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**Geodynamics and mineralizations of Paleoproterozoic formations
for a sustainable development**

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GEODYNAMIQUE ET MINERALISATIONS EN AFRIQUE DE L'OUEST POUR UN DEVELOPPEMENT DURABLE



15, 16 Octobre 2018, Université Félix HOUPHOUËT-BOIGNY, Abidjan-Côte d'Ivoire

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Petrographic and Geochemical features of low to medium grade birimian metasedimentary rocks of the comoe basin (North of Alépé-South east part of Côte d'Ivoire)

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The ComoeBirimian Basin outcrops in three different countries (Côte d'Ivoire, Ghana and Burkina Faso). The southern part of this basin located in Côte d'Ivoire, precisely close to Alépé consists of metasedimentary rocks, affected by the low (greenschist) to medium (upper amphibolite) grade metamorphism. Petrographic studies of those rocks highlighted the presence of paragneisses, micaschists, mylonites, metawackes and schists. Paragneisses and micaschists are evolving according to the mineral composition from west to east and from south to north, respectively.

Using major elements, two main sedimentary units have been distinguished: shales group (micaschists, mylonites and schists) and sandstones group (paragneisses and metawackes). Rocks affected by medium metamorphism grade (in majority sandstones) located in the southern part show low PIA and CIA indexes. While PIA and CIA indexes are high for rocks located in the north part affected by greenschist metamorphism grade (in majority shales). PIA, CIA indexes with A-CN-K interpretation indicate that probably chemical weathering in the source area and recycling processes have been more important in the northern rocks (lower metamorphism) relative to the rocks affected by medium metamorphism grade (most of paragneisses). Shales samples have undergone a post-depositional K metasomatism.

Geochemical data suggest that the metasedimentary rocks come from intermediate to mafic igneous provenance, with the Archean greenstone sediments signature. The low ratio of Th/U below 3.5, for Comoe Basin metasedimentary rocks indicates that the source is mantle-derived volcanic rocks. Trace and major elements features suggest that the deposition of those rocks took place in island arc setting.

Keywords: Petrographic, Geochemistry, metasedimentary rocks, Birimian, Comoe Basin

Paleoproterozoic crystallization and metamorphism and Neoproterozoic shearing of high grade gneisses from the Kandi shear zone in Central-Bénin (Dahomeyides fold belt, West Africa)

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The Kandi shear zone is a segment of the huge shear zone that extends from the Hoggar mountains (Algeria) to the Atlantic coast in Bénin and continues down to northwest Brazil. In the Savalou area in Central-Bénin, the Kandi shear zone exposes the association of high-grade deformed granulites and amphibolites facies gneisses and migmatites, various types of granitoids, low-grade metavolcanic and sedimentary formations (the Idahou-Mahou basin) and low-temperature tectonites (low-temperature mylonites, ultramylonites and cataclasites) occurring as several kilometric-scale bands.

In order to better understand geodynamic evolution of the western Panafrican Dahomeyides fold belt, radiometric ages (U-Pb) were carried out on zircons from the high grade metamorphic rocks of the Kandi shear zone (granulites and amphibolites facies gneisses). The zircons from the felsic granulites of Savalou yield a Paleoproterozoic age of 2091 ± 14 Ma and 2057 ± 8 Ma interpreted as crystallization and metamorphic recrystallization in granulite facies condition, respectively. The amphibolites facies gneiss gives a Neoproterozoic age of 606 ± 5 Ma that corresponds to the mylonitic deformation associated to the shearing in amphibolites facies metamorphism condition. The Neoproterozoic shearing imprint is marked by a mylonitic foliation that strikes NS and dips steeply to vertical and a sub-horizontal mineral lineation together with the common dextral kinematic indicators in agreement with transcurrent shear zone.

These ages obtained on the granulite and amphibolite gneiss from the Kandi shear zone in Central-Bénin are similar with those obtained on the felsic granulite and mylonitic granodiorite in Cariré region along the Transbrasiliano lineament (da Silva Amaral et al., 2012). This comforts the correlation between the Kandi shear zone and Transbrasiliano lineament.

Keywords: Bénin, Savalou-Kandi shear zone, geochronology, Dahomeyides Belt.

Reference

da Silva Amaral, W., dos Santos, T.J.S., Wernick, E., de Araújo Nogueira Neto, J., Dantas, E.L., Matteini, M., 2012. High-pressure granulites from Cariré, Borborema Province, NE Brazil: Tectonic setting, metamorphic conditions and U-Pb, Lu-Hf and Sm-Nd geochronology. *Gondwana Research*, doi: 10.1016/j.gr.2012.02.011.

Aeromagnetic modeling of Precambrian subsurface structures of the Tasiast area, NW Mauritania : Mining consequences

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The NW sector of Mauritania represents the Archean province of the Reguibat Ridge. It is mainly composed of the typical Archean cratonic association of granitoid gneisses, greenstone belts and granites. The greenstone belts contain high mineral potential, mainly gold. This is particularly the case of the Chami Greenstone Belt, which hosts the large Tasiast gold mine whose gold deposits are hosted along a NS oriented shear zone with a surface of $70 \times 15 \text{ km}^2$.

The mineral-bearing bodies of Tasiast are presented in both forms of (i) veins of quartz-carbonate-white feldspar-pyrrhotite-pyrite, veinlets of quartz-carbonated containing gold, and (ii) adjacent gold disseminated and hosted within rocks from green schist to amphibolite facies, banded iron formations (BIF) with magnetite-quartzite, and adjacent volcano-clastic rocks. The whole of the

seminalizations follow a series of reactivated thrust faults, including Tasiast and Piment fracture zones (Heron et al., 2016). At the northern end of the Chami Greenstone Belt, Piment mineralizations are hosted within BIF, felsic volcanic rocks, and associated clastic rocks, while in its western branch, they are hosted within mafic rocks (Sedore and Masterman, 2012; Heron et al., 2016). The clay alteration and the high salinity of fluid inclusions indicate possible orogenic gold deposits dated between 1.85 Ga and 1.5 Ga (Higashihara et al., 2004; Marutani et al., 2005).

Thanks to the available aeromagnetic data recorded at 100 m elevation northern Chami area, suitable computations on the anomaly map reduced to the pole were used to propose a subsurface structural model. In fact, upward continuations, apparent magnetic susceptibility, directional derivatives, analytical signal, 3D Euler deconvolution and spectral analyses were investigated to build this model (Thompson, 1982; Blakely and Simpson, 1986; Reid et al., 1990; Cowan and Cowan, 1993; Blakely, 1996; Mushayandebvu et al., 2001; Roest et al., 1992). They helped decipher the main evidenced structural features with the main NNE-SSW, NW-SE and $\sim N120^\circ$ directions, identified on most all computed maps combined with in situ measurements. They probably correspond to mafic dykes, fault zones rooted up to 5 km depth, particularly to the North, SW and NE, and southwards and westwards by spectral analyses and 3D Euler deconvolution, respectively (Fig. 1). The base is deeper towards the West and South and outcrops towards the North in agreement with the geological observations. In addition, the high values of magnetic susceptibility (χ_m) measured in situ on BIF (25.7-35.10⁻³SI) south of Akjoujt could be the origin of magnetotectonic sources associated with magnetic minerals for gold bearing and base metals exploration.

Keywords: dykes, shears, Precambrian, modelling, aeromagnetism, subsurface structures, gold mines

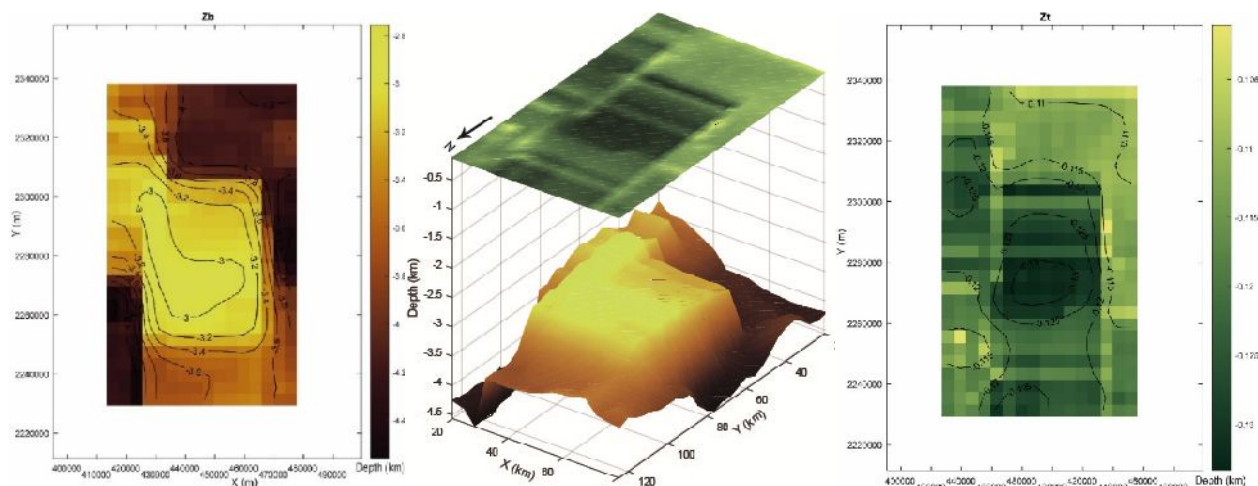


Fig. 1. Projection of 3D solutions of the spectral analysis (Okubo et al., 1985 ; Tanaka et al., 1999) showing the base (Zb : "bottom") and top (Zt : "top") geometries on the left (right) side (isocontours, km), respectively. The scales of the depths are given in km.

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Mineralogical, chemical and geotechnical characterization of bentonite deposit from the Kert Basin (northern Morocco)

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Most Moroccan bentonite deposits are located in northeastern Morocco, in the Nador region. This natural resource is linked to the volcanic activities of Gorougou and its satellites. The present work focuses on the study of Trebia bentonite deposit located 18 km west of the city of Nador, on the western flank of the Tidiennit volcanic massif. Tight sampling was carried out. The raw samples were subjected to several analytical tests such as geotechnical identification tests, namely water content, organic matter, calcimetry and sand equivalent. The granular repair was carried out using the laser particle size. The extracted clay fraction was prepared as a powder and oriented

aggregate and then analyzed with DRX. The clay procession was differentiated by comparison of the three routine test diffractograms (normal, ethylene glycol, heating to 500°C). The analysis of the disoriented powder spectrum allowed the mineralogical characterization of the raw samples. The particle size analysis shows that the Trebia materials analyzed are characterized by the composition, in variable proportions, of five size fractions present in each sample: clay, silt, fine sand, medium sands and coarse sands, with the presence of very coarse sands in some samples. Thus, a large variation in particle size with a clay fraction ($<2\ \mu\text{m}$) ranges from 1.665 to 9.094 %, the silt fraction from 20.817 to 92.794 % and a sand fraction from 1.272 to 77.518 %.

Petrographic study (thin section, XRD and FTIR), shows that these bentonites are constituted in large majority by montmorillonites resulting from volcanic glass. The Atterberg limits show that all Trebia bentonites are characterized by high plasticity.

Keywords: Characterization, Clay, DRX, Laser granulometry, Northeast Morocco, Montmorillonites

Contribution of geophysics to the study of the Gouméré gold mineralization (northeast of Côte d'Ivoire): induced magnetometry and polarization

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In West Africa, Birimian formations generally masked by laterites, are well known for their precious metal content. In the Gouméré region of northeast Côte d'Ivoire, geophysical studies (magnetism and induced polarization) showed the presence of three lithological complexes: granodiorites, mafic formations and a complex of sedimentary and volcano-sedimentary formations. Tectonics are dominated by NS, NE-SW and ENE-WSW oriented faults. Induced polarization (IP) studies revealed that sulphide mineralization is "disseminated" in mafic volcanic formations and granodiorites, and is mostly associated with quartz veins and veins. This militates in favor of a model of "hydrothermal" type mineralization with structural control.

Keywords: Magnetic anomaly, IP anomaly, Birimian, Gouméré

Contribution of Remote Sensing and Geographic Information Systems to the Mapping of the Geological Structures of a Segment of the Pan-African Chain of Dahomeyides in northwest Benin

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The mapping of geological structures is essential in prospecting for mineral and hydrogeological resources by allowing the location of deposits and sites of interest. Thus in the Donga Department, the resolution of the problems related to exploration and mining but also those related to the protection and sustainable management of groundwater resources necessarily involves the lithostructural mapping of this portion of the northwest segment of the Pan-african chain of Dahomeyides in Benin. Remote sensing and GIS remain well undeniable tools in the mapping of geological formations, favorable sites for mineral exploration and indicators of presence of water, which are linear structures (Youan Ta et al., 2014).

This study aims to map the lithological and structural units of the department of Donga, an area located in northwestern Benin where different geological units outcrop.

The realization of this study was possible following the acquisition and use of a material consisting of image data, mapping databases and field data. The use of the techniques of the Analysis with Principal Selective Components (ACPS), the RGB coding, the computation of the indexes allowed the highlighting and the mapping of the large geological formations forming this northwest segment. The spatio-directional Sobel and gradient filtering methods applied to the images led to the development of the detailed linear map. Field trip missions (fieldwork and geophysical surveys) have collected various information relating to the nature and location of outcrops and structural measurements. The synthesis of all these results in a GIS allowed the development of the geological map and fractures of the study area. It has 745 major fractures.

The teleanalytical geological map obtained clearly shows the contours of the various units (gneiss, migmatites, quartzites and granulites) which are sometimes intruded by rare granitic intrusions. The contact zone between migmatitic gneisses and blastomylonites and mylonites with a strong structural tendency has also been highlighted, as well as the northern and southern boundary between migmatitic gneisses and granitoid migmatites. The study of the fracturing intensity reveals the highly fractured nature of the Donga Department, particularly in the North and South. This remote sensing cartography contributed to the updating of the map of the different geological formations and structural elements. This will facilitate prospecting for mineral and hydrogeological resources in this part of Benin.

Keywords: geological mapping, linear structures, mineral resources, hydrogeological, spatio-directional filtering

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Target areas for Uranium exploration from airborne geophysical data using weights of evidence analysis - Hoggar region, Algeria

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The Hoggar region of south Algeria is a vast and difficult access geographic area of high mineral potential. Using classical exploration method which is based on searching prospect information from known mineral occurrences reduces success potential. Actually, modern scientific exploration approach consists of GIS integration and combination of geo-information data from multiple sources and of diverse nature using comprehensive analysis based on mathematical and statistical methods. This innovative approach leads directly to increase success deposits discovery and reduce exploration risk.

Since a number of uranium occurrences and deposits are known in the Hoggar regions, the weights of evidence analysis approach could be tested and implemented for potential mapping and new target-area recognition. This technique is a Bayesian statistical method that uses the conditional probabilities to predict a hypothesis about the occurrence of mineralization on the basis of the combination of airborne geophysical datasets.

Various geophysical evidential maps, completed from the airborne magnetic and gamma spectrometric survey of the Hoggar are considered. The methodology is based on the measured association between known uranium occurrences and the values on the maps used as predictors to evaluate and locate all possible other locations using the calculating spatial association weights. The method belongs to a group of methods suitable for multi-criteria decision making.

The obtained uranium potential map identifies new interesting unrecognized sites as potential targets for uranium mineralization on which more detailed follow-up surveys can be planned to better evaluate the effectiveness of the results.

Keywords:

Morphological features from Seguela diamonds placers related to Cretaceous kimberlites (central-western Côte d'Ivoire)

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Seguela diamonds in central-western Côte d'Ivoire, derived from weathered kimberlites and colluvia and alluvia diamond placers. Kimberlite mineralogy component are mainly olivine, enstatite, phlogopite, amphibole, chromite, Mg-ilmenite, and diamond. Twenty-six diamond samples description in terms of size, weight, morphology, color, fluorescence and inclusions of microdiamonds through macroscopy, microscopy and MEB lead to show morphological features. The most informative trends reflected by the Seguela diamonds are probably related to the increasing development of dodecahedral forms at the expense of octahedral.

These trends associated with the relative abundance of transitional forms indicate that most diamonds apparently originated as octahedral and many were later modified into dodecahedral forms. Dissolution is the principal morphological process. Seguela diamonds bearing prospect products stones which weight varied from 0.3 carat to 4 (27 carats the most important). Most microdiamonds are either non-fluorescent or only very weakly fluorescent. Concentrations of

minerals inclusions range from colorless to pale green to black and some have been tentatively identified as garnet, olivine, pyroxenechromite, spinel and graphite.

Keywords: Kimberlite, octa-dodecahedral forms, diamond, dissolution, Seguela, Côte d'Ivoire

Petrology and geochemistry of ultramafic xenoliths cumulates related to Seguela diamondiferous kimberlite and lamproite (central-western Côte d'Ivoire)

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The Seguela kimberlites located 30 km North of Seguela city in the central-western part of Côte d'Ivoire are characterized by the presence of a lot of olivine pyroxenite xenoliths that are characteristic of the lithospheric mantle. The study of these xenoliths provides an opportunity of understanding the lithospheric mantle underneath the region. These xenoliths are formed by olivine (forsterite; Fo₉₀), enstatite, phlogopite, amphibole, chromites and Cr-spinels. Enstatites have relatively high Mg# ($Mg/(Mg+Fe^{2+}) > 0.8$). The olivine pyroxenite xenoliths have Mg# higher than the host kimberlite, and their high Cr (>3000 ppm), Ni (>1000 ppm), Co, Cu, V, and Zn contents are indicative of affinity with alkaline ultramafic rocks.

Compared with kimberlites, these olivine pyroxenite xenoliths show high enrichment in HFSE, LILE, REE. Their low La/Yb (<14) ratios, and Ba (<150 ppm), Rb (<50 ppm) and Nb (<6 ppm) contents indicate high degree of partial melting. Zr/Hf (39) and Nb/Ta (14) ratios support their lithospheric mantle origin. The age of these olivine pyroxenite xenoliths as derived from zircon is Paleoproterozoic. The geochemical signatures observed on these olivine pyroxenite are different from those of continental basalts. This indicates that the arc magmatism in the region derived from ancient subduction process in that affected the composition of the lithospheric mantle modification and led to the continental tholeiitic arc signatures observed on olivine pyroxenite xenoliths from Côte d'Ivoire.

Keywords: Xenoliths cumulates, geochemistry; Cretaceous kimberlites, petrogenesis, Côte d'Ivoire

The chemical diversity of tektites from Ivory Coast: new insight from portable XRF

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Introduction: Various types of rock melts are generated by meteoritic impacts. Their origin is still not understood in detail despite intense geochemical investigations and modeling attempts (Artemieva, 2002). Tektites are among these impact-related melts. The present study is aimed at characterizing the geochemistry diversity of Ivory Coast tektites which are related to the Bosumtwi impact structure in Ghana. The scatter of chemical signatures may reflect both diversity of precursor materials around the Bosumtwi impact crater and the processes of formation. The exploration of the chemical diversity in chemical signatures of tektites is limited by number of available samples for traditional-destructive-laboratory analyses process (e.g. ICP-MS). Here we explore the value of using the non-destructive portable XRF (X-ray fluorescence) for this purpose based on a collection of tektites of the SODEMI (Société de Développement des Mines de Côte d'Ivoire). Given the large error bars associated with this technique, it is important to determine whether the chemical diversity may be observed beyond uncertainties.

Samples and analytical techniques: 34 samples of Ivory Coast tektites were analyzed using a portable XRF for 31 major and trace elements. Major elements were measured with the mining mode and trace elements were analyzed with the soil mode. Measurement last 120 seconds for the mining mode, and 90 seconds for soil mode.

Results: Average major and trace element data of Tektites are given in Fig 1.

Discussion: The major element concentration in Ivory Coast tektites are relatively homogeneous.

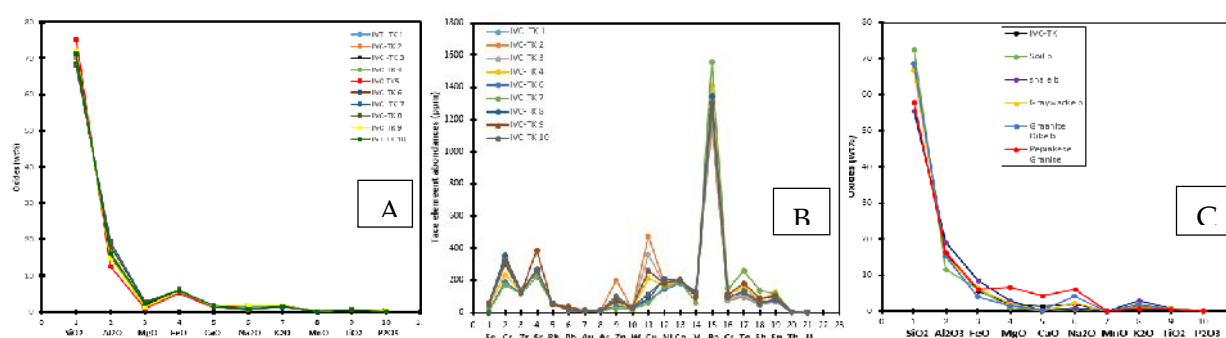


Fig 1 : Average major and trace element signature of Ivory Coast tektites. showing the homogeneity of major elements in 9 selected tektites (A), the variation of some trace elements of 9 selected tektites (B), and major element of country rocks from Bosumtwi (C) (data from Bohama et al., 2002) compared to composition of 9 selected tektites from Ivory Coast.

However, some trace elements (Cr, Sr, Zn, Cu and Te) show notable chemical heterogeneity (Fig. 1B). These chemical signatures are broadly consistent with reported geochemical data (Koeberl et al., 1997) and the observed scatter is well above the limit of detection of the portable XRF. The fact that highly refractory elements show a wide range of concentration indicates that heterogeneity of the source material, rather than impact metamorphism, is responsible for the range of concentrations observed for these elements. For instance, Zn ranges from 66 ppm to 103 ppm in brecciated greywacke and phyllite which dominate the geology around the crater, while Cr ranges from 241 ppm to 540 ppm in small dykes and pods of granitic intrusives. These chemical signatures could readily explain the ranges of variations of Zn and Cr in tektites.

Acknowledgements: The museum of SODEMI is acknowledged for granting access to their collection of tektites.

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Meteorite impacts in West African Craton

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Meteoritic impacts are one of the most important geological processes affecting composition, structure, energy budget and evolution of planets. Following the differentiation of the Earth, the impact of asteroids and comets contributed to build the reservoir of water in the mantle (Daly and Schultz, 2018). They are also likely involved in explaining the present concentration of siderophile elements in the mantle (Willbold et al., 2011), which later concentrated in the crust, forming ore deposits of economic interest. Though the impact flux decreased with time, meteoritic impacts affected the entire history of the Earth. Impact structures are the most obvious indications of these asteroid impacts. There are 190 known impact structures on Earth, which document the last 2 billions years of cratering history (Impact crater database, consulted on August 27th, 2018, <http://www.passc.net/EarthImpactDatabase/>). Older events have been likely erased from the surface of the Earth, by the combined action of tectonic deformation and erosion, but have left possible traces in the sedimentary records, such as the Archean spherules (Simonson and Glass, 2004).

Some of the preserved impact structures (about 1/3rd) are associated with mineral deposits (e.g., Cu-Ni, PGE, Zn, Au, Pb) or hydrocarbons (Koeberland Henkel, 2005). A fraction of these deposits are or have been exploited (e.g.; Ni-Cu-PGE in Sudbury, Gold in Vredefort are the most famous examples). Some of the known impact structures are also sites of geotourism, and may represent a local source of income. Impact structures have their intrinsic scientific value. They are considered as analogues for planetary impacts. Understanding geophysical, geochemical, or mineral signatures associated with impacts on other planets (e.g., geophysical signatures of impact basins on the Moon, or secondary phases associated with impact-hydrothermalism on Mars) lead to planetary scientists to carry specific investigations on terrestrial impact structures.

Known impact structures are not homogeneously distributed at the surface of the Earth. Large impact structures are preferentially found in Archean and Paleoproterozoic units. The distribution of known impact structures also depends of the number of trained geologists who know the criteria to recognize shock metamorphism in the field (shatter cones), or under the microscope (shocked minerals).

The West Africa Craton hosts several potential impact structures, and known impact structures, which are underexplored. We will review in this presentation the most outstanding questions regarding impact structures in the West African Craton, and the current effort of training for the training of students in this field of research in West Africa. This current effort is part of the Africa Initiative for Planetary and Space Science (<http://africapss.org>), which has been endorsed by many institutions, and scientists in Africa and outside Africa.

Many of the potential structures are currently situated in unsafe areas in Mauritania, Mali, and Niger, and their exploration is – at best – very challenging. For these structures, preparatory work may be carried out, such as compilation of existing remote sensing and geophysical data, and field

mission planning, to be ready when conditions of exploration will hopefully become safer. One important potential impact structure is the depression of Velingagara in Casamance (Senegal). Covered with sediments, the next step here requires a drilling program in the center of the basin. Known impact craters in the West Africa craton have been investigated at various levels, but, west African geologists were not often associated to these investigations. There is room for research programs based on the known west African impact record involving students and researchers in West Africa. For instance, current research are being conducted about the radiometric signature of the Bosumtwi impact structure (Baratoux et al., in revision) and about the associated field of tektites in Ivory Coast (Avo et al., this abstract volume) and future work will also focus on the Mauritanian impact record.

Acknowledgments

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Tectonic evolution of the Kédougou Kéniéba Inlier

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The Kédougou-Kéniéba Inlier (KKI) represents the westernmost part of the Paleoproterozoic domain of the West African Craton. It is built of the Mako volcano-plutonic belt in the west and the Diale-Dalema and Kofiseris in the east. The Mako belt, the Diale-Dalema, and Kofi sedimentary series are intruded by a large number of Eburnean magmatic rocks of variable ages and geochemical signatures. The most voluminous are the plutons of the Saraya batholith and the Faleme volcano-plutonic belt. The Mako belt comprises the oldest lithologies found, such as

tholeiitic basalts, the Badon granodiorite and Sandikounda tonalite gneiss dated at 2213-2194 Ma (Dia et al., 1997; Gueye et al., 2007; Theveniaut et al., 2010). The Diale-Dalema series is made of metagreywackes, metapelites, and metacarbonates intercalated with volcanic units. The Kofi series contains metagreywackes and metapelites and minor metacarbonates. The precise deposition age of the protoliths of the metasediments is unknown due to the lack of systematic detrital zircon geochronology; however some units are as old as 2165 Ma (Hirdes and Davis, 2002). The Faleme volcano-plutonic belt straddles the Senegalo-Malian boundary and was emplaced at ca. 2100-2080 Ma (Hirdes and Davis, 2002; Labert-Smith et al., 2016). Plutons of the Sarayabatholith, dated at 2079 ± 2 Ma, intrude the Diale-Dalema-Kofi series in the south (Hirdes and Davis, 2002).

Previous studies are focused on different parts of the KKI either in Senegal or Mali and propose a polyphase tectonic evolution (e.g. Ndiaye et al., 1989; Gueye et al., 2008; Diene et al., 2015; Masurel et al., 2017; Diatta et al., 2017). The only work working at the scale of the whole KKI is that of Ledru et al. (1991). This work proposes an original tectonic synthesis at the scale of the KKI based on a new lithologic-structural map at 1:500,000 constrained by airborne geophysical data and field observations.

Five major deformation events were documented in the KKI. The first deformation D_1 is characterized by E-W oriented steeply dipping penetrative metamorphic foliations and isoclinal folds, scarcely found in the field across the whole KKI and well visible in the airborne magnetic data. This deformation event affects the Mako belt and Diale-Dalema series but not the Faleme belt nor the Kofi series suggesting that it operated before ~2100 Ma. The second deformation phase D_2 affects all volcanic and sedimentary units in the KKI and is characterized by NNE-SSW trending steeply dipping penetrative foliation, thrust faults, and tight to isoclinal folds refolding at places the E-W structures, suggesting an E-W shortening under a pure shear dominated regime. This phase is also responsible for tectonic burial of metasediments of the Diale-Dalema series and it occurred at ca 2090-2080 Ma as constrained by geochronological data (Kone et al., this abstract volume). The following deformation D_3 is characterized by NE-SW trending dextral subvertical shear zones operating under ductile to brittle ductile conditions. The D_3 is interpreted as a continuum of D_2 , representing a switch to predominant transcurrent deformation under simple shear regime. This phase also marks the beginning of the tectonic exhumation of the high grade metamorphic rocks found in the Saraya pluton surroundings along the faults and/or due to the erosion of the thickened orogen. NS to NNE-SSW oriented steeply dipping sinistral shear zones reactivate at places the pre-existing structures and suggest a progressive anticlockwise rotation of the shortening direction in a continuum of deformation during the D_4 . During this phase occurred the final exhumation of the metasediments and their heating, which is contemporaneous and slightly post-date the Saraya pluton emplacement. The exhumation is associated with an extension in a NE-SW direction. Metamorphic ages on monazite and garnet suggest that this happened at ca 2060-2050 Ma (Kone et al., this abstract volume). Many plutons, including the Saraya granite, show syn-kinematic deformation features and/or penetrative magmatic foliation. The regional-scale shear zones associated with the D_3 and D_4 are well visible in the airborne magnetic data. The last deformation observed at regional scale, D_5 , is characterized by NE-SW, NW-SE and E-W oriented brittle faults found in the field and also in magnetic data.

The polyphase tectonic evolution documents a transition from an early collision of a volcanic arc towards the continental collision and build-up of the Eburnean orogenic belt by tectonic thickening and magma input until final stages of orogenic maturation and collapse, marked by tectonic exhumation of high grade metamorphic rocks.

Acknowledgements: We wish to gratefully acknowledge AMIRA International and the industry sponsors, including AusAid and the ARC Linkage Project LP110100667, for their support of the WAXI project (P934A).

Keywords: West African Craton, Kedougou-Kenieba Inlier, Senegal, Mali, Tectonics, Structural Evolution, Paleoproterozoic

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Tectonic and geochemical control of Ag in Imiter II: Implications for the local exploration (Eastern Saghro, Anti-Atlas, Morocco)

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Imiter is a world-class silver deposit located on the northeastern side of the Saghro Massif. The mineralization is hosted mainly in the metalliferous shales in the summit position of the lower Cryogenian complex. They overflow slightly into conglomerates and Ediacaran tuffs when they are located in the mineralized zones. Structural events and especially faults have been of great interest in this study since they most often coincide with highly mineralized zones.

Background surveys and sample sounding of Imiter II sector (structures R3, R4 and R6) have shown the close relationship between EW faulting and argentiferous mineralization. Three fault families oriented EW, ENE-WSW and NE-SW contributed to the formation of extensive pull-apart

basins with consequent argentiferous mineralization. Late NE-SW faults with no mineralization affect the mineralized levels by normal sinistral movement. A detailed structural kinematic study at the level of the structures of Imiter South, Igoudrane and wells 4 has shown the continuity of this model along the fault of Imiter. The host rock of silver mineralization in the R3, R4 and R6 structures is represented mainly by metalliferous shales. The silver paragenesis is represented by the amalgam Ag-Hg, sulfoantimonides and sulfoarsenides of silver. It is also associated with sulphides (galena, pyrite, mispickel, ...), oxides and carbonates. The geochemical data show a clear affinity between Ag and PbS in the structures R3, R4 and R6, unlike the structures B1 and SS1 where Ag is rather correlated with ZnS.

Key words: mineralization, Imiter II, faults, metalliferous shales, Ag, sulfosalts, PbS, ZnS

Petrogenetic relationship and rare metal mineralizations (Nb-Ta, Li, Be, Cs ...) in the Issia placer, Côte d'Ivoire: petrography, geochemistry and metallogenic implications

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The frequently observed spatial link between the rare-metal mineralizations of alluvial, eluvial and colluvial placers and the granitoids led very early to many questions about the possible existence of a genetic link. In order to constrain the primary source of niobium-tantalum oxides and to propose an implementation model, several studies were carried. A geochemical study by total rock analyses of the granitoids distributed over all the study area. Except the sample DAL06 which is an enclave in DAL05 massif, all the granitoids are peraluminous of type S and I and of the highly potassium calc-alkaline series. The S-type granitic formations are those located in the south of the Issia region and around the metasediments and have the lowest K/Rb (<170), K/Cs (<2500) and Nb/Ta (<8.5) ratios. A mineralogical study focused on the electron microprobe analysis of granite micas as well as pegmatites and Nb-Ta minerals from the different columbo-tantaliferous sites were performed. LA-ICPMS analyses revealed the presence of lithic micas and significant Cs₂O concentration (17.27%) in some pegmatites, characteristic of highly evolved granitoids resulting in LCT (Lithium-Cesium-Tantale) pegmatites. The analysis of the Nb-Ta minerals (columbo-tantalite and tapiolite) of the different placer deposits shows that the columbo-tantaliferous material has been slightly remobilized and mixed, allowing the reconstruction of the initial distribution of pegmatites around their granite precursor. The Nb, Ta and Be mineralization of the Issia placers are located south of the study area and more precisely at the limit of the metasediments and the S-type granitoids.

Keywords: columbo-tantalite, pegmatite, granitoides, metasediments, lithium, cesium

Characterization of the Southern MaradiBasement deformation in the Maraka-Chirguéarea (northeastern edge of Benin-Nigeria Shield)

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The southern Maradibasement represents thenorthern borderof the Benin-NigeriaShield belongingto the Pan-African mobile belt, which is located on the eastern part ofthe West African Craton (Fig. 1). The Benin-Nigeria Shield consists mainly ofmigmatites, gneisses, metavolcano-sediments and granitoïdswhich ages rangefrom Birimian to Pan-African (Turner, 1983; Dada, 1998; Caby et al., 2001).However, in the South Maradi area, Birimian formation hasnot yet been highlighted.

Petrofabricsanalysis highlights the existence of at least two deformation phases calledD₁ and D₂. The first one (D₁) is ductile to semi-ductile and the second one(D₂) is brittle.

The first deformation phase D₁is reportedingneisses, migmatites, schists and granitoïds. Itincludes three stages (D_{1a}, D_{1b} and D_{1c}). The first stageD_{1a} is related to a migmatizationperiodmarked by the formation of anisopachousfolds more or less affected by ductile shearing. The D_{1b} stageis characterized by a ductile coaxial deformation characterizedby theregionalschistosity or foliationS₁with N20° to N50°trending plane.TheD_{1c} stageis a mylonitization period. It ischaracterized by a semi-ductile noncoaxial deformation. Structural objects show the transition to sinistral or dextral sigmoid S/C fabrics.

The D₂deformationphase, essentially brittleis marked by two types of fracture cleavagewithN35° andN120°trending planes.

Key words: Pan-African mobile zone, Benin-Nigeria Shield, migmatization, mylonitization

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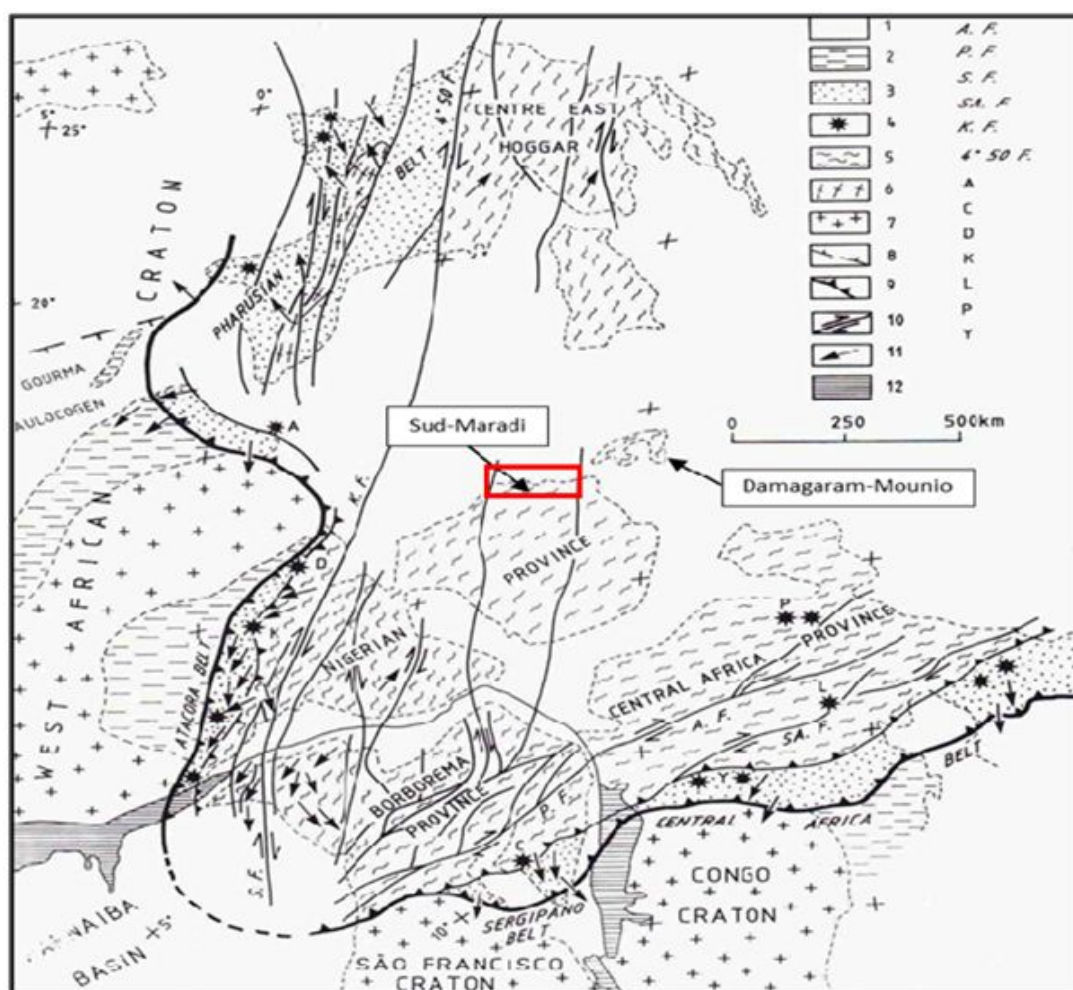


Fig. 1: Localization of southern Maradi basement (Castaing et al., 1993). 1. Phanerozoic cover ; 2. Proterozoic cover, 3. Pan-African volcano-sedimentary belts ; 4. Main mafic and ultramafic massifs highlighting the suture zone; 5. Gneiss, metasediments, migmatites and mono- or poly-cyclic granitoids; 6. In Ouzal and Iforas Eburnean granulites; 7. Cratons at 2 Ga ; 8. Aulacogen of Gourma ; 9. Major external thrusts; 10. Main shear zones ; 11. Tectonic transport direction of nappes ; 12. sea ; Faults of AF: Anaga-Adamaoua; PF: Pernambuco; SF: Sobral; SAF: Sanaga ; K.F.: Kandi ; A, C, D, K, L, P, Y: Metamafic complexes of Amalaoulaou, Canindé, Dérouvarou, Kabyé, Lom, Poli, Yaoundé.

Petrography and Geochemistry of volcanic and plutonic rocks of the southern part of the Toumodi-Fètékro green stone belt

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Our study area is the southern part of Toumodi-Fètékro green stone belt, located in the center of Côte d'Ivoire. Petrographic data show that the south of the belt is made of mafic to intermediate metavolcanic rocks with composition variation from basaltic to andesitic. Mafic lavas are usually massive, foliated or sheared of ten reaching amphibolites facies. In Addition, we have some acidic

metavolcanic rocks made of dacites, rhyodacite and rhyolites. The plutonic rocks are comprised of gabbros, dolerites, diorites, granodiorites and granites. The presence of lavas, pillow-lavas and volcanoclastics (lapilli tuff, breccia, ash deposit and ignimbrites) reveal that effusive, submarine and explosive volcanism prevailed during the setting of Toumodi-Fètékro belt, respectively. Major and trace element analyses of volcanites and plutonites indicate that intermediate and acidic facies are more abundant than basalts. Geochemical trends observed denote that olivine, pyroxene, magnetite and plagioclase were the major phases that precipitated during magmatic evolution. The basalts multi-element normalized diagrams show significant enrichment in LILE and a weak Nb-Ta negative anomaly, indicating a back-arc context. The most differentiated facies are derived from the parent magma of basalts by fractional crystallization. The major and trace elements indicate the persistence of archaic processes during the emplacement of these rocks. The REE modeling shows that the basalts come from partial melting at a rate of 10 to 20 % from a source composed of spinelhercynite originated in Depleted MORB Mantle (DDM). From a geodynamical point of view, we sustain the rifting of the Archean continent which could allow in a first stage the contamination of the depleted mantle magmas. In addition, this option explains more the predominance of acid facies compared to mafic facies. The subsequent recycling of magmas in a volcanic arc environment in the active continental margin has completed the geochemical features of the volcanic and plutonic rock in the southern Toumodi-Fetékro belt.

Keywords: Côte d'Ivoire, Toumodi-Fètékro, Birimian, rifting, active continental margin, back-arc.

Mapping tectonic structures of Kédougou-Kéniéba Inlier (Eastern Senegal) from satellite (LANDSAT-7 ETM⁺ / SRTM) and airborne geophysics imageries

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The lineaments of the Kédougou-Kéniéba Inlier (KKI) were mapped from the processing of several types of images: (i) various coloured combinations Red-Green-Blue of 1 to 7 bands and the panchromatic band (8) of a set of images of the thematic mapping (Thematic Mapper) of Landsat-7 satellite (ETM7⁺); (ii) SRTM image (Shuttle Radar Topography Mission) or DTM (Digital Terrain Model) of the Endeavour space shuttle; (iii) as well as the aeromagnetic image of the study area. Five groups of NS, NNE-SSW, NE-SW, EW and NW-SE lineament directions were identified from these images. The NNE-SSW and NE-SW oriented lineaments are the most frequent. The NS oriented lineaments often correspond to a straightening of those oriented NNE-SSW. The EW and NW-SE oriented lineaments are rarely observed and they often intersect with previous ones. Field structural data indicate that most of these lineaments correspond to shear and/or thrust faults, or to dykes. The NE-SW oriented lineaments would be the oldest. They are generally relative to reverse shear zones and thrust faults which are associated with the D₁ Eoeburnean phase of deformation. NS and NNE-SSW oriented lineaments correspond to faults and shear zones, mainly sinistral,

associated with NW-SE oriented lineaments. These three sets of lineaments form a conjugated system fault, associated with the sinistral transpression phase of the D₂ Eburnean deformation phase. The occurrence of all these structures would be related to the Eoeburnean, Eburnean and post-Eburnean orogenic events. Indeed, the doleritic dykes, which have been dated between 1600 Ma and 1100 Ma, show ductile deformation which testifies a post-Eburnean tectonic event (Kibarian or Hercynian?) subsequently affecting the Paleoproterozoic formations of the KKI.

Keywords: Eburnean, Landsat-7 ETM+ images, Shears, aeromagnetism, lineament

Structural evolution of the Paleoproterozoic formations of the Kédougou-Kéniéba Inlier, Eastern Senegal

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Our lithologic and structural field data are combined with image data from air borne geophysics and Landsat and Aster satellites as well as with geochemical and geochronological data from the literature to better constrain the geodynamic evolution of the Birimian formations of the Kédougou-Kéniéba Inlier (KKI). The lithological analysis together with the available geochronological and geochemical data indicates an achronic evolution from west (Mako Super group) to east (Dialé-Daléma Super group). This evolution started by the emplacement westward of an ophiolitic sequence in a deep oceanic environment. It is followed by an intermediate to felsic calc-alkaline volcanism very developed in the eastern part and emplaced in a shallow environment.

The structural results show a polyphase Eoeburnean to Eburnean deformation. The first deformation phase is tangential tectonics associated to large overthrust folds (P₁) and localized thrusts. It affects the ophiolitic sequence of the Mako Green belts as well as some Dialé-Daléma volcano-sediments and sediments. This phase is Eoeburnean and would have occurred between 2170 Ma and 2140 Ma. It mainly affects the formations of the green belt rocks of the Mako Super group which constitutes the oldest segment of the KKI (2220-2060 Ma). The Eoeburnean D₁ deformation phase is accompanied by the emplacement of granitoid σ_1 (2213-2160 Ma) characterized by syntectonic ductile structures (folds, planar and linear fabrics). The Eburnean D₂ deformation phase is a transpressive tectonics broad lysinistral which would have occurred between 2130 Ma and 2080 Ma. It involved wide thrust sheared corridors (MTZ, FSM) and a P₂ folding with tilted and curved axis.

The D₃ phase is a dextral transtension which reactivates the former structures and creates extensional zones to various scales associated with normal faults. The Eburnean granitoid σ_2 (2150-2100 Ma) and π_3 (2090-2040 Ma) emplaced during and after the two Eburnean orogenic phases.

Keywords : Eoeburnean, Eburnean, Birimian, transpression, transtension, Kédougou-Kéniéba

Study of the Haut-Sassandra granitoids (Midwest of Ivory Coast): towards a geodynamical evolution model

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The oldest parts of the African continent, the so-called West African Craton (WAC), are the focus of world wide research not only because they represent primary constraints for our understanding of the early evolution of the Earth, but also because of their significant potential. This work contributes to the understanding of the geological and geodynamical evolution of the WAC, by an integrated analysis of air borne geophysical and petrology data constrained by field structural, lithological, geophysical, and geomorphological observations acquired around the gionnamed Haut-Sassandra in the west of Ivory Coast. Magnetic Air borne data aided in the mapping because there gionis densely covered allowed to define the geometry of the different massifs. Three rock types can be distinguished: migmatite, granodiorite and megacrystic or porphyritic two micas leucogranite. The petrological results of this study suggest that the granitoid domains are formed by per aluminous and metaluminous rocks. The general geochemistry of the granitoids involves from Na-rich calc-alkaline to K-rich alkaline. The penetrative structures (mineral lineation, and sinistral shear) were overprinted by extensive SSW to NNE (N20° to N40°) shear zones which are well visible in the magnetic data. These granites have caused contact metamorphism, and a real soat the origin of important pegmatitic, pneumatolytic and hydrothermal processes, that are the origin of rich metallogenic nature of this region. The northern part of this region is migmatized. The granitic panels are cross-cut by a NE-SW to ENE-WSW oriented fracture system, which favors numerous vein-like fractures, including aplites, pegmatites, tourmalinites, greisens and quartz.

The basement of this region represents the Birimian part of the WAC and appears then structured by several geological events. The nature of the protoliths might be tracked using geochemical data. The potential source of the former Birimian sediments will be discussed.

In addition, U-Pb datings and low-temperature thermochronology data on apatite minerals will be carried out to constrain the formation age of different massifs and to trace the thermal history of rocks and evaluate their rate of denudation. This will allow to quantify the rate of uplift or vertical tectonics (isostasy or simple denudation) and the rate of erosion that has contributed to create the present-day flat topography. This part will make it possible to model the paleorelief and to help understand the current geomorphology of the WAC.

Keywords: West African Craton, Ivory Coast, magnetic airborne data, granite, low-temperature thermochronology

Occurrence of the Cap carbonates related deposits on the eastern edge of West African Craton (SE Man Shield, Fingoun area): implication for the Neoproterozoic glaciations

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Neoproterozoic glacial deposits are systematically followed by enigmatic carbonates deposits well identified on several continents including Africa (Font, 2005). These carbonates deposits commonly called Cap carbonates are regarded as important keys for understanding the Neoproterozoic glacial events.

At least three glacial episodes are known during the Neoproterozoic (Hoffmann et al., 2004; Font, 2005): the Sturtian (750-700 Ma), the Marinoan (635 Ma) and the Gaskiers (580 Ma) glaciations. The Sturtian and the Marinoan are Early and Late Cryogenian glacial deposits, respectively, whereas the Gaskiers correspond to the Ediacaran glacial deposits.

The West African basins (Taoudenni, Voltas and Gourma) contain Late Cryogenian glacial deposits overlaid by carbonates that have been assimilated to postglacial carbonates (Trompette, 1973; Affaton 1990; Miningou et al., 2017).

The Firgoun area deposits, located on the eastern edge of the West African Craton area (Fig. 1), are assumed to be the equivalent to the basal deposits of the Ydouban Group (Gourma Basin).

In Firgoun area, the uppermost deposits include matrix-supported diamictites, cherts and carbonates. The occurrence of diamictite deposits, interbedded into the marine quartzitic sandstones beds and the presence of more or less recrystallized limestones and silexites could be considered as parts of the well-known Neoproterozoic Triad.

Two kinds of carbonate rock lithofacies have been observed: unmetamorphosed brown dolomitic limestones and white marbles. The dolomitic limestones exhibit a cavernous appearance probably due to a post-depositional dissolution phenomenon (Fig. 2a). Marbles are massive deformed rocks (metacarbonates), with a milky white to pinkish appearance (Fig. 2b).

Keywords: Cap carbonates, Diamictites, Neoproterozoic, glacial deposits, Firgoun

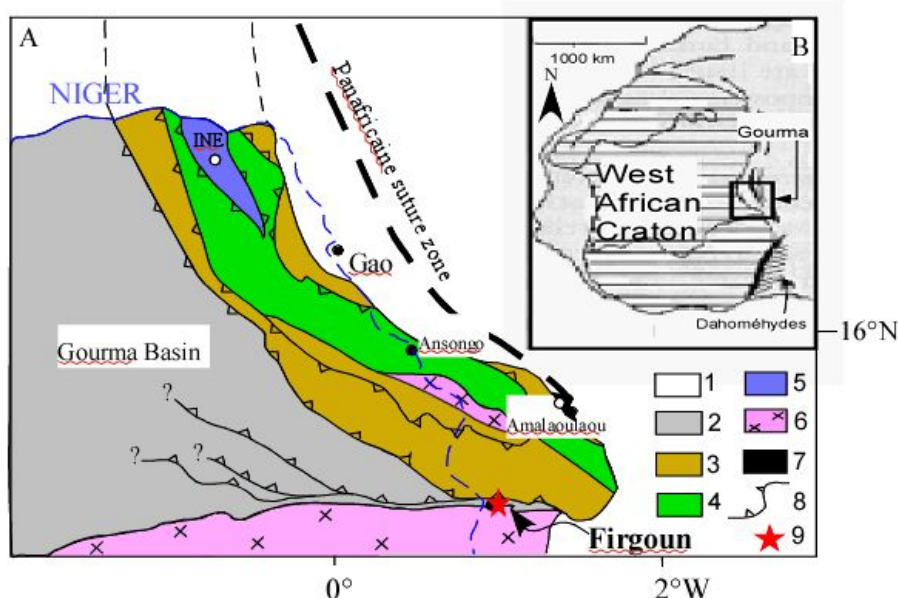


Fig.1. (A) Geological sketch map locating the Firgoun area into the southeastern of the Gourma Basin (from Caby et al., 2008). (B) Location of the Gourma Basin on the eastern border of the West African Craton (from Attoh and Nude, 2008). 1. Phanerozoic; 2. Gourma basin; 3. External nappes; 4. Internal nappes with HP-LT;

5.UHP metamorphism (INE:Inedem);6. Paleoproterozoic rocks of the WAC and Bourré Inlier; 7.Mafic-ultramafic massifs; 8.Major thrust; 9. Study area.

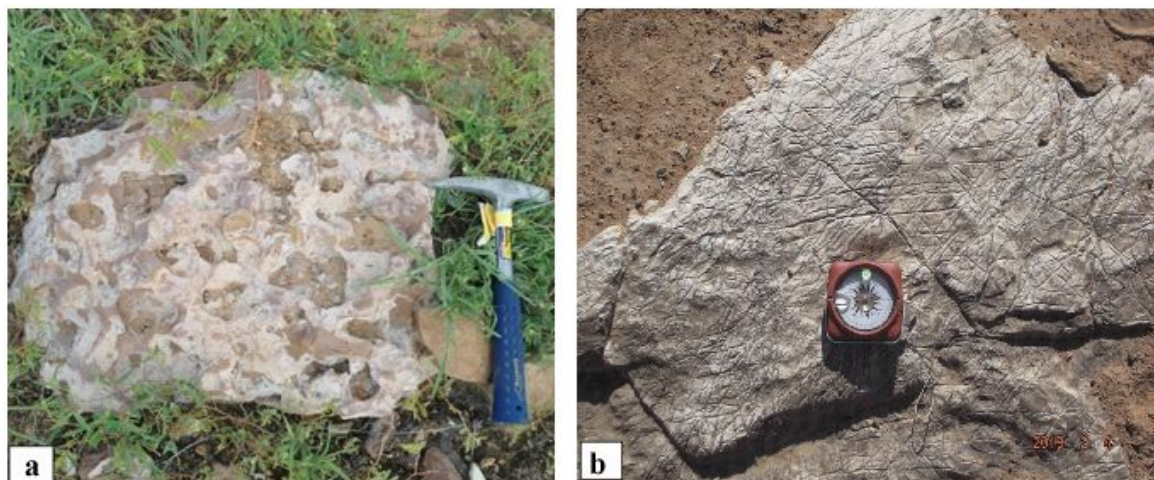


Fig. 2. Carbonates deposits observed in Firgoun area (a) Brown dolomitic limestones exhibiting a cavernous appearance, followed by quartzitic sandstones sequences which include diamictite deposits, (b) White marbles with a milky white to pinkish appearance. These marbles display many fractures.

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Municipal Wastes Conversion: The Energy Valorization of waste by Pyrolysis

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The whole world is committed to economic development and the continuous improvement of living conditions, thus the problem of depletion of the limited resources of our planet and the management of waste become crucial. The global consumption and depletion of materials were highlighted in the Millennium Development Goals formulated in the year 2000 by the United Nations. A set of goals were formed with a heavy importance put on the 7th Goal "To Ensure Environmental Sustainability" (Millennium Assessment, 2005). Additionally, the 2008 Waste Framework Directive includes a 50% recycling target for waste from households, to be fulfilled by 2020 (European Environment Agency, 2013).

Pressures on the global environment have led to calls for an increased use of renewable energy sources. Municipal wastes disposed of at open dumping sites, pose health risks, contaminate surface water and release greenhouse gases such as methane. However, these wastes could be considered as a potential source of renewable energy. This paper will present a brief review of the main conversion processes, with specific regard to the Thermo-Chemical conversion in general and Pyrolysis technology in particular.

Keywords: Waste Conversion, Renewable Energy, Pyrolysis

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Chemical and mineralogical characterization of archeological ceramics from Aghmat site (VIIth Century) (southern Morocco)

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The aim of this paper is to study Aghmat archaeological materials (VIIth centuries) using two types of ceramics collected from a recent archaeological excavation in Aghmat region (Morocco) in order to enhance documentation, conservation and restoration issues, then putting into value the architectural heritage. Fortuitously discovered in 2005, Aghmat village has allowed the reformulation of several hypotheses about Aghmat population skills in construction and

handicrafts. Even though the areal extent of this archaeological site exceeds 20 km², no traces of furnaces have been found yet, only ruins of buildings and streets. Bricks and pottery samples were the most abundant types of ceramics founded. Mineralogical and chemical analyses of this materials provided information about the origin of raw materials and manufacturing process. Firing conditions have been estimated (mostly using temperatures from 800°C to 900°C). The chemical compositions indicated that SiO₂, Al₂O₃ and Fe₂O₃ are major elements while K₂O and MgO are less abundant. The ceramics were produced using at least two raw materials, non calcareous clay of Permo-Triassic age for bricks, and carbonate Quaternary clays for pottery samples, as the calcium oxide content is generally more than 10%. The differences identified through morphological analysis and experimental results were cross referenced with historical data, allowing a scientific interpretation, supported by experimental results and contrasted to historical information.

Keywords: Archaeology, Aghmat ceramics, Pottery, manufacturing process, Morocco

K, Th, U patterns in Paleoproterozoic formations from airborne radiometric and ground-based measurements - Insights into superficial processes

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K, Th, and U are incompatible elements, with various degrees of mobility with respect to aqueous alteration and are considered as good tracers for magmatic and fluid-rock interactions. Endogenic and superficial processes are responsible for the distribution of these elements at the surface. Endogenic (partial melting, fractional crystallization, hydrothermal alteration...) and superficial processes (erosion, in-situ alteration, transport and mixing) do not operate at the same scales and are expected to produce different spatial patterns. These elements may be mapped at various scales from airborne or hand-held radiometric (gamma ray) techniques, and multi-scale statistical analyses may provide new insights into processes at work. Following earlier work focusing on K, Th, U distributions in Paleoproterozoic formations in Eastern Senegal (Fall et al., 2018), we focus here on the analysis of variograms, which reflect the spatial correlation of concentrations as a function of distance and direction.

Variograms are calculated from regional radiometric data (in the south part of the Kedougou-Kenieba inlier and the two parts of the Saraya granite, 250 m line spacing), from higher-resolution airborne radiometric data acquired with a helicopter in the mineralized zone of the Petowal deposit (Toro Gold) and using a hand-held spectroradiometer (FPGRS) for the acquisition of ground-based radiometric data with a resolution of 5 m, over typically surface areas of 150x150 m²). Calculation of variograms for large data sets (in the case of radiometric data) are achieved in Fourier space (Marcotte, 1996).

Systematic behaviors are noted for all variograms: the variance of Th generally increases more rapidly (with distance) than the variance of U, and K (relatively to the absolute concentration). The behavior reflects the higher mobility of K and low mobility of Th. One exception to this behavior has been noted for the Saraya granite, where the variance of U shows a sharp increase at the small scale. Significant observations are also noted when orientation is taken into account. The variance

is shown to increase more rapidly for K, Th, and U, within the Sarayagranite in a direction perpendicular to the major structural orientations of the inlier. This anisotropic behavior is lost, especially for K, and to some extent for U, in the southern part of the granite, which is covered by alluvial material and transported or in-situ regolith. These preliminary results suggest that spatial K, Th, U pattern may be useful, in conjunction of other geophysical data sets, to decipher surficial geological processes.

Keywords: Paleoproterozoic, granite, variogram

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Chromites of the Makalondi greenstone belt (Niger Liptako Province, West Africa)

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The Makalondi greenstone belt is located in the Niger Liptako Province which corresponds to the northeastern edge of the Man Shield (West African Craton). Many chromite indexes have been found in meta-ultrabasites, metabasites and their alterites (Fig. 1). These meta-ultrabasiterocks are represented by talc-schists, talc-chloritoschists, while the metabasites rocks are represented by chloritoschist and slatyamphibolites. The mineralization appears with lens shaped deposits of chromitite, which can reach 45m long.

The methodological approach implemented consists of a field study followed by a polarizing metallographic microscopic analysis (Fig. 2). The N100° trending regional schistosity and foliation are molded around the chromitelenses. These lens show magmatic “bedding” (Figs. 2A,B) marked by an alternation of chromite-rich levels relayed by talc-chlorite rich levels. According to the classification of Dill (2010), these chromite indexes can be ranged in the magmatic chromium mineralization of stratiform type or podiform type in an ophiolitic complex or in a Bushveld type complex.

The eluvial indexes are represented by pebbles and angular to subangular heterometric blocks more or less rich in chromite (Figs. 2C,D). This may explain the contents variations for which Machens (1964) gives up to 31% in Cr₂O₃ whereas Hassan and Marcos (1983, 1984) give a value of 17.35%.

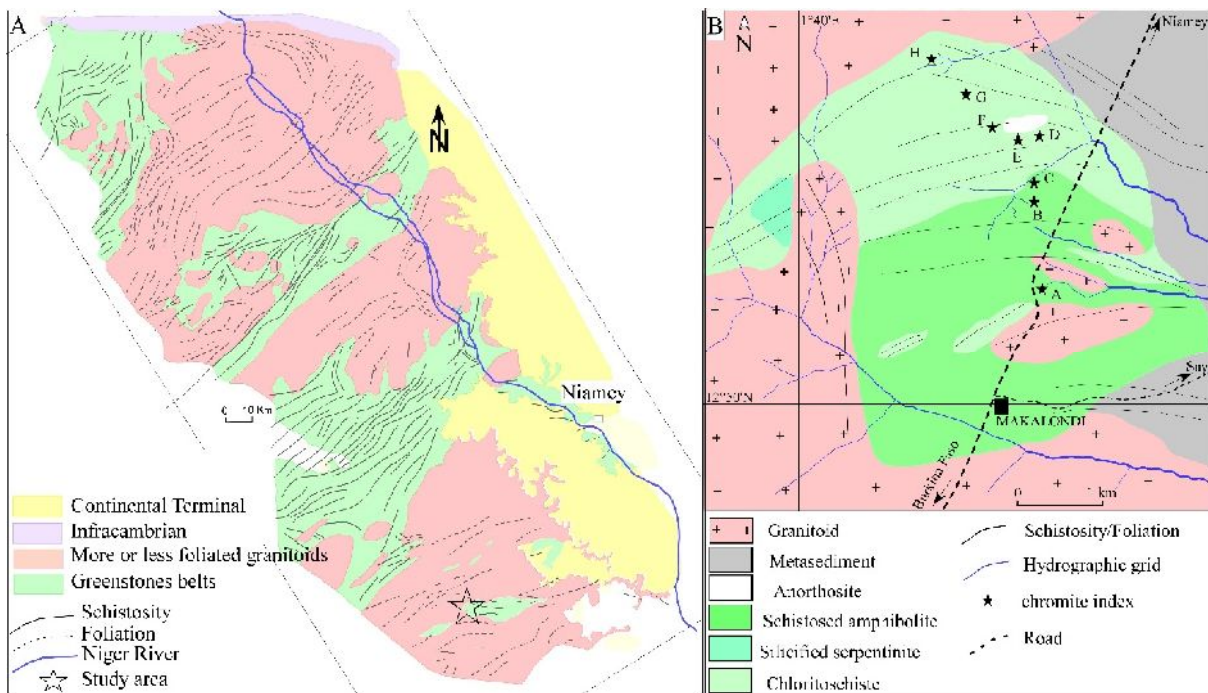


Fig. 1: (A) Location of the study area in the NigerLiptako province (Machens, 1967, modified). (B) Distribution of the chromite indexes (Machens, 1973, modified).

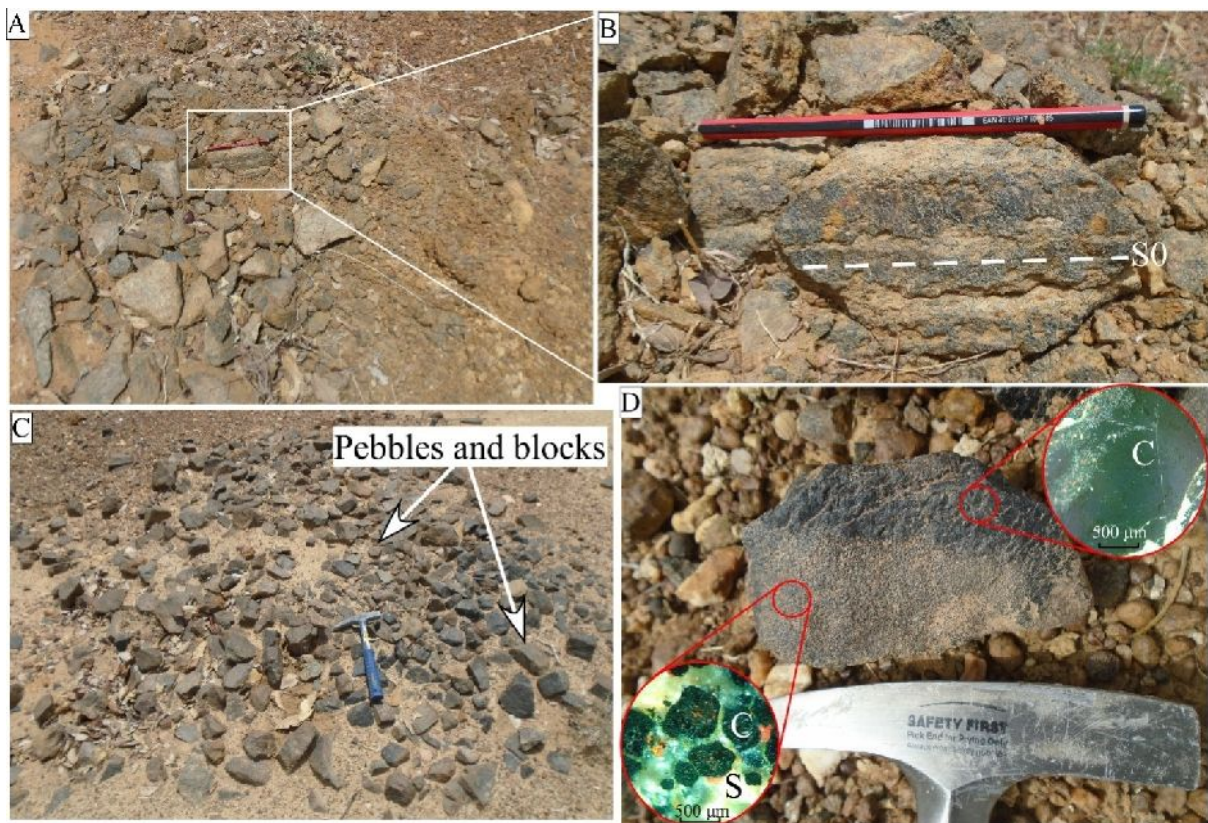


Fig. 2: A- and B- indexes (H index, Fig. 1B) of chromite with magmatic "bedding" S₀; C- Pebbles and blocks of chromite; C- and D- (B Index, Fig. 1B) Pebbles having levels with massive chromite (C) and levels of isolated chromite crystals in a silicated gangue (S).

Keywords: Makalondi, chromitite, podiform type, ophiolitic complex, Bushveld complex

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Alteration processes of the Paleoproterozoic manganese protomylonites of North Téra: mineralogy and geochemistry (Niger Liptako Province, West Africa)

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The manganese deposit of North Téra is located in the western side of the Diaborou-Darbani greenstone belt in the Niger Liptako Province (Northeastern part of Man Shield, West African Craton) (Fig. 1).

Manganese mineralization bearing rocks are mainly gabbros (a kind of garnet-rich quartzite of the spessartine type) whose borders consist of a high concentration of Mn oxide concretions (Fig. 2A).

The methodological approach implemented consists of a field study followed by a polarizing microscopic analysis in transmitted and reflected light and a geochemical analysis.

North Téra gabbros originate from Birimian manganese-rich sediments metamorphism in amphibolite facies (Soumaila, 2000; Soumaila and Garba, 2006).

The supergene alteration, more or less important, has developed on the gabbro protomylonites a saproplitic profile, whose setting up condition were recently described by GarbaSaley et al. (2017).

The macroscopic analysis of the manganese deposits samples (Fig. 2B and C) combined with the metallographic microscopic and geochemical analysis confirms that manganese mineralization originated from weathering processes.

The first oxide that forms around the garnets is nsutite, while the mesostasis is invaded by pyrolusite (medallion of Fig. 2D) with lenses of lithiophorite destabilizing in favor of pyrolusite. In the botryoidal concretions, the latter forms an alternation with the psilomelane rich in Ba (8101 ppm) in the uppermost levels (Fig. 2D).

The abundance diagram shows that the normalized Rare Earths compared to PAAS derived from a plagioclase-rich quartzitic source. This observation is corroborated by a positive anomaly in Eu

(Fig. 3A). Otherwise, the high levels of transition elements (Ni, V, Co and Cr) highlight the involvement of a basic source.

The contents of major elements show a significant leaching, with an increase in those of Mn and Al, during the increasing of the weathering. The CIA and PIA indices move in the same way towards high values leading to the Al_2O_3 pole on the Al_2O_3 -CaO * + Na₂O-K₂O diagram. This indicates an increasing alteration along the profile, according to an alteration path from plagioclase-smectite to kaolinite on the one hand, and illite to kaolinite on the other hand (Fig. 3B).

Keywords: Gonditeprotore, Manganese, North Téra, supergene alteration, Birimian.

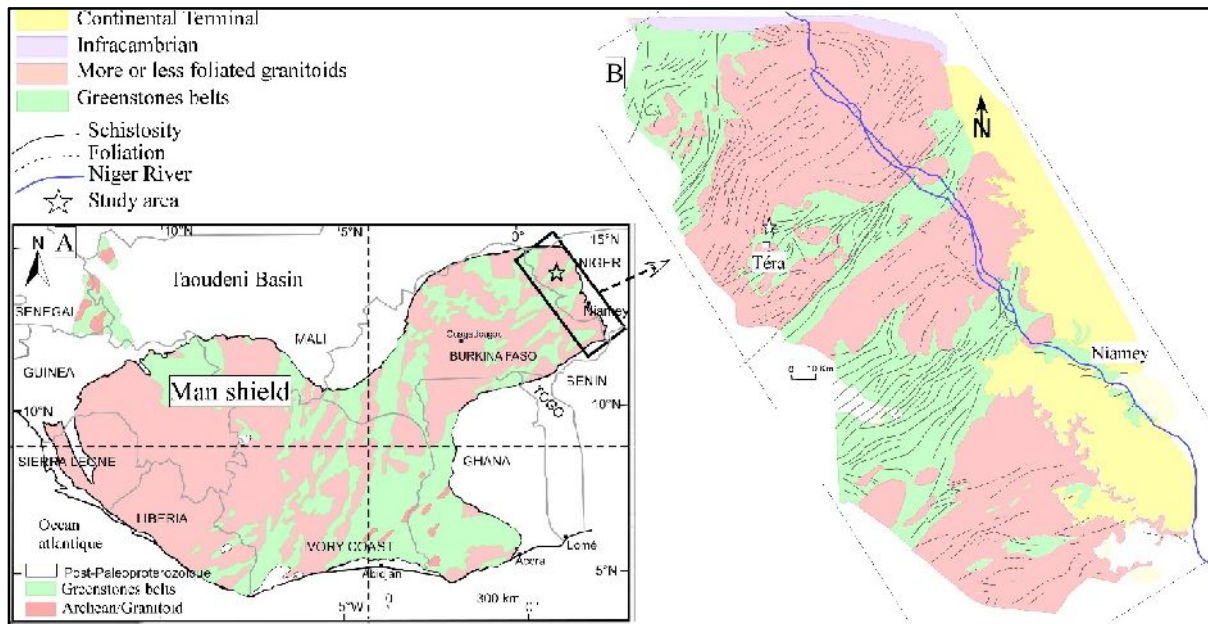


Fig. 1: (A) Simplified geological map of the Man's Shield (Milési et al., 1989) and (B) location of the study area in the Niger Liptako province (Machens, 1967, modified).

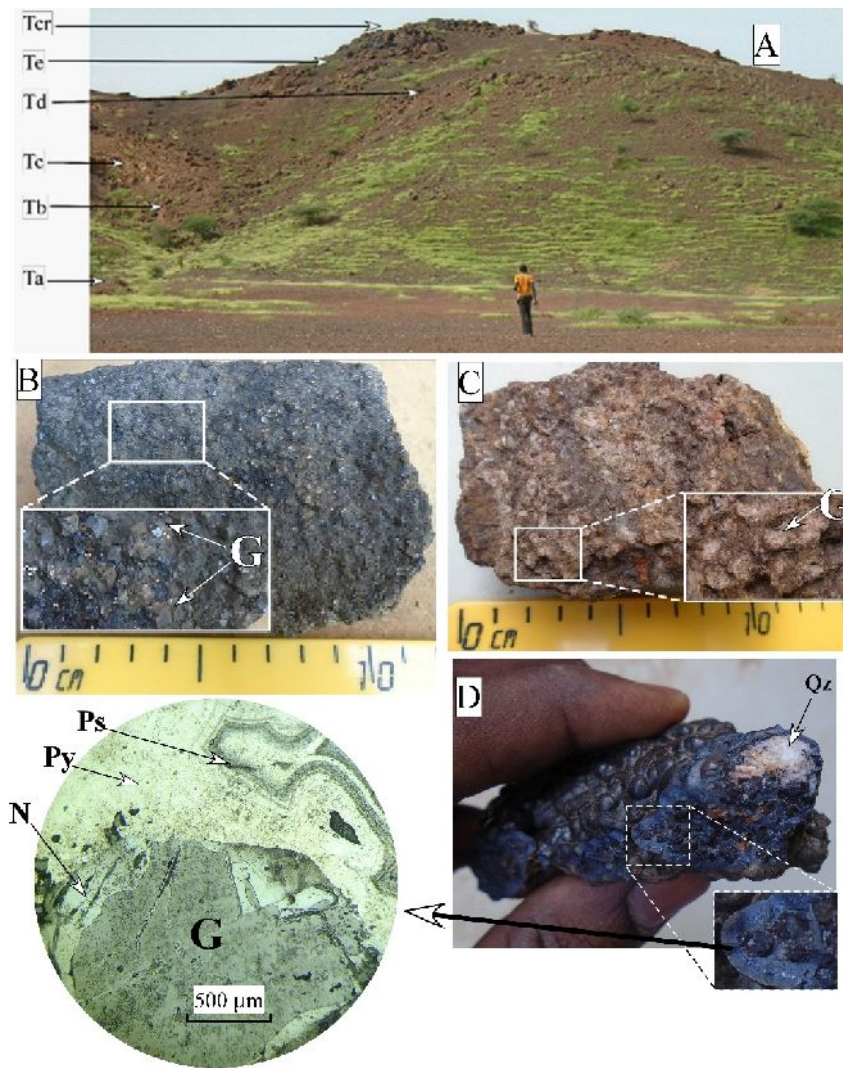


Fig. 2: Northern Téra manganese deposits: A- positioning of the sampling points (Ta, Tb, Tc, Td, Te and Tcr) on the main hill of manganese investigated; B-epigenization of garnet (G) in a dark brown to blackish gangue; C-replacement of garnet (G) by brownish products of oxides and/or hydroxides of manganese; D-Concretion of manganese oxide with garnet constituting the heart of the visible concentric layers, and its microscopic correspondent (reflected light, Nic) showing a concretion of pyrolusite (Py) and psilomelane (Ps) which develop around an automorphic garnet (G) heart that transforms into Nsutite (N).
G: garnet, N: nsutite; Ps: psilomelane; Py: pyrolusite; Qz: quartz.

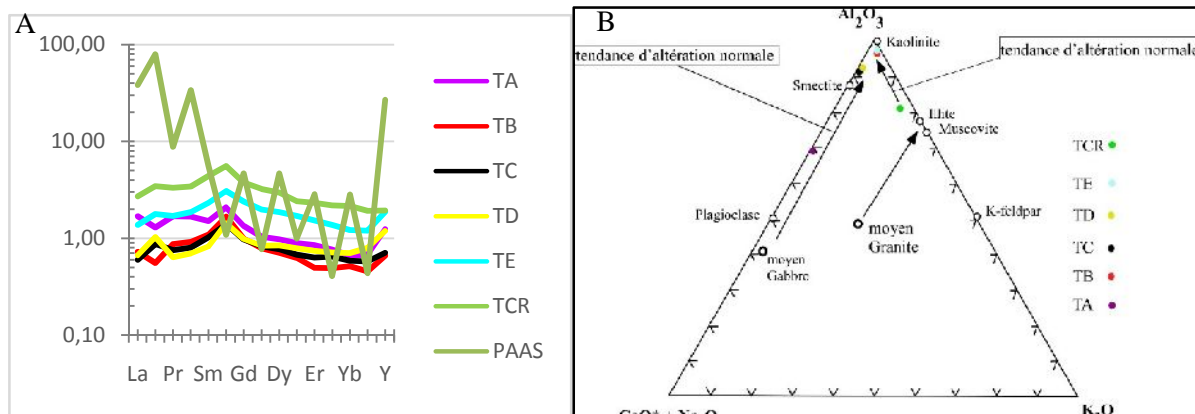


Fig. 3: the analytical points of the North Téra samples in the references diagrams : (A) Abundance diagram of standardized Rare Earth Elements relative to PAAS (Taylor and McLennan, 1985);(B) Alteration evolution in the ternary diagram $\text{Al}_2\text{O}_3\text{-K}_2\text{O-(CaO + Na}_2\text{O)}$ (Nesbitt and Young, 1982).

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Sedimentological characterization of subsurface training of the Tertiary-Quaternary of the Dabouregion, south of Ivory Coast

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About 239 samples of cuttings from two drillings located in Dabou were the subject of sedimentological (lithological, granulometric and morphoscopic analyses) studies in this work. The aim is to identify the origin of these sediments and to specify the factors and phenomena involved in their transport and deposition during the Tertiary-Quaternary period. After a detailed lithological description of each sample, the sandy fractions were treated according to conventional particle size methods. The formations penetrated in the two wells consist of lateritic clays, yellow clays, clay sands and coarse sands. The analyzed sands are coarse and testify to the different variations in the energy of the stream that transported the sediments. These coarse sands represent the main aquifer. The hyperbolic granulometric facies is dominant in the study area, indicating a variation in streamflow during sedimentation. The predominantly rounded to sub-rounded quartz grains suggest a relatively distal supply source, while their blunted, blunted appearance suggests a

stay in the aquatic environment. The sands of these two wells could be accumulated in a beach-type deposit and coastal dune area.

Keywords: Dabou, sedimentology, Tertiary, Quaternary, facies, aquifer

Quantitative and qualitative analysis of groundwater resources in Katiola area

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The increasing pressure from development of cultivated areas and demographic increase on water resources have spawned in Katiola area water stress. This study aims to make quantitative and qualitative analysis of Katiola area water resources. We used descriptive statistical analysis, multivariate and spatial analysis on 83 boreholes spread throughout the area. In quantitative terms, 63% of borehole flows are low and indicated to HV supply (hydraulic village), about 37% of boreholes are ranging between medium and high flow class and indicated to HVA supply (improved hydraulic village). The most productive water arrivals (AE) are located in the first 35 m depth under the alteritic layers. Schist aquifers are more productive than granite aquifers and give real hydrogeological potentialities to search for best flow. In qualitative terms, the groundwaters of Katiola area are less mineralized. The mineralization of waters is influenced by the petrographic type of rocks, especially by the contribution of hydrogencarbonates (HCO_3^-) and calcium (Ca^{2+}) in water. Therefore, 62% of water points have high iron concentrations. High iron levels are related to the geology of the study area, specifically by the contribution of biotite and Birimian schist mineral characteristics of the host rocks.

Keywords: Groundwaters, analysis, Katiola, Côte d'Ivoire

Precambrian basement mapping from interpretation of aeromagnetic data in northwest of Côte d'Ivoire

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The regional aeromagnetic map of Seguela, in the northwest of Côte d'Ivoire have been digitized and processed to provide new geological and structural information about the study area. Firstly, some filters such as reduction to equator, upward continuations, first derivatives and analytic signal have been carried out to locate and delineate the formation boundaries and the geological contacts. There is a good correlation between the most magnetic anomalies and some geological outcrops within the study area. Structural interpretation allowed to identify several faults oriented

EW and NE-SW. But other structural directions such as NNW-SSE, WNW-ESE, NW-SE and NNE-SSW have been indicated as well. Secondly, the basement depths for rocks as granites, amphibole biotite bearing-granites, granodiorites, migmatites, gneisses and greenstones, have been estimated using Euler deconvolution. The results obtained show depth ranging from 100 m to 1070 m. This depth estimation has been used to realize a basement topography model. Thus, this study on aeromagnetic data interpretation is used as an aid to geological mapping in Precambrian field and may give some basic element for mineral exploration.

Keywords: aeromagnetic, geological mapping, processing, Precambrian, Côte d'Ivoire

The Samapleu mafic-ultramafic dyke: an Eburnean (2.09 Ga) intrusion mineralized in Ni-Cu sulfide in the northern part of the so-called stable Archean domain-western Ivory Coast (Future first Nickel-Copper deposit in West Africa)

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Samapleu dyke belongs to the Yacouba layered complex which intrudes the Archean Kenema-Man Craton (located about 100 km west of the Sassandra Fault in the so-called stable Archean domain) in the Samapleu-Yorodougou area, western Ivory Coast. This dyke dips at 70°-80°SE with a total thickness of 120 to 200 m, comprising an ultramafic unit (websterites, peridotites) and mafic unit (gabbro-norites, norite and anorthosite) arranged symmetrically with mafic layers at the center and ultramafic layers at both margins. Contacts with the country rock gneiss are characterized by a hybrid zone that is a few meters thick and composed of plagioclase-orthopyroxene.

The ages obtained on zircons in the country rock gneisses and granulites, as well as in the hybrid facies, yield Archean ages of ~2.78 Ga (Liberian). The ages obtained on rutiles in the hybrid zone give also a U-Pb age of 2.09 Ga (Eburnean), which is interpreted as the age of contact metamorphism and emplacement of the intrusion in the lower crust at a depth of about 25 km.

The dyke age (U-Pb age obtained on rutiles 2.09 Ga, an Eburnean age recently discovered) shows that the northern part of the so-called stable Archean domain (Western Ivory Coast) has been affected by Eburnean geodynamic events.

Thus, the age obtained on the dyke in addition to the basaltic composition of the parent magma shows that this dyke may then be related to the location of the plume-related oceanic flood basalts of the Birimian sequence or the Eburnean tectonic convergence between the Birimian crust (central and eastern Ivory Coast) and the Archean craton between 2.1 and 2.05 Ga.

The Samapleu dyke contains Ni and Cu sulfide deposit which is disseminated mainly in pyroxenite or occurs as subvertical and semi-massive to massive sulfide veins. The sulfide textures range from matrix, net-textured, droplets or breccia textures and composed of pentlandite, chalcopyrite, pyrrhotite and rare pyrite.

The revised Samapleu deposit mineral resource estimate includes an indicated mineral resource of 14.1 million ton (Mt) grading 0.24% nickel and 0.20% copper and, together with an inferred

mineral resource of 26.5 Mt grading 0.24% nickel and 0.18% copper ([http://samaresources.com, 2017](http://samaresources.com,2017)). This dyke whose mineralization will be exploited soon, would become the first in West Africa.

Keywords: Ivory Coast, Man, Archean domain, Eburnean Samapleu mafic-ultramafic dyke, Ni-Cu sulfide

Saharan Aquatic Ecosystems: Environmental Challenges and Mining Prospects

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The Sebkhass and Chotts are continental endorheic basins and they occur frequently in desert areas (Sahara), obeying under severe climatic conditions as well as significant variation of temperatures and evaporation rates between different seasons. Winter is characterized by a temperature that can reach 0°C and exceeds 50°C during the summer period. The rate of evaporation is extremely important, especially during summer (exceeding 400mm). These depressions highlight a particular topography, where altitudes can exceed 37m below sea level, thus contributing in the input of an important quantity of water, with diverse chemical compositions. The feeding of these aquatic environments is through the discharge of groundwater, surface water (drainage and sometimes wastewater) and rainwater. These conditions make it possible to follow the evolution of filling of these basins during the following months: December, January and February, whereas the evaporation processes begin with the increase of temperature by the month of March. The process of crystallization of evaporitic minerals is also started (calcite, gypsum, halite,...). Isothermal evaporation of ChottBaghadad brines shows an evaporitic sequence as the following: gypsum Halite Picromerite Epsomite Sylvite.

These areas are characterized by economic concentrations of several chemical elements such as: Na, Cl, K, Mg, Li, etc. On the other hand, the Saharan aquatic ecosystems are very weak and are dramatically degraded. Sebkhass and Chotts are used as outlets for sewage, drainage and sometimes for the industrial water, contributing in the degradation of these environments. The present work aims at the diagnosis of the state of the environment and the mining potentialities of Sebkhass and Chotts in the Algerian Sahara.

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Petrography and geochemistry of volcano-sedimentary and plutonic formations of the Agbahou gold deposit, Côte d'Ivoire

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Located southwest of Toumodi-Fettekro Birimian greenstone belt, in the centre-west of Côte d'Ivoire, Agbahou gold deposit contains three major lithological units: (i) a volcano-plutonic unit composed of basaltic to andesitic lavas, sills of microdiorite and microgabbro; (ii) a volcano-sedimentary unit containing volcanoclastites (of basaltic and dacitic compositions) and sediments (shale and metagraywacke); (iii) the late felsic dykes (rhyolite and rhyodacite), probably contemporaneous with the granitoids, form the third unit. These lithologies have undergone phenomena of metamorphism and hydrothermal alteration. The metamorphism is greenschist facies, but can reach the amphibolite facies in deformation zones and around granitoid intrusions. Carbonation, silicification and sulphidation are the most important hydrothermal alterations in the Agbahou deposit and to a lesser degree chloritization, sericitization and albitization. Basalts are tholeiitic and the most differentiated facies are calc-alkaline. Lithophilic element enrichment (LILE) and negative Nb and Ta anomalies suggest that the basalts probably have developed in a subduction context. However, these rocks show an affinity close to N-MORB. Their source may be a spinel lherzolite. The most differentiated facies are derived from these basalts by fractional crystallization. Metasediments are linked to the field of an active continental margin.

Keywords: Côte d'Ivoire, Birimian, Agbahou, subduction, active continental margin

Features of a New Type of Mineralization in Léo-Man Shield (West Africa Craton): Volcanogenic Massive Sulfide (Zn-Pb-Cu-Ag) deposit of Tiébélé, Southern Burkina Faso

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Twenty years after the discovery of the Perkoa Zn-Ag deposit, another type of Zn-Cu-Pb ± Ag Volcanogenic Massive Sulfide (VMS) subgroup of occurrences forming a district has been highlighted within the Paleoproterozoic Birimian Greenstone Belts of the West African Craton in Burkina Faso.

The geology of the area is characterized by a series of dominantly mafic volcanic rocks with intercalated black shales which increase in proportion upwards in the stratigraphy. This stratigraphic package is overlain by a felsic volcanic sequence comprising reworked tuff and

rhyolite. Although mineralization is locally associated with sedimentary rocks, it is more commonly found in rhyolites in a dominantly greenschist facies. The main lithologies in the mafic sequence range from basalt to andesite with associated gabbro. The felsic sequence consists of dacite to rhyolite with associated granitoids (granite-granodiorite-tonalite). The volcanic rocks are commonly tholeiitic ($Zr/Y=2-4.5$) with relatively high Zr and Y content, although a limited number of samples plot in transitional ($Zr/Y=4.5-7$) or calc-alkaline ($Zr/Y=7-25$) fields. Rhyolites, which constitute the main mineralized rocks at Tiébélé, have similar key trace element signatures to other rhyolites-related known VMS systems worldwide.

Detailed investigations identified at least four VMS targets notably at Koubongo, Nabenia, Loubel and AVV (Aménagement de la Vallée des Voltas) extending over an area of 332 km².

Typical mineral assemblages defining VMS occurrences are mainly hosted by meta-sedimentary rocks and rhyolite but are also found as veins in tonalite. These assemblages can be grouped into four different styles: (i) Variably banded massive sulfides dominated by sphalerite over galena, pyrite, and chalcopyrite within metasediments; (ii) Pyrite-rich or pyrrhotite banded type associated with sphalerite, chalcopyrite, and galena within silicified and carbonatized units; (iii) Disseminated and finely oriented sulfides, including pyrite - pyrrhotite - magnetite \pm sphalerite within quartz-phyric rhyolite; and (iv) Fracture filling pyrrhotite-rich - magnetite - sphalerite mineralization possibly within tonalite. Irrespective of the style of the mineralization, chemistry of altered and least altered rhyolite reveals a significant increase in $Mg \pm Fe$ and H_2O , and a loss of K within mineralization associated alteration. This may suggest sea water leaching of underlying (?) mafic and sedimentary rocks, with Mg-Fe transfer into the rhyolites concomitant with the loss of K. This paper highlights the features of new occurrences of VMS mineralization type within the Birimian system of West Africa. We think this could help for new discoveries along the belt.

Acknowledgement : Prof. Alain Bernard, director of the laboratory of Applied Mineralogy and geochemistry at the University of Brussels provided facilities and assistance with SEM and XRD.

Discovery of gold mineralization in the ferruginous sandstones of Kandi basin (North-East Benin)

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Iron ore of Kandi basin represents the upper horizon of the Continental Terminal formation (Alidou, 1983). Deposits containing mineralized levels with a thickness of 4 m in average, consist of ferruginous sandstones and indurated laterites, sometimes cuirassed (Thoenes, 1974). They lie through an unconformity on a 15 m thick layer of kaolinitic clay (Fig. 1).

This ore long prospected for its high iron content, is full of other hidden and much more valuable metalliferous substances: it is gold disseminated in the intergranular spaces of ferruginous sandstones.

Microscopic studies (polished sections) followed by geochemical analysis confirmed the presence of this precious metal whose exploration can lead to an economically exploitable deposit. It is in a

complex consisting of sulphides including pyrite, chalcopyrite, galena, blende, malachite and azurite.

Reported for the very first time by our research, this precious metal shows in some samples taken at a single point grades three times higher than gold's crustal clark (0.015ppm). This geochemical anomaly marks the presence of gold in the ferruginous sandstones of Kandi Basin.

Keywords : Gold mineralization, metalliferous, Gold's mark, Continental Terminal

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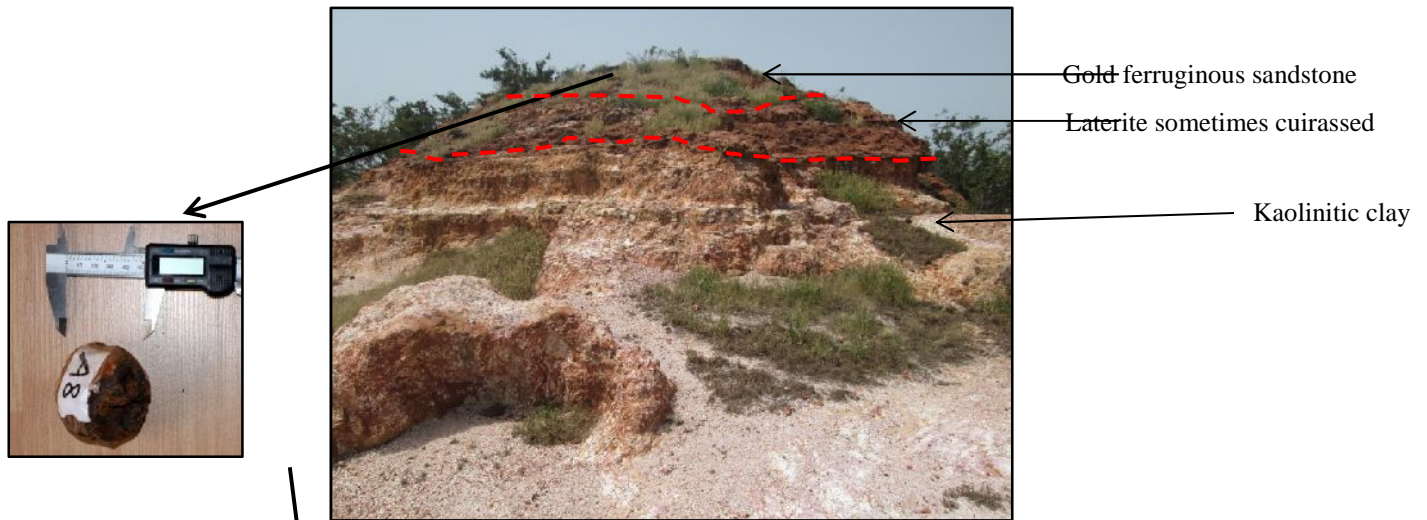


Fig.1 :Lithostratigraphy of the Continental Terminal showing the gold layer

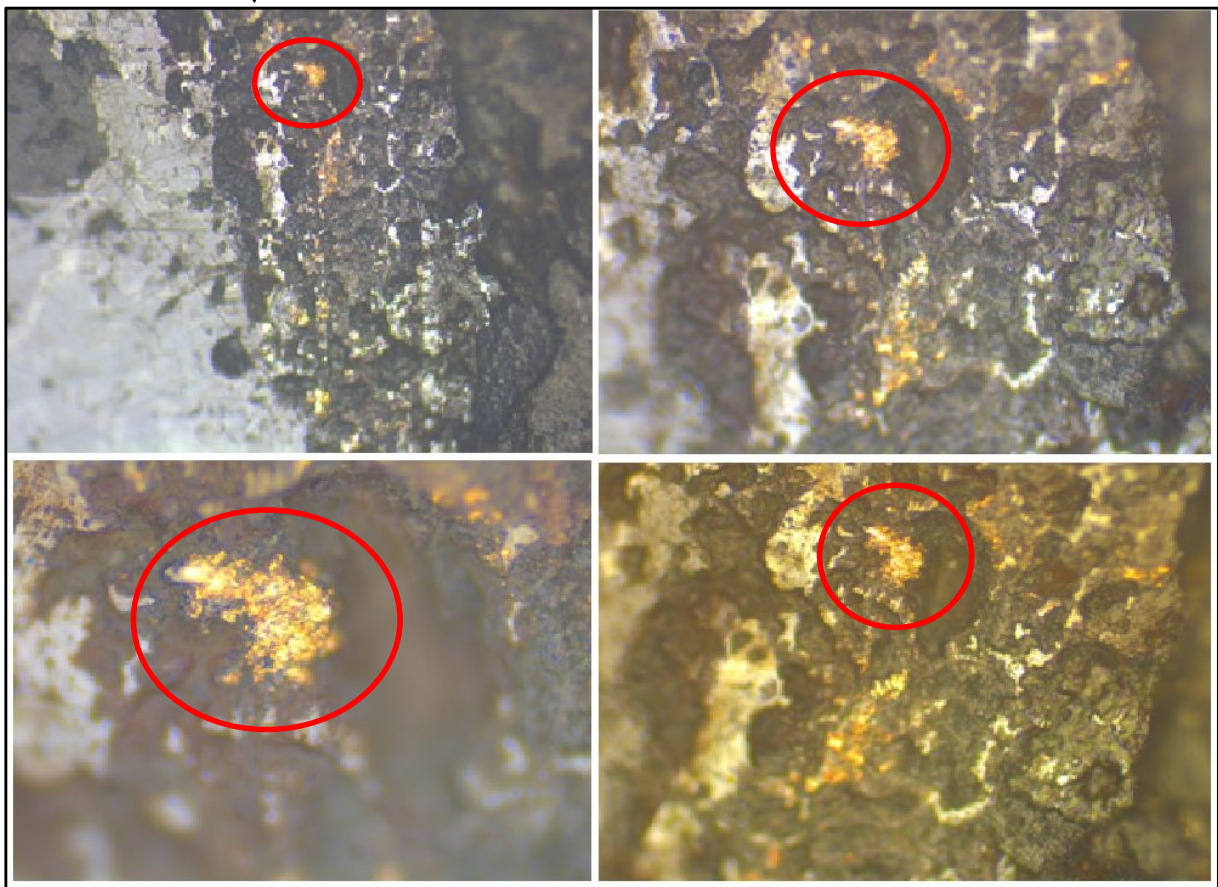


Photo 1: Gold observed in polished section at different magnifications

The West African Exploration Initiative (WAXI): 12 years of integrated research for development

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The eleven-year AMIRA International Project P934 'West African Exploration Initiative' (WAXI), now in its third phase, has the dual aims of scientific research focused on increasing our understanding the tectonic and regolith settings of ore deposits, and the development of the research and training capacity of West African geological surveys and universities. We describe the drivers for the WAXI initiative, as well as key research and capacity building outcomes. The WAXI project is a public-private partnership that has brought together seventy of the principal stakeholders in the domain of minerals exploration in West Africa:

- The government surveys and departments of mines of eleven West African states (Burkina Faso, Ghana, Guinea, Ivory Coast, Liberia, Mali, Mauritania, Niger, Sierra Leone, Senegal and Togo)
- Seven West and South African universities (from Burkina Faso, Côte d'Ivoire, Ghana, Mali, Senegal and South Africa)
- Thirty-four international mining companies
- Researchers from twelve European and Australian research institutions
- AMIRA International, an independent association of minerals companies that develops, brokers and facilitates collaborative research projects
- NGOs based in Burkina Faso, Ghana and Luxembourg
- A professional training centre based in Burkina Faso.
- National research and aid agencies in South Africa, France and Australia

The shared challenges facing geoscientists wishing to undertake scientific research in West Africa (from industry, governments and academia) include the limited flow of scarce government resources to STEM activities in general, and geoscience research in particular. In 2014, the Science, Technology, Engineering, and Mathematics (STEM) sector made up only 29% of all research in Sub-Saharan Africa (excluding South Africa, [World Bank and Elsevier, 2014](#)). National research priorities across Africa do include a range of activities related to geoscience research, in particular Energy, Natural Resource Management and Information and Communications Technology. Nevertheless the low proportions of the Gross Domestic Product (GDP) spent on research in West Africa (often less than 1%) coupled with the overall low levels of GDP, mean that even as priority areas the available budgets are small, and funds available for basic research are limited. This contrasts with the significant revenue flow that many West African countries receive as the result of mining activity, and the costs of managing the environmental impacts of mining (and in particular by variably regulated artisanal mining).

The WAXI project has a series of overlapping research goals, and is globally aimed at improving our understanding of the tectonics, metallogensis and landform evolution of the West African Craton. In parallel the project aims to support the development of geoscience capabilities in the short, medium and long term. Immediate support for company staff improves their capacity to undertake exploration in the region; training geological survey staff improves their ability to

provide geoscience data to end users, and scholarships and access to equipment for graduate students prepares them for work in all sectors of minerals geoscience, and trains the next generation of university lecturers.

This initiative demonstrates the significant research and development achievements that can be made when the different stakeholders in the minerals sector (industry, academia, government and non-government organisations) work together to achieve their diverse goals.

The WAXI project in numbers:

- 12 countries
- 73 partners over 11 years
- 97 Postdoc, PhD, Masters and Honours personnel, 60% of them African
- 85 International Publications
- 650 GB exploration geoscience database
- 1800 person-days of technical training in West Africa
- 650,000 km² of geophysically constrained geological mapping

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First in situ U-Pb dating of supergene copper mineralization: case study from Atacama desert, Chile.

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Direct dating of copper mineralization remains challenging, yet an important objective for both metallogenic studies and prospecting purposes. Here we present a first attempt of U-Pb dating of copper-rich minerals from the Mina Sur exotic deposit from the Chuquicamata copper mine (Chile).

The Mina Sur exotic copper deposit is located in northern Chile, within the Chuquicamata mining district, about 6 km south of the world class Chuquicamata porphyry copper deposit. It was discovered in 1957 from drilling in sub-alluvial channels and copper extraction began in 1969 (Mortimer et al., 1977). The copper mineralization consists mainly of chrysocolla, Mn-rich chrysocolla (also known as copper-pitch or black chrysocolla), pseudomalachite bedding and atacamite emplaced mainly as cement in gravels but also filling fractures in the bedrock. Geomorphological, mineralogical and structural studies have shown that the Mina Sur deposit is derived from the lateral migration of copper-rich solutions from the Chuquicamata porphyry deposit. The latter was formed by the 33-31 Ma old hydrothermal alteration (Ar/Ar dating of K-

feldspar and sericite) of the 35-33 Ma old porphyry (U/Pb dating on zircon). However, the age of the Mina Sur exotic deposit is unknown.

A suite of Mn-rich chrysocolla clasts surrounded by pseudomalachite layers have been characterized and dated by in-situ U-Th-Pb LA-ICP-MS analyses. The data obtained on pseudomalachite define a concordant date of 19.5 ± 0.2 Ma, which is interpreted as crystallisation age of the pseudomalachite layers. In the Mn-rich chrysocolla clasts, the data yield concordant to sub-concordant dates between 13.6 ± 0.2 Ma to 5.8 ± 0.1 Ma (under ns-LA-Q-ICP-MS) and 24.1 ± 0.3 Ma to 6.0 ± 0.1 Ma (under fs-LA-HR-ICP-MS). These dates are therefore not consistent with the date obtained on the pseudomalachite layers that coat them. This could reflect either Pb loss linked to late fluids that affected specifically these clasts or an analytical bias due to the fact that there is no chrysocolla standard available for in-situ U-Pb dating. However, the consistency of the results obtained for Mn-rich chrysocolla clasts on ns-LA-Q-ICP-MS and fs-LA-HR-ICP-MS is promising.

This preliminary study demonstrates, for the first time, that supergene copper mineralization can be dated by the U-Th-Pb method. Furthermore, the age obtained on pseudomalachite indicate that Mina Sur deposition took place at ca. 20 Ma, about 10 Ma after the unroofing and hydrothermal alteration at Chuquicamata, a result that is consistent with the supergene ages already known supergene in the mining district.

Keywords: supergene copper mineralization, Atacama Desert, U-Pb *in situ* dating, chrysocolla, pseudomalachite.

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Petrologic, geodynamic and geochemical studies of Tertiary and Quaternary lavas of western Senegal

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The volcanic formations of the western province of Senegal are located in the extreme west of the Senegalo-Mauritanian Basin. They are constituted by a Tertiary volcanism spread around the Cape Verde Peninsula and the Thiès Plateau and a Quaternary volcanism found in the northwest point of the Cape Verde Peninsula (Crevola et al., 1994). A main phase of lateritic weathering separates both these volcanic activities. The aim of this study is to determine the petrographic, geodynamic and geochemical features of these Tertiary and Quaternary lavas.

The petrographic studies revealed that the Tertiary lavas are sodic mafic rocks, alkaline types, strongly sub-saturated and not differentiated. The description of the thin sections indicates microlithic porphyritic and doleritic intersertal textures. The rocks are generally constituted of olivines, clinopyroxenes, plagioclases, opaque minerals, mesostase and sometimes of nephelines.

The facies, which constitute the Tertiary lavas, are basalts, basanites and nephelinites; and those of the Quaternary lavas are basalts and hawaiites (dolerites).

The Cape Verde Peninsula is tectonically unstable because of the disturbances connected to the brittle tectonics, which occurred after the Atlantic rifting. The latter is at the origin of the separation of the African and American plates during the Jurassic era. This zone is made of a connection of normal submeridian faults bounding horsts (Ndiass, Dakar) and grabens (Rufisque) accompanied by several magmatic activities.

The geochemical studies of major trace and rare earth elements dating from the Tertiary and Quaternary lavas allowed us to emit the following hypotheses (Yatte, 2017):

- The Tertiary and Quaternary lavas could be from a source with low rate of partial melting (high Nb/Zr ratios) : lower mantle ;
- The Quaternary lavas could undergo a phenomenon of contamination by the crust during the ascent of magma towards the surface of the earth (high SiO₂ and ID values, rich values of normative hypersthene) ;
- The Tertiary and Quaternary lavas are genetically linked with positive anomaly in Eu, Nd and Ta and negative in K, Rb and Pb, showing a character of OIB with low degree of partial melting ;
- The Tertiary and Quaternary lavas are alkaline basalts from OIB of intraplate type from the lower mantle (the E-MORB, N-MORB and OIB are less concentrated in trace elements than the Tertiary and Quaternary lavas).

Keywords : Argon, Tertiary, Quaternary, rare gases, Cape Verde Peninsula, Senegal.

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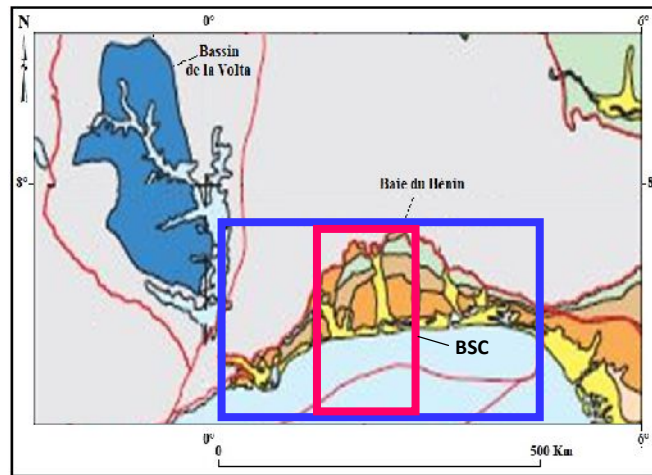
Proof of existence of pre-rift deposits and hydrocarbon potential of Neocomian sediments in the coastal sedimentary basin of Benin

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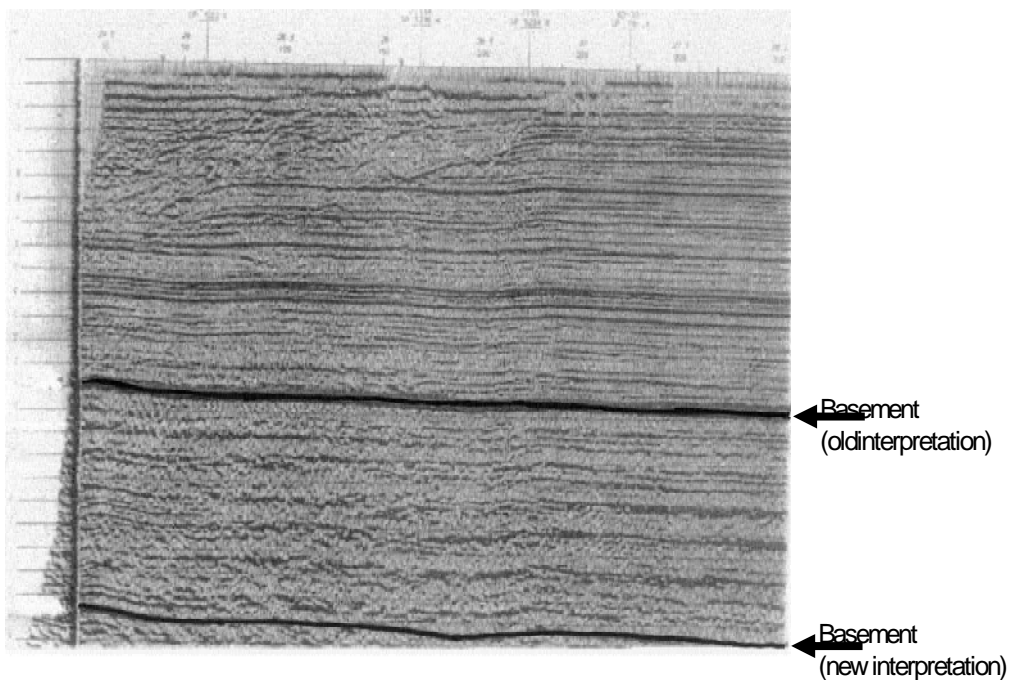
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The coastal sedimentary basin (BSC) of Benin belongs to the Dahomey Embayment, a province with high petroleum potential.



This study, based mainly on observation and description of outcropping sediment, interpretation of geophysical data (seismic and diagraphic for three wells), petrographic and geochemical study by pyrolysis Rock-Eval 6 have confirmed the existence of pre-rift deposits (Paleozoic?) and out the hydrocarbon potential of Neocomian formations inaugurate the rifting in the Embayment. Indeed, a review of old sections interpreted showed packet parallel reflectors below the seismic horizon previously considered as the basement, suggesting the presence of older sediments than the Neocomian (Lower Cretaceous).

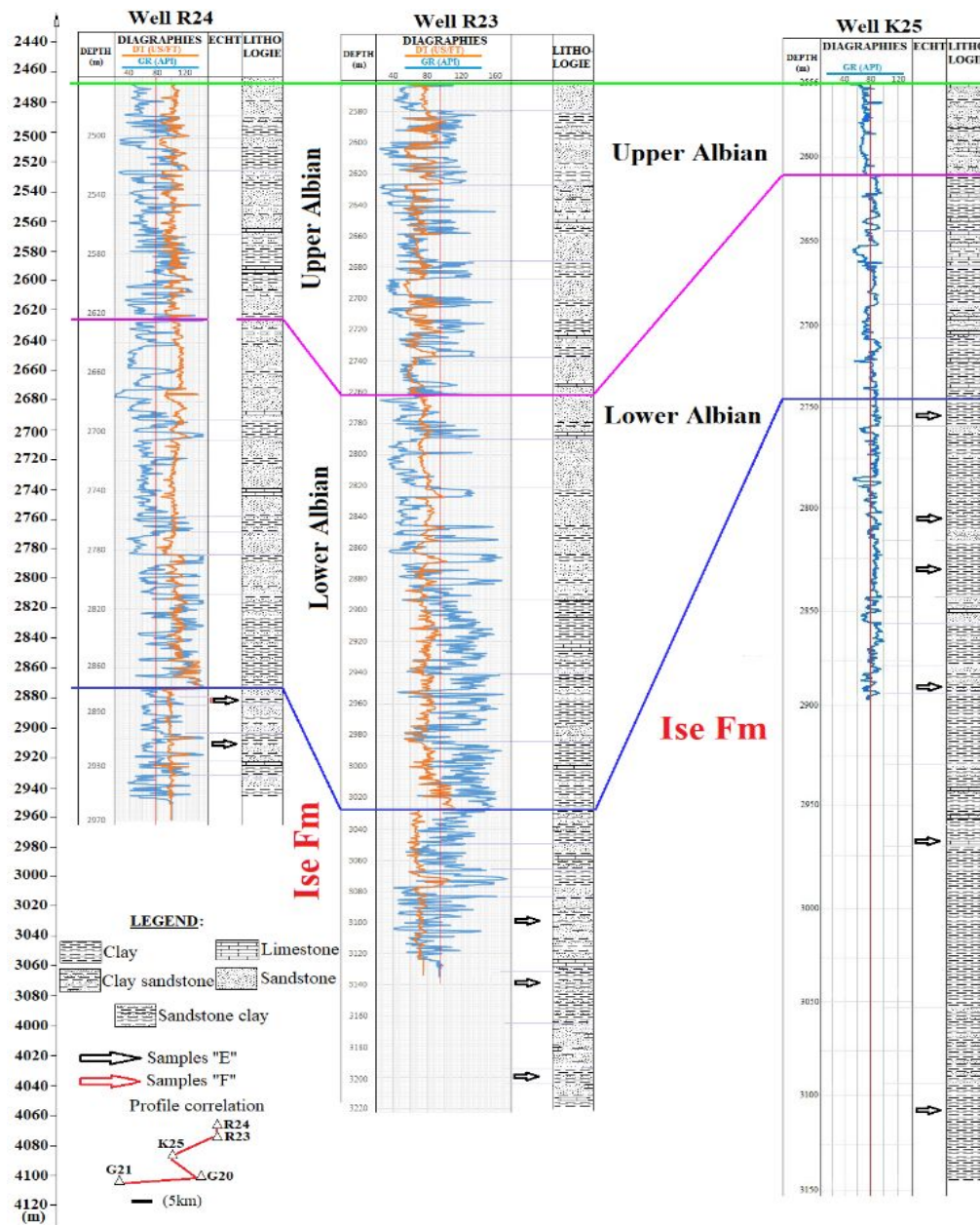


The presence in the northern edge of arkosic sandstone basin mapped as sediment of ancient Paleozoic volcano-sedimentary basin confirms the existence of pre-rift sediments in the basin.

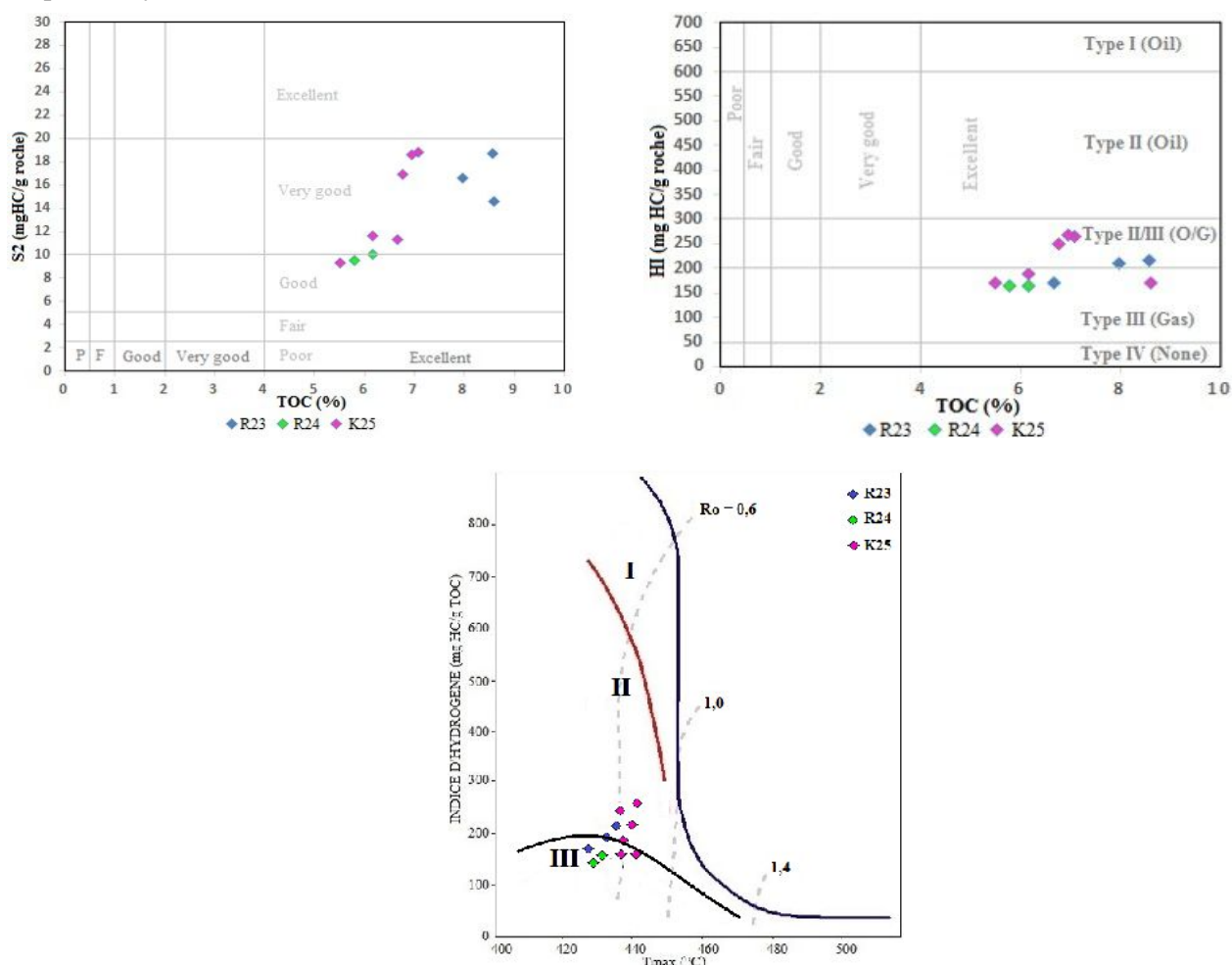


Arkosic
sandstone

Furthermore, Neocomian sediments are two dominant facies (sandstone and clay) characterized by gamma ray values ranging from 19.5 to 163 API with frequent values between 40 and 120 API.



The average values of the TOC and S₂ obtained from the Rock-Eval 6 analysis identified clay levels of 6.93% and 14,18mgHC/g, respectively. Moreover, the values of the maximum temperature (T_{max}) and the Hydrogen Index (HI) are ranging from 427 to 441°C and 163 to 268mgHC/gTOC, respectively.



Keywords : Coastal basin of Benin, pre-rift deposit, Neocomian sediment, hydrocarbon potential, source rock, kerogen.

Reworking crustal between the Hadean-Archaeon-Paleoproterozoic in the Sassandra-Cavally (SASCA, SW of Ivory Coast): Constraints of U-Pb and Lu-Hf isotopes

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The SASCA domain located east of the Sassandra Fault in southwestern Ivory Coast contains evidence of interaction between Archean and Paleoproterozoic crusts. We present new data from this area by coupling U-Pb and Lu-Hf techniques carried out on zircon grains of grey gneiss and intrusive potassic granite. Our objective is to show the crustal growth and the recycling since Hadean to Archean and interaction with the juvenile Paleoproterozoic crust. Indeed, the grey gneiss belonging to the TTG series has essentially Archean ages from 2826 to 3236 Ma, whose Hf (t) values are below the CHUR with TDM model ages between 3.6 and 4.2 Ga. However, potassic granite shows values of Hf (t) that lie on both sides of the CHUR between -13.1 and +2.2 with model ages of 3.5 and 2.5 Ga and a magmatic age of ca. 2100 Ma. Our data suggest the existence of a very early mafic protocrust differentiating without any mantle material from the Hadean to Archean, thus forming an Archean crust, protolith of SASCA grey gneiss. The recycling of this Archean crust with the addition of juvenile magmas from the mantle resulted in the formation of a new crust very potassic ca. 2100 Ma during the Eburnean orogeny. It is the first time that the implication of this Hadean period in the growth and recycling of the ancient crust is demonstrated in the West African Craton.

Keywords: Metamorphism, U-Pb on monazite, Ivory Coast, Paleoproterozoic

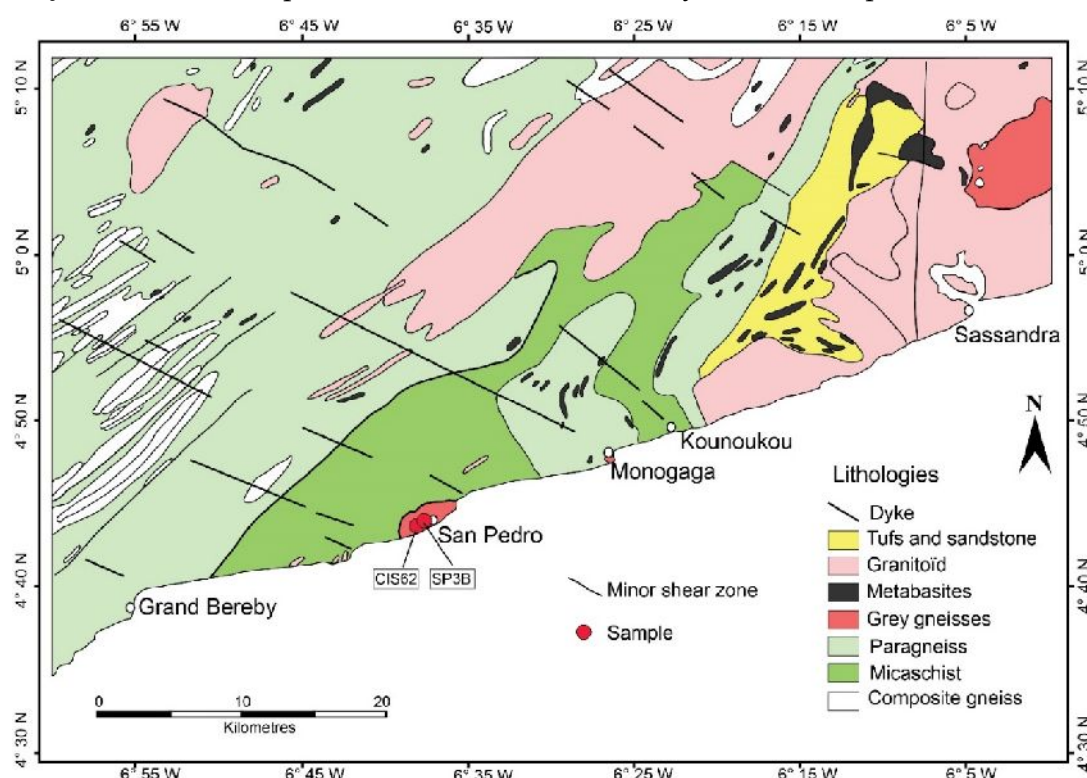


Fig.1: Geological map of the study area. Red circle shows the location of the studied samples (after Papon, 1973).

Unraveling the Age of HT Metamorphism in Eastern Senegal: Evidence from U-Pb *in-situ* Analyses on Monazite and Sm-Nd Garnet Geochronology

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Metasediments of the Paleoproterozoic Diale Dalema Basin are affected by a polyphase metamorphic evolution during the Eburnean Orogeny (2.25 - 2.00 Ga). The garnet-staurolite-sillimanite metapelites contain two generations of garnet. Garnet porphyroclasts wrapped in the S₃ schistosity contain inclusions of chlorite, epidote, biotite, ilmenite, plagioclase, and quartz that delineate the S₂ schistosity. The development of S₃ is coeval with the growth of inclusion-free rims around the garnet porphyroclasts and by garnet neoblasts. Garnet porphyroclast displays a zoning pattern typical of prograde metamorphism associated with decompression from 9 to 6 kbar and an increase in temperature from 550 to 620°C. Monazite neoblasts in the S₃ schistosity yield LA-ICP-MS U-Pb ages of 2052 ± 7 Ma and 2048 ± 8 Ma, whereas inclusions in staurolite yield an older age at 2090 ± 16 Ma.

Sm-Nd garnet geochronology yields a bulk garnet age of 2080.2 ± 7.7 Ma on garnet porphyroclasts and 2049.1 ± 3.1 Ma on neoblasts. The results highlight an agreement between U-Pb ages from monazites and Sm-Nd ages from metamorphic garnets. The oldest ages are interpreted as the age of the prograde regional metamorphism during burial, while the youngest are attributed to the thermal peak.

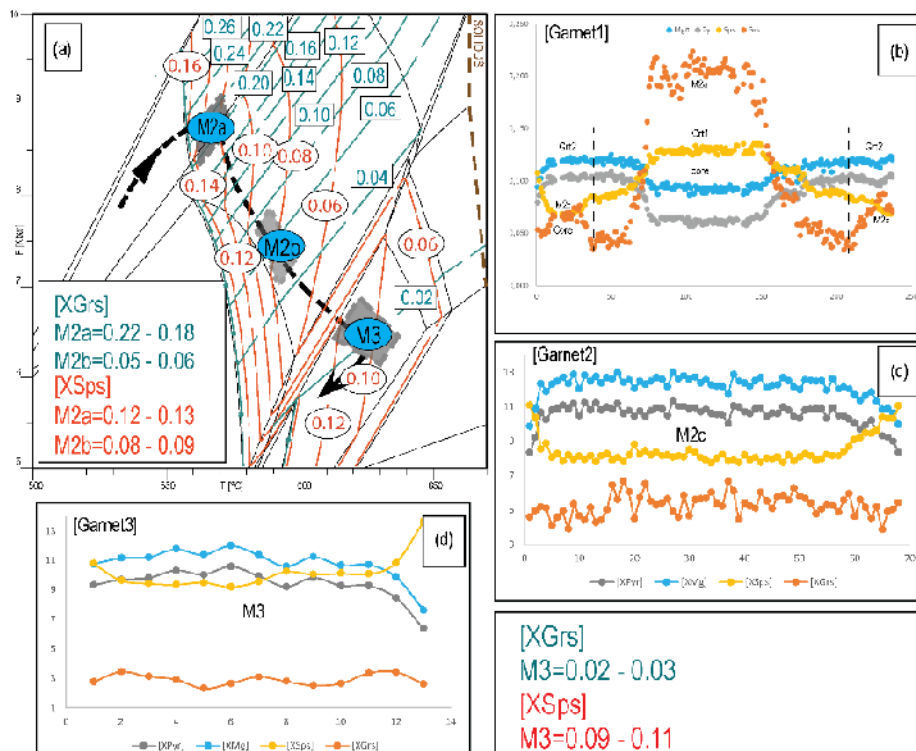


Fig. 1: MnNCKFMASHTi P-T pseudosection illustrating phase equilibria for metagreywacke sample 44a2 and the chemical composition variation along radial profiles generation garnets g1, g2, g3.

Contribution of remote sensing and geophysics to water-drilling implementation in Kong (northeastern Côte d'Ivoire)

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The need to refer to groundwater for the drinking water supply of cities has made it imperative to search for structures leading to high flows (more than 10 m³/h) in the crystalline formations of Kong. With the support of the National Office of Drinking Water (ONEP), two sites have been studied. The following methods have been implemented: 1) Remote sensing for mapping of lineaments that are assimilated to bedrock faults; 2) geomorphology and geophysics, which have focused on the analysis of the surface state of the preselected sites, their characterization, and the selection of borehole locations. The statistical processing of the map of lineaments obtained shows three main directions N130°-140°, N50°-60° and N30°-40°. The geophysical work allowed to reinforce the knowledge of the geological structure of the basement by the confirmation of the lineaments of direction N47°, N77° and N147°, the identification of fractures oriented N50°, N126° and N70° and by the characterization of fracturing zones favorable to the presence of crack aquifers. Drilling on the fracture N50° gave a flow rate of 16 m³/h with productive fractures at 24, 25, 28, 69, and 71 m depth, respectively. This has helped to overcome the water supply problem in Kong.

Keywords: fracture, remote sensing, drilling, lineaments, geophysics, Kong

15, 16 Octobre 2018, Université Félix HOUPHOUËT-BOIGNY, Abidjan-Côte d'Ivoire

Study of the burial site of Akouédo landfill (Abidjan) using electrical resistivity method: implication on the risk of the Continental Terminal aquifer contamination

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Located in east of Abidjan district (South of Côte d'Ivoire), Akouédo landfill was subject to ageophysical study coupled with a drilling cuts analysis to determine a possible stratigraphic model of Akouédo area and estimate the solid waste buried volume in this landfill. The results show a lithostratigraphic model which reveals the presence of moderately resistant surface formation, clay sand, followed by clay lenses and sandy clay with reduced thickness. This lithological ensemble surmounts very thick sandy formation, which constitutes Continental Terminal aquifer. All these formations are finally based on granite and schistosed basement whose roof is estimated at 80 m depth. The clay, which is the only impermeable layer that can hinder liquid pollutants migration from landfill to Abidjan aquifer, has lenticular and especially discontinuous shape with varying thicknesses (sometimes 1m to 6m). This poor distribution of clay formations on Akouédo landfill site implies probable mobility of liquid pollutants towards the Continental Terminal aquifer. Overall volume of solid waste is estimated at 32854800 m³ from the entire Akouédo landfill.

Keywords: Côte d'Ivoire, lithostratigraphy, lenticular, discontinuous, pollutant

The SASCA Domain in the South west Côte d'Ivoire: stronger actions between Archean and Birimian (Man-Leo Rise, West African Craton)

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In the Man-Leo Rise, the Archean-Birimian (Paleoproterozoic) Transition Zone is located between the Archean domain limited by the Sassandra Fault and the 6°W longitude in the Baoulé-Mossi domain. This Transition Zone is isotopically characterized by the presence of Archean inheritance frequently indicating by some zero to negative Nd, Archean U-Pb inherited ages and the occurrence of Archean relicts. The most important interactions are observable in the SASCA Domain in particular from Balmer to Monogaga in San Pedro region (at the Atlantic coast). In that respect, an Eburnean pegmatite canatectite granite with a 3 Ga Nd model age has sheared the Archean gneisses (U-Pb on zircon at 3.2 Ga and Nd model age at 3.4 Ga). At Monogaga, the

Archean gneisses (Nd model age at 3.3 Ga) are in contact with Birimian juvenile magmas (Nd model age at 2.6 Ga). So far, it is only in this part of the Man Rise that such interactions occur. The Archean gneisses in contact with the Birimian juveniles formations reinforce the idea that the Archean protocontinent was geographically close during the genesis of the Birimian juvenile domain. In this juvenile domain, the Nd are in the interval +2 to +3 at 2.1 Ga while in the depleted mantle there are around +5 to +6 at the same period. This difference could be caused by the existence of inherited components, probably of Archean age, on the whole of the Birimian magmatism. An Archean protocontinent rifting would better explain such a contamination rather than oceanic plateaus generated without direct link with Archean and which would exclude such interactions.

Keywords: Archean, Birimian, SASCA domain, inheritance, contamination, rifting, Côte d'Ivoire

Reevaluation of Leonian and Liberian events in the geodynamical evolution of the Man Rise (West African Craton)

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The Leonian (3300-3000Ma) and Liberian (2900-2700Ma) events are the most remarkable magmatic and tectono-metamorphic events of the Archean domain of the Man Rise. Naturally, the Liberian overprints very often the Leonian and sometimes obliterates it. In Ivory Coast, the in-situ dating by LA-ICPMS of zircons of the charnockite of Mangouin (MANG) and the augenorthogneiss of Lagoulalé (LAG) allowed to revalue the ages of these two tectono-metamorphic events. The charnockite represents the paroxysm of Liberian metamorphism whereas the augenorthogneiss would be set up at the end of this tectono-metamorphic event. The age of the charnockite of Mangouin is 2798±7Ma and that of the augenorthogneiss of Lagoulalé is 2794±12Ma. These ages are in agreement with previous geochronological data obtained by TIMS single-grain evaporation (Kouamelan et al., 1997). However, we note a Leonian inheritance at 3121±37Ma in the heart of a grain of zircons of the augenorthogneiss. This inheritance indicates that the charnockite of Mangouin and the augenorthogneiss of Lagoulalé arise, either partially, or totally, from the melting of Leonian formations. The Nd model age at 3250Ma for these rocks is in agreement with this inheritance. The zircons of MANG as those of LAG have high Th/U ratio (> 0.2); they are thus of magmatic origin. The interactions between Archean and Proterozoic (Birimian) formations are more and more highlighted. We suggest that they took place initially in the context of rifting of the Archean proto-continent between 3200 and 2700Ma. During this period, oceanic crust and a volcanic arc system associated with subduction zones are generated and are recycled later by Burkinian orogeny which is going to set up the Dabakalian magmas between 2500 and 2200Ma (early Birimian).

Keywords: Leonian, Liberian, Birimian, tectono-metamorphic event, rifting, volcanic arc

Geochemical and Sr-Nd isotopic constraints on the petrogenesis of Paleoproterozoic alkaline rocks from Kiemou, Ninakri and Okrouyo (Ivory Coast, West African Craton)

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The Paleoproterozoic lands of the West African Craton (WAC) have a weak occurrence in alkaline plutons. In Côte d'Ivoire, most of these geological formations are distributed along the leucogranite batholith of Ferkessédougou. Samples studied here come from the localities of Kiemou, Ninakri and Okrouyo. They are generally nepheline syenites, quartz syenites and alkaline granites. Syenitic bodies have a shoshonitic, metaluminous affinity while the granites are strongly potassic and weakly peraluminous. We also note a moderate Na₂O/K₂O ratio, a high MgO contents (up to 2.05%), a high content of incompatible elements, in particular LILE (Rb, Cs, K, Th) and LREE, high splits of LREE/HREE, negative Nb-Ta anomalies, small Eu anomalies for syenitic facies, and more pronounced anomalies for granites.

The mineralogical assemblage is made of diopside, augite, magnesio-hornblende, biotite, alkali feldspars, plagioclase, apatite, zircon, sphene, allanite, fluorite and magnetite. The differentiation of these alkaline rocks was controlled by a fractional crystallization process. Initial ⁸⁷Sr/⁸⁶Sr ratios are low (0.6902-0.7006), Sm / Nd isotopic data (positive εNd 0.86 to 3.14) indicate juvenile character; these values being also close to zero show a slight crustal contamination. These plutons are usually originated from a depleted mantle. All the rock formations from Kiemou, Ninakri and Okrouyo display geotectonic signatures of A2-type (IAB) granites, i.e. post-collision. We can therefore say that the alkaline magmatism manifested itself in a single phase in this part of the WAC. Therefore all these alkaline plutons are late-orogenic and non-anorogenic.

Keywords: pluton, alkaline, Paleoproterozoic, Côte d'Ivoire, WAC

Petrographic and geochemical study of Birimian mafic and ultramafic complexes of the Mako super-group (eastern Senegal)

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The Birimian magmatic formations (except granitoids) of the Mako super-group (Eastern Senegal) were analyzed in the Mako village sector, a key sector where ultramafic series are notably exposed. These magmatic formations are represented by: i) mafic series, the most abundant, consisting of pillow basalts, massive basalts and gabbros which form either homogeneous masses sometimes associated with basalts, or bodies bordering ultramafic rocks, or veins intersecting the other facies;

these mafic series are found in enclaves within the granitoids; ii) differentiated ultramafic rocks composed of several types of rocks (lherzolite, harzburgite, clinopyroxenite) in plurikilometric massifs (Lamé massif) where they appear as monocrystalline bodies (wehrlite or lherzolite) as in Mako, Lamé, Koulountou and Sofia ; ultrabasic rocks form scales within the mafic series; (iii) mafic to differentiated volcanic rocks (basalts, andesites, dacites, rhyolites) outcropping in the form of metamorphic to decametric veins intersecting previous mafic and ultramafic rocks. These veins with the exception of rhyolites contain centimetric enclaves at decametric of gabbros. The different series are affected by a schistosity underlined through a paragenesis of greenschist facies marked by the development of sericite, chlorite, epidote, amphibole of actinote type, quartz and albite.

The geochemical study of magmatic minerals (chromites, olivines, clinopyroxenes, orthopyroxenes, amphiboles) and rocks made it possible to distinguish two magmatic series: i) a tholeiitic series and ii) a calc-alkaline series. The tholeiitic series is double with two sub-series called tholeiites 1 and tholeiites 2 each consisting of ultramafic rocks, gabbros and basalts. These three lines (tholeiites 1, tholeiites 2 and calc-alkaline) are evidenced from the rare earth spectra of rocks. Tholeiites 1 have an almost flat rare earth spectrum ($\text{LaN}/\text{SmN}=0.74\text{--}1.14$ and $\text{LaN}/\text{YbN}=0.82\text{--}2.05$), whereas tholeiites 2 are more enriched in light TR ($\text{LaN}/\text{SmN}=1.25\text{--}1.75$) and show a more pronounced light/heavy TR fractionation ($\text{LaN}/\text{YbN}=2.04\text{--}3.71$). The calc-alkaline series, clearly identified in the field by its veinic volcanic nature intersecting tholeiitic rocks, is more enriched in light TR ($\text{LaN}/\text{SmN}=2.06\text{--}3.51$) and poorer in heavy TR with more sloping spectra ($\text{LaN}/\text{YbN}=4.70\text{--}13.97$). These geochemical characteristics are confirmed by the isotopic data. The tholeiitic series 1 ($n=22$) has a mean initial isotopic composition characterized by $^{87}\text{Sr}/^{86}\text{Sr}=0.701736 \pm 10$ and $\epsilon\text{Nd} (2.1\text{Ga})=3.51 \pm 0.01$. The tholeiitic series 2 ($n=14$) has a mean initial isotopic composition characterized by $^{87}\text{Sr}/^{86}\text{Sr}=0.702601 \pm 19$ and $\epsilon\text{Nd} (2.1\text{Ga})=3.05 \pm 0.01$. Finally, the calc-alkaline series ($n=7$) has a calculated mean initial isotopic signature of $^{87}\text{Sr}/^{86}\text{Sr}=0.702090 \pm 9$ and $\epsilon\text{Nd} (2.1\text{Ga})=2.70 \pm 0.02$. The isotopic and trace elements data show a magmatic evolution from a depressed source (tholeiites 1) to a more enriched source represented by tholeiites 2 and calc-alkalis, respectively.

The analysis of the tholeiitic and calc-alkaline magmatism in the Mako sector makes it possible to envisage for the Birimian series an evolution from a geodynamic context of frank oceanic type or back-arc type towards a subduction environment.

Keywords: Birimian, Makosupergroup, isotopes, trace elements, calc-alkaline, oceanic basin, subduction

Magmatism, dynamism and mineralization: example of the Tifrittrough (western Algeria)

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Northwest Algeria is punctuated by outcrops of Palaeozoic age oriented along a NE-SW direction. This alignment is of Atlasic type and could continue from Ghar-Rouban to the Zaccar massif, along with the Tifrittrough and the Bechtout massif (Fig. 1).

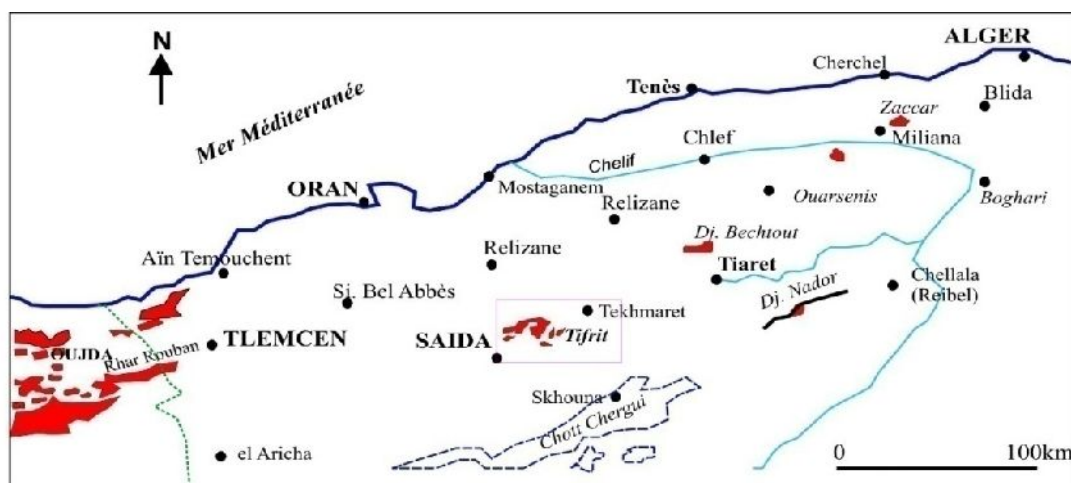


Fig. 1: location of the Palaeozoic massifs of Western Algeria (Lucas, 1952, modified)

Our study focus on the Tifrit trough to clarify Palaeozoic volcanic and para-volcanic emissions. Indeed, we preceded by a cartographic study on topographical background, on photo-aerial and on satellite image in order to determine the geochronology, dynamic and structural aspect of the primary magmatism of this region of the highlands, Northwest of Algeria. The western part of Tifrit presents two types of Palaeozoic magmatic outcrops with a semi-extrusive and extrusive character: (i) microgranite stocks and rhyolite dykes with ante-Mesozoic ages as they are reworked in the micro-conglomerates dated Infra-Lias; (ii) dacitic breccias, basalt flows and microdolerite veins.

The evolution of this crystallophyllian primary sedimentary basin is closely related to tectono-magmatic activities. The study of Palaeozoic igneous facies as well as mafic, intermediate and felsic ones, shows geodynamic contexts of a basin having acquired its construction during the orogenic Variscan cycle like their homologues in Eastern Morocco (Hoepffner, 1987) and in Western Europe.

These facts are demonstrated thanks to the petrographic study of the intra-Visé and dacitic breccias (Mahmoudi, 2009) that remakes sedimentary, metamorphic and volcanic fragments. The engine of the construction of this basin would imply a transtensive and transpressive tectonics accompanied by magmatism and an epi- and anchi-zonal metamorphism in sedimentary sequences: sandy-pelitic, arkosic and psammitic.

The mineralization associated with these types of basins are mainly sulphides, oxides, sulphates and native metals of vein types and in disseminations emplaced during post-magmatic and hydrothermal processes in close relationship with Hercynian and Alpine tectonics.

Keywords: Magmatic, mineralization, post-magmatic, tectonic, hydrothermal, Palaeozoic, Hercynian, Alpine, Tifrit, Saida

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Kourki molybdenum porphyry and copper system (Liptako, North Niger)

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Kourki's molybdenum-copper porphyry is located in the Birimian Liptako-Nigerian formations (Téra region) (Fig. 1). This deposit was discovered by Machens (1964). In geochemistry, it assembles molybdenum mineralization which is an original style in the Middle Precambrian (Gravesteyn, 1966; Jeambrun, 1967; Machens, 1973).

Thus, on the basis of successive trenches, the Kourki deposit has large volumes of rocks (estimated at 160 million tons) (Machens 1964); the genetic and spatial linkage of intrusions-related mineralization with a porphyry texture. Machens (1964) characterizes this deposit as being of molybdenum and copper porphyry.

The objective of this work was to better describe these mineralizations and compare them with Phanerozoic porphyry systems.

The Kourki geology shows a granodiorite tonalite pluton in contact with dioritic intrusions in the north, clastic sediments in the east, and volcanoclastic rocks in the southeast. The pluton is intersected by porphyry intrusions, in the form of dykes and irregular bodies that have been observed in outcrop and boreholes (Ranc, 1975). The lithogeochemical study shows that it is a calc-alkaline plutonic series characteristic of an arc environment. Field relationships have identified large areas of quartz hydrothermal breccias within the pluton. They were set up by hydraulic fracturing along areas of weakness. The wide openings sometimes allowed tilts and some corrosion of the fragments. Mineralization in Mo-Cu is exclusively hosted in the Kourkigranitoid, whose composition varies from tonalite to granodiorite and porphyry intrusions (Fig. 2). It is composed of pyrite, molybdenite, and chalcopyrite, with some chalcocite. Molybdenite occurs in association with quartz breccia, in the form of stockworks and veinlets, and disseminated mineralization. The alterations include a potassium alteration, with biotite and K-feldspars, and an intense hematization. Phyllic alteration is poorly developed (Ranc, 1975).

Kourki's porphyry system probably appears as Birimian. Re-Os isotope dating on pyrite-molybdenite provides ages around 2141 ± 17 Ma.

All these data show that Kourki porphyry represents a characteristic system of an arc environment, quite comparable to those of the Cordillera.

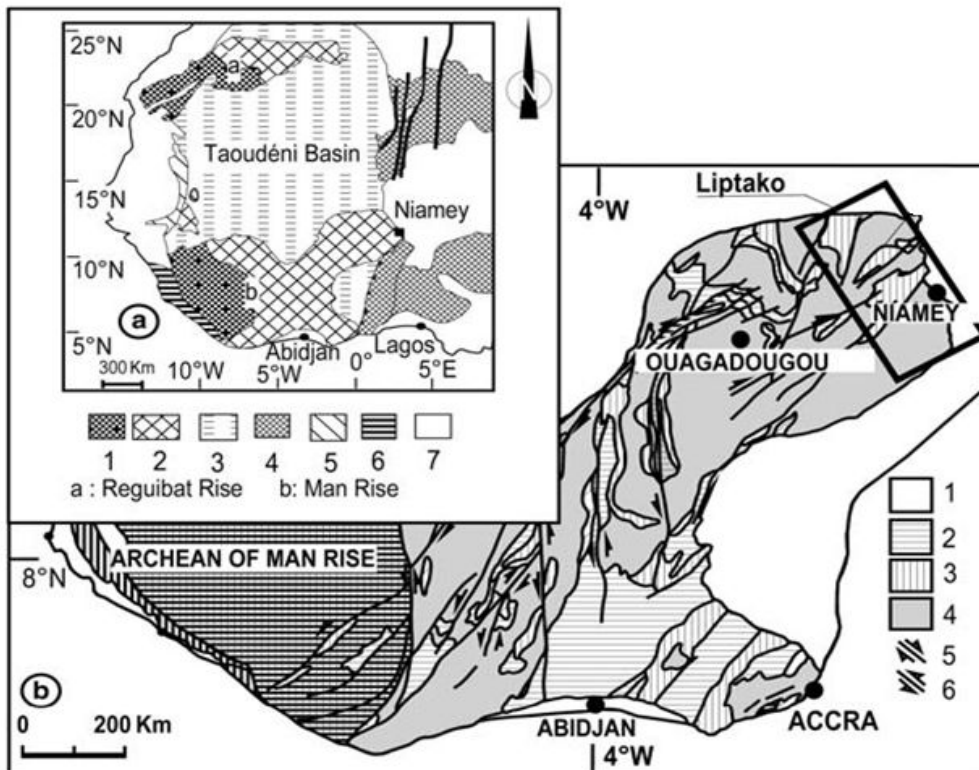


Fig. 1. (a) Main geological features of the West African Craton. 1, Archean rocks; 2, Birimian rocks; 3, Precambrian sedimentary basins; 4, pan-African chain; 5, Hercynian chain; 6, reactivated basement; 7, Phanerozoic sedimentary basins. (b) Geological map of the ManRise (Milesi et al., 1989, modified) and location of Liptako. 1, Phanerozoic cover; 2, Birimian sedimentary and volcano-sedimentary rocks; 3, Birimian greenbelts; 4, granitoids; 5, dextral faults; 6, sinistral faults.

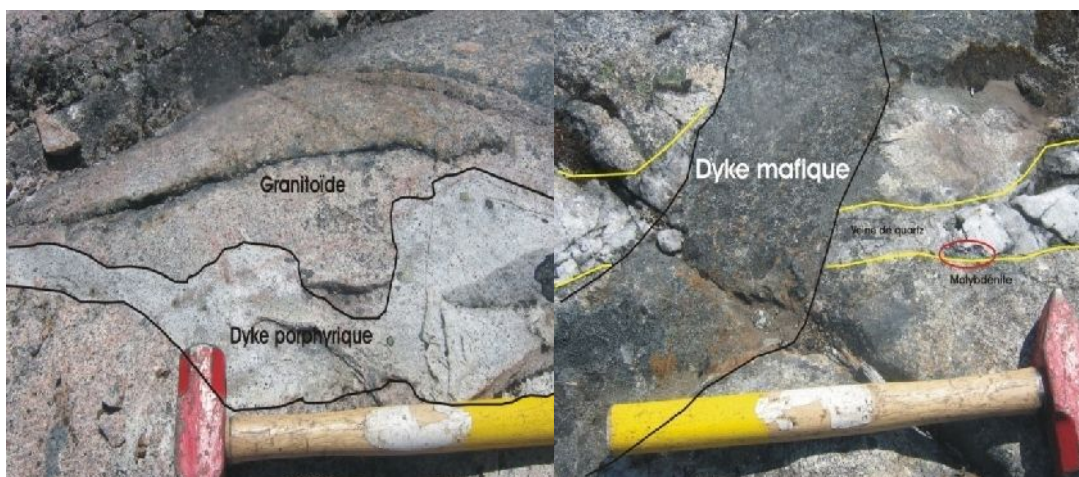


Fig. 2.(a) QP-type porphyry dyke intersecting the granitoid, molybdenum index, (b) mafic dyke intersecting a mineralized quartz vein.

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Physical volcanological features of pillow lavas from the Palaeoproterozoic Mako Supergroup, Eastern Senegal

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The c. 2.2 Ga Mako Supergroup is found in the western part of the Kedougou-Kenieba Inlier of the Palaeoproterozoic Birimian Belt of the West African Craton, in SE Senegal. The lower part of the Mako Supergroup consists of tholeiitic pillow lavas overlying gabbros and ultramafic rocks. The pillow lavas are overlain by metacherts, shales, and carbonate rocks. They are intruded by calc-alkaline plutons and dykes, and overlain by a calc-alkaline volcanic succession. The total succession is interpreted to represent an ophiolitic oceanic crustal section (ultramafic rocks, gabbros, pillow lavas and deep sea sedimentary rocks), into which an island arc plutonic and volcanic calc-alkaline suite was emplaced.

The Mako pillow lavas were examined in outcrops along the Gambia River at Badian, near Mako, at Kérékounda, and from Sandikounda, about 150 km N of Mako. Most of the pillows have typical flattened balloon shapes, with broad convex upper surfaces, and more pointed rounded protuberances extending into the space between underlying pillows. The pillows are surrounded by prominent fine-grained (originally glassy) chilled margins, about 1-2 cm in width. In general their shapes show little external tectonic strain imposed on the pillow lavas. Some pillows are locally highly deformed, due to having been evacuated of lavas from their still molten interiors, resulting in flaccid, crumpled shapes like burst balloons, as they were plastically deformed, while still hot, under the weight of the overlying pillow lava pile. The interior of many pillows show empty irregular shaped vacuoles and lithophysae (flattened subhorizontal cavities), formed by outflow of lava after a larger proportion of cooling and crystallization of the lava had occurred. Vesicles present in pillow margins are generally very small, and show a narrow range in diameter, averaging about 3 mm. This indicates large palaeodepths, consistent with eruption in a deep-water mid-ocean ridge environment. At Badian, one pillow exterior showed 2-3 mm spaced slightly

arcuate parallel grooves, extending for up to 10 cm along a whole side of the pillow- these are interpreted as extrusion-related striations produced when lava is extruded from a hackly, irregular fracture in the glassy exterior rind of a pillow with a still molten interior. Other features associated with the pillow lavas are hyaloclastic breccias- which may represent broken glassy pillow rinds (pillow block breccias), and other kinds of volcanic breccias, formed on the ocean floor. Many of these breccias are cemented with milky quartz, probably due to hydrothermal silica exhalations, which are also related to the formation of laminated banded cherts, and silica veins cementing carbonate breccias deposited above the pillow lavas. Some of the quartz veining was very early, since thin quartz veins are ptlygmatically folded (similar to mudcrack infills in sedimentary rocks) due to compaction of the volcanic pile- indicating they were injected into fractures while the lava was still hot. The physical volcanological features of the Mako pillow lavas indicate a dynamic sea-floor environment of deposition, with contemporaneous hydrothermal activity, very similar to mid-ocean ridge environments in modern oceans.

Keywords: lithophysae, hyaloclastites, vesicles, extrusion striations

Palaeoproterozoic high $\delta^{13}\text{C}$ carbonates from the Mako Super group, Eastern Senegal: A first record of the Lomagundi Carbon Isotope Excursion in West Africa

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The succession of the Palaeoproterozoic Birimian belt of the Kedougou-Kenieba Inlier of western Senegal is subdivided into the Mako and Diallé-Daléma supergroups. The c. 2.2 Ga Mako Sgp consists of tholeiitic pillow lavas overlying gabbros and ultramafic rocks. The pillow lavas are overlain by metacherts, shales, and carbonate rocks. This assemblage represents a deep-water, oceanic crust succession. It is intruded by calc-alkaline plutons, and covered by calc-alkaline lavas and pyroclastic rocks of the upper Mako Sgp, representing an oceanic island arc. The Diallé-Daléma Sgp consists of a thick (8-10 km) volcano-sedimentary succession, with calcitic and dolomitic marbles, conglomerates, breccias, greywackes, sandstones, shales, and ash beds, possibly deposited in a back-arc basin [1].

Carbonate rocks of the Mako Supergroup lie directly above tholeiitic pillow lavas, with associated banded cherts and some thin organic-rich black shales. These rocks also include hyaloclastic breccias, containing angular fragments of vesicular basalt, formed by explosive eruption of basalt on the seafloor and enclosed in a carbonate matrix. The Mako Sgp carbonates are mainly dolomitic marbles with minor calcitic marbles. Their C isotopic composition shows $\delta^{13}\text{C}$ values ranging between +7.9 and +11.2‰ V-PDB (n=18), indicating that these carbonates were deposited during the Lomagundi Carbon Isotope Excursion (LCIE) in seawater composition between c. 2.2 and 2.06 Ga, recorded by high $\delta^{13}\text{C}$ values of sedimentary carbonates with this age [2]. Their stratigraphic position and high $\delta^{13}\text{C}$ values are similar to those of marbles associated with seafloor pillow lavas in the Ruwenzori Belt, Uganda [3]. Although the isotopic systems have

been disturbed by metamorphism, as shown by large variations in $\delta^{18}\text{O}$ and Mn/Sr values, the high $\delta^{13}\text{C}$ values indicate a source from ^{13}C -enriched seawater. The sedimentary carbonates of the MakoSgp have a tentative Pb-Pb age of 2.15 Ga [4]. They overlie pillow lavas, which have yielded age of c. 2.197 Ga [5], and, since they display the LCIE, their age is constrained between c. 2.2 and 2.06 Ga. In contrast, metacarbonates from two quarries near Ibel, located in the Diallé-Daléma Supergroup, consist of highly deformed calcitic and ferroan, dolomitic marbles, with $\delta^{13}\text{C}$ values ranging between -1.9 and +2.5 ‰ V-PDB (n=30). These $\delta^{13}\text{C}$ values are within the range of normal marine carbonates, and are similar to previously reported $\delta^{13}\text{C}$ values of the Diallé-Daléma Sgp metacarbonates from Ylimalo along the Falémé River, ranging from +0.3 to +1.7 ‰ V-PDB (n=4) [6]. The Diallé-Daléma Sgp metacarbonates have a Pb-Pb age of 2065 ± 33 Ma [7]. Since they post-date the LCIE, their depositional age is likely to be in the range 2060-2030 Ma.

Keywords: dolomites, hyaloclastites, hydrothermal silica, sea-floor

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CO₂-emanating thermal springs as potentially lethal geohazards in the Dallol region, Danakil Depression, Ethiopia, and the Hierapolis-Pamukkale region, Turkey

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Volcanoes and associated volcanic springs and emanations are potential human and animal health hazards which have been documented in many places since ancient times (Master, 2016). Carbon dioxide (CO₂) is an abundant volcanic gas, which is emitted during volcanic eruptions and in geothermal areas, and is particularly insidious and dangerous because it is odorless, and denser than air. The Afar region of northern Ethiopia is one of the most tectonically active regions in the world, and is the site of abundant recent volcanic activity and seismicity. The hot springs at Dallol in the northern Danakil Depression, Afar, are well known for their hydrothermal deposits of brightly coloured iron-rich salts. The source of the springs is probably from meteoric waters, which have interacted with magmatic rocks and magmas, from which their abundant contained gases, including CO₂, are derived. Near Dallol, the Black Water and Gaet'ale thermal springs have been observed with fountaining jets of hot hypersaline Fe-rich brines, especially after the seismovolcanic crises of 2005 (Master, 2016). Many dead birds were observed around the Gaet'ale springs and lake (and also Black Spring), and locals have observed the birds dying due to gas emanations from the lake. The thermal springs and lakes near Dallol may pose a dangerous (and even potentially

deadly) health hazard for human visitors (Master, 2016).

In SW Turkey, the Pamukkale springs and travertine terraces of the non-volcanic Denizli basin are situated next to the ancient Phrygian town of Hierapolis, which was famed for its thermal springs, first described by the classical geographer Strabo (c.65 BCE- c.24 CE). In 2013, an Italian archaeological team led by Francesco d'Andria announced the discovery, in Hierapolis, of the Ploutonion, a temple dedicated to Pluto, Greek god of the underworld, and regarded in ancient times as the gates of Hades. Strabo, describing the Ploutonion, reported that "this space is full of a vapor so misty and dense that one can scarcely see the ground. Any animal that passes inside meets instant death. I threw in sparrows and they immediately breathed their last and fell" (Master, 2016). D'Andria reported that "several birds died as they tried to get close to the warm opening, instantly killed by the carbon dioxide fumes" (Master, 2016). As a safety precaution, d'Andria's excavations at the Ploutonion have subsequently been covered up again (as observed by the author in June 2016), because of the risk of CO₂ exposure to tourists, who are free to wander around the ruins of Hierapolis, one of Turkey's top tourist attractions. In 2016, a local excavator in Hierapolis, who had illegally dug into an ancient grave while searching for artefacts, was overcome with carbon dioxide poisoning, and died in the local hospital, most likely from the effects of acute carboxyhaemoglobinaemia. Although birds and small animals are known to have succumbed to the CO₂ from the Ploutonion at Hierapolis since antiquity, this is the first recorded human casualty, and serves as a warning about the potentially lethal nature of the thermal springs at Pamukkale-Hierapolis.

Keywords: Afar, Gae'tale, Ploutonion, dead birds, human casualty

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The tectono-magmatic framework to gold mineralization in the Sadiola-Yatela gold camp and implications for the paleotectonic setting of the Kédougou-Kénieba inlier, West Africa

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The Kédougou-Kénieba inlier is the westernmost exposure of Birimian crust in the West African Craton and a world-class gold province as it hosts several multi-million ounce gold deposits (e.g., Sadiola, Yatela, Yalea, Gara, Gounkoto, Massawa, Fékola). In addition to this gold endowment, the inlier also hosts a large iron resource associated with the Falémé Fe-skarns. The Sadiola-Yatela gold camp is located in Mali and hosted by detrital sedimentary rocks (e.g., wackes, arenites, siltstones, and argillites) and impure carbonates of the Kofi Series. Limited detrital zircon geochronological data indicates that rocks of the Kofi Series deposited between ca. 2120 and 2100 Ma. Within the camp, these supracrustal rock sequences strike NNW-SSE to NS, with steep dips and reversals in stratigraphic younging implying tight to isoclinal folding and locally reverse

faulting. This period of basin inversion is correlated with D_{1S} (~EW-directed shortening) and occurred coevally with upper-greenschist-facies metamorphism between ca. 2100-2090 Ma. Widespread high-K calc-alkaline to peraluminous biotite-muscovite S-type granites intruded country rocks between ca. 2090 and 2060 Ma (U-Pb, Zr). The vast majority of the Eburnean plutons are characterised by negative Nb-Ta anomalies, marked Pb positive anomalies, and high LILE/HFSE ratios. This onset of such voluminous magmatic input into the crust is correlated with a switch to transpressional deformation D_{2S} (bulk incremental deformation under NW-SE- to NNW-SSE-directed shortening). The later deformation event was associated with the formation of a spaced axial-planar cleavage, interference patterns, and ultimately sinistral strike-slip along discontinuous, low-displacement, brittle-ductile NNE-striking faults synchronous with economic gold mineralization.

When integrated with published data for the Kédougou-Kénieba inlier, the results of this study indicate (1) an evolution from primitive arc magmas to increasingly evolved high-K calc-alkaline granitic melts as a result of crustal thickening during the Eburnean orogeny combined with fractionated crystallisation and melting-assimilation-storage-homogenisation processes;

(2) intermediate to felsic volcanism and batholith emplacement in the Falémé area at ca. 2080 Ma likely mark the transition between compressional and transpressional deformation;

(3) the late Eburnean tectono-thermal event between ca. 2080 and 2060 Ma is proposed as the geodynamic engine that empowered gold mineralization in the Kédougou-Kénieba inlier.

The Eburnean Tinguicht pluton (Yetti domain, Algeria), emplacement evidenced by geological and geophysical data

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The Tinguicht pluton is part of the 2.07 Ga post-collisional magmatic suites that intruded the Yetti Paleoproterozoic volcano-sedimentary series of the western part of the Eglab Shield (West African Craton). It represents one of the most recent units of these suites. The deformation of the structures is restricted to fracturing and faulting practically in this NW-SE elliptic and unfoliated pluton.

New geological and geophysical (structural, microstructural, magnetic and aeromagnetic) data are shown in order to analyze the relationship between the Eburnean Tinguicht pluton emplacement and the related NNW-SSE major mega-shear zone, separating the Yetti and Eglab domains, in particular. A structural analysis was performed by mapping the magnetic structures (foliation and lineation) using AMS to constrain the context of the regional post-collisional evolution of the Eglab shield. The combination of the results of all the used approaches leads to a new and enriched image of this granitic pluton and of its tectonic emplacement context. The elliptic shape of the granitic body and the AMS strain pattern are consistent with the presence of a NNW-SSE major structure. This direction is also one of the major directions highlighted by the aeromagnetic data.

This study thus evidences the role of the pre-existing major shear zones in controlling emplacement of post-collisional Paleoproterozoic plutons like Tinguicht, as shown for Drissa pluton in the Eglab domain earlier.

The implication of early architecture for gold endowment in a low strain environment; the Yaouré orogenic gold deposit, Côte d'Ivoire

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The 1.5 MozYaouré gold mine is located in the Bouafle greenstone belt in central Côte d'Ivoire. The low aspect ratio of the belt area where the deposit occurs contrasts with the NE-SW trending acuate Birimian granite-greenstone belts of the West African Craton. Country rocks in the Yaouré area occur in a poorly-deformed to undeformed state. Field data indicates that strike-slip faults bounding a 10km-scale intra-belt basin acted as key controls on the structural geometry of the gold deposit.

Gold mineralization at Yaouré is polyphased. It first occurs within a conjugated set of strike-slips following the same orientations as the margins of a volcano-sedimentary basin present north of the deposit. These orientations are also borrowed by calc-alkaline dykes, emplaced prior to shortening. A second mineralized event is marked by a thrusting episode crosscutting strike-slips, within which mineralization occurs as an 'en echelon' vein array associated with low to no displacement. The geometry and the kinematics study of the thrusts support a bulk incremental deformation under low differential stress leading to multiple slip increments and episodic fluid discharge. Although strike-slips and thrusts display different timing and hydrothermal alteration styles, they both developed during an EW shortening event that corresponds to the regional belt main shortening event.

This study presents an unusual orogenic gold mineralization setting in a poorly studied area and highlights the importance of early extensional tectonics as a controlling factor for the location of orogenic gold mineralization.

Architecture and petrography of syn-D₂ Eburnean granitoids: example of Massawa and Sofia deposits (Kanoumba permit, Kedougou Inlier, Senegal)

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The West Africa Birimian terranes has been interpreted as polycyclic evolution resulting of a collision phase (D₁) followed by transcurrent phases D₂ and D₃ described as regional sinistral and dextral shears zones postdating eburnean granitoids (Ledru et al., 1989, 1991; Milesi et al., 1992).

The area of study is located between the Mako volcanic belt and the Diale-Daleme Basin separated by the Main Transcurrent Shear (MTZ). It hosts two orogenic gold deposits (Massawa and Sofia) delineated by two major structures: the NE trending MTZ and the Sabodala Shear zone (SSZ). Massawa deposit is located along the MTZ where andesitic to dioritic rocks with various

volcanosedimentary to sedimentary formations are dominantly cropping out. Sofia deposit is located nearby the SSZ which constitutes its western limit, the lithological context are represented by basaltic and ultramafic rocks.

The study has highlighted a new structure parallel to this MTZ with 50 m average thickness and delineating a NE tuffaceous horizon intruded by sub-rounded to rounded granitoids. The western and eastern limits of this major accident are marked by coeval injections of felsic rocks. The detailed analysis of this structural interface shows that the main shear zones, foliations and lineation trend NE to NNE parallel to the MTZ. Additional ENE-WSW foliations network has also been identified. The schistosity shows two main directions NE and NW. Fold axis and axial planes are NS and NE to NW oriented, respectively. The general behavior of the structural interface could be related to the D₂ phase characterized by NE-SW to NS subvertical foliations associated with asymmetric folds and stretching lineation parallel to the axial planes of the fold.

Granitic plutons with different shapes, sizes and compositions appear concordant or discordant to the MTZ. The Tinkoto pluton is a concordant and locally elongated shape of leucocratic granodiorite to monzogranite composition with a grainy and equant texture associated with rare pegmatites. It is associated to other small intrusions all arranged along the MTZ accident. The Dioudioukounkou is a NS elongated granodioritic pluton with a notable modal composition of potassic feldspar and platinum anomalies.

Dioudioukounkou and Tinkoto plutons affiliated to the Mako volcanic belt are dated between 2082 Ma and 2076 Ma (Hirdes and Davis, 2002; Gueye et al., 2007, 2008). They exhibit a variety of geometric and petrographic characteristics suggesting differences in their context of emplacement. Dioudioukounkou associated to Sofia deposit is supposed syn-D₂ and Tinkoto associated to Massawa deposit could be late D₂ to D₃ related.

Keywords: Syn-D₂, MTZ, SSZ, granite, Massawa, Sofia, Kedougou

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Petrographic and geochemical characterization of the Archean fine granitoid: Example of the Bakoudou gold deposit in Gabon

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The Bakoudou gold deposit is located in southeastern Gabon in the province of Haut-Ogooué, specifically on the Chaillu Massif about 700 km south-east of Libreville, 40 km south of the village of Bakoumba and 60 km southwest of Franceville. It is hosted in granitoids belonging to the Archean basement of the Chaillu massif, and dated between 2880 Ma and 2550 Ma (Caen-Vachette et al., 1988; Prian et Johan, 1989; Thomas et al., 2001; Chevallier et al., 2002; Bouton et al., 2009; Thiéblemont et al., 2009). These granitoids have a large lithological diversity due to the existence of several plutonic episodes (Prian et Johan, 1989; Thomas et al., 2001; Chevallier et al., 2002; Bouton et al., 2009).

The petrographic study of granitoid Bakoudou allowed us to distinguish three facies of rocks namely the gray granitoids (quartz diorite and granodiorite), with the same mineralogical composition consisting of plagioclase, hornblende, biotite, quartz, low potassium feldspar, accessory minerals (zircons, apatite) and opaque minerals. The leucocratic porphyry pink granitoid (granite) is composed mainly of plagioclase, potassic feldspar, quartz, biotite, accessory minerals (zircons, apatite) and opaque minerals. The evolution of quartz diorites to granites results in a decrease in plagioclase and amphibole levels, and a progressive increase in the quartz and potassium feldspar content.

The geochemical study (major, trace and rare earth elements) of our samples allowed us to show that the granitoids of Bakoudou are magnesian rocks, calc-alkaline to calcic. They have a moderately potassic calc-alkaline affinity, with meta-aluminous to weakly hyper-aluminous character. All these rocks show geochemical signatures of volcanic arc granitoids, which implies their formation under the influence of a subduction zone.

The evolution of the chemical compositions in major, trace and rare earth elements, as well as the petrographic data allow to conclude that the studied rocks come from the same source of mantle magma with a probable crustal contamination, and that the links between the different facies are governed by fractional crystallization processes.

Keywords: Gabon, granitoid, Bakoudou gold deposit, geochemistry, petrography

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Veins generations and associated gold deposition in the Bonikro deposit, Fettekro greenstone belt, Côte d'Ivoire

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The Fettekro greenstone belt is one of the most productive gold belts in Côte d'Ivoire. In its southern part, the intensive exploration through this Birimian belt has revealed the gold deposits of Agbahou, Bonikro and Hiré aligned in a linear distance of 40 km, thus, forming the Oumé-Hiré gold district.

The Bonikro gold deposit presents three lithological units: the mafic volcanic unit of basaltic to andesitic composition in the East, the westerly volcano-sedimentary unit made of shales, siltstone and pyroclastic lavas (basaltic to dacitic) and the felsic plutonic and dykes made of granodiorite, pegmatite, acidic lava and aplite in the center of the deposit. The deposit is dominated by a major structure: the Bonikro Shear Zone (BSZ).

The strong hydrothermal activity occurred in Bonikro can be observed by the sericitisation, the silicification, the chloritisation, the albitisation in the granodiorite and also the presence of three veins generations: sheeted, planar and transversal.

The sheeted veins are earlier: thick (1cm) and sub-parallel sets of quartz and feldspar veins: milky quartz (70 to 80%), albite (5-10%) scheelite (up to 15%) and pyrite (up to 5%). They are characterized in the granodiorite by the fluorescent scheelite. Most of the deposit visible gold is located in the sheeted veins. The planar veins support the powellite minerals. The transversal veins are late and composed of: milky quartz (40%), calcite (30%), albite (10%), biotite (15%), and sulfides (molybdenite up to 5%). The molybdenite is the principal sulfide here. Each vein has its minerals and resumes a generation of setting.

The sheeted veins have not been notified in other Côte d'Ivoire gold deposits. These veins are known in Canada and Australia with the scheelite as the main mineral. These veins have been evoked to explain the gold deposition process in these areas and to give to the intrusive, a possible primary source of the metal. In Bonikro, each singular vein is associated with stages of gold deposition.

Keywords: Birimian, gold, Bonikro deposit, sheeted veins, Fettekro greenstone belt.

Kinematic of shear zones from central Burkina Faso (West Africa) using anisotropy of magnetic susceptibility and microstructures

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In the Palaeoproterozoic terranes of west Africa, the great lineaments are always considered as transcurrent faults. The present study is focused on these transcurrent faults over three areas of Burkina Faso (Kaya, Ouagadougou and Pô) with a total surface around 36300 km². These terranes are mainly composed of low grade metamorphic rocks also call greenstones, a first generation of granitoids with TTG affinity and a second generation of granitoids (calc-alkaline granites, alkali-granites and syenites). Using magnetic fabrics from anisotropy of magnetic susceptibility (AMS) measurements on granitoids, the following main conclusions can be drawn. The orientations of the AMS fabrics and microstructures allow to distinguish:

- Transcurrent shear zones in the strict sense,
- Transpressional shear zones and,
- Shear zones with predominant flattening.

Examination of microstructures show that along some of the shear zones, rocks acquire their fabrics at solid state (high or low temperature). This observation shows that these rocks were emplaced before or during the shearing. The other rocks which display a magmatic fabric were probably emplaced after the shearing. In these conditions, microstructures constitute an excellent criteria for relative chronology.

Keywords: lineament, transcurrents shear zone, fabric, AMS, microstructure

High-resolution landform-regolith mapping in a greenstone belt context of the Soudanian zone: Implications to mineral exploration

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We present a new protocol of high-resolution landform-regolith mapping that takes into account the specificity of West African morpho-climatic context and allows for the definition of new soil geochemical exploration criteria. Particular attention was given to glaci/pediments that are transportation slopes occupying an overwhelming part of the subregion. The map is based on extensive fieldwork and complementary photo-interpretation. Field mapping was undertaken at 1:10 000 scale on the basis of Lidar data converted into topographic sheets with 1 m contours. Twenty map units have been defined that are grouped under four main types of landform-regolith association. The first type relates to the relicts of the West African paleo-landscape sequence: (i) paleo-landscape relicts with their pristine capping duricrust (bauxite and/or ferricrete), (ii) paleo-landscape relicts from which the duricrust cap was stripped-off, (iii) erosional paleo-landscape relicts exposing an earlier regolith that it contributed to exhume and (iv) residual

hills resulting from the degradation of the paleo-land surfaces. The second type comprises recent erosional landscapes exposing various types of material: (i) bedrock and saprock, (ii) saprolite, (iii) various weathering horizon(s) under scree-capped slopes and (iv) lithosoils. The third type comprises functional land surfaces and their clastic sedimentary overburden in transit: functional pediment/glacis and alluvial fans. The fourth type corresponds to accumulation landforms that are represented by alluvial terraces along the main mature river drains.

Given the nature of the regolith exposed by each landform-regolith map unit, the twenty map units have been grouped into four categories to produce a soil prospectivity map. This map aims to help interpreting soil geochemical surveys and targeting favourable sampling sites where the regolith is still linked to its underlying parental bedrock. Apart from being key for interpreting surface geochemical anomalies, such maps should further help locating unsuspected resources (concealed under transported regolith) and targeting areas of potential supergene concentration of metals.

Effect of kaolinite amendment on rice tolerance to iron toxicity

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Shorted accesses to the industrial silicon for the control of iron toxicity in the rice-growing is limiting this farm practice whatever efficient however. Hence, the opportunity is to explore kaolinite (54.7% SiO₂) potential as a natural and cheap source of silicon for rice growing. Pot experiment was set applying 900 ppm of iron in 5 kg of sand as substrate before applying five treatments of kaolinite (T0 = 0 kg kaolinite/ha, T1 = 366 kg kaolinite/ha, T2 = 1735 kg kaolinite/ha, T3 = 1097 kg kaolinite /ha and T4 = 1465 kg kaolinite/ha) in a randomized complete block design with five repetitions.

The results show kaolinite improvement effect in rice growth and the development of root stuff under iron toxicity condition (900 ppm Fe). The evidence of the root stuff development was shown by the increasing of length (16-20 cm) with the treatments T3 and T4 against 12 cm observed in treatment T0. Microscopic observation of the rice roots showed an increasing of the number of root ramifications consequently to kaolinite level. Only primary ramifications were observed in T0 when secondary and tertiary ramifications were observed with the treatments T3 and T4. In consequence, the grain yield was accordingly in the range of 4.25 t/ha (T0) and 8.69 t/ha (T4).

Therefore, the research recommends the kaolinite as sustainable way of iron toxicity management with the dose 1465 kg of kaolinite/ha corresponding to 800 kg of SiO₂/ha.

Hydrocarbon Potential Evaluation of Albian Shales from Offshore Benin Basin (Benin, West Africa)

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By concentrating more than 5% of the world production, the Gulf of Guinea is, since 1980, one of the key points of the world oil exploration. In this oil province, the Albian Formation has an oil interest and has a regional distribution in the basins of Tano (Ivory Coast), Saltpond (Ghana), Togo, Benin and Adje field (Nigeria). The offshore of the Benin coastal basin is at the heart of this great oil province and from this point of view arouses a proven interest. Lithostratigraphic and oil drilling data led to the evaluation of the hydrocarbon potential of the Albian parent rocks in four wells (R23, R24, G20 and G21) of the offshore part of Benin coastal basin. These Albian source rocks are represented by black shales. Indeed, the unnamed "Albian Training" consists of marine sandstones and shales with some organic-rich black shales and minor limestone. The shale contains 300m in deep water. Maturity (R_o and T_{max}) and petroleum potential assessment (TOC and Rock-Evalpyrolysis) analyses enabled the characterization of 165 rock samples (cuttings and swc). The results of these analyses have (1) revealed that these source rocks contain Type II/III and Type III kerogens and are all mature with varying levels of maturity (R_o data between 0.69 and 1.10; T_{max} between 434°C and 465°C); (2) showed that these parent rocks are rich in organic matter (TOC data between 0.51 and 5.32%) and have medium to excellent oil potential (S_2 data between 0.5 and 11.06 mg HC/g rock); (3) led to the realization of four geochemical logs. These logs constitute a determining stage towards the realization of the geochemical charts aiming to determine the geographical and stratigraphic extension active portions of source rocks. The attempts oil-oil and oil-source rock correlations based on the analysis of the geochemical ratios of markers (CPI ; Pr/Ph ; Pr/nC17 and Ph/nC18) did not allow to specify the origin of these oils but with all the same contributed to differentiate analyzed oils. Some complementary analyses by methods Gas Chromatography/Mass Spectrometry (GC-MS) will contribute to precise these correlations in order to reduce the risks of oil exploration.

Keywords: Offshore Benin Basin, Albian shales, hydrocarbon potential, geochemical markers

Contribution to the knowledge of the Doropo region geology in North-Eastern Côte d'Ivoire (Ampella-Centaminlicence)

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The Birimian terranes of the West African Craton (WAC) is composed of granitoids and greenstone belts and represent an attractive target for mineral exploration. Unfortunately, these areas are very often affected by intense weathering surface which hinders geological field mapping and structural studies. This is the case of the Doropo region in north-eastern Côte d'Ivoire, where very little geological work has been done outside the exploration activities carried out by Ampella-Centamin. In order to better understand the geology of this region, two research projects have been initiated. One develops the Birimian litho-structural framework in this part of Côte d'Ivoire by combining satellite and geophysical images (aeromagnetic and radiometric) with field

observations in a Geographic Information System. The other studies the geodynamic context of these formations as well as their period of implementation using geochemical and geochronological data. We present here the preliminary results of the litho-structural study.

The petrographic study of the region identified: biotite granite, pink granite, migmatitic granite, amphibole granodiorite, diorite, dolerite and amphibolite. In the field, granite and granodiorite outcrops are intersected by pegmatite veins. Biotite granite remains the most common formation and is observed throughout the study area. Pink granite occurs in the Kodo and Kakota areas. Granodiorite is found in the Taboura and Gbabédjou sectors where it outcrops in the form of domes or as an enclave in biotite granite. The main ferromagnesian minerals in this rock are biotite and green hornblende. The diorite outcrops in contact with the biotite granite. Dolerite dyke has only been encountered in core samples from diamond drilling. Concerning amphibolite, it is always in enclave either in granite or in granodiorite. It is found in the areas of Kakota, Gbabedjou and Lagbo-Danoa.

The teleanalytical study of Landsat8 OLI images has produced a linear map showing the major orientations NW-SE and NE-SW. In the field, the data collected identified fractures, both dextral and sinistral strike-slip fault, shear bands, sigmoid, folds and stretching lineation. All these structural elements attest that the Doropo region formations are affected by a predominant brittle and ductile deformation.

Keywords: Geology, structural, Doropo, Landsat8 OLI image

Geoelectric study of aquifer system. Case of localities of Dabakala (North of Ivory Coast)

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This work aims to study the geometric characteristics of basement aquifers, from electrical geophysics, in order to determine their hydrogeological functioning. This study is being conducted in some localities in Dabakala (northern Côte d'Ivoire), where access to drinking water is most often problematic. First, it consists to identify the fracture networks and the weathering profile of the basement, from the parallel profiles of resistivity and from the interpretation of the electrical sounding curves, respectively. Then, to study at the local scale, the geometric characteristics (weathering thickness, orientations, dip and depth of fractures) of the aquifer system. Finally, to study the hydrogeological functioning of these aquifers. The latter consists in relating, firstly the position and the orientation of the fractures with the existing watercourses and, on the other hand, the depth of the fractures observed on the curves of sounding with that of the water arrivals in the existing drillings. The analysis of parallel profiles highlights several lines of fractures of various orientations. These are in conformity with those met in the basement of the Dabakala department. The NE-SW and NW-SE accidents are the most represented and correspond to the Birimian and Liberian directions, respectively. NS and EW fractures are also identified. These geological accidents show a subvertical dip and in their extension intersect streams near the prospected zones. Their functioning is therefore linked to that of surface water. Electrical soundings have shown that the thickness weathering rarely exceeds 20 m. The depth of fractures

identified with the electrical soundings correspond to the different water arrivals observed with the previous drillings.

Keywords: Geophysics, resistivity profile, electrical survey, aquifer, Dabakala

Introduction to Birimian volcanology

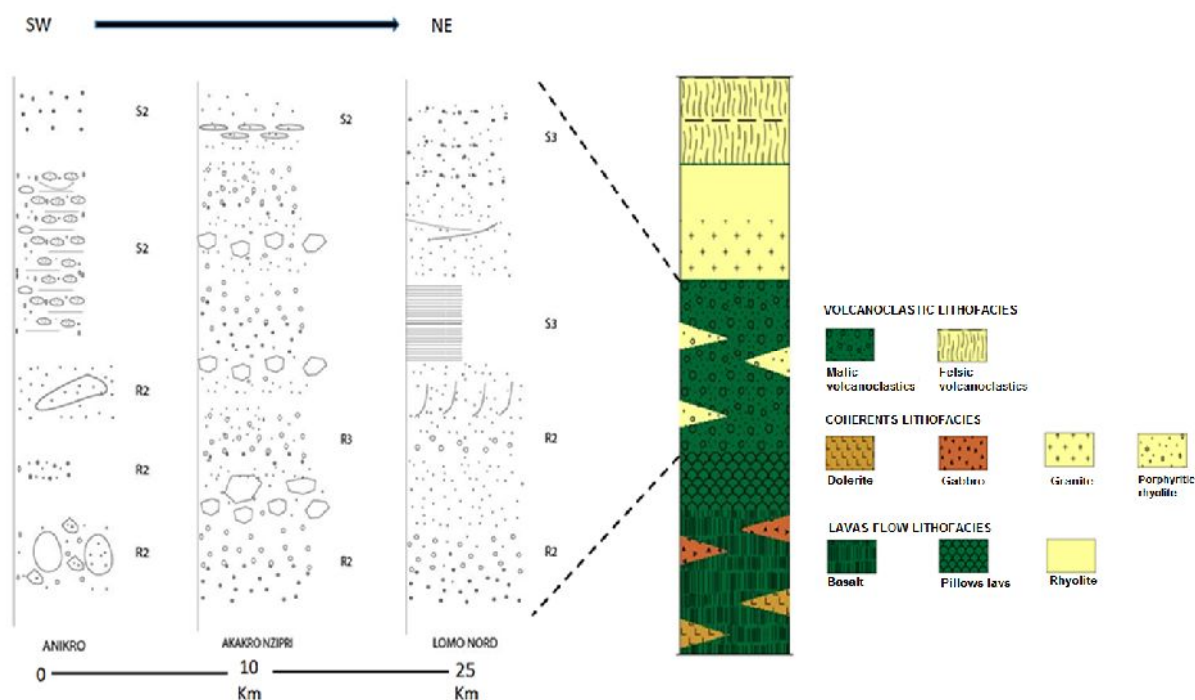
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Geodynamic models have listed ideas that the Birimian Gold Province is the result of subduction or rifting. The authors who have worked in this field have all shown the great diversity of formations that abounds the Birimian. In their studies, they just reported the presence of mafic volcanics without giving more information about their origin. It is for this reason that this study was conducted to determine their origin. To do this, we used cartography, macroscopic and microscopic petrography and sedimentological analyses. All this has made it possible to define five lithofacies that are the coherent mafic and coherent felsic facies, the lava flow facies, the felsic volcanoclastic and volcanosediments and the mafic volcanoclastic facies. The facies of mafic volcanoclastics consist of pyroclastic fallout deposits, avalanche deposits, hyperconcentrated debris flow deposits and also river deposits. These formations would constitute the avalanche phase during the slide during the collapse stage of a volcanic structure. They are therefore epiclastics.

Keywords: Fettékro, Birimian, avalanche debris, collapse, epiclastic, volcanoclastics



Geodynamic evolution of Eburnean rocks in southern Côte d'Ivoire

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To understand the geodynamic evolution of the Eburnean, our investigations focused on the volcano-sedimentary rocks, as well as the granitoids of the Comoé Basin and its surrounding. Geochemical analysis revealed tholeiitic volcanic rocks, sedimentary rocks from the erosion of a granitoid-migmatitic basement, and granitoids containing crustal and mantle components. Four deformation events (D₁-D₄) can be distinguished in southern Côte d'Ivoire. Crustal thickening, which occurs during phase D₁, led to the emplacement of syntectonic plutons. D₂ is also accompanied by a significant contribution of granites and granodiorites rich in biotite and sometimes amphibole. D₃ and D₄ are late stages and responsible for crenulation cleavage and dolerite dykes, respectively. Regional greenschist to lower amphibolite facies metamorphism, locally contact metamorphism and intense folding characterize Eburnean deformation phases. The data synthesis indicates steep lineations promote diapiric and vertical tectonic movement. Sagduction is the major tectonic mechanism that is more consistent with the granitoids of the study area in particular and with Archean and Proterozoic formations. The tectonic structures observed in the region are related to the convergence between two thermally different lithospheres, a weak and warm juvenile crust and an Archean craton.

Keywords: Côte d'Ivoire, Comoé Basin, Eburnean orogeny, sagduction, convergence

Metallogeny of the South West African Craton: a mineral system approach

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Mineral deposits are a local manifestation of a range of earth processes that take place at different temporal and spatial scales (e.g. [McCuaig et al., 2010](#)). At the lithospheric scale geodynamic process and associated lithospheric structure is now commonly proposed to apply a strong control on metal endowment of mineralised provinces ([Begg et al., 2014](#)). Increasing high-resolution geochronological constraints on ore deposits further suggest that deposits form during a very narrow time interval during a prolonged geodynamic evolution suggesting a transient regional scale geodynamic setting (i.e. tectonic plate reorganisation), geodynamic transition from long compression period to a period of transcurrent tectonics ([Goldfarb et al., 2005](#)). At the regional scale, inferred basement architecture is proposed to apply a multi-scale control on mineralised

camp localisation. Often cryptic in the rock record, spatial and temporal mapping of fluid pathways (magmatic and hydrothermal) may be targeted indirectly through deciphering the lithostratigraphic record.

Similar to most Precambrian Terranes, the South West African Craton (SWAC) exhibits a protracted tectonic evolution of which only the latest structural increment is preserved. An insight into the early stages the SWAC formation may however be gathered through careful lithostratigraphic analysis and correlations of its supracrustal cover. Despite numerous studies of the SWAC the regional scale, lithostratigraphic sequence remains largely unconstrained (e.g. Abouchami et al., 1990). The unconstrained lithostratigraphic column has led to uncertainty over the nature and timing of the tectonic processes at play at the time of mineralisation. The lithostratigraphic compilation derived as part of the WAXI2 research project allows for craton wide lithostratigraphic compilation that may be used to assess the tectonic evolution of the SWAC (Davis et al., 2015).

As an outcome of this investigation it is suggested that the lithostratigraphic record deposited between ca. 2300 and 2050 Ma can be correlated and mapped across the entire SWAC. Within this framework it is possible to identify distinct depositional cycles, which allow for further our understanding of the tectonic environment associated with the SWAC development. Within this time period, major breaks in the lithostratigraphy are observed to occur at ca. 2180, 2150, 2115 and 2100 Ma.

The period from ca. 2180 to 2150 Ma represents the first major change, with the cessation of tholeiitic to calc-alkaline volcanism. Basalts are replaced, on a domain wide scale with intermediate-felsic extrusive lavas and pyroclastic deposits; this is indicative of the beginnings of convergent tectonic setting.

The second major event recognised in the stratigraphic record is the cessation of volcanism at ca. 2150 Ma and the onset of large scale/massive sedimentation. This boundary is observed across the domain. Initially reworked volcanic material dominates before grading into thick sequences of greywacke at ca. 2130 Ma. This represents the amalgamation of arc-like domains followed by their uplift and erosion leading to the formation of large sedimentary basins.

The third major event recognised across the craton is the deposition of late basins at ca. 2115- 2097 Ma (e.g. Tarkwa). The deposition narrow elongate basins, and short depositional window are indicative of a change in the regional tectonic over the deposition of the greywacke basins that precede it.

The restart and shift in volcanism to the western Baoule-Mossi domain at ca. 2100-2070 Ma represents a fourth major stratigraphic, and first major diachronous geological event in the Baoule-Mossi domain.

Finding its foundation in the concept of mineral system approach and taking examples ranging in scale from craton to deposit scale, this study demonstrates how the development of a unified lithostratigraphic analysis may provide tools for the development of a metallogenic model critical to support mineral exploration strategies.

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Occurrence of some dinokyst within the subsurface gray clays of Upper Maastrichtian to Danian (K/PG) in the region of Eboinda: implications for palynostratigraphy, paleoenvironment and paleobiogeography

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Upper Maastrichtian to Danian (K/PG) sediments from the Eboinda region (south of Côte d'Ivoire), are here subject of lithographical, palynological (palynostratigraphy, palaeoenvironment, paleogeography) studies. Marine dinocysts assemblage and terrestrial pollens and spores, relatively more abundant, are well preserved in the sections. The marine dinocysts include diverse species of the genera *Dinogymnium*, *senegalinium*, *andalusiella* and spiniferites. operculodinium, homotryblum, damassadinium, cerodinium, andalusiella. A Maastrichtian age is suggested for the subsurface gray clays facies in the study area based on LAD of *Dinogymnium acuminatum* and *Cerodinium granulostriatum*. The assembly of the Danian is determined in the sections through the bioevents of dinocysts; the LAD of *Cerodinium diebelli* and the presence of the *Damassadinium californicum* species. The preponderance of the group of the peridinieae and fibrocysta indicate that the sedimentation of Upper Maastrichtian was done in an inner neritic environment with a large productivity. In the Danian, the predominance of the group of the gonyaulacoids and fibrocysta suggest neritic environment inner to external with low productivity, and with relatively high salinity as that happens in open sea. According to Lentin and Williams (1980), quantitative analyses of dinoflagellate cysts attributed deposits to a paleogeography tropical to subtropical province.

Keywords: Upper Maastrichtian-Danian, palynology, dinoflagellate, Eboinda area

New SHRIMP-U-Pb zircon ages of the Paleoproterozoic metasedimentary and plutonic rocks of the Massigui Square Degree (Southern Mali)

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The Massigui square degree, situated in Southern Mali, is located to the NW of the Man Shield, southern West African Craton (WAC), which is made of an Archean domain to the west (Kénéma-Man domain) and a Paleoproterozoic domain to the east (Baoulé-Mossi domain). Through its proximity to the Archean craton, it is a key area for understanding the amalgamation of these two components of the WAC.

The Massigui region consists of Birimian volcanosedimentary sequences intruded by large Eburnean magmatic intrusions ranging in composition from diorite to monzogranite, through monzodiorite, monzonite and granodiorite. The volcanosedimentary sequences are mostly made of biotite \pm muscovite quartzofeldspathic metasediments, in which felsic metavolcanic levels are intercalated. The metasediments are made of metagreywackes, metapelites, schists and locally micaschists. The metagreywackes contain amphibole and garnet, and can be rich in microcline and contain locally pinnite. They differ from the metapelites by the size of grain and the proportion of the matrix. Metavolcanic rocks are usually metadacites and metarhyolites. Metamorphism reached upper greenschist facies, and amphibolite facies close to large plutonic bodies or within the Banifing Shear Zone (BSZ). The Massigui region is transected by a large NE-SW oriented shear zone that extends for hundreds of km and referred to as the BSZ.

New SHRIMP U-Pb geochronological data were obtained from five samples of plutonic rocks and three samples of metasedimentary rocks of the Massigui Square Degree (MSD). Zircon SHRIMP U-Pb ages of granitoids and dioritoids indicate a major period of magmatic activity at c. 2100 Ma (Massigui quartz monzodiorite: 2112 \pm 5 Ma, granodiorite: 2103 \pm 5 Ma, pink quartz monzonite: 2095 \pm 9 Ma; Syobougou quartz microdiorite: 2102 \pm 10 Ma; Tiéfala foliated quartz micromonzodiorite: 2106 \pm 11 Ma). SHRIMP U-Pb ages of detrital zircons show that the sources of the sediment are exclusively Birimian, with three well-defined detrital ages at 2125 \pm 8 Ma (22% zircons), 2148 \pm 6 Ma (28%) and 2215 \pm 13 Ma (14%).

The combination of new data with historical datasets provides a useful opportunity to refine time constraints on the source and the tectonic context of the MSD as well as derive constraints toward a geodynamical model for this Birimian segment and the Eburnean orogeny.

Keywords : Massigui, U-Pb, zircon ages, SHRIMP, metasedimentary rocks, plutonic rocks, southern Mali

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Water resource and sustainable development in Ivory Coast

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The aim of this study entitled is to understand if the management of groundwater resources in the Ivory Coast can contribute to the sustainable development. Bibliographic, demographic studies completed and interviews have been performed to collect data from the quantity and quality of groundwater in Ivory Coast. A correlative study has allowed assessing the effect of human activities coupled with the new climate change on the quantity and quality of water resources throughout the Ivorian territory. This territory is divided into two hydrogeological provinces: the discontinuous aquifers (97% of the territory) and the continuous aquifers (3%). These two domains totalizes 37.7 billion m³ of groundwater resources compared to only 29 billion m³ of surface water. These groundwater resources, which are essential for the economic, social and cultural development of Ivory Coast are strongly impacted by the combined action of the new climate and human activities. Indeed, the problems identified are: (i) degradation of surface water quality and excessive extraction of groundwater; (ii) extraction of groundwater by drilling without administration authorization; (iii) lack of funding for deepening knowledge of groundwater resources; (iv) sanitation problems in cities; (v) extraction of sand from the Ebriélagoon; and (vi) recurring floods that reduce the quantity of groundwater and degrade their quality. According to these results and the objectives defined by the [Council of Canadian Academies \(2009\)](#), it can be noted that the environmental and human conditions in Ivory Coast do not militate in favor of sustainable management of groundwater.

Keywords: Groundwater, sustainable development, Ivory Coast, climate change, human activities

Evolution of the dissolved oxygen content of water during the Coniacian-Santonian interval from the KM well of Côte d'Ivoire

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The study of foraminifera recovered from 38 cuttings samples from KM well (Côte d'Ivoire sedimentary basin) allowed to describe the paleoenvironment of the interval 2074 m to 1687 m. the samples yielded 258 foraminifera specimens with 32 planktonics (12.4%), 92 agglutinated foraminifera (35.66%) and 134 calcareous benthic (51.94%). Coniacian-Santonian interval was dated by the first occurrences or last occurrences of planktonic foraminifera. The base of this interval is

characterized by shallow water and oxygen-poor habitat. The top is marked by deep marine conditions with an increase in dissolved oxygen causing microfossils proliferation both on the bottom and in the water column.

Keywords: Foraminiferous, paleoenvironment, Coniacian-Santonian, Ivory Coast