

Geology and Exploration, and Recovery of Placer Gold Deposits of the Precambrian Arabian-Nubian Shield (ANS) of the Red Sea Hills, Gebiet Almaaden District, NE Sudan

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Abstract - The major theme of the present study is to determine total potential of alluvial gold reserves in wadi Gebeit and some of its tributaries (Wadi East and West Gebeit) within the area of the study area as indicated is located between Longitudes 36° 40' & 37° 00' and Latitudes 20° 45' & 21° 15' N with an area of about 11.5 Km² approximately. The area as a whole is part of Arabian-Nubian Shield. Geologically it consists of Proterozoic rocks of Nafirdeib series; volcanic and volcano-sedimentary rocks cover the terrain. These rock types have been subjected to regional metamorphism to green schist facies, folding and faulting. These were later reworked by the invading gold bearing hydrothermal solutions that now exist as quartz lodes, veins, vein-lets and sand their alteration zones as primary gold.

The study of stream sediments gold evaluation a systematic grid sampling is done by digging pits of 20X40m² all over the selected area in wadi Gebeit and its tributaries. All stream sediments in the area are highly over turned by the artisanal using dozers, excavators, and loaders. These tools are destroyed the geological features of the area and mixing the weathered bed rocks with the overlain soil. The total volume of the studied stream sediments is 711,692 m³ which represent the geological reserve, with average gold grade 0.30g/ m³. The gold reserves in the study area are 230 kilograms, of fine and medium grains. The ground water resources availability is restricted in wadi Gebiet and Adalaweib. Pumping test reveal that the production of the boreholes varies from 4 m³/hr to 6 m³/hr and combinely the total production of the operational boreholes about 75 m³/hr.

Keywords: Gebeit mine, Red Sea Hills, Gold in Placer.

I. Introduction

The gold in Sudan is no doubt is known as a vital precious metal since the Pharoanic decades of more than 3500 years ago. This is clearly seen in the old working, traditional mills made of stones and also the processing tools that remain till now in the area. Local peoples obtained the visible gold from both auriferous quartz veins and their alteration zones inside the old mines or from residual soils and stream sediments using the mineral detector devices.

In this study the team is carry stream sediment assessment to evaluate and detect the actual alluvial gold reserves in wadi Gebeit and its tributaries (Wadi East Gebeit and Wadi West Gebeit).

1.1 Purpose of the Project

The aim of this paper is to obtain the gold reserves in the alluvial sediments together with assessment of water availability to operates the proceeding gold. It is a collaboration of extensive efforts and continuous team work of different specialists on geology, hydrogeology, mineralogy, engineering, and social sciences. Various methods and different technologies were utilized to process gold including panning, binocular microscope, electromagnetic separation, and lab testing. This research is to establish

areas of high potential gold grades and their reserves in stream sediments and water availability that to be enough for erecting the plant for gold processing the purpose of this study.

1.2 Location and Accessibility

The study area is located adjacent to the Red Sea coast in the north east of Sudan (Fig. 1). It is located in the Red Sea State. Port-Sudan is the capital of the state. The study area is located between Longitudes $36^{\circ}40'$ & $37^{\circ}00'$ E and Latitudes $20^{\circ}45'$ & $21^{\circ}15'$ N.

Gebait Almaadin mining area is easy to be reach all over the year from Khartoum to Port-Sudan, the capital of the Red Sea State. The asphalt highway is a convenient choice that extends for more than 800 km together with flight ways. From Port-Sudan asphaltic road to Mohammed Gol village covers 148 km of the 253 km distance between Gabeit Almaadin and Port-Sudan. The remainder 105 km. is an unpaved road between Mohammed Gol village and Gabeit Almaadin, any truck can make the trip to the area during all seasons (Fig. 1).

1.3 Physiographic Studies

The Red Sea area is categorized as an arid zone, with rain fall mainly in winter; annually rain fall is between 75-100 mm approximately. The area is characterized by a relatively high humidity especially in the vicinities near and around the Red Sea Coast. The temperature may reach more than 37°C in the summer and $7-10^{\circ}\text{C}$ in the winter season.

The vegetation is very poor or absent on the hill side and restricted mainly on and around valley deposit where the subsurface water is available during the rainy season. The vegetation in the area consists mainly of bushes, small trees of seyal (*Acacia Spirocarpa*), some Arak, Heglig, Haraz, and Sider.

The drainage system is mainly informed of net work dried stream valleys, partially filled with water in the rainy season. The drainage pattern is forming denderitic, rectangular and parallel, which reveal lineaments structures, faults, joints and shear zones. The local people obtain water mainly from hand dug wells along the wadies cracks, ponds and dam across valleys that drifting to the Red Sea.

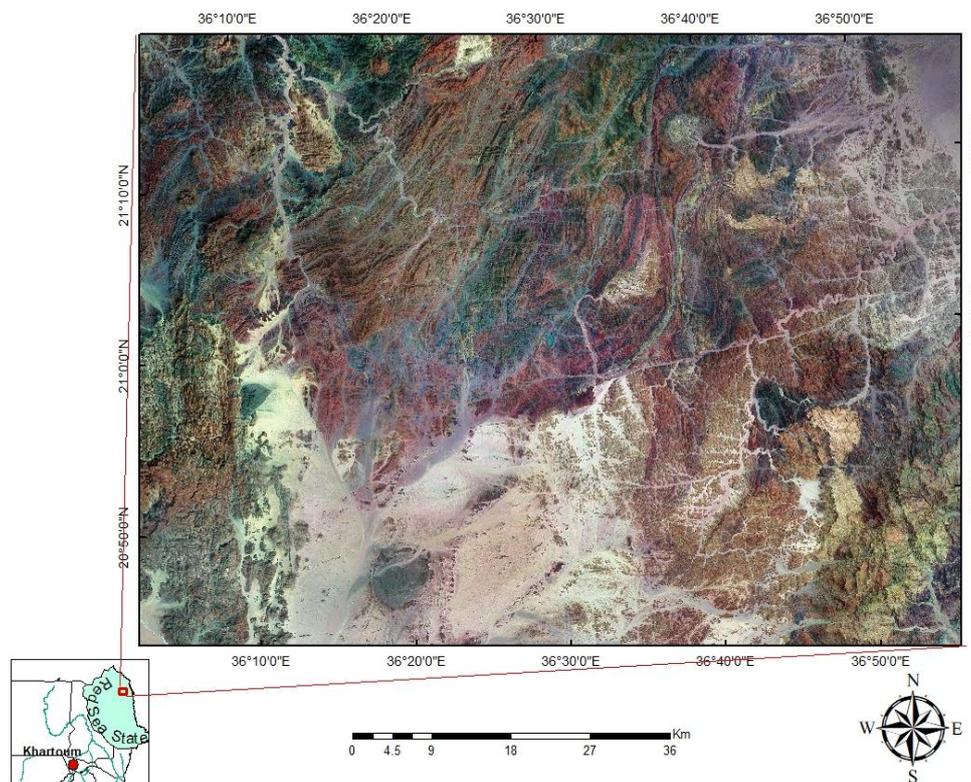


Figure 1: Location Map showing the study area

II. Geological Setting

The area is located within the Arabian-Nubian Shield (ANS). The geological successions are represented by the Precambrian volcano-sedimentary units that overlain by intrusive complexes of granitoids and Mesozoic Nubian Sandstone Formation that followed by Quaternary Superficial deposits. These are grouped into and named as Nafirdeib series, Kashebib series, and Awat group.

The Nafirdeib series, the most common geological features in the area is composed of low grade volcano\volcano clastic rocks (andesitic tuffs, agglomerates and lavas) with subordinate meta-sediments (quartzites and marbles).

Kashebib series is gneiss, amphibolite, schist and migmatite, which is exposed in the south of Gebeit mine area. The Awat group is characterized by sedimentary mudstones and siltstones. The region affected by intrusion of gabbroic to granitic batoliths that cut by felsic and intermediate to basic dyke swarms.

The area is subjected to a series of NE trending regional scale fold axis and poly-phase brittle faulting of NE, NW and EW trending sets. These are the most common tectonic movement in its geological era (Fig. 2).

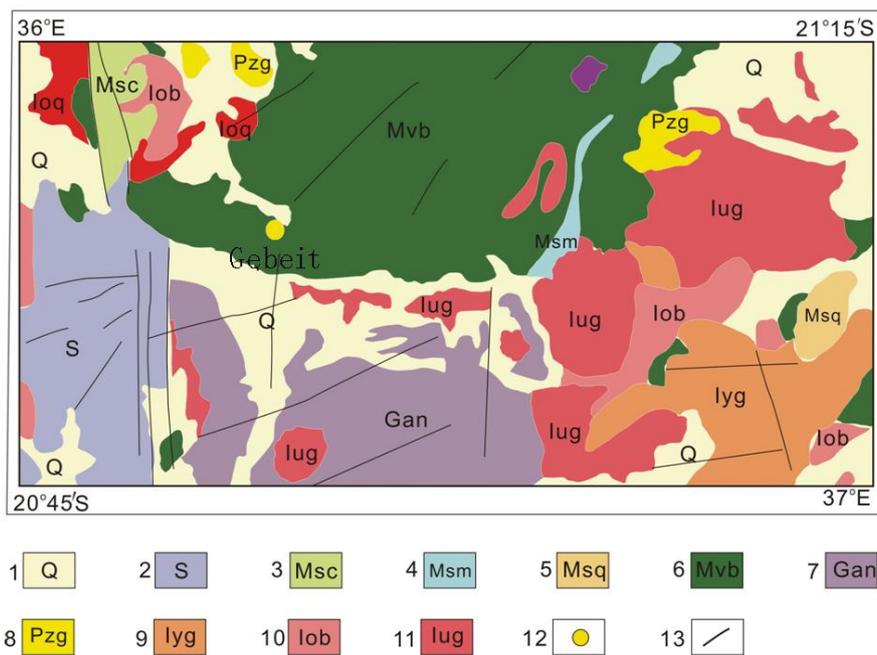


Figure 2: Regional Geological Map

1. Quaternary; 2 Silurian sandstone, shale and tillite; 3 Late Proterozoic conglomerate, sandstone, phyllite and schist rock; 4 Marble; 5 Quartzite; 6 Medium basic metavolcanics; 7 Gneiss; 8 Paleozoic granite; 9 Pan-African end granite; 10 Pan-African collision granite; 11 Late proterozoic gabbro; 12 Gold Mine; 13 Fault

2.1 The Geology of Gebeit Mining Area

The Nafirdeib group is almost representing the most lithological units in Gebeit gold mine area. These are andesite volcanic rocks and volcanic sedimentary rocks are consequently overlain by Quaternary sediments.

This lithology mainly includes thinly laminated tuff, pyrite-bearing shale and volcanic debris tuff. The major strike is NE-SW with SE or NW trend and dip of 50-90° (Adde, et al, 1995). Planar cleavage parallel to layer is widely developed. In the area where tectonic stress concentrates, the rock is strongly deformed to become schist with yellowish-brown colour after weathered, rich in tight folded quartz vein. Ankerite bands are also developed along tuffaceous shear zone the lithology includes andesite, and andesite cataclastic rock cap and unconformity contacted with overlapping tuff group. The rock in this group is slightly folded with gentle dip of 15-45°. Some andesite shows false directional breccia, slight cleavage and special massive structures. Andesite clastic rock is composed of surrounded-angular volcanic debris (the biggest size up to 0.8m) and crystallization matrix (Shandong Bureau of Geology Nov. 2009), (Fig.3). Quaternary sediments are eluvial, deluvial superficial deposits of channel alluvium in large seasonal streams. They are mainly inform of boulders, gravels, sands and silts that derived from weathering of the preexisting rocks, (Fig.3).

2.1.1 Structure

Gebeit anticline fold developed with SE axial direction and SE dipping in Gebeit Gold Mine Area. The formation in southeastern wing dips southward and the formation in northeastern wing dip northward.

Fractures are well developed, which can be divided into NWW, NW, EW, NS and NE direction according to fault directions. The fracture is composed of ductile-brittle shear zone (gold-bearing) and brittle fracture zone.

Shear zone (gold-bearing) is generally, composed of massive dark grey quartz vein, altered tuff with quartz vein and fractured rock.

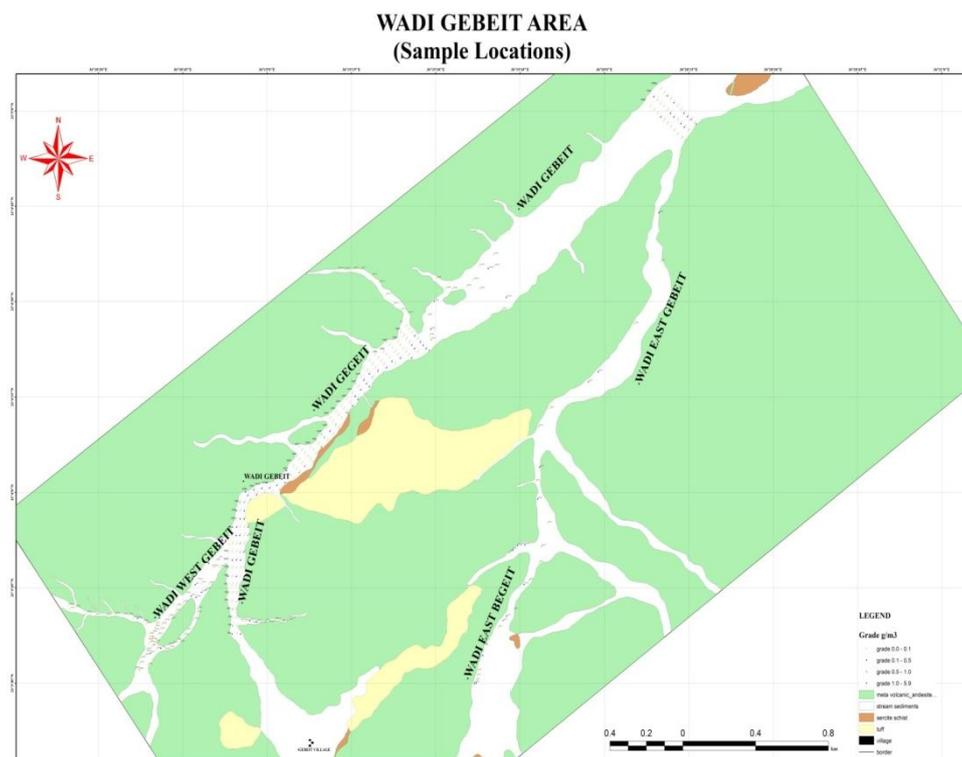


Figure 3: The Geology of Wadi Gebeit Area (Gebeit Mining Area) and samples location

III. Material and Methods

This work includes office, and field work, together with various methods and different technologies that were utilized to process gold including panning, binocular microscope and electromagnetic separation. Pumping test methods are done for water availability (quantity and quality). The data has been processed and final study is established. This work is mainly restricted on previous data that being done before in the study area. The data that collected represent maps, geological sections, and geological reports done by Robertson Research International (RRI)(1980) Ltd., Minex Minerals (Sudan) Ltd., Geological Research Authorities of Sudan (GRAS), and Shandong Provincial Bureau of Geology and Mineral Resources.

The data has been processed and hence we select three promising areas for alluvial gold evaluation. These areas are, Wadi Gebeit, Wadi East Gebeit and Wadi West Gebeit. The drainage pattern maps are used as quid for studying the alluvial gold deposits in the three selected areas, Wadi Gebeit, Wadi East Gebeit, and Wadi West Gebeit and their tributaries alluvial deposits were grid sampled by digging pits with 20 X 40 square meters intervals along the stream floor (Fig.3).

The total samples from the three areas is 373, two of them are as bulk samples of 0.3 cubic meter each. The sample weight is 20Kg, being panned obtaining the gold and heavy minerals. The heavy concentration that obtained from the panned samples composed mainly of gold, pyrites, arsenopyrites, magnetite,ilmenite, haematite etc. All the 373 samples were separated manually by hand magnet to avoid magnetic mineral such as magnetite. The resultant is electromagnetically separated to get rid of the diamagnetic and moderately magnetic minerals (ilmenite, haematite and etc.). Then the gold is separated from the heavy minerals

using binocular microscope together with physical properties identifications. The separated gold particles of each sample are weighed using a sensitive balance.

IV. The Geology of Gebeit Area and Gold Mineralization and Their Relationship

4.1 Geology

The Gebeit mining area geology is characterized by volcano-meta sedimentary rock units. These are tuffaceous units with pyrites, sheared lithic tuffs with quartz veins and andesites.

Gold mineralization in stream sediments derived originally by disintegration and transportation of auriferous fragments of the volcano-sedimentary rocks and lodes zones. Gold obtained in most of streams in the vicinity around Gebeit mining area. Only three major streams are studied in detailed for gold evaluation and reserve calculation (Fig.3).

4.2 Factors Controlling Formation of Gold in Placer Deposits

Factors controlling formation of stream gold in placer deposits; some of the geological and geomorphological factors that control the concentration of gold and associated minerals along Gebeit streams are as follows: The physico-chemical behaviour of provenance rocks, i.e. igneous and metamorphic rocks and the effect of various geological processes have played a vital role in contributing sediments to form a placer deposit. The climate has a great role to play in decomposing and disintegrating the rocks and mineral fragments, that get liberated and concentrated. The drainage pattern and their high density, coupled with topographic and structural elements played prominent role in the supply of material along the networking of the drainage system in locale.

4.3 Gold mineralization

In Gebeit area the gold lodes are mainly obtained in auriferous shear zones of lithic tuffs, ferruginous schist in andesites and lithic tuffs boundaries or in whitish-gray quartz within andesites.

The major potential gold bearing lodes in Gebeit mining area are Arsenic lode, East Gebeit, Marble Bar, Vein 18 and Vein 13 beside the Wadi lode, X and Y lodes which are witnessed active mining operation, also obtained in Ohaf, Tagoti East, Grabien, Wadi Tuwiya, Adalaweib and West Gebeit.

The lode zones composed mainly of quartz veins of multi colors, bluish-grey, whitish-grey, white with carbonates and dark blue. They are varying in thickness from few centimeters to about 3metres (Adde, et al., 1995). These quartz veins are inform of, discontinuous lenses and stringers with dip varies from flat at Marble Bar to almost vertical at Adalweibarea.

4.4 Gold Enrichment in Stream Sediments

Gold in stream sediments is derived originally from the destruction of primary rocks of quartz veins, vein-lets, and alteration zones that obtained during the injection of hydrothermal mineralizing solutions. During the weathering processing (mechanical and chemical) of the auriferous lode zones, the gold is undergone mobilization, then redeposit and concentrated around the source as residual or transported far and deposited as, colluvial or alluvial (placer gold deposits).

The alluvial ore deposits of the streams, composed of gold, rock fragments of andesites (inform cobbles, gravels), quartz, ankerites, and fine clays, embedded on weathered andesites and volcanic tuffs. These deposits are poorly rounded sometimes angular in shape indicating that they are unsorted. The surrounding rocks of andesites and the volcanic tuffs and their shear zones are represent the main source of the deposits. The sedimentary cover varies from 0.3meters in residual soil to more than 3.8 meters in the alluvial deposits (Plate 1).

Three areas were selected and subjected for gold exploration. These are Wadi Gebeit, Wadi East Gebeit, and Wadi West Gebeit. The three areas witnessed artisanal gold workings.

In Wadi Gebeit, (Fig. 3) the exploration of gold in the stream sediment deposits (alluvial) is done by means of exploratory pits that dug to the bedrock with 20X40m2 grid. Other two areas (Wadi East Gebeit and West Gebeit), the exploratory pits were dug randomly along the streams plain to determine the distribution of gold and its areas of concentration (Fig. 3).



Plate 1: Wadi Gebeit area where the wadi is in the centre of the photo looking north. Artisanal alluvial mining taking place in the wadi floor

4.5 Gold and Associated Minerals in Stream Sediments

4.5.1 Gold

The majority of the stream sediments samples show visible gold particles in their heavy concentrate. This indicates a wide distribution of gold in all streams in the Gebeit area. Due to its high density gold is generally, in the stream sediments, enriched downwards in bars of the meandering areas (Plate 2). The visible gold range in sizes from nuggets, medium to very fine, with irregular shape and sometimes sharp edges, the particle-size distribution of gold is sparsely scattered throughout presented in various forms (Mitchell et.al., 1997).

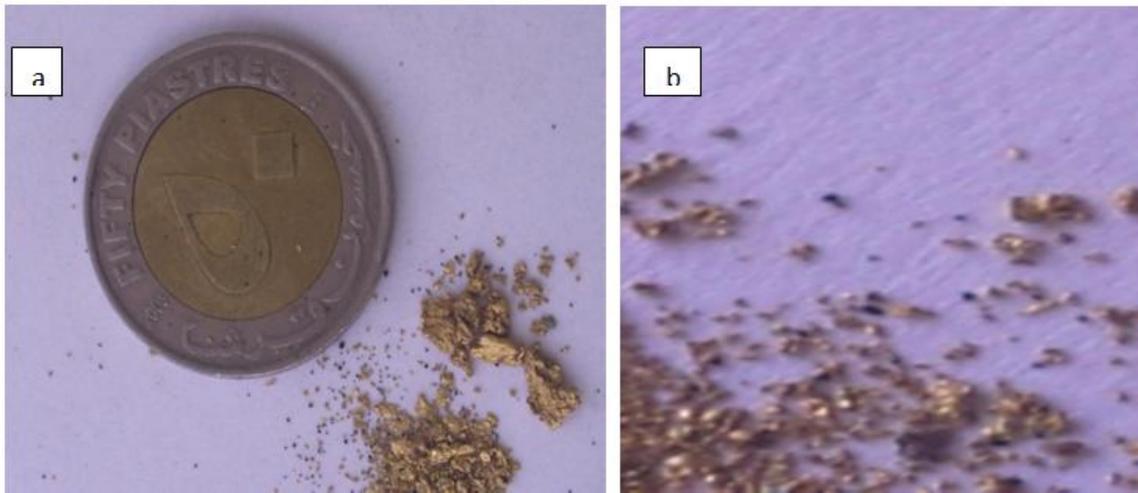


Plate 2: Wadi East Gebeit is in the centre of the photo, looking northeast. Artisanal alluvial mining taking place in the wadi floor

4.5.1.1 Grain Size and Shape of the Gold

The total weight of 8,420kg were panned and processed for gold using electromagnetic separator and binocular microscope. The total of nearly 250,000 gold grains was collected, 70% of them are fine; 20% medium and 10% by weight is coarse grained.

These gold grains show slightly sub-rounded surfaces, lumpy or films in shape which indicates that the primary source of the gold is nearby. The diameter of the largest gold grain (nugget) in the panned samples is 0.4 mm, weighing 0.35gram, (Plates 3a&b).



Plates 3a&b: Gold nuggets and fine in Gebeit Stream ore Deposits

4.5.2 Associated Minerals

Gold in Gebeit mining area is associated mainly with sulphides such as pyrite, arsenopyrites, and hematite. Other minerals such as, tourmaline and manganese are uncommon in the area, together with the light minerals such as quartz and sericite mica. These minerals were deposited probably together with gold from the mineralizing solutions.

4.6 Genesis

The stream sediments carry the gold are formed by weathering and transporting of host-rocks and quartz veins by means of mechanical and chemical processes. These sediments carried by water or winds and deposited in the seasonal streams or valleys. The gold was transported and deposited in the stream bed as alluvial. The distribution of gold in the stream beds is not even within the alluvial sediments. Mostly gold has more concentration along the streams in bars of the meandering areas (Plates 1&2).

V. Gold Evaluation and Reserves Calculation

The gold evaluation was restricted in wadi Gebeit and its two major tributaries, which are Wadi East and Wadi West Gebeit streams (Fig. 4). Gold mineralization in stream sediments derived originally from auriferous sheared volcano-sedimentary rocks by means of chemical and mechanical weathering.

5.1 The Wadi Gebeit Gold Deposits Evaluation

Wadi Gebeit is one of the main seasonal stream in the Gebeit area, it is extends generally, NE towards the Red Sea. The deposits of the stream consist mainly of andesite fragments, tuffs and clays. The work is mainly for gold evaluation in Wadi Gebeit which is a continuation, fill in gap, and confirmation to previous work done by Minex Minerals (Sudan) Limited Co. and GRAS (Figs. 4&5).

The alluvial ore deposits of the streams are composed of rock fragments of andesites, quartz, ankerites, and fine clays, found inform cobbles, gravels and clays embedded on weathered andesites. These deposits are sub-rounded in shape indicating that they are moderately sorted valley placers, the size of (-1cm) is 70% when the sample sieved.

A detailed Grid sample study is done in its upper stream portion (second order) about one kilometer a parts North of Gebeit village. These samples cover the main stream and other two tributaries (Fig. 4). The work is primary done by digging pits with 20X40 square meters intervals, samples were taken every one meter depth.

A total of 261 samples were taken from the stream floor, (two are bulk samples, each of 0.3 m³). The majority of these samples when panned, gave appreciable amount of free visible gold, (Tables 2&3)

The alluvial deposits of the studied portion in wadi Gebeit cover an area of 0.30 km². The average thickness of the sedimentary covers is 1.14 meter (Plate 1). The total volume of the sedimentary covers in the area under study is 237,893m³, which represent the geological ore reserve of Wadi Gebeit.

For this area the gold grade ranged from not detected (ND) to **5.92 grams** per cubic meter. 80% of the Gebeit Stream samples gave positive results.

The total gold reserve in the study portion of Wadi Gebeit is **62.138 kg** (Table 1). This indicates that the Wadi Gbeit area is feasible for free gold processing plant. The gold grade showed erratic concentration in the wadi Gebeit stream sediments, (Figs. 5 & 6). The concentration of gold mineralisation in study area opened always towards the tributaries of the main stream (upstream), while it is highly diluted toward downstream (Fig.4).

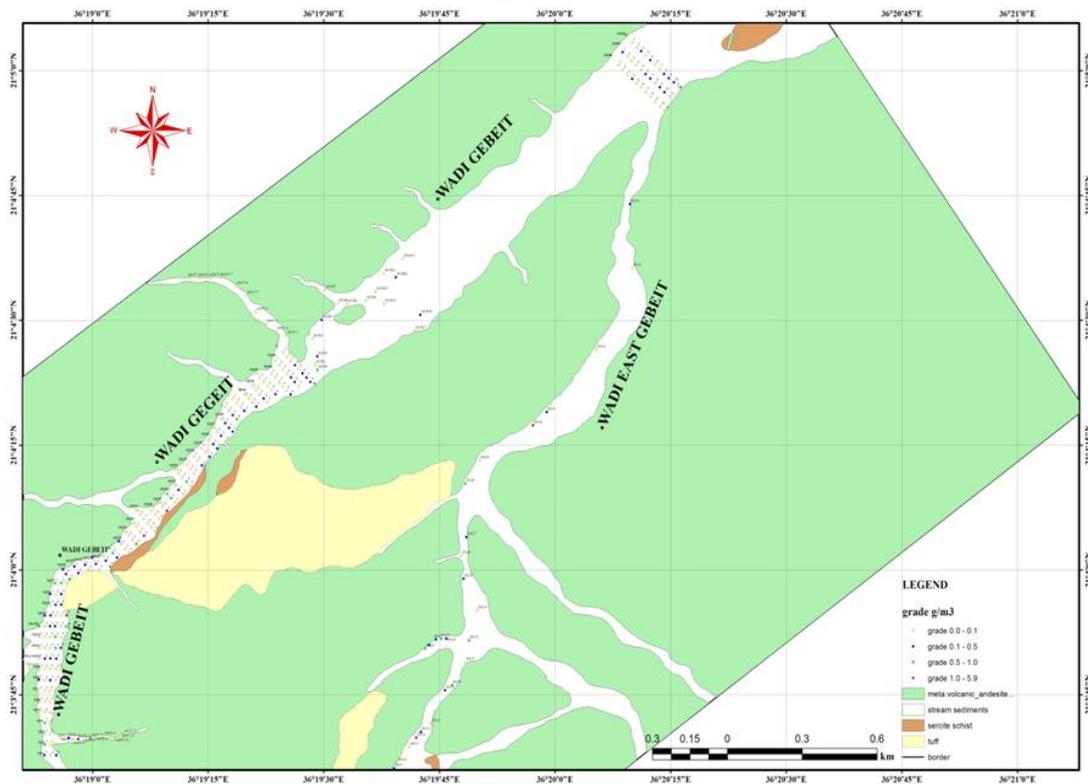


Figure 4: Wadi Gebeit Stream sediments sample locations

Table 1: Wadi Gebeit Stream Sediments Gold Evaluation

Section No.	Profile No.	Length (m)	Average Width (m)	Average Depth (m)	Volume (m ³)	Average Gold grade (g/m ³)	Gold Reserve (kg)
Section 1	GS1 → GS17	640	65.7	1.2	50457.6	0.64	32.29
	EG1 → EG12	265	21.4	0.75	4253.25	0.56	2.38
Section2	GS18 → GS21	187	58.5	1.16	12689.82	0.3	3.80
Section3	GS22 → GS28	270	80	0.996	21513.6	0.44	9.47
	GS29 → GS36	340	66	0.47	10546.8	0.2	2.11
	GS37 → GS42	255	105	1.6	42840	0.13	5.57
	GS43 → GS46	175	153	1.2	32130	0.08	2.57
	GS47-1GS47-11	60	160	0.97	9312	0.016	0.148
Section 4	GS48 → GS50	100	285	1.9	54150	0.07	3.80
Total		2,292	110.51	1.14	237,893.1	0.30	62.138

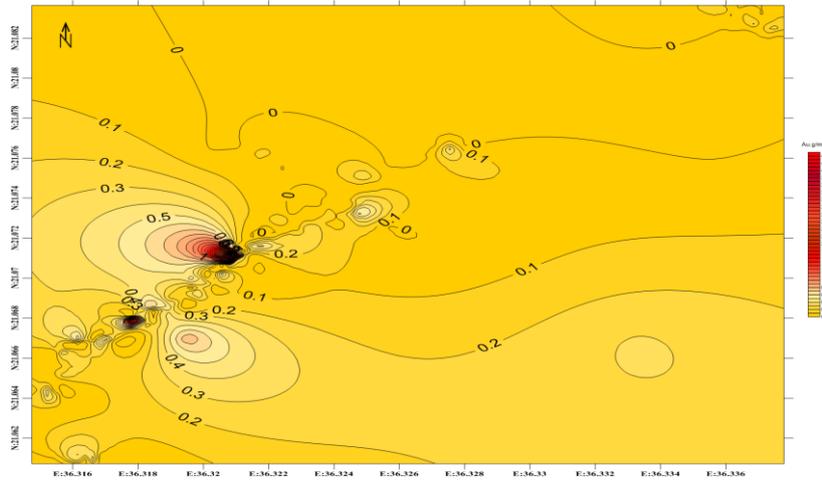


Figure 5: Wadi Gebeit Gold 2D Iso-Concentration Map

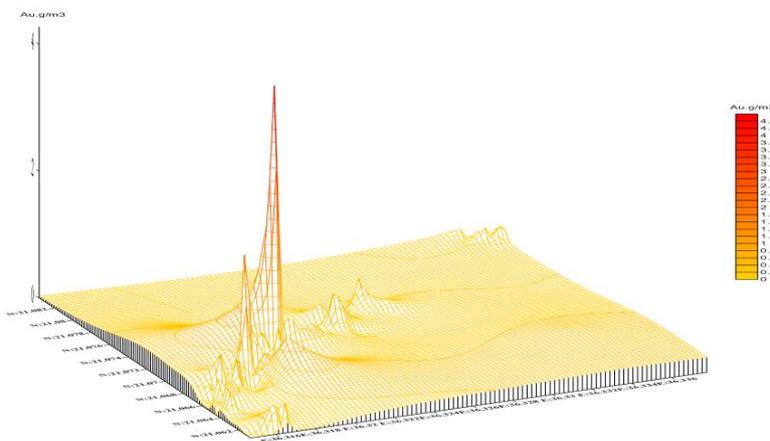


Figure 6: Wadi Gebeit Gold 3D Iso-Concentration Map

5.2 Wadi East Gebeit Gold Deposits Evaluation

Wadi East Gebeit is one of the main seasonal stream in the area, it is obtained east of Gebeit village, extends generally, NNW to joint with Wadi Gebeit. The deposits of the stream consist mainly of meta-volcanic fragments, quartz gravel, tuffs and clays (Plate 4). The work is done mainly for gold evaluation.



Plate 4: Wadi East Gebeit is in the centre of the photo, looking northeast. Artisanal alluvial mining taking place in the wadi floor

The alluvial ore deposits of the streams, composed of gold, rock fragments of andesites, quartz, ankerites, and fine clays, embedded on weathered andesites and volcanic tuffs. These deposits are poorly rounded sometimes angular in shape indicating that they are unsorted gulch placers. The size of (-1cm) is 70-75% when the sample sieved.

The samples are taken with variables intervals from its upper stream portion up to its junction with wadi Gebeit for **3.75** kilometers distance, (Fig. 7). These samples cover the Wadi East main stream, (Plate 4). The work is primary done by digging pits along the stream floor every one meter depth. A total of **34** samples were taken from the stream floor. The majority of these samples when panned gave appreciable amount of free visible gold, (Table 2). The Alluvial deposits of the wadi East Gebeit cover an area of **0.20** square kilometers, with an average width **107.50** meters, (Fig.7) and (Plate4). The average thickness of the sedimentary cover is 1.3 meters. The total volume of the sedimentary covers in the area under study is **243,165** m³, which represent, the geological ore reserve in Wadi East Gebeit, (Table 2). For Wadi East Gebeit area the gold grade ranged from not detected (ND) to **2.40** grams per cubic meter. 90% of the East Gebeit stream samples gave positive results,(Figs. 8 & 9).

Table 2: Wadi East Gebeit Stream Sediments Gold Evaluation

Section No.	Profile No.	Length (m)	Average Width(m)	Average Depth(m)	Volume (m ³)	Average Gold grade (g/m ³)	Gold Reserves (kg)
Section1	EG13 → EG37	1,005	105	1.2	127032	0.5	63.516
Section2	EG38 → EG46	1,740	107.5	1.3	243165	0.4	97.266
	Total	2,745	106.25	1.25	370,197	0.45	160.782

The total gold reserve in the study portion of Wadi East Gebeit is **160.782** kg (Table 2). This indicates that the Wadi East Gebeit area is feasible for free gold processing plant.

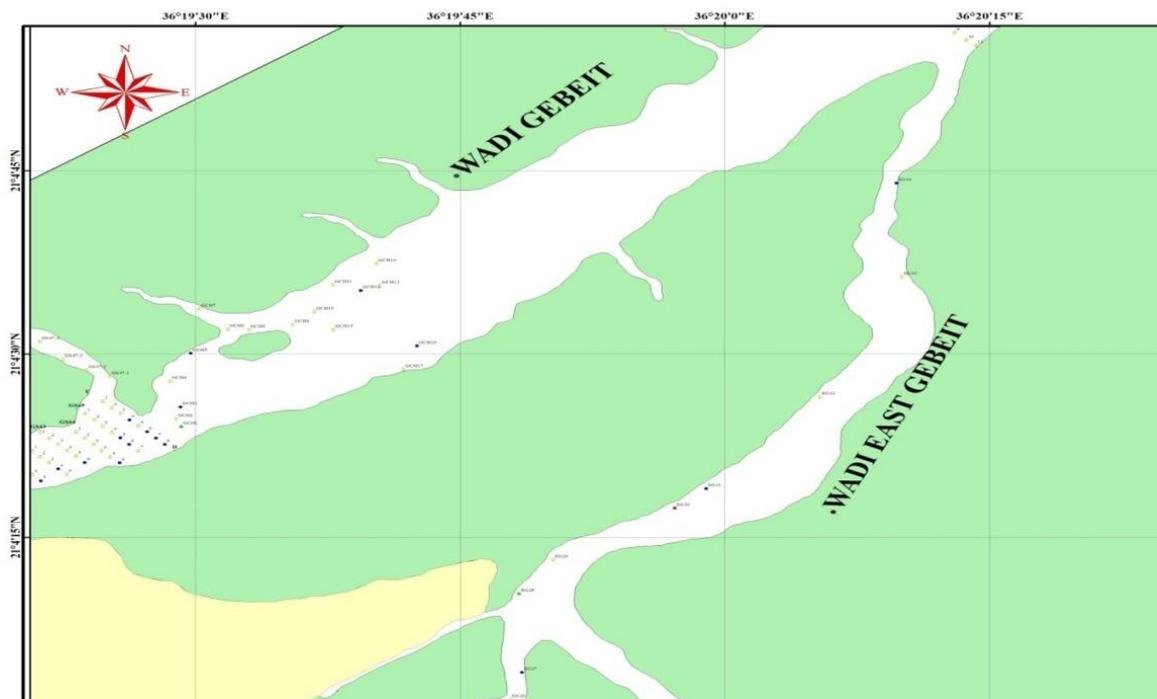


Figure 7: Wadi East Gebeit Stream Sediments Sample Locations

5.3 The Wadi West Gebeit Gold Deposits Evaluation

Wadi West Gebeit is one of the main seasonal stream in the area, it is obtained west of Gebeit village, extends generally, NNE to joint with Wadi Gebeit. The deposits of the stream consist mainly of meta-volcanic fragments and clays. The work is mainly done for alluvial gold evaluation in Wadi West Gebeit.

The alluvial ore deposits of the streams are composed of gold, rock fragments of andesites (found inform cobbles, gravels and pebbles), quartz, ankerites, and fine clays, embedded on weathered andesites and volcanic tuffs. These deposits are poorly rounded sometimes angular in shape indicating that they are moderately sorted gulch placers. The size of (-1cm) is 60-70% when the sample sieved.

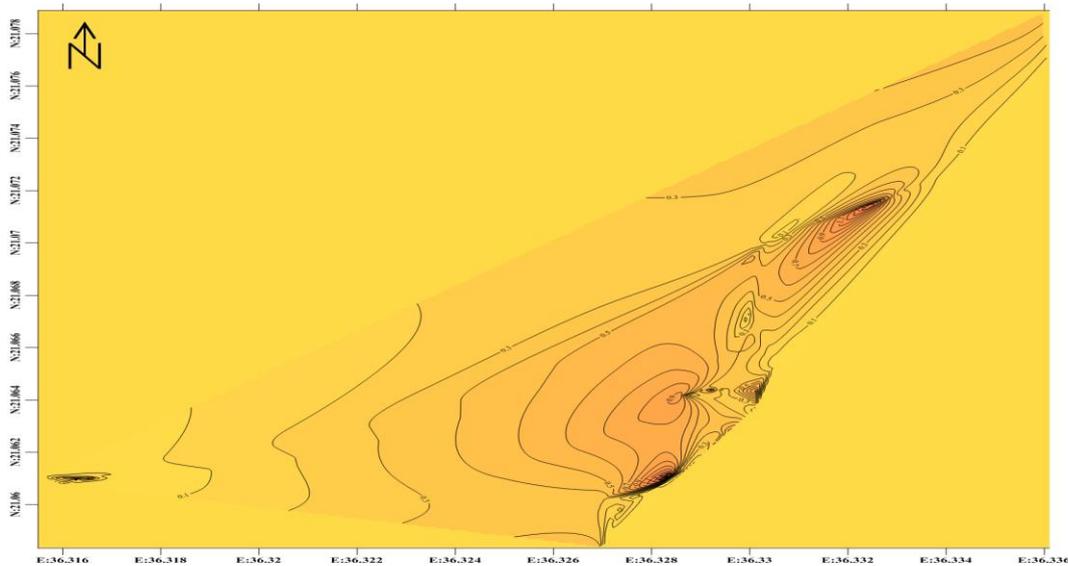


Figure 8: Wadi East Gebeit shows Gold 2D Iso-Concentration Map

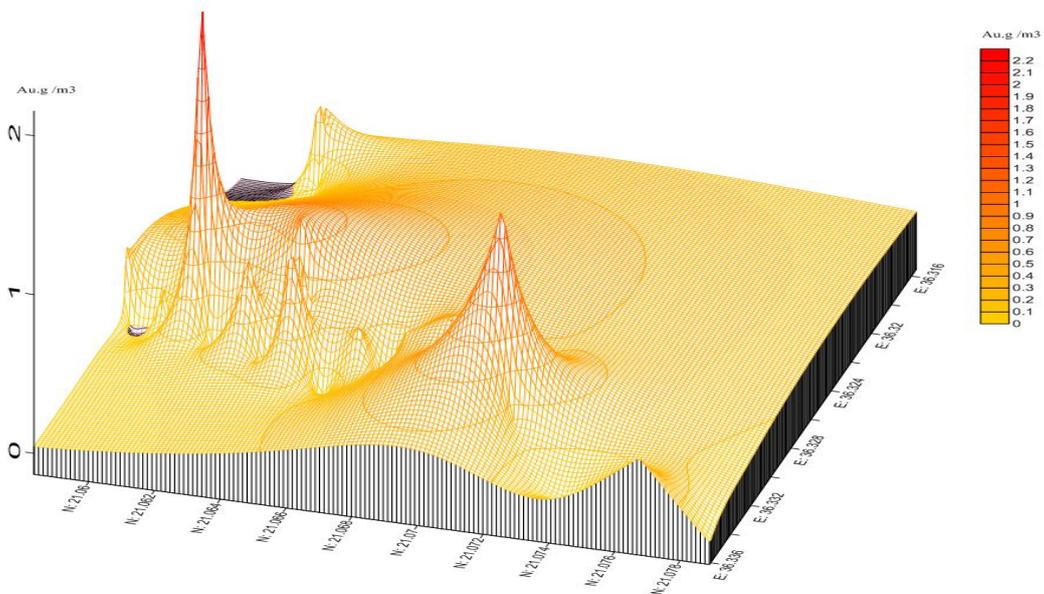


Figure 9: Wadi East Gebeit shows Gold 3D Iso-Concentration

The samples are taken with variables intervals from its upper stream portion (second order) up to its junction with wadi Gebeit for about 1.0 kilometer distance (Fig. 10). The work is primary done by digging pits along the stream floor with variable intervals. Samples were taken every one meter depth.

A total of 78 samples were taken from the stream floor and its tributaries. The majority of these samples (53 samples), when panned, gave appreciable amount of free visible gold. This reveals 68% of the West Gebeit stream samples gave positive results, (Table 3).

The Alluvial deposits of the wadi West Gebeit cover an area of **0.05** square kilometers (Plate 5), with average width 60meters. The average thickness of the sedimentary cover is 1.2 meters. The geological ore reserve in Wadi West Gebeit is 104,000m³, which represent the total volume of the sedimentary cover in the area under study. This obtained average gold grade 0.061 g/m³ (Table 3). For Wadi West Gebeit area the gold grade ranged from not detected (ND) to **0.80** grams per cubic meter (Table 3).

Table 3: Wadi West Gebeit Stream Sediments Gold Evaluation

Section NO	Profile NO	Length (m)	Average Width(m)	Average Depth(m)	Volume (m ³)	Average Gold grade (g/m ³)	Gold Reserves (kg)
Section1	(WG1-WG16 , WG20 -WG29 , WG31)	510	100	1.1	56100	0.08	4.5
Section2	(WG30 , WG32, WG35 -WG54 , WG64 -WG65)	280	87	0.9	23385.6	0.05	1.169
Section3	Part1 (WG66 -WG78)	330	25.5	1.3	10939.5	0.034	0.372
	Part2 ((WG17-WG19 WG55 -----WG63))	350	26.9	1.4	13181	0.08	1.05
Total		1,470	59.85	1.20	103,606.1	0.061	7.091

The total gold reserve in the study portion of Wadi West Gebeit is **7.091** kilograms,(Table 3). This indicates that the Wadi West Gebeit area is feasible for free gold processing plant if mining is selectively restricted to areas of high concentration and that is due to the erratic distribution of gold concentration, (Figs. 11&12).

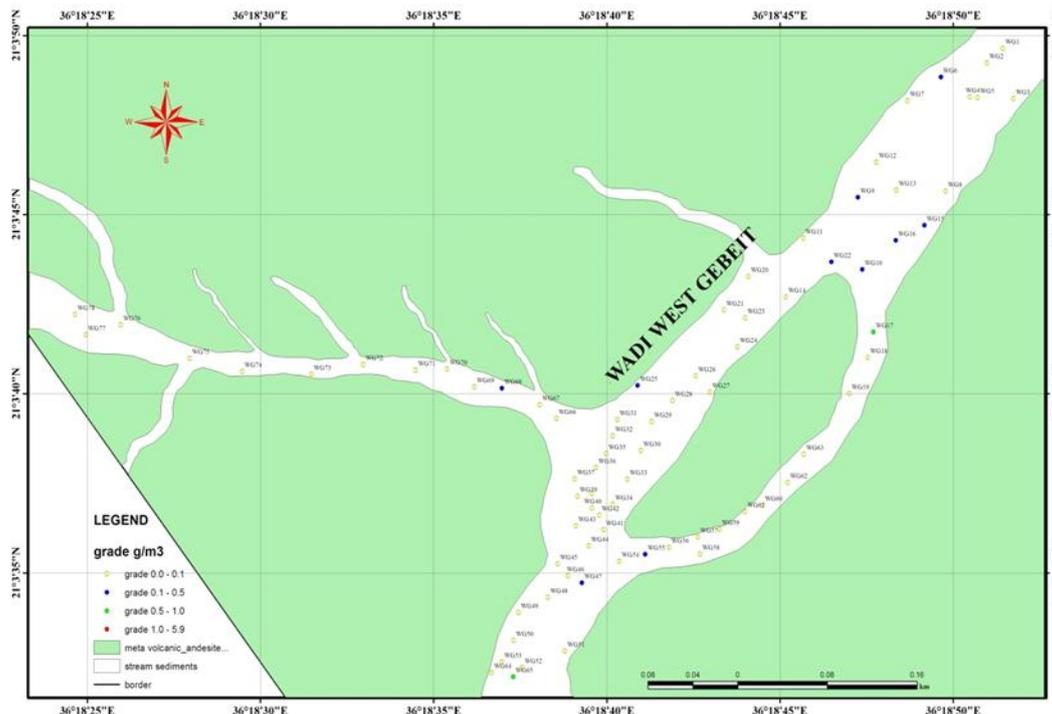


Figure 10: Samples Location Map for Wadi West Gebeit



Plate 5: Wadi West Gebeit area where the wadi is in the centre of the photo looking southwest, artisanal alluvial mining taking place in the wadi floor

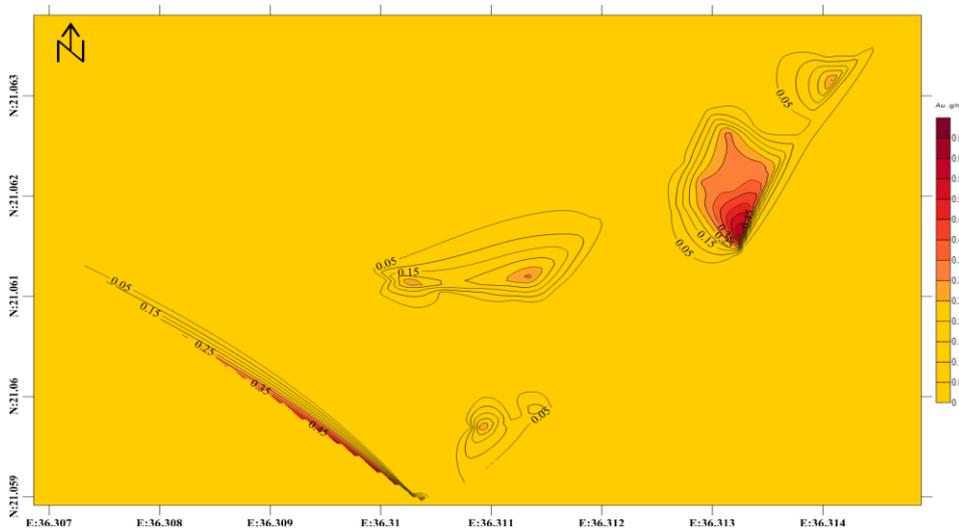


Figure 11: Wadi West Gebeit shows Gold Iso-Concentration Map

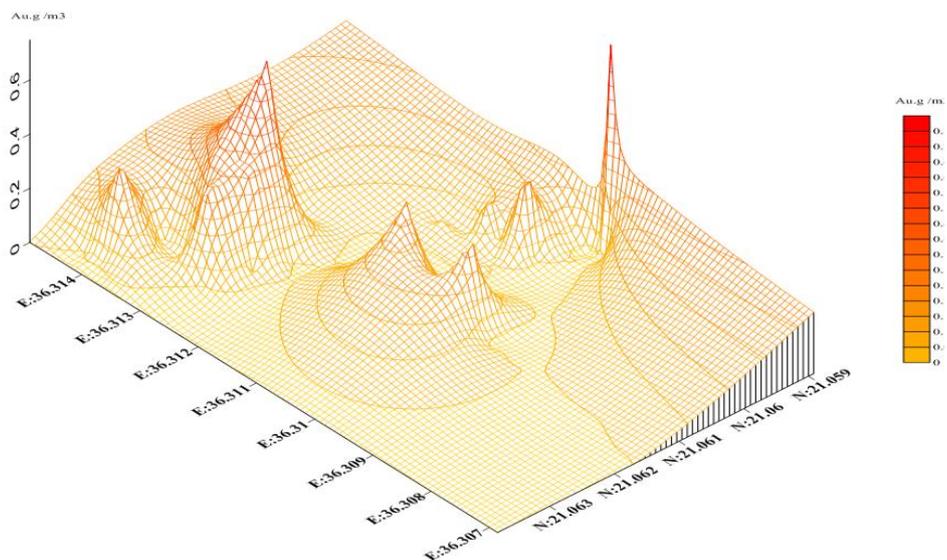


Figure 12: Wadi West Gebeit shows Gold 3D Iso-Concentration Map

VI. Geostatistical Analysis for the Gold Grain-size in Gebeit Area

6.1 Data Analysis

Data analysis which forms a small portion of the overall scheme of the work has the potential of revealing database errors which can be detrimental to the efficient reporting of resource volume, grade and classification. The histogram has been used to graphically examine the data-set (Fig.13). In addition to the graphical examination, descriptive statistics were carried out to compute statistical measure such as mean, mode, variance, standard deviation etc (Table 5).

6.2 Geo-spatial Interpolation

Geo-spatial technique was used for the interpolation of the gold grade and grade thickness of the deposit to determine the weighted average. The method used in this study is the inverse distance weighting (IDW) method which estimates spatial variability of parameters based on the weighting of neighborhood sample points. Several authors (Al-Hassan et al., 2015; Tulay et al., 2015; Meternicht et al., 2003) have used the technique to analyze the spatial variability of gold grade in fluvial sediments and other soil parameters.

The idea behind IDW interpolation is based on Tobler’s first law of geography (1970) which states that “All places are related, but nearby places are more related than distant places”. The estimation of values for unsampled areas is primarily based on the nearest point than further away sampled points. To satisfy the Tobler’s law IDW uses another exponential number which gives more weighting to the close points during its estimation. For the purpose of this study, exponential power of two (2) is used for the interpolation of the various parameters. This value is known to be the best exponential values that best fit the IDW estimation (Al-Hassan et al., 2015; Isaaks et al., 1989). To evaluate the accuracy of the estimation cross validation using the root mean square error (RMSE) was initiated. This validation has been recommended by authors (Tulay et al., 2015; Metternicht et al., 2003; Webster et al., 2001).

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N \{z(x_i) - \hat{z}(x_i)\}^2}$$

(Metternicht et al., 2003) (xi) is the estimated (predicted) value, the known value is represented by z, N is the number of samples and RMSE is the root mean squared error. Getting predictions values close to the observed values gives a small RMS error. These smaller values are preferred as far as the geostatistical interpolation is concerned. Although RMS error is able to tell much about the accuracy of the estimation, errors may still exist within neighborhood sample points (Al-Hassan et al., 2015; Siddig, et al., 2022) (Table 4&5).

Table 4: Summary Statistics of the Grain Sizes of Placer Gold Gebeit Almaaden

Variable	Minimum	Maximum	Range	Sum	Mean	Median	Standard Deviation	Skewness
Gold Size	14	1298	1284	1417	354.25	52.5	629.63	1.99

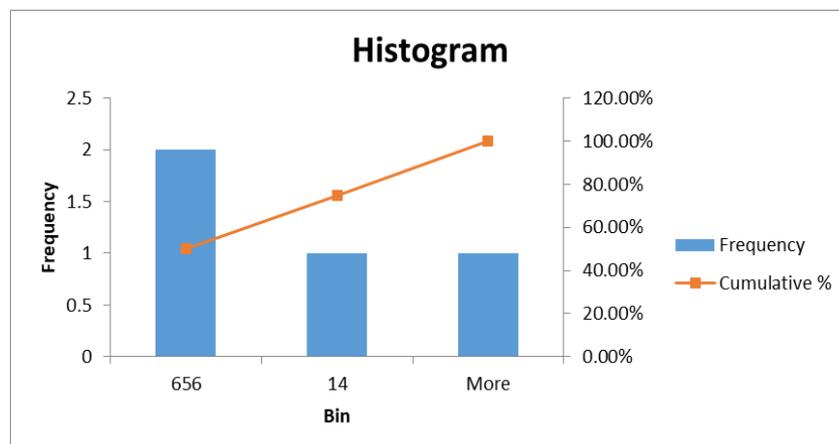


Figure 13: The histogram Plot of the Gold Grade with a Positively Skewed Data

6.3 Resource Estimation

The resource potential was estimated to know the amount of fine gold within the study area after the estimation of the mean gold grade and gravel thickness. The method used for the resource potential here is given as $P=VG$ after Chirico et al., (2013), where P is the estimated resource potential of the study area, V is the volume of the gravel section (deposit) and G is the mean (average) grade of the deposit. The mean grade used for the final calculation of the gold resource potential was derived from the generated grade estimation from the IDW model.

Table 5: Reveals the Percentages of the Grain Sizes of Placer Gold Gebeit Almaaden

% of Grains	Gold Size	No of Grains
1.0	Coarse	14
5.1	Medium	72
91.6	Fine	1298
2.33	V. Fine	33
100.03	Total	1417

VII. The Gebeit Mine Old Tailings

These tailings are located NW, North and around the existing shaft, (Plates 6a&b). They are varying in depth from 1-3 meters. Three channel samples sample were taken downwards in the tailings for two meters depth. The gold assays of these three samples are quite good. Table 6 shows the gold concentration in the two mentioned samples.

Table 6: Gold Assays of the Gebeit Mine Old Tailings

No.	Status	Grade (Au g /t)
1	Tailing (1)	2.9
2	Tailing (2)	2.4
3	Tailing (3)	2.4

The average gold grade of the gold in the old tailings is 2.6 g/t. However, it's highly recommended to do detailed and systematic sampling for the tailings to determine the actual gold tonnage. Also a suitable processing plant is to be obtaining for gold extraction from the tailings.

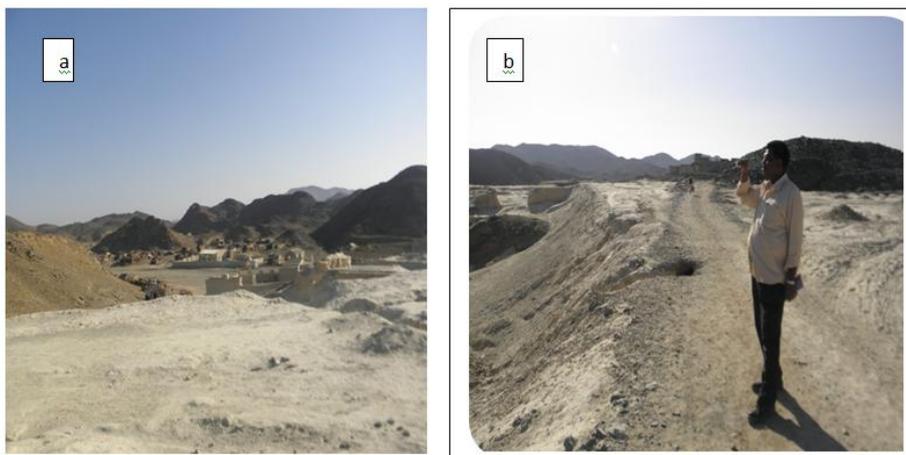


Plate 6a &b: Old Tailings of Gebeit Mine looking North-East

VIII. Discussion and Conclusions

In the study area recent mining activities went back to the early Twentieth Century, which Gebeit Mining area is part of it. The different placer deposits of the region are the product of the geomorphological evolution and climatical history of the Ariabian-Nubian Shield (ANS), where primary gold mineralization and rocks of significant gold content exist in a vocano-sedimentary setting.

The present study determine total potential of alluvial gold reserves in wadi Gebeit and some of its tributaries (Wadi East Gebeit and Wadi West Gebeit) in an area of 11.5 Km² approximately. This study area reveals that gold is found in all of the streams of the mentioned area (Fig 4). The stream sediment panning results show that most of the samples have gold grade ranged from (ND) to 5.92g/m³. The total volume of the studied streams is 711,692 cubic meters. The average gold grade varies from 0.30 at Wadi Gebit, 0.45 in wadi East Gebitand 0.06 in Wadi West Gebeit. The average gold grade of the whole area is 0.30 g/m³.

The estimated gold reserves in the streams sedimentary cover in the studied area is 230 kilograms approximately. Actually 69.9% of that gold reserve obtained from Wadi East Gebeit (160.8 kg.), wadi Gebeit 27% which is 62.1kg, and 3.1% from, wadi West Gebeit (7.1kg.). Therefore, the possibility of free gold processing plants in the Gebiet area is highly recommended. The gold extraction by this panning process is almost not more than 50-55%,so we expect this percentage will increase to 65 -70% by well adopted mechanical separation plant. Further exploration is needed for the area of wadi East Gebeit and its tributaries to fill in gaps because it is rich in alluvial gold.

It highly recommended starting mining operation in the areas of high gold concentrations in the stream alluvial ore deposits. Pumping test reveals that the water production of the boreholes varies from 4m³/hr to 6m³/hr and combinely the total production of the operational boreholes is about 75m³/hr. The ground water resources of wadi Gebiet and Adalaweib need detailed geophysical works to find and estimate the potentiality of the aquifers. It is highly recommended for digging better to obtain satisfied water for the free gold processing plants. The area south of Gebeit village is also promising for alluvial gold in the majority of its streams. It is highly recommended to do detailed exploration in south Gebeit area to obtain the feasibility of its gold. In the area of study there are many stream witnessed strong artisanal workings so they will be promising areas in future for alluvial gold deposits exploration.

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Citation of this Article:

Elzien, M. S., Basheer, A. E., Osman, M. B., Elhag, A. B., Basher, A. Elubid, Altigani, M. A. H., “Geology and Exploration, and Recovery of Placer Gold Deposits of the Precambrian Arabian-Nubian Shield (ANS) of the Red Sea Hills, Gebiet Almaaden District, NE Sudan” Published in *International Research Journal of Innovations in Engineering and Technology - IRJIET*, Volume 7, Issue 1, pp 38-54, January 2023. Article DOI <https://doi.org/10.47001/IRJIET/2023.701008>
