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

Mineral Potential for Volcanogenic Massive Sulfide Deposits in the Islamic Republic of Mauritania:

Phase V, Deliverable 77

By Cliff D. Taylor and Stuart A. Giles

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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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Volcanogenic Massive Sulfide Deposits

1 Summary

Potential for base- and precious-metal-bearing volcanogenic massive sulfide deposits (VMS) exists in Mauritania in the greenstone belts of the southwestern Rgueïbat Shield and in the allochthonous portions of the central and southern Mauritanides. Additional potential exists for VMS deposits within the Tiris Complex of the central Rgueïbat Shield. Volcanosedimentary successions of Paleoproterozoic rocks of the northeastern portion of the Rgueïbat Shield are also permissive for volcanogenic massive sulfide deposits. These types of mineral occurrences are common features of marine volcanosedimentary successions worldwide and can be of almost any age, although Proterozoic examples are less abundant.

Contents

Figures

Tables

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	kilowatt hour (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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2 Introduction

Volcanogenic massive sulfide (VMS) deposits are stratabound accumulations of sulfide minerals that precipitate at or near the sea floor in spatial, temporal, and genetic association with contemporaneous volcanism (Franklin and others, 2005). These deposits are also commonly referred to as volcanic-hosted massive sulfide deposits (VHMS) especially in the Australian literature (for example, Large, 1992), and as volcanic-associated massive sulfide deposits (VAMS; for example, Franklin and others, 1981). These terms are considered completely analogous for the purposes of this report. In detail, the terminology is not completely interchangeable as VMS refers to a genetic class of deposits and the other terms specify volcanic host rocks (Franklin and others, 2005). A typical deposit consists of two parts: a concordant, stratiform massive sulfide lens (>60 percent sulfide minerals) overlying a discordant pipe or inverted funnel shaped zone consisting of crosscutting, sulfide-bearing, feeder veins in altered footwall strata, called the stockwork or stringer zone (fig. 1). They form at spreading centers and in collisional oceanic or ocean-continent environments during periods of extension that allow for crustal thinning and upwelling of mantle material to shallow crustal levels. The resulting volcanism and emplacement of co-genetic intrusions act as heat engines that drive the circulation of seawater through deeply penetrating faults and fractures where water-rock reactions leach metals from the footwall. Mineral deposition occurs at or near the seafloor when ascending hot metal-rich fluids undergo a change in temperature, pH, and activity of sulfur. Specific mineralogical compositions and metal endowments of VMS deposits are variable depending upon the factors above and upon the composition of the host rocks; typically however, these deposits are Cu-Zn-Pb ±Au±Ag-bearing and can contain a wide variety of associated elements such as As, Sb, Bi, Sn, Tl, and Hg. In general, VMS deposits associated with mafic volcanic rocks tend to be Cu-Zn-rich, whereas deposits in felsic rocks may also contain significant Pb. VMS deposits are typically small to medium sized accumulations of 1–10 million tonnes of massive sulfide grading 5–20 percent

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combined metal. They are attractive exploration targets and generally occur in clusters of deposits of the same sub-type and age, related to a common volcanic event.

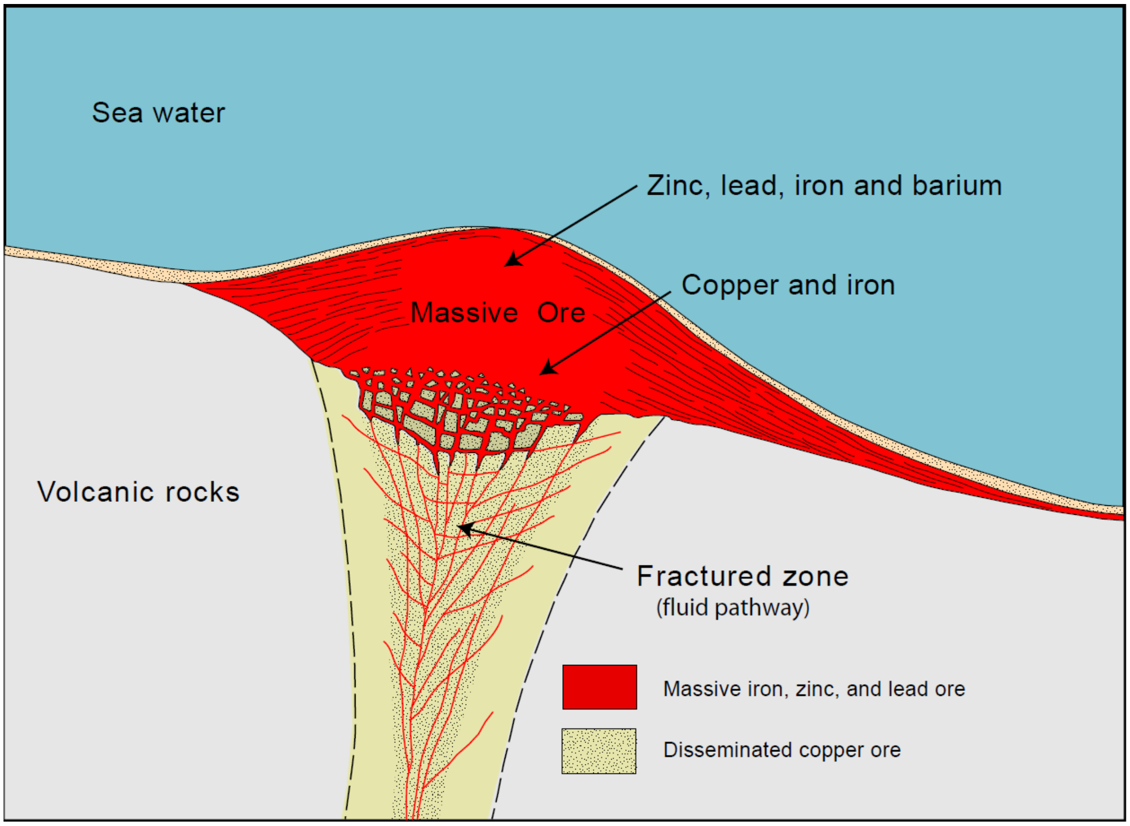

Figure 1. Idealized diagram of a typical volcanogenic massive sulfide deposit. Stippled pattern at sediment-water interface indicates presence of disseminated sulfides in sediment cover (yellow) on the flanks of the massive sulfide mound. Dashed lines and yellow pipe-like feature beneath massive ore shows the extent of hydrothermally altered rock (modified from Lydon 1988).

VMS deposits as a class have been subdivided by a variety of criteria, mostly determined by their metal composition (Cu-Pb-Zn ratios), geologic setting, or host rock composition. Additionally, and unfortunately, the VMS literature is rife with an entrenched terminology of sub-types that draw analogies with well-known, well-studied VMS districts (for example, Kuroko-type, Besshi-type, Noranda-type, and Cyprus-type) that imply the characteristics of a "typical" deposit in the named district. Published USGS VMS deposit sub-type models follow this practice (Cox and Singer, 1986). Recent classifications (Barrie and Hannington, 1999; Franklin and others, 2005; Galley and others, 2007) are based on lithostratigraphic associations of the deposits, which have a more direct link to geodynamic processes and thus provide a better basis for establishing exploration criteria.

The VMS classification scheme used in this report follows the usage of Franklin and others (2005) with the older district-specific terminology used in parallel to provide a link to the established USGS ore deposit models guidebook (Cox and Singer, 1986) terminology. VMS deposits are grouped into five lithostratigraphic sub-types using sequence boundaries defined by major time-stratigraphic breaks, faults, or major subvolcanic intrusions: (1) Bimodal-mafic, typified by mafic flows and <25 percent felsic strata that occur in incipient-rifted suprasubduction zone oceanic arcs (e.g., Noranda, Urals, Kuroko-type of USGS usage), (2) mafic, typified by ophiolitic sequences with <10 percent sediment that occur in primitive oceanic backarcs (for example, Cyprus, Oman, Cyprus-type of USGS usage), (3) pelite-mafic, typified by subequal amounts of pelite and basalt (including sills) that occur in mature oceanic backarcs (e.g., Windy Craggy, Kieslager, Besshi-type of USGS usage), (4) bimodal-felsic, typified by 35–70 percent felsic volcaniclastic strata that occur in incipient-rifted suprasubduction zone epicontinental arcs (for example, Skellefte, Tasmania), and (5) siliciclastic-felsic, typified by continent-derived sedimentary and volcaniclastic strata that occur in mature epicontinental backarcs (for example, Iberian Pyrite Belt, Bathurst). Each of the five sub-types can be further divided on the basis of the predominant lithofacies, into flow-, volcaniclastic-, or sediment-dominated settings (Franklin and others, 2005).

3 Potential for VMS Deposits in Mauritania

3.1 Southwestern Rgueïbat Shield

Review of PRISM-I studies by the BGS in the Mesoarchean greenstone belts of the southwestern Rgueïbat Shield suggests that despite the apparent lack of thick felsic volcanic rock sequences, there is abundant evidence for mafic volcanic rock dominated volcanosedimentary successions, typical of island arcs, that are permissive for VMS deposits (Pitfield and others, 2004; Gunn and others, 2004). In the Tasiast-Tijirit terrane, seven separate greenstone belts should be broadly considered permissive for a variety of VMS sub-types within the supracrustal sequences currently lumped into the Lebzenia Group (fig. 2). Additionally, the Saouda Group of the southern Choum-Rag El Abiod terrane is considered permissive for similar reasons. The common association of mesothermal gold deposits and VMS deposits in greenstone belts (Goldfarb and others, 2001) is encouraging due to the numerous examples and high potential for gold of this type in the southwestern Rgueïbat Shield. Additionally, several Cu-Ni-Co occurrences suggest the presence of ultramafic rocks and magmatic sulfide deposits, which are also commonly associated with VMS (fig. 2). Currently no occurrences in the Mauritanian National inventory thought to be of the VMS type are located in the southwestern Rgueïbat Shield. The absence of known VMS occurrences in the Tasiast-Tijirit terrane is troubling given the numerous gold occurrences and may be related to the nature of the Mesoarchean volcanism in this region of Mauritania.

The Rgueïbat Shield in northwestern Mauritania consists of the exposed Archean portion of the West African Craton. Recent mapping by the BGS (Pitfield and others, 2004; O'Connor and others, 2005) divides this part of the Shield into two terranes separated by a major arcuate north-northeast- to north-trending shear zone named the Tacarat-Inemmaudene Shear Zone (TISZ; Key and others, 2008). The eastern Choum-Rag el Abiod terrane consists primarily of granulite facies metamorphic rocks as old as 3,500 Ma of the Amsaga Complex that are cut by major granitic and less commonly by mafic-ultramafic bodies, which range in age from 3,000 to 2,700 Ma. Older fragments of preserved crustal material consisting of greenstone remnants (amphibolites) in migmatitic gneisses are probably about 3,200 Ma in age. This region is interpreted as the dismembered and reworked root zone of a typical granite-greenstone assemblage (Gunn and others, 2004). The western Tasiast-Tijirit terrane consists of a typical Archean granite-greenstone assemblage exposed at shallower levels than the Choum-Rag el Abiod terrane and are thus much less sheared and tectonized than the similar-age rocks to the east. The oldest rocks are variably migmatized tonalitic gneisses that are cut by younger granitic phases and tectonically or unconformably underlie the greenstone belts (fig. 2).

The Tasiast-Tijirit terrane consists of three major lithologic groups: (1) migmatitic gneisses that are the oldest rocks in the terrane and underlie the greenstone belts, (2) greenstone belt lithologies, and (3) younger granitoid intrusions consisting of gneissic granites, biotite-tonalites-granodiorites (including rocks with abundant secondary epidote) and late xenolithic, leucocratic biotite-granites of the Tasiast Suite and gneissic granites of the Tacarat Suite which also intrude the Choum-Rag El Abiod Terrane. Granulite facies rocks of the Choum-Rag El Abiod terrane are not present in the Tasiast-Tijirit terrane (Pitfield and others, 2004).

The migmatitic gneisses consist predominantly of gray tonalitic gneiss cut by up to four generations of intersecting felsic pegmatitic veins, and by much less common metamafic dikes. The metamafic dikes are relatively late intrusions and cut most felsic veins. The veins make up over 20 percent of the rock volume and have a complex history of emplacement separated by periods of ductile shearing. The youngest (muscovite and biotite-bearing) pegmatitic veins post-date the various episodes of ductile shearing, but are cut by brittle fractures. Metamafic dikes are curviplanar features up to about 1m in thickness and can be traced across the larger exposures for tens of meters. Geochemical studies by the BGS on the migmatitic gneisses of both the Tasiast-Tijirit and Choum-Rag El Abiod terrane indicate that the Tasiast-Tijirit gneisses are consistently more silicic, plotting in the rhyolite field of a total alkalai-silica diagram, and appear more fractionated. They are interpreted as a calc-alkaline magmatic arc crust underlying the greenstone belts (Pitfield and others, 2004). A single U-Pb zircon age of approximately 2,970 Ma (Chardon, 1997) and Nd model ages of 3,050 to 3,100 Ma provide the only age contraints on the gneissic basement rocks (Key and others, 2008).

The main greenstone belts in the Tasiast-Tijirit terrane are named, from east to west, the Tijirit, Ahmeyim, Sebkhet Nich, Kreidat, and Chami greenstone belts. Two smaller greenstone belts to the west of the Chami belt are called the Hadeibt Agheyâne and Hadeibt Lebtheinîyé greenstone belts and are collectively referred to as the Lebzenia greenstone belts (fig. 2). These greenstone belts consist predominantly of mafic metavolcanic and siliciclastic metasedimentary rocks metamorphosed at low- to medium-grades. Altered basalts and gabbros that include amphibolite schists, siliciclastic rocks and banded ironstones dominate the various greenstone belts. Ultramafic rocks are locally common (for example, Sebkhet Nich Greenstone Belt). Ferruginous quartzites and banded ironstones are common in the Chami Greenstone Belt and the two westernmost greenstones. Intermediate to felsic metavolcanic rocks are rare. Actinolite schists are most common near contacts with intrusions such as syenites, gabbros and late-stage granites. Metasedimentary rocks are locally recrystallized to actinolite-chlorite-quartz, and sericite-quartz schists. The greenstone belts are locally intensely sheared especially along competency contrasts between lithologic units, and major ductile shear zones control both the current shape of the belts as well as folds within the belts.

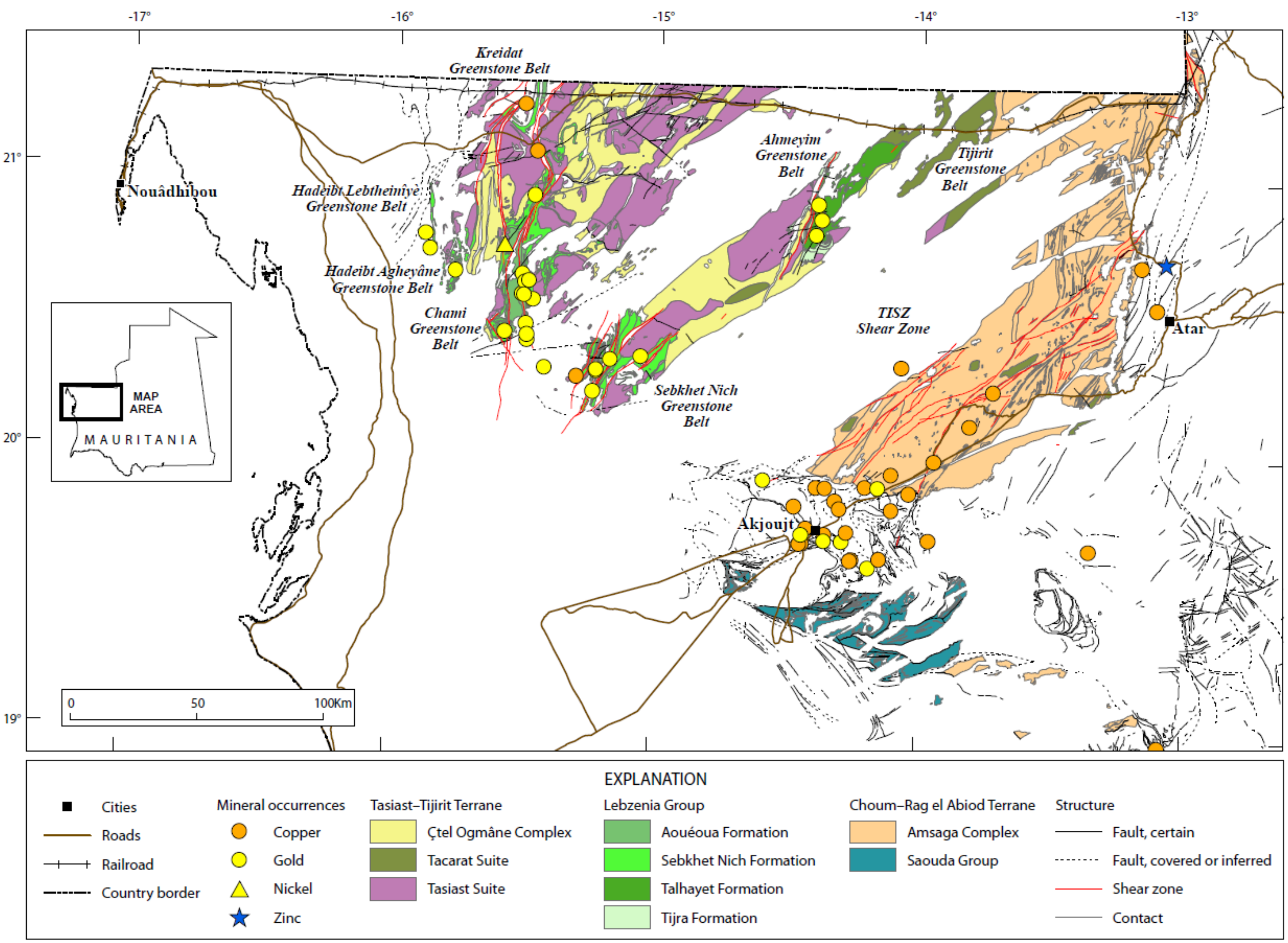

Figure 2. Simplified geologic map of the southwestern Rgueïbat Shield showing the Choum-Rag el Abiod and Tasiast-Tijirit terranes. The principal greenstone belts and mineral occurrences discussed in the text are shown.

Lithologies in the various greenstone belts are lumped into the Lebzenia Group. Four formations are recognized within this group and include: the Talhayet Formation and Tijraj Formation in the Ahmeyim Greenstone Belt, the Aouéoua Formation in the Chami Greenstone Belt, and the Sebkhet Nich Formation from the greenstone belt of the same name (Pitfield and others, 2004). The Tijraj and Aouéoua Formations are dominated by metasedimentary rocks with a significant felsic to intermediate volcanic component. The Talhayet and Sebkhet Nich Formations are characterized by basaltic greenstones and ultramafic rocks with synvolcanic intrusive sheets. In the Ahmeyim Greenstone Belt the Tijraj Formation is overlain by the Talhayet Formation and exhibits a transitional contact from a dominantly sedimentary to dominantly mafic volcanic assemblage. Mapping by the BGS suggests that the Tijraj Formation was folded about NW-trending axes before deposition of the Talhayet Formation. However, there is no obvious break in the apparent transitional sequence. The Aouéoua Formation forms the fault-bounded synformal core to the contiguous Chami and Kreidat greenstone belts and appears to overlie the mafic-ultramafic rocks of the Formation de Sebkhet Nich. In the Sebkhet Nich Greenstone Belt, the greenstone sequence is characterized by metasedimentary units structurally overlain by metabasaltic lavas and mafic sheets that are in turn overlain by ultramafic rocks. The same greenstone association flanks the Aouéoua Formation in the Chami and Kreidat greenstone belts and characterizes the volcanosedimentary succession in the Hadeibt Agheyâne and Hadeibt Lebtheinîyé greenstone belts as well. Thus, if the Talhayet and Sebkhet Nich Formations are correlatable, then the most likely depositional sequence assuming no overthrusting or inversion would place the Tijraj Formation at the base, overlain by the Talhayet and Sebkhet Nich Formations, with the Aouéoua Formation (dated at 2,968±2Ma) at the top (Pitfield and others, 2004).

Tectonic reconstruction of the southwestern Rgueïbat Shield by the BGS (Pitfield and others, 2004) suggest that amalgamation of two crustal blocks consisting of the western Tasiast-Tijirit terrane and the eastern Choum-Rag el Abiod terrane occurred along the TISZ, a transpressive ductile suture zone showing sinistral horizontal offset and east-directed thrusting on its eastern side at about 2,954 Ma (fig. 2). They are distinguished by differing early Archean geological histories. Higher-grade metamorphic rocks including major charnockitic gneiss sheets dominate the Choum-Rag el Abiod terrane and migmatitic tonalite gneisses are the dominant lithology in the Tasiast-Tijirit terrane. Geochemical characteristics of the tonalite gneisses suggest they represent a calc-alkaline magmatic arc basement to the volcanosedimentary rock successions (greenstone belts) that were emplaced at about 2,968 Ma.

Reconstruction of the greenstone belts of the Tasiast-Tijirit terrane suggests that the volcanosedimentary rocks may have originally formed a more continuous carapace over the gneissic basement. The larger greenstone belts may originally have been volcanic centers and display a wide range of volcanic lithologies including felsic volcaniclastics. Indications of water depth are sparse, however BGS mapping suggests that metasedimentary rocks of the Ahmeyim Greenstone Belt successions preserve a transition from shallow subaqueous deposition in the north to deeper water turbiditic deposition in the south (Pitfield and others, 2004). Phyllite horizons within the metasedimentary rocks are interpreted to represent volcanic tuffs, which further suggest a shallow subaqueous to subaerial volcanic source. Geochemical studies of basaltic to intermediate extrusive rocks in the greenstone belt succession exhibit T-MORB to E-MORB affinities followed by subduction-related island arc affinities consistent with initial rifting of the Tasiast-Tijirit terrane basement followed by the development of a more mature island arc setting. The Aouéoua Formation, which forms the fault-bounded core of the contiguous Chami and Kriedat greenstone belts, consists predominantly of metasedimentary rocks with intermediate and felsic volcanic rocks and is interpreted as a possible transtensional volcanosedimentary basin fill (Pitfield and others, 2004). Nd model ages of 3,050 to 3,600 Ma on the felsic rocks suggest derivation from older crustal material (Key and others, 2008).

Available geochronologic constraints suggest that volcanism immediately preceded the collision of the Choum-Rag El Abiod and Tasiast-Tijirit terranes. Volcanism ceased by approximately 2,965 Ma and was followed by collision of the two crustal blocks by approximately 2,954 Ma. Emplacement of voluminous tonalitic plutons at approximately 2,920 Ma occurred throughout the western terrane and shearing in both terranes commenced after amalgamation resulting in significant dismemberment of the greenstone belts. Geochemical studies indicate that the tonalites are metaluminous, calc-alkaline, magmatic arc-type granitoids. Thus, the entire cycle of rifting and island arc formation with subsequent plate collision and post-collision subduction-related arc magmatism took place over a period of about 50 Ma towards the end of the Mesoarchean. Later anorogenic magmatism at approximately 2,700Ma occurred throughout both terranes and marks the first period of crustal reworking in the southwestern Rgueïbat Shield (Pitfield and others, 2004).

Very little information is available regarding the size or origins of the two crustal blocks prior to their amalgamation along the TISZ. Based on clear differences in the composition and metamorphic grade of the two juxtaposed gneissic basements, they are suggested to be allochthonous. Westward dipping gneissic fabric within the TISZ suggests that the Tasiast-Tijirit terrane was emplaced on and overlies the Choum-Rag el Abiod terrane (Pitfield and others, 2004; Key and others, 2008). This would imply a continent-continent collision. However, there are no data to suggest that closure of an intervening ocean occurred. A series of small ultramafic bodies of unknown origin, some of which are weakly layered dunites with centimeter-scale layers of chromitite, are present along the western edge of the Choum-Rag el Abiod terrane and in the eastern portion of the TISZ but not in the Tasiast-Tijirit terrane. These could be interpreted as remnants of oceanic crust except that geophysical data show an absence of features that would indicate the presence of (a rare Archean) ophiolite along the suture (Finn and others, 2015). The ultramafic bodies may represent suprasubduction zone ultramafic intrusions or Alaska/Urals-type annular intrusions above an eastward dipping subduction zone. However, textural relationships suggest that they were emplaced after the granulite facies metamorphic event at approximately 2,900 Ma that affects both terranes and mineral chemistry suggests they are more similar to stratiform layered intrusions (Taylor and others, 2015). Similarly, all geochemical data available on mafic volcanic rocks in the greenstone belts suggest their derivation from an uncontaminated or slightly contaminated depleted mantle source with the less abundant intermediate and felsic volcanic rocks displaying “subduction related” signatures. None of the volcanic rocks analyzed to date exhibit N-MORB geochemistry or primitive radiogenic isotopic signatures indicative of oceanic crust.

The nature of the collision and the environment of formation of the volcanosedimentary successions in the greenstone belts of the Tasiast-Tijirit terrane has direct implications for the types of VMS deposits that should be present and on the favorability of the successions. The absence of oceanic crust clearly eliminates the possibility of discovering VMS of the mafic type (Cyprus-type of USGS usage). The presence of both mafic-dominated sequences related to incipient rifting and sedimentary sequences with arc-related intermediate and felsic volcanic rocks suggests that the terrane is permissive of the bimodal-mafic (Kuroko-type of USGS usage) and pelite-mafic (Besshi-type of USGS usage) types of VMS deposits. Therefore, future exploration for VMS in the Tasiast-Tijirit terrane should expect to find either Cu-Pb-Zn±Ag±Au or Cu-Zn±Au enriched occurrences of massive sulfide. It should also be expected that barite will not be an associated gangue phase as known examples of VMS deposits of Mesoarchean age are devoid of barite due to the low content of sulfate in Mesoarchean ocean water (Kerrich and others, 2005).

Although the greenstone belts of the Tasiast-Tijirit terrane are regarded as permissive for the occurrence of bimodal-mafic and possibly pelite-mafic types of VMS deposits, the complete absence of known VMS occurrences suggests that the favorability of the area is low. The reason for the absence of known VMS occurrences is unclear and may only partially be due to the lack of targeted exploration in the region. Due to the clear potential for the discovery of orogenic gold deposits in the region, the exploration maturity is relatively high compared to other regions of Mauritania. Since the 1990s the region has been explored for orogenic gold and nickel sulfide by several different companies and agencies resulting in the collection and analysis of over 18,000 geochemical samples followed by a significant amount of drilling (see exploration summary in Gunn and others, 2004). The reason for the absence of known VMS occurrences in the region may be related to the Mesoarchean tectonic character of the greenstone belts and the perceived paucity of deeper submarine volcanosedimentary sequences and lack of significant amounts of primitive volcanic rocks indicative of oceanic island arcs. A similar absence of VMS deposits in the Neoarchean greenstone belts of India, southern Africa, and Western Australia has been attributed to the eruption of volcanic rocks through continental crust as in the Tasiast-Tijirit terrane in contrast to the abundant occurrence of VMS in the Abitibi Belt of Canada where voluminous sequences of primitive oceanic arc volcanic rocks are present (Kerrich and others, 2005).

3.2 Central and Southern Mauritanides

Evaluation of PRISM-I summary data for the central and southern Mauritanides suggest that potential exists for a number of different types of VMS deposits.

3.2.1 Central Mauritanides.

The area here referred to as the central Mauritanides, consists of the Akjoujt area, also called the Inchiri district. Mineralized host rocks in the district are dominantly Neoproterozoic through lower Paleozoic supracrustal rocks consisting of metabasalts, sediments, banded iron formation, and lesser intermediate to felsic metavolcanics of the Oumachoueima Group. These rocks are host to a large number of copper and gold occurrences thought to be of the iron oxide copper-gold type (IOCG), including the Guelb Moghrein mine that is currently in production (see Fernette, 2015a). Similar to the southern Mauritanides, this region was affected by Pan-African through Hercynian deformation that produced a structurally complex zone of thrust nappes, together referred to as the Akjoujt nappe pile, that juxtaposes slices of the Mesoarchean basement and associated supracrustal rocks with slices of the Proterozoic supracrustal sequence (fig. 3 and table 1).

Current understanding of the age contraints on the supracrustal rocks of the district are conflicting and raise the possibility that both the host rocks and mineral occurrences could be as old as Mesoarchean to as young as Neoproterozoic. Until the ages of these rocks are resolved, the relationship of the central Mauritanides to either the greenstone belts of the Tasiast-Tijirit terrane or to the younger rocks of the southern Mauritanides remains in question. Similarly, uncertainty exists as to the true nature of the copper-gold occurrences in the district. Although current work at Guelb Moghrein has resulted in its assignment to the IOCG class of mineral deposits, previous work in the district raised the possibility that Guelb Moghrein and other occurrences may be VMS deposits (Ba Gatta, 1982) or possibly skarn-like deposits related to regional metamorphism (Goldfarb and others, 2015; Fernette, 2015a). Although none of the known occurrences in the district are currently assigned to the VMS class of deposits, the volcanosedimentary sequences of both the Mesoarchean Saouda Group and the Neoproterozoic Oumachoueima Group are permissive of the occurrence of VMS deposits. Currently all known occurrences of Au and Cu±Au are hosted in rocks of the Oumachoueima Group. Reasons for the absence of mineral occurrences in all other rocks of the Inchiri district are unclear.

Rocks in the Inchiri district are an allochthonous package consisting of Mesoarchean to Paleoproterozoic gneisses and metamafic volcanosedimentary rocks in tectonic windows within an imbricated supracrustal nappe pile of Paleoproterozoic to Neoproterozoic rocks of wide-ranging lithologies. This infrastructural allochthon (Pitfield and others, 2004) was emplaced over autochthonous to para-autochthonous rocks of the Amsaga Complex and foreland basin sedimentary rocks of the Taoudeni Basin during the Pan African through Hercynian Mauritanide orogeny. The allochthon consists of four internally imbricated nappes (fig. 3 and table 1).

The Agoualilet Group, consisting of a mafic melange interspersed with siliciclastic sedimentary rocks, forms the root zone and regionally extensive basal nappe of the allochthon. It forms a western block at the southwestern edge of the Akjoujt nappe pile and an eastern block well to the southeast of the Ijibbitene nappe (fig. 3). The Tamagot basement window or tectonic inlier, together with the Bou Kerch nappe, are located along the eastern edge of the Agoualilet Group root zone southwest and south of the village of Akjoujt. These rocks consist of the Tamagot orthogneiss and mafic igneous rocks, banded iron formation (BIF), and sedimentary rocks of the Saouda Group that together exhibit characteristics of an Archean granite-greenstone association. They are the oldest rocks in the allochthon and are thought to be an eastward-transported southern section of the Mesoarchean Tasiast-Tijirit terrane. In the Bou Kerch nappe, rocks of the Saouda Group tectonically overlie and are imbricated with quartzitic metasediments of the Agoualilet Group (fig. 3; Pitfield and others, 2004).

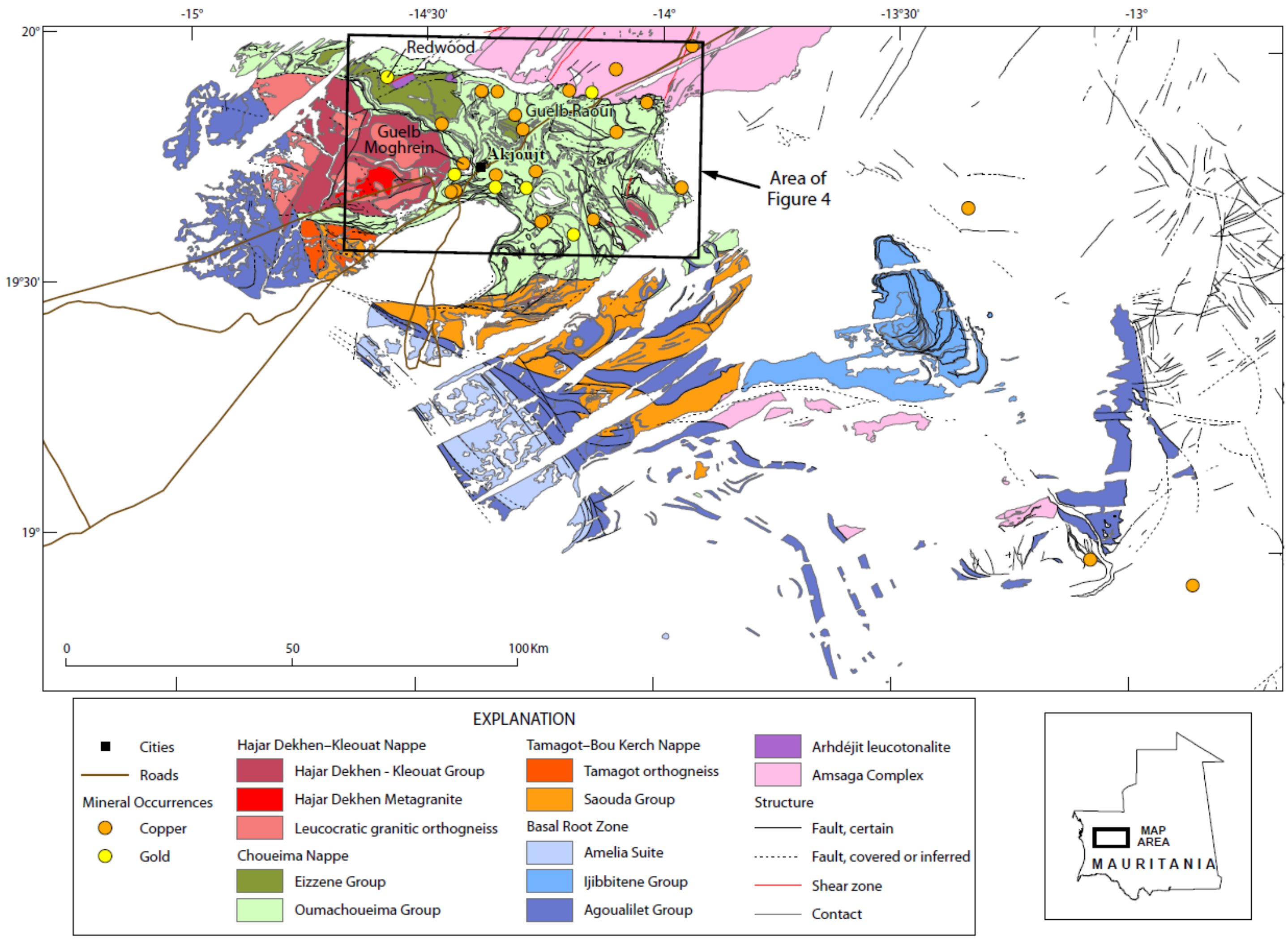

Figure 3. Simplified Geology of the of the Inchiri district showing the various nappes and tectonic windows of the Akjoujt nappe pile and deposits and mineral occurrences discussed in text.

Table 1. Tectonic units and component lithostratigraphic groups of the Akjoujt nappe pile (from Pitfield and others, 2004).

Tectonic unit	Lithostratigraphic divisions	Metamorphic grade
Hajar Dekhen nappe	Hajar Dekhen-Kleouat Group	Middle to upper amphibolite facies
Choueima nappe	Oumachoueima and Eizzene Groups	Prehnite-pumpellyite to upper greenschist facies
Basal nappe	Agoualilet Group	Lower to middle greenschist facies
Bou Kerch nappe	Saouda Group	Upper greenschist to middle amphibolite facies

To the east and north, the Tamagot window and Bou Kerch nappe are overthrust by the Choueima nappe, which comprises the volcanosedimentary host rocks to numerous mineral occurrences of the Inchiri district. The nappe is centered on the village of Akjoujt (fig. 3) and consists of the Eizzene and Oumachoueima Groups separated by an angular unconformity. The older Eizzene Group consists of a lower sequence of mafic volcanic rocks, the Raoui Formation, overlain by the Khmeiyat Formation consisting of BIF and semipelitic schists. The Eizzene Group is unconformably overlain by the Oumachoueima Group, which commences with the Atilis Quartzite member of the clastic Irarchene El Hamra Formation. The Irarchene El Hamra Formation is overlain by volcanogenic sedimentary rocks and BIF of the Atomai Formation, which is in turn overlain by proximal volcanic to distal volcaniclastic rocks of dominantly intermediate composition of the Sainte Barbe Formation. The Sainte Barbe Formation is capped by a widespread marker unit consisting of chert and BIF of the Lembeitih Formation. The stratigraphy culminates in a monotonous pile of submarine basalts and related microgabbroic intrusive rocks of the Akjoujt Formation (Pitfield and others, 2004). Detailed geology of the Akjoujt nappe pile is shown in figure 4. The stratigraphy of the Akjoujt nappe pile and possible correlations to other rocks described in this section is shown in figure 5.

The structurally highest nappe in the Akjoujt nappe pile is the Hajar Dekhen-Kleouat nappe which overlies the Choueima nappe primarily to the west of Akjoujt (fig. 3). Rocks of the Hajar Dekhen-Kleouat Group consist of amphibolite facies supracrustal metamorphic and granitic rocks. Previously thought to consist of overthrust basement, the nappe also contains rocks of the Eizzene and Oumachoueima Groups. Correlation of rocks in the Hajar Dekhen-Kleouat nappe depend on the age and correlation of the Eizzene Group (Pitfield and others, 2004).

An additional nappe is located to the east of the Akjoujt nappe pile and consists of metavolcanosedimentary rocks of the Ijibbitene Group (fig. 3). The Ijibbitene nappe is tentatively correlated with the lower part of the Choueima nappe (Pitfield and others, 2004).

The task of defining rock packages in the Inchiri district that are permissive for the occurrence of VMS deposits is hampered by the structural complexity for the region. Because VMS deposits are syngenetic accumulations of ore minerals that form on and just beneath the seafloor during the construction of volcanosedimentary sequences, factors that control their distribution include primary structural and volcanostratigraphic features such as: high-angle, synsedimentary normal faulting, evidence for the emplacement of synvolcanic intrusions and co-genetic extrusive rocks, changes in the style of volcanism (for example, transitions felsic to mafic volcanic rocks) and proximal to distal successions of volcanic rocks, volcaniclastics, and volcanogenic sedimentary rocks. These features are important in identifying heat engines necessary to drive convective hydrothermal circulation through subseafloor metal source-rock packages and locating the more favorable flanks of constructive volcanic edifices that may give way to adjacent fault grabens or second order basins that serve as depositories for the volcanosedimentary host rocks and associated exhalative sulfide accumulations. Such primary relationships in the Mesoarchean to Neoproterozoic rocks of the Inchiri district are obscured by Pan African to Hercynian tectonic events that happened tens to hundreds of million years after deposition of permissive host rocks.

At the most basic level, rocks considered permissive of VMS deposits in the Inchiri district include all identifiable submarine volcanosedimentary sequences. Additional favorable criteria include the presence of synvolcanic intrusions and volcanosedimentary sequences that show a change in the style of volcanism or the presence of multiple volcanosedimentary cycles. More detailed studies necessary to define volcanostratigraphy or identify synsedimentary faults and local volcanosedimentary depositories within the district are not available.

Both the western and eastern blocks of the basal nappe composed of the Agoualilet Group contain volcanosedimentary rocks and associated co-genetic (?) intrusions that are permissive of VMS deposits (fig. 3). The western block contains a melange of metabasic intrusive rocks with lenses and screens of metavolcanic, metaultramafic and metasedimentary rocks named the Amleila Suite that is overlain along its eastern side by a 2–4 kilometer (km)-wide strip of basaltic metavolcanics and lesser metagabbroic intrusive rocks of the Adam el Bouje Formation (Pitfield and others, 2004). This core of the western block is surrounded on all sides by predominantly quartzites and other sedimentary rocks of the Toueirja Subgroup that are of uncertain relationship to the Agoualilet Group volcanosedimentary rocks, and that extend to the south as individual nappes or slices. Rocks of the Toueirja Subgroup are not regarded as permissive of VMS deposits.

The eastern block consists of the polydeformed volcanosedimentary succession of the Treïfiyat Formation. The formation is characterized by an association of metabasaltic lavas and volcaniclastics, calc-chlorite±sericite schists, metasiltstones, calc-quartzites, metalimestones and rare banded iron formation units. It is exposed over a large area to the south and southeast of the Ijibbitene Massif and overlies and is imbricated with basement rocks of the Amsaga Complex (fig. 3). For the purposes of this report the entire mapped exposure of the Treïfiyat Formation is considered permissive for the occurrence of VMS deposits in the absence of more detailed mapping. It is noteworthy that Pitfield and others (2004) describe volcanic facies transitions near the Tamarkart escarpment that include semi-massive mafic volcanic rocks and highly carbonated blocky volcaniclastic rocks that become schistose and are cut by lenticular quartz-ankerite-calcite ± pyrite veins.

Correlation of the metamafic igneous suite of the Agoualilet Group with the Gorgol Noir Complex of the Southern Mauritanides (Pitfield and others, 2004; see below) supports the permissive nature of these rocks in the Inchiri district. The submarine metabasaltic volcanics of Adam el Bouje Formation (western block) and Treïfiyat Formation (eastern block) are comparable to the El Gueneiba Group volcanic rocks whereas the fragmented intrusive metamafic-metaultramafic complex paired with quartzites of the Toueirja Subgroup has many similarities with the Gadel Group (Pitfield and others, 2004). The El Gueneiba Group is interpreted to be a rift basin assemblage of mafic volcanic rocks and associated sedimentary rocks and the Gadel Group, an ophiolite mélange composed of a structurally complex assortment of mafic volcanic rocks and sedimentary rocks juxtaposed with gabbros and ultramafic rocks. The presence of numerous mafic-type (Cyprus-type) VMS occurrences in the southern Mauritanides implies favorable potential for similar deposits in the Agoualilet Group of the Inchiri district. However, there are no geochemical or geochronological data available for rocks of the Agoualilet Group with which to further evaluate either the type of volcanism or correlation with similar rocks in the southern Mauritanides.

The current understanding of the Saouda Group in the Tamagot window and Bou Kerch nappe (fig. 3) suggests that these predominantly mafic metavolcanic rocks with ubiquitous BIF represent an Archean (?) granite-greenstone sequence that may be related to the Tasiast-Tijirit terrane. The granite-greenstone-like geometry is primarily based on the complexly interfolded nature of the Saouda Group greenstones with orthogneiss in the Tamagot window and is extrapolated to the mafic metavolcanosedimentary succession of the Bou Kerch nappe. Available geochronologic data on these rocks are sparse and are limited to ^{40}Ar-^{39}Ar studies (Dallmeyer and Lécorché, 1990a). A total gas age of 2,035 ±11 Ma was obtained for an amphibole concentrate from Saouda Group rocks of the Bou Kerch nappe. Argon dating of muscovites from a garnet-mica schist and a leucogratic gneiss from the Saouda Group gave mixed Mesoproterozoic and upper Paleozoic ages, however these data display internally discordant spectra that suggest thermal disturbance of mineral systems as old as 2,600 Ma (Pitfield and others, 2004). Correlation of mafic metavolcanic rocks in the Zemzem tectonic window of the southern Mauritanides with the Saouda Group of the Inchiri district and a U-Pb zircon age of 2,683±22 Ma on an associated Zemzem metamicrogranodiorite strengthens the probability that rocks of the Bou Kerch nappe are at least Neoarchean age (Pitfield and others, 2004). However, as discussed above, the greenstone successions of the Tasiast-Tijirit terrane are Mesoarchean in age and are approximately 300 million years older than rocks of the Saouda Group. Thus, the association of greenstones of the Saouda Group with comparable rocks in the Tasiast-Tijirit terrane is tenuous. No geochemical data are available for comparison.

There are currently no known mineral occurrences of any type present within rocks of the Saouda Group. The dominantly metamafic assemblage contains two major lithologies: amphibolites and metamafites, and chloritic schists. The amphibolites are generally medium to fine grained and are mostly slatey to schistose. Medium grained amphibolites may represent co-genetic micrograbbroic intrusions. A small layered gabbro body associated with serpentinites and metacarbonate rocks (marble) is restricted to the southern limit of exposure of the Saouda Group/Bou Kerch nappe. The chloritic schists include variably quartzitic chlorite-sericite and calc-chlorite-sericite schists, which contain thin metalimestone horizons (Pitfield and others, 2004). The presence of ubiquitous thin and impersistent BIF and lesser metachert layers throughout both major lithologic assemblages indicate that seafloor exhalative processes responsible for Algoma-type iron formation were operative during deposition of the mafic volcanosedimentary succession and are encouraging for the possible occurrence of mafic volcanic rock-related VMS. Without further geochemical data on the metavolcanic rocks or descriptive information on mineral occurrences, the entire Saouda Group must be regarded as permissive of mafic- and possibly pelite-mafic-types of VMS. The absence of intermediate to felsic volcanic rocks precludes the presence of other VMS subtypes.

The Choueima nappe overthrusts the Bou Kerch nappe and consists of at least two major volcanosedimentary successions separated by an unconformity (figs. 4 and 5). The lower Eizzene Group forms the first succession and is dominated by mafic volcanic rocks overlain by BIF and semipelitic schists. The Eizzene Group is present in two outcrop areas to the north of Akjoujt near the northern margin of the nappe (fig. 4). The lower portion of the Eizzene Group consists of monotonous metabasalts of the Raoui Formation; in contrast to metavolcanic rocks of the Oumachoueima Group, co-genetic intrusive rocks are absent. Geochemical data for Raoui Formation metabasaltic rocks indicate subduction-volcanic arc affinities (Pitfield and others, 2004). The overlying Khmeiyat Formation is marked by a regionally extensive BIF at the base followed by an entirely metasedimentary succession characterized by low-grade, pelitic to semi-pelitic schist-phyllites with psammitic subgraywackes, quartzites, and intermittent thin BIF (Pitfield and others, 2004). Based on these descriptions and the favorable presence of exhalative iron formation, the Eizzene Group is permissive of pelite-mafic-type VMS. Of the many mineral deposits and occurrences that occur in the Choueima nappe, only two occurrences are hosted in rocks of the Eizzene Group. The Redwood gold occurrence is located near the northern limit of outcrop of the Khmeiyat Formation and is described as visible gold and high gold analytical values in northeast-trending ferruginous quartz veins cutting brittle-fractured quartzites. The Guelb Raoui copper occurrence is described as malachite hosted in quartzite in the Raoui Formation on Guelb Raoui (Marsh and Anderson,2015).

The second volcanosedimentary succession of the Choueima nappe consists of the Oumachoueima Group (fig. 5), which hosts the majority of known mineral occurrences of the Inchiri district. It is the most aerially extensive rock unit present in the district and occupies the majority of the center, northern, and northeastern portion of the Akjoujt nappe pile (fig. 4). It overlies the Amsaga terrane above a major sole thrust fault along the northern margin of the district and is in thrust contact with the overlying Hajar Dekhen-Kleouat nappe along a curvilinear western boundary. From its unconformable basal contact with the Eizzene Group, the Oumachoueima Group passes upwards from siliciclastic through pelitic sedimentary rocks into andesite-dacite derived volcaniclastic and proximal volcanic rocks followed by submarine basaltic flows and synvolcanic intrusions. BIF units occur at several stratigraphic levels within the Group (Pitfield and others, 2004).

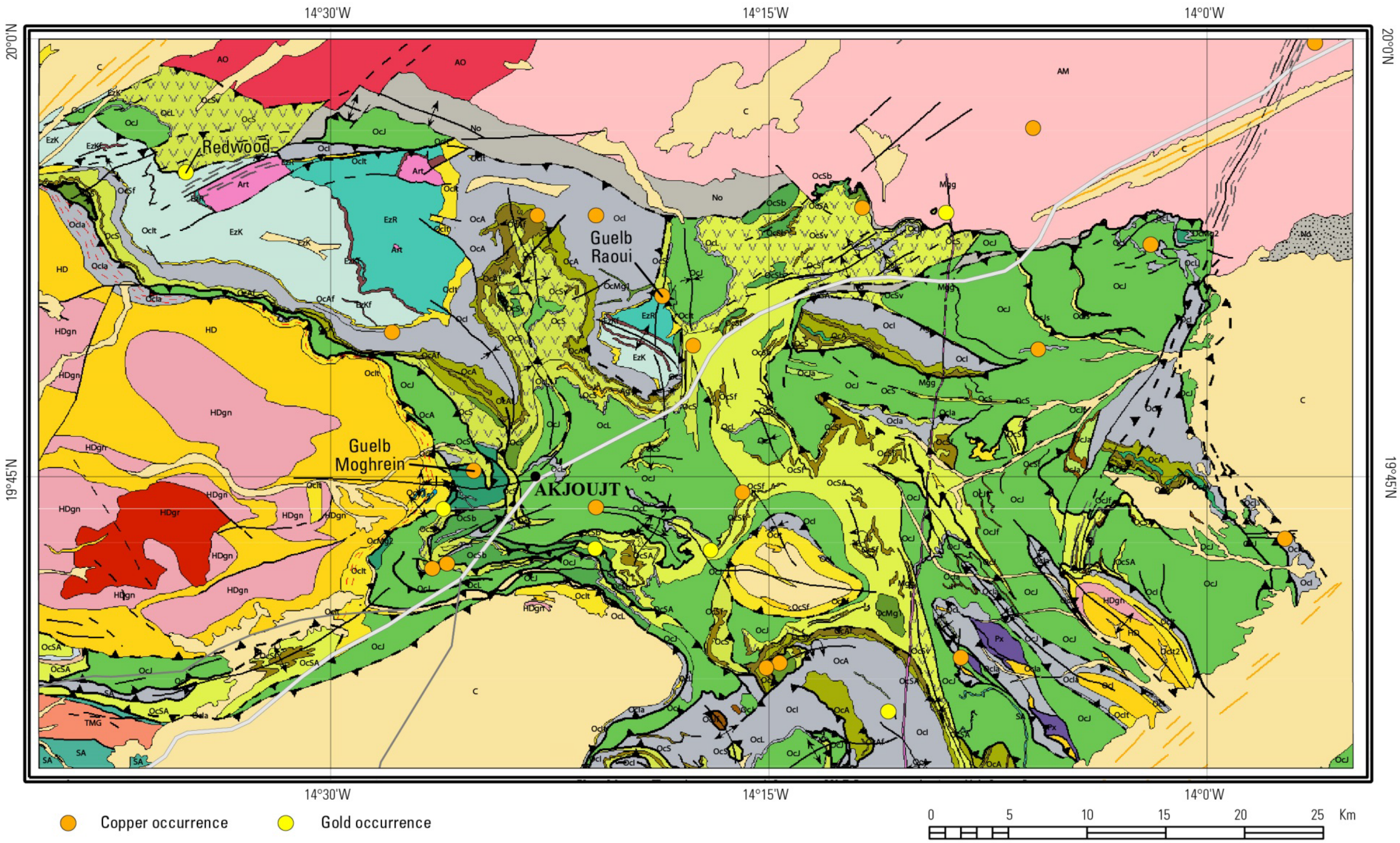

Figure 4. Detailed geology of the Akjount nappe pile (from Pitfield and others, 2004).

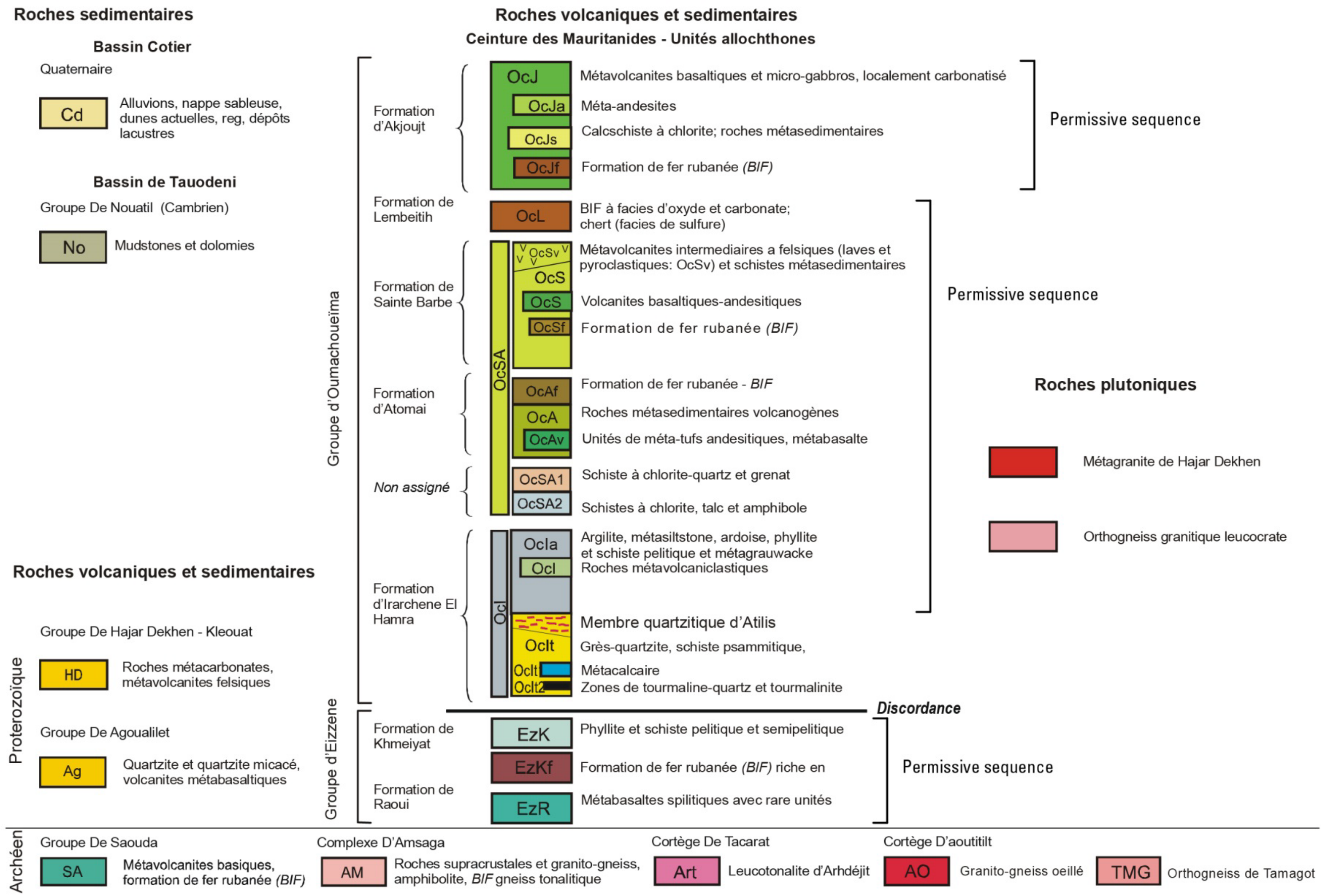

Figure 5. Stratigraphic section and correlation diagram of rocks in the Akjoujt nappe pile (from Pitfield and others, 2004).

The basal sedimentary portion of the sequence, the Irarchene El Hamra Formation, transitions from the Atilis Quartzite Member at its base into dominantly quartz-chlorite±muscovite schists (fig. 5). The schists contain quartz-rich subgraywackes and thin quartzites in the lower part and thin greenish volcanogenic metagraywackes towards the top. Rare amygdaloidal metabasalt flows and metabasic sills are also present (Pitfield and others, 2004). The overlying Atomai Formation is dominantly composed of volcanogenic siltstone and graywacke metamorphosed to chlorite±sericite+quartz±carbonate schists with quartz-carbonate-magnetite BIF horizons ranging up to several tens of meters in thickness. The BIFs vary in composition but are dominated by Fe-carbonate and quartz with unevenly distributed magnetite. Tabular to podiform coarse-grained ankeritic Fe-Mg carbonate ± quartz and magnetite occur sporadically within or adjacent to the iron formations. Fine grained, massive, millimeter- to centimeter-scale banded, oxide facies hematite-magnetite-quartzite BIF ± muscovite, chlorite, and tourmaline are also present and contain introduced calcite and Fe-carbonates. Thin units of locally pillowed metabasalt and metamicrogabbro sills occur sporadically in the upper part of the formation (Pitfield and others, 2004). Pitfield and others (2004) describe an area of undifferentiated Irarchene El Hamra and Atomai Formation rocks in the antiformal window between the Hajar Dekhen and Kleouat subareas of the overlying nappe that contain massive amphibolites and garnet porphyroblastic quartz-mica-chlorite schists with up to 35 percent sieve-textured garnets. In thin section these rocks consist of equal proportions of garnet, quartz, and chlorite with minor muscovite, biotite, clinozoisite, accessory zircon and opaque ore minerals (ore mineralogy not described). Mineral textures suggest that garnet formation relates to an early event.

The Sainte Barbe Formation overlies the Atomai Formation and consists primarily of intermediate to felsic volcanics and related volcaniclastic rocks. To the northeast of Akjoujt in the area of the Irarchène massif the Sainte Barbe Formation consists of proximal volcanic facies such as extensive lavas, pyroclastics, welded tuffs and agglomerates and may represent an eruptive center. Compositionally, the Sainte Barbe volcanic rocks range from andesite to dacite with lesser high-K basalts and quartz-phyric rhyolites. Southward of the Irarchene massif the Sainte Barbe volcanic rocks become increasingly dominated by lapilli-sized volcaniclastic rocks at the expense of lavas and coarse pyroclastics. South of the main Nouakchott-Atar highway the formation is represented by fine volcaniclastic sedimentary rocks that are virtually indistinguishable from rocks of the underlying formation (Pitfield and others, 2004).

Geochemical analyses of mafic volcanic rocks from the lower part of the Oumachoueima Group display distinctive subduction-related volcanic arc signatures similar to mafic rocks of the Eizzene Group. Synvolcanic microgabbroic intrusions in the lower part of the Oumachoueima Group also have clear subduction-related volcanic arc geochemical signatures (Pitfield and others, 2004) and are probably co-genetic.

The Sainte Barbe Formation culminates in a regionally distinctive BIF marker horizon named the Lembeitih Formation (fig. 5), which is generally less than 10 meters (m) thick and varies from recrystallized pyritic chert in the Guelb Moghrein mine, to quartz-magnetite or hematite iron formation towards Loueibda, and quartz-carbonate-magnetite banded iron formation in the El Joul-El Khader area. The uppermost unit of the Oumachoueima Group overlies the Lembeitih BIF and consists almost entirely of submarine basalts, microgabbros and their tectonized equivalents of the Akjoujt Formation. The dominant rock type is a fine-grained non-porphyritic tholeiitic metabasalt that is rarely well exposed and occasionally exhibits shapes that may be pillows. The microgabbros, interpreted as synvolcanic intrusives, are almost as common in some areas. The synvolcanic metamicrogabbro intrusions locally form block fields and are amphibolitic but primary igneous texture is still discernible (Pitfield and others, 2004). In contrast to other mafic rocks of the Eizzene and Oumachoueima Groups, the geochemistry of the Akjoujt basalts indicate a change in both composition and volcanic style from subduction related arc affinities to those more closely related to E-MORB or T-MORB magmas.

With regard to the occurrence of VMS in the Eizzene and Oumachoueima Groups, the variation in the geochemistry and the changing style of the volcanosedimentary successions described above are quite significant. Three separate volcanosedimentary sequences with associated co-genetic (?) synvolcanic intrusions, exhalative iron formation, and possibly with associated hydrothermal alteration are present and are all permissive for the occurrence of different subtypes of VMS. The basal metavolcanic sequence and overlying politic sedimentary rocks of the Eizzene Group are permissive of pelite-mafic-type VMS. The next permissive sequence is perhaps the most favorable and consists of the upward transition from siliciclastic sedimentary rocks and quartz-chlorite±muscovite schists with synvolcanic intrusions of the Irarchene El Hamra Formation and Atomai Formations grading into the andesite-dacite derived volcaniclastic and proximal volcanic rocks of the Sainte Barbe Formation. The abundance of BIF and the possibility that the garnet-bearing schists may represent aluminum-rich hydrothermal alteration related to seafloor hydrothermal systems are favorable indicators for the occurrence of pelite-mafic-type VMS, and the evolution of the sequence to include probable volcanic centers with intermediate to felsic volcanism is permissive of bimodal-felsic type VMS. Finally, the abrupt transition to the primitive, mafic dominated volcanic style of the Akjoujt Formation exhibiting submarine basaltic flows and synvolcanic intrusions that may indicate evolution of the system into a deeper back arc-like tectonic setting. The Akjoujt basalts are permissive of mafic and pelite-mafic types of VMS.

Due to the complex structural relationships in the Akjoujt nappe pile, age relationships of rocks in the Oumachoueima Group are critical for establishing the volcanosedimentary history of the district and consequently the metallogenic history. The prime example is the conflicting age assignments for the Akjoujt Formation basalts. Structural and stratigraphic reconstructions place the Akjoujt basalts above the Lembeitih BIF at the top of a succession that is generally regarded to be Neoproterozoic in age based on detrital and inherited U-Pb zircon determinations (Pitfield and others, 2004). However, authigenic monazite and xenotime from Guelb Moghrein mine ore assemblages hosted by the Akjoujt Formation yield much older U-Pb dates of 2,492 Ma on monazite and 1,742 Ma on xenotime. These ages are interpreted as minimum ages of mineralization and remobilization, respectively. Additional conflicting data include a reported K-Ar date of 393 Ma on metamorphic muscovite, K-Ar dates on skarn minerals ranging between 829 and 626 Ma, an $^{40}Ar/^{39}Ar$ date on amphibolite of 1.7 Ga, and a K-Ar date on metagabbro of 3.6 Ga. (Marutani and others, 2005; Meyer and others, 2006). New detrital zircon data obtained by the USGS during this study, including from sedimentary rocks below the ore-hosting volcanic rocks, show no evidence of material older than Neoproterozoic (fig. 6; Bradley and others, 2015). Numerous workers have commented on the abundance of iron formation in the district and that the general appearance and structural style of the metamafic volcanosedimentary sequences are similar to Archean greenstone sequences. It is likely that tectonic windows of Archean rocks similar to the Tamagot window and the Arhdejit leucotonalite are present in the Akjoujt nappe pile and are as yet unidentified.

In contrast to the absence of base and precious metal occurrences in the other thrust nappes and tectonic windows of the Inchiri district, the Choueima nappe is well mineralized with over 18 known Au and Cu±Au deposits and occurrences including the currently producing Guelb Moghrein mine (Marsh and Anderson, 2015). Most if not all of these occurrences are hosted in Fe-Mg-rich metacarbonate bodies in breccias and shear zones associated with Pan African to Hercynian thrust faulting and appear to be epigenetic, structurally controlled styles of mineralization. They are currently regarded as unusual, carbonate-hosted variants of IOCG deposits (Kolb and others, 2008; Kirschbaum, 2011). However, possibilities also include skarn, orogenic gold, and VMS deposit types (see Goldfarb and others, 2015; Fernette, 2015a). Despite the permissive characteristics of the volcanosedimentary successions in the Inchiri district described above, none of the known occurrences exhibit features that are best attributed to syngenetic VMS types of mineral deposits. Reviews of the characteristics and available data for the known occurrences of the district are therefore provided in companion reports by the USGS (see Goldfarb and others, 2015; Fernette, 2015a).

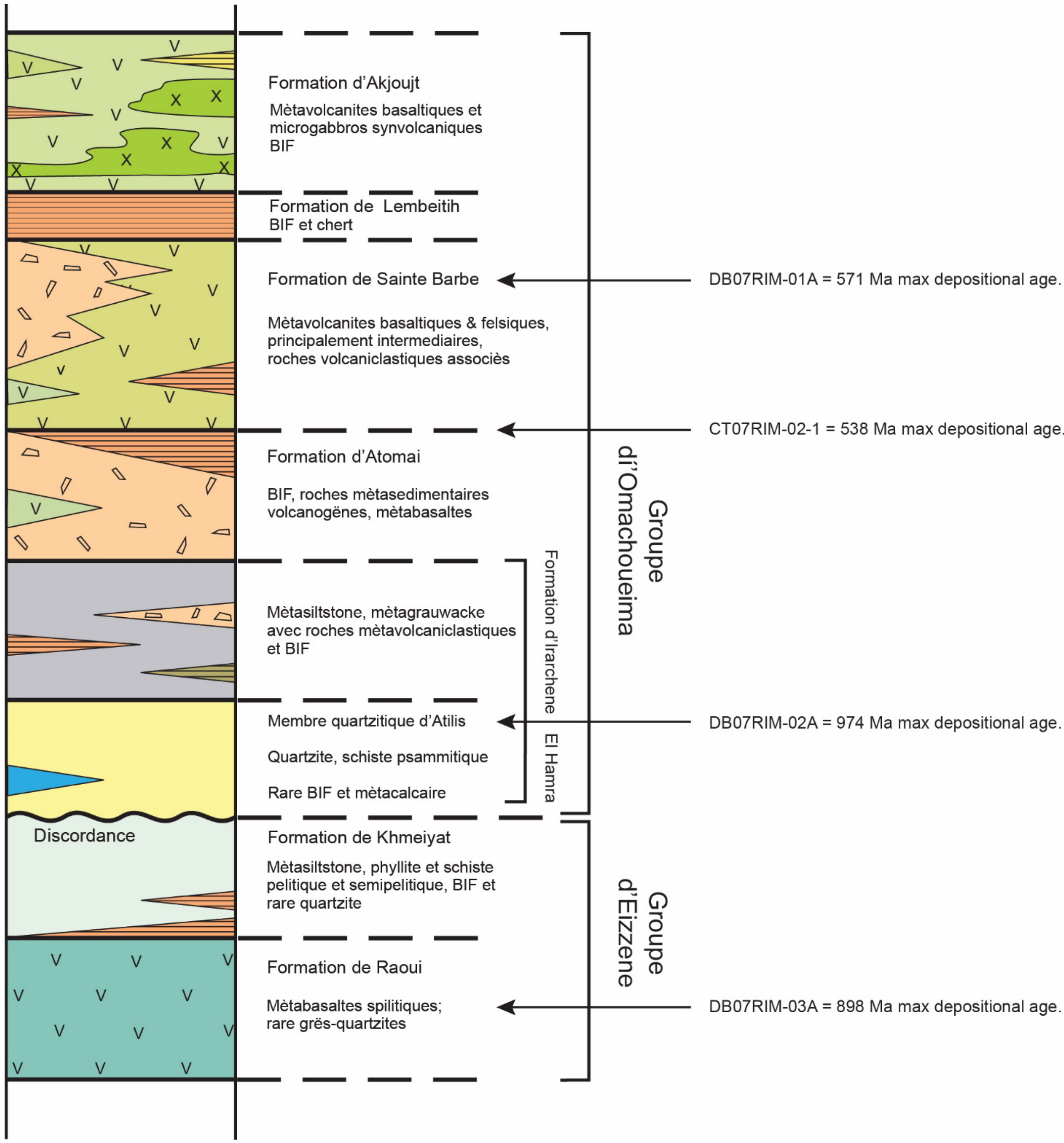

Figure 6. Detrital zircon maximum depositional ages of rock units in the Chouiema nappe. Structural-stratigraphic column (from Pitfield and others, 2004).

3.2.2 Southern Mauritanides

The area here referred to as the southern Mauritanides consists of the Mauritanide orogen from about latitude 17° south to the Senegal border. The host rocks in the southern Mauritanides are dominantly Neoproterozoic through Cambrian metasedimentary and metavolcanic units that were accreted to and thrust upon the Gondwanan continental margin during early Paleozoic Pan-African tectonism in West Africa. Collision with the North American craton during Hercynian times (approximately 330–270 Ma) reactivated many of the structures from this earlier collisional orogen and formed the Appalachian-Mauritanian belt, which later broke apart during Triassic rifting.

Numerous occurrences of variably mineralized stratiform Mn-Ba- (Cu, Zn, Pb, Fe, Au, Ag, As, Sb, Mo) are hosted primarily in felsic metavolcanic rocks and metasediments of the El Mseigguem Group and to a lesser extent in the overlying metasedimentary rocks of the El Ghabra Group of the Mbout Supergroup. These occurrences are best exemplified by Bou Zrabie, Mbout, Harach, and Ouechkech, and exhibit features that are similar to bimodal-mafic-type (Kuroko-type) VMS deposits or pelite-mafic-type (Besshi-type) VMS deposits. Despite the structural complexity of the southern Mauritanides, the persistence of mineralized stratigraphic horizons at many of these occurrences that are traceable for up to 15 km, suggests the potential for additional discoveries. The comparison of the southern Mauritanides with the metallogeny of the southern Appalachians is also regarded as favorable. In the Appalachians early Paleozoic gold-rich VMS deposits were sometimes misclassified as epigenetic orogenic gold deposits; both deposit types could also be present in the Mauritanides (Goldfarb and others, 2015). Some uncertainty regarding the assignment of deposit type exists, as metallogenic interpretations of the region by the BGS (Gunn and others, 2004) and BRGM (Salpeteur, 2005) suggest that these occurrences may be sedimentary exhalative (SEDEX) type occurrences. However, the presence of SEDEX deposits is regarded as unlikely given the tectonically active, non-basinal environment of the Mauritanide chain (Mauk, 2015).

Additional potential exists in the southern Mauritanides for the occurrence of mafic-type (Cyprus-type) Cu-Zn±Au VMS deposits associated with the podiform chromite deposits in the mafic-ultramafic ophiolitic rocks of the Gorgol Noir Complex. A number of oxide capped Fe-Cu-Au, deposits such as Kadiar, Oudelemguil, Daiguili, and especially Hassi el Aoueija have been described as "Guelb Moghrein-type" occurrences hosted in chlorite-talc schist and iron carbonate (Gunn and others, 2004). However, these occurrences are hosted in rocks of the El Gueneiba Group, interpreted to be a rift basin assemblage of mafic volcanic rocks and associated sediments and the Gadel Group, an ophiolite mélange composed of a structurally complex assortment of mafic volcanic rocks and sedimentary rocks juxtaposed with gabbros and ultramafic rocks. This geologic and tectonic setting is permissive of mafic-type (Cyprus-type) VMS deposits.

The southern Mauritanides consist of a north-south trending pile of thrust slices of allochthonous and parautochthonous units juxtaposed against the Neoproterozoic to Paleozoic rocks of the western Taoudeni Basin foreland sequence (Le Page, 1988; Pitfield and others, 2004). The parautochthonous zone lies between the foreland and the infrastructural allochthonous zone to the west and consists of deformed sedimentary rocks of the Adrar Supergroup imbricated with local basement inliers or tectonic windows (such as the Zemzem window). The infrastructural allochthonous zone consists of imbricated ophiolites, continental margin rift-facies and calc-alkaline igneous complexes. Two major tectono-stratigraphic divisions are recognized in the southern Mauritanides: (1) the western side of the allochthon consists of calc-alkaline metavolcanic and metasedimentary supracrustal rocks with mainly greenschist facies mineral assemblages, collectively termed the Mbout Supergroup, and (2) an eastern belt consisting of a tectonic melange and associated metavolcanic and intrusive rocks, termed the Gorgol Noir Complex, typified by greenschist to high- pressure amphibolite facies mineral assemblages (fig. 7; Pitfield and others, 2004).

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 Hercynian time. 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 Appalachian deformation at about 300 Ma.

Mbout Supergroup

The Mbout Supergroup consists of four parallel north-south trending zones separated by east-directed thrusts. The two outer zones consist of the El Harach Group in the east and the El Fadra Group in the west and are dominantly pelitic metasedimentary sequences. The El Harach Group is essentially a metasedimentary unit with minor metamorphosed bimodal volcanic intercalations in its southern outcrops. There is little to constrain possible interpretations for the origin of the sequence but the lateral continuity of relatively thin quartz-arenite units suggests incursions of sand and tuff into a mud-dominated marine sequence. The northern outcrops are dominated by altered semipelitic to pelitic sedimentary rocks thought to be proximal deposits derived from a granitic source. The two central zones consist of the El Ghabra and El Mseigguem Groups and are characterised by intermediate to felsic metavolcanic rocks.

The El Mseigguem Group (fig. 7) is divided into two formations. The Bathet Jmel Formation is dominated by metabasic rocks intercalated with pelitic schist and the structurally underlying Ouechkech Formation is composed largely of felsic metavolcanics and subvolcanic intrusions and discontinuous slivers of meta-andesitic rocks. The metabasic volcanic rocks of the Bathet Jmel Formation include intensely foliated fine-grained chlorite schist (possibly a metatuff) with a variable proportion of 1–2 millimeter feldspar porphyroclasts, and more massive volcanic breccia. The metabasite locally contains manganiferous garnet, which is associated with pods of complex manganiferous alteration, which at least in part pre-dates the regional foliation. Manganese mineralization is well-developed 6 km east of Mbout in a zone up to 30 m wide and exposed over 2 km along strike. Massive, brecciated and vein-hosted Mn-oxide occurs with variable amounts of barite and quartz, the latter also forming late irregular veins and quartz reefs which are in part mylonitised. The manganese mineralization can be traced northwards along this zone for more than 30 km.

The Ouechkech Formation consists of basal metaandesitic rocks and highly silicic felsic metavolcanic rocks consisting mostly of fine to medium grained, quartz-feldspar-sericite-schists. Geochemical profiles indicate a subduction-related arc type setting with some within-plate affinities. The presence of chlorite in the metapelites and epidote in the felsic schists suggests greenschist facies metamorphic grade. Garnet occurs locally in the metabasic volcanic rocks but is probably related to early host rock alteration rather than an indicator of higher metamorphic grade. The nature of the original depositional environment is masked by intense deformation. However, a clastic texture in the greenstone breccia units is preserved and it is likely that these represent units of lapilli tuff and (or) pillow breccia. Fine-grained chloritic and felsic schists probably represent tuffs, and feldspar-rich chlorite schists may represent tuffs or feldspar-phyric lavas (Pitfield and others, 2004). Available geologic descriptions suggest that the Formation may represent a shallow marine to emergent volcanosedimentary edifice. A felsic pluton cutting the metavolcanic rocks of the Ouechkech Formation yielded a U-Pb zircon age of 637±5Ma, whichprovides a minimum age for the El Mseigguem Group (Pitfield and others, 2004).

Co-genetic granites are assigned to the Kelbé Suite. The Kelbé Suite consists of an assembly of potassic granites that have been emplaced within the Mbout Supergroup and are dominantly hosted by felsic to intermediate volcanic rocks of the El Ghabra and El Mseigguem Groups (fig. 7). Lithological types range from mesocratic monzodiorite to leucosyenogranite, but the suite is mainly composed of strongly deformed two-mica granites. The mixed S-type and I-type characteristics of the intrusions suggests emplacement during progressive plate closure and collision (island arc-continent and continent-continent). The age relationships of the granites further suggest that the El Mseigguem Group volcanic rocks are younger than those of the El Ghabra Group (Pitfield and others, 2004).

The El Ghabra Group is a mixed sequence of basic through intermediate to felsic metavolcanic and metasedimentary rocks that tectonically overthrust the El Mseigguem Group to the east and are in turn overthrust in the west by the El Fadra Group. This calc-alkaline assemblage is typical of a subduction-related volcanic arc association characteristic of tectonically active continental margins. It is divided into three formations consisting of tectonically upper and lower schists of the Oued Erdi and Ould Moïlïd Formations separated by a conspicuous outcrop of arenitic quartzite named the Oua Oua Formation.

The Oued Erdi Formation is host to known VMS occurrences in the El Ghabra Group. It consists of mixed schists of volcanogenic derivation and includes basic to intermediate and felsic volcanic rocks. The metabasic to metaandesitic volcanic rocks (prasinites) have distinctive dull green to bluish-green weathered appearance due to chlorite and epidote which is associated with quartz, feldspar, and variable amounts of pyrite and other opaque minerals. Volcaniclastic textures are locally preserved. Secondary carbonate associated with quartz and chlorite is common and more basic lithologies contain talc. Meta-andesite is fine-grained and epidote-rich with quartz, feldspar and altered mafic grains. Some of the best exposures of metavolcanic lithologies are around El Ghabra village immediately west of the northern part of the Oua Oua hills (fig. 7). Fine grained schistose metadacites host a number of mineral occurrences north of El Ghabra village. Clastic textures are locally preserved. The rocks are locally phyllitic with pyrite cubes in a very fine-grained groundmass. Secondary epidote is common. Previous workers have interpreted them as metafelsic volcanic rocks. Minor quartzite beds in the schist are also present and contain barite seams. Elsewhere the Oued Erdi

Formation is dominated by variably chloritic quartz-sericite-hematite-schist. Altered horizons of sericitic quartzite, pelitic schist and chlorite schist occur on a scale of several meters to tens of meters near the structural top of the mixed schist unit near Foum El Gleitat. The minimum age of the El Ghabra metavolcanic rocks is established by the 680 Ma age of the crosscutting Kelbé Suite granites (Pitfield and others, 2004).

Like the El Harach Group, the El Fadra Group is dominantly a pelitic metasedimentary sequence. It is characterized by schistose volcaniclastic and epiclastic metasedimentary rocks with subordinate units of felsic to mafic volcanic rocks. The most common rock types are sericite schists and phyllites, mica schists, arkosic or felsic schists, schistose metasiltstones, felsic arenites, graywackes and metatuffs. Carbonates, quartzites, prasinites and metagabbros are locally present. The metasiltstones and fine meta-arenites locally carry disseminated pyrite. The metagabbros are strongly foliated to semischistose and are interpreted as early intrusions (Pitfield and others, 2004).

Quartz veins as well as larger elliptical bodies ('reefs') of white quartz are common throughout the outcrop area of the Fadra Group and are generally orientated N-S with individual lenses up to several hundred meters in length and tens of meters thick. The larger quartz reefs have multiple injections of milky and clear quartz commonly associated with brittle fractures. Zones of more complex quartz-carbonate-hematite veining and are likely more permissive of orogenic gold occurrences than VMS. No visible gold was detected. Muscovite and minor amounts of pyrite are locally associated with quartz (Pitfield and others, 2004). Due to the dominantly sedimentary nature of both the El Harach and El Fadra Groups, they are not regarded as part of the permissive tracts for VMS in the southern Mauritanides.

Gorgol Noir Complex

The Gorgol Noir Complex consists of ophiolite and continental margin–rift facies sequences divided into three tectonically imbricated groups, each with characteristic lithologies (fig. 7). First, the upper western Guidamaka Suite consists of massive gabbro and associated more felsic intrusive rocks. The intrusive suite has many of the characteristics of a plagiogranite association but is metasomatically altered and exhibits some crustal inheritance. Second, the lower eastern El Gueneiba Group consists of a middle-upper greenschist facies oceanic lithospheric or ophiolitic association dominated by metabasaltic rocks. The metabasic rocks have characteristics of submarine thoeiitic basalt but exhibit a more alkaline or transitional within-plate chemistry. Finally, the central Gadel Group is interpreted as a melange composed of a range of lithologies including serpentinite and quartzite (Pitfield and others, 2004). It consists of an internally imbricated middle to lower amphibolite facies continental margin rift-facies association containing major tectonic rafts of the El Gueneiba Group and is tectonically intercalated with deformed parautochthonous sedimentary rocks of the Taoudeni Basin in the extreme south. The Gadel Group melange occurs structurally below as well as above the El Gueneiba Group, which suggests that the metavolcanic rocks form one or more very large units in the form of frontal klippen within the mélange (Pitfield and others, 2004).

Lithologies within the Gadel Group consist of two major associations: (1) a predominantly magmatic association including ultramafic rocks (serpentinites), metabasalts, ferruginous jaspilites, garnet amphibolites, albitites, metagabbros, greenschists, and metacarbonate rocks, and (2) a siliciclastic metasedimentary association consisting of muscovite and kyanite quartzites with or without garnet and staurolite, and pelitic mica schists. Because the Gadel Group is a tectonically imbricated mélange, no lithostratigraphic or tectonostratigraphic succession can be defined. However, in general, a simplified succession of serpentinites associated with talc schists, greenschists, ferruginous quartzites, amphibolites and jaspilites in the west transition eastward into kyanite-staurolite-garnet quartzites and micaschists, muscovite quartzite, muscovitic schists and local amphibolites (Pitfield and others, 2004). The serpentinite bodies form the main areas of high relief in the group and have a wide range of appearances and variable primary and secondary mineralogy. They are commonly capped by birbiritic gossans that have secondary chert and carbonate filling fractures that separate clasts of the host serpentinite. The serpentinites are usually sandwiched between mylonitic, variably ferruginous quartzites and (or) quartz-muscovite/sericite-schists. Talc-schists invariably form lenticular bodies that are rarely more than several hundred meters in length and are always enclosed by serpentinite. Geochemical profiles for the serpentinites suggest a within plate, non-arc environment of formation. Ferruginous jaspilites and subordinate BIF are common within the Gadel Group melange and form resistant, black-weathered low ridges. They are mostly associated with the pelitic schists, mafic and ultramafic rocks (Pitfield and others, 2004).

Less common metamafic volcanic rocks consist of quartz-chlorite-schists and green amphibole-quartz-plagioclase-schists. All the amphibole and (or) epidote schists, epidosites and chlorite schists have a chemical composition close to tholeiitic basalt and have geochemical profiles that are characteristic of within-plate magmas. Tectonically aligned lenses of garnet amphibolite and pyroxenite are present and in contrast to other mafic and ultramafic rocks in the group, exhibit geochemical profiles characteristic of subduction-related volcanic arc rocks. Gneissic quartzofeldspathic schists and feldspathic muscovite schists are also present and are considered to be highly tectonized granitic sheets that are correlated with the Guidamaka Suite. Both mafic volcaniclastic rocks, interpreted as pillow breccias and pelitic schists in the Gadel Group contain local concentrations of malachite (Pitfield and others, 2004).

No direct U-Pb zircon dates are reported for rocks of the Gadel Group. $^{40}Ar/^{39}Ar$ incremental release ages for hornblende and muscovite concentrates suggest that post-metamorphic cooling occurred following distinct Neoproterozoic tectonothermal events at approximately 700–720 Ma and 640–650 Ma (Dallmeyer and Lécorché, 1989). The younger episode is related to the Pan-African 1 continental collision and broadly corresponds to U-Pb dates obtained for the syn- to post-kinematic granitoid suites of Guidamaka (665Ma) and Selibabi (637Ma; Pitfield and others, 2004). Muscovite within Gadel Group lithologies cooled through argon closure temperature between approximately 570 and 595 Ma (Pitfield and others, 2004). The Gadel Group mélange is interpreted to represent a major tectonic suture. The ultramafic rocks represent tectonized oceanic lithosphere. They are commonly associated with ferruginous jaspilites and metacarbonate rocks. The mafic rocks have two distinct geneses: one suite is comparable to the El Gueneiba Group metabasaltic rocks (described below) with a within-plate chemistry, whereas the amphibolites have a composition more typical of a subduction-related volcanic arc derivation. Their association with distal turbidites is consistent with their oceanic origins (Pitfield and others, 2004).

The El Gueneiba Group is imbricated with and locally incorporated within the Gadel Group (fig. 7). It is characterized by calc-chlorite schists, chlorite±talc±amphibole schists and deformed metabasalts (pillow lavas and breccias) metamorphosed to middle-upper greenstone facies. The Group remains undifferentiated in the southern Mauritanides with the exception of intrusive suites of the Guidamaka Suite (fig. 7). Less common lithologies include quartz-sericite-phyllites, chlorite-quartz-schists, deformed metabasalts with quartz-carbonate segregations associated with pillow breccias, ferruginous jaspilites, metakeratophyres, and massive, fine-grained marble with pyritic clots. Local intercalations of BIF lithologies are present and consist of millimeter-thick iron-rich seams with magnetite and/or hematite separated by thicker siliceous bands of quartz and chert. Quartz veins are extremely common and a veneer of vein quartz gravel covers large portions of the outcrop area (Pitfield and others, 2004).

Geochemical profiles of major lithologies of the El Gueneiba Group show wide variation from patterns consistent with alkaline, within plate tectonic settings to subduction-related volcanic arc patterns. The presence of pillows in the metabasaltic volcanic rocks suggests deposition in a submarine setting. The El Gueneiba Group is interpreted to consist of a disrupted ophiolite consistent with the rest of the Gorgol Noir Complex. Intrusive (?) relationships with dated granitic rocks of the Guidamaka Suite suggest a minimum age of 665±2.7 Ma (Pitfield and others, 2004).

The Guidamaka Suite is a gabbro-granodiorite suite that forms the uppermost thrust slice of the Gorgol Noir Complex and is locally emplaced within the El Gueneiba Group. The dominant rock type is a coarse hornblende gabbro with more felsic lithologies mostly consisting of medium to coarse tonalite-granodiorite. Gabbroic and granodioritic components grade into each other. They are mostly massive rocks that are cut by brittle fractures that are locally infilled by epidote veins. Xenoliths of metabasic schists, hornblendite and quartz-epidote rock are locally abundant and variably assimilated. Geochemical profiles are indicative of a subduction-related arc setting. The relationship of the gabbro-granodiorite suite to the other groups is uncertain. The gabbroic suite is intensely deformed at its margins and displays fabrics observed throughout the Complex suggesting that it was emplaced prior to or early in the tectonic history. Gabbro is not a common component of the Gadel Group melange. Therefore, the gabbro and other intrusive rocks may be genetically associated with the allochthonous calc-alkaline magmatic arc represented by the Mbout Supergroup (Pitfield and others, 2004).

Based on the above descriptions there are numerous features of the Gadel and El Gueneiba Group rocks such as pillow basalts, co-genetic mafic and ultramafic intrusive bodies, ferruginous jaspilites, BIF, malachite-bearing volcaniclastic rocks and pelitic schists that are permissive of mafic-type (Cyprus-type) VMS deposits. The presence of podiform chromite deposits and a number of known Cu±Au occurrences increases the favorability of the permissive rock sequences. Current interpretations of the timing and origins of the intrusive suites of the Guidamaka Suite suggest that they are not co-genetic with the Gadel and El Gueneiba Groups and are therefore not considered permissive of mafic-type VMS.

Numerous metallic mineral occurrences are present in the southern Mauritanides and in addition to VMS include a variety of mineral deposit types such as orogenic gold (see Goldfarb and others, 2015), Guelb Moghrein-like IOCG (see Fernette, 2015a), Cu-Ni-PGE-bearing magmatic sulfide deposits, and podiform chromite±PGE deposits (see Taylor and others, 2015). Due to the recognized potential of the region, the area has been the subject of multiple exploration campaigns dating to the first surveys by the BRGM from the mid-1960s to the mid-1970s, followed by various collaborations of the OMRG with the BRGM and a German private company, Otto Gold, through the mid-1990s. In 1995, exploration rights to the M40 concession area covered a 20,000 square kilometer (km^2) section of the Southern Mauritanides from just north of the Bou Zrabie and Kadiar occurrences to the border with Senegal. Their work included stream sediment, panned concentrates and BLEG sample surveys, and detailed studies at 28 prospects, using shallow soil sampling, trenching/pitting, rock chip sampling, geophysical surveys and geological mapping. RC drilling (51 holes, 4,180 m) was carried out at several targets with limited diamond drilling (5 holes, 808 m) at a few localities. Over 20,000 geochemical samples were ultimately collected and analyzed (Gunn and others, 2004). As a result of these various programs, the basic geological relationships at many of the more important mineral occurrences have been documented. Gunn and others (2004) provide excellent descriptions of many of the known prospects based on their review of previous work and fieldwork during the BGS program in 2003. Below, their descriptions of several of the best known bimodal-mafic (Kuroko-type) or bimodal-felsic VMS occurrences in the Mbout Supergroup of southern Maruitania are described followed by descriptions of several of the best known mafic-type (Cyprus-type) VMS occurrences in the Gorgol Noir Complex with minor modifications. Where applicable, additional observations and data resulting from USGS fieldwork in October, 2007 are provided. Results of geochemical analyses are presented in table 2.

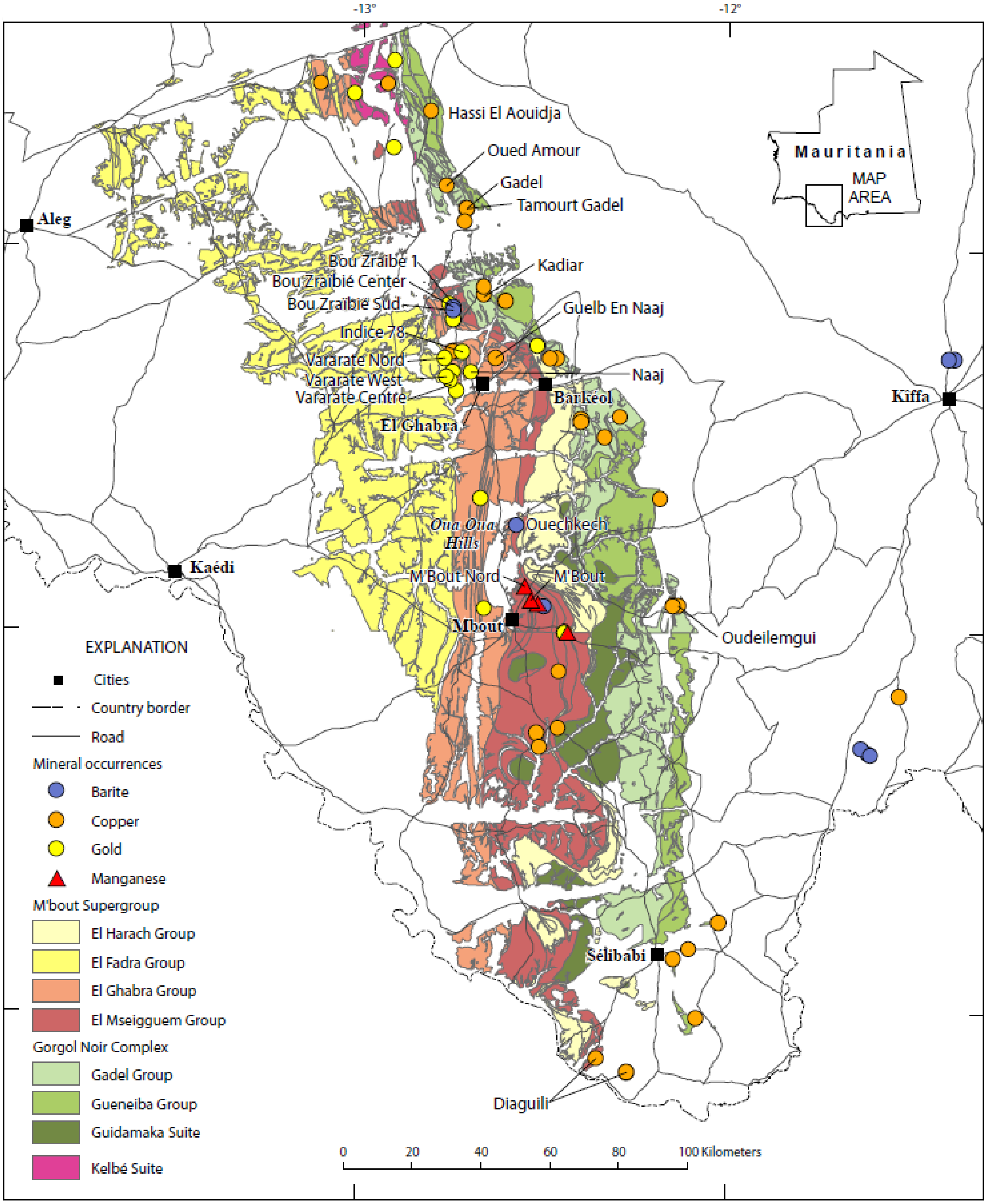

Figure 7. Tectonostratigraphic units of the infrastructural allochthon in the southern Mauritanides and locations of mineral deposits and occurrences discussed in text.

Bimodal-Mafic (Kuroko-Type) or Bimodal-Felsic VMS Occurrences in the Mbout Supergroup of the Southern Mauritanides

The Bou Zrabie Occurrence

The Bou Zrabie prospect is located in the northwestern quadrant of the Mbout 1:200,000 scale map sheet, about 40 km north-west of Barkéol (fig. 7). It consists of a thin horizon of stratiform Ba-Mn mineralization with associated enrichments in Cu, Zn, Pb, Ag and Au. It is hosted by dominantly felsic metavolcanic rocks of the Ouechkech Formation of the Mbout Supergroup. The oxidized Fe-Mn cap to the main mineralized zone forms a prominent low-lying approximately north-northwest trending hill about 400 m long and up to 100 m wide. The mineralized horizon is exposed sporadically over almost 3 km of strike and dips at 40–50º towards the southwest. It is exposed in low elongate ridges of quartz-hematite rock with common strike-parallel boudinaged quartz veins, up to 1 m thick. Local zones include discordant quartz veins and quartz vein breccias. No barite-bearing sediments were identified in these zones away from the main occurrence. Late discordant faults, oriented 030º, 060º and 100º, disrupt the stratigraphy at several points. They are associated with quartz vein stockworks that locally contain hematite (Gunn and others, 2004).

The first systematic investigations at Bou Zrabie were conducted by the BRGM in the late 1960s (BRGM, 1975). These involved trenching, pitting and detailed soil sampling and demonstrated the polymetallic nature of the mineralization. Further trenching by OMRG and Otto Gold in 1989–1990 confirmed the Mn, Ba, Pb, Zn, Cu and Ag enrichments and identified significant Au values, including up to 3,300 ppb over a 2 m interval in a trench (OMRG – Otto Gold, 1990). Further detailed studies by BRGM – OMRG were carried out in 1993–1994 (BRGM, 1995). These involved detailed geological mapping over a 3 km strike length and trenching at 50 m intervals across the strike. These investigations revealed considerable lateral and vertical variation in the thickness and continuity of the host-rocks to the stratiform Mn-Ba horizon. This layer is commonly 1–2 m thick although locally it is thickened by folding up to 12 m. Elsewhere, it forms two or three layers with a combined maximum thickness of 2.8 m. The wallrocks vary from sericitic schists (tuffs), to chloritic tuffs and pyritic quartzites. The lithologic variations were interpreted to reflect original facies variations at the time of exhalative mineralization. Gold enrichment was identified in several zones in the trenches including at the main gossan, and with quartz veins and in pyritic quartzite. Several values between 2–10 ppm Au were reported, locally with high Ag (maximum 600 ppm). No clear evidence in support of a syngenetic Au enrichment was found and it was noted that several trenches rich in gold are located close to discordant late faults with associated quartz veining that disrupt the stratigraphy at several locations. Accordingly an epigenetic origin of the gold cannot be ruled out (Gunn and others, 2004).

Further detailed studies by BRGM-OMRG in 1994–1995 involved additional trenching, detailed ground magnetic, IP and SP surveys and drilling (BRGM, 1995). Two inclined cored boreholes (aggregate 179 m) were drilled beneath gold-rich zones found in trenches and to test the source of IP anomalies beneath the main central outcrop. Geochemical data from borehole BZS1 revealed generally low Au values (150–340 ppb) in the main Ba-Mn horizon, but somewhat higher values (up to 600 ppb over 1 m) in chloritic tuffs with disseminated barite about 7 m below the main Ba-Mn horizon.

Similarly, generally low Au values were reported in the main Ba-Mn horizon in borehole SBZ2. However, 10 m below this level high Au values (3 m around 1.8 ppm Au) were reported in a fractured and folded zone in chloritic tuffs rich in Fe-oxides and with narrow bands rich in barite (Gunn and others, 2004).

The most recent exploration at Bou Zrabie was conducted by General Gold International (GGISA) in 1996–1997 (General Gold International, 1997). They carried out detailed soil sampling over a grid 5 km in length parallel to the strike. Soil geochemical results included significant Ba enrichment over more than 3 km. Within this zone coincident Cu, Pb, Zn and As anomalies occur over restricted areas but are most conspicuous in the vicinity of the 400-m-long central outcrop. Gold is also locally enriched in soils, reaching a maximum in the area around the central outcrop. Detailed magnetic and EM surveys were also conducted. The magnetic data delineated the mineralization well and highlighted numerous late cross-cutting faults. The EM survey identified a conductive zone about 700 m in length with the highest conductivity located beneath the main central outcrop. Two IP lines were surveyed in the southern part of the grid to investigate high-amplitude magnetic anomalies. However neither IP anomalies nor EM conductors were identified in this sector (Gunn and others, 2004).

Diamond and RC drilling (12 holes, 1,517 m) by GGISA investigated these soil anomalies and the conductive body indicated by EM surveys in the central zone. This confirmed the presence of a thin (1–2 m) massive sulfide (chalcopyrite and sphalerite) body of stratiform mineralization associated with barite and hematite. Gold values were highly variable with a maximum of 1.5 ppm over 1 m. Maximum values for Zn and Cu were 1 m @ 1.4 percent and 3 m @ 1.97 percent, respectively (Gunn and others, 2004).

Field examination of the Bou Zrabie prospect by the BGS confirmed that the main zone of exposed mineralization consists of a siliceous Fe-Mn oxide cap passing laterally eastwards into an inclined zone of barite-rich schist within predominantly recrystallized felsic metavolcanic (?) rocks. Fracture-controlled epidote veining is widespread in both the siliceous cap and immediately adjacent metasedimentary rocks. Locally centimeter-scale patches of orange-pink coloration within the barite-bearing schists may be vestiges of K-feldspar alteration (Gunn and others, 2004).

Field examinations of the Bou Zrabie Sud and Bou Zrabie 1 occurrences (as listed in Marsh and Anderson, 2015) were made by the USGS in November, 2007. The description above by the BGS of the “central zone” is consistent with relationships observed at Bou Zrabie Sud. The quartz-veined gossan described as occurring 3 km to the north is consistent with our observations at Bou Zrabie 1. The Fe-oxide-silica-rich cap at Bou Zrabie Sud is cut by two east-west trending trenches, one near the south end of the outcrop and the other near the north end, that expose steeply westward-dipping quarz-muscovite±barite schists oriented 350º. Abundant veins of massive to specular hematite-quartz±barite cutting variably Fe-oxide and epidote altered felsic schists are the most notable features in outcrop (fig. 8*A–D*). Two thin barite-rich lenses (30 cm and 7 cm separated by one meter of schist) are present in the north trench and contain minor blue fluorite. No sulfide minerals have survived oxidation in outcrop. Geochemical data on samples collected from Bou Zrabie Sud and Bou Zrabie 1 are provided in table 2. Notably, samples at Bou Zrabie Sud contain 0.5–2 ppm Au, 3–35 ppm Ag, and 1.1–3.8 percent Pb along with anomalously high values of Ba, Mn, and Sb. Values for Cu and Zn are anomalous but less than 1,000 ppm. The most notable feature of two samples collected from the quartz-veined gossan at Bou Zrabie 1 (fig. 9) are anomalously high Ba and approximately 19–22.6 percent Mn content. High Ce values in all samples are interpreted as evidence for the originally marine exhalative nature of the mineralized intervals at both occurrences.

Volcaniclastic textures are present in outcrop at the top of the low ridge at Bou Zrabie Sud and pass rapidly eastward into platey, fissile, orange schist (probably metatuff) and then through an area of quartz veining into a buff-colored, quartz-rich volcanogenic metasedimentary rock approximately 300 m east of the ridge (fig. 10). U-Pb age determinations on detrital zircons from this metasedimentary rock gave a maximum depositional age of 567 Ma (Bradley and others, 2015), which conflicts with the minimum age for the El Mseigguem Group, Ouechkech Formation of 637±5Ma described above (Pitfield and others, 2004).

In summary, stratiform polymetallic sulfide-barite mineralization is widely developed at Bou Zrabie in a sequence of quartz-chlorite-sericite±barite schists and rhyolite. Ba values are enriched more or less throughout this section, peaking at 3–6 percent around and within the massive sulfide zone. The latter consists of one or two thin zones of pyrite-sphalerite-chalcopyrite giving rise locally to values of 1–2 percent Cu, Pb, and Zn. Zinc is enriched at levels of approximately 2,000 ppm over a 15–25-mm-wide interval. The controls on the distribution of gold in the Bou Zrabie area are unclear. The high values reported sporadically at surface are probably due to supergene enrichment. In drillcore and in trenches Au values are not correlated with overall metal abundance. It is suggested that introduction and (or) re-distribution of Au related to fluid flow and quartz veining associated with late tectonic events is probably a significant control. Elsewhere in the district quartz vein float and outcropping quartz reefs, mainly concordant with the regional strike, are abundant and indicate the importance of large-scale extension and fluid flow in the area. However, it should be noted that GGISA carried out a program of quartz vein sampling in the area and failed to identify any significant Au anomalies (Gunn and others, 2004).

A

Figure 8*A*. Photo of thin fissile quartz-muscovite±barite felsic schist in south trench at Bou Zrabie Sud. USGS photo.

B

Figure 8*B*. Photo of massive hematite-quartz-carbonate vein in north trench at Bou Zrabie Sud. USGS photo.

Figure 8*C*. Photo looking to the south along the ridge axis from the north trench at Bou Zrabie Sud. USGS photo.

Figure 8*D*. Massive, 30-centimeter-thick barite lens in north trench at Bou Zrabie Sud. USGS photo.

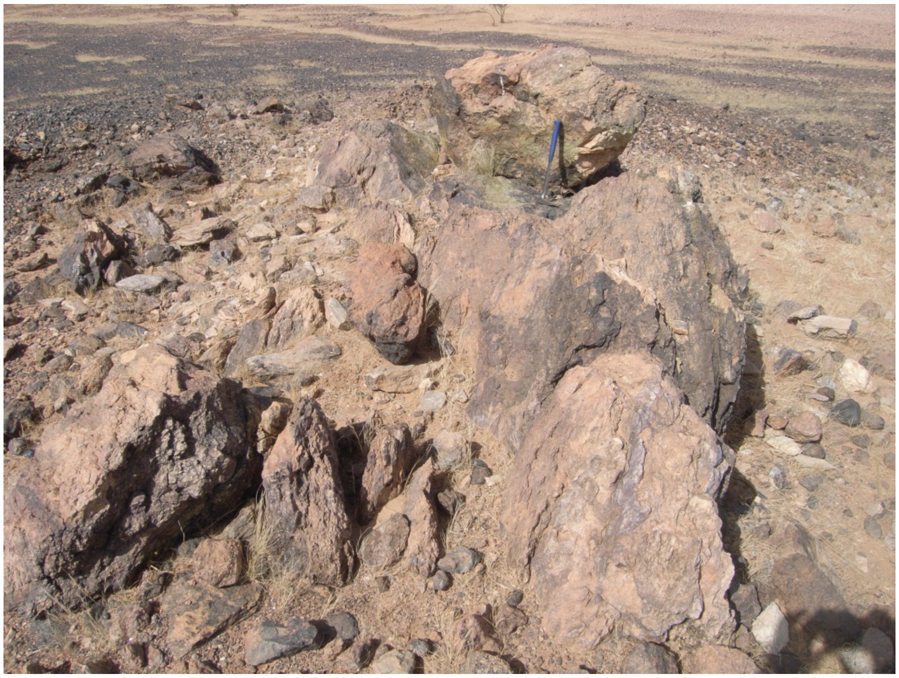

Figure 8*E*. Photo looking north at northern end of ridge at Bou Zrabie Sud. Greenish coloration near hammer is epidote alteration. Note centimeter-scale late barite veining in right foreground. USGS photo.

A

Figure 9*A*. Outcrop of quartz-barite veined gossan at Bou Zrabie 1. View south along axis of gossan; Bou Zrabie Sud occurrence is visible on skyline. USGS photo.

B

Figure 9*B*. Close-up of quartz-barite veined gossan at Bou Zrabie 1. USGS photo.

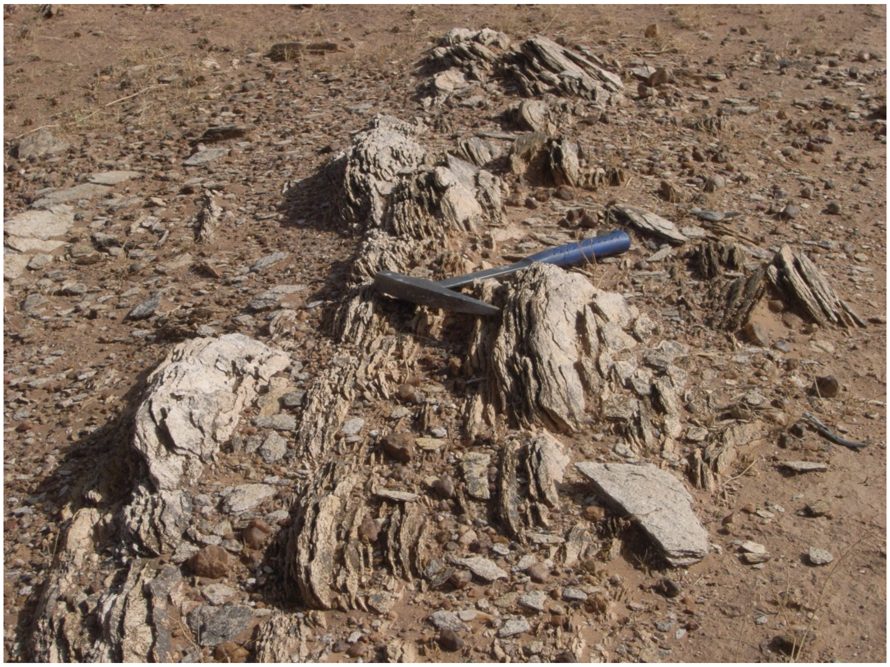

Figure 10. Outcrop of Ouechkech Fm. quartz-rich volcanogenic metasedimentary rock 300 meters east of the Bou Zrabie Sud occurrence. U-Pb detrital zircon maximum age of 567 Ma. USGS photo.

The Mbout Occurrence

Occurrences of stratiform Mn±Ba mineralization occur over a strike length of about 15 km extending northwards from about 6 km east of the town of Mbout (fig. 7). They are hosted by a sequence of metasedimentary rocks (chert, siltstone and sandstone) underlain by quartz-mica schist (metarhyolite) that belong to the Bathet Jemel Formation. This area was first studied by BRGM in the late 1960s, but the first detailed systematic investgations were carried out by OMRG in 1984–1985. As at Bou Zrabie, the mineralization shows a wide range of lateral variations in form and texture including massive, streaky, siliceous, pyritic and breccia-hosted variants. The mineralization consists of a 2–5 mm thick Mn-rich horizon with barite and traces of malachite, magnetite, hematite and gahnite. It dips westwards at 10–30º, and is associated with coincident zone of shearing and thrusting. Brecciated mylonitic quartz veins and silicification are widespread in the footwall, especially in the south of the zone. Analysis of rock and stream sediment samples confirmed a similar polymetallic signature to Bou Zrabie, with anomalous values of Cu, Zn, Pb and Ag, locally accompanied by As, Mo and Sb. Sporadic gold anomalies were also identified in stream sediments near the stratiform polymetallic mineralization.

BRGM undertook two main phases of work in this zone between 1993 and 1995 (BRGM, 1994 and 1995). This involved detailed geological mapping, rock chip sampling and drainage sampling over an area of 140 km^2. This work revealed the disruption of the stratiform mineralization by deformation: locally the main Mn layer was shown to be thickened by folding, sometimes repeated by thrusting, but, most commonly, shearing and thrusting excised this layer such that it can be traced only for about 4 km of the total mapped strike length of 15 km. Systematic sampling of trenches (39 in total) failed to identify significant Au values with a maximum of 600 ppb over 2 m. However follow-up studies of gold drainage anomalies identified an enrichment of Au (3.1 ppm over 2 m) in siliceous mylonites associated with discordant shear zones close to the main mineralized interval. In addition more detailed drainage sampling confirmed the broad dispersion of gold in the area with four main anomalies defined to the west and south-east of the main Mn-Ba occurrence in areas underlain by metasedimentary rocks.

GGISA subsequently undertook a program of shallow RC drilling to evaluate the exposed stratiform mineralization, possible footwall quartz veining and areas of anomalous gold geochemistry (General Gold International, 1997). They drilled 10 RC holes for a total of 660 m but failed to identify significant gold or base-metal values. The best intercept was 2 m around 115 ppb Au between 24–26 m in borehole PDMB 10 near the northern end of the exposed mineralization.

Geochemical analyses of samples collected at Mbout and Mbout Nord occurrences by the USGS in 2007 are shown in table 2. With the exception of high Ba and Mn (up to 33.7 percent) values, samples show only minor enrichments in As, Mo, and Sb. Samples of massive barite-manganese oxide and muscovite schist host rock show elevated Ce values consistent with derivation from seawater in contrast to quartz-rich samples that may indicate secondary hydrothermal mobilization into veins.

The Ouechkech Occurrence

Mineralization was discovered at Ouechkech by GGISA during regional geological reconnaissance in 1995–1996 (General Gold International, 1997). This occurrence consists of a prominent hill, about 80 × 50 m, of massive stratiform barite-Fe-Mn mineralized rock surrounded by pyritic-chloritic schist assigned to the Formation de Bathet Jmel. It is located about 20 km north along strike from the Mbout Mn-Ba occurrences (fig. 7). Quartz veining and brecciation are widespread. The exposed mineralization has been affected by complex multi-phase deformation that has folded and disrupted millimeter- to centimeter-scale banded barite and Fe-Mn oxide mineralization. Small scale (millimeter-decimeter) isoclinal folds are truncated by later fractures, shearing and quartz veins such that lateral continuity of the mineralization is limited. Rock sampling by GGISA yielded highly anomalous Pb, Zn, Ba and As values but no significant Au values. GGISA drilled 3 RC holes (140 m) to investigate the buried extension of the exposed mineralization. This confirmed that the mineralization has been intensely folded and is associated with anomalous Pb, Zn, Ba and As, but no attendant high Au values. It is suggested that the limited drilling carried out by GGISA could have been better targeted as it failed to intersect any mineralization as thick as that exposed on the main hill. However the structural complexity of this zone may rule out any significant extension of the exposed mineralization, either down-dip or along strike, and hence the economic potential of the prospect is low.

Field examination of the Ouechkech occurrence in November, 2007 by the USGS confirmed the description by the BGS above (fig. 11*A–B*). The entire outcrop appears to consist of tectonically banded barite and Fe-Mn oxides cut by later quartz veins. Geochemical analyses of samples collected from the occurrence indicate high Ba content and Mn up to 15.4 percent. All other metals of economic interest are present only in slightly anomalous concentrations (table 2).

A

Figure 11*A*. View of the Ouechkech occurrence from the south. USGS photo.

B

Figure 11*B*. Photo of massive, tectonically banded Mn-Fe oxides on the east side of the Ouechkech occurrence cut by late quartz veins. USGS photo.

Table 2. Selected elemental geochemistry data for samples collected from VMS occurrences in Mauritania during November 2007 USGS fieldwork. Four-acid digestion ICP-AES-42 data with the exception of Au, which is by fire assay ICP-AES analyses.

Field No.	Mineral occurrence	Host Rock	Sample Description	Au ppm	Fe %	Ag ppm	As ppm	Ba ppm	Bi ppm	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cu ppm	Mn ppm	Mo ppm	Ni ppm	Pb ppm	Sb ppm	Te ppm	W ppm	Zn ppm
CT07RIM49-1	El Aouidja	Gueneiba Gp-Oued Amour Fm	malachite-quartz veined goethite	0.022	23.9	21	24	74	0.4	0.3	0.85	5.6	16	73200	3780	1.19	89.1	57.8	0.17	0.3	0.5	78
CT07RIM50_1	Kadiar #1	Gadel Gp	silicified chlorite schist or quartzite	0.012	2.52	<1	13	64	<0.04	<0.1	1.27	63	802	70.2	453	0.25	388	3.6	0.13	<0.1	7	44
CT07RIM50_2	Kadiar #1	Gadel Gp	silicified chlorite schist or quartzite	0.021	3.01	<1	23	334	<0.04	<0.1	1.72	25.5	433	25.8	2320	0.45	557	3.5	0.24	<0.1	4.2	32
CT07RIM51_1	Kadiar #1	Gadel Gp	silicified chlorite-sericite-carbonate schist	<0.005	0.66	<1	<1	281	<0.04	<0.1	9.36	5	6	17	313	0.13	23.2	4.7	<0.05	<0.1	0.1	11
CT07RIM52_1	Kadiar #1	Gadel Gp	jaspilite	2.46	23.6	2	12	68	1.99	1.2	4.76	25.9	84	362	579	1.6	612	126	13.9	1.2	2.8	2200
CT07RIM52_2	Kadiar #1	Gadel Gp	talc schist breccia	0.034	7.08	<1	5	28	<0.04	0.3	0.65	51	151	2270	397	0.98	524	9.9	0.17	<0.1	<0.1	584
CT07RIM53_1	Kadiar #1	Gadel Gp	malachite coated silicified gossan breccia	0.314	33.3	<1	57	106	0.19	0.7	2.65	244	27	41900	2740	3.98	1310	70.1	2.79	0.3	<0.1	2010
DC07RIM24_1	Kadiar #1	Gadel Gp	gossan	0.364	34.8	<1	46	41	0.28	0.9	6.4	334	19	12700	1570	4.27	1000	52.6	3.65	0.5	0.2	1880
DC07RIM25_1	Kadiar #1	Gadel Gp	quartz vein	0.007	0.24	<1	5	37	<0.04	<0.1	0.37	2.8	236	3.7	197	0.07	34.7	3.7	0.14	<0.1	0.3	4
DC07RIM26_1	Oumou Kadiar	Gadel Gp	quartz vein	0.068	0.51	<1	<1	59	<0.04	<0.1	4.48	3	151	4.4	175	<0.05	5.9	3.5	<0.05	<0.1	<0.1	3
CT07RIM54-3	Bou Zrabie Sud	El Mseigguem Gp-Ouechkech Fm	epidote altered muscovite schist	0.936	0.96	3	984	868	0.05	0.8	44.3	1	2	962	297	3.11	3.1	38100	2.05	<0.1	0.7	915
CT07RIM54-4	Bou Zrabie Sud	El Mseigguem Gp-Ouechkech Fm	barite-hematite schist	0.512	2.83	35	45	3660	0.16	0.9	26.2	1.2	3	325	20700	11.1	1.6	11000	1.39	0.1	1	449
CT07RIM54-7	Bou Zrabie Sud	El Mseigguem Gp-Ouechkech Fm	massive barite-fluorite	2.07	0.21	14	14	4730	0.12	6.4	33.5	0.4	1	319	303	0.35	1.6	3040	1.52	<0.1	1	476
CT07RIM54-8	Bou Zrabie Sud	El Mseigguem Gp-Ouechkech Fm	massive barite	0.194	4.39	<1	48	1870	0.05	2.6	33	0.5	3	116	3050	0.62	1.2	5110	42.6	<0.1	7.7	458
CT07RIM56_1	Bou Zrabie 1	El Mseigguem Gp-Ouechkech Fm	quartz veined gossan	0.023	3.66	<1	85	9200	<0.04	1.3	7.82	4.7	3	7.8	179000	6.28	0.8	32.9	1.54	<0.1	0.4	72
CT07RIM56_2	Bou Zrabie 1	El Mseigguem Gp-Ouechkech Fm	Fe-silica-carbonate gossan	0.015	2.61	<1	46	9050	<0.04	0.9	20.5	2.2	7	17.9	226000	4.26	2.4	19.8	0.69	<0.1	3.6	53
CT07RIM57-1	Naaj	El Ghabra Gp-Oued Erdi Fm	quartz -Fe oxide vein breccia	0.013	5.04	<1	8	205	1.83	0.1	23	3.1	18	22.5	672	65.2	6.5	25.1	2.74	0.7	1.1	7
CT07RIM57-3	Naaj	El Ghabra Gp-Oued Erdi Fm	massive Fe oxide gossan	0.008	5.79	<1	23	294	1.81	<0.1	71.2	2.1	35	14.7	420	6.63	5.1	66.3	2.7	0.6	1.3	6
CT07RIM58_1	Ouechkech	El Mseigguem Gp-Bathet Jmel Fm	barite-Mn oxide	0.008	5.51	<1	6	2660	0.16	<0.1	0.96	0.4	1	34.8	2280	5.28	2.2	97.7	7.69	<0.1	11.2	6
CT07RIM58-2	Ouechkech	El Mseigguem Gp-Bathet Jmel Fm	quartz veined hematite and Mn oxides	0.011	7.56	<1	31	>10000	0.06	0.7	15.1	5.8	4	4.4	154000	2.93	1.1	91.3	4.46	<0.1	4.2	132
CT07RIM58-3	Ouechkech	El Mseigguem Gp-Bathet Jmel Fm	chlorite schist	<0.005	1.93	<1	1	8540	0.08	<0.1	67.7	3.3	2	8.9	924	0.52	3.7	11.3	0.36	0.1	2.5	89
GB07RIM69A	Vararate Nord	El Fadra Gp-Oued Kav Fm	quartz sericite vein	<0.005	0.16	<1	<1	202	<0.04	<0.1	3.46	1.9	1	3	268	0.2	2.4	5.1	0.08	<0.1	1.2	2
GB07RIM70B	Vararate West	El Fadra Gp-Oued Kav Fm	quartz vein	0.118	0.11	2	4	5470	0.21	<0.1	1.73	2	4	26	440	0.51	1.5	203	0.37	<0.1	41.4	18
GB07RIM71A	Vararate Centre	El Fadra Gp-Oued Kav Fm	quartz-visible gold-pyrite-sericite vein	34.7	5.61	2	8	64	27.1	<0.1	4.14	26.9	41	218	83	11.9	23.9	20.3	2.22	6.7	133	11
GB07RIM71B	Vararate Centre	El Fadra Gp-Oued Kav Fm	quartz-visible gold-pyrite vein	8.59	7.93	<1	12	66	4.17	<0.1	3.06	64.5	45	64.3	176	1.4	63.5	20.7	2.35	7.3	83.4	19
GB07RIM71C	Vararate Centre	El Fadra Gp-Oued Kav Fm	quartz-pyrite vein	0.063	0.1	<1	2	32	0.35	<0.1	0.7	0.7	5	17.2	55	<0.05	1.6	13.2	0.08	<0.1	74.9	3
GB07RIM71D	Vararate Centre	El Fadra Gp-Oued Kav Fm	quartz-visible gold-pyrite-sericite vein	65.9	9.38	<1	9	98	12.5	<0.1	23.4	37.7	23	25.6	155	0.87	37.8	11.8	0.6	11.3	38.8	12
GB07RIM76A	M'Bout Nord	El Mseigguem Gp-Bathet Jmel Fm	massive manganese oxide	0.039	1.16	<1	298	>10000	1.71	1.5	176	17.1	27	58	337000	118	28	128	1390	0.2	119	378
GB07RIM76C	M'Bout Nord	El Mseigguem Gp-Bathet Jmel Fm	muscovite schist	0.018	2.39	<1	30	3090	0.29	<0.1	100	6	14	15.2	3630	1.5	4.5	12.4	15.1	<0.1	17.8	70
GB07RIM77A	M'Bout	El Mseigguem Gp-Bathet Jmel Fm	quartz/manganese oxide	0.036	2.05	<1	<1	744	0.09	0.5	3.05	1.3	20	28.7	22200	1.4	1.5	103	2.82	<0.1	22.6	104
GB07RIM77B	M'Bout	El Mseigguem Gp-Bathet Jmel Fm	quartz/manganese oxide	0.025	22.7	<1	<1	6190	0.15	2.2	6.79	10.8	14	<0.5	25700	0.82	0.8	40.3	1.16	<0.1	15.8	585
GB07RIM77C	M'Bout	El Mseigguem Gp-Bathet Jmel Fm	quartz/manganese oxide vein	0.244	16.4	<1	1	>10000	0.57	0.4	2.32	1.2	102	24.8	6040	0.4	0.9	32	2.94	<0.1	153	83

The Harach Occurrence

Another minor occurrence of stratiform Mn-barite-limonite mineralization discovered by GGISA is located at Harach (fig. 7), at a similar stratigraphical level to the Ouechkech prospect about 13 km to the south (General Gold International, 1997). At Harach the mineralization is exposed in a low-lying outcrop about 40 m long and 15 m wide. GGISA identified significant Ba (up to 23 percent) and As (up to 1,400 ppm) in rock chip samples from 2 m channels. Attendant minor enrichments in Pb and Zn were noted but Au values were uniformly low.

The Vararate South Occurrence

In 1995–1996 GGISA identified a high-tenor soil anomaly in Ba and Au extending over about 600 m north–south at the southern end of the Vararate quartzite (General Gold International, 1997). At Vararate South (fig. 7), minor enrichments in Cu, Pb and Zn were also observed. This anomaly included outcrops of stratiform, banded white and gray barite exposed sporadically over a strike length of about 500 m intercalated with and underlying a prominent ridge of sericitic quartzite. It is underlain by metasandstones, siltstones and quartzite. Local small-scale open folds are present in the barite beds which generally dip westwards at about 30º with a strike between 350º and 005º. Quartz veins, commonly hematitic, are widespread within the quartzites of this zone. They are mostly concordant with the strike of the enclosing rocks and may attain widths of several meters. Another conspicuous trend is oriented approximately 305º. GGISA excavated eight trenches across the exposed barite over a 600 m strike length. Ba values between 20–30 percent were recorded in every trench, together with local enrichments in Au (maximum 550 ppb), Pb (maximum 6,500 ppm) and Zn (maximum 4,300 ppm). GGISA drilled 5 RC holes (390 m) along three sections over a strike length of 310 m. These boreholes confirmed the downdip continuity of the barite-rich horizon, locally accompanied by high Pb values (maximum 2,460 ppm). Sporadic high Au values, up to a maximum of 450 ppb over 1 m, were reported in association with quartz veining.

The Vararate West Occurrence

Stratiform barite mineralization was discovered by Otto Gold at Vararate West (fig. 7), immediately west of the Vararate Centre prospect (OMRG–Otto Gold, 1990). They identified anomalous values of Au (up to 855 ppb), Cu, Zn and Pb in the hanging wall of the barite-rich beds. The exposed mineralization consists of two major outcrops, about 800 m apart, up to 6 m wide of thinly bedded (centimeter-scale) barite which dips westwards at about 35º. Limonite stained voids after pyrite are locally present in the barite.

Follow-up investigations were carried out by GGISA in 1996–1997 (General Gold International, 1997). They identified anomalous Pb in association with the high Au and Ba in the hanging wall zone. GGISA drilled a single RC borehole (100 m) which demonstrated the continuity of mineralization at depth with 4 m @ 24 percent Ba between 40–44 m associated with gold enrichment over 14 m, peaking at 430 ppb Au in a single 2 m sample. The highest Au value however was reported from a one-meter sample with conspicuous quartz veining in the immediate hanging wall of the stratiform mineralization. The mineralized layer occurs in the Formation d'Oued Kav, overlain by quartzites, with siltstone, sandstone and chert with minor pyrite and calcite veining in the footwall.

In November 2007 site examination and limited sampling was conducted by the USGS at the Vararate Nord, Centre, and West occurrences. At Vararate Centre, multiply cross-cutting quartz veins in quartzite (fig. 12*A*) and quartz-sericite schists were observed containing goethite pseudomorphs after pyrite and numerous cube-shaped voids (figs. 12*A* and *B*). Visible gold was observed in multiple samples. Geochemical analyses (table 2) of samples are highlighted by samples containing 35 and 70 ppm gold and anomalously high Bi, Mo, Te, and W. This suite of elements almost certainly indicate that the quartz-sulfide veins observed are related to an orogenic gold mineralizing event that is younger and unrelated to the stratiform mineralization described above (see Goldfarb and others, 2015).

A

Figure 12*A*. Close-up of cross-cutting quartz veins in quartzite at Vararate Centre with numerous cube-shaped voids. USGS photo.

B

Figure 12*B*. Close-up of goethite pseudomorphs after pyrite in quartz vein cutting limonite altered quartzite at Vararate Centre. USGS photo.

The Oued d'Amour Occurrence

Stratiform metabarite with copper showings were discovered approximately 1.5 km southwest of the village of Oued d'Amour (17°10'02"N., 12°46'17"W.) within mafic rocks of the Gadel Group (Gorgol Noir Complex) an imbricate mélange of ultramafic rocks, metamafites, quartzites, schists and jaspilitic ironstones (fig. 7). This complex forms part of the axial suture zone of the Mauritanide infrastructural allochthon.

The host rocks are layered garnet para-amphibolites within a sequence of kyanite-bearing muscovite-quartz-chloritoid schists and kyanite-bearing garnet-muscovite quartzites with thin ferruginous jaspilites and hornblende metamicrogabbro sheets. The garnet-amphibolites comprise a garnet-hornblende-quartz-plagioclase assemblage with about 20 percent amphibole and a quartz content of approximately 25 percent. They exhibit varying degrees of layering with a centimeter to meter-scale alternation reflecting different proportions of mafic and felsic minerals.

The metabaritic units are up to 2 m thick and locally form outcrops several meters wide as folded subhorizontal sheets. These fine- to medium-grained rocks are poorly foliated and consist of barite with minor amounts of quartz, muscovite and kaolinite (after feldspar?). Further south along strike outcrops on the Oued d'Amour watercourse exhibit meter to 10 meter-scale F1 recumbent isoclinal folds. The layering is locally attenuated and disrupted. F2 folding has occurred about NNW-trending axes with subvertical dips to the ENE and WSW. Rods of vein quartz are coaxial with the extension lineation which plunges shallowly to the NNW.

Copper mineralization in the form of malachite and subordinate azurite mostly occurs on foliation planes that dip at a moderate to steep angle to the NE (47–82º,047–050º). The copper mineralization crosscuts and clearly postdates the metabaritic host. Some of the muscovitic shear planes may be the conduits for localization of the copper.

The metabaritic units are clearly stratiform and exhibit evidence of at least two phases of folding and shearing which has led to their partial dismemberment. The layered garnet amphibolites may be calc-silicate rocks derived from shaly limestones or calcareous shales. More uniform orthoamphibolites have the geochemical characteristics of low Ti continental tholeiites (Remy and others, 1987). The metabaritic rocks have formed syngenetically or during an early stage of formation of the melange by replacement of a more permeable quartzo-feldspathic unit. Epidote-plagioclase-calcite-quartz schists at a similar stratigraphic level along the Oued d'Amour gorge course exhibit indications of copper mineralization (malachite smears on schistosity planes). This type of low-grade copper mineralization would be expected to migrate during later tectonism into low stress areas such as provided by the more competent units.

The Indice 78 Occurrence

BRGM identified significant Cu-Au enrichment in soils over a distance of 1.8 km along a north-south contact zone between meta-andesite and metarhyolite at Indice 78, 12 km north-west of El Ghabra, in the northern part of the Mbout map sheet (BRGM, 1994 and 1995: fig. 7)). Trenching over the six main anomalous sites failed to reveal significant Cu-Au values. BRGM also identified a visible-gold-bearing quartz vein, informally referred to as the Godoj vein. This vein trends at 030º and is about 1 m thick. It has been traced for 30 m in a chloritic tuff. Mineralogical studies carried out by BRGM on oxidized bedrock samples from the trenches revealed two distinct phases of mineralization: an early phase consisting of disseminated, locally banded, chalcocite and bornite that is low in Au, hosted in the andesitic lavas and carbonate-altered tuffs; and an epigenetic stage of Cu and Au associated with extensional quartz veins. The veins are best developed in proximity to faults trending between 060º–100º, that displace the chloritic tuff carrying the stratiform mineralization. Overall no Cu-Au intersections of potential economic importance were identified, but the widespread occurrence of disseminated Cu sulfides in the epidotised tuffs with the carbonate lenses requires further investigation. VLF surveys are recommended to look for quartz vein structures similar to the Godoj vein.

GGISA extended the target area at Indice 78 to a total of 4.5 km along this contact zone but identified only sporadic Au and non-coincident Cu anomalies in soil samples (General Gold International, 1997). They identified abundant quartz veins, generally trending between 340º and 360º, but the Au contents of most were very low. An exceptional value of 700 ppb Au was reported in one sample. In 1997 GGISA drilled a single RC borehole (100 m) to investigate the andesite-rhyolite contact at the site where maximum Au values in soil were found. This hole intersected the target contact and associated quartz veining , however the interval lacked significant gold or base metals.

Surface exposure of this zone is sporadic. Secondary copper minerals in bedrock and in trench debris consist of minor to locally abundant malachite and subordinate azurite in epidote-silica rocks (probable meta-andesites), in chloritic schists (probable tuffs) and locally in both early concordant and late discordant quartz veins. Rhyolitic volcanic rocks are apparently restricted to a zone generally less than 5 m wide, to the west of the meta-andesite which itself outcrops over a width up to about 100 m. Detailed geological maps prepared by GGISA of the Indice 78 zone indicate the presence of discrete carbonate bands extending along strike for several meters. These were not located during the BGS study; however, carbonate was widely recognized in small veinlets, generally only a few millimeters wide, in the silica-epidote rocks. At the northern end of the mineralized zone, carbonate is more extensively developed and occurs as coarsely crystalline (up to 1 cm) irregular patches and segregations, up to a few centimeters wide and traceable over a few meters. This pale brown carbonate contrasts with the more widespread white carbonate found in narrow veinlets and fracture coatings.

The BGS conducted mineralogical studies of 3 samples of epidote-silica rocks that contained variable amounts of carbonate. One epidote-silica-dominant rock was cut by numerous veinlets of quartz-carbonate-plagioclase and chlorite. All analyzed carbonate grains were calcite, and the only metallic phases identified were hematite and chalcocite. The timing of metal deposition relative to the development of the propylitic (epidote-carbonate) assemblage is unclear.

The mineralization at Indice 78 may be similar to the carbonate-hosted Guelb Moghrein IOCG type, although there is no indication of the extensive development of coarse Fe-Mg carbonate, and it is here interpreted to represent bimodal mafic-typeVMS mineralization with gold introduced into the system, or remobilized, during later deformation and quartz veining.

The USGS attempted to locate the Indice 78 occurrence during fieldwork in November, 2007. Relationships as described above were not observed at the coordinates provided in the National Mineral Occurrences database (Marsh and Anderson, 2015) and it is suspected that the coordinates provided are in error.

The Guelb Naadj Occurrence

The Guelb Naadj prospect was discovered by BRGM who panned gold at a site immediately south of the north-south trending Guelb Naadj ridge, 7 km north-west of El Ghabra (BRGM, 1994; fig. 7). GGISA carried out follow-up soil sampling in 1995–1996 and identified sporadic Au enrichment over 3 km strike, associated with local weak Cu, Pb and Zn anomalies (General Gold International, 1997). The prospect is underlain mainly by sericitic and chloritic schists, interbedded with silica-epidote rock (meta-andesite?), and fine-grained, strongly recrystallized felsic rocks, probably metarhyolite, locally showing remnants of possible primary banding. To the west, these rocks are overlain by metasandstone and quartzite. A distinctive unit of quartz-muscovite schist with abundant kyanite forms a prominent ridge at the southern end of the prospect. Early discontinuous quartz veinlets parallel to strike are widespread, while there is also local intense development of discordant quartz veins, stockworks and breccias. GGISA mention “carbonate” in their descriptions of Guelb Naadj. However, BGS observations of carbonate were restricted to local millimeter-scale patches and sub-concordant stringers of brown (Fe-Mg?) carbonate. Field observations suggest that the Guelb Naadj ridge has been the focus of deformation, faulting and recrystallization. The origin of the kyanite-rich schist may be related to Al-rich alteration localized by a north-south structure.

GGISA drilled 6 RC holes (350 m) at Guelb Naadj to investigate the anomalous values of Au and Cu values in soils (General Gold International, 1997). No significant geochemical anomalies were identified in the RC samples. It was suggested that the anomalous soil geochemistry was related to sporadic Au enrichment in quartz veins.

A site examination at the Guelb Naadj occurrence (as opposed to the Guelb En Naadj occurrence located approximately 8 km to the northeast; Marsh and Anderson, 2015) confirmed the relationships as described above by the BGS. A prominent low ridge consisting of west-dipping, reddish, hematitic quartz-muscovite schist with abundant kyanite localizes numerous massive white quartz veins that are cut by iron oxide veins (fig. 13*A–B*). Massive white quartz also occurs as matrix to breccias and possible ankerite (dark brown Fe-Mg-Mn carbonate) was observed lining selvages of veins in country rock. The ridge is underlain to the east by light orange, fissile, muscovite schists (metatuffs?) with abundant kyanite and a prominent low ridge in the plain approximately 100 m east of the ridge consists of a parallel, discontinuous massive white quartz vein. Outcrop on the dip-slope of the ridge to the west consists of metasedimentary rocks containing a conglomeratic unit composed of stretched clasts of iron formation or hematite-schist. No sulfide minerals were observed at the site and two geochemical analyses of gossan and Fe-oxide rich vein breccia were unremarkable.

A

Figure 13*A*. View looking north at the Guelb Naadj occurrence. Ridge axis is composed of kyanite-bearing, hematitic quartz-muscovite schist cut by massive white quartz veins and breccias. USGS photo.

B

Figure 13*B*. Close-up of brecciated white quartz vein material at the Guelb Naadj occurrences cut by gossanous Fe-oxides. USGS photo.

Mafic-Type (Cyprus-Type) VMS Occurrences in the Gorgol Noir Complex of the Southern Mauritanides

The Kadiar Deposit

An important occurrence of Cu-Au mineralization with some similarities to Guelb Moghrein is situated at Kadiar, about 95 km north of Mbout and 30 km north-west of Barkéol in the Mbout map sheet. It is situated in the Gorgol Noir Complex along the thrust contact between the dominantly metabasaltic rocks of the El Gueneiba Group to the east and the Gadel Group to the west. The latter consists of an imbricated melange of variably mylonitic and ferruginous sericitic quartzites with ultramafic rocks and serpentinites. These form tectonic lenses that rarely exceed several hundred meters in length and at Kadiar the pods are often only a few meters long and are enclosed within a talc schist host.

The silica-iron cap overlying the mineralization at Kadiar was discovered by BRGM during regional mapping in 1965–1966 (BRGM, 1994). Subsequent investigations consisting of extensive trenching, detailed geophysical surveys and drilling 12 diamond drillholes were carried out between 1968 and 1970. High Cu and Au values, with maximum values of 2.9 percent and 8 g/t respectively, were reported in drilling beneath the main gossan. This early phase of drilling demonstrated that the cap is underlain by a lens of silicified carbonate (ankerite) between 30 and 60 m wide that hosts the majority of the mineralized rock. This body is at least 350 m in length and dips towards the south-west at about 60º. In the central zone tested by drilling the mineralized lens is not exposed at surface and pinches out rapidly at depth, disappearing below about 80 m. The ore mineral assemblage consists of malachite, chalcopyrite and pyrite with minor pentlandite, bravoite, millerite and traces of chromite. BRGM estimated a resource in the iron cap of about 1 million tonnes @ 0.3 g/t Au, with 0.5 percent Cu, minor Zn and traces of Ag. The carbonate body is flanked by chloritic schists, calcareous and dolomitic schists, mica schists and quartzites.

In 1989–1990 OMRG and Otto Gold carried out further detailed surveys including detailed mapping and 200 m of trenching. This work confirmed the presence of high Cu values and identified associated enrichments in Zn (up to 1,200 ppm), and Ni (up to 1,300 ppm). However, gold values were generally low (≤135 ppb).

Subsequently BRGM, in conjunction with OMRG, carried out further detailed work at Kadiar. This involved 1:2,000 scale mapping and rock chip and soil sampling at 50 m centers (BRGM, 1995). This mapping indicated the presence of several imbricated thrust sheets consisting of serpentinites, overlain, in turn, by iron-stained sericitic schists, chloritic and talcose schists, locally pyritic, chloritic schists containing lenses of carbonate and, at the top, thin sericitic quartzites. Small lenticular gossans a few tens of meters in length were also identified along strike to the north and south of the main gossan and on a parallel axis about 120 m to the west. This indicates that the mineralization is not confined to a specific horizon or that it is repeated by thrusting. Three extensive areas, each more than 200 m in length, of anomalous geochemistry were identified over areas of exposed iron-silica cap and pyritic talc-chlorite schists.

The highest Au values reported in surface rock samples were about 800 ppb, with several Cu values in the range 2,000–8,000 ppm, Zn in the range 1,000–4,000 ppm, Ni 1,000–10,000 ppm. Most Cr values were below 2,500 ppm, although a single gossan sample with 2,577 ppm Cu and 1,320 ppm Zn contained >13,000 ppm Cr.

In 1995 BRGM drilled another inclined borehole into the main gossan to study the nature and form of the carbonate-hosted sulfide mineralization beneath (BRGM, 1995). This borehole collared about 6 m west of the oxide cap intersected a series of quartzites, tuffs, chloritic and talc schists, serpentinite intercalated with red schists containing carbonate bands, passing downwards into 6 m of dolomitic-ankeritic carbonate with disseminated pyrite. The basal 26 m of the borehole was in talc-chlorite schists, siliceous schists and tuffite intercalated with black schist rich in pyrite and with traces of malachite. BRGM reported enrichments in Li and B in chlorite schists above the serpentinite. A red pyritic schist immediately above the serpentinite was enriched in Ni, Cu, Zn and V. The only Cu values of potential economic significance (2,600–7,600 ppm) were restricted to the ankeritic carbonate zone. Only three Au values exceeding 100 ppb were reported, with a maximum of 154 ppb. These occur in association with carbonate bands in the chlorite schists and in the talc schists close to a carbonate band at the contact with black schist enriched in Ba, K, V, Cr and Ni.

In 1994–1995 BRGM carried out prospecting for similar Fe-oxide silica caps in the area between Kadiar and Ghabra in the chloritic schists and serpentinites of the Gadel Group (BRGM, 1995). The only significant result reported was the discovery of a chloritic schist with oxidized pyrite and including carbonate and barite in its matrix that contained 296 ppb Au. This discovery, located about 3 km north-west of a high amplitude magnetic anomaly close to Guelb Jmelanie, indicates that there is good potential in this zone for the discovery of further mineralization comparable with that at Kadiar.

GGISA conducted little work at Kadiar, but confirmed the association of the mineralization with carbonate alteration, suggesting a possible analogy with Guelb Moghrein (General Gold International, 1997).

A site visit to the Kadiar occurrence (listed as the Kadiar 1 occurrence in the Mauritanian National Mineral Occurrences Database; Marsh and Anderson, 2015) by the USGS in November, 2007 confirms the observations described above by the BGS. A transect across strike from west to east about 400 m to the south of the main knob on the occurrence (fig. 14*A*) traversed from pervasively iron-altered and silicified chlorite schists composing the highest north-south trending ridge to the west of the occurrence (fig. 14*B*; samples CT07RIM-50-1 and 2, see table 2) into a 20-m-wide band of near vertical chlorite-sericite- and talc-schists. This band is in contact to the east with a 20-m-thick band of silicified gossan possibly overlying serpentinine followed by a second 80-meter-wide zone of chlorite-sericite schist. This unit is in contact eastward with a 30-m-wide, black to dark red silicified gossan with jaspilite and minor malachite, and talc-schist breccia that is on strike with the main knob 400 m to the north (fig. 14*C*; sample CT07RIM-52-1 and 2, table 2). East of the jaspilitic gossan is another band of chlorite-sericite-carbonate schist cut by centimeter-scale quartz veinlets (fig. 14*D*; sample CT07RIM-51-1, see table 2). The main knob consists of silicified gossan and jaspilite with abundant malachite (fig. 14*E*; samples CT07RIM-53-1 and DC07RIM24-1). No primary sulfides were observed.

A

Figure 14*A*. View to the northeast at the Kadiar 1 occurrence from the prominent north-south trending ridge to the west. USGS photo.

B

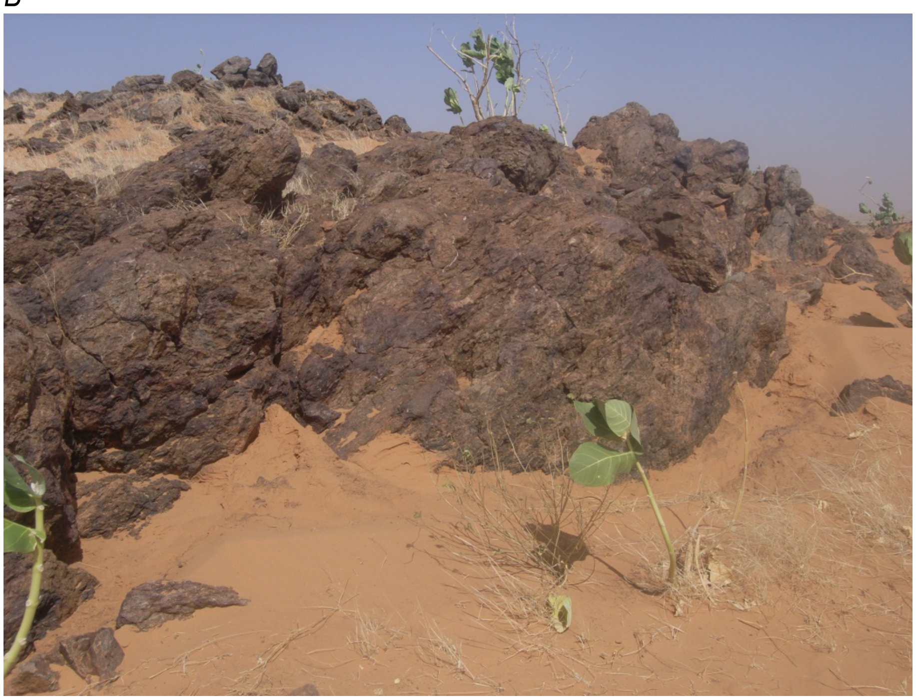

Figure 14*B*. Gossanous iron-oxide rich outcrop on ridge to the west of Kadiar 1.
Rock consists of pervasively iron-altered and silicified chlorite schist or quartzite. USGS photo.

C

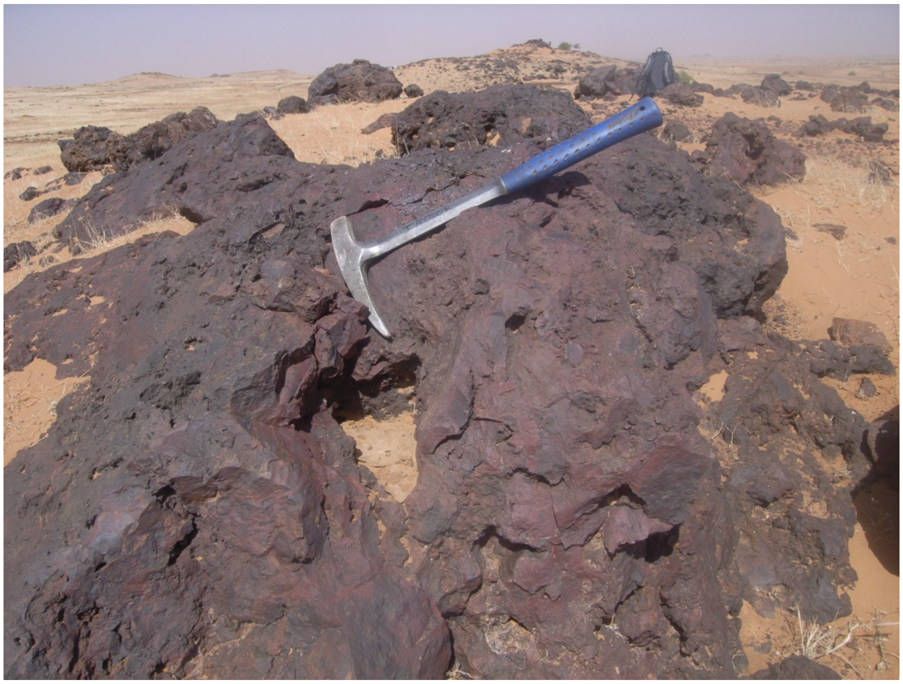

Figure 14*C*. Central band of siliceous gossan and jaspilite at Kadiar 1. USGS photo.

D

Figure 14*D*. Chlorite-sericite-carbonate schist on east side of central jaspilitic gossan at Kadiar 1. USGS photo.

E

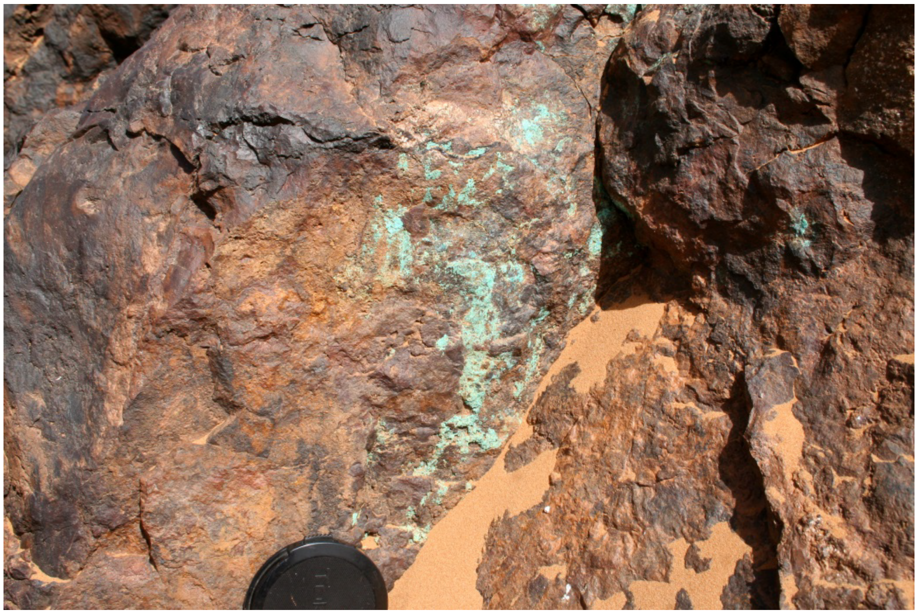

Figure 14*E*. Close-up of silicified gossan with malachite at the main outcrop at Kadiar 1. USGS photo.

Geochemical analyses of samples collected at Kadiar generally show low level Au, As, Co, Cr, Cu, Mn, Ni, Sb, and Zn enrichments with Au values in several samples up to 300 ppb, and Cu values in the silicified gossan at the main knob of 1.3 and 4.2 percent copper and 334 ppm and 244 ppm Co, respectively. Geochemically, the most interesting sample was the silicified gossan-jaspilite (CT07RIM-52-1) collected along strike approximately 200 m south of the main knob. This sample contains 2.5 ppm Au, 2 ppm Ag, 2 ppm Bi, 14 ppm Sb, 1.2 ppm Te, and approximately 0.2 percent Zn. The USGS samples in general contain metal tenors in the same range as previously collected surface samples at Kadiar. Importantly, however, both Cu and Au enrichments are higher than previously reported and the possible Co enrichments would represent an important economic factor in the future development of the occurrence.

Geological relationships and the geochemical signature at Kadiar are interpreted to be most consistent with a mafic-type (Cyprus-type) VMS deposit. Although there are some geochemical similarities between the metal suites present at Guelb Moghrein and Kadiar, the absence of Sn, W, U, REE, and Ti at Kadiar and the presence of low level Zn enrichments, the presence of volcanosedimentary layers reminiscent of the ochres reported from VMS deposits in Cyprus, and the stratiform aspect of Kadiar are all consistent with a VMS model. Salpeteur (2005) noted that the only iron oxide mineral present at Kadiar is hematite and that magnetite, which is commonly in IOCG deposits, is absent. The area is currently (November 2012) under concession to OreCorp Mauritania SARL which is exploring it using a VMS deposit model (OreCorp, 2012).

The Hassi el Aoueija Occurrence

Previously unreported copper showings were located by the BGS in the Moudjeria map sheet approximately 3 km south of the village of Hassi El Aoueija (fig. 7) in two parallel west-northwest-trending ferruginous banded jaspilite units that form conspicuous rocky features. The northern ridge is located at 17º21'47"N., 12º48'54"W. and the southern ridge at 17º21'40"N., 12º48'56"W. The trend of the jaspilites contrasts with the regional NNW strike and they are probably located on a major F1 fold hinge or an F2 monoclinal inflection. The jaspilite units form part of the Aoueija Formation, a fragmented ophiolitic assemblage, and elsewhere are commonly interbedded with metalimestones. The Cu occurrence is located close to the major thrust contact where the Aoueija Formation overthrusts the Djonaba Group (allochthonous basal Taoudeni Adrar Supergroup). The jaspilites may be truncated eastwards along a NW-trending massive quartz-hematite±pyrite reef.

The northern ridge exhibits shallow northward-dipping breccia veins cutting the moderately SSW-dipping jaspilite (44–52º/200–216º). The breccia veins are infilled with hematite and quartz. Fine examples of nests of botryoidal hematite indicate open space filling. An early phase of quartz introduction has been subsequently brecciated and infilled by hematite. The outcrop is gossanous with boxworks encrusted with secondary Fe-oxides. Malachite is evident on bedding plane surfaces adjacent to the breccia veins but is not observed in the veins themselves. The zone of mineralization can be traced for approximately 300 m westwards into a block field where the material shows traces of malachite, chalcopyrite and pyrite. The weakly mineralized zone is 6–8 m thick.

The southern ridge consists of a more degraded outcrop with a more pervasive secondary impregnation of Fe-oxides. The feature is up to 30 m wide and appears to consist of two subparallel jaspilitic units which close off to the west. These may be the limbs of a decameter scale F1 isoclinal fold. Pervasive quartz stringers are both concordant and crosscutting. The copper mineralization (dominantly malachite and secondary Cu oxides) is only observed in the southern limb, which is up to 8 m wide and possibly thickens to 15 m in the hinge zone. The copper minerals occur as patchy impregnations.

Chiron (1965) reported Cu mineralization close to El Aoueija (17º22'30"N., 12º49'30"W.) in a sequence of chlorite schists, prasinites and jaspilites. The schists are associated with ferruginous carbonates that have been interpreted to indicate possible similarities with the mineralization at Guelb Moghrein. The ore mineral assemblage consists of chalcopyrite, malachite and hematite as fine disseminated grains, infilling millimeter-scale cavities and in cross-cutting quartz veinlets. The BRGM reported Cu values up to 1.34 percent in rock chips but there is no information concerning its extent or if any further exploration has since taken place (Gunn and others, 2004). It is suggested that the primary Cu mineralization may have been of VMS Cyprus type subsequently remobilized during deformation and hosted now by jaspilites that were favourable host rocks on account of both their brittle physical properties and their chemical properties. Any significant similarity with Guelb Moghrein remains to be substantiated. Beds of Fe-Mg carbonates were observed during mapping of the district by the BGS but no mineralization was observed in association with them. Similarly there is no evidence of magnetite nor any geochemical data in support of the Guelb Moghrein analogy at Hassi el Aoueija.

A site examination of the Hassi el Aoueija (named El Aouidja in the Mauritanian National Mineral occurrences database; Marsh and Anderson, 2015) occurrence by the USGS in November 2007 confirmed the field relationships described above. The two east-west trending ridges are approximately 200 m apart and consist predominantly of white quartz veins cutting massive goethite and jaspilite with minor malachite. A cemented drillhole collar near the western end of the northern ridge was noted and was apparently drilled by SNIM in 2003, however results are unknown (fig. 15*A–B*). A single sample of quartz veined, malachite-rich massive goethite was collected from the southern ridge and analyzed (fig. 15*C*; table 2). Results indicate that the sample contains 7.3 percent Cu, 21 ppm Ag, and anomalous As and Mn. A second malachite-rich quartz veined sample containing a micaceous mineral was processed for a geochronological determination by the $^{40}Ar/^{39}Ar$ technique, however, the mineral separate was not found to be an argon-bearing phase (probably pyrophyllite). USGS interpretation of field relationships and geochemical data suggest that the Hassi el Aoueija occurrence is a mafic-type (Cyprus-type) VMS with similarities to Kadiar and other Cu occurrences in the Gorgol Noir Complex.

A

Figure 15*A*. View along the northern ridge at the Hassi el Aoueija occurrence. USGS photo.

B

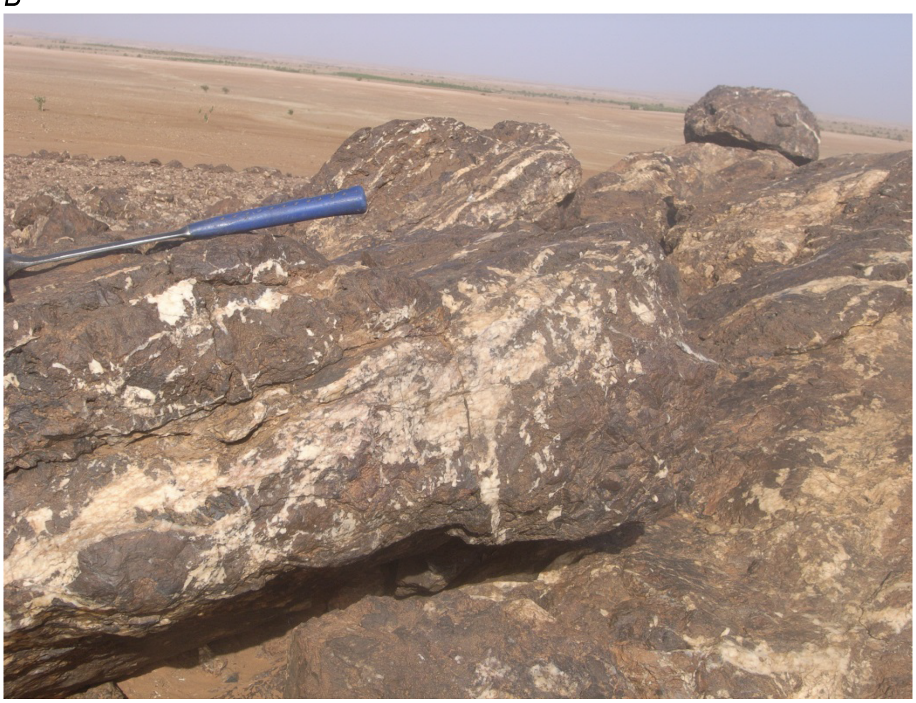

Figure 15*B*. Close-up of quartz veined gossan on the northern ridge at the Hassi el Aoueija occurrence. USGS photo.

C

Figure 15*C*. View to the south from the northern ridge at the Hassi el Aoueija occurrence of quartz-veined gossan capping the southern ridge. USGS photo.

The Tamourt Occurrence

Additional copper showings in the Moudjeria 1:200,000 scale map sheet occur approximately 6 km west-northwest of the village of Djonaba and approximately 6 km east-northeast of the dam at Tamourt Gadel (fig. 7). They are hosted by narrow calc-quartzite and carbonate facies BIF units within garnet mica schists that form subdued outcrops among block fields (17º06'31"N., 12º42'55"W.). The host rocks consist of part of the Gadel Group, a rift-basin assemblage which overthrusts the ophiolitic units (El Gueneiba Group) of the Gorgol Noir Complex. This unit exhibits the highest grade of regional metamorphism within the southern Mauritanide belt (for example, amphibolite facies muscovite-garnet-staurolite-kyanite assemblages). The carbonate-rich units are generally less than 1 m thick and strike north-northwest with the regional trend and exhibit a subvertical dip (WSW and ENE). The lamination is locally preserved and centimeter-decimeter-scale, tight to isoclinal folds can be discerned. The schists exhibit two slight subparallel schistosities (S1 85º/100º; S2 70–74º/074–080º). The S1 is more or less coplanar with the bedding. The more consistent S2 locally forms a well-developed crenulation cleavage.

The mineralized units are conspicuous by their gossanous honeycombed ochreous appearance and presence of malachite. Float blocks of mineralized material were found further to the southwest (for example, 17º06'34"N., 12º42'56"W.) containing both malachite and secondary Cu oxides. In this particular area there is also a suite of north-northeast-trending smoky black to gray quartz veins. However the specific association with carbonate-bearing lithologies is clearly of greater importance and may be compared with the Guelb Moghrein type of Cu mineralization. Traces of Cu/Fe oxides were also observed in calc-quartzites at 17º07'10"N., 12º41'05"W.

3.3 Northeastern Rgueïbat Shield

Several areas of the Mesoarchean and Paleoproterozoic portions of the northeastern Rgueïbat Shield, here considered as the area northeast of Choum, contain supracrustal rock sequences that are permissive for VMS deposits. In the Mesoarchean portion of the Shield, studies by the BRGM (Marot and others, 2003) suggest that the poorly understood granulite facies gneiss, migmatite, amphibolite, metapyroxenite, and marble within the TRla and TRle units of the Tiris Complex have relatively undetermined potential for VMS deposits. This is in part based on the ubiquitous presence of Algoma-type iron formation throughout the region that indicates that seafloor exhalative processes were active during deposition of the host rocks. Although more detailed study is required, the TRla and TRle units of the Tiris Complex (Lahondère and others, 2003) are considered permissive for VMS deposits.

Geologic mapping in the Tiris Complex by the BGS (O'Connor and others, 2005) breaks the complex into three lithodemic units defined as the El Gheicha, Mirikli, and El Khadra Formations. Although correspondence of the units is not exact, the TRla unit equates to the El Khadra Formation and the TRle unit equates to the Mirikli and El Gheicha Formations. BGS work (O'Connor and others, 2005) further identifies mappable units of Algoma-type iron formation (unit TRfe), which are ubiquitous throughout the Mirikli and El Khadra Formations, but are rare in the predominantly aluminous gneisses of the El Gheicha formation. However, at present there are no known base or precious metal occurrences within any of these rocks, suggesting that they are of low priority for future exploration.

The northeastern Rgueïbat Shield is composed of Paleoproterozoic (Birimian) to Neoproterozoic granitoids and supracrustal rocks of the West African Craton. This region is characterized by a series of volcanosedimentary belts and associated batholithic-scale granitic intrusive suites emplaced during the Eburnean orogeny from about 2,150–2,000 Ma. Two major sets of shear zones are present oriented NNW-SSE and E-W and often bound the volcano-sedimentary belts and (or) batholiths. French workers divide the northeastern Shield into four major lithologic groupings by age consisting of (1) an early Birimian (>2,150 Ma) group of primarily metamafic volcanosedimentary rocks including from west to east, the Rich Anajim, Aguelt abd el Maï, Ghallamane and Tsalabia el Khadra Complexes, (2) a middle Birimian (2,150–2,120 Ma) group of intrusive granites including from west to east, the Adam Anajim Suite, and the Tin Bessaïs and Tmeïmichatt Ghallamane Complexes, (3) a late Birimian (2,070–2,060 Ma) group of volcanosedimentary sequences of low metamorphic grade including from west to east, the Legleya, Imourène and Blekhzaymat Groups accompanied by similar-aged granites of the Gleïbat Tenebdar Suite, and (4) a latest Birimian (2,040–2,000 Ma) group of voluminous magmatic rocks including the Adam Esseder Complex and the Sfariat, Yetti, Bir Moghrein and Tigsmat el Khadra Suites (Lahondère and others, 2003). With the exception of the Blekhzaymat Group, most of the volcanosedimentary sequences are relatively restricted in area and occur as roof pendants and screens within and adjacent to the areally extensive granitic batholiths and other intrusive suites primarily in the central area of the northeastern Shield (fig. 16).

Several of the supracrustal volcanosedimentary sequences contain known occurrences of Mn, Cu, Pb, Zn, +- Ag, Au, Ba, Sb, Cd, and Bi that have been identified as possible VMS deposits by the BRGM (Marot and others, 2003). BRGM authors have compared these occurrences with the Perkoa Zn-Ag deposit in Burkina Faso, which is hosted in a similar sequence of Paleoproterozoic (Birimian) supracrustal rocks. Supracrustal sequences that are considered permissive for VMS deposits by the BRGM (Marot and others, 2003) include the early Birimian Aguelt abd el Maï, Ghallamane and Tsalabia el Khadra Complexes, and the late

Birimian Blekhzaymat Group, particularly in the Aguelt el Fersig and Ameina sectors (fig. 16). The Rich Anajim Complex is here considered equally permissive of VMS deposits due to its general similarities with the other early Birimian sequences. The late Birimian Legleya and Imourène Groups are also here considered permissive because of their similarity to the Blekhzaymat Group. Although these supracrustal sequences are not known to contain VMS mineral occurrences, the poor exposure and absence of VMS-specific exploration in these sequences suggest that their potential is relatively untested.

The Rich Anajim Complex (fig. 16) is a metamorphosed supracrustal sequence consisting of metapyroxenites, amphibolites, dolomitic marbles, magnetite quarzites and migmatitic paragneiss that constitute broad mapped areas on both sides of the Sfariat belt in the southwestern portion of the Paleoproterozoic Shield. The southern outcrop area lies wholly within the granitic rocks of the middle Birimian Adam Anajim Suite and the northern outcrop area lies between the Sfariat Belt and granitic rocks of the Gleïbat Tenebdar Suite. The Rich Anajim Complex is divisible into lithostratigraphic packages consisting of gabbros and basalts thought to be of back-arc origin, a set of closely associated ferruginous quartzites and marbles, and a paragneiss suite derived from pelitic and calcareous sandstones. The ferruginous quartzites form resistant ridges that vary from 2 to 10 m in width and are composed primarily of magnetite, quartz, and hematite. Iron content of these Algoma-type BIF units ranges from 30 to 35 percent (Lahondère and others, 2003).

The Aguelt abd el Maï Complex (fig. 16) is an areally restricted unit occurring as thin sheets, roof pendants, and enclaves of gneissic to mylonitic textured supracrustal rocks between granitic rocks of Adam Esseder and Tmeïmichatt Ghallamane Complexes. The predominant lithologies are a fine grained metamafic rock and dark-colored porphyroclastic rocks with subordinate amphibolites and melagabbros. Metasedimentary rocks include quartzites and calc-silicate gneisses (formerly calcareous sandstones and marbles). The metamafic rocks consist of metamorphosed porphyritic dacites and rhyodacites. The amphibolites contain pyrite partially converted to hematite. The screens and enclaves are highly attenuated and discontinuous and occur on scales of meters to kilometers in length. Outcrops are wider to the south and contain higher proportions of amphibolites, quartzites, and marbles (Lahondère and others, 2003).

The Ghallamane Complex (fig. 16) is primarily of sedimentary origin and consists predominantly of fine grained biotitic paragneiss with subordinate quartzite, conglomeratic arkoses, metapelites, and calcic paragneiss. It crops out primarily in the south central portion of the northeastern Shield and occurs as roof pendants and enclaves within the middle Birimian granitic rocks of the Tmeïmichatt Ghallamane Complex. Minor enclaves of mafic rock are present, however, their relationship to the metasedimentary rocks is uncertain. Similar to the Aguelt abd el Maï Complex, it is an areally restricted unit that occurs as enclaves meters to kilometers in size with the widest outcrops located in the central and northeastern part of its exposure. The lack of identifiable co-genetic intrusions and metavolcanic rocks and the predominantly metasedimentary character of the Complex suggest that the potential for discovery of VMS occurrences in these rocks is low.

The Tsalabia el Khadra Complex (fig. 16) is an areally more extensive supracrustal sequence located to the east of the Ghallamane Complex in the central part of the northeastern Shield. The largest contiguous block is located toward the northern end of its mapped extent and has dimensions of approximately 90 × 20 km. The Complex consists of metapyroxenites and metagabbros, mafic metahyaloclastites, amphibolites locally associated with quartzites and lenses of marble, locally manganiferous quartzites, meta-andesites, metarhyolites, epiclastites and tuffaceous schists and locally conglomeratic meta-arkoses (Lahondère and others, 2003). The Complex is fault bounded to a greater degree than the previously described units and is within or in contact with granitic rocks of the middle Birimian Tin Bessaïs and Tmeïmichatt Ghallamane Complexes and the latest Birimian Adam Esseder Complex.

Geochemical analyses of amphibolites and metabasaltic rocks from all of the early Birimian supracrustal sequences yield N-MORB elemental patterns consistent with their derivation in an oceanic environment. Geochemical characteristics of intermediate volcanic rocks are more consistent with derivation in a calc-alkaline, volcanic arc environment. Together these data are interpreted to represent a back-arc or intra-arc environment of formation of the early Birimian supracrustal sequences of the northeastern Shield (Lahondère and others, 2003).

In their consideration of the potential for VMS-type mineralization in the early Birimian supracrustal sequences, BRGM authors (Marot and others, 2003) note that there has been very little previous exploration specifically for VMS deposits and that exploration is severely hampered in the shield by the extensive regolith cover and generally poor outcrop. As a result, the detailed studies of volcanosedimentary facies transitions, proximal to distal relationships, recognition of synsedimentary faulting and depositional features, and identification of volcanic edifices with subvolcanic co-genetic intrusions that would be desirable for VMS exploration programs are not available. Marot and others (2003) suggest that the Tsalabia el Khadra Complex is the best studied and most prospective of the various supracrustal sequences. The complex contains a permissive suite of rocks characterized by a submarine mafic volcanic association containing hyaloclastites and possibly volcaniclastic breccias derived from pillow lavas, magnetite-bearing chert with local hematite-carbonate alteration, and manganiferous horizons with local silica-carbonate alteration in association with volcanogenic sedimentary rocks with evidence of input from continental sources consistent with an intra- or back-arc environment. Thus this sequence, and by extension the other early Birimian sequences, should be considered as permissive of bimodal-mafic, (Kuroko-type), pelite-mafic (Besshi-type) and possibly siliciclastic-felsic (Iberian Pyrite Belt, Bathurst district, Canada) types of polymetallic VMS deposits.

No polymetallic mineral occurrences suggestive of VMS mineral systems are known in the northeastern Shield. Marot and others (2003) note the presence of two Mn occurrences in the Tsalabia el Khadra Complex at Bir Caleh in the north and an unnamed occurrence in the south (fig. 16). Exploration by Ashton Mining Ltd. in 1997 in the Tsalabia license area highlighted three areas of iron-rich rock (pseudo-gossan) with anomalous gold values between 100 and 200 ppb. In 1998–1999 Normandy LaSource found 28 areas in the Karet license area with anomalous Au and polymetallic geochemical signatures (Au±As, Cu, Ag or Mn±Au, As, Cu) primarily in chert facies quarzites with hematite±magnetite±secondary Mn minerals. Focus on these rocks and geochemical characteristics resulted in location of another 43 new anomalies; among which, 25 Mn anomalies corresponded to ribboned black cherts with garnet or Mn oxides, with banded ferruginous quartzites (BIF) with magnetite±hematite ±siderite, with black siltstones with garnet or Mn oxides± carbonates, or with ribboned carbonates with Mn oxides. Sixteen anomalies corresponded to ribboned cherts with iron oxides±pyrite. Finally two chalcopyrite occurrences were located, however it is not clear whether the chalcopyrite was related to syngenetic processes (Marot and others, 2003). No information regarding the tenor of the geochemical anomalies or reports of the exploration programs described above were available to the USGS. Locations of these unnamed anomalies and brief descriptions of the geological relationships at each site are provided in Marsh and Anderson (2015)

Marot and others (2003) also comment that the supracrustal sequences of the Aguelt abd el Maï and Ghallamane Complexes both contain disseminated chalcopyrite, malachite, and chrysocolla in submarine metavolcanic rocks that they suggest may be related to syngenetic mineralizing processes. Brief information on anomalies in these belts are also provided in Marsh and Anderson (2015).

The (from west to east) Legleya, Imourène, and Blekhzaymat Groups all consist of late Birimian volcanosedimentary rocks that are similar enough in rock type and composition to be considered together for the purposes of this report (fig. 16) . They consist primarily of intermediate to felsic eruptive rocks and associated reworked volcanogenic sedimentary rocks including lahars, graywackes and sandstones that occur in shallow extensional basins on the middle Birimian granitic rocks. Deposition of these rocks in north-northwest trending elongate blocks was probably controlled by the regional trend of shear zones and major faults. Where stratigraphic relationships are not obscured by deformation and segmentation resulting from the voluminous intrusion of latest Birimian granitic rocks, a general depositional sequence consists of a basal conglomerate derived principally from the middle Birimian granites with clasts of rhyolite, microgranite, and diabase, overlain by increasingly fine grained arkose and sandstone interbedded with intermediate to felsic ash tuffs, followed by ignimbrites, followed by lavas. However, latest Birimian intrusive rocks obscure these relationships and the late Birimian successions usually appear as roof pendants and sheets of volcanic rocks (ignimbrites and tuffs) or co-genetic (?) hypovolcanic rocks (granophyres and microgranites). The envelopment of the volcanosedimentary successions by the latest Birimian magmatism causes local development of hornfels and remelting of the older rocks. In several locations volcanosedimentary sheets of late Birimian rocks consisting of intermediate volcanics and associated sedimentary rocks are crosscut by domes and associated ignimbrites of rhyolite suggesting a temporal evolution towards more evolved felsic volcanism (Lahondère and others, 2003).

In their review of the VMS potential of the Paleoproterozoic volcanosedimentary successions of the northeastern Rgueïbat Shield, BRGM authors (Marot and others, 2003) focus on the potential of the Blekhzaymat Group and mention particularly the Aguelt el Fersig and Ameina sectors (fig. 16). However, USGS review of the geology of these successions suggests that all three Groups are equally permissive of VMS deposits and that the Aguelt el Fersig and Ameina sectors should be considered as areas more favorable for exploration within the Blekhzaymat Group. However, the near absence of mafic igneous rocks, the lack of any indicators of submarine deposition of the successions, and clear indication of subareal deposition of ignimbrites and tuffs are all factors that suggest the favorability of the successions for discovery of VMS deposits is low. The preponderance of intermediate to felsic volcanic rocks with variable proportions of associated volcanogenic sedimentary rocks suggests that if VMS mineralization is present in these successions it is most likely to be of the siliciclastic-felsic type (Iberian Pyrite Belt; Bathurst district, Canada).

The Legleya Group (fig. 16) is the westernmost of the three late Birimian volcanosedimentary successions and occurs primarily as a north-northwest trending basin sandwiched between exposure of the Gleïbat Tenebdar Suite of granitic rocks in the area to the northeast of Bir Mogrein. Two smaller, much narrower basins occur as subparallel belts to the southeast and are encompassed by granitic rocks of the Adam Esseder Complex. The larger basin to the northwest contains several uranium occurrences associated with pyrite and silica associated with the Gleïbat Tenebdar Suite near the southern end. The southwestern of these two latter belts are associated with pyrite-bearing siliceous breccias associated with mylonitization and shearing.

Seven occurrences of this type are noted by BRGM authors and are thought to be mesothermal or perhaps epithermal in origin (Marot and others, 2003). The northeastern belt contains a number of shear zone-hosted uranium occurrences in the Tenebdar area (fig. 16) and are thought to be mesothermal vein-type occurrences (Marot and others, 2003; Fernette, 2015b). There are currently no known occurrences in the Legleya Group that are thought to be of the VMS type. The epigenetic character of all the known occurrences further suggests that volcanism may have been almost entirely subaerial in nature.

The Imourène Group (fig. 16) is centrally located in the Paleoproterozoic portion of the Shield and primarily occurs as discontinuous and widespread roof pendants in granites of the Adam Esseder and Tin Bessaïs Complexes, and Yetti Suite. There are no known base metal or gold mineral occurrences currently located in the belt and the majority of known occurrences are shear zone-hosted (mesothermal) uranium showings or U, Th, REE occurrences associated with latest Birimian alkaline granites and phonolite bodies associated with the Tigsmat El Khadra Suite Marot and others, 2003; Fernette, 2015b; Taylor and Giles, 2015). A few poorly described occurrences such as Tachleift and Bir Bou Agba contain red jaspers and disseminated pyrite in silicified intermediate to felsic volcanic rocks or silicified breccias with pyrite and arsenopyrite, respectively, however they are interpreted to represent epithermal mineral occurrences (Marot and others, 2003; Marsh and Anderson, 2015). Marot and others (2003) state that Normandy LaSource explored the southern portion of the belt (Alous Tmar sector) for gold without success. There are currently no known occurrences in the Imourène Group that are thought to be of the VMS type. Similar to occurrences in the Leglaya Group, the epigenetic character of all the known occurrences in the Imourène Group suggests that volcanism may have been subaerial in nature.

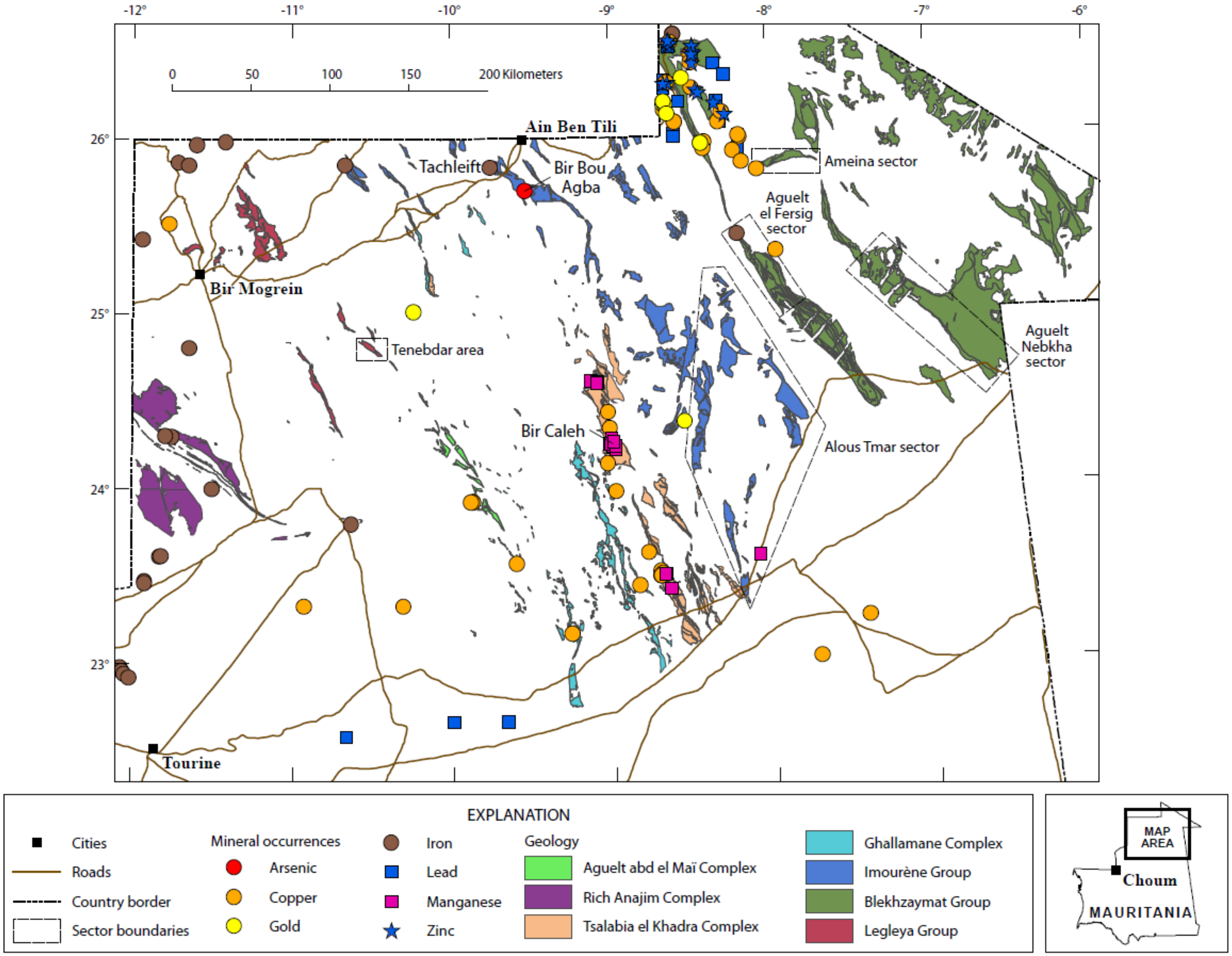

Figure 16. Simplified geologic map of the Paleoproterozoic portion of the northeastern Rgueïbat Shield showing the locations and associated VMS occurrences of the early Birimian and late Birimian volcanosedimentary successions described in the text. Paleoproterozoic intrusive rocks not shown.

The Blekhzaymat Group (fig. 16) is the easternmost late Birimian volcanosedimentary succession and is present in approximately three north-northwest trending, wide swaths that are partially disrupted by batholith-scale granitic rocks of the Yetti Suite. The northern end of the belt is currently of interest for orogenic gold occurrences along regional-scale shear zones (Goldfarb and others, 2015) and the central portion of the belt is being prospected for hamada (calcrete) uranium occurrences (Fernette, 2015b). Prior to the current exploration in the area for uranium and gold, Ashton Mining Ltd. and BPGC exploration programs located approximately 175 occurrences generally described as polymetallic±Au mesothermal veins or disseminations associated with silica, pyrite, and iron oxides (Marot and others, 2003).

BRGM authors note, however, that the area has not been the subject of directed exploration for VMS and that the potential of the region is largely untested. For example in the southern sector of the central swath of the Blekhzaymat Group, an area referred to as the Aguelt Nebkha sector (fig. 16), Ashton Mining Ltd. (presumably during an exploration program for orogenic gold deposits) located 33 separate sites of anomalous gold (>118 ppb in lag deposits or in rock). Of these, 17 occurrences located in rock outcrop were described as being associated either with quartz veins containing carbonates and iron oxides or with ferruginous ribboned chert (Marot and others, 2003). While most if not all of these occurrences are probably correctly attributed to mesothermal Au-quartz vein occurrences, the occurrences associated with the ferruginous cherts are similar to the ferruginous and Ba-Mn mineralized cherts of the Tsalabia el Khadra Complex that are interpreted to have affinities to the siliciclastic-felsic type of VMS deposits as described above.

The Aguelt el Fersig and Ameina sectors (fig. 16) are regarded as more prospective of VMS deposits than other areas of the Blekhzaymat Group due to their similarity with the relationships described in the Tsalabia el Khadra Complex (Marot and others, 2003). The Aguelt el Fersig sector, which is located in the center of the western-most Florence-El Khdar swath of Blekhzaymat Group rocks, is described as containing volcanogenic sedimentary rocks with manganiferous chert layers similar to those observed in the Tsalabia el Khadra Complex. The cherts, however, apparently contain less manganese and the host rocks have a more continental influence marked by the presence of distal volcanic rocks produced during episodes of explosive volcanicity. This sector of the Blekhzaymat Group contains at least a dozen unnamed occurrences of red, black, or ferruginous cherts that are variably described as containing disseminated pyrite or iron oxides (Marsh and Anderson, 2015). The Ameina sector, a southeast-northwest trending outcrop area located to the northwest of the Aguelt Nebkha sector in the central swath of Blekhzaymat Group rocks, is devoid of known occurrences. However it is marked by a central silica-pyrite altered ridge approximately 10 km long that is interpreted as possibly a syngenetic feature (Marot and others, 2003).

In summary, there are seven major volcanosedimentary supracrustal sequences, four of them early Birimian in age and three of them late Birimian, that are broadly considered permissive of hosting VMS deposits. The four early Birimian belts, the Rich Anajim, Aguelt abd el Maï, Ghallamane, and Tsalabia el Khadra Complexes are characterized by the presence of mafic to felsic volcanic rocks and associated sedimentary rocks and are considered permissive of bimodal-mafic, (Kuroko-type), pelite-mafic (Besshi-type) and possibly siliciclastic-felsic (Iberian Pyrite Belt, Bathurst district, Canada) types of polymetallic VMS deposits. Of these, the Tsalabia el Khadra Complex is the best explored and contains the highest number of favorable indicators of the possible presence of VMS mineral systems (Mn-Ba occurrences, jaspilites, pyritic cherts, evidence of submarine deposition of host rocks, and so forth, as described above).

The three late Birimian belts, the Legleya, Imourène, and Blekhzaymat Groups, are characterized by the near absence of mafic rocks and are composed primarily of intermediate to felsic volcanic rocks, volcanogenic sedimentary rocks, and the presence of co-genetic hypabyssal intrusions of intermediate to felsic composition. Interpretations of the depositional basins containing these rock sequences suggest that they may have been shallow subaqueous to predominantly subaerial based on the absence of clear evidence for subaqueous deposition of the volcanic rocks and the presence of abundant tuffs and particularly, ignimbrites. However, the presence of minor iron formation and chert indicates that at least some portions of the volcanosedimentary sequence must have been deposited under subaqueous conditions and are therefore permissive of siliciclastic-felsic type VMS systems. The Blekhzaymat Group is regarded as the most favorable of the three late Birimian belts largely based on comparison of similar geology to the Tsalabia el Khadra Complex and the minor presence of favorable indicators (ferruginous cherts, stratiform silica-carbonate alteration) in the Aguelt el Fersig and Ameina sectors.

The lack of mineral occurrences in the Paleoproterozoic portion of the Shield that are currently interpreted to be of the VMS class of deposits is discouraging. The lack of VMS mineralization combined with the evidence that suggests that significant portions of the rock sequences in these belts were subaerially deposited suggests that the potential for discovery of a significant economic deposit is low. However, it should be noted that this low potential is offset by the marked lack of detailed volcanostratigraphy, poor geologic exposure under vast areas of regolith, and the near absence of targeted exploration for VMS deposits.

4 Permissive Tracts for VMS Deposits in Mauritania

Tracts considered permissive for deposits broadly classified as VMS are shown on figure 17. The single most fundamental criteria required of rock sequences that are permissive of VMS deposits is that they represent a volcanosedimentary succession that was deposited subaqueously in a marine environment. Criteria for the delineation of these tracts are based upon permissive geology as described in BGS and BRGM reports and is broken out primarily at the Group level. A second major criterion for selection of tracts is the distribution of known occurrences of copper, lead, zinc, gold, barite, iron, and manganese where they are hosted within permissive host rocks. Thirteen tracts are defined as follows: In the Mesoarchean rocks of the southwestern Rgueïbat Shield: (1) a tract is drawn based upon the supracrustal sequences currently lumped into the Lebzenia Group to encompass the seven separate greenstone belts of the Tasiast-Tijirit terrane; and (2) a tract is drawn on the Saouda Group of the Choum-Rag El Abiod terrane in the Inchiri district. The tract in the Tasiast-Tijirit terrane has been extended under cover using aeromagnetic data. In the central Mauritanides, (3) a tract is drawn on the Neoproterozoic volcanosedimentary sequences of the Akjoujt nappe pile and includes permissive sequences in the Agoualilet Group, specifically the Amleila Suite (currently correlated with the Guidamaka Suite) and the Adam el Bouje and Treïfiyat Formations, and the Eizzene and Oumachoueima Groups. In the southern Mauritanides two separate tracts are drawn upon; (4) felsic metavolcanic rocks and metasediments of the Mseigguem Group and to a lesser extent in the overlying metasedimentary rocks of the El Ghabra Group; this tract contains the VMS occurrences of Bou Zrabie, Mbout, Harach, Indice 78, and Ouechkech, and the; (5) mafic-ultramafic ophiolitic rocks of the Gorgol Noir Complex. This tract contains possible VMS deposits such as Kadiar, Oudelemguil, Daiguili, and especially Hassi el Aoueija. These occurrences are hosted in rocks of the El Gueneiba Group, interpreted to be a rift basin assemblage of mafic volcanic rocks and associated sediments, and the Gadel Group, an ophiolite mélange composed of a structurally complex assortment of mafic volcanic rocks and sediments juxtaposed with gabbros and ultramafic rocks. In the Mesoarchean portion of the northeastern Rgueïbat Shield; (6) a tract is drawn upon the TRla and TRle units of the Tiris Complex due to the possible association of VMS deposits with Algoma-type BIF. In the Paleoproterozoic portion if the northeastern shield, separate tracts are drawn upon the early Birimian: (7) Rich Anajim Complex, (8) Aguelt abd el Maï Complex, (9) Ghallamane Complex; and (10) Tsalabia el Khadra Complex. Tracts are also drawn on the late Birimian; (11) Legleya Group; (12) Imourène Group and; the (13) Blekhzaymat Group.

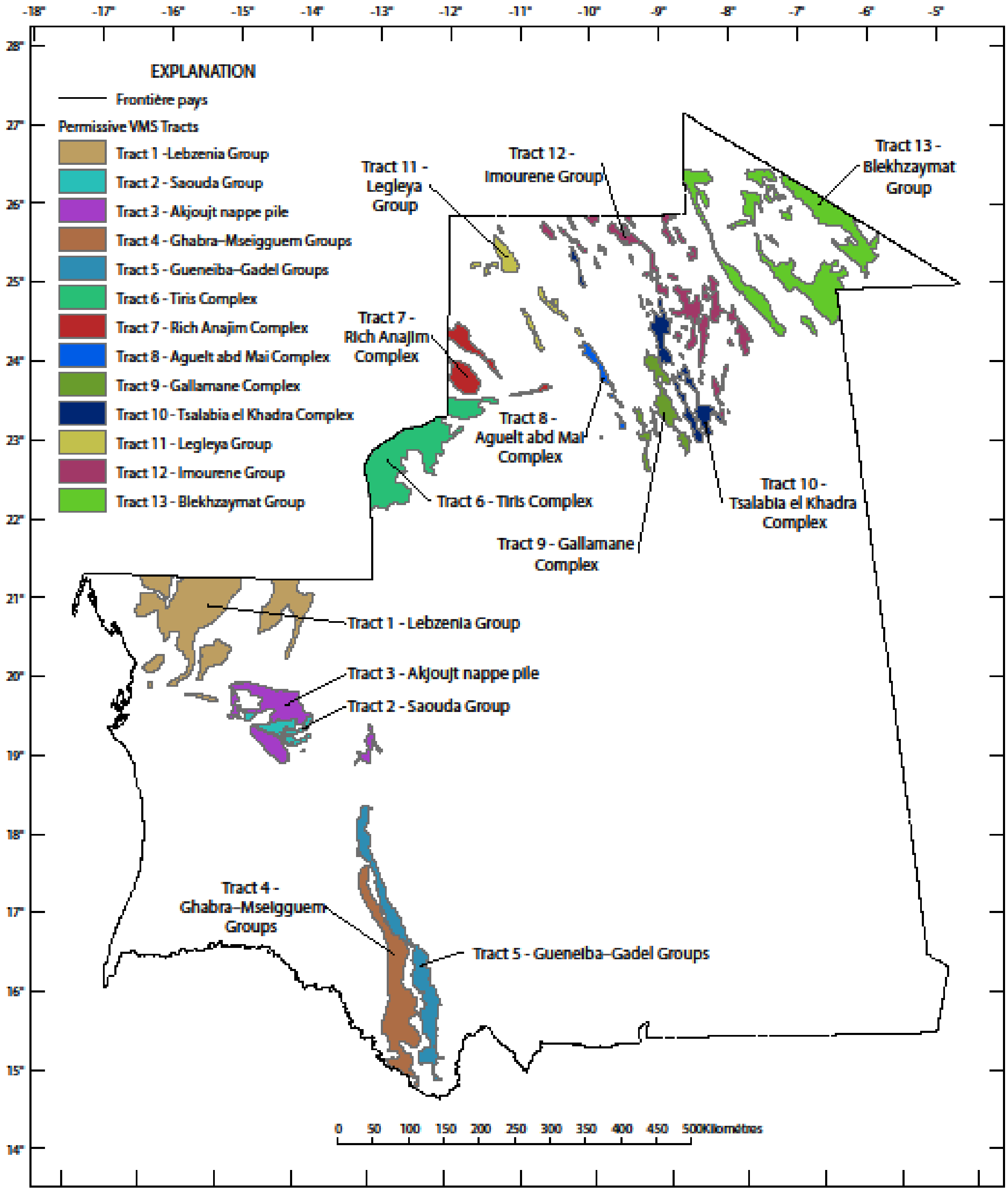

Figure 17. Permissive tracts for volcanogenic massive sulfide deposits in Mauritania.

5 Conclusions

Potential for VMS deposits in Mauritania exists within volcanosedimentary sequences of the Rgueïbat Shield and the central and southern Mauritanides. Thirteen permissive tracts have been drawn based upon permissive geology at the group, complex, or suite level and on the distribution of known occurrences thought to belong to the VMS class of deposits. Currently there are no known VMS mineral occurrences in any of the Mesoarchean or Paleoproterozoic supracrustal sequences in Mauritania. The Neoproterozoic rocks of the Oumachoueima Group in the Central Mauritanides contain numerous Cu±Au occurrences, however none are unequivocally recognized as VMS occurrences. Two separate Neoproterozoic volcanosedimentary sequences in the Southern Mauritanides each contain numerous of bimodal-mafic (Kuroko-type) or bimodal-felsic and mafic-type (Cyprus-type) VMS occurrences, respectively and are the most favorable supracrustal sequences in Mauritania for the additional discovery of VMS deposits.

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