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Graphical Abstract

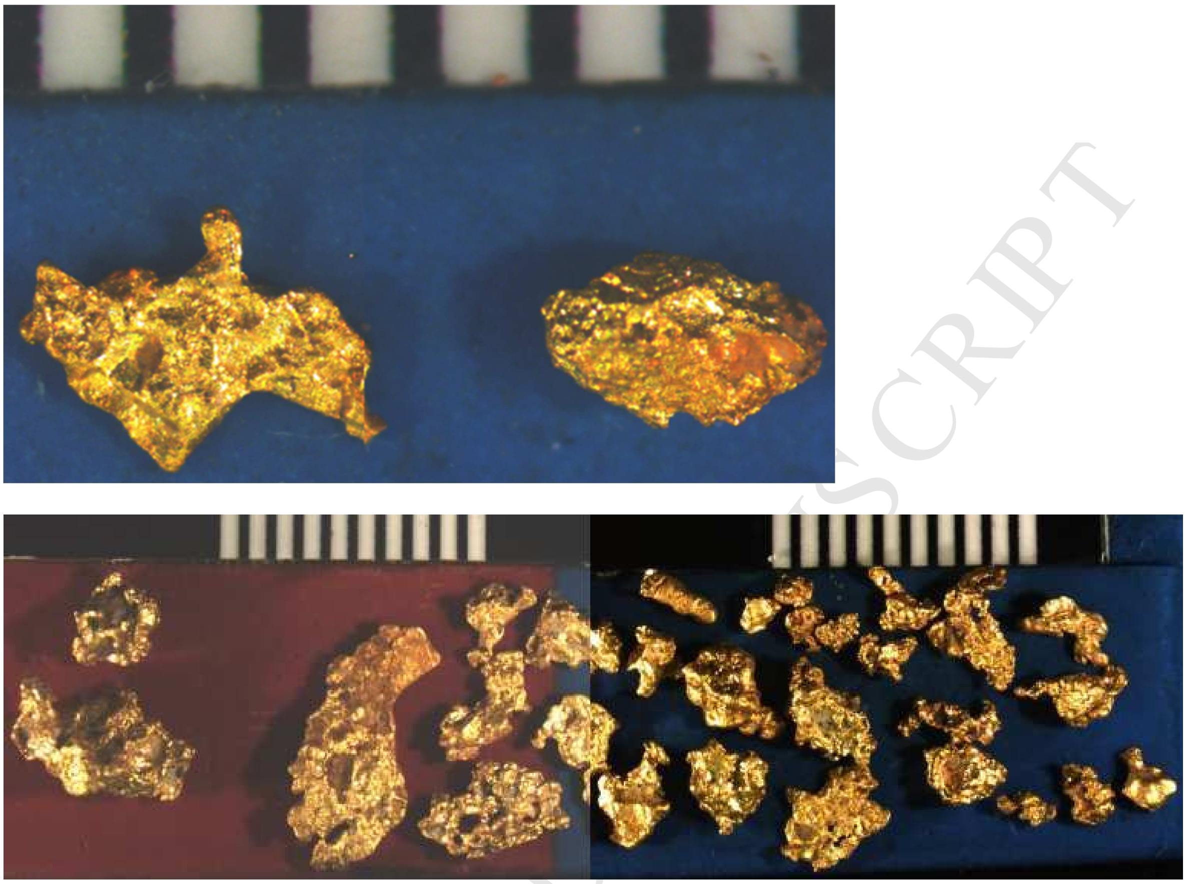

Fig.6: - Angular eluvial gold grains (Samples G8, G9, and G10). Scale bar is in mm.

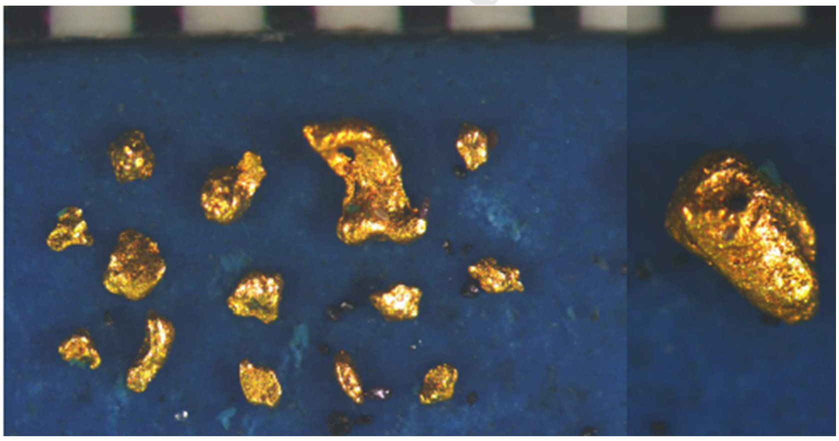

Fig.7: rounded to elongate alluvial gold grains from Nkolmedoum. The general outline of these grains is regular and surface topography tends to be smooth (Scale bar in mm).

Microchemical characterization of placer gold grains from the Meyos-Essabikoula area, Ntem complex, Southern Cameroon

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Abstract

Gold occurs as a native metal, usually containing silver, and in some cases mercury, copper, and palladium. It may also occur as inclusions within sulfur-rich minerals, such as pyrite and arsenopyrite. The style and variety of gold mineralization is influenced by the geological setting, chemistry of the ore fluids, and the nature of their interactions with rocks. Gold grains liberated from bedrock into surficial sediments during weathering and erosion are chemically stable and may be characterized according to their mineralogy: i.e the alloy composition and suite of mineral inclusions revealed within polished sections, characteristics faithful to gold from the hypogene source. This approach has been applied to placer gold grains from the Meyos-Essabikoula area, Cameroon, where the source of gold is not yet confirmed due to poor outcrop exposure.

A total of 221 alluvial gold grains from 10 sites, tributaries of Sing and Bivele River over the Ntem Complex have been studied using Electron Probe Micro-Analysis (EMPA) to determine the concentration of minor alloying metals, (notably Au, Ag, Cu, and Hg) and Scanning Electron Microscopy (SEM) in order to evaluate the assemblage of mineral inclusions within the gold. Most of the grains are sub-rounded with pitted surfaces and inclusions of pyrrhotite, acanthite, and chalcopyrite were observed. The grains are Au-Ag alloys ranging from 54.4-99.8 wt% Au, 0.1-48.4 wt% Ag, 0.1-0.8 wt% Hg and 0-0.3 wt% Cu. The presence of Fe oxide (magnetite) inclusions containing Cr and V (to around 5 wt %) has not been reported elsewhere and suggests a strong interaction between hot reducing ore fluids and local mafic lithologies.

Keywords: Microchemical characterization, Placer gold, Alluvial and eluvial sediments. Gold morphology, Meyos-Essabikoula area, Ntem complex.

1. Introduction

The Meyos Essabikoula area is located within the Ntem Complex of southern Cameroon, which represents the north-western part of the Congo Craton in Central Africa (Maurizot *et al.*, 1986; Nédélec *et al.*, 1990; Goodwin, 1991). This is part of Archean terranes bearing Archean lode gold deposits in Africa (Foster and Piper, 1993). The area comprises of the Archean Ntem Unit to the southeast and the Paleoproterozoic Nyong Unit to the northwest. Mineral exploration, in the last decade, within the southern district of Cameroon focused on this area because of the abundant and widespread occurrences of placer gold, which supports extensive artisanal mining. Exploration has identified a wide range of placer gold deposits, however much work is needed to constrain the gold reserves in the area and their sources.
Recent studies show that the source(s) of the primary gold in south Cameroon is largely unknown (Suh *et al.,* 2006; Omang *et al.,* 2015). This is due to several factors, including the dearth of literature on primary gold mineralisation in the area, lack of adequate outcrops for detailed mapping and sampling, and thick lateritic cover, which makes the geochemical signature of underlying mineralization in soils difficult to determine in regional geochemical surveys.

In cases such as this, valuable information regarding the origins of gold can be obtained from the study of the microchemical signature of detrital gold grains. Grains of native gold are chemically stable within most environments on the Earth's surface, and thus gold grains liberated from the hypogene ore are normally unchanged on passing from bedrock into surficial sediments as a result of weathering and erosion. They may be characterized according to both their alloy composition and the suite of minerals present as inclusions. This approach permits identification of populations of placer gold grains derived from different sources often through correlation of assemblages of mineral inclusions with specific alloy compositions (Chapman *et al*., 2009; Chapman *et al.,* 2016; McLenaghan and Cabri, 2011; Hancock and Thorne, 2011; Moles *et al*., 2013, Omang *et al*., 2015). The technique has been applied to facilitate both local and regional analyses of the variation in gold signature and relationship to host lithology (Naden *et al*., 1994; Leake *et al.*, 1997; Chapman *et al.,* 2000a b; Omang *et al.,* 2015); used as a tool in the exploration process (Potter and Styles 2003); and to identify broad differences in signatures of gold from specific styles of mineralization (Chapman *et al.,* 2017a, b). Using this approach in Cameroon, Omang *et al.,* (2015) suggested an ultramafic source rock for the Nyong gold grains while the Lom grains were likely derived from hydrothermal quartz veins. The overall morphology of gold grains reflects their transport history, with characteristics inherited from the hypogene setting evident in the populations derived for the eluvial environment. Several studies have shown the evolution of the grain morphology of gold particles as a function of the distance travelled from the source (Knight *et al* 1999a,b; Townley et al. 2003, Crawford, 2007). However, there are no general criteria by which distance to the source may be accurately estimated in all sedimentary environments. The present study focuses on the microchemical signature of alluvial gold grains from the Meyos-Essabikoula area with a view to illuminating the nature and location of potential primary source(s).

2. Geographical and geological setting

The Meyos-Essabikoula study area is located in Southern Cameroon, about 32 km west of the city of Sangmelima. The area is characterized by a continuous chain of topographic highs and deeply incised valleys. The area lies within longitude 11º38′ E - 11º48′ E and latitude 2º52′ N - 2º58′ N (Fig.1). It is an integral part of Southern Cameroon, represented topographically by the Ebolowa 4 c and 4d maps at a scale of 1:50000. The Meyos-Essabikoula area lies at the transition between the continental equatorial climate and the equatorial monsoon climate with an annual precipitation of 1672.2 mm/yr and an average temperature of 24 °C. The Meyos-Essabikoula area is located within the Ntem Complex at the northern part of Congo craton (Fig. 2). The Meyos-Essabikoula area is drained by rivers Abolo, Bivele and Sing, and their tributaries. These water bodies form a vast dendritic network of streams flowing in the SSE-NNW, SE-NW, N-S directions.

The Ntem Complex represents the north-western part of the Archaean Congo craton in Central Africa (Clifford *et al.*, 1970; Cahen *et al.*, 1976; Bessoles and Trompette, 1980) and is very well exposed in southern Cameroon (Rocci, 1965; Maurizot *et al.*, 1986; Goodwin, 1991). It is limited to the north by a major thrust that marks the contact with the Pan-African orogenic belt (Yaounde group) and is composed of various rock types, with rocks of the tonalite-trondhjemite-granodiorite (TTG) suite constituting the greater part (Nedelec *et al.*, 1990). Three main rock types, the charnockitic suite, granodioritic suite and the tonalitic suite constitute the TTG unit. The tonalitic suite (Nedelec *et al.*, 1990) is exposed to the north and is strongly mylonitized and retrogressed along the fault boundary with the Pan-African orogenic belt. The granodioritic suite forms distinct massifs within the dominantly charnockitic rocks.

The S0 structural surface is basically NW–SE in the charnockitic suite, NNE–SSW to almost E–W in the tonalitic suite and E–W to WNW–ESE in granodiorites, indicating structural discordances and suggesting a polyphase structural set-up in the Sangmelima TTG (Shang, 2001). Furthermore, charnockitic xenoliths occur in granodioritic and tonalitic massifs. Exposures of supracrustal rocks (banded iron formations and sillimanite-bearing paragneisses) that represent remnants of greenstone belts form xenoliths in TTG rocks (Nsifa *et al.*, 1993). Late- to post-tectonic granitoid and syenites with alkaline affinity intrude the TTG (Kornprobst *et al.*, 1976; Nedelec, 1990; Tchameni, 1997; Tchameni *et al.*, 2000, 2001; Shang, 2001; Shang *et al.*, 2001a, b), and clearly postdate the major crustal forming episode. Doleritic dykes of Eburnean (2.1Ga) age (Toteu *et al.*, 1994; Vicat *et al.*, 1996) represent the last magmatic activity in the Ntem complex.

Structural studies suggest two major episodes of deformation in this geological domain. The first deformation episode is characterized by vertical foliation, stretching and vertical lineation and isoclinal folds. These structural elements could mark the diapiric emplacement of the granitoids (Shang, 2001a; Tchameni *et al.*, 2001). The second major tectono-thermal event is marked by the development of sinistral shear planes trending north-south to N45E, and partial melting of charnockitic and tonalitic members of the TTG suite and the greenstones, described as post-Archaean and post-charnockitic migmatisation by Nsifa and Riou (1990). Although the timing of this second tectono-thermal event is not well known, Rb–Sr whole-rock data from Lasserre and Soba (1976) suggest that this event could have occurred during the Eburnean orogeny. Toteu *et al.* (1994) dated the peak of this metamorphism at about 2050Ma, using U–Pb zircon data on metamorphic rocks from the Nyong series.

In the Meyos-Essabikoula area, the rock types are orthogneiss, amphibolites, quartzites, granites, tonalite–trondhjemite–granodiorite (TTG), charnockites and quartz veins (Fig. 3).

Gold exploration in this area is artisanal, with no available published data on the nature of gold deposition and petrogenesis.

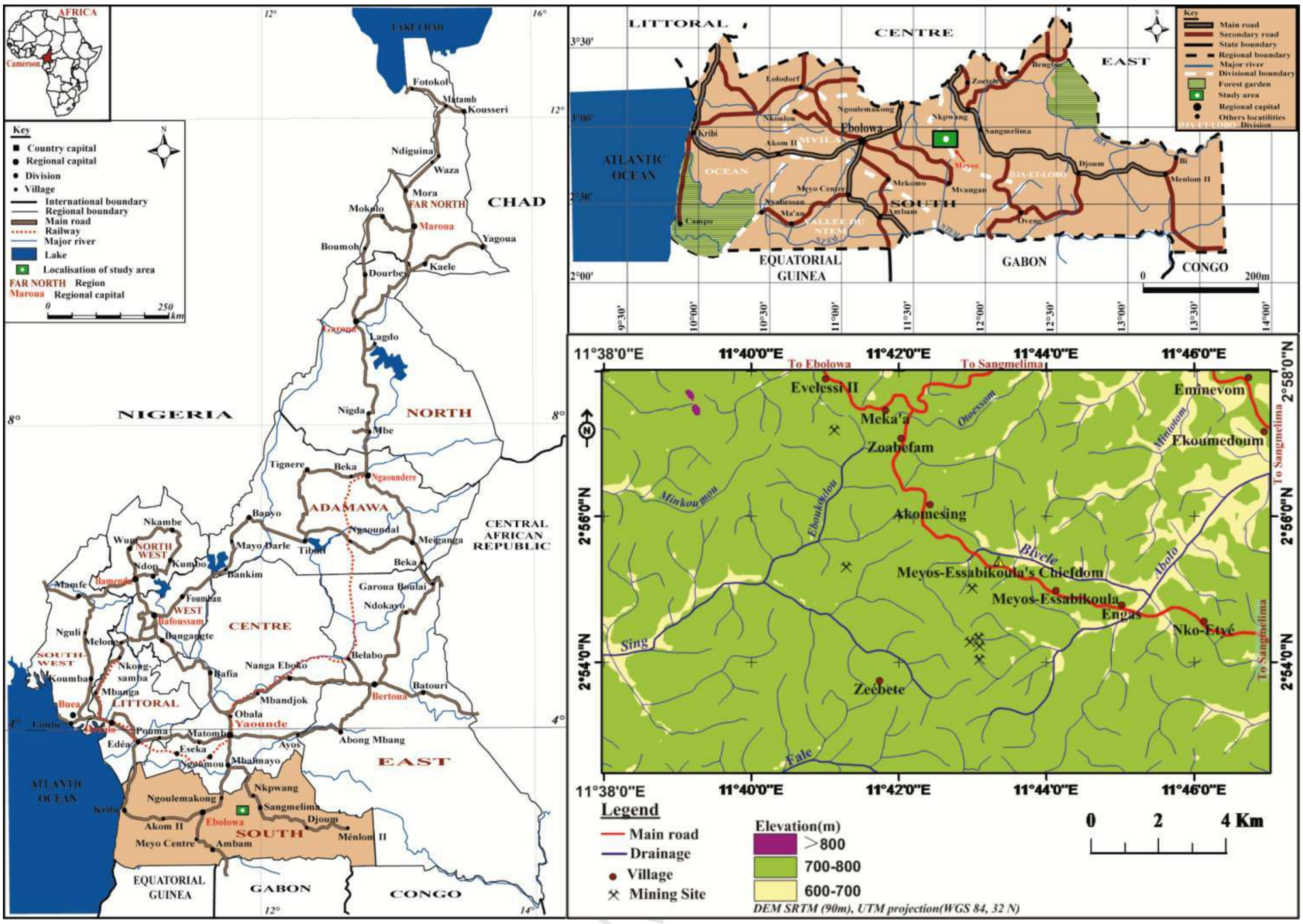
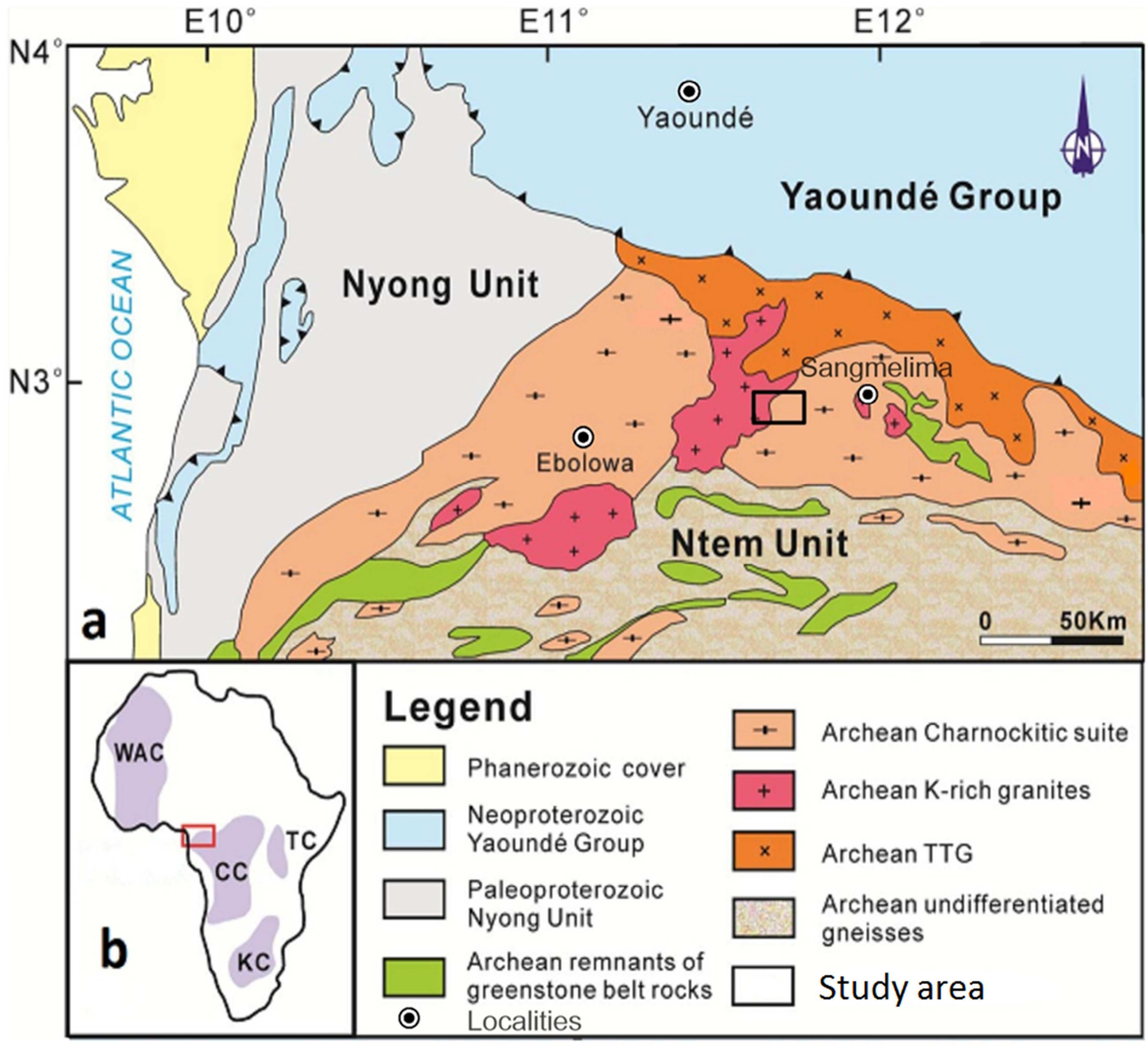


Fig.1: Location map of Meyos Essabikoula showing the road map of Cameroon with an inset of the map of Africa (top left), the road map of the South Region of Cameroon (top right) and the road map of Meyos Essabikoula, showing artisanal mining sites.



(Fig.2): a-Geological sketch map of southwestern Cameroon (modified after Maurizot *et al.*, 1986; Tchameni *et al.*, 2010); b- showing the major Precambrian units and WAC: West African Craton; CC: Congo Craton; TC: Tanzanian Craton; KC: Kapvaal Craton.) (In Li *et al.*, 2016).

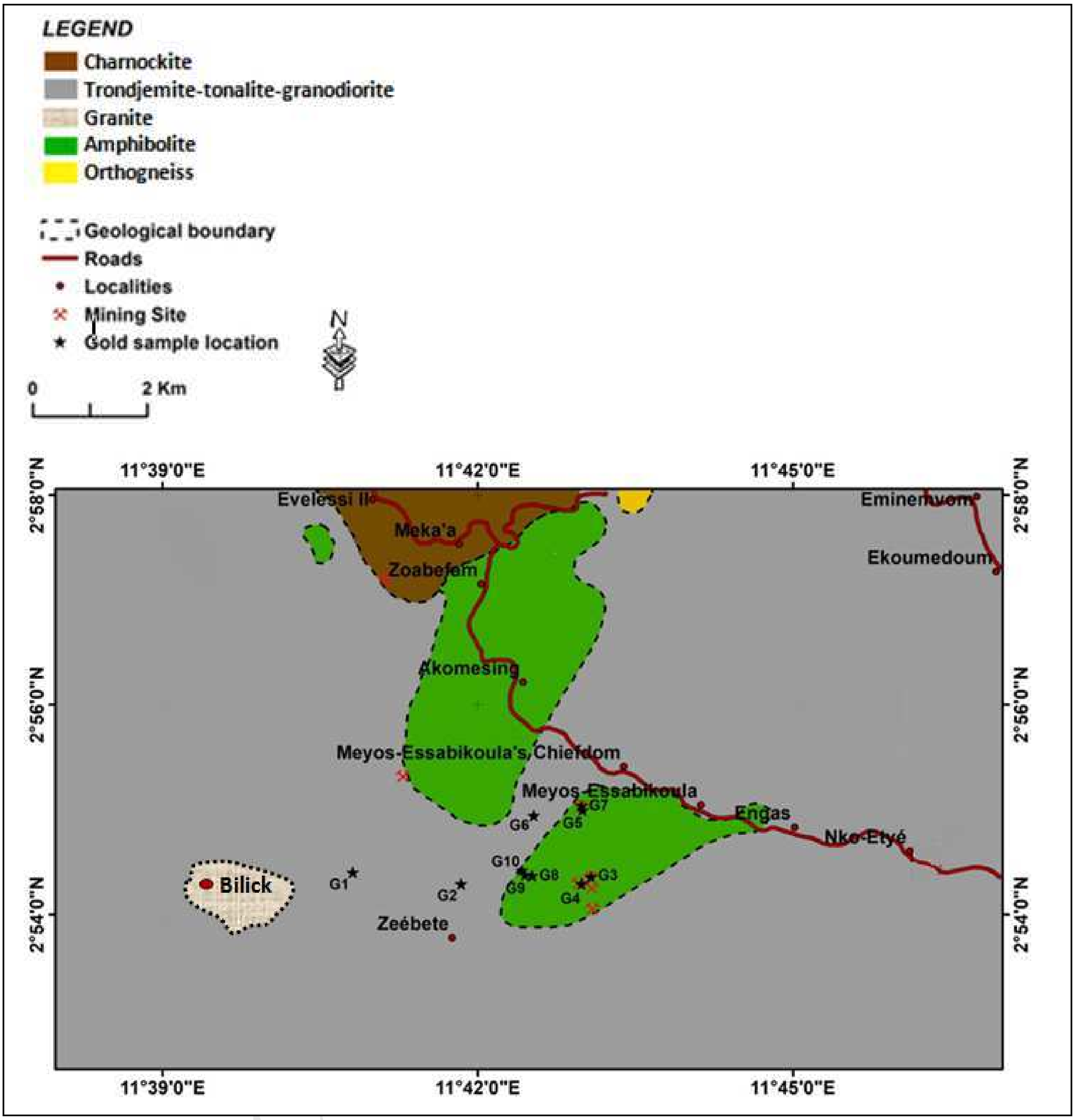


Fig.3: Sketch geological map of study area, showing the distribution of rock out crops and placer gold occurrences.

3. Methodology

Sampling sites were chosen on the basis of their proximity to artisanal workings or the opportunity to dig pits to the bedrock interface. Gold grains samples used in this study were collected from 10 sites on tributaries of the Sing and Bivele rivers (Fig. 5) over the Ntem Complex. Details of the locations and grain microchemistry of samples used in the present study are presented in Table 1.

Gold grains were collected by hand feeding gravel into a gravity-fed sluice (Fig. 4A). Auriferous gravel was collected from different types of environment: active placer mining areas, previously mined areas, river spits (e.g. Fig 4B), stream beds and unmined natural stream environments. The heavy mineral concentrate from each locality was hand-panned to separate the gold grains.

The grains were photographed to record their morphological characteristics prior to mounting according to size, setting in epoxy resin and polishing as described in Chapman *et al.*, (2000a). Analysis was undertaken as described by Chapman *et al.* (2017a). The alloy composition was determined for Au, Ag, Cu, and Hg using a Joel 8320 Super probe at the University of Leeds. Inclusions were identified using the EDS facility of an FEI Quanta 650 FEG ESEM SEM. Some inclusions were analysed using the EDS facility of the SEM to generate the semi-quantitative measurement of Cr in Fe oxide.

The Ag content of a population of placer gold grains is generally the first parameter studied when establishing a microchemical signature, even though ultimately it may not prove the most useful in determining the source style of mineralization (e.g. Chapman *et al.* 2017a,b). The use of increasing Ag vs cumulative percentile plots has become a standard methodology for comparing the range of Ag values of individual grains present within populations of different sizes. This approach permits identification of compositional sub-populations, which may be compared between localities to establish different gold types present in different areas. Where detectable, Hg and Cu contents are used as additional discriminants in establishing microchemical signatures, however in the present study the values of Hg are almost all below the limit of detection, and Hg is not considered further.

Approaches to the characterization of mineral inclusion suites vary according to the amount of data available which is, in turn, a consequence of overall abundance and population size. Various studies have utilized triangular diagrams indicating relative abundance of mineral classes within different assemblages (Chapman *et al.*, 2000a), although these have the disadvantage of ignoring the significance of specific minerals whose presence may be informative. Spider diagrams, which depict the relative abundance of different minerals alleviate this issue but quickly become difficult to interpret when more than 3 or 4 assemblages are superimposed on the same diagram (Chapman *et al.* 2017b). In the present study, inclusions were extremely scarce, but nevertheless, mineral speciation provides an informative avenue of study.

Fig.4: (A) Methodology of collection of gold grains. (B) Example of an excavated pit at Gatan locality.

4. Results

4.1 Gold grain morphology

Based on morphological characteristics, shape, outline, surface, associated primary crystal imprints, mineral inclusions and flatness index, two main gold grains groups were determined. The first group (Group 1) is represented by gold grains recovered from the eluvial (localities G8 and G9 (Fig. 6). Their angular and rough nature with adhering quartz and crystal imprints indicates minimal or no fluvial travel.

The second group of grains comprises rounded to oval particles, and in many cases slightly elongated shapes (Fig. 7). The outline is relatively regular and surface topography tends to be smooth. Primary mineral imprints are diffuse and associated minerals consist only of iron oxides (rare) and clay coatings. Impact and groove marks are common.

4.2 Gold alloy composition

4.2.1 Silver (Ag)

The silver contents of all sample populations are presented in Figure 8a which shows some clustering of plots with outliers (G1 G8 and G4). The other plots in figure 8 have been constructed to more clearly show the relationship between samples from localities which are adjacent or possibly related by drainage. Some of these samples contain a relatively small number of gold grains (<15) and in these cases, it is not generally possible to draw strong conclusions from the data sets. Nevertheless figure 8b shows that gold from the adjacent sites of G5, G6 and G7 yield a similar range of Ag values, whereas sample G1, which is geographically separate, comprises mainly very low Ag alloy. Samples G3 and G4 exhibit the same range of Ag alloy between 0 and around 5% and also a similar range of higher Ag alloy, although this feature is more pronounced in the gold from G4. The two eluvial samples from Nkoul Medoum, (G8 and G9) show the narrowest predominant range of Ag contents, but the two curves are not coincident. The nearby placer sample of G10 shows features of both, as does sample G2 collected approximately 1.5 km downstream.

Table1: Description of sample sites and general information concerning gold grains recovered

Sample No./ Locality	Coordinates	Au% Range	Au% Mean	Ag% Range	Ag% Mean	Hg% Range	Hg% Mean	Cu % Range	Cu % Mean	Sample description
G1 Bilick (n=08)	2°54′24.2″ 11°40′48.6″ 705m	88.78-99.56	97.41	0.06-11.19	2.10	0.14-0.26	0.20	0.03-0.34	0.16	Alluvial samples obtained from a first-tier stream, which is a tributary of the River Sing. Samples were obtained at 0.6m depth from pits. The course of the stream was diverted to allow digging of the pit.
G2 Bilick (n=10)	2°54′17.6″ 11°41′50.6″ 702m	85.42-99.75	93.88	0.27-40.71	6.17	0.08-0.33	0.21	0.03-0.14	0.08	
G3 Zalom (n=18)	2°54'21.6" 11°43'4.8" 707m	73.77-99.29	92.31	0.40-26.39	7.62	0.06-0.36	0.19	0.01-0.19	0.08	
G4 Gatan (n=30)	2°54′17.5″ 11°42′59.3″ 718m	50.45-99.59	89.76	0.31-48.36	13.14	0.06-0.83	0.20	0.00-0.28	0.06	Alluvial samples obtained from a first-tier stream which is also a tributary of the River Bivele. Samples were obtained at 0.6m depth from pits. The course of the stream was diverted to allow digging of the pit.
G5 Gatan (n=12)	2°54′59.8″ 11°42′59.9″ 698 m	87.93-99.44	95.32	0.39-11.74	4.58	0.13-0.29	0.22	0.02-0.19	0.10	
G6 Gatan (n=09)	2°54′56.6″ 11°42′32.0″ 706m	74.77 99.68	94.03	0.29 24.85	5.87	0.15 0.30	0.23	0.00 0.27	0.10	
G7 Gatan (n=04)	2°55′02.2″ 11°42′59.4″ 725m	73.60-98.38	90.91	0.63-27.34	9.24	0.11-0.23	0.17	0.00-0.10	0.05	Alluvial samples from a mine pit dug in a valley. The wetland is within the catchment of River Bivele.
G8 Nkolmedoum (n=09)	2° 54' 22.3" 11° 42' 31.2" 712m	81.71-97.41	90.51	4.43-19.96	10.68	0.09-0.32	0.19	0.00-0.09	0.04	Eluvial sample taken from exposed soil profile. This area is also drained by River Sing.
G9 Nkolmedoum (n=25)	2° 54' 22.7" 11° 42' 27.0" 712m	56.79-98.51	92.96	0.85-42.53	6.50	0.07-0.26	0.18	0.01-0.14	0.08	Eluvial gold grains from a slope in Nkolmedoum area. This area is downslope from the Nkolmedoum swamp
G10 Nkolmedoum (n=99)	2° 54' 25.2" 11°42'25.2" 712m	52.87-99.32	90.52	0.14-47.24	9.16	0.05-0.37	0.20	0.00-0.27	0.08	Alluvial gold grain from the swamp of River Sing.
Total (221)										

n = Number of grains

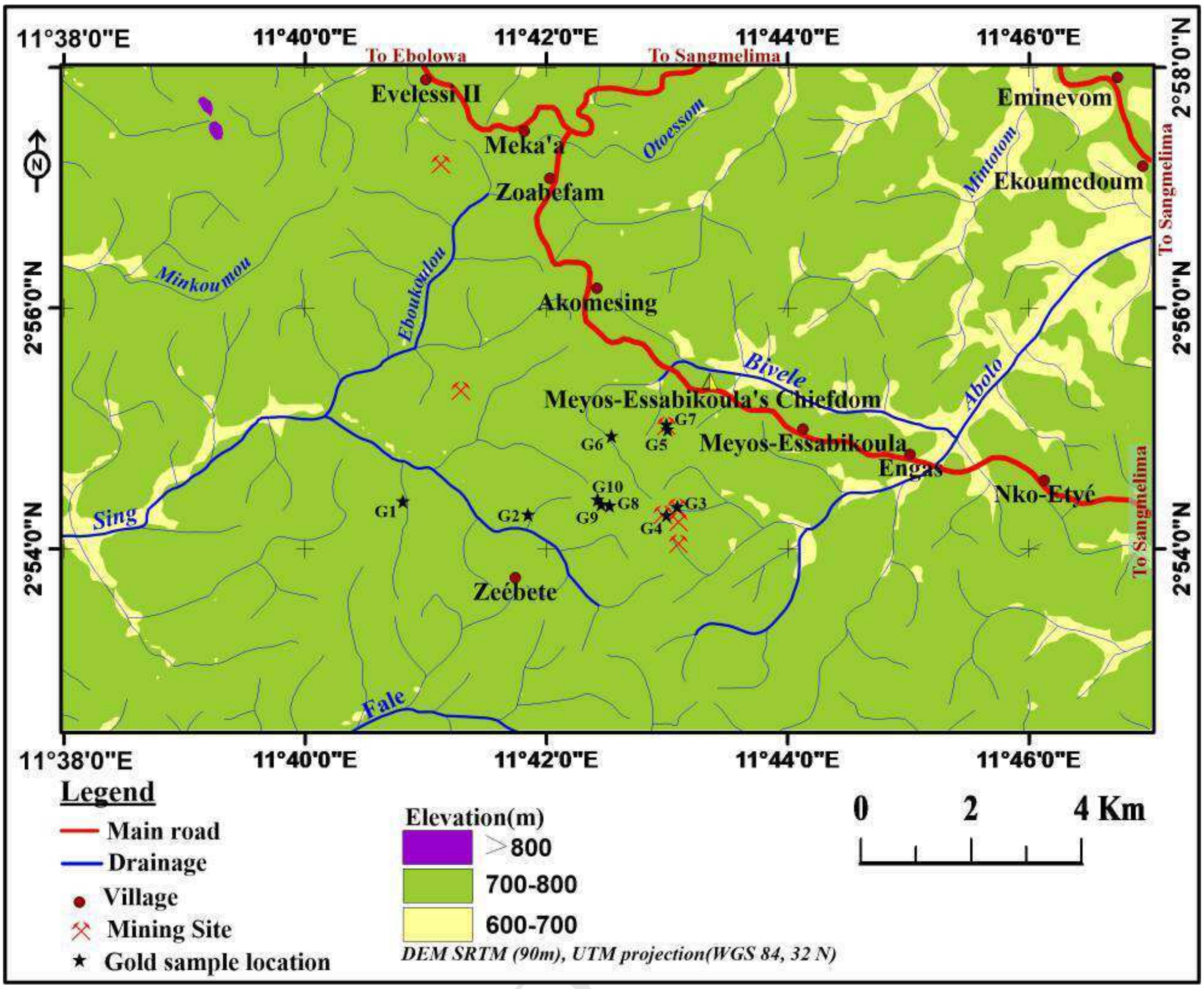


Figure: 5: Sample location in relation to the tributaries of the Sing and Bivele Rivers

G1, G2: Bilick ; G3 : Zalom; G4, G5,G6,G7: Gatan; G8,G9,G10: Nkolmedoum

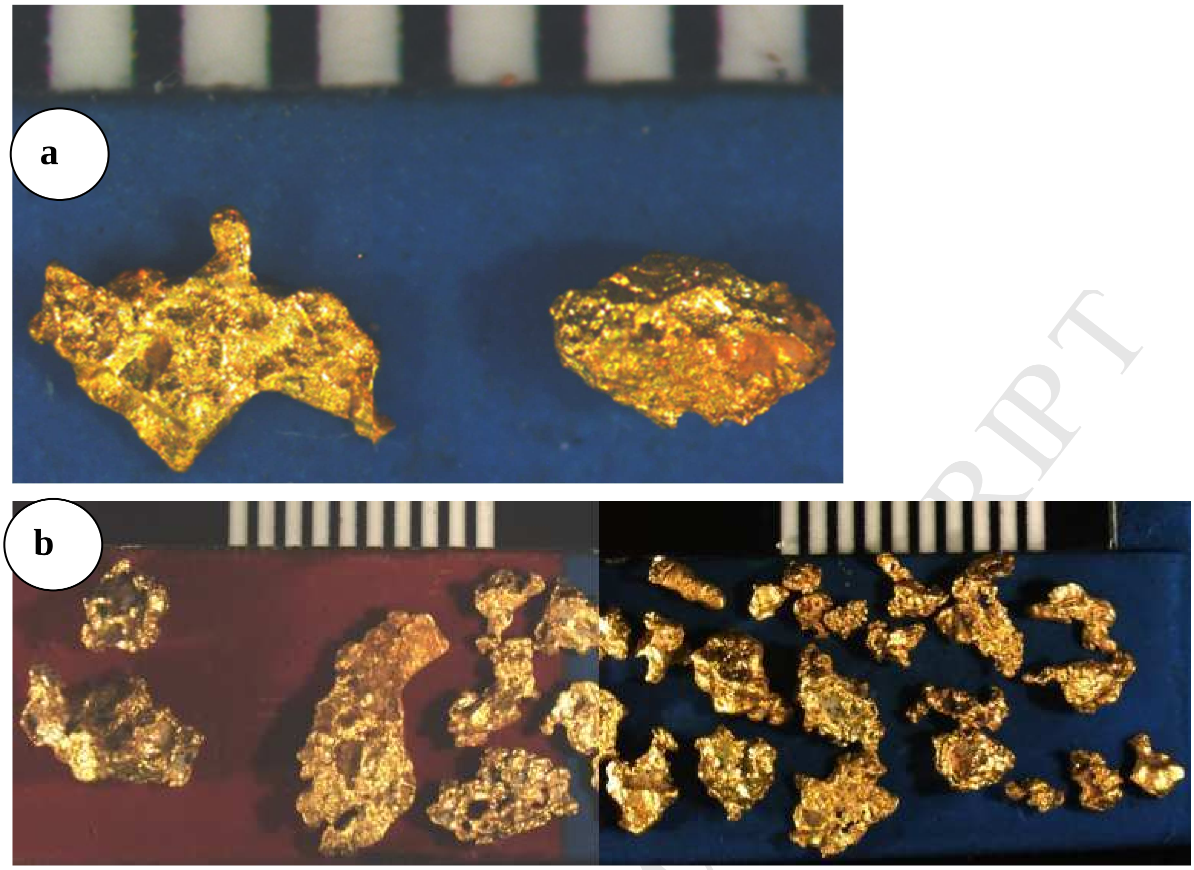


Fig.6 (a and b): Group 1- Angular eluvial gold grains (Samples G8, G9, and G10). Scale bar is in mm.

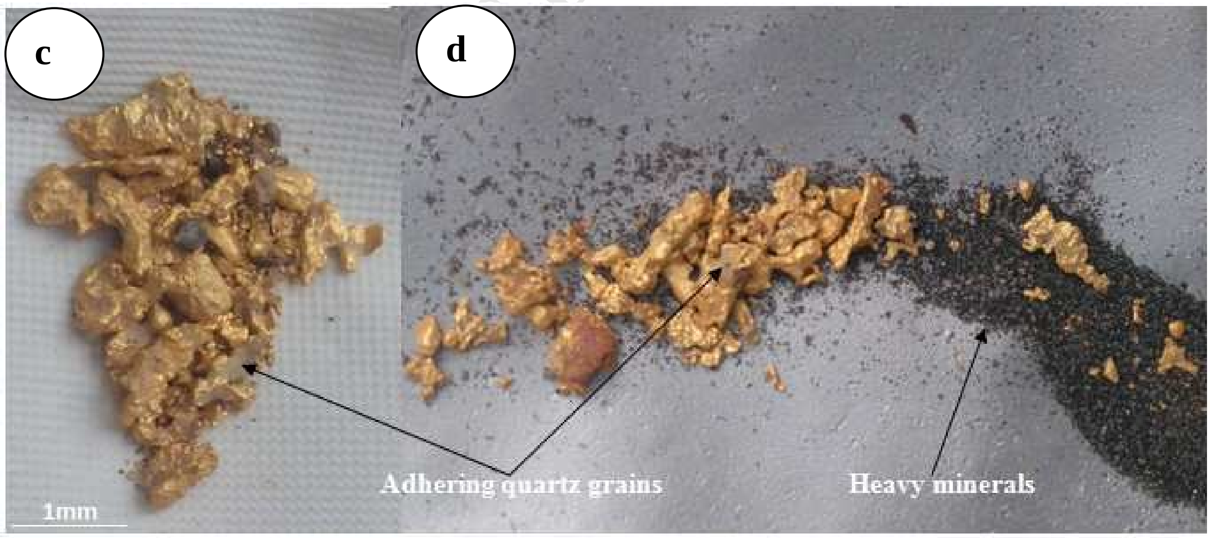


Fig.6 (c and d): Gold grains recovered from G8 and G9 localities captured immediately after panning showing adhering quartz grains and associated heavy minerals.

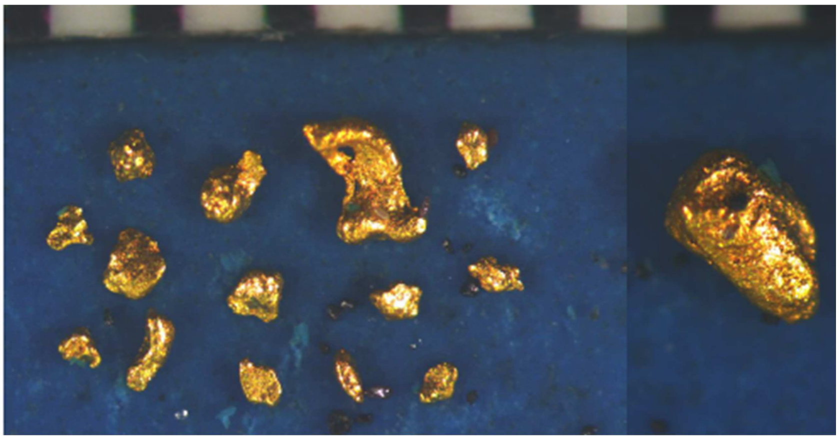


Fig.7: Group 2- rounded to elongate alluvial gold grains from Nkolmedoum. The general outline of these grains is regular and surface topography tends to be smooth (Scale bar in mm).

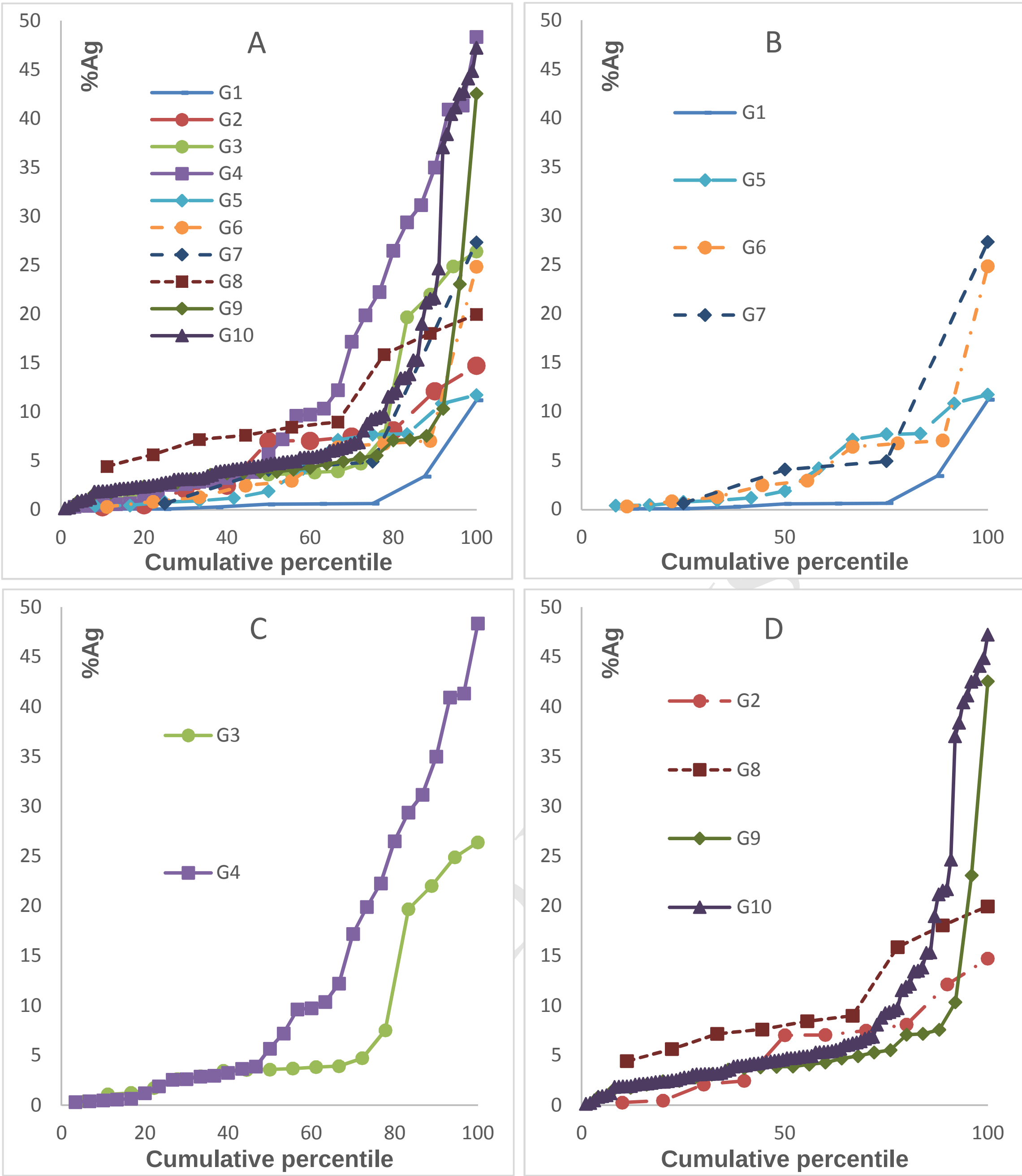


Fig. 8: Silver content of populations of gold grains from the study area: (A) comparison of signatures from all populations studied;(B): Comparison of signatures from adjacent placer localities, plus G1;(C): Comparison of the signatures of gold from adjacent placer localities G3 and G4;(D): comparison of silver contents of eluvial populations G8 and G9 with the adjacent placer population (G10) and a more distal placer sample (G2).

Table 2: Summary of the microchemical signature of all gold grains in which inclusions were identified

SAMPLE	Inclusion assemblage (Opaque)	Nonopaque	Au Wt%	Ag Wt%	Cu Wt%	TOTAL
G1	Fe oxide		88.70	11.10	0.04	99.98
G3		Ca- amphibole	98.04	1.73	0.11	99.99
G3	Ilmenite		96.10	3.56	0.05	99.94
G4	Fe oxide		96.62	2.87	0.05	99.75
G4	Fe oxide		89.64	10.20	0.07	100.00
G6		Tremolite	97.30	2.34	0.10	99.99
G7		Calcium carbonate	95.70	4.08	0.07	99.99
G8	Fe oxide +Cr		90.79	8.89	0.05	99.99
G8		Ca,Mg,Fe carbonate	93.12	6.62	0.05	100.00
G9		Olivine. Clinopyroxene	97.80	1.64	0.14	99.80
G9	Fe oxide + Cr. Fe oxide		95.07	3.80	0.08	99.11
G9	Fe oxide + Cr. Fe oxide		96.93	2.45	0.10	99.60
G9	Fe oxide + Cr + V, ilmenite		92.10	7.56	0.04	99.89
G9		K spar	56.79	42.53	0.01	99.40
G9		FeMg carbonate	94.95	4.68	0.05	99.86
G10	Fe oxide, silica		97.46	2.24	0.13	99.97
G10	Fe oxide		94.07	5.57	0.06	99.84
G10	Fe oxide		77.78	21.68	0.00	99.63
G10		Clinopyroxene	86.47	13.40	0.02	100.00
G10	Fe oxide + Cr		96.22	3.16	0.10	99.72
G10	Fe oxide + Cr		78.18	21.55	0.00	99.91
G10	Fe oxide		99.32	0.22	0.11	99.89
G10	Chalcopyrite/Silver sulphide (trace Cu)		90.65	8.79	0.08	99.75
G10	Fe oxide		88.00	11.55	0.02	99.82
G10		Ca carbonate	97.08	2.66	0.09	100.00
G10	Fe oxide + Cr+V		93.59	5.31	0.07	99.21
G10	Fe oxide + Cr		87.71	11.90	0.02	99.79
G10	Pyrrhotite		96.42	2.80	0.09	99.48
G10		Biotite	96.65	3.14	0.08	100.00
G10	Ilmenite		97.60	2.10	0.16	100.00

4.2.3 Copper (Cu)

Majority of the gold grains contain Cu, which can be used with Au alloy in conjunction with the associated Ag to identify discrete compositional fields (Chapman *et al.* 2017b). Fig. 9 shows the general inverse relationship between Ag and Cu for the whole population of gold grains. This feature appears to be generic (Moles *et al.* 2013, Chapman *et al*, 2017b) and it appears that the Cu content is largely controlled by the Ag content of the Au alloy. Thus, in the majority of cases, Cu in Au-Ag alloy may not be a useful discriminator. Nevertheless, figure 9 suggests that there are three main compositional fields, namely high >0.15 wt % Cu, low Ag, low 0-0.15 wt % Cu and low 0-10 wt% Ag, and low Cu < 0.2 wt % and high Ag >10 wt %.

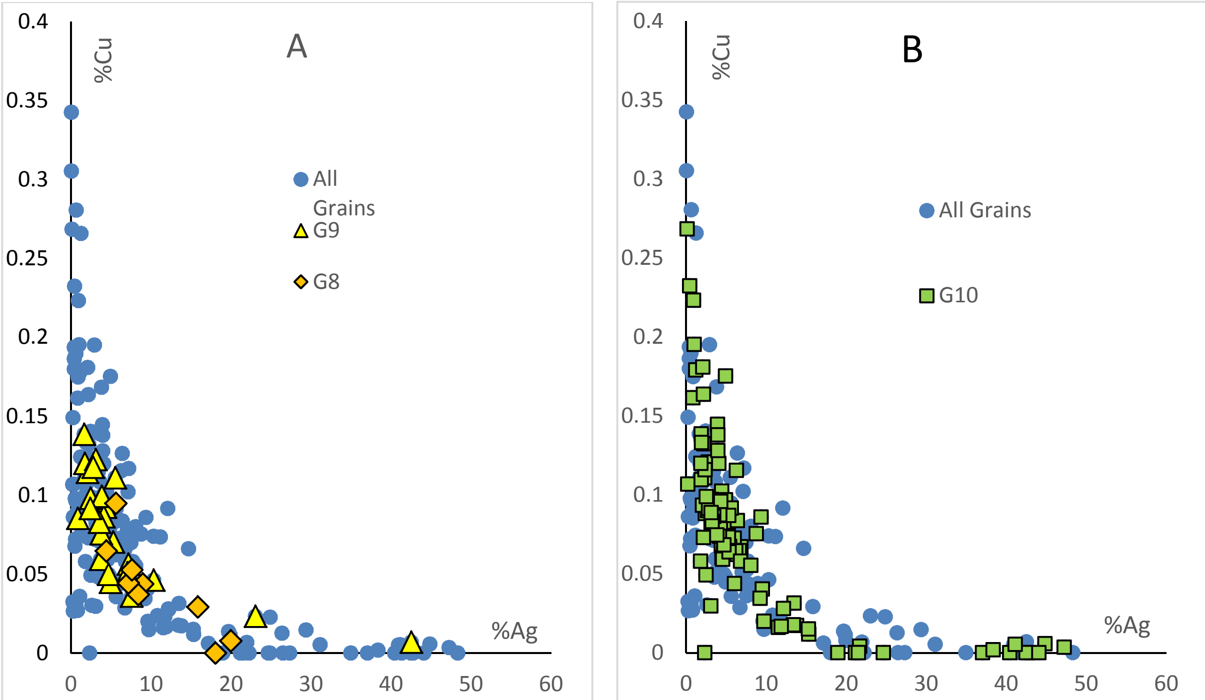


Fig. 9: Eluvial environments conform to the high Cu field, but a small number do occur within the high Ag field. A similar approach to the gold grains from the adjacent placer sample (G10) has been undertaken in Figure 9B, but here the full range of compositions is represented.

4.2.4. The inclusion assemblage

Inclusions were generally between 10 and 20 µm in cross-section to a maximum of 50 µm. These inclusions occur either as simple minerals or comprise complex intimate associations of several phases that are described in Table 2. The number of inclusions recorded in the 221 grains was very low, however, it is clear that iron oxide ± Cr and V is the most important single inclusion specie. Chalcopyrite, pyrrhotite, and acanthite were also observed. Mineral inclusion characteristics observed are presented in Figs. 10 and 11.

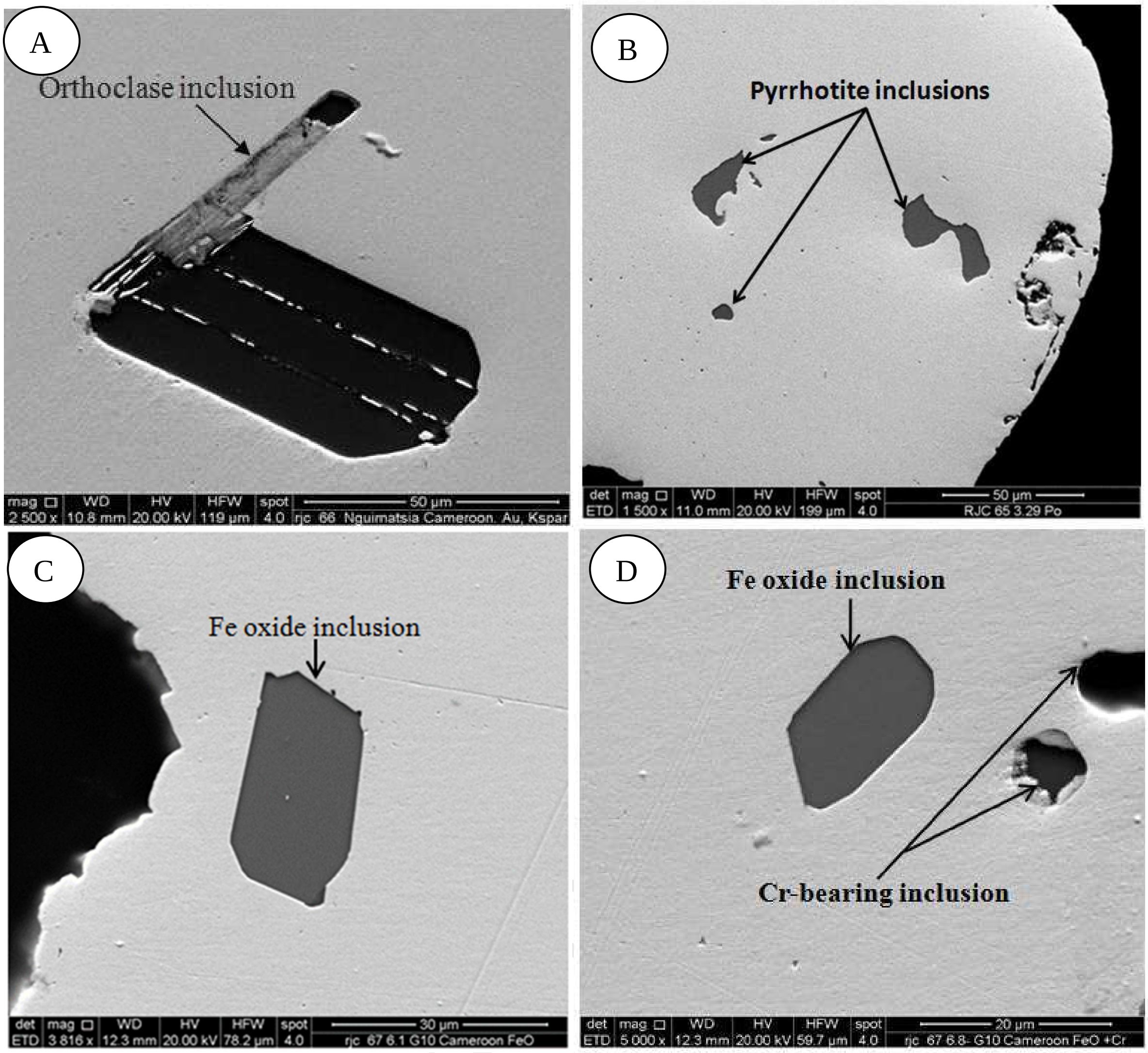


Fig.10: Back-Scattered Electron (BSE) images of typical inclusions in placer gold grains. (A) Orthoclase inclusion in-filled by Au alloy in gold grain. (B) Pyrrhotite in detrital grain.(C) Typical Fe oxide inclusion in eluvial gold grain. (D) Representative Fe oxide containing about 5% of chromium (Cr)

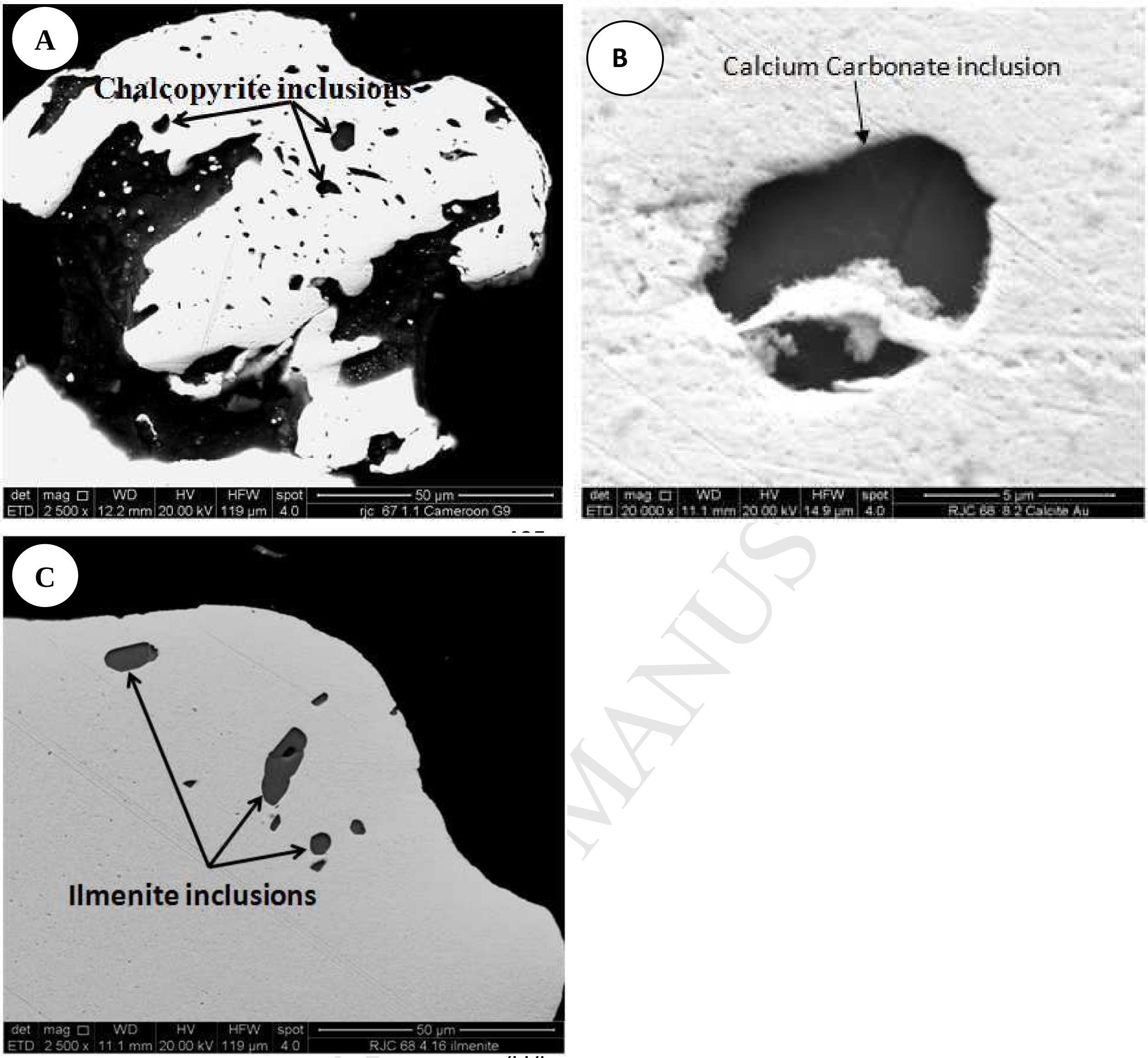


Fig.11: Back-scattered Electron (BSE) images of some silicate, carbonate and oxide inclusions of placer gold grains. (A) Chalcopyrite inclusions in gold grain. (B) Calcium carbonate inclusion in gold grain from site G7. The calcium carbonate grain is bridged by secondary Au which postdates it. (C) Ilmenite inclusions in gold grain from site G4.

5. Discussion

5.1. Interpretation of Gold morphology

Eluvial gold from Nkolmedoum (G8 and G9) exhibits a fragile crystalline form and pristine faces bearing the imprint of quartz crystals and/or magnetite, which together provides evidence of very limited transport and therefore a restricted local source. The in-situ source of these gold particles remains unknown; however, a secondary origin may be discounted because of the inclusion suite, which contains chalcopyrite, pyrrhotite, and acanthite.

5.2 Interpretation of the Gold Microchemical Signature

Figures 8 and 9 show that there is no single signature which defines all the individual samples. As the gold composition is a proxy for the conditions of precipitation within a hydrothermal regime (Gammons and Williams-Jones 1995), it is concluded that there are different sources of gold in the study area. In this scenario, the eluvial samples are more likely to represent individual gold occurrences and hence show a tighter compositional range. This is consistent with the variation in both Ag and Cu depicted in Figures 8D and 9B.

The spatial relationships between samples show relationships consistent with their localities. The placer sample from Nkolmedoum (G10) shows characteristics compatible with both local eluvial samples (G8 and G9). The adjacent placer samples of G3 and G4 show the same two ranges of Ag contents, but in different proportions, suggesting differing contributions from the same two source signatures. Similarly, samples G5, G6, and G7 show a consistent Ag range notwithstanding the small sample sizes. Sample G1 is geographically distinct but even so may share the low Ag signature with some grains from the nearest locality of G2. Overall the evidence from alloy signatures suggests that there are multiple sources, which individually may exhibit a restricted Ag range in the regional sample set.

From the perspective of exploration, it would be highly beneficial to develop an overarching deposit model, and commonly the inclusion assemblages provide the best source of information in this regard. In the majority of studies such as this, the inclusion suite of 'ore minerals' such as sulfides, sulfarsenides and tellurides provide discriminants whereby a signature may be established. In the present study, insufficient sulfide inclusions were observed to apply this approach, and characterization has relied mainly on interpreting the significance of oxide, carbonates and silicate inclusion species. Figure 12 shows the Ag compositions of gold grains which host different types of silicate, oxide and carbonate inclusions. Low inclusion abundance precludes the identification of clear compositional fields, but there is no clear correlation between inclusion species and Ag content, except that inclusions may be scarce in higher Ag gold alloy.

Magnetite inclusion within gold showed a range of Cr and V in the 0-c 5% range, as measured by semi quantitative analysis by EDS. These concentrations are far higher than those recorded in hydrothermal magnetite from several ore deposit types (Nadoll et al. 2014). These authors report the highest values of a few thousand ppm in magnetite from magmatic hydrothermal systems, but these values are up to an order of magnitude lower than those recorded in the present study. Nadoll et al. (2014) note that incorporation of V in the magnetite lattice increases with both temperature and decreasing fO_2, and a reducing environment is consistent with the observation of a pyrrhotite inclusion in another gold grain. These authors also note that some of the highest Cr and V values in magnetite in magmatic hydrothermal systems were a consequence of fluid- wall rock interaction.

The presence of amphibole minerals within the gold grains is challenging to interpret in the absence of the petrology of the hypogene ore. The presence of these minerals suggests a relationship with amphibolites, but the mechanism of their incorporation into particulate gold remains unclear.

The presence of calcite and ankeritic dolomite inclusions is compatible with interaction of a CO_2 – rich fluid with mafic lithologies. Additionally the presence of a quartz inclusion indicates a mineralizing fluid not in equilibrium with an amphibolite. In summary, substantially evidence of the gold mineralization suggests mineralizing fluids in equilibrium with amphibolite (likely reducing) and that this interaction accounts for the mineralogy and geochemistry of the inclusion suite within the gold. Some of the gold appears to have been deposited by mineralizing fluids in equilibrium with felsic rocks (hence the quartz and K-feldspar inclusions) and oxidizing (hence carbonate inclusions). It also seems likely that the fluids were relatively hot and reducing, promoting high Cr and V substitution in magnetite.

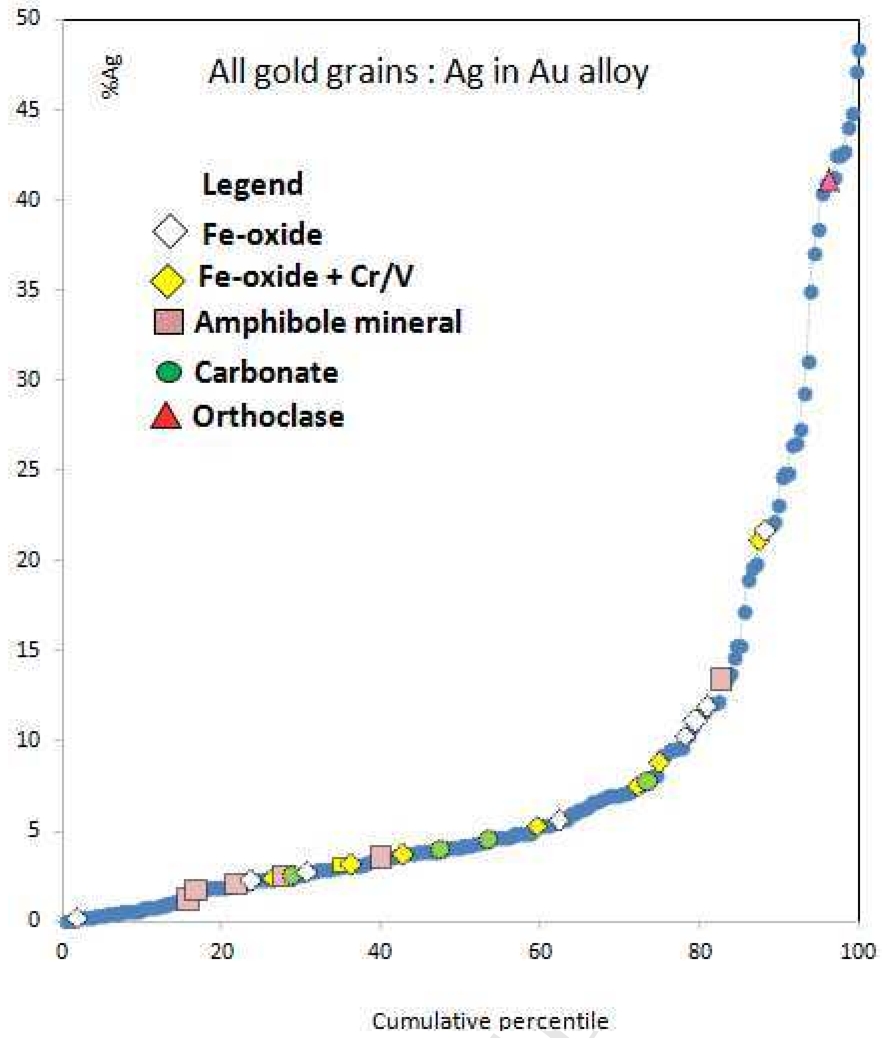


Figure 12: Relationship between inclusion species and host alloy.

5.3 Comparison of gold signature with those associated with other styles of mineralization

The gold signature recorded in this study is distinct from those reported for other styles of mineralization globally. The available evidence suggests that hot reducing fluids interacted with amphibolites to generate the inclusion signature observed here. This mechanism would explain major differences between the signatures of the gold studied here and those recorded in gold from other mineralizing systems globally. An overview of gold microchemical signatures from different deposit styles was provided by Chapman et al. (2009). Gold from Phanerozoicorogenicsettings typically exhibits an inclusion signature of sulfides± sulfarsenides ±sulfosalts, whereas gold from Archaen orogenic mineralization often yielded a

Bi-Te association. Subsequent detailed studies of gold from other Phanerozoic orogenic gold areas in the Canadian Cordillera have reinforced this compositional template, (Chapman et al 2010a,b, 2016). Gold from magmatic hydrothermal system has proved to be compositionally distinct, as calc alkaline porphyries and associated epithermal systems in Yukon showed a generic Bi-Pb-Te-S association in the inclusion assemblage (Chapman et al 2017b) whereas gold from alkalic porphyry systemsin British Columbia were identifiable through their Hg-Pd inclusionsignature (Chapman et al. 2017a).

Finally, various studies have suggested a mechanism of gold growth in tropical environments, (e.g Bowell et al. 1993) however the nature of the mineral inclusions recorded in this study demonstrate that the gold grains are detrital in origin and preserve hypogene mineralogy as inclusions.

6. Conclusions

Studies of eluvial and placer gold grains from the Meyos-Essabikoula area within the Precambrian basement complex of Southern Cameroon have constrained the nature of the hypogene sources, which remain undiscovered. Morphologically, placer gold grains show a wide variety of shapes, but the fragile crystalline form and pristine faces on most eluvial grains provides evidence of very limited transport and therefore a restricted local source. Subtle differences in the Ag contents of populations of gold grains supports a hypothesis of multiple sources, which are represented to varying degrees in the placer populations according to their spatial relationship with different drainages. Although the in-situ sources of these gold particles remains unknown, a secondary origin may be discounted because of the mineralogy of the inclusion suite.

Overall the gold alloy composition is predominantly a binary Au-Ag alloy with minor contribution from Cu.

The alloy composition alone is not particularly diagnostic of a specific source style or host lithology, however Fe-oxide inclusions, sometimes containing Cr and V, are relatively common and suggest that the ore fluids interacted with local amphibolite, a hypothesis consistent with the presence of carbonate inclusions. Interpretation of the V and Cr content of magnetite suggest that these fluids were reducing and relatively hot.

This study has provided a platform for further exploration to investigate the significance of the gold- amphibolite association suggested here. The project outcomes provide a clear example of the benefit of gold grain studies in terranes of poor exposure.

Acknowledgments

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Figures

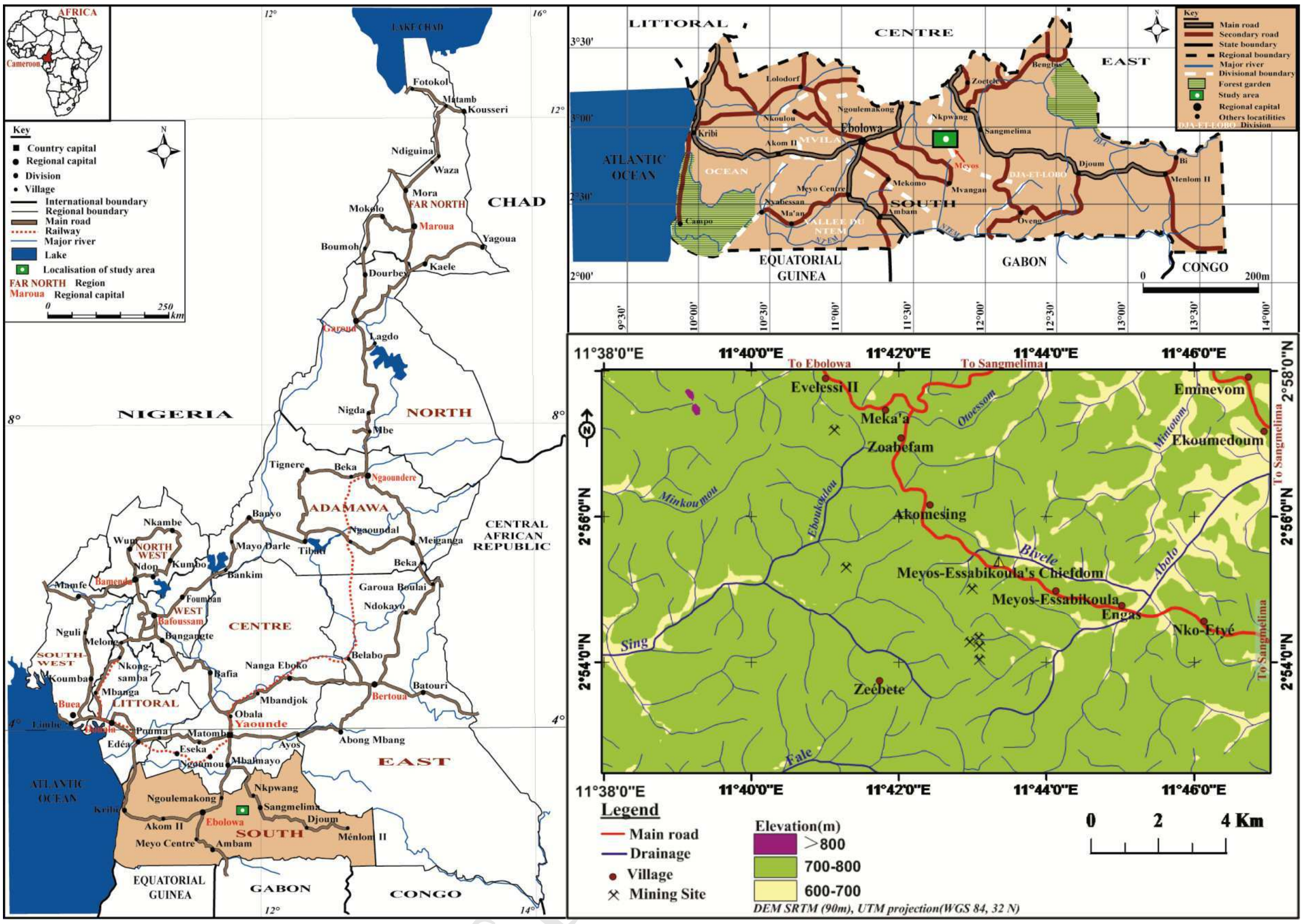
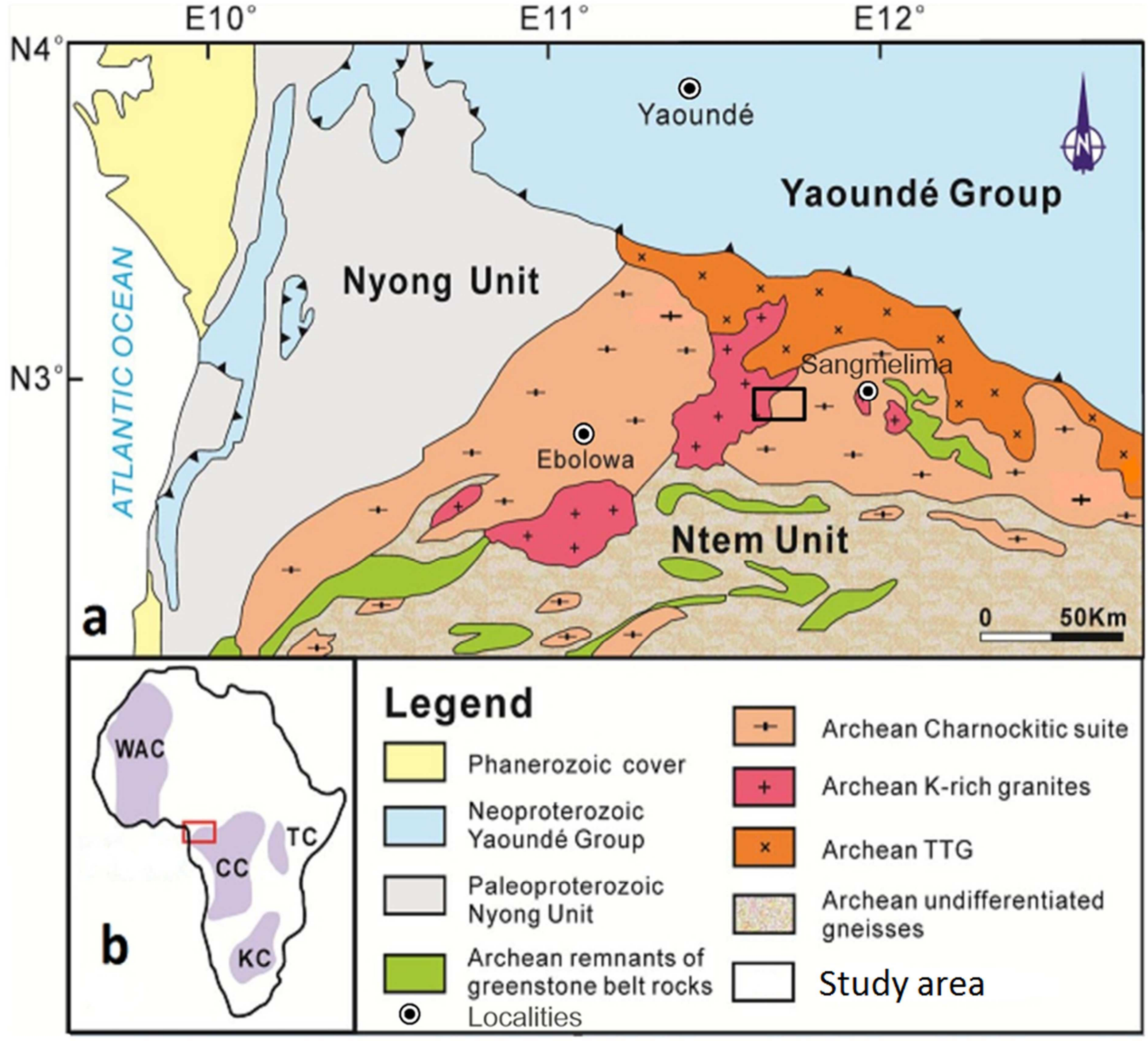


Fig.1: Location map of Meyos Essabikoula showing the road map of Cameroon with an inset of the map of Africa (top left), the road map of the South Region of Cameroon (top right) and the road map of Meyos Essabikoula, showing artisanal mining sites.



(Fig.2): a-Geological sketch map of southwestern Cameroon (modified after Maurizot *et al*., 1986; Tchameni *et al.*, 2010); b- showing the major Precambrian units and WAC: West African Craton; CC: Congo Craton; TC: Tanzanian Craton; KC: Kapvaal Craton.) (In Li *et al.*, 2016).

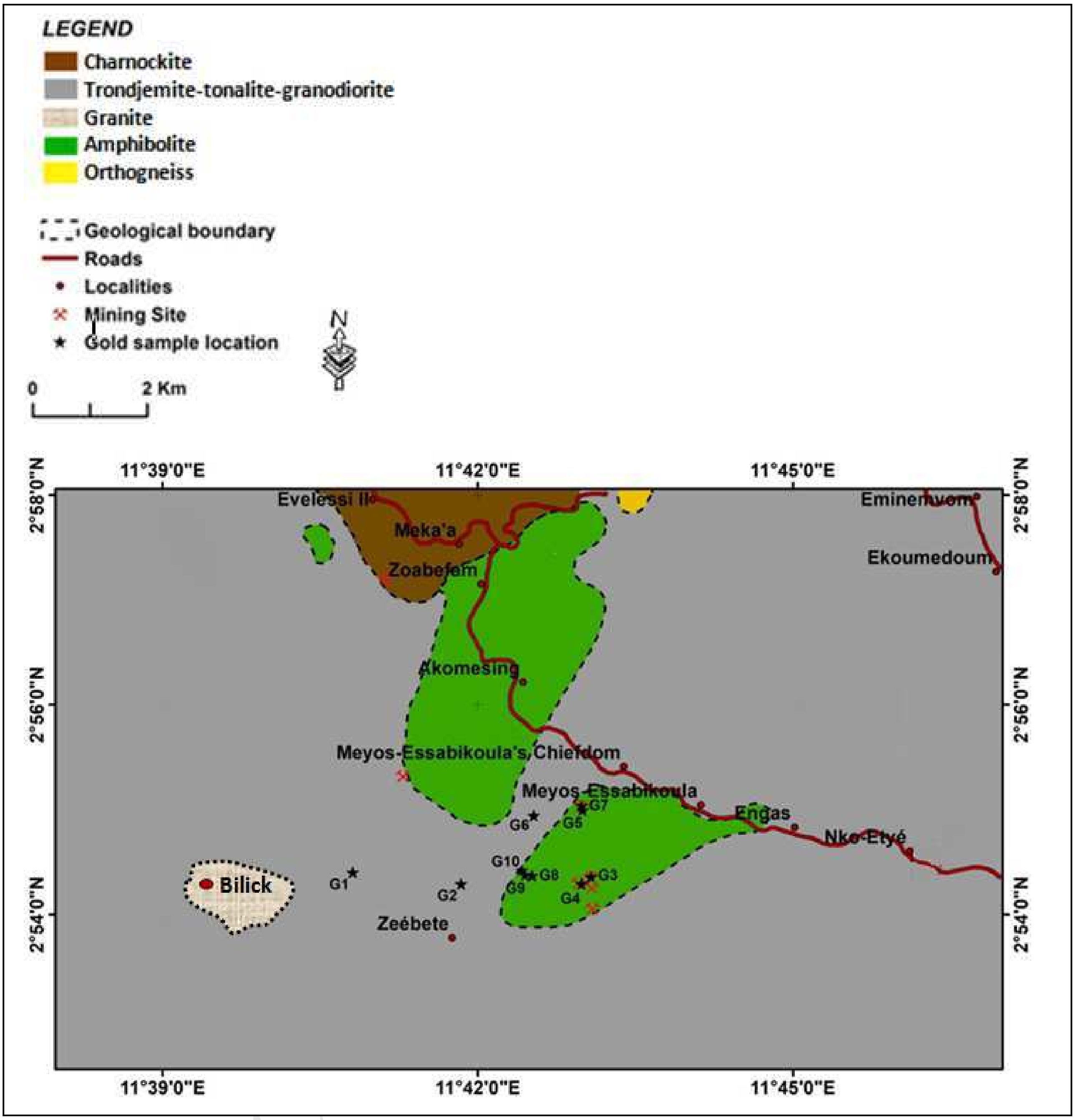


Fig.3: Sketch geological map of study area, showing the distribution of rock out crops and placer gold occurrences.

Fig.4: (A) methodology of collection of gold grains. (B) Example of an excavated pit at Gatan locality.

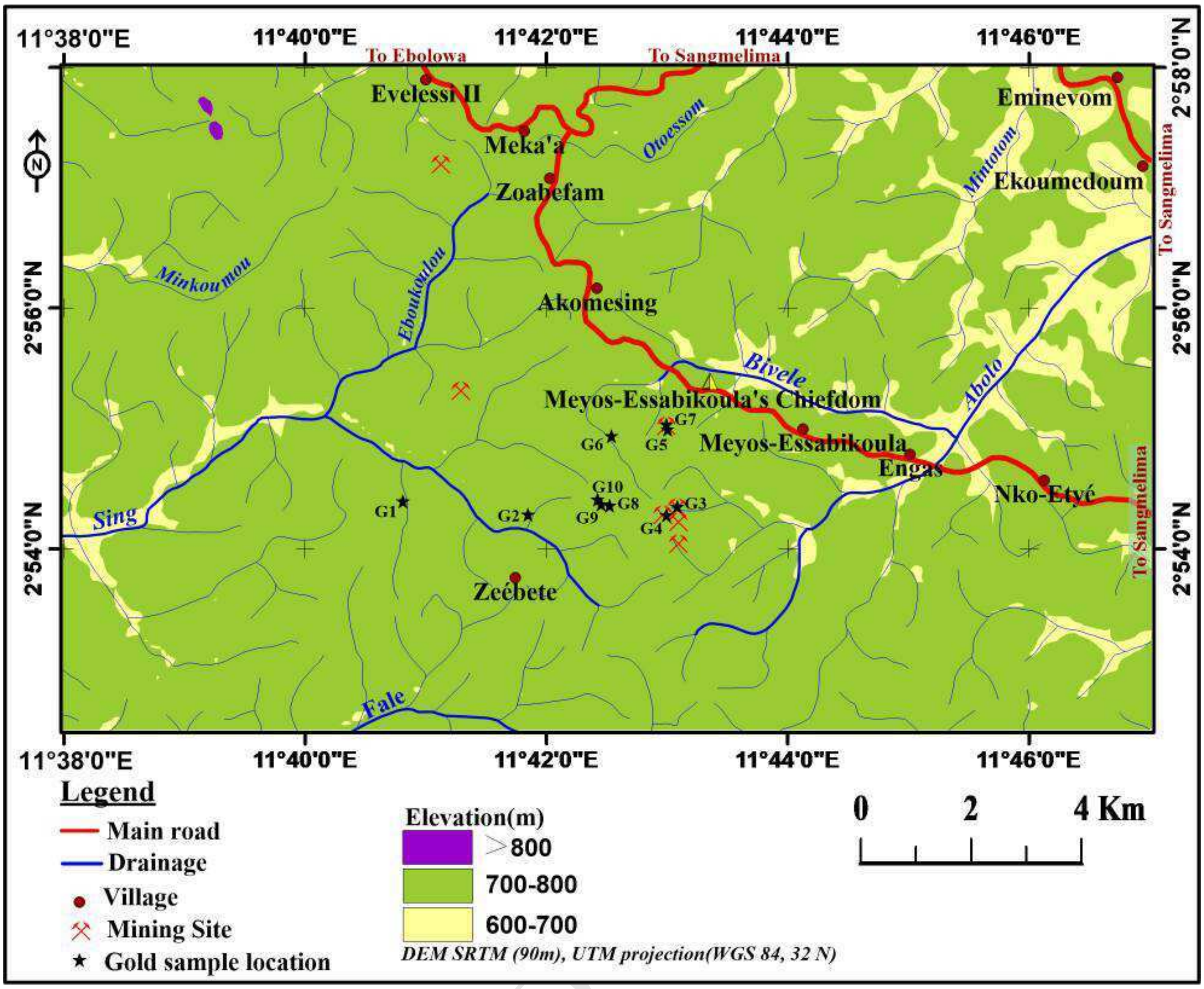


Figure: 5: Sample location in relation to the tributaries of the Sing and Bivele Rivers

G1, G2: Bilick ; G3 : Zalom; G4, G5,G6,G7: Gatan; G8,G9,G10: Nkolmedoum

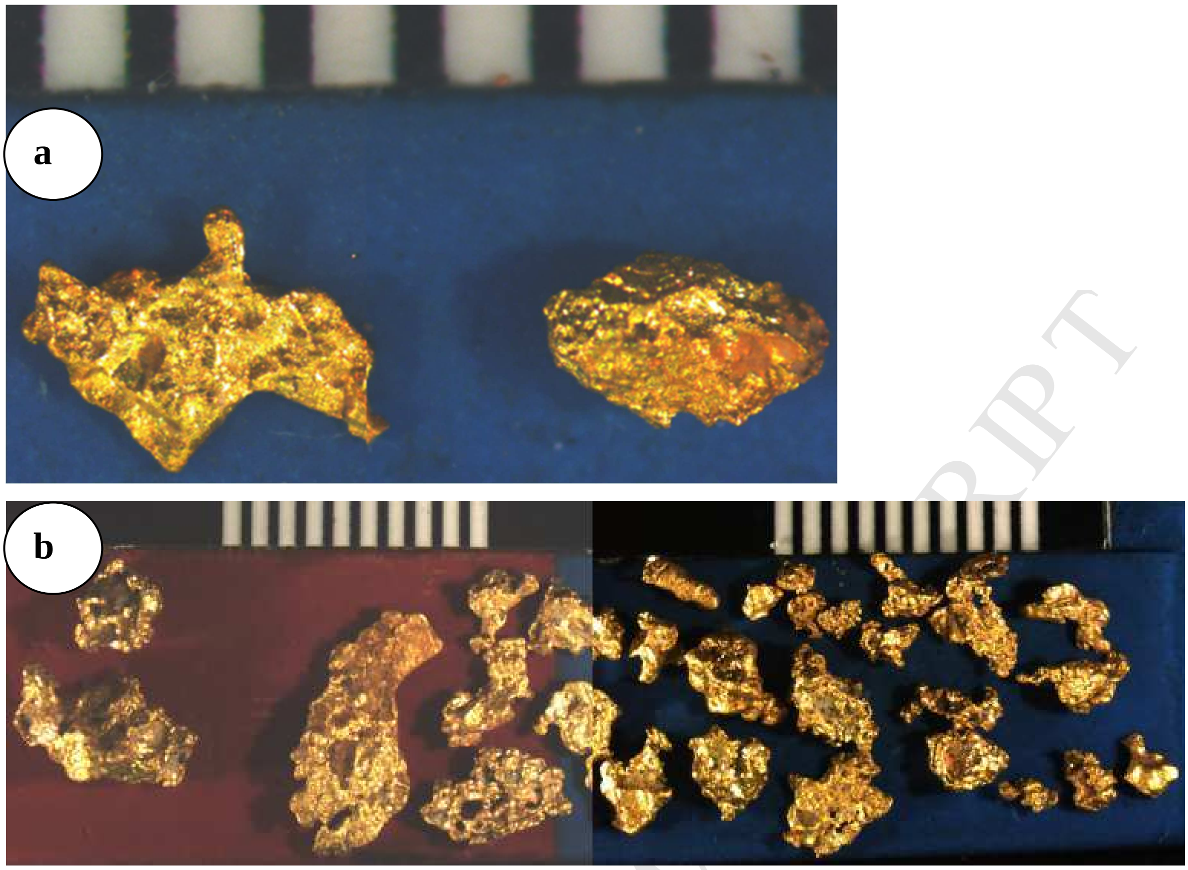


Fig.6a: Angular Gold grains defined as Group 1.Scale bar is in mm. Sample from Nkolmedoum locality.

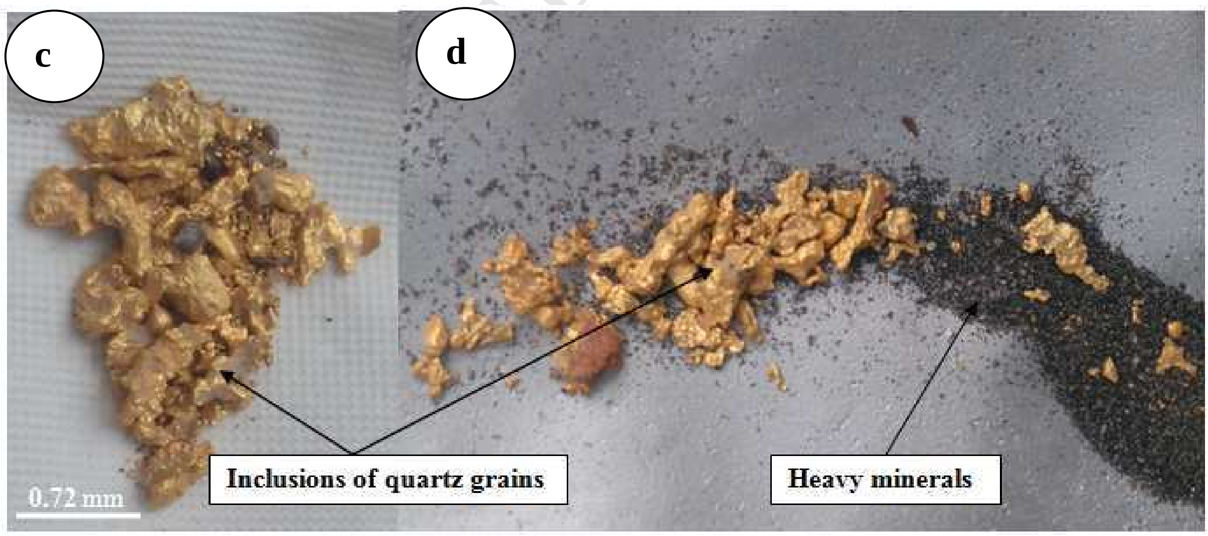


Fig.6 (c and d): Gold grains recovered from G8 and G9 localities captured immediately after panning showing adhering quartz grains and associated heavy minerals.

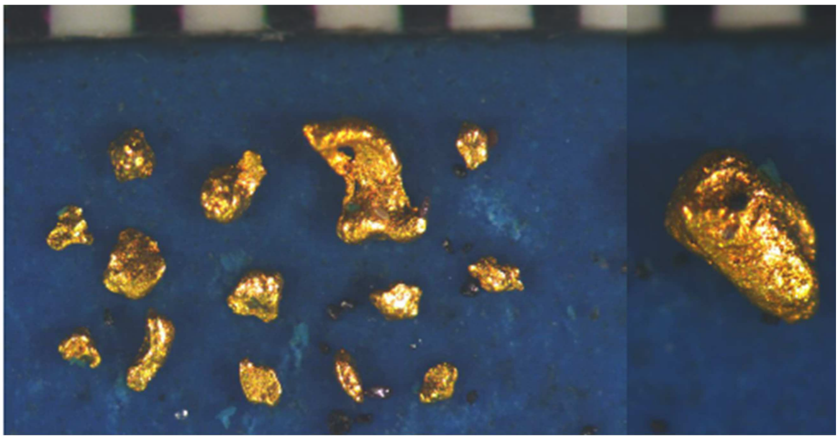


Fig.7: Group 2- rounded to elongate alluvial gold grains from Nkolmedoum. The general outline of these grains is regular and surface topography tends to be smooth (Scale bar in mm).

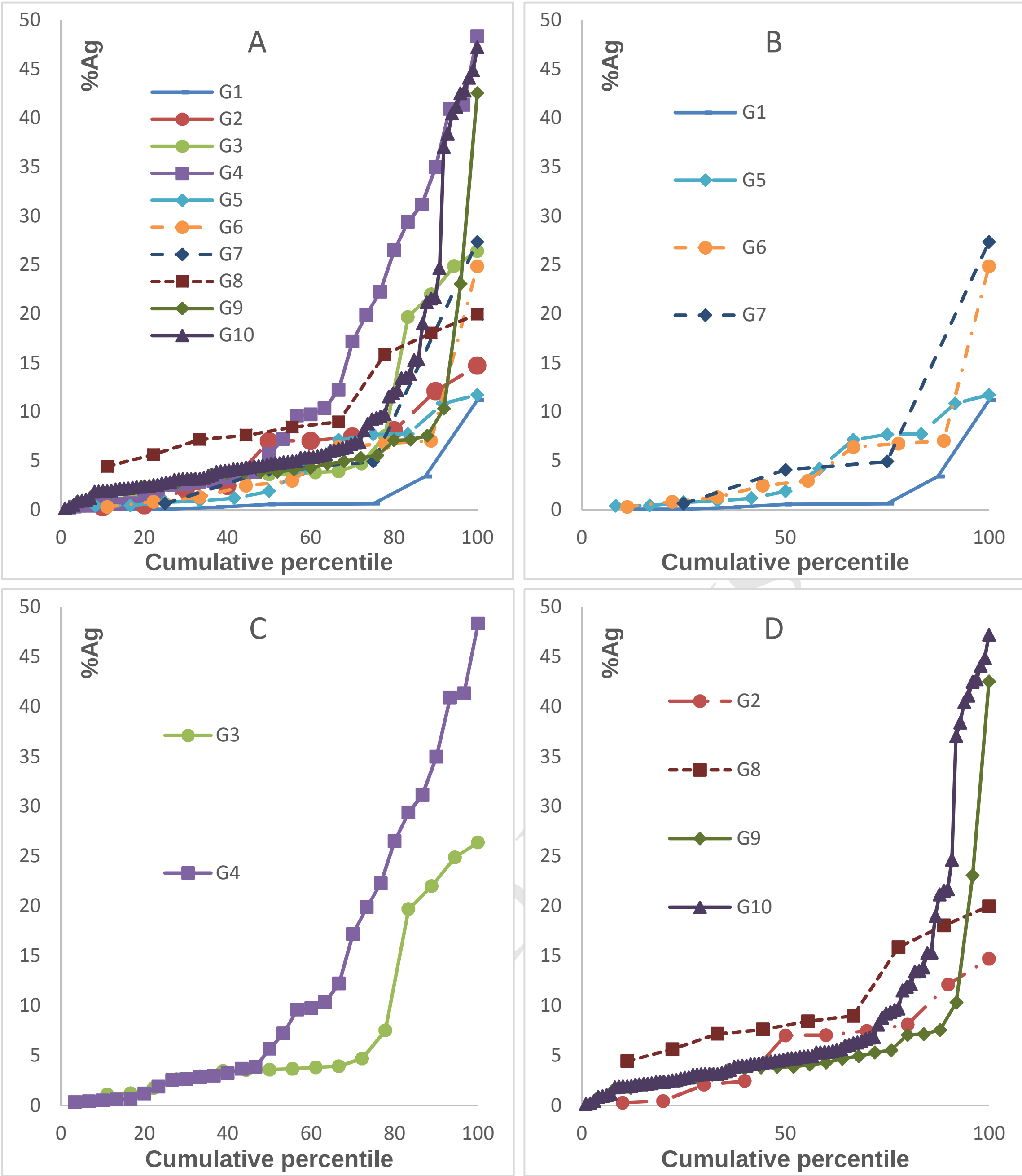


Fig. 8: Silver content of populations of gold grains from the study area: (A) comparison of signatures from all populations studied;(B): Comparison of signatures from adjacent placer localities, plus G1;(C): Comparison of the signatures of gold from adjacent placer localities G3 and G4;(D): comparison of silver contents of eluvial populations G8 and G9 with the adjacent placer population (G10) and a more distal placer sample (G2).

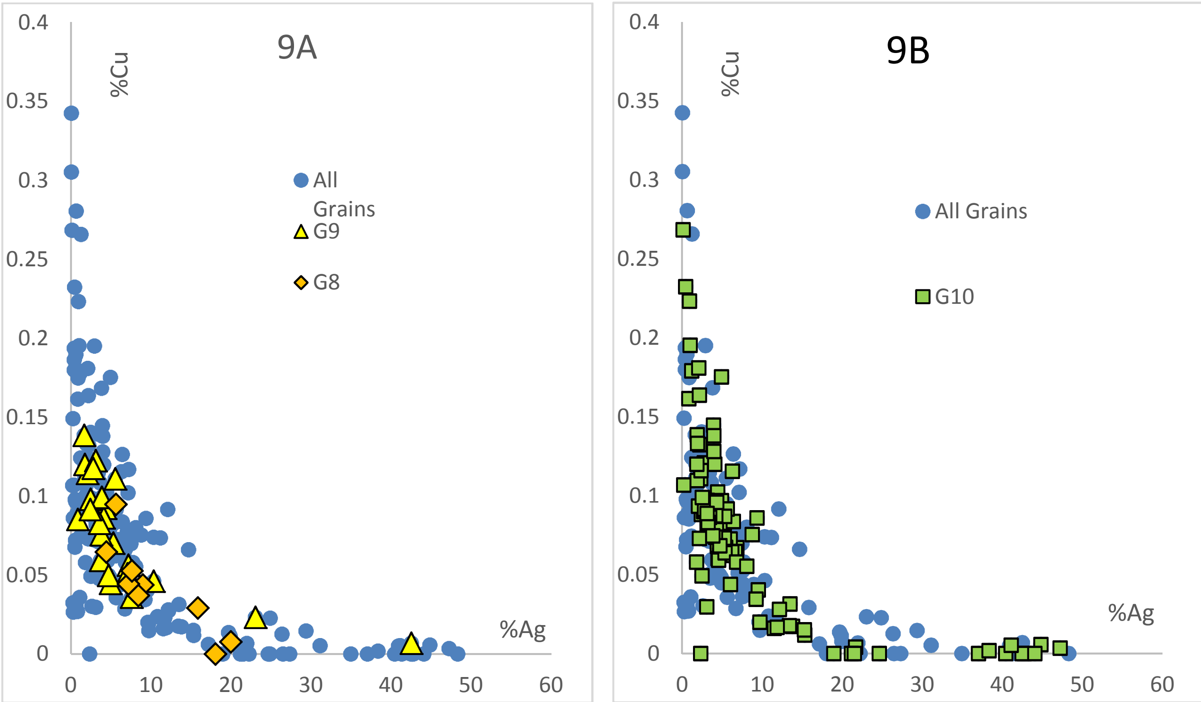
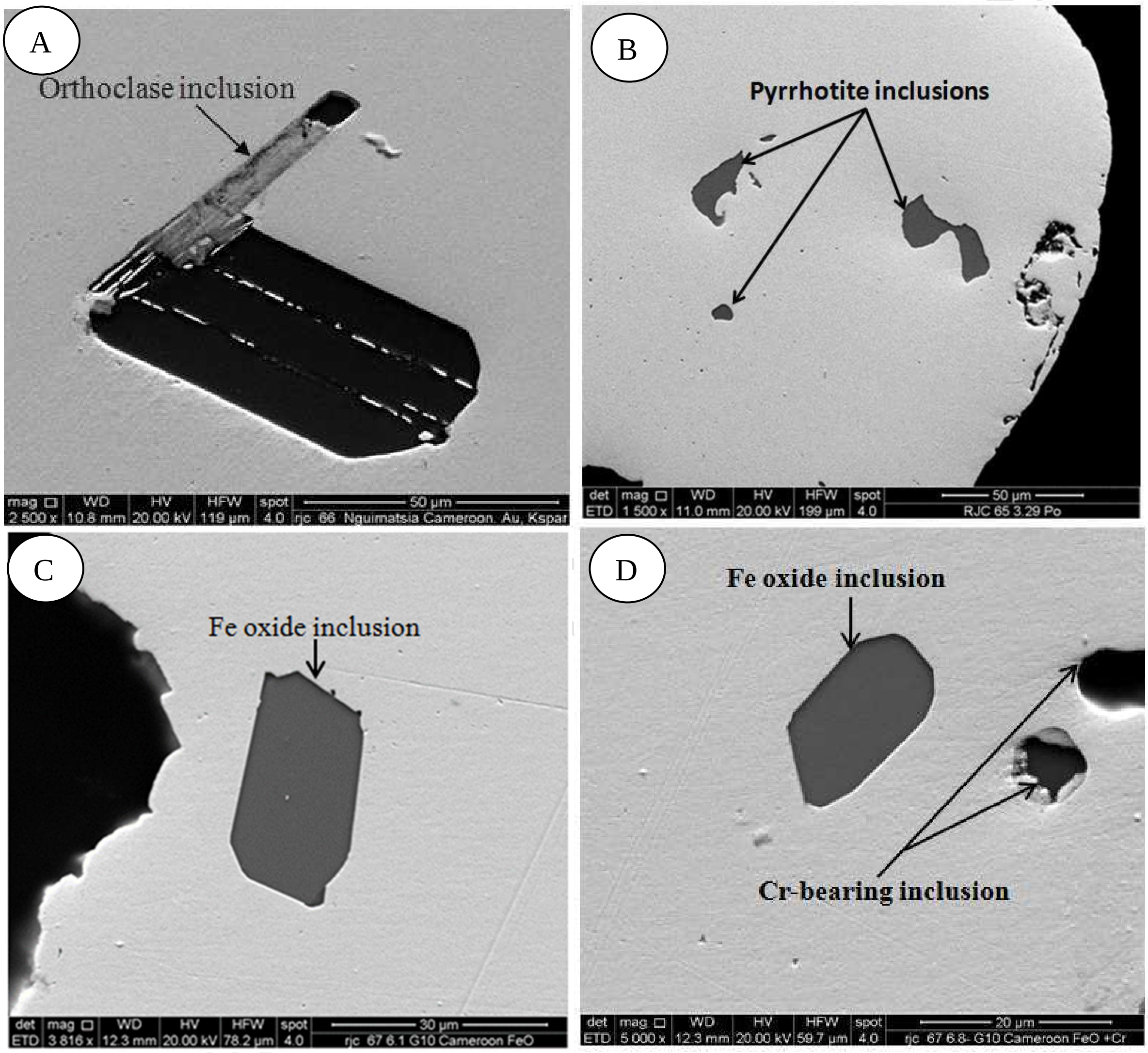


Fig. 9: eluvial environments conform to the high Cu field, but a small number do occur within the high Ag field. A similar approach to the gold grains from the adjacent placer sample (G10) has been undertaken in Figure 9B, but here the full range of compositions is represented.



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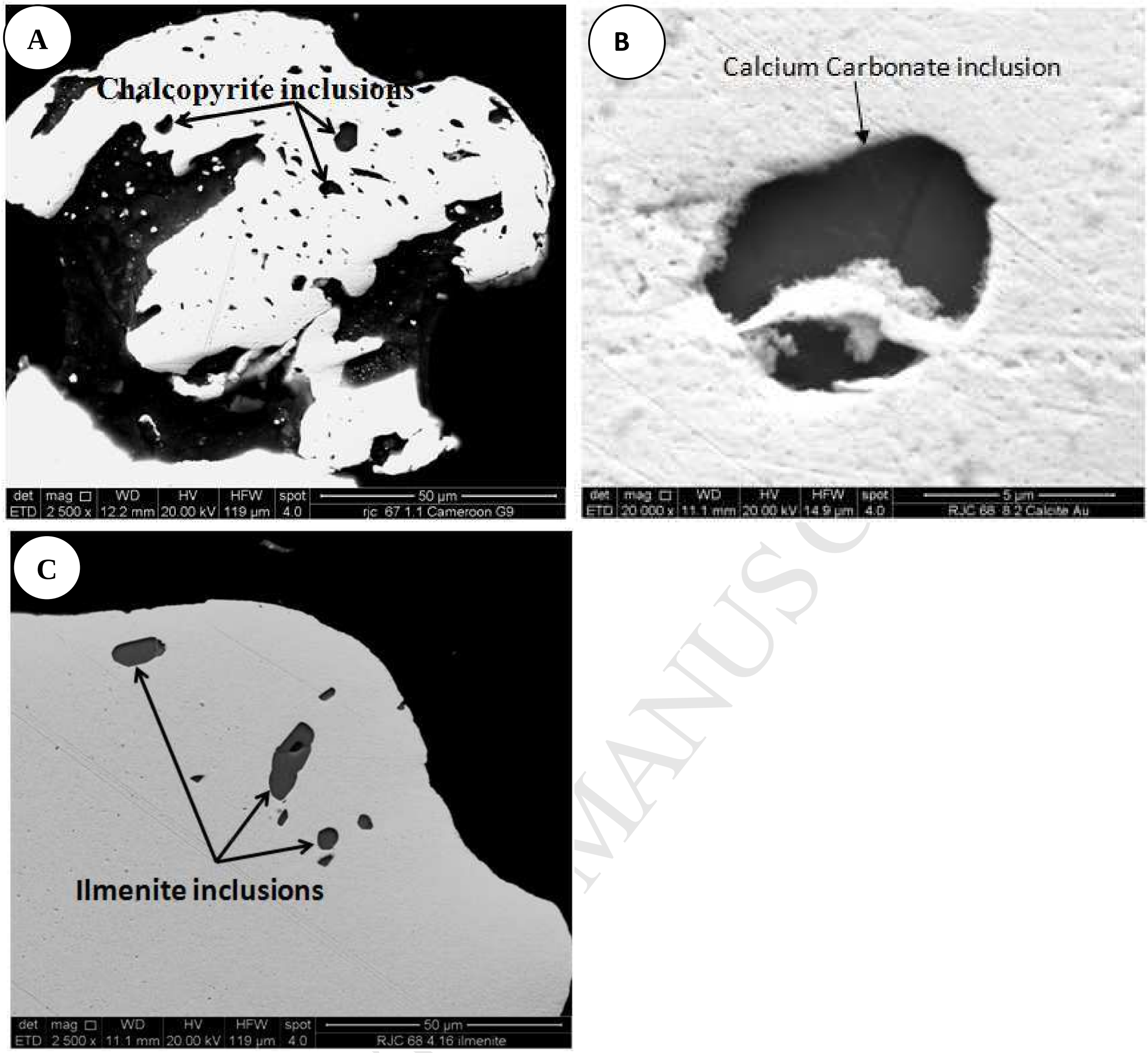

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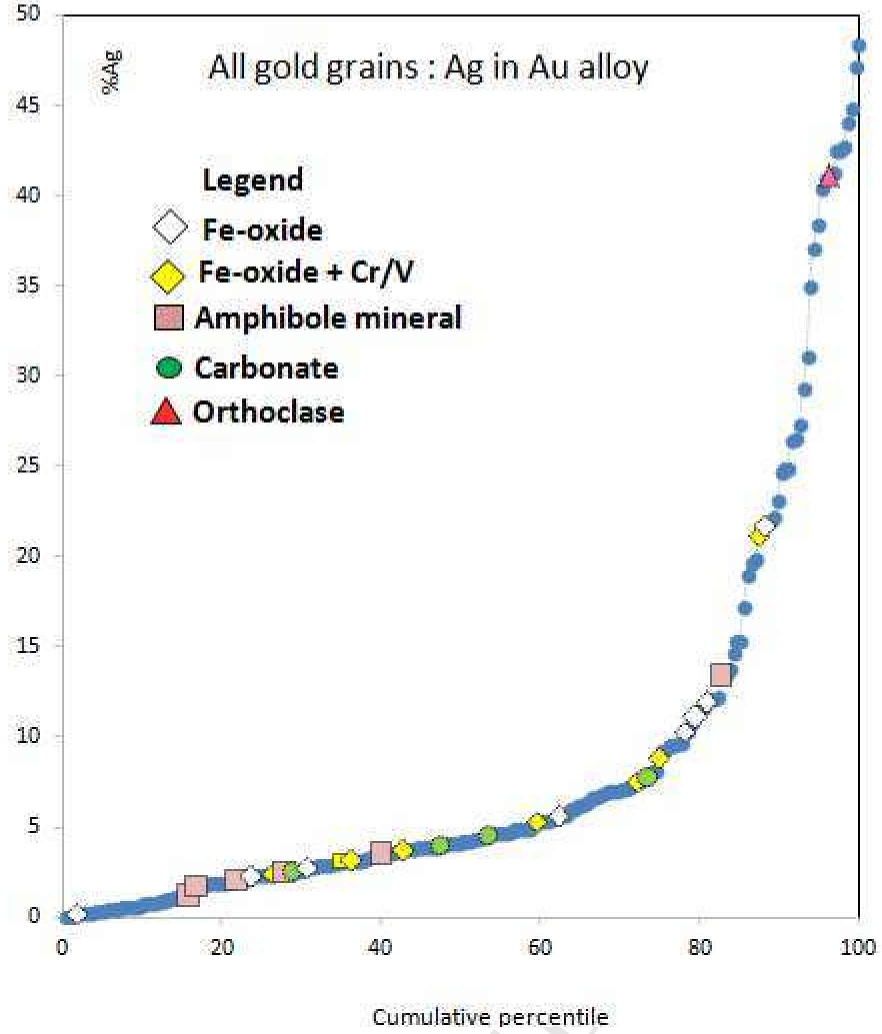

Figure 12: Relationship between inclusion species and host alloy.

Highlights

Morphologically, placer gold grains show a wide variety of shapes, but the fragile crystalline form and pristine faces on most eluvial grains provides evidence of very limited transport and therefore a restricted local source.

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The gold alloy composition is predominantly a binary Au-Ag alloy with minor contributions from Cu. Magnetite inclusions, sometimes containing Cr and V, are common and suggest a relationship between gold mineralization and local amphibolite.