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Second Projet de Renforcement Institutionnel du Secteur Minier de la République Islamique de Mauritanie (PRISM-II)

Iron Oxide Copper-Gold Deposits in the Islamic Republic of Mauritania:

Phase V, Deliverable 79

By Gregory L. Fernette

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Multiple spellings are used in various literatures, and may be reflected in the text.

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or for stratigraphic nomenclature.

The report is being released in both English and French. In both versions, we use the French-language names for formal stratigraphic units

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Iron Oxide Copper-Gold Deposits in the Islamic Republic of Mauritania

1 Summary

Mauritania hosts one significant copper-gold deposit, Guelb Moghrein and several occurrences, which have been categorized as iron oxide copper-gold (IOCG) deposits but which are atypical in some important respects. Nonetheless, Guelb Moghrein is an economically significant mineral deposit and an attractive exploration target. The deposit is of Archean age and is hosted by a distinctive metacarbonate rock which is part of a greenstone-banded iron formation (BIF) package within a thrust stack in the northern part of the Mauritanide Belt. The surrounding area hosts a number of similar copper-gold occurrences. Based on the characteristics of the Guelb Moghrein deposit and its geologic environment, five tracts which are considered permissive for IOCG type mineralization similar to Guelb Moghrein have been delineated.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
decimeter (dm)	0.32808	foot (ft)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic kilometer (km^3)	0.2399	cubic mile (mi^3)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)
metric ton per day	1.102	ton per day (ton/d)
megagram per day (Mg/d)	1.102	ton per day (ton/d)
metric ton per year	1.102	ton per year (ton/yr)
	Pressure	
kilopascal (kPa)	0.009869	atmosphere, standard (atm)
kilopascal (kPa)	0.01	bar
	Energy	
joule (J)	0.0000002	kilowatthour (kWh)

ppm, parts per million; ppb, parts per billion; Ma, millions of years before present; m.y., millions of years; Ga, billions of years before present; 1 micron or micrometer (μor μm) = 1 × 10^{-6} meters; Tesla (T) = the field intensity generating 1 Newton of force per ampere (A) of current per meter of conductor

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Coordinate information is referenced to the World Geodetic System (WGS 84)

Acronyms

AMT	Audio-magnetotelluric
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BIF	Banded iron formation
BLEG	Bulk leach extractable gold
BGS	British Geological Survey
BRGM	Bureau de Recherches Géologiques et Minières (Mauritania)
BUMIFOM	The Bureau Minier de la France d'Outre-Mer
CAMP	Central Atlantic Magmatic Province
CGIAR-CSI	Consultative Group on International Agricultural Research-Consortium for Spatial Information
DEM	Digital Elevation Model
DMG	Direction des Mines et de la Géologie
EC	Electrical conductivity
EMPA	Electron Microprobe Analysis
EM	Electromagnetic (geophysical survey)
EOS	Earth Observing System
eU	Equivalent uranium
GGISA	General Gold International
GIF	Granular iron formation
GIFOV	Ground instantaneous field of view
GIS	Geographic Information System
HIF	High grade hematitic iron ores
IHS	Intensity/Hue/Saturation
IAEA	International Atomic Energy Agency
IOCG	Iron oxide copper-gold deposit
IP	Induced polarization (geophysical survey)
IRM	Islamic Republic of Mauritania
JICA	Japan International Cooperation Agency
JORC	Joint Ore Reserves Committee (Australasian)
LIP	Large Igneous Province
LOR	Lower limit of reporting
LREE	Light rare-earth element
METI	Ministry of Economy, Trade and Industry (Japan)
MICUMA	Société des Mines de Cuivre de Mauritanie
MORB	Mid-ocean ridge basalt
E-MORB	Enriched mid-ocean ridge basalt
N-MORB	Slightly enriched mid-ocean ridge basalt
T-MORB	Transitional mid-ocean ridge basalt
Moz	Million ounces
MVT	Mississippi Valley-type deposits
NASA	United States National Aeronautics and Space Administration

NLAPS	National Landsat Archive Processing System
OMRG	Mauritanian Office for Geological Research
ONUDI	(UNIDO) United Nations Industrial Development Organization
PRISM	Projet de Renforcement Institutionnel du Secteur Minier
PGE	Platinum-group elements
RC	Reverse circulation drilling
REE	Rare earth element
RGB	Red-green-blue color schema
RTP	Reduced-to-pole
SARL	Société à responsabilité limitée
SEDEX	Sedimentary exhalative deposits
SIMS	Secondary Ionization Mass Spectrometry
SNIM	Société National Industrielle et Minière (Mauritania)
SP	Self potential (geophysical survey)
SRTM	Shuttle Radar Topography Mission
SWIR	Shortwave infrared
TDS	Total dissolved solids
TIMS	Thermal Ionization Mass Spectrometry
TISZ	Tacarat-Inemmaudene Shear Zone
TM	Landsat Thematic Mapper
UN	United Nations
UNDP	United Nations Development Program
US	United States
USA	United States of America
USGS	United States Geological Survey
UTM	Universal Transverse Mercator projection
VHMS	Volcanic-hosted massive sulfide
VisNIR	Visible near-infrared spectroscopy
VLF	Very low frequency (geophysical survey)
VMS	Volcanogenic massive sulfide deposit
WDS	Wavelength-dispersive spectroscopy
WGS	World Geodetic System

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By Gregory L. Fernette[1]

2 Introduction

The Guelb Moghrein copper-gold deposit in Mauritania, which is currently being mined, is considered by many to be an IOCG type deposit (Strickland and Martyn, 2001, Gunn and others, 2004, Murakami, 2004, Murakami and others 2005, Kolb and others, 2006, 2008, Meyer and others, 2006, Cox and Singer, 2007 Sakellaris and Meyer, 2008, Hitzman, 2008, Kirschbaum and Hitzman, 2008, Kirschbaum, 2011a, b). IOCG deposits can be economically significant, with some deposits (for example Olympic Dam in Australia) having copper resources that exceed many porphyry copper deposits (Williams and others, 2005). Because of the economic significance of IOCG deposits their simple presence in a country can attract exploration interest.

IOCG deposits are a diverse group of mineral deposits recognized relatively recently that are characterized by the association of iron oxide minerals with copper and possibly gold as economic metals (Hitzman and others, 1992). Recent discussions and classifications of IOCG deposits include Williams and others (2005), Cox and Singer (2007) and Groves and others (2010).

Williams and others (2005) characterized IOCG deposits as those that included: (1) copper with or without gold as economic minerals; (2) hydrothermal vein, breccia and (or) replacement styles of mineralization, characteristically in specific structural sites; (3) abundant magnetite and (or) hematite; (4) iron oxides with low titanium contents compared to most igneous rocks, and; (5) absence of clear spatial associations with intrusive rocks. Groves and others (2010) argued that the classification of Williams and others (2005) was too broad and suggested a more restrictive characterization, "IOCG sensu stricto" which included the following: (1) copper plus gold as economic metals; (2) hydrothermal characteristics and structural controls, commonly with breccias; (3) abundant low titanium (Ti) iron oxide minerals

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(magnetite and hematite) and (or) iron silicates (grunerite, iron (Fe) actinolite, fayalite); (4) Light Rare Earth Element (LREE) enrichment and low sulfur-bearing sulfide minerals, including chalcopyrite-bornite-chalcocite-and pyrrhotite; (5) lack of abundant syn-sulfide quartz veins, and; (6) a temporal relationship with magmatism but no close spatial relationship with causative intrusives.

3 Potential IOCG Deposits and Occurrences in Mauritania

3.1 Guelb Moghrein Copper-Gold Deposit

The Guelb Moghrein deposit is located in western Mauritania in the Akjoujt area, which is also referred to as the Inchiri District by Gunn and others (2004). Ancient copper workings were noted by the French military in 1931 and sampled by the Bureau Minier in 1946 (Blanchot, 1947). Attempts to mine the deposit started in the 1950s and continued until the early 1990s when General Gold International succeeded in recovering 156,000 ounces of gold from mine tailings between 1993 and 1996 (Gunn and others, 2004). First Quantum Minerals Ltd. acquired a majority interest in the deposit in 2004 and started commercial production in 2006 (First Quantum Minerals Ltd., 2012a). Mine production in 2011 was 3,610,000 tonnes of ore at an average grade of 1.4 percent copper with an additional 35,281 ounces of produced gold (First Quantum Minerals Ltd., 2012b). Total proved and probable reserves as of December 31, 2011 were 32,060,000 tonnes at 1.09 percent copper and 0.79 grams per tonne (g/t) gold. Measured and indicated resources were 30,940,000 tonnes of sulfide mineralization at 1.18 percent copper and 0.77 g/t gold and 120,000 tonnes of oxide mineralization at 1.58 percent copper and 1.30 g/t gold. (First Quantum Minerals Ltd., 2012b).

The Guelb Moghrein deposit occurs within the northern Mauritanide Belt (fig. 1). The Mauritanide Belt is a polyorogenic domain comprising an east verging fold-thrust belt extending along the west margin of the West African Craton from Senegal to the Western Sahara which was thrust onto the West African Craton in the late Paleozoic (Variscian) (Villeneuve, 2008). The Mauritanide Belt consists of an imbricated collage of Neoproterozoic to Lower Paleozoic rocks with local tectonic inliers and thrust slices of Archean to Paleoproterozoic basement (Pitfield and others, 2004). It records a poly-phase tectonothermal evolution consisting mainly of two 'Pan African' (Late Proterozoic and Ordovician-Silurian) as well as Hercynian (late Paleozoic) orogenic events (Clauer and others, 1989, Dallmeyer and Lécorché, 1989, 1990a, 1990b, Dallmeyer and Villeneuve, 1987, Lécorché and others, 1989).

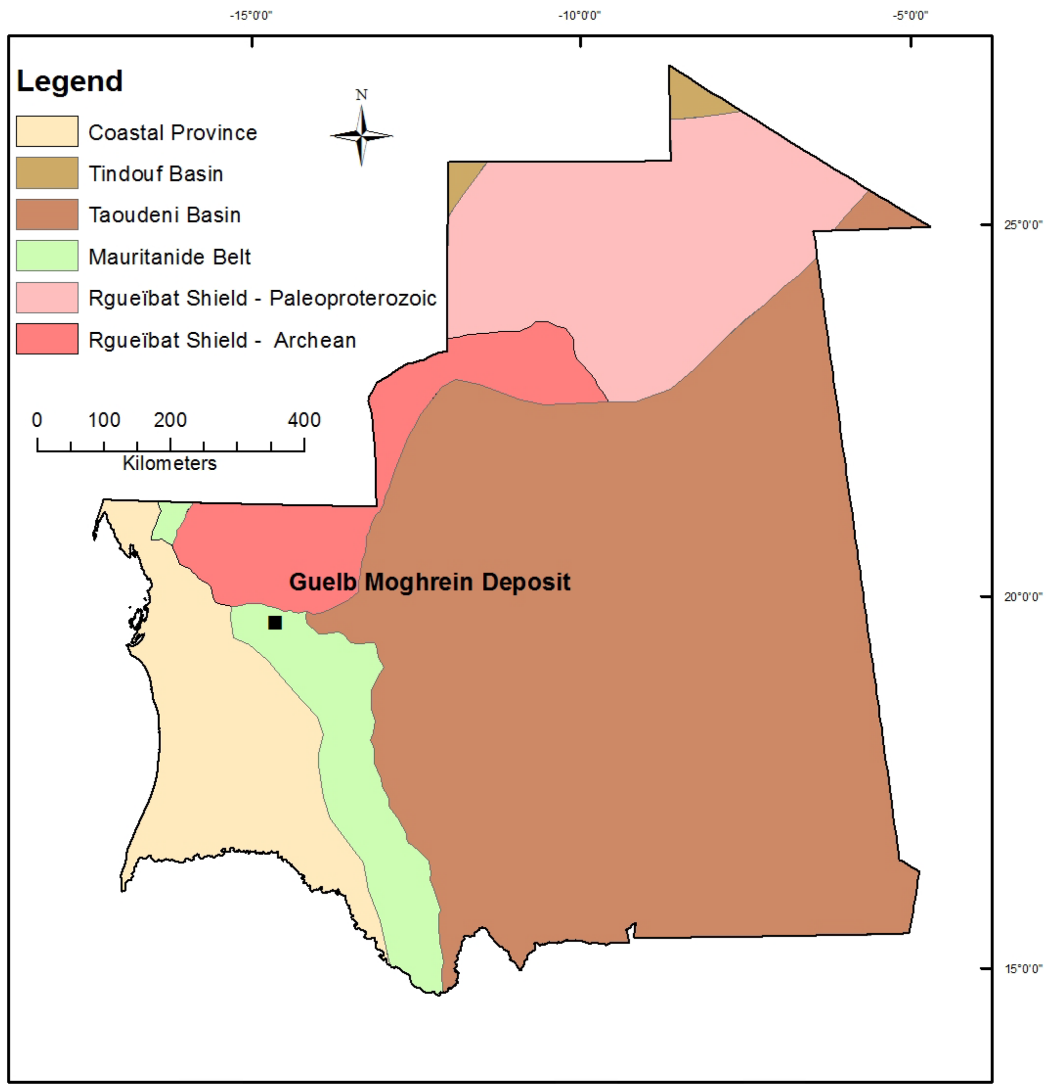

Figure 1. Location and geologic setting of the Guelb Moghrein copper-gold deposit Mauritania.

The geology of the Mauritanide Belt varies somewhat between the north and south in Mauritania. The northern and northwestern Mauritanides extend from Western Sahara to the Akjoujt area in Mauritania. In this area supracrustal nappes are thrust to the east and northeast onto the Archean Tasiast-Tijirit terrane (Maurin and others, 1997, Pitfield and others, 2004). In the Akjoujt area the belt has a western inflection, placing it into contact with the Rgueïbat Shield where the frontal units of the thrust stack within the Mauritanide Belt are thrust onto the Archean basement and the foreland of the Taoudeni Basin (Pitfield and others, 2004).

The south-central Mauritanides, which extend from central Mauritania southward to Senegal, consist of a north-south trending pile of thrust slices of allochthonous and parautochthonous units juxtaposed against the Paleozoic rocks of the Taoudeni basin (Le Page, 1988). Within the belt are four parallel north-south trending zones separated by east-directed thrusts comprising, from east to west, an imbricated ophiolite, a continental margin-rift facies association, an eastern calc-alkaline igneous complex and a western calc-alkaline igneous complex (Pitfield and others, 2004, Lahondère and others, 2003, 2004, 2005, Caby and Kienast, 2009).

Dallmeyer and Lécorché (1989, 1990a, b) obtained $^{40}Ar/^{39}Ar$ ages on metamorphic minerals throughout the central and southern Mauritanide Belt and concluded that region had been affected by three orogenic events in Neoproterozoic, Cambrian and Variscian times. Caby and Kienast (2009) reevaluated the data of Dallmeyer and Lécorché (1989, 1990a, b) and proposed a simpler metamorphic and tectonic history of late Paleozoic (Hercynian) plate convergence, which induced docking of Laurentia against the 670 Ma western arc domain and a compressive, nappe forming, episode correlating with the Appalachian deformation at about 300 Ma.

The Akjoujt area, located in the northern Mauritanides, is situated in a major oroclinal bend in the Mauritanide Belt where it turns westward to follow the southern edge of the Rgueïbat Shield. In this area the rocks consist of a system of overlapping thrust sheets or a “thrust stack” which differs lithologically from those in the central and southern Mauritanides (Martyn and Strickland, 2004). The Akjoujt package is bounded to the north and east by a sole-thrust contact with the Archean Amsaga Terrain of the Rgueïbat Shield (Gunn and others, 2004). Supracrustal rocks in the Akjoujt area consist of two sequences: the lower Eizzene Group and the Oumachoueima Group. The Eizzene Group is composed primarily of metabasalts and banded iron formation, which is overlain with angular unconformity by the Oumachoueima Group. The Oumachoueima Group is made up of siliclastic sediments capped by a thick section of submarine basalts and dolerites (Martyn and Strickland, 2004). Partially migmatized leucogranite sheets and pegmatites, which occur in areas of overthrust basement in the Akjoujt area, are the only igneous rocks which intrude the Oumachoueima Group (Martyn and Strickland, 2004).

Age dates by multiple workers indicate that the mineralization and host rocks at Guelb Moghrein are Archean in age. Two types of hydrothermal monazite and xenotime associated with primary sulfide ore were dated by (Kolb and others, 2006). Type I monazite and xenotime yielded an age of approximately 2,492 Ma, which was concluded to be the age of the copper-gold mineralization. Type II grains showed an age of 1,742 Ma, which was interpreted to indicate a later generation of hydrothermal fluid flow. $^{40}Ar/Ar^{39}$ data from biotite and hornblende in samples of metavolcanic rocks from the northern Akjoujt area showed that closure temperatures last occurred at about 2,400 and 1,850 Ma (Clauer and others, 1991). An $^{40}Ar/Ar^{39}$ age from hornblende in metagabbro collected at the southern margin of Guelb Moghrein mine yielded an age of 3,597±101 Ma (JICA 2005a, H. Murakami, personal commun, 2012).

Copper-gold-cobalt mineralization at Guelb Moghrein occurs in discrete tabular breccia zones developed parallel to D_2 shear zones within metacarbonate rock composed of magnesite and dolomite (Strickland and Martyn, 2001, Kolb and others, 2006). The mineralization and host metacarbonate lie within a thrust zone which separates meta-rhyolite of the St. Barbe Volcanic Unit from the overlying Akjoujt metabasalt unit (fig. 2), (Kolb, and others, 2006, Kirschbaum, 2011a). The ore consists of carbonate breccia with a matrix of mainly Fe-Mg clinoamphibole and magnetite with lesser amounts of chalcopyrite, pyrrhotite and other sulfide minerals (Murakami, 2004, Murakami and others, 2005, Kolb and others, 2006).

Massive sulfide-arsenide-gold mineralization with associated monazite and xenotime formed at P-T conditions of about 410 °C and 2–3 Kbar (Kolb and others, 2006). The metacarbonate host rock has been variously interpreted as a metasediment (Ba Gatta, 1982, Pouclet and others, 1987, Kolb and others 2006, Meyer and others, 2006, Kirschbaum, 2011b) or as a hydrothermal alteration product (Strickland and Martyn, 2001, Martyn and Strickland, 2004). Geochemical analyses by Kolb and others (2008) show that the unit is characterized by high XMg (=36) of Fe-Mg carbonate, an REE pattern and $\delta^{13}C$ values (-18 to -17‰) which suggest that the rock formed as a marine precipitate similar to Archean BIF.

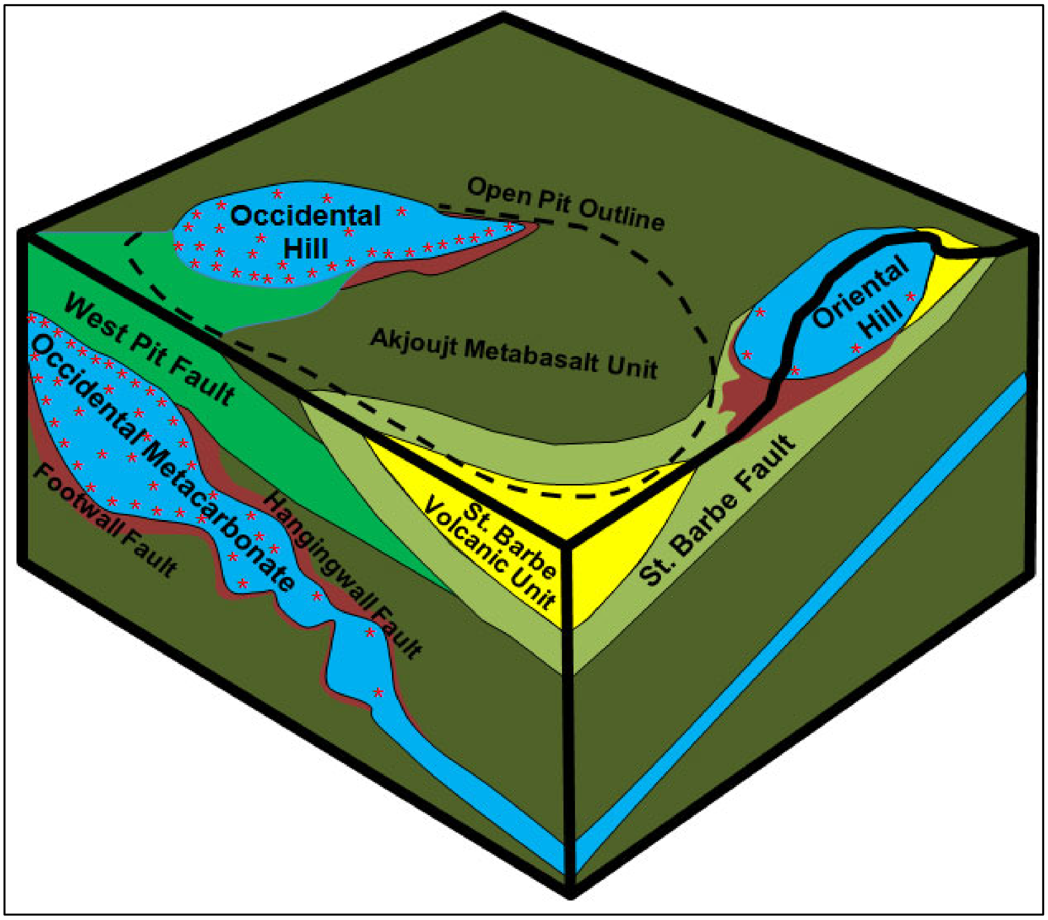

Figure 2. Schematic structural interpretation of the Guelb Moghrein deposit (from Kirschbaum, 2011a). Used with permission.

The wall rocks surrounding the mineralized metacarbonate underwent albitization prior to and during greenschist to amphibolite grade metamorphism followed by potassic alteration which formed a 40 meter (m) wide biotite zone during amphibolite grade metamorphism (Kirschbaum, 2011a, b). In addition to the zoned alteration which envelopes the mineralized zone, high angle calcite-quartz-pyrrhotite-chalcopyrite veins occur in the hanging wall of the deposits (Hitzman, 2008).

Reconnaissance fluid inclusion studies of quartz veins from the footwall greenschist at Guelb Moghrein showed polyphase inclusions containing daughter halite crystals with gaseous inclusions (JICA, 2005b). Homogenization temperatures of the inclusions ranged from 240 to 320 °C and salinity values from 33 to 39 weight percent NaCl equivalent.

Stable isotope analyses were carried out on samples of magnetite, grunerite, graphite and sulfides from Guelb Moghrein by Sakellaris and Meyer (2008). $\delta^{34}S$ values cluster around zero, corresponding to published values for magmatic and metamorphic sulfur and the δD fluid values typical of metamorphic waters. The combined oxygen and hydrogen isotope composition of the fluid plots in the field of metamorphic waters with a narrow range of $\delta^{18}O$ versus δD values, reflecting a lack of mixing with surface waters. Based on these data, Sakellaris and Meyer (2008) conclude that the sulfur and ore fluids are of metamorphic origin and that the most likely source of the metal enriched fluid were the host metabasalt units.

The Japan International Cooperation Agency (JICA) conducted a rock geochemical survey over the Guelb Moghrein deposit and immediate surroundings (JICA, 2005b). Factor analysis of the silver, arsenic, bismuth, cobalt, copper, germanium, indium, nickel, selenium, tin, tellurium, and zinc data, with a factor loading value of greater than 0.7, shows a strong correlation with gold concentration whereas there is a strong negative correlation between gold and chromium (JICA, 2005b). Analysis of metallurgical samples of oxide ore shows TiO_2 of 0.03 percent and 24 ppm chromium (Strickland and Martyn, 2001).

Guelb Moghrein shares many characteristics of some IOCG deposits such as having copper and gold as economic minerals, structural control, abundant breccias in the ore zone, low titanium iron oxides, chalcopyrite and pyrrhotite as the dominant sulfides, and a lack of quartz veins. However, no other IOCG deposits are hosted by iron rich carbonate, so Guelb Moghrein is atypical of known IOCG deposits generally (Kirschbaum, 2011a, b). In addition, there is a possibility that the mineralizing fluids are of metamorphic origin and the deposit therefore is not a true IOCG (Sakellaris and Meyer, 2008).

3.2 Other Copper and Gold Prospects in the Akjoujt Area

There are several other copper and (or) gold occurrences in the Akjoujt area (fig. 3, table 1). USGS personnel visited Guelb Moghrein (no. 01, fig. 3, table 1) and a number of other prospects in 2007. The principal prospects are described below and the characteristics of the occurrences are summarized in table 1.

The El Khader prospect (no. 02, fig. 3, table 1) was explored starting in 1953 and a number of zones of hematite and goethite derived from weathering of a 60-m-thick ferruginous carbonate body were delineated (Strickland and Martyn, 2001). The prospect consists of a 2,000 × 60 m gossan associated with a carbonate stockwork and an extensive zone of albite-oligoclase, sericite, and Fe-chlorite alteration (Martyn and Strickland, 2004). Gunn and others (2004) also report “conspicuous” sodic alteration “in some zones” at El Khader. The host rocks are dolerite and felsic meta-volcaniclastic rocks of the Irarchene El Hamra Formation (Strickland and Martyn, 2001, Gunn and others, 2004). The gossan and alteration zone occur in a domal structure at the intersection of a northeast trending antiform, which deforms the thrust sheets in the area and transgresses the stratigraphy and thrusting.

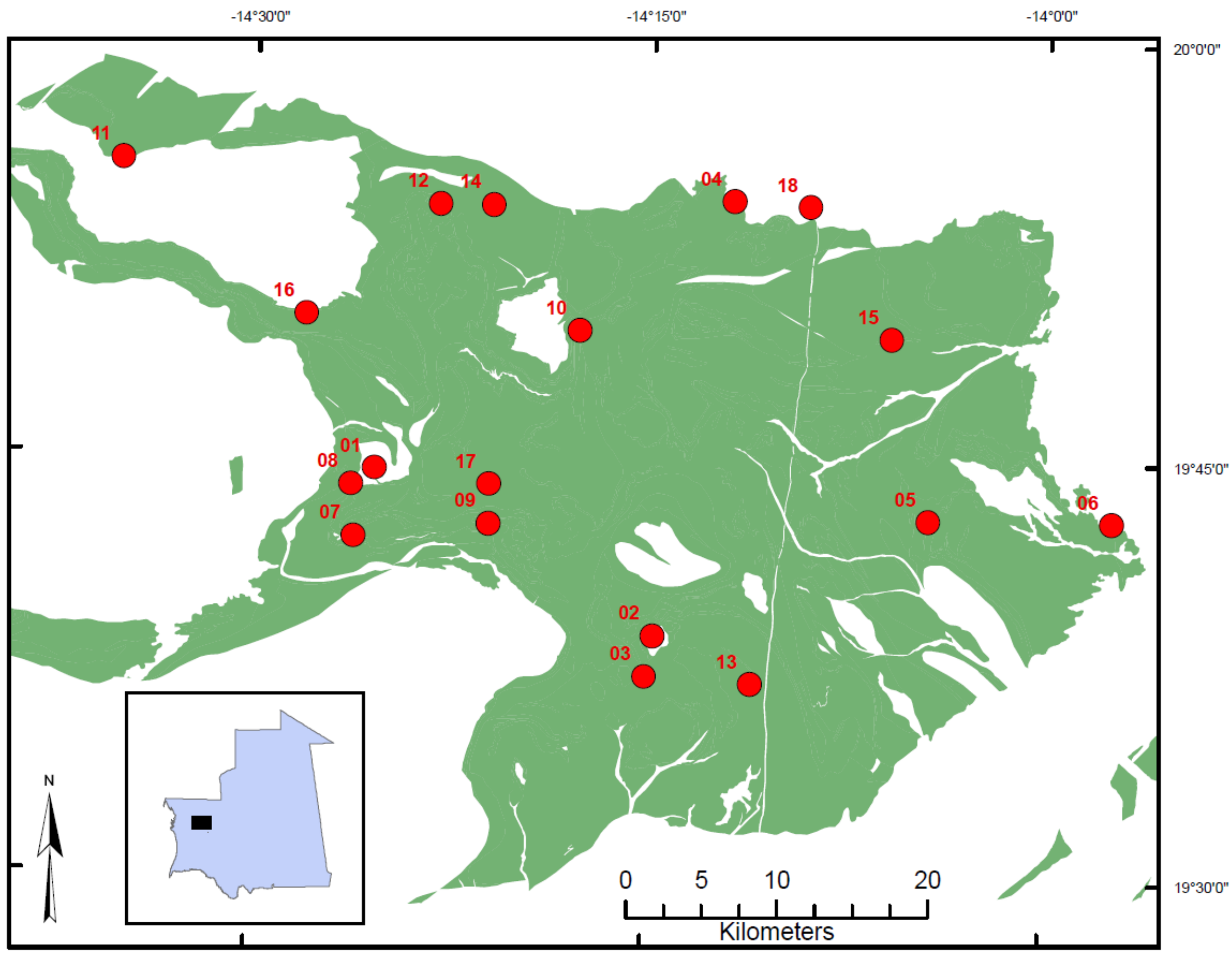

Figure 3. Map of the Akjoujt area showing distribution of the Oumachoueima Group (green) and copper and gold mineral occurrences (red dots).

Early exploration at the El Khader prospect focused on iron and delineated a resource of 11 million tonnes at 51 percent iron, which was later increased through further exploration to 18 million tonnes (Gunn and others, 2004). Subsequent exploration focused on gold and copper mineralization, which occurs in carbonate exposed on the north flank of the dome. Gunn and others (2004) report 2 g/t gold over 15 m of mineralized interval and 4 g/t gold over 3 m associated with copper and manganese enrichment in an oxidized carbonate body. Later drill holes intercepted 3 m containing 1.62 g/t gold, with a maximum 2.81 percent copper over 4 m and 91 ppm cobalt over 5 m schist, quartz schist and ferruginous quartzite.

The El Khader Breche prospect (no. 03, fig. 3, table 1) consists of a zone of brecciation 300-m-long and 3–5 m thick. Rock samples collected from the breccia zone contain 1.5 and 3.5 g/t gold over several meters as well as anomalous amounts of copper, molybdenum, tungsten, arsenic and tin (Gunn and others, 2004). Drilling intersected minor veining and fractures filled with siderite, calcite, pyrite, chalcopyrite and pyrrhotite in schist and quartzite underlain by metadolerite. Maximum values of 0.4 g/t gold, 0.27 percent copper and 72 ppm cobalt from trench samples are reported to be supergene by Gunn and others (2004).

The Sainte Barbe prospect (no. 04, fig. 3, table 1) is a group of ancient mine workings excavated on zones of malachite, chrysocola, and azurite associated with quartz-ankerite veins that cut a 25-m-thick ferruginous carbonate unit (Strickland and Martyn, 2001). Copper-gold bearing minerals are reported at four places in the prospect. The minerals occur in subhorizontal bodies of Fe-Mg carbonate within a thrust sequence of chloritized mafic and felsic metavolcanic rocks assigned to the Sainte Barbe Formation (Gunn and others, 2004). The area was explored by trenching and a shallow adit. Gunn and others (2004) report trench samples which contained 1.12–2.46 g/t gold over trench widths of 2.5 m.

The Tabrinkout prospect (no. 05, fig. 3, table 1) was originally reported as a tungsten occurrence (BRGM, 1975) but was later explored for copper and gold. The prospect consists of an area 3 kilometers long and up to 300-m wide containing multiple narrow east-trending zones of carbonate alteration within faulted and thrusted mafic and felsic metavolcanic rocks of the Sainte Barbe Formation (Gunn and others, 2004). An irregular stockwork and lenses of coarse grained Fe-Mg carbonate with numerous quartz veins containing gold and secondary copper minerals is referred to as 'quartz mylonite" by Gunn and others (2004). The prospect was explored by trenches, several shallow shafts, and drill holes. Trench intercepts of 22 m at 4.6 g/t gold, 10 m at 2.9 g/t gold, and 8 m at 4.2 g/t gold, and reverse circulation drill hole intercepts of 4.1, 3.8 and 2.4 g/t gold over 2 m are reported by Gunn and others (2004). Rock geochemical data for the Tabrinkout area has a similar statistical pattern to Guelb Moghrein with bismuth, copper, lead, antimony, selenium, tin and tellurium showing a strong correlation with gold (JICA, 2005d).

Table 1. Copper and (or) gold deposits and occurrences in the Akjoujt area, Mauritania.

Map No.	Name	Host Lithology	Associated Structure	Alteration	Mineralization	Breccia	Quartz Veins
01	Guelb Moghrein	Fe-Mg carbonate	Thrust faults		Gold, chalcopyrite, magnetite	Yes	
02	El Khader	Ferruginous carbonate	Post thrust faults	Albite-oligoclase, sericite, Chlorite			
03	El Khader Breche	Schist and quartzite	Thrust faults		Chalcopyrite	Yes	
04	Sainte Barbe	Fe-Mg carbonate	Thrust faults	Chlorite	Chrysocolla, azurite		
05	Tabrinkout	Quartz mylonite	Faults, thrusts	Carbonate	Gold, malachite		Yes
06	Tabrinkout Est	Foliated quartz veins			Malachite		Yes
07	Masse	Carbonate lenses	Shear		Malachite, magnetite		
08	Camel Tick	Basic volcanic rocks	Shear zones, thrust faults	Carbonate			
09	El Joul	Fe-Mg carbonate	Thrust faults		Malachite, gold, magnetite		
10	Bou Serouai	Carbonate			Malachite		
11	Redwood	Mafic volcanics	Wrench Fault	Carbonate			Yes
12	Atomai Nord	Carbonate lenses		Silicification			
13	Anomalie A1	Chlorite and quartz schist		Calcite, siderite, quartz	Gold		Yes
14	Guilabet El Louebda	Metabasic rocks	Thrust zone	Carbonate	Malachite		
15	Khatt El Bagra	Amphibolite			Chalcopyrite		
16	Khemyat El Khadra	Quartzite, greenstone		Carbonate, quartz	Malachite, chalcopyrite		Yes
17	Françoise	Chlorite schists		Quartz, carbonate	Malachite, chrysocolla		Yes
18	Guleb Hadej	Mylonite		Carbonate	Gold	Yes	Yes

The Tabrinkout Est prospect (no. 06, fig. 3, table 1) is a zone of foliated quartz veins with lesser amounts of carbonate and malachite stain 100 m long and 15 m wide within the Irarchene El Hamra Formation of the Oumachoueima Group (Gunn and others, 2004). The prospect was explored by trenching and trench intercepts of 10.2 and 9.1 g/t gold over 2.0 m were reported but could not be confirmed by later resampling (Gunn and others, 2004).

The Masse prospect (no. 07, fig. 3, table 1) comprises the Masse I, II and III copper occurrences, which are located south of the Guelb Moghrein deposit. Individual copper occurrences consist of lenses a few meters thick and up to 200 m long containing disseminated magnetite and malachite on fractures in carbonate lenses. The host rocks are sheared metavolcanic and metasedimentary rocks of the Sainte Barbe Formation (Gunn and others, 2004).

The Camel Tick (no. 08, fig. 3, table 1) "prospect" consists of basic volcanic rocks, carbonate alteration, shear zones and thrust faults which are coincident with a magnetic anomaly that appears to be unrelated to BIF. The area was identified as an exploration target by Eden (2003) using GIS based prospectivity analysis.

The El Joul Prospect (no. 09, fig. 3, table 1) comprises two occurrences of secondary copper minerals, gold and magnetite associated with bands and pods of Fe-Mg carbonate (Gunn and others, 2004). The carbonate bodies at the two occurrences are within a thrust zone which cuts metavolcanic and metasedimentary rocks of the upper part of the Oumachaoueima Group. The two showings, which are referred to as El Joul Ouest and El Joul Est, may be part of the same mineralized zone (Gunn and others, 2004) and are discussed as one prospect. At El Joul Ouest the mineralized carbonate has been traced over a strike length of 800 m and is up to six meters thick, parts of which have been explored by drilling and trenching. Gunn and others (2004) report intercepts of 6.2 g/t gold over 2 m, and 0.8 g/t gold over 11.5 m in trenches and drill hole intercepts of 4.0 m at 1.6 g/t gold and 4.0 m at 1.25 g/t gold. The El Joul Est showing, located 10 km along strike from El Joul Ouest, consists of two mineralized carbonate zones hosted by chlorite schist with lesser amounts of graphitic schist and ferruginous quartzite. Part of El Joul Est was explored by trenching and drilling. Gunn and others (2004) report that two drill holes intercepted 4.0 m at 5.1 g/t gold and 4.0 m at 5.65 g/t gold and another drill hole intercepted 1.0 m at 500 ppm cobalt.

Bou Serouai (no. 10, fig. 3, table 1) is a small copper showing consisting of malachite in a 1 meter thick zone of carbonate and iron oxide minerals hosted by chloritic schists, probably of the Sainte Barbe Formation (Gunn and others, 2004). The prospect was explored by trenching which revealed one intercept of 5.5 g/t gold over a width of 0.30 meters.

The Redwood Prospect (no. 11, fig. 3, table 1) is an area of ferruginous carbonate altered mafic volcanic rocks of the Eizzene Group, which hosts a discontinuous zone of quartz veins with associated magnetite and carbonate boxwork veinlets. The carbonate altered zone is 1,500 m long and occurs within a wrench fault. Gunn and others (2004) report that rock samples from the prospect contain up to 11.4 g/t gold and 5,200 ppm copper.

The Atomai Nord prospect (no. 12, fig. 3, table 1) is composed of three mineralized areas within a 1000-m-long and 5 m thick elongate zone of silicified carbonate lenses, which contain minor amounts of malachite, pyrite and limonite (Gunn and others, 2004). The alteration and mineralization are within a shallow dipping thrust fault which crosses tuffs and BIF of the Atomai Formation and metasediments of the Irarchend El Hamra Formation. Gunn and others (2004) report that surface samples of copper mineralization contained grades up to 2.9 percent and that one drill hole intercepted 2.8 m at 0.22 percent copper and 6.5 m at 0.03 percent copper.

Anomalie A1 (no. 13, fig. 3, table 1) is an elongate north-south trending soil geochemical anomaly with values up to 1.7 ppm Au (Gunn and others, 2004). The anomaly is underlain by a gently dipping metabasic intrusion 2- to 20-m-thick, which cuts gray schist of the d'Irarchene El Hamra Formation. The anomaly was investigated by trenching and two RC drill holes (Gunn and others, 2004). Trench samples showed 6 m at 1.7 g/t gold and 12 m at 1.3 g/t gold over the intrusion. The best drill hole intercepts were 3.9 g/t gold over 1 m, and 0.23 percent copper and 120 ppm cobalt over 3 m. The mineralization occurs in chlorite and quartz schists and is associated with quartz veining, calcite and minor siderite and pyrite (Gunn and others, 2004).

The Guellabet El Louebda occurrence (no. 14, fig. 3, table 1) is described as minor malachite, pyrite and limonite within carbonate altered metabasic rocks (Gunn and others, 2004). The alteration zone is within a thrust zone which dips gently to the south. According to Gunn and others (2004) the best intercepts from one hole drilled at the prospect were 2.8 m at 0.22 percent copper and 6.5 m at 0.03 percent copper.

Four other copper occurrences have only brief descriptions. At the Khatt el Bagra occurrence (no. 15, fig. 3, table 1) chalcopyrite is reported in greenstone (Marsh and Anderson, 2015). The Khemyat El Khadra (No. 16, fig. 3, table 1) occurrence comprises unspecified copper minerals in quartz veins within quartzite and ferruginous greenstone (Marsh and Anderson, 2015). The Francoise occurrence (No. 17, fig. 3, table 1) comprises malachite and chrysocolla in quartz veins and carbonates (Marsh and Anderson, 2015). At the Guelb El Hadej occurrences (no. 18, fig. 3, table 1) is described as a mylonite zone with carbonate, quartz veins and brecciated carbonate (Gunn and others, 2004).

3.3 Possible IOCG Occurrences in the Southern Mauritanide Belt

Gunn and others (2004), Higashihara (2005), JICA (2005c), Salpeteur (2005) and Marutani and others (2009) suggested that there is potential for Guelb Moghrein type Cu-Au mineralization in the southern Mauritanide Belt and refer to specific prospects including Kadiar, Indice 78, Guelb Naadj, Diaguili and Guidimaka as examples of IOCG type deposits. Within the Southern Mauritanide Belt, the Kadiar, Indice 78, and Oudelemguil prospects occur in proximity to each other and the Diaguili and Guidimaka prospects form a second group located further south. The discussion below focuses on these two groups.

Kadiar is one of the most significant copper prospects in the Mauritanide Belt and has been the focus of considerable exploration (Gunn and others, 2004). The area is currently (September 2012) under concession to OreCorp Mauritania SARL which is exploring the prospect using a volcanic-hosted massive sulfide (VHMS) deposit model (OreCorp, 2012). The prospect consists of a copper and gold-bearing siliceous gossan which overlies a lens of silicified ankerite containing lesser amounts of malachite, chalcopyrite and pyrite. The mineralization is hosted by the Gorgol Noir Complex along the thrust contact between the dominantly metabasaltic rocks of the Groupe d'El Gueneiba to the east and the Groupe de Gadel to the west (Gunn and others, 2004). The host lithologies at Kadiar are chloritic schist, calcareous schist, mica schist and quartzite and the carbonate zone occurs within an imbricated thrust zone with serpentinite and talc schists (Gunn and others, 2004, Salpeteur, 2005). Surface rock samples show maximum values of 800 ppb gold, 200 to >8,000 ppm copper, 100 to 4,000 ppm zinc, 1,000 to 10,000 ppm nickel and 2,577 ppm chromium.

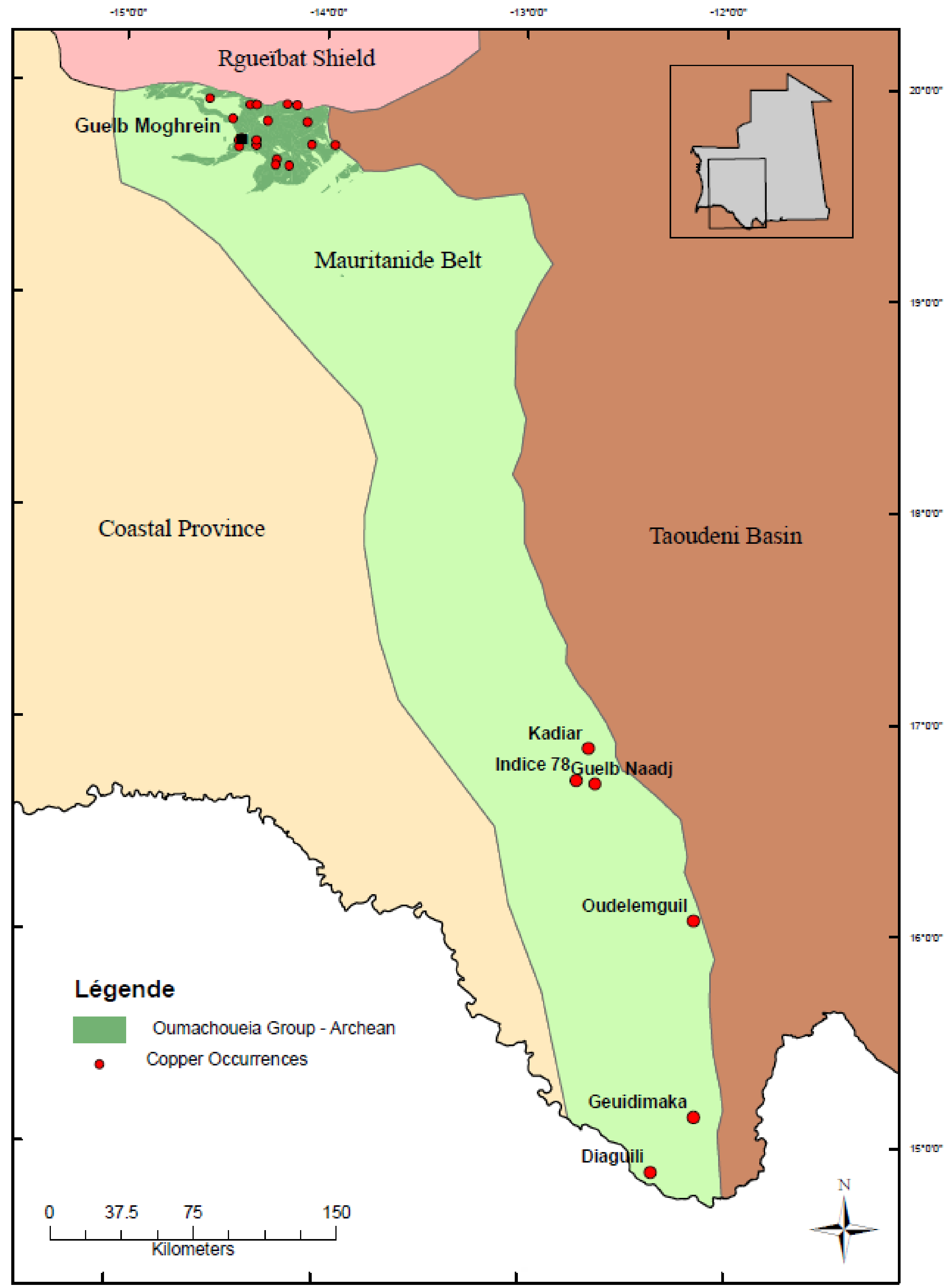

Figure 4. Copper occurrences of the Mauritanide Belt.

JICA (2005e) and Marutani and others (2009) consider the Kadiar prospect to be the same deposit type as Guelb Moghrein (IOCG). However Salpeteur (2005) notes that the only iron oxide mineral present at Kadiar is hematite and that magnetite, which is commonly in IOCG deposits, is absent. For this reason he questions whether Kadiar should be considered IOCG type mineralization instead of a VHMS-type deposit.

The Indice 78 prospect, originally identified by soil sampling, consists of a 4.5-km-long zone of propylitic alteration containing disseminated copper sulfide minerals and numerous quartz veins localized along the contact between meta-andesite and metarhyolite (Gunn and others, 2004). Within the alteration zone, carbonate minerals occur in veinlets and as irregular coarsely crystalline patches, which lead Gunn and others (2004) to suggest that the copper mineralization might be similar to that observed at the Guelb Moghrein deposit; however, they conclude that the mineralization is more likely of VHMS type.

The Guelb Naadj prospect is underlain by recrystallized felsic rocks that contain abundant quartz veins, with local development of stockwork veins and breccias where gold was found in panned concentrate samples from nearby drainages. Only minor carbonate alteration was noted in a field examination by Gunn and others (2004), who also report that no significant mineralization was intercepted by holes drilled at the prospect.

The Oudelemguil prospect is a group of five copper-gold-silver bearing veins that lie within a north-south trending area of hydrothermal alteration 600 m long and 100 m wide (JICA, 2005f). Individual veins are 0.4 to 0.8 m thick and extend up to 300 m along strike. The host rocks are serpentinites and metagabbros of the Groupe de Gadel (Gunn and others, 2004). Maximum analytical values from samples collected at the prospect by JICA show 34.4 percent copper, 0.59 g/t gold and 196 g/t silver (JICA, 2005f).

The Diaguili prospect is a zone of north-northeast trending fractures cutting talc schists, chlorite schists and carbonate altered serpentinites (Salpeteur, 2005). Disseminated chalcopyrite, bornite, magnetite and malachite occur within the fractures. The copper mineralization is confined to a narrow silicified fault zone in an area of jaspilites, serpentinites, chloritic schists and siltstones exposed on two prominent hills separated by a discordant fault zone (Gunn and others, 2004).

3.4 Discussion

The rocks in the Akjoujt area differ significantly from those of the central and southern Mauritanide Belt (Strickland and Martyn, 2001, Martyn and Strickland, 2004). The sequence is dominated by mafic volcanic rocks with abundant interlayered BIF. The rocks are of Archean age whereas the oldest rocks in the central and southern Mauritanide Belt are Neoproterozoic in age (Dallmeyer and Lécorché, 1989, 1990a, b, Lécorché and others, 1989, Pitfield and others, 2004).

The rocks that underlie the Akjoujt area are allochthonous and were thrust into their current position. However the source of the allochthonous blocks is not known. Vauchez and others (1987), LeFort (1988), and Villeneuve (2008) report sinistral strike-slip faulting along the southern edge of the Rgueïbat Shield (fig. 1). Since the Akjoujt allochthon package was thrust into its present position from the west it is possible that it was originally part of the Rgueïbat Shield, possibly the same Archean greenstone-BIF package as the Tasiast area.

Of the 19 identified copper and (or) gold occurrences in the Akjoujt area, five have significant quartz veining in the mineralized zone. These occurrences are probably not IOCG type as quartz veins are generally not abundant in IOCG type deposits (Groves and others, 2010).

The Atomai Nord, Bou Serouai, Camel Tick, El Joul, El Khader, El Khader Breche, Guilabet El Louebda, Masse and Sainte Barbe prospects all have similarities to Guelb Moghrein and may be IOCG type occurrences. There are insufficient data on the remaining occurrences to determine their type of mineralization.

The copper and (or) gold occurrences in the Southern Mauritanide Belt are all associated with accreted metamorphic rocks, which include ultramafic bodies typical of suture zones (Caby and Kienast, 2009, Goldfarb and others, 2015). The lenses of intense carbonate alteration, silicification and quartz veining, often with associated chromium-rich micas, are typical of "listwaenite" a style of hydrothermal alteration common in major fault and suture zones (Buisson and Leblanc, 1986). The southern copper occurrences, such as Diaguili and Guidimaka, are also associated with jaspilite (red jasper), hematite and podiform chromite occurrences. These features are common in Cyprus type massive sulfide deposit systems. In contrast, the age of the host rocks making up the southern Mauritanides is Neoproterozoic (Dallmeyer and Lécorché, 1989, 1990a, b, Lécorché and others, 1989, Pitfield and others, 2004) in contrast with the Archean age of the Akjoujt area sequence.

Geochemical data also suggest that the copper and (or) gold occurrences of the Central and Southern Mauritanides are distinct from those of the Akjoujt area. PRISM rock samples taken at or near Cu-Au occurrences in the Akjoujt area typically show <100 ppm chromium (Eppinger and others, 2015). This is consistent with the geochemical data of JICA (2005a) from Guelb Moghrein. In contrast, Cr values in PRISM samples taken at or near copper occurrences in the southern Mauritanide Belt are higher. Chromium values are 237 and 290 ppm in samples taken near Kadiar, 22, 23 and 2,670 ppm in samples taken near Indice 78, 1,195 and 1,440 ppm near Oumdelemguil, 118 ppm near Diaguili and >10,000 ppm near Diaguili Est.

Based on their geologic and geochemical characteristics it is concluded that the copper and (or) gold occurrences in the southern Mauritanide Belt are not IOCG type deposits.

4 Permissive Tracts for Iron-Oxide Copper-Gold in Mauritania

The critical features which characterize the Guelb Moghrein deposit are:

- Copper-gold-magnetite association
- Greenstone-BIF host package which has a distinctive aeromagnetic signature
- Iron-rich carbonate host rocks
- Archean mineralization age, and
- Low Cr values in the deposit and surrounding rocks.

These characteristics have been used to define geologic tracts which are considered permissive for IOCG mineralization similar to Guelb Moghrein (fig. 5).

Tract IOCG-1: Akjoujt 1 is considered permissive for the presence of IOCG type mineral deposits based on the presence of an economic copper-gold deposit; Guelb Moghrein, a number of other IOCG type occurrences in the area and of the host Archean greenstone-BIF package. The boundary of the tract is delimited by the outcrop of the Oumachoueima Group with the addition of a one kilometer buffer.

Tract IOCG-2: Akjoujt 2 is considered permissive tract based on the elongate aeromagnetic highs and iron occurrences present to the south of the Akjoujt 1 tract. The tract is defined based on extent of the sinuous aeromagnetic anomalies.

Tract IOCG-3: Bou Lanouar 1 is located in northwest Mauritania just east of the village of Bou Lanouar. Outcropping rocks in the area are Tertiary sedimentary rocks, however the aeromagnetic data show a pattern of sinuous magnetic highs similar to those of the Akjoujt area.

East of the covered area, in the Rgueïbat Shield, Archean rocks of the Groupe de Lebzenia crop out and there are several gold and BIF occurrences. To the north in Western Sahara Neoproterozoic rocks of the Mauritanide Belt outcrop and a Neoproterozoic eclogite have been reported in the Tarf Magneina Unit (Le Goff and others, 2001). The area defined by the aeromagnetic anomaly could represent magnetic Proterozoic rocks of the Tarf Magneina or Archean rocks. Based on the second possibility the area is considered as permissive for IOCG deposits.

Tract IOCG-4: Bou Lanouar 2 is located south of tract IOCG-3. It is considered permissive for IOCG type deposits based on the same criteria as tract IOCG-3.

Tract IOCG-5: Archean consists of areas within the Rgueïbat Shield which are underlain by Archean supracrustal rocks. The Akjoujt package might represent slices of Archean greenstone belts from the Rgueïbat Shield thrust into their current position. Metavolcanic rocks from Akjoujt area and greenstone belts within the Rgueïbat Shield are of island arc origin based on their geochemistry (Gunn and others, 2004, Pittfield and others, 2004, Kolb and others, 2008). The greenstone belts in the Rgueïbat Shield are also of Archean age. For example, the Chami Greenstone Belt in the Tasiast-Tijirit Terrane has an age of 2,968 Ma and accretion and associated shearing has been dated at 2,954 Ma (Pitfield and others, 2004). Murakami (personal commun., 2012) obtained an age of 3,596±101 Ma for the host rocks at Guelb Moghrein and D2 thrusting and mineralization has been dated at 2,492 Ma (Kolb and others, 2008).

Tract IOCG-5 is composed of multiple areas delineated by Archean supracrustal rocks filtered for metavolcanic and metasedimentary lithologies, the host rocks at Guelb Moghrein.

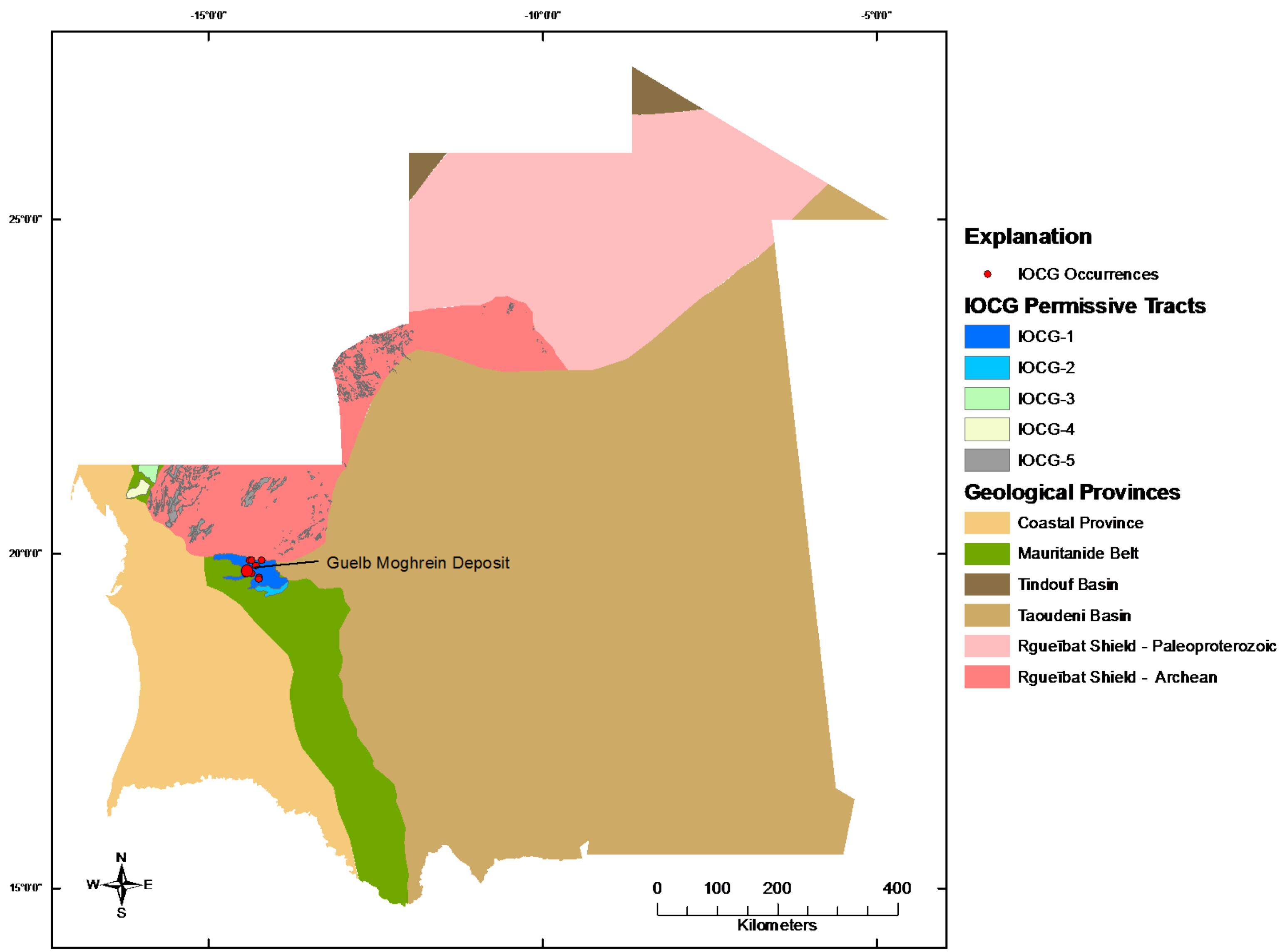

Figure 5. Permissive tracts for IOCG deposits in Mauritania.

5 Conclusions

The origin of the Guelb Moghrein deposit, the most economically significant copper-gold deposit in Mauritania, is problematic. While it shows many of the characteristics of IOCG deposits, it is also atypical in some critical aspects. These include the fact that the deposit is hosted by carbonate rocks as well as the metamorphic nature of its ore-forming fluid as opposed to igneous-source fluids typical of IOCG deposits as suggested by stable isotope data. Nonetheless, it is an important mineral deposit regardless of its origin and examination for additional similar deposits in Mauritania is justified.

Geologic and geochronological data indicate that the Guelb Moghrein deposit is of Archean age and formed prior to the formation of the mainly Proterozoic rocks of the rest of the Mauritanide Belt. Therefore the southern Mauritanide Belt, which consists mainly of rocks of Neoproterozoic and younger age, is not considered permissive for Guelb Moghrein-type mineral deposits as suggested by some previous workers.

The geologic characteristics of the deposit and its host package are typical of Archean greenstone-BIF belts. The regional tectonic setting supports the idea that the deposit and its host rock package could have been thrust into their present position from the west and may have originated in the Archean Rgueïbat Shield. The characteristics of the Guelb Moghrein deposit were used as a basis to delineate areas that are considered to be permissive for similar deposits. Five tracts have been defined which are considered permissive for the occurrence of IOCG type mineral deposits.

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