:
3. Ferrous Iron oxides alteration displayed tie relationship (only at the named areas) between it and airborne radioactive zones which illustrated in (Fig.15) as:

- Natash volcanics.
- G. Dihmit.
- G. Umm Naqa.
- G. Abu Marw.
- G. Ghadir-Ib.
- G. Uqab El Nugum
- G. Nikeiba.
4. Ferrous Silicate alteration exhibited a relationship between it and all airborne radioactive zones except Urf Abu Hamam area located at the center of the northern part of the study area. These radioactive zones are illustrated in (Fig.16) like:

a) Natash Volcanics.
b) Homor Akarim.
c) G. Ghurab Ar Rayan.
d) G. Ghurab Al Atshan.
e) Sikhat Al Jallabah.
f) Rawad El Kabsh.
g) Khushaybat Umm Safi.
h) G. Nikeiba.
i) G. Uqab El Nugum.
j) G. Ghadir-Ib.
k) G. Abu Marw.
l) G. Umm Naqa.
m) G. Dihmit.

5. Ferric Iron alteration showed a relationship (only at the named areas) between it and airborne radioactive zones which are illustrated in (Fig.17) as:

a) G. Nikeiba, and b) Rawad El Kabsh area.

6. Epidotization alteration showed a relationship (only at the named areas) between it and airborne radioactive zones which are illustrated in (Fig.18) as:

a) Homor Akarim.
b) G. Ghurab Ar Rayan.
c) G. Ghurab Al Atshan.
d) G. Dihmit.
e) G. Uqab El Nugum.

7. Chloritization alteration exhibited a relationship (only at the named areas) between it and airborne radioactive zones which are illustrated in (Fig.19) as:

a) Homor Akarim.
b) G. Ghurab Ar Rayan.
c) G. Ghurab Al Atshan.
d) Khushaybat Umm Safi.
e) G. Abu Marw.
f) G. Uqab El Nugum.

**Figure 17:** Band ratio 4/2, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).

**Figure 18:** Band ratio 6/4, alteration represents as red pixels superimposed on natural color mosaic image (R: G: B 4:3:2).
e) Crosta method

Minimizing the number of spectral bands input for principal component analysis ensures that certain materials will not be unambiguous, mapped into only one of the principal component images. The methodology is called Crosta Technique or Feature-Oriented Principal Components Selection (FPCS). The method does not require detailed knowledge of the spectral properties of target materials; also no atmospheric or radiometric correction is needed. PCA on raw, un-stretched data is found to be effective in all cases. The main aim of PC analysis is to data remove redundancy in multispectral data. This technique can be applied on four or six bands of Landsat 8 data (Crosta and Moore 1989). For indicating Hydroxyl alteration two reflectances Landsat 8 bands (5, 6) and two absorption bands (2, 7) have been selected (Table 3). Applying these selected bands in a principal component analysis process for each scene separately to produced four PCs for VNIR-SWIR bands. Eigenvector statistics of input bands (Table 4) reflects that PC4 is a well indicator to Hydroxyl alteration, and by applying the thresholding process which applied in band ratio technique (Table 5) hydroxyl alterations areas will appear as red color (Fig.20). And for indicating Iron oxide alteration, two reflectance bands (4, 6) and two absorption bands (2, 5) have been selected (Table 3). Applying these selected bands in a principal component analysis process produced four PCs for VNIR-SWIR bands. Eigenvector statistics of input bands reflects that PC4 is a good indicator to Iron oxide alteration (Table 6) and the thresholding process (Table 7) show that Iron oxide alterations areas will appear as red color (Fig.21).

<table>
<thead>
<tr>
<th>Type of Alteration</th>
<th>Landsat 8 (selected bands)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High reflectance</td>
</tr>
<tr>
<td>Hydroxyl Alteration</td>
<td>Band 5</td>
</tr>
<tr>
<td></td>
<td>Band 6</td>
</tr>
<tr>
<td>Iron Oxide Alteration</td>
<td>Band 4</td>
</tr>
<tr>
<td></td>
<td>Band 6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scene no.</th>
<th>PC</th>
<th>Band 2</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Band 7</th>
<th>Eigenvectors</th>
<th>Eigen %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene A</td>
<td>PC1 0.385 0.515 0.549 0.535 22786.38 92.53</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC2 0.914 -0.101 -0.270 -0.284 1335.55 5.42</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC3 0.123 -0.850 0.401 0.318 431.34 1.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC4 0.020 -0.046 -0.682 0.730 72.83 0.30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scene B</td>
<td>PC1 0.482 0.503 0.510 0.505 23311.57 96.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC2 0.786 0.110 -0.391 -0.466 628.68 2.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC3 0.379 -0.813 0.005 0.443 158.11 0.65</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>PC4 -0.078 0.273 -0.766 0.576 56.77 0.24</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Scene C</td>
<td>PC1 0.410 0.532 0.522 0.526 27350.86 93.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC2 0.910 -0.182 -0.263 -0.264 1649.74 5.65</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC3 -0.062 0.798 -0.566 -0.198 131.79 0.45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PC4 -0.016 0.217 0.582 -0.784 42.99 0.15</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5: Eigenvector values statistics of selected Iron Oxide alteration bands for each scene separately

<table>
<thead>
<tr>
<th>Scene no.</th>
<th>PC1</th>
<th>Band 2</th>
<th>Band 4</th>
<th>Band 5</th>
<th>Band 6</th>
<th>Eigenvalues</th>
<th>Eigen %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene A</td>
<td>0.416</td>
<td>0.529</td>
<td>0.525</td>
<td>0.520</td>
<td>22226.96</td>
<td>90.30</td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td>0.904</td>
<td>-0.151</td>
<td>-0.282</td>
<td>-0.284</td>
<td>2182.84</td>
<td>8.87</td>
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</tr>
<tr>
<td>PC3</td>
<td>-0.099</td>
<td>0.828</td>
<td>-0.469</td>
<td>-0.290</td>
<td>140.64</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>PC4</td>
<td>-0.015</td>
<td>0.104</td>
<td>0.651</td>
<td>-0.751</td>
<td>62.90</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td>Scene B</td>
<td>0.485</td>
<td>0.511</td>
<td>0.502</td>
<td>0.501</td>
<td>23564.32</td>
<td>97.32</td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td>0.711</td>
<td>0.132</td>
<td>-0.148</td>
<td>-0.674</td>
<td>484.29</td>
<td>2.00</td>
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</tr>
<tr>
<td>PC3</td>
<td>0.465</td>
<td>-0.405</td>
<td>-0.575</td>
<td>0.538</td>
<td>149.30</td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td>PC4</td>
<td>0.205</td>
<td>-0.747</td>
<td>0.629</td>
<td>-0.068</td>
<td>14.67</td>
<td>0.06</td>
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<tr>
<td>Scene C</td>
<td>0.413</td>
<td>0.533</td>
<td>0.529</td>
<td>0.515</td>
<td>27699.37</td>
<td>94.23</td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td>0.899</td>
<td>-0.115</td>
<td>-0.264</td>
<td>-0.331</td>
<td>1519.43</td>
<td>5.17</td>
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<tr>
<td>PC3</td>
<td>0.111</td>
<td>-0.423</td>
<td>-0.429</td>
<td>0.790</td>
<td>165.76</td>
<td>0.56</td>
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<tr>
<td>PC4</td>
<td>0.097</td>
<td>-0.723</td>
<td>0.683</td>
<td>-0.030</td>
<td>12.17</td>
<td>0.04</td>
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<tr>
<td>Scene D</td>
<td>0.424</td>
<td>0.539</td>
<td>0.520</td>
<td>0.510</td>
<td>22926.95</td>
<td>91.43</td>
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<tr>
<td>PC2</td>
<td>0.877</td>
<td>-0.058</td>
<td>-0.268</td>
<td>-0.395</td>
<td>1950.29</td>
<td>7.78</td>
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<tr>
<td>PC3</td>
<td>0.186</td>
<td>-0.473</td>
<td>-0.407</td>
<td>0.759</td>
<td>184.30</td>
<td>0.73</td>
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<tr>
<td>PC4</td>
<td>0.129</td>
<td>-0.695</td>
<td>0.702</td>
<td>-0.088</td>
<td>14.74</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

So, PC1 is the "albedo and topography" image, PC2 describes the contrast between the SWIR and the visible region, PC3 is brightest for vegetation, and PC4 highlights hydroxyl-bearing minerals Table 2. And in Table 3, PC1 is the "albedo" image, PC2 describes the contrast between the IR and the visible region, PC3 is brightest for vegetation, and PC4 highlights Iron Oxides.

Table 6: The thresholding values of Hydroxyl alteration selected bands for each scene separately

<table>
<thead>
<tr>
<th>Scene no.</th>
<th>Mean (µ)</th>
<th>Standard Deviation (σ)</th>
<th>Threshold Value (µ+1* σ)</th>
<th>Threshold Value (µ+2* σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene (A)</td>
<td>116.79</td>
<td>74.79</td>
<td>191.58</td>
<td>226.32</td>
</tr>
<tr>
<td>Scene (B)</td>
<td>123.41</td>
<td>75.61</td>
<td>199.02</td>
<td>230.86</td>
</tr>
<tr>
<td>Scene (C)</td>
<td>100.03</td>
<td>68.99</td>
<td>238.03</td>
<td>248.23</td>
</tr>
<tr>
<td>Scene (D)</td>
<td>96.61</td>
<td>67.44</td>
<td>231.5</td>
<td>221.33</td>
</tr>
</tbody>
</table>

Table 7: The thresholding values of Iron Oxide alteration selected bands for each scene separately

<table>
<thead>
<tr>
<th>Scene no.</th>
<th>Mean (µ)</th>
<th>Standard Deviation (σ)</th>
<th>Threshold Value (µ+2* σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scene (A)</td>
<td>120.20</td>
<td>53.06</td>
<td>226.32</td>
</tr>
<tr>
<td>Scene (B)</td>
<td>120.06</td>
<td>55.4</td>
<td>230.86</td>
</tr>
<tr>
<td>Scene (C)</td>
<td>140.43</td>
<td>53.9</td>
<td>248.23</td>
</tr>
<tr>
<td>Scene (D)</td>
<td>108.53</td>
<td>56.4</td>
<td>221.33</td>
</tr>
</tbody>
</table>
So, from (Figs. 20 & 21) we can indicate that:

1. In the Hydroxyl alteration (Fig.20), Homor Akarim area, G. Ghurab Ar Rayan, G. Ghurab Al Atshan, G. Nikeiba, Khushaybat Umm Safi, Rawad El Kabsh, Sikait El Jallabah, G. Dihmit, and G. Uqab El Nugum (a, b, c, d, e, f, g, h, and i, respectively) showed tie relationship with airborne radioactive zones.

2. And in the Iron Oxide alteration (Fig.21), Urf Abu Hamam area, Natash Volcanics, Homor Akarim area, Sikait El Jallabah, G. Ghadir ib, G. Abu Marw, and G. Uqab El Nugum (a, b, c, d, e, f, and g, respectively) showed tie relationship with airborne radioactive zones.

These tie relationships give us an initial indication for a prospecting radioactive exploration for the same alterations distribution in the study area which didn’t survey by airborne. (Fig.22) shows the promising radioactive 9 zones in the unsurvey area and the authors classified it as zones according to host rock where most of the host rocks are granitic rocks.
Figure 22: Showing the promising zones in the unsurvey area of Wadi Jararah-Wadi Kharit area, South Eastern Desert, Egypt.

- Zone 1: associated with granitic rocks like (G. el-Dob Neiya and G. Zabara), meta-volcanic, metasediments, and meta-gabbro rocks.
- Zone 2: Mainly associated with granitic rocks like (G. Duwaiq, G. Nuqus, G. Ras Sha’it, and G. El Faliq) with some meta-gabbro and volcanic rocks.
- Zone 3: mainly associated with ring complex (G. Abu El Khruq).
- Zone 4: mainly associated with Natash Volcanic.
- Zone 5: mainly associated with granitic rocks (east G. Muqtil)
- Zone 6: associated mainly with metavolcanic rocks and some granitic rocks like (G. Hashanib and G. Sheikh Shalby) with meta-gabbro.
- Zone 7: mainly correlated with granitic rocks like (G. el Homur and G. Humriet Muqbad) with metasediments and ring complex (G. Kahfa).
- Zone 8: associated with Cetaceous formation (Abu Aggag Fm and Timsah Fm) with some metasediments and meta-gabbro.
- Zone 9: mainly granitic rocks like (G. Hodein).

IV. Conclusion

Airborne gamma-ray spectrometric measurements provide a good method for determining the radioactive zones at Wadi Jararah-Wadi Kharit area (in the surveyed area) through the interpretation of ternary images and the spatial distribution of the relatively high concentration of eU, eU/K, and eU/eTh variables, these zones are G.Abu Marw, G.Uqab El Nugum, G. Umm Naqa, G. Ghadir ib, G.Dihmit Sikhat Al Jallabah, Rawad El Kabsh, Khushaybat Umm Safi, G.Nikeiba, G. Ghurab Al Atshan, G. Ghurab Ar Rayan, Hmors Akarim, G.Abu Gihan, Alu Abu Hamam area, and Natash Volcanics. And through using different band ratios of Landsat images as (6/7, 4/2, ......and so on) and applying Crosta technique for indicating hydroxyl and iron oxide alterations, we could find tie relationship between radioactive zones (only at named zones) in the surveyed area and explore a new promising zones in the unsurvey areas like, G. el-Dob Neiya, G. Zabara, G. Duwaiq, G. Nuqus, G. Ras Sha’it, G. El Faliq, G. Abu El Khruq, G. el Homur, and G. Humriet Muqbad.

Acknowledgment

I wish to express my deep thanks and gratitude to Spaceborne Geophysics department (NMA) for it help and encouragement during the course of this work.

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