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SOURCES OF SOME HEAVY MINERALS AND THEIR ASSOCIATION WITH GOLD-BEARING STREAM SEDIMENTS IN THE GAGARE DRAINAGE BASIN, WONAKA SCHIST BELT, NORTHWESTERN NIGERIA

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ABSTRACT
Nigerian gold mineralization has been identified to occur in primary, eluvial and alluvial forms, with around 90% of production coming from the alluvial sources. The Wonaka Schist belt has been recognised to consist of placer gold with mostly erratic and irregular distributions within the river systems. Despites such occurrences, the distribution, sedimentology and provenance of the alluvial sediments in the region are not well studied. This study examined the granulometric attributes, transport history and heavy mineral distribution associated with the placer gold mineralization. These were achieved through field mapping, grain size analysis, binocular microscopy and gold-heavy mineral correlations. Fluvial deposited angular to sub-angular gravel, sand, silt and clay cutting across the metasediments and granitoids make up the stream sediments in the area. These sediments are mainly medium to coarse-grained sand particles, which exhibit well to poor sorting (0.56 – 2.23) and coarse skewness (0.06 – 0.46). Environmentally stable minerals including zircon, rutile, tourmaline and garnet are dominant within the heavy mineral concentrates, with varied proportions of mafic silicate minerals indicating immature types, typical of sediments close to the source area. The results of granulometric analyses and the occurrence of mafic silicate minerals indicate immature sediments, transported by low to high energy fluvial system not far from the sediment source. Gold and rutile, which despite having dissimilar specific gravities were found to correlate positively which may be indicative of the occurrence of an orebody, consistent with auriferous mineralization related to deformational and alteration stages of orogenies.
Keywords: Wonaka Schist Belt; Placer gold deposits: Heavy minerals; Rutile; Granulometry; Stream sediments

INTRODUCTION

Gold (Au) occurrence in Nigeria is predominantly associated with supracrustal (schist) belts in the western half of the country (Garba, 2003; Amuda *et al.,* 2013). Some of the most significant deposits found in the Maru, Anka, Tsohon Birnin Gwari, Kwaga, Malele, Gurmana-Shiroro, Minna-Suleja, Mahuta, Bin Yauri, Egbe-Isanlu, Iperindo-Igun, Okolom-Dogondaji and Shaki areas (Ramadan and Abdel Fattah, 2010; Geoprobe, 2014a & b), with a few occurrences outside these areas (Garba, 2003; Usman, 2014). Approximately 90% of Nigeria's total gold production has been from alluvial deposits derived from primary gold mineralization in the basement rocks (Obaje, 2009).

Primary gold mineralization has been documented in several schist belts in northwestern Nigeria (Elueze, 1981; Garba, 2002), with primary gold deposits reported in the Maru, Anka and Kushaka Schist belts, but the proximal Wonaka and Malumfashi schist belts were not reported (Woakes and Bafor, 1984). However, the Wonaka schist belt is fast gaining importance among the schist belts in northwestern Nigeria due to reported occurrence of gold placer deposits (e.g. Amuda *et al.,* 2013; Geoprobe, 2014a&b) and intensive artisanal mining activity. The increasing interest in the area due to the gold mining activities have placed the Wonaka schist belt in an important position as a prospective major gold-producing area within the northwestern Nigeria.

Gold mineralization in this schist belt is primarily hosted in alluvium within the catchment of River Gagare, notably at Gidan Boss, Dutsen Butsa, Mada, Kutcheri, Dankaya, Wonaka, Fura-Girke, River Yankuzau, and Gidan Chido (Amuda *et al.,*2013; Geoprobe, 2014a and b). Such extensive distribution of alluvial gold and impressive tenor of gold output requires sufficiently large or widespread primary gold sources. Yet, the alluvial gold mineralization has remained puzzling without identified primary sources in both proximal and distal areas.

In this contribution, the paper presents the sedimentological, microscopic and heavy mineral analyses of the alluvial placers within the Mada and Wonaka regions. The study incorporates field investigation, granulometric, and heavy mineral analyses to provide valuable information to sediment provenance, transport pathways and depositional history. The results present an opportunity to get insights into the primary source(s) of the placer gold deposits, identify more prospecting localities and the gold exploration potential of the Wonaka schist belt.

1. GEOLOGIC SETTING

The study area is part of the Nigerian Basement complex, which is part of the Pan-African mobile belt situated east of the West African Craton and north-west of the Congo Craton. The rocks of the Nigerian Basement Complex are believed to be the results of at least four major orogenic cycles of deformation, metamorphism and remobilization (Obaje, 2009), corresponding to the Liberian (c. 2700 Ma), the Eburnean (c. 2,000 Ma), the Kibaran (c. 1,100 Ma), and the Pan-African cycles (c. 600 Ma). Consequently, four major lithological units are distinguishable, namely; The Migmatite – Gneiss Complex, the Schist Belt (Metasedimentary and Metavolcanic rocks), the Older Granites (Pan African Granitoids) and Undeformed Acid and Basic Dykes. The basement complex is intruded by Mesozoic Calc-Alkaline Ring Complexes (Younger Granites) and unconformable overlain by Cretaceous and younger sediments.

The Wonaka schist belt consists of hornfelsic schist mainly; fine-grained quartz-biotite schist that contains sillimanite, garnet or cordierite; forming a monotonous expanse with constant foliation trend (Obaje, 2009). It lies northwest of Malumfashi schist belt, and has a distinctive composition and metamorphic region than the other schist belts, with thin beds of calc-silicate rocks widely distributed within (Usman and Ibrahim, 2018). The Wonaka schist belt is fast becoming one of the most endowed schist belts of Nigeria in terms of Au mineralization due to widespread occurrence of Au placer deposits. Gold mineralization in the Wonaka schist belt occurs along the stretch of the River Gagare Basin with extensive but non-uniform, erratic distribution.

The Gagare fluvial system dominates the hydrological framework of the study area. The Gagare River has its source in Precambrian crystalline terrain in Bakori town, Katsina state, and flows downstream in a northwest direction for over 200 km eventually joining the Rima River in Sokoto. The River drains the geologically heterogeneous highlands of the Wonaka schist belt on its course, through extensive hydrographic networks (Fig.1). Although the Gagare is an ephemeral system with flow peaks during the rainy season (May/June to October/November), the drainage density and surface runoff are high on the basement complex rocks of the high plains, and the River and its tributaries carry a large volume of sediments when they flood. On entering the level plains, these rivers lose energy and deposit large amounts of sediment along the plain.

MATERIALS AND METHODS

Study Area

The study was undertaken within the drainage basin of River Gagare, east of Gusau town of Zamfara State Nigeria. The area is bounded between latitudes 12° 03′ 46″N to 12° 24′ 10″N and longitudes 06° 49′ 00″E to 07° 00′ 32″E (Fig. 1), within the Federal Survey Map Sheets 54 Gusau (NE and SE). It covers about 632 Km^2 and is accessible via the Kotorkoshi - Mada road that stems from the federal road (A126) that links Funtua and Gusau. Accessibility within the study area, however, is provided by the network of numerous roads and tracks that consist of untarred, lateralized feeder roads and all-season footpaths.

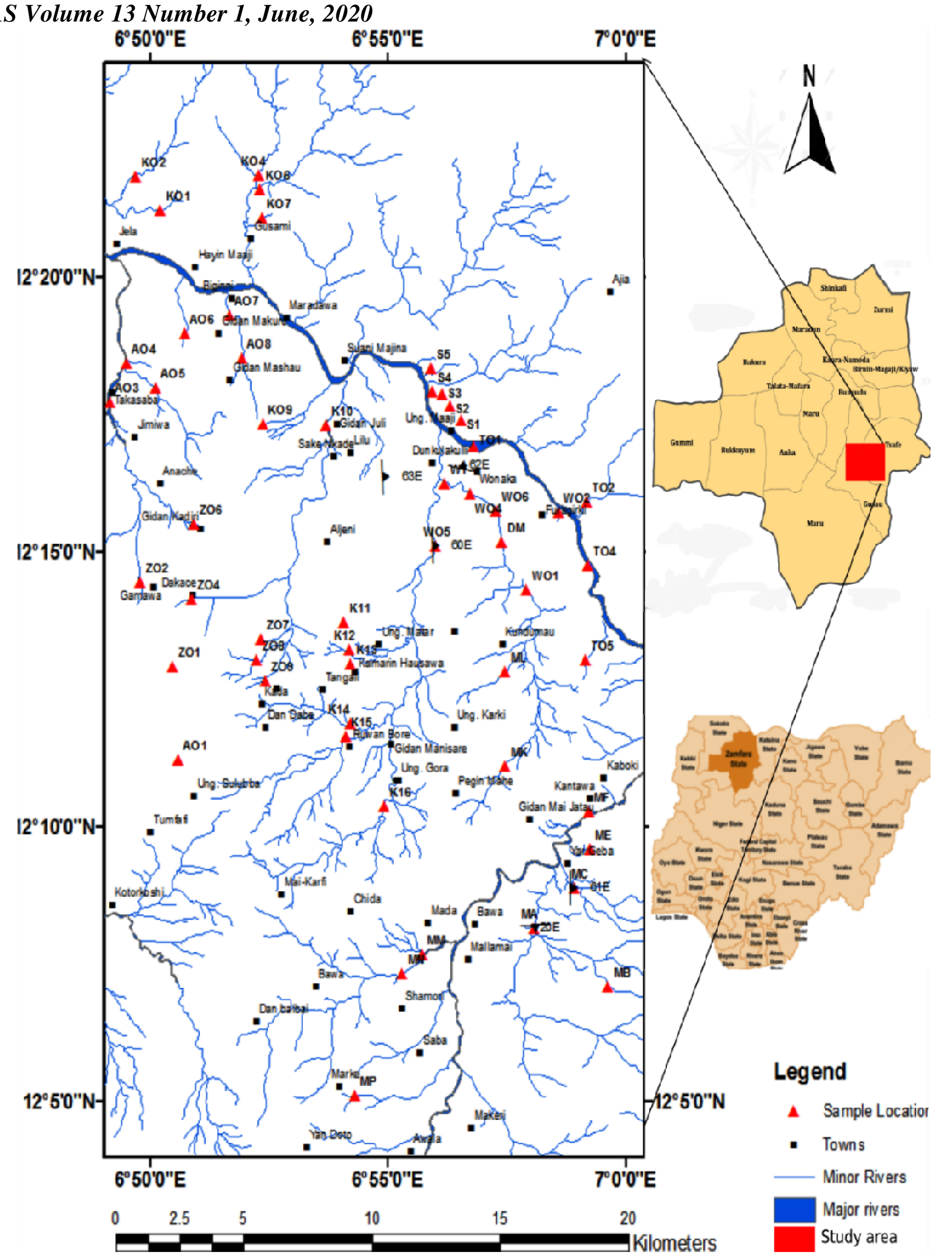

Figure 1: Study area map showing the drainage system and distribution of the sampling points.

Field studies and sample collection

Detailed field mapping aimed at understanding the geology, placer Au system and sample collection was undertaken. Stream sediment samples were collected from 1st, 2nd and 3rd order, active, undisturbed streams channels and also from their confluences with the two main rivers (Rivers Gagare and Mada). A total of 67 samples were obtained and reduced through panning in the field (Plate 1). Ten (10) representative samples were selected for the analyses based on the catchment areas, generated from the Digital Elevation Model [DEM] (Fig. 3).

Plate 1: Stream sediment sampling in the study area. A) About 15 kg of representative composited stream sediment samples were collected at the middle of the channel at a depth of 20 to 90 cm at each location - to avoid the thick accumulation of seasonally deposited sands; spade was used to scoop the sample into stainless steel, flat-bottomed conical pan or sample sac. B) To avoid sampling mixed sediments resulting from flood flow, the samples were taken at zones of high energy - indicated by coarser sediment accumulations, at bends within the channels, intersections of tributaries (confluences), and places where the flow has been interrupted by rock bars or other natural traps that favour heavy mineral accumulation. C) At the site of sampling where surface water was not available, a hole was dug to access water usually to a depth of less than a meter. D) The heavy mineral concentrates were extracted from the collected material by panning. E) During repeated shaking cycles, the lighter particles were washed and dispensed while the heavier settled down the pan. This process was repeated until a residue of heavy minerals was obtained.

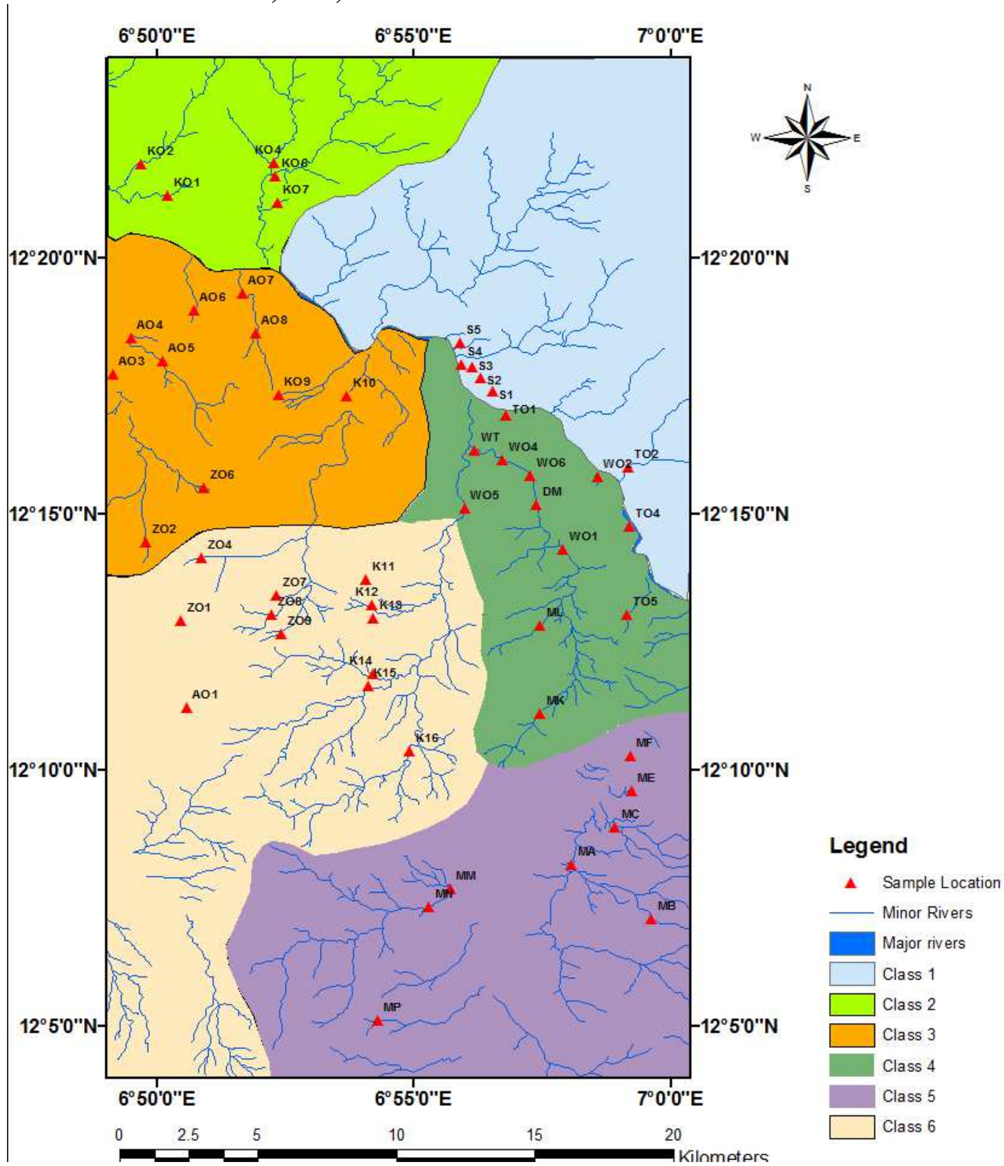

Figure 2: Distribution of the samples into classes, based on the corresponding watershed.

Heavy mineral concentrate (HMC) samples were obtained and stored in a well-labelled polythene bags secured with a loose knot and transported in an upright position. At the base camp, the samples were air-dried for a week and repackaged for analysis. During sampling, sources of contamination such as river and collapsed banks, riparian zones, roads, bridges, habitation and winnowed sediment areas were avoided. Others sources of contaminants avoided include; areas of limited sediment accumulation, sampler induced contamination from jewellery, pan and shovel, metal sampling box etc.

Granulometric Analysis

This was carried out using samples from the gold-bearing stream sediments to determine the grain size distribution and was carried out at the Sedimentology Laboratory, Department of Geology, Usmanu Danfodiyo University, Sokoto, Nigeria. Subsequently, calculations, deductions and interpretations were made based on Folk and Ward (1957) to determine the mean distribution, sorting and skewness. From the results, cumulative curves and histograms were generated following standard procedures. Grain sizes corresponding to the 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles were obtained and used to compute the mean, median, standard deviation (sorting) and skewness (Friedman, 1979).

Binocular Microscopy

This technique was used to examine the grains' occurrence, morphology, measure their dimension and to select gold-bearing representative samples for further study. This was undertaken at the Microscope Laboratory, Department of Geology, Ahmadu Bello University, Zaria, Nigeria. The grains were subsequently classified to represent different surface morphology and representative grains were chosen for detailed analysis of the physical characteristics such as roundness, outline, folding and flatness.

RESULTS AND DISCUSSION

Grainsize of Gold-bearing Stream Sediments

Grain size analysis of the gold-bearing stream sediments was carried out to determine the environment of deposition and probable transport history. The grain size distribution of sediments is used as a complementary interpretational tool for analysis of facies and paleoenvironments (Lawal *et al.,* 2017). The raw results of the grain size analysis are presented in (Appendix 1). The grain size data were plotted on cumulative frequency curves (Fig 4). The mean, standard deviation and skewness of the ten different representative samples were derived from the grain analysis data as shown in Table 1.

Table 1: Grain size analysis of some representative samples of the stream sediment collected from the study area

Sample	Mean grain size (ϕ)	Std. Deviation/sorting (ϕ)	Skewness
WT	-0.77	1.90	0.46
Z07	-0.77	0.92	0.12
T05	-0.63	1.87	0.19
W02	-0.67	1.60	0.40
T01	-0.63	1.33	0.22
W04	-0.52	1.24	0.07
MM	-1.43	2.16	0.18
ML	-1.42	1.75	0.06
K02	-0.48	0.56	0.18
Z01	-0.21	2.23	0.25

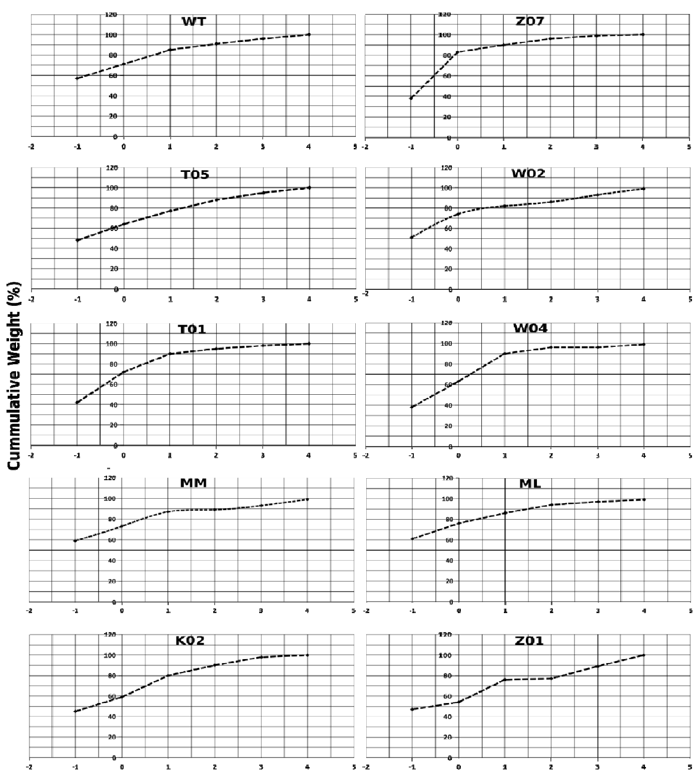

Figure 3: Cumulative frequency curves of representative samples of the study area

Gagare River and associated streams compose of gravel, sand, silt and clay-sized materials. The grains show angular to sub-rounded shapes. The fluvial systems transect the metasediments and granitoids of the Wonaka Schist Belt which Grant (1978) noted has a similar setting geographically, albeit of relatively different metamorphism with other Schist belts in Northern Nigeria, most of which have been reported to host Au mineralization of similar styles (Ramadan and Abdel-Fattah 2010).

The sediments are composed mainly of medium to coarse-grained sand. The remainder of the grains falls within the gravel and clay sizes. Such distribution of grain sizes indicatesa transport medium of relatively high energy with occasional variationin energy. Sorting parameter shows that the sediment ranges from poorly sorted to moderately well sorted (Table1), indicating that the sediment has been transported not too far from the source. The sorting of the sediment also supports a relatively high energy transport medium e.g. river.

The skewness shows that most of the samples are coarsely skewed (Table1). Hence, the studied sediment samples are composed mainly of coarse to nearly symmetrical skewed grains. This is interpreted as evidence that the sediments are products of weathering that have been transported not so far away from the source. This is also consistent with a flow regime near the middle when referenced in terms of distance from the source.

The univariate analysis confirms the fluvial nature of the sediments, dominated by streams and rivers in the study area. Bivariate plot of skewness against the sorting of grains based on Friedman, (1979) show the samples plotting mainly on the bottom right of the plot, suggesting fluvial deposition. (Fig 5).Incorporating the poor to moderate sorting of grains as well as the coarse skewness, there is consistency; the stream sediments are considered products of fluvial flow that passed through periods of high and low energy, that deposited the sediments somewhere between more proximal and distal positions of the flow (e.g. Lawal *et al.,* 2017).

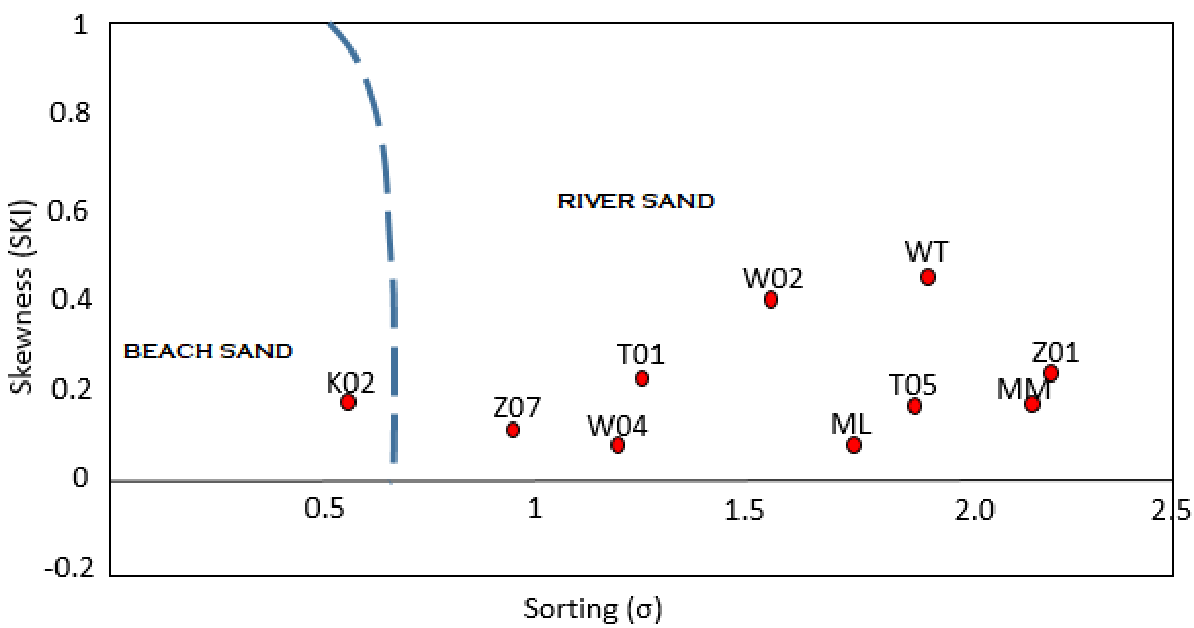

Figure 4: Bivariate plot of the skewness and sorting (data are taken from Table1) showing the fluvial origin of the sampled stream sediments in the studied area (modified after Friedman, 1979; Lawal *et al.,* 2017).

Gold-Bearing Heavy Minerals

Heavy minerals that occur together with the gold were visually recovered and subsequently examined using a binocular microscope to obtain information that was used in determining transport distance and nature of the bedrock (e.g. McClenaghan, 2011). A total of 1564 heavy minerals grains were analyzed and counted using Galehouse (1971) ribbon counting technique. The individual heavy minerals found in association with the gold are zircon, tourmaline, rutile, staurolite, kyanite, magnetite, garnet, amphibole, epidote and ilmenite (Fig. 6).

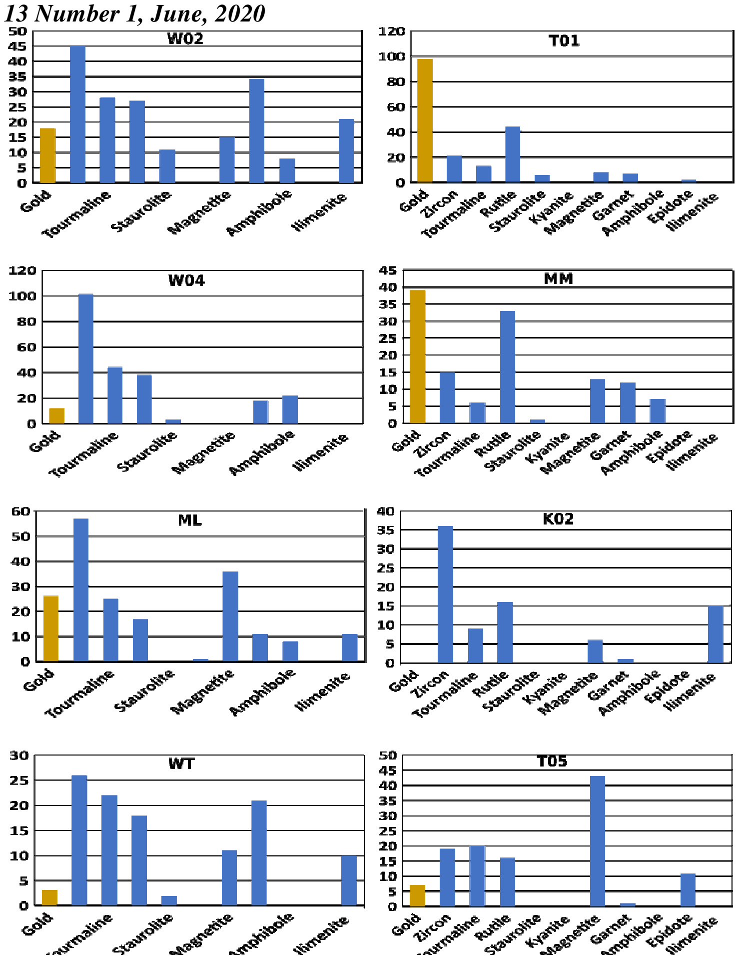

Figure 5: Bar charts illustrating the distribution of heavy minerals per sample

Description of Heavy Minerals

Amphiboles: occur as elongated dark green to brownish coloured striated minerals with some displaying strong lustre. Most of the occurrences of the minerals were from 1st order and 2nd order streams (Fig. 7).

Garnet: this occurs as red to pink equant minerals; it occurs within streams draining from quartz-mica schist within which primary occurrence was also observed and in classifying the grains as almandine (iron-rich variety)

Ilmenite: this occurs as dark greyish tabular grains with a metallic lustre which were not magnetic when subjected to the magnetic mineral separator; a distinguishing feature used to differentiate it from magnetic.

Kyanite: this occurs as a colourless elongate grain with striated lines showing its good multidirectional cleavages.

Magnetite: this occurs as mostly euhedral to subhedral grains (but also rounded anhedral) showing the characteristics octahedral crystal shape. The grains occur relatively smaller in the samples

Rutile: rutile occurs as elongated reddish-brown grains with a metallic lustre. They occur mostly as small grains with some occurring as subrounded.

Staurolite: these are elongated grains that appear orange and dark brown that looks similar to garnet but having smaller and elongated grains

Zircon: this occurs as relatively the smaller grains of light to colourless, mostly subrounded mineral. They are mostly elongated

Tourmaline: mostly euhedral and well-formed crystals commonly in a wide range of colours such as pink, brown, black and green.

Epidote: this mineral occurs as light green with some larger crystals of it occurring as dark green. This only occurs in two of the samples analysed and relatively less within these samples (Table 2). Occurring as elongate grains which differentiate it from similar green minerals e.g. olivine, pumpellyite, chloride, pyroxene etc.

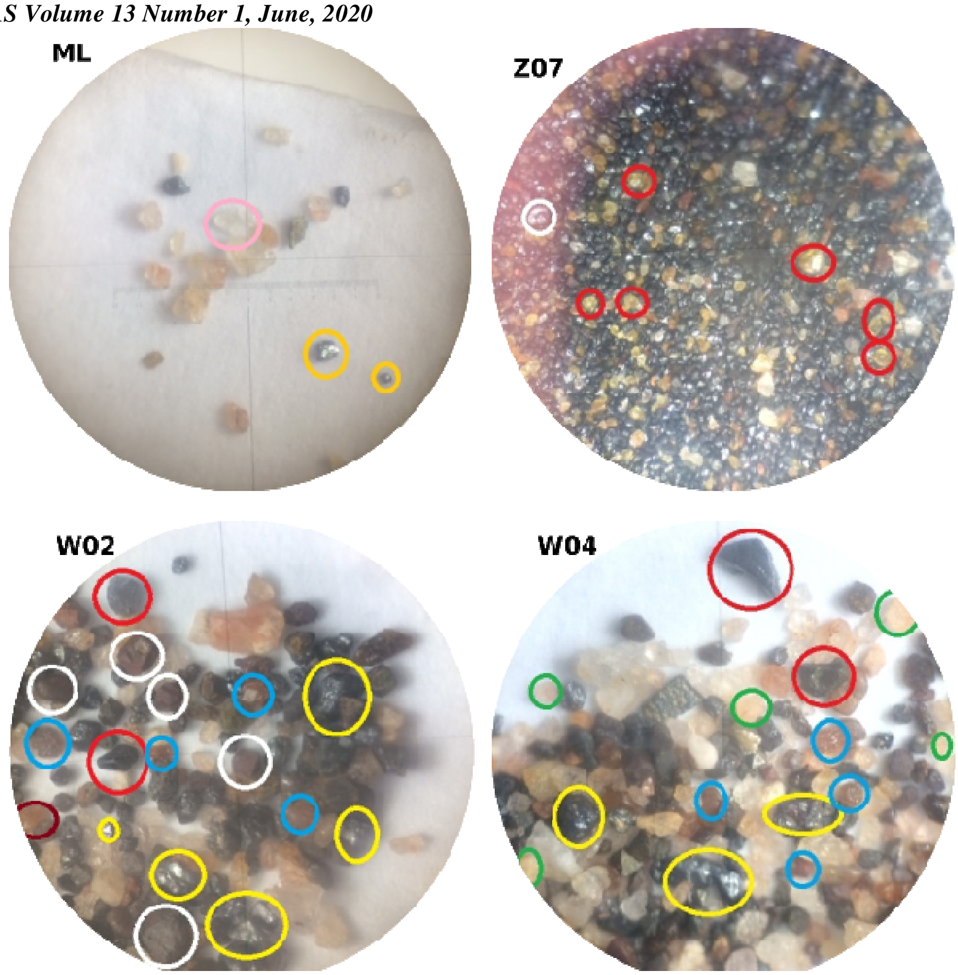

Figure 6: Incident light images of heavy mineral concentrates. Pink circle = Kyanite; yellow circle = magnetite; Blue circles = garnets; Red circles = tourmaline; white circles = rutile; green circles = zircon.

Table 2: Heavy minerals within gold-bearing samples in the study area

S/No.	Mineral	W02	T01	W04	MM	ML	K02	WT	Z07	T05	TOTAL
1	Zircon	45	21	101	15	57	36	26	83	19	403
2	Tourmaline	28	13	79	6	25	9	22	41	20	243
3	Rutile	27	44	38	33	17	16	18	33	16	242
4	Staurolite	11	6	3	1			2			23
5	Kyanite					1					1
6	Magnetite	15	8		13	36	6	11	26	43	158
7	Garnet	34	7	19	12	11	1	21	5	1	111
8	Amphibole	8		22	7	8			16		61
9	Epidote		2							11	13
10	Ilmenite	21				11	15	10			57
11	Others	39	25	72	9	16	43	23	17	8	252
	Total	228	126	334	96	182	126	133	221	118	1564

A simple correlation was carried out to highlight relationship(s) between the gold and other heavy minerals present, a positive correlation was observed between gold and rutile (Table 3). Rutile (TiO_2) is a common constituent of metamorphic rocks ranging from eclogite to greenschist facies (Liou *et al.,* 1998). As Clark and William-Jones, (2004) suggested, anomalous rutile compositions may reflect significant metal concentrations in many types of ore bodies.

Table 3: Simple correlation between gold and heavy minerals present in the analyzed samples

	Gold	*Zircon*	*Tourmaline*	*Rutile*	*Staurolite*	*Kyanite*	*Magnetite*	*Garnet*	*Amphibole*	*Epidote*	*Ilmenite*
Gold	1.00										
Zircon	-0.36	1.00									
Tourmaline	-0.39	0.90	1.00								
Rutile	0.64	0.27	0.22	1.00							
Staurolite	0.37	-0.04	0.09	0.39	1.00						
Kyanite	0.04	0.15	0.05	-0.35	-0.26	1.00					
Magnetite	-0.20	-0.15	0.05	-0.50	-0.36	0.48	1.00				
Garnet	-0.05	0.15	0.30	0.12	0.76	-0.04	-0.33	1.00			
Amphibole	-0.25	0.91	0.81	0.45	0.02	0.06	-0.17	0.26	1.00		
Epidote	-0.02	-0.38	-0.14	-0.28	-0.19	-0.15	0.62	-0.43	-0.38	1.00	
Ilmenite	-0.29	-0.09	-0.12	-0.52	0.43	0.22	-0.10	0.52	-0.25	-0.35	1.00

Agangi *et al.* (2019) explored the applicability of rutile as a pathfinder for orogenic gold deposits. They concluded that the placer gold deposit in three different Precambrian terrains (Capricon Orogen, Barberton Greenstone Belt and Ashanti Belt) is related to the rutile that formed during deformational and alteration stages of the orogeny. This is consistent with the structurally controlled origin of most primary gold mineralization reported in Nigeria (Garba, 2003).

The placer gold deposit of the study area could be related in origin with the associated rutile, however, it should be noted that even though both gold and rutile qualify as heavy minerals (specific gravity >2.8), the specific gravity of gold (19.1) is much greater than that of rutile (4.5) thus that will explain the absence of gold in some locations were rutile was present.

Environmentally stable minerals like zircon, rutile, tourmaline and garnet are dominant within the HMCs obtained within the Gagare main river and higher-order streams with an insignificant amount of mafic silicate minerals while 1st and 2nd order streams sampled have a large proportion of mafic silicate minerals that are vulnerable to dissolution during alteration at ambient conditions; an indication of immaturity, a situation typical of sediments that are close to the source area.

These show the different degrees of maturity of the stream sediments and proximity to the source, based on the modal abundance, (Weibel, 2003). They are most probably products of physicochemical weathering of the bedrocks in the study area, indicated by the occurrence of common rock-forming minerals in the stream sediments and their presence in all samples.

CONCLUSION

Gold mineralization in the Wonaka schist belt occurs along the stretch of the River Gagare Basin with extensive but non-uniform, erratic distribution mainly within fluviatile sediments. From the sedimentological analyses, bivariate plots of skewness against sorting indicate fluvial deposition. The poor to moderate sorting of grains, coarse skewness are all consistent with stream sediments that are products of fluvial flow that passed through periods of high and low energy and were deposited somewhere between more proximal and distal positions of the flow. Although environmentally stable minerals like zircon, rutile, tourmaline and garnet are dominant within the HMCs obtained within the Gagare main river, there is also a large proportion of mafic silicate minerals that are vulnerable to dissolution during alteration at ambient conditions; an indication of immaturity, a situation typical of sediments that are close to the source area.

The gold grains occur in association with other heavy minerals such as zircon, tourmaline, rutile and garnet. A positive correlation was observed between the gold grains and the rutile suggesting a similar origin for both. Thus, with further geochemical and dating analysis the rutile might be applicable as a pathfinder mineral for the placer gold mineralization in the Wonaka schist belt area.

CONFLICT OF INTEREST

The authors declare no conflict of interest

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