Contribution to the provenance and paleoclimate of the Lower Paleozoic sandstones of Naqus Formation, Wadi Qena, Northern Eastern Desert: Integration of support petrography, mineralogy and geochemistry

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ABSTRACT

This study focuses on the Lower Paleozoic sandstones of the Naqus Formation exposed on the western margin in the northern part of Wadi Qena “Eastern Desert” Egypt, to identify the possible source, geotectonic setting and weathering effects, using integrated petrographical and geochemical approaches. The Naqus sandstones (Cambro-Ordovician) overlies unconformably Precambrian crystalline rocks (mainly igneous and metamorphic rocks) of the Arabo- Nubian Shield in the study area and overlie unconformably by shallow marine sediments of the Coniacian transgression (Galala Formation). It consists of a succession of white, massive cross-bedded pebbly coarse to medium grained sandstones. The Formation implies highly textural maturity, medium to fine grained and limited effect of diagenetic processes. Petrographically, the Naqus sandstones are classified as quartz arenites, highly enriched in quartz and deposited of the Paleozoic Era at Wadi Qena area where it is have studied and discussed the age and stratigraphy have assigned by Abdallah et al., [1] to be Ordovician-pre Cambrian age, however, in north Wadi Qena, he arised the age of this early Paleozoic sandstone to the Carboniferous (Sommer El- Qaa Formation). On the

INTRODUCTION

The use of geochemical composition of siliciclastic sedimentary rocks is a function of the complex interplay of various variables such as provenance [50,6,64], the weathering and erosion [51,82], the tectonic setting of the depositional basins [10,11,17] and post- depositional changes [26,23,24].

The sedimentary rocks of Wadi Qena range in age from Paleozoic to Quaternary. Many authors have studied and discussed the age and stratigraphy of the Paleozoic Era at Wadi Qena area where it is differentiated into several formal rock units [36,7,42,71,1,37,86,76].

In the Eastern Desert, north of Wadi Qena, the exposed Lower Paleozoic rock units represented by the Araba and Naqus formations [81]. The term Naqus Formation was first proposed by Said [70]. The sandstone of the Naqus Formation has been described as a “Nubian type” because of its similarity to other similar sandstones exposed in North Africa, northern Saudi Arabia and Jordan [9,20,21,11]. Everywhere, sediments of the Naqus Formation are recognized from their strikingly white cross-bedded pebbly coarse-to-medium grained sandstones, which represent an abrupt change from the underlying red laminated fine-grained sandstone and siltstone beds of the Araba Formation. The Naqus Formation exhibits an unconformable relationship with the overlying rock unit [41]. In some places, the Naqus Formation is unconformably overlain by Carboniferous rock units, whereas in others it is unconformably overlain by Cretaceous rock units.

At north Wadi Qena, the Naqus Formation was assigned by Abdallah et al., [1] to be Ordovician-pre Cambrian age, while considered by Wanas and Soliman [79] to be of Early Paleozoic age on the basis of its stratigraphic position. Klitzsch [43] considered this formation in Sinai to be of Early-Cambrian age, however, in north Wadi Qena, he arised the age of this early Paleozoic sandstone to the Carboniferous (Sommer El- Qaa Formation). On the
other hand, Tawfik et al., [76] assigned it as of Cambro-Ordovician in age.

Nagm and Wilmsen [54] reported that most of the Paleozoic sediments at Wadi Qena deposited under non-marine conditions. Issawi and Jux [36] interpreted this formation as fluvo-glacial sediments deposited by the great Sahara glaciers that covered vast parts of north western Africa during the Upper Ordovician- Silurian Period. Abdallah et al., [1] emphasized that the Naqus Formation at Wadi Qena was deposited under predominantly fluvial braided channel system.

The distribution of the Paleozoic sediments are well developed in the northern part of the Wadi Qena and more or less controlled by older, pre-Cenomanian structural events [71,37,54]. The first marine transgression took place during the Late Cenomanian Galala Formation which overlies unconformably the Naqus Formation.

The most studies on the Naqus sandstones of the western margin of the northern part of Wadi Qena have concerned with the stratigraphy and /or sedimentology, no detailed studies on their geochemistry and tectonic setting have been made. In the present study the authors focus on the geochemical composition, mineralogy and petrography studies to draw a finer picture of their provenance, source weathering history, and tectonic setting of deposition.

**Lithostratigraphy:**

The Naqus Formation occurs as scattered outcrops in the area of study, in a series of hills and mesas that lie between Lats. 27° 46' 55'' - 27° 55' 55'' N and Longs. 32° 31' 12'' - 32° 35' 28'' E (Fig.1). The Naqus Formation has a preserved thickness ranges from ~22 m to ~120 m at the study area. Two stratigraphic sections, located on the western margin in the northern part of Wadi Qena have been measured, where the Wadi Qena separates between the Precambrian rocks in the eastern side and the Phanerozoic sedimentary rocks including the white sands of Naqus Formation in the western side. The first section (1) measured ~106 m thick while, the second section (2) measured ~120 m thick. The Araba Formation is not recorded in the studied areas and the sedimentary succession starts with the Lower Paleozoic Naqus Formation.

Generally, the Naqus Formation in the study area overlies unconformably the basement rocks (mainly igneous and metamorphic rocks) of the Arabo- Nubian Shield. The Naqus Formation is characterized by its white color, and has more or less the same lithological characters in the both sections. Commonly, it mainly consists of massive sandstones. They are medium-to-fine grained, moderately-to-well sorted, moderately-hard to semi-friable, occasionally friable, subrounded to rounded, occasionally subangular, kaolinitic in parts with different sizes of rounded to subrounded coarse quartz grains distributed haphazardly and some lenses of kaolin distributed randomly throughout the whole sequence especially at the upper part. At certain horizons, the sandstones are characterized by planar and trough cross-beddings change to flat-bedded. The upper contact of the Naqus sandstones does not occur in section (1), while section (2) overlain unconformably by shallow marine sediments of the Cenomanian Galala Formation which is made up of ~15 m thick of greenish, yellow shale, sandy marl intercalated with claystone, siltstone, sandstone, fossiliferous limestone and thick oyster beds (Fig. 2).

![Fig. 1: Geologic map of the study area (Wadi Qena, Northern Eastern Desert). After Geological Survey of Egypt [30].](image-url)
**Materials and Methodology**

Two stratigraphic sections, located on the western margin of the northern part of Wadi Qena have been measured (Fig.1). Thirty one representative samples were collected from the sandstone beds of the Naqus Formation. A total of twenty sandstone samples were selected for determining the petrographic characteristics by examining their thin sections under polarizing microscope. Twelve selected sandstone samples were chosen to identify the clay fractions by X-Ray diffraction analysis following the method described by Carroll [14]. Three oriented mounts were prepared for each sample: untreated, glycolated and heated at 550°C for two hours. Semi- quantitative determination of the identified clay minerals was undertaken based on the method adopted by Pierce and Siegel [61]. X-Ray diffractograms were obtained using Philips X–Ray diffractometer model PW/1710 with monochromator, Cu-α radiation (λ=1.542 Å) at 40 KV, 35 mA and scanning speed of 0.02°/sec. Also, scanning electron microscopy (SEM) was utilized for selected samples to study the composition, morphology and crystallinity characteristics of the recorded clay minerals and to clarify some petrographic details.

X–Ray fluorescence technique is used for the analysis of major, trace and some rare earth elements. Thirty one samples were chemically analyzed for their major element concentration, while trace and rare earth element concentrations were determined in ten selected samples representing the two sections at the studied area. The XRF analysis was carried out for powder (<74 μm) samples using X- Ray fluorescence equipment PW2404 with six analyzing crystals.

**Results and Discussion**

**Petrography:**

According to the classification proposed by Pettijohn et al., [60], the sandstones of the Naqus Formation are mainly arenites, entirely composed of quartz, from 88 to 95 % at section (1) and from 89 to 95 % at section (2). The Quartz grains are commonly clear and rarely cloudy. Generally, quartz grains are medium -to -fine grained although a few are coarse or very fine. They are generally subrounded to rounded, randomly oriented, subequent to slightly elongate. They are moderately- to- well sorted and have open- to- moderately grain packing (Plate Ι: B). They are predominantly monocrystalline, while a few are Polycrystalline. Monocrystalline quartz grains showing both uniform and undulose extinctions (Plate Ι: A & C). Inclusions of heavy minerals are rarely recorded in some samples and represented by rounded to well rounded, randomly oriented, subsequent to slightly elongate. They are moderately- to- well sorted and have open- to- moderately grain packing (Plate Ι: B). The original boundaries of the grains are preserved and are distinguished by the presence of thin films of dust like inclusions, indicating a multicyclic history.

The groundmass of the studied sandstones is mainly represented by variable amounts of argillaceous matrix together with scarcity of calcite.
and silica. The matrix is represented mainly by uncommon clay and rarely silty clay. The silica is represented as microcrystalline silica occurring as pore fillings and as silica overgrowths (Plate I: D & B). Calcite cements are very minor, occasionally etched and corroded the peripheries of quartz grains (Plate I: A).

The petrographic examination revealed that quartz is the dominant detrital mineral. The relatively high proportion of monocrystalline quartz grains may be attributed to the disaggregation of original polycrystalline quartz during high energy and/or long distance transport from the source area [18, 80, 76]. The dominance of uniform and undulose quartz grains indicate plutonic origin and highly mineralogical mature rocks [62]. Inclusions of rounded to well rounded grains of zircon and tourmaline within quartz grains may suggest that derivation either from igneous or metamorphic rocks [12, 52]. Abrasion of overgrowths assigned by Mankiewicz and Steidtman [47] as indication of recycling sediments. The absence of feldspars and scarcity of rock fragments indicate that the source was subjected to intensive chemical weathering for long period [5].

The studied sandstones exhibit a limited effect of diagenetic changes including chemical compaction effect and cementation. Chemical compaction has resulted in the development of less commonly various types of pressure solution contacts between grains among which the tangential, straight or concave-convex. The minor proportions of silica which present either as microcrystalline silica filling pores and as overgrowths on detrital quartz grains in some samples. The microcrystalline silica that fills pores may be attributed to the silica-rich meteoric waters which might have taken place shortly after deposition. On the other hand, the recorded quartz overgrowths were the result of slow deposition of silica during the burial stage. The rarely proportions of carbonate may be attributed to the movement of circulating water in deeper zones. The absence of Fe-rich silicates suggested that an intensive weathering for the Naqus sandstones either of the source area or during transportation to the basin of deposition.

Clay mineralogy:

The X-ray diffraction analysis of the Lower Paleozoic sandstones of the Naqus Formation reveals that kaolinite is the sole clay-mineral constituent in the measured sections. Based on the sharpness and intensities of the diffractions peaks [73, 14] and the number of reflections [39], the reported kaolinite is mainly moderately-crystallized. The common of moderately-crystallized kaolinite suggests that it is chiefly of detrital inheritance and deposited in fluvial environment [22, 39, 4, 46].

On the other hand, the identified clay minerals were studied by SEM (Plate I: E & F) which shows that kaolinite is the sole clay-mineral in the studied sandstones of the Naqus Formation. The kaolinite is found as coarse-to medium sized particles and aggregates, moderately-crystallized with some pores and fine-grained sand that may reflect a detrital origin [40]. The absence of the criteria including booklet shape, the authigenic vermiciform, and anhedral and blocky crystals indicates that kaolinite is mainly of detrital origin [13, 44].

The origin of detrital kaolinite (allogenic) has been interpreted by many workers as to be a product of intense chemical weathering of feldspars and micas in predominantly acidic igneous and metamorphic rocks or their detrital weathering products under tropical to subtropical humid climatic conditions with abundant rainfall and relatively high degree of leaching [85, 22]. This accordance with the present work, the reported kaolinite may be come from weathering horizons and/or soils on sedimentary and quartz-bearing plutonic rocks. The resulted materials were transported by rivers to the basin of deposition.

Geochemistry:

Thirty-one sandstone samples are analyzed for major elements and compared with the average composition of the Passive Margin Sandstones [10], Post-Archaean Australian Shale “PAAS” reported by Taylor and McLennan, [77] and Upper Continental Crust “UCC” [69], (Table 1). The trace and some rare earth elements are also compared with the average values of the PAAS and UCC listed in Table (2). The correlations between these elements are listed in Table (3).

i) Major elements:

SiO$_2$ values in Wadi Qena sandstones of the Naqus Formation range from 88 to 95 %, averaging 93 %. This value is generally very higher than those of the “UCC” reported by Rudnick and Gao, [69], the PAAS [77] and the Passive Margin Bhatia, [10], (66.6, 62.8 and 81.95 %; respectively), Table (1). The high silica content of the studied samples could be attributed to their silty/sandy nature or controlled by the sand fraction. The high concentrations of SiO$_2$ indicated that the sources of the detrital should have been composed virtually entirely of quartz [29].

SiO$_2$ values show negative correlations with several major elements (Table 3) indicating quartz intensity [53]. The designative negative correlation between SiO$_2$ and Al$_2$O$_3$ (r= -0.98) indicated that hydrodynamic separation of clays and quartz during deposition and much of the SiO$_2$ is present in quartz minerals [3]. The major elements TiO$_2$, CaO and P$_2$O$_5$ show positive correlations with Al$_2$O$_3$ and negative correlations with SiO$_2$, confirming that much of SiO$_2$ is present as quartz grains.
Plate I: (A) Photomicrograph showing quartz arenite consisting mainly of medium- to coarse, moderately sorted, subrounded to rounded and monocrystalline quartz grains which display uniform or, less commonly, slightly undulose extinction. Notice, minor calcitic cement corrodes quartz grains at their peripheries (Sec. 1, S. No. 4, C.N.). (B) Photomicrograph showing open- to- moderately grain packing with worn overgrowths (Sec. 1, S. No. 14, C.N.). (C) Photomicrograph showing quartz arenite consisting mainly of coarse, moderately sorted, rounded to subrounded, monocrystalline quartz grains which display uniform or, less commonly, slightly undulose extinction with various types of pressure solution contacts between grains (Sec. 2, S. No. 19, C.N.). (D) Photomicrograph showing monocrystalline, fine to medium, moderately sorted quartz grains which was diagenetically cemented by microcrystalline silica with part of polycrystalline quartz pebble grain (Sec. 2, S. No. 25, C.N.). (E) SEM photomicrograph showing detrital kaolinite found as coarse-to medium, moderately-crystallized with some pores filling and grain rimming/coating around quartz grains (Sec. 1, S. No. 14 & Sec. 2, S. No. 29).

The studied sandstones are highly depleted in the entire major elements except SiO₂ (due to enrichment in quartz) than those recorded by Rudnick and Gao [69], Taylor and McLennan [77] and Bhatia [10]. This suggests intense degree of weathering and reworking that removed ferromagnesian minerals and feldspars. Generally, the studied sandstones have higher SiO₂ average (93 %) and moderately Al₂O₃ (average 4.98 %) with low Al₂O₃/SiO₂ ratios (0.05) and Fe₂O₃ + MgO average (0.06 %), (Table 1). These are comparable to those of the passive margins sandstones of Bhatia [10]. The Al₂O₃ values are positively correlated with Ti₂O, P₂O₅, and CaO (r = 0.57, r = 0.42 and r = 0.82; respectively, Table 3) indicating that these elements are primarily controlled by the contents of the clay minerals [48].

ii) Trace elements:

The strong positive correlation between SiO₂ and Nb (r = 0.94) and moderately with the most the trace elements (Sr, La, Rb, Zr, Zn, Co and V) suggest that
most of the trace elements are concentrated in the sandstone fraction (Table 3). Cr and Ni are show moderate positive correlations with Al₂O₃, suggesting association with aluminosilicate clay phases. The Y contents show poor positive correlation with SiO₂ (r = 0.08) and negative correlation with Al₂O₃ (r = -0.16). However, the positive correlations with Fe and Ti (r = 0.45 and 0.24, respectively), indicate its association with Ti-Fe oxides or an additional source as heavy minerals containing Y such as monazite, [45].

The studied sandstones have higher values of the large ion lithophile elements (LILE), (e.g. Ba and Sr) than those of the UCC and PAAS values, with the exception of Rb and K contents. Also, they are characterized by high content of the high field strength elements (HFSE, Zr, Sr, Y, Nb and La) with respect to those of the UCC and PAAS values. The higher field strength elements (HFSE) to the UCC are revealed felsic sources [84]. The higher Zr abundance suggests preferential concentration of detrital zircon. The high concentrations of Zr, La, Nb, Zn, Ba, Sr and Ce suggest an intensive chemical weathering of the source rocks.

iii) Normalized pattern:

The primary characteristics of the source rocks of detrital sediments may be completely destroyed or changed during deposition, thus, the sediments supply the only records of the source and its tectonic setting [11].

The concentrations of the major and trace elements in the investigated samples have been normalized to the average content in the Upper Continental Crust (UCC) reported by Rudnick and Gao, [69] and the Post-Archaean Australian Shale (PAAS) given by Taylor and McLennan, [77], (Figs. 3 :a and b). The UCC and PAAS normalized pattern indicated that the sandstones of the Naqas Formation are generally enriched in SiO₂ (Fig. 3a) and depleted in the other major elements, which reflect that most of SiO₂ present as quartz. Depletion of Ca, Na and Mn refers that the studied sediments subjected to intensive chemical weathering.

The normalized pattern for the studied trace and rare earth elements can be classified into three groups (Fig. 3b). Elements are enriched relative to the UCC and PAAS such as, Ba, Zr, Sr, Nb, La, Ce, while Y is enriched relative to the UCC and Rb respect to the PAAS. The enrichment of most of these elements may reflect the abundance rate of felsic components in the source rocks. The next group comprises Cu, Ni, Cr and V which are lower than PAAS and UCC, indicating the negligible role of mafic provenance. The third group consists of Pb, the concentration of which is most comparable to that in the UCC and PAAS, indicating that it not changes during the weathering processes.

### Table 1: Chemical composition of the major elements and their elemental ratios, CIA, PIA, CW and IVC of the studied sandstones.

<table>
<thead>
<tr>
<th>Section</th>
<th>Tm</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>TiO₂</th>
<th>Fe₂O₃</th>
<th>MgO</th>
<th>MnO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>LOI</th>
<th>FeO</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>SiO₂</th>
<th>TiO₂/Al₂O₃</th>
<th>P₂O₅/Al₂O₃</th>
<th>LOI/Al₂O₃</th>
<th>FeO/Al₂O₃</th>
<th>CaO/Al₂O₃</th>
<th>Na₂O/Al₂O₃</th>
<th>K₂O/Al₂O₃</th>
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<th>ICY</th>
<th>ICV</th>
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Note: The averages for UCC given by Rudnick and Gao [69], PAAS given by Taylor and McLennan [77] and Passive margin by Bhatia [10].

ICV= Index of Compositional Variability  
CIW= Chemical Index of Weathering  
PIA= Plagioclase Index of Alteration  
CIA= Chemical Index of Alteration  
PAAS= Post-Archaean Australian Shale.
Table 2: Chemical composition of the trace elements (ppm) and their elemental ratios of some selected samples of the studied sandstones.

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<td>0.00</td>
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Table 3: Correlation coefficient of the major and trace elements for the investigated sandstones.

| SiO2 | Al2O3 | TiO2 | Fe2O3 | MgO | CaO | Na2O | K2O | P2O5 | LOI | Bu | Cr | Nb | Ni | Rb | V | Zn | Zr | Sr | La | Ce | La | Cu | Pb |
|------|-------|------|-------|-----|-----|------|-----|------|-----|----|----|----|----|----|---|----|----|---|---|---|----|----|----|----|
| 0.00 | 0.00  | 0.00 | 0.00  | 0.00| 0.00| 0.00  | 0.00| 0.00  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|

Fig. 3: Concentrations of the major (a) and trace (b) elements in the studied sandstones normalized to the averages for PAAS [77] and UCC [69].

Geochemical classification and maturity of the Naqus Formation:

Identification of the textural and geochemical maturity of sediments helps confine their origin, the influence of weathering and clay mineral content [33,15]. The petrographic study indicated that the sandstones of the Naqus Formation are classified as quartz arenites. Geochemically, the studied samples lie in the quartz arenites field (Figs. 4: a and b). This indicates that the sediments in Naqus Formation are geochemically and texturally mature and derived from active tectonically source [31,60].
Fig. 4: Classification plots for the Wadi Qena sandstones: (a) Classification plot on the diagram adopted by Herron (1988), LA = litharenite; SA = Sublitharenite; SR = Subarkose. (b) Classification plot on the diagram proposed by Pettijohn et al., [60]

With an increasing degree of weathering, alumina content is enhanced and those of ferromagnesian compounds decreased and reflect the maturity of sedimentary rocks. The evaluating rock maturity, the Index of Compositional Variability (ICV) [15,63] is commonly used. The ICV is defined as:

$$ICV = \frac{Fe_2O_3 + K_2O + Na_2O + CaO + MgO + MnO}{Al_2O_3}$$

The ICV values of the sandstones of Naqus Formation range from 0.04 to 0.12 average 0.07 (Table 1). These values are lower than those of the PAAS and the UCC values (0.85 and 1.2; respectively), indicating that the studied sediments are compositionally highly mature. The high maturity of the studied sandstones and high weathering intensity suggest inactive uplift and erosion of the source. Compositionally mature sediments characterize tectonically quiescent or cratonic environments [85] where sediment recycling is active, but may also be produced by intense chemical weathering of first-cycle material [8].

Alteration and weathering effect:

The effects of alteration on the fresh composition of the source material due to chemical weathering processes of the source rocks can be expected from the $Al_2O_3-(CaO^* + Na_2O)-K_2O$ diagram proposed by Fedo et al., [23]. Consequently, the weathering history and diagenesis of the studied sandstones can be evaluated by several methods; plotting samples on the (A-CN-K) triangular diagram, the Chemical Index of Alteration (CIA = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$; Nesbitt and Young, [55]; the Chemical Index of Weathering (CIW = $[Al_2O_3/(Al_2O_3 + CaO^* + Na_2O + K_2O)] \times 100$; Nesbitt and Young, [55] and the Plagioclase Index of Alteration (PIA= $([Al_2O_3 - K_2O]/[Al_2O_3 + CaO^* + Na_2O]) \times 100$; Harnois, [31]. $CaO^*$ denotes the calcium from silicate minerals only.

In the A-CN-K diagram for the Naqus Formation sandstones (Fig. 5), all the studied samples plot in the A apex (kaolinite composition) and conformed to the A-CN edge. This pattern suggests that the sediments of the Naqus Formation were affected by high degree of kaolintization as also confirmed by SEM. The dissolution and alteration of unstable grains such as feldspar and granitic rock fragments guide to kaolintization.
CIA values could also be influenced by tectonism, higher and more homogeneous CIA should be produced in stable tectonic conditions undergoing stable condition of weathering [58]. In contrast, active uplift produces a range of CIA values for sediments eroded during non-steady state weathering. The CIA values can also be presented on an Al₂O₃-(CaO* + Na₂O)–K₂O ternary diagram [23]. All the samples plot in the top of the diagram at the kaolinite composition, which indicates the high degree of alteration and weathering [23]. Consequently, the higher CIA values in the studied sandstones and linear trends in A–CN–K (Fig. 5) indicate that they were derived from steady state weathering and inactive tectonism, which conformed by the geochemical classification. The high average CIW value (99.57%) can be due to either absence of intense recycling in a humid climate or intense recycling in an arid/semiarid climate.

**Fig. 5:** Plotting of chemical index of alteration (CIA) with ternary plots of Al₂O₃-(CaO* Na₂O)-K₂O shows the weathering trend and alteration in Wadi Qena sandstones after Nesbitt and Young [56] and Fedo et al. [23].

On average, the CIA, CIW and PIA average values of the studied samples are (99.35, 99.57 and 97.96 %; respectively), (Table 1). These values suggest that the studied sandstone samples were subjected to intensive weathering either of the original source or during transportation before deposition.

Also, the combination of the Index of Compositional Variability (ICV) of Cox et al. [15] and the Chemical Index of Alteration [55] can also be used to evaluate the maturity and weathering intensity [2]. The Wadi Qena sandstones have ICV values ranging from 0.04 to 0.12, average 0.07 and CIA ratios ranging from 99.12 to 99.70, average 99.35 (Table 1). The ICV values are thus lower whereas CIA are higher than the PAAS values (0.85 and 88.32; respectively; Taylor and McLennan, [77] and those values of the UCC (1.2 and 53.4; respectively; Rudnick and Gao, [69]). (Fig. 6). Consequently, the Wadi Qena sediments are geochemically more mature, and were derived from an intensive weathered source. The higher CIA value reveals that the climate is relatively warmer [88].

**Fig. 6:** CIA versus IVC for the studied sandstones. The PAAS data from Taylor and McLennan [77] and the UCC from Rudnick and Gao [69].
Climatic condition:

The plot of SiO$_2$ against (Al$_2$O$_3$ + K$_2$O + Na$_2$O) proposed by Suttner and Dutta, [74] was used to recognize the maturity of the sandstones of the Naqus Formation as a function of climate (Fig. 7). This plot revealed that the study samples are highly mature and formed under semihumid to humid climatic condition.

Sediments are responsible to leach alkali and alkaline earth elements (e.g. Na, Ca and K), but also retain some stable elements (such as Al and Ti) in their residual constituents during the passage from source terrane to depositional site [34]. K$_2$O/ Al$_2$O$_3$ ratios range from 0.001 to 0.003 (Table 1) indicate the intensive weathering in the sources [68]. Roaldset [65] mentioned that the relation between K$_2$O/Al$_2$O$_3$ and MgO/Al$_2$O$_3$ can be used to differentiate between marine and non-marine sediments. Applying this relation (Fig. 8) revealed all the studied sandstone samples plot in the fresh water field, which is in agreement with Abdallah et al., [1] and Nagm and Wilmsen [54]. Also, the concentration of Ni in the studied sandstones samples average 2 ppm indicated that they are deposited in fresh water condition [78].

Fig. 7: Plots of the studied sandstones in the diagram proposed by Suttner and Dutta [74].

Fig. 8: Plots of the studied sandstones on the diagram adopted by Roaldset [65].

Provenance and tectonic setting:

Provenance of the sandstones can also be evaluated by using the major element discrimination adopted by Roser and Korsch [67]. Therefore, the geochemistry of sedimentary rocks is strongly related to the tectonic setting in which they were deposited. The plots of the studied sandstone samples on the diagram adopted by Roser and Korsch [67] suggests that the sandstones of Naqus Formation are derived from mature polycyclic continental sedimentary rocks (Fig. 9). The discriminate degrees of Bhatia [10] and Roser and Korsch [66] favor a passive margin setting for the sandstone samples of Naqus Formation (Figs. 10 and 11). Passive margin sediments are derived from stable continental and
deposited in intra-cratonic basins or on passive continental margins [66]. Also, the high SiO$_2$/Al$_2$O$_3$ (average 20.77; Table 1), powerfully suggest that the Naqus sandstones derived from recycled older rocks and from stable continental source away from the rift area and deposited in a passive margin of a syn rift basin.

Major and trace elements, including REE contents, may supply constructive information for the provenance and tectonic setting of clastic sediments were not influenced by metamorphism, diagenesis or weathering [50,57]. The Al and Ti exhibit low solubility during weathering and transportation processes [72,75]. The Al$_2$O$_3$/TiO$_2$ ratios (Table 1) of the studied sandstones averaging 28.59 indicated that those related to the felsic source rocks (21 to 70 for felsic igneous rocks, [35,59]. The K$_2$O/Na$_2$O ratios can be considered as a chemical provenance indicator. The higher values of these ratios (1) reflect those derivate from the granites rather than from the basic rocks [62]. Also, the higher Ba/Co ratios (Table 2) are revealed that these sediments derived from the weathered felsic-granitic rocks [16] . These are conformed with normalized pattern of trace elements (Fig. 4b).

![Fig. 9: Plots of F1 and F2 discriminate on the diagram proposed by Roser and Korsch [67].](image-url)

The high TiO$_2$/Al$_2$O$_3$ ratios are reflect a strong association to the parent rock and used as an indicator of provenance of siliciclastic sediments, [31]. Table (1) shows that the average values of TiO$_2$/Al$_2$O$_3$ ratios for the studied sandstones (0.04) which is comparable to that of the passive margin values as agreed in (Figs. 10 and 11).

On the other hand, plotting of TiO$_2$ versus Ni on the diagram proposed by [25], shows that all the studied sandstone samples lie nearly the acidic field (Fig. 12). These revealed that they were derived from mature polycyclic continental sedimentary rocks and conforms to the plots of (Fig. 9). The Nb/Y ratios range from 1.766 to 2.11 (average 1.93) (Table 2), which indicate to acidic igneous rocks [87] and the reworked source for these sandstones, which confrimable with (Fig. 12) and the petrographic study.
Fig. 11: Plots of studied sandstones on the diagram adopted by Roser and Korsch [66].

Fig. 12: Plots of the studied sandstones on the diagram adopted by Floyd et al., [25].

The Cr/V ratios range from 0.053 to 0.286 (average 0.142) and Y/Ni ratios varies from 25 to 50 (average 35.4), (Table 2). The low Cr/V and high Y/Ni ratios indicate that the studied samples are mainly sourced from the felsic rocks, which are characterized by Cr/V ratios less than 8 and Y/Ni ratios greater than 0.5 [50,19] (Table 2, Figs. 13 and 14). This result is disagreement with Karada [38]. The Cr/V ratios are plotted against the Y/Ni ratios to differentiate the relative contribution from ophiolitic, mafic and felsic source [77,51,83,84]. Plots of these sandstone samples from the Nqaus Formation show significant input from felsic sources (Fig. 15).

Fig. 13: The source and compositional discrimination plots of Cr versus V diagram proposed by McLennan et al., [50].
Some immobile elements, such as Th, Sc, Nb, Zr, Ti, Y, La, Hf, Ta, and Yb, have been used to determine the paleotectonic settings of clastic sediments [32,11,49]. Sediments from passive margins to active continental margins through continental island arcs to oceanic island arcs show systematic increases in the Ti/Zr and V/La ratios. The Ti/Zr and V/La ratios in the studied sandstones of the Naqus Formation indicate that more conformable in composition than those of the passive margin sediments. The abundances of Zr and La are revealed that felsic source for the Naqus Formation sandstones, which is conformed with (Figs. 13 and 14).

The geochemical differences among the sandstone samples may be the result of varying; the composition of the source terrain, the degree of chemical weathering, the hydrodynamic sorting of minerals during transportation and deposition, and the post-depositional alteration. Applying the relation between Nb and Zr according to Fralick and Kronberg [27] and Fralick [28], (Fig. 16) revealed that all the studied sandstone samples were sourced from similar materials and the chemically immobile elements, which indicated that these sediments may be, subjected the similar behavior during the transportation. Points that fall off the line (sample numbers 3, 18 and 28) do not satisfy one or more of the above criteria.
Fig. 16: Plots of Nb and Zr discriminate on the diagram proposed by Fralick and Kronberg [27] and Fralick [28].

Conclusions:

The Naqus Formation (Cambro-Ordovician?) exposed on the western margin in the northern part of Wadi Qena overlies unconformably Precambrian crystalline rocks (mainly igneous and metamorphic rocks) of the Arabo- Nubian Shield and overlain unconformably by shallow marine sediments of the Cenomanian transgression (Galala Formation). It chiefly consists of white, massive sandstones, displaying diverse primary sedimentary structures. They classify as quartz arenites, deposited under fluvial environment and tectonically inactive source. This formation is highly mature, SiO₂ content (average 93 %) and very low ICV (average 0.07) than the PAAS and UCC values and entirely detrital. The CIA, CIW and PIA average values (99.35, 99.57, and 97.96%; respectively) and the dominance of kaolinite clay mineral suggested that the Naqus Formation sandstones are subjected to the intensive chemical weathering either of the original source or during transportation before deposition under a humid- semihumid climate prevailed from the end of the Neoproterozoic to the end of Cambro-Ordovician time. The estimated geochemical parameters reveal that the sandstones of Wadi Qena are felsic-granitic sources and the reworked quartzose sedimentary provenances. They are originated by recycling of the older sedimentary and igneous rocks and passive margin setting for the provenance.

Therefore, the petrographic and geochemical data suggested that the sandstones of the Naqus Formation were derived from the Precambrian basement complex of the Arabo- Nubian Shield and were deposited in a passive continental margin setting after the stabilization of the Arabian Shield following the Late Pan- African Orogeny.

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