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Dynamic interaction in tropical Africa: IGCP-616Y and IGCP 646 projects and events

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The scientific objectives and research program of the IGCP-646 project (2015–2018) cuts across many disciplines and includes various aspects of continental basement geology, resource exploration (mineral, water and hydrocarbons), geohazard mitigation, and climate change, all of which are of critical importance to developing countries, particularly in parts of West Africa where population pressures are on the rise. Considerable emphasis was placed on capacity building, creation of opportunities for young scientists to undertake higher degrees programs, knowledge transfer and training. The SIDA-funded “pilot project” IGCP-616Y (started in 2012), focused on three objects (i) crustal architecture, tectonic evolution and regional geology of Central Africa and the connection with NE Brazil; (ii) the Mesozoic continental rifting and breakup leading to a better integration of the onshore and offshore geology; (iii) clarification and quantification of the links between basement structures, neotectonics, climate change and landscape evolution. The IGCP-616Y and IGCP-646 projects consisted of over 250 researchers, from different countries. In the course of the projects, six annual meetings, four field trips/workshops, as well as several training sessions were organized. Here we provide a summary of the scientific targets of the projects and a summary of the organized activities.

Introduction

At the northern border of the Archean Congo-craton, regional Pan-African strike-slip shear zone and associated compressional structures such as thrust, folds and foliations (Kankeu et al., 2012; Danguene et

al., 2014) point to a complex transpressional tectonic evolution perhaps involving zones of pull-apart which allowed the ascent of the magma/granitoids into an original Gondwana context. The regional significance and the genetic links between the geodynamic processes that form the belt and primary ore formation are still to be clarified. The location, type and evolution of the Mesozoic-Cenozoic fault-bounded sedimentary basins of central Africa Rift Systems (CARS) more or less rich in oil and gas resources (Izuchukwu et al., 2009a, b) have been controlled by tectonic activity accompanying the rifting and separation of West Africa from Brazil and the opening of Atlantic ocean during the Cretaceous. Further work is needed to document continuous tectonic activity accompanying the rifting and better integrate onshore and offshore geology on both sides of the Atlantic. Within plate Cenozoic magmatic activity along the Cameroon Volcanic Line (CVL) is also largely determined by the reactivation of early formed lithospheric structures. How deep Precambrian structures do reactivate, the manner of the reactivation and its precise influence on later structural development are still controversial. More recent earthquakes in west and central Africa appear to be spatially related to the pre-existing Pan-African shear zones which may thus be in a state of continuing-reactivation and therefore, zones of potentially high geological risk both for people and for infrastructure. The spatial association of historical and recent earthquakes and pre-existing lithospheric structures still a matter of debate.

Differential vertical movements at both regional and local scale may have resulted in landscape instability and rapid geomorphic evolution. This is associated with significant changes in tectonic topography and landscape evolution. Unfortunately the interrelationship of basement structures, neotectonics, paleoclimatology, and landscape evolution is still somewhat ambiguous. There is also widespread evidence and recognition that fluctuations in climate affected regional environments in central Africa by modified rainfall and hydrological characteristics resulting in heavy rainfall, landslide, flood and drought,

aggravated by urban development, roads and agricultural activities including livestock and farming up the hills. The degree and extent of regional or local climate fluctuation/change and its influence on weathering depths and decomposition of rock make options available to population poorly known.

The long and short-term dynamic interaction between basements studies, active tectonics, climate change, landscape evolution and sustainable management of scarce natural resources like water and oil remain poorly constrained in west and central Africa as they might be in other parts of the world. The project aimed to maintain the existing team built upon precursor IGCP-616Y project and to continue the multi-disciplinary investigations on crustal architecture, clarify and quantify the link between basement studies, neotectonics, climate change, and landscape evolution. The aim was to exploit existing interest and activity and especially work to involve more isolated scientists and teams, fill the remained gaps and introduce all previous and new data into a single holistic pattern of dynamic interaction in tropical environment.

IGCP-616Y and 646 Working Group

The number of participants of the IGCP-616Y and IGCP-646 projects increased regularly from 36 in 2012 to 256 in 2018 (from 15 countries). A significant part of the participants to the activities of IGCP-616Y and IGCP-646 consisted of young researchers from developing countries. The gender ratio was skewed towards males (2/1). During the duration of the projects, several annual workshops were organized, including when possible, a combination of (1) scientific sessions (poster and oral presentation), (2) fieldwork campaigns with support from local mining companies, (3) post-conference fieldworks and (4) training course and/or field school. The training courses focused on “modern field and laboratory-based techniques” applied to geosciences. The main objectives of the field school were to (i) address the gap in much of western and central Africa between the growing demand for highly trained geoscientist and researchers on one hand, and the extremely limited capacity in the field of geosciences on the other hand, (ii) upgrade geoscience training through specialized programming that involves education and research with emphasis on high tech methods and instrumentation (GPS tracking, AMS sampling, Remote sensing ground thrusting), (iii) provide young geoscientists and students with exposure to field geoscience. Numerous peer-reviewed papers were published.

The IGCP-616Y/646 official websites (www.igcp616Y.org/www.igcp646.org) contain all information about the projects, participants, meetings, field trips, and publications. It also includes the abstract volume of the IGCP-616Y and 646 meetings, field trip guide books, photo gallery, annual reports and annual assessment by IGCP Scientific board.

IGCP-616Y and 646 Events, Activities and Achievements

2012-Opening Year-IGCP/SIDA 616Y Launching Field Meeting and Workshop in Yaoundé, Cameroon

The launching field meeting and workshop of the SIDA-supported



Figures 1. (a-b) 2012, First IGCP 616Y meeting in Yaoundé, Cameroon. (a) conference photo taken in the Goethe Institute in which the meeting was held. (b) post meeting field trip in the Archean Ntem complex which represented the northern part of the Congo Craton. (c-d) 2013, Second IGCP 616Y meeting in Yaoundé, Cameroon, (c) Group photo taken in front of the Center for German African scientific Cooperation in which the meeting was held. (d) post conference field trip in the Neoproterozoic pan-African formation of the Yaoundé Unit. (e) 2014, Second field trip of IGCP 616Y in Ebolowa, Southern Cameroon.

Young Scientist project took place in Yaoundé, Cameroon (3–5th December 2012), organized by B. Kankeu (Institute for Geological and Mining Research, IRGM), with 40 participants from 05 countries (Fig. 1). Twenty abstracts were accepted for oral presentations or posters. The program included one day of scientific session (Opening Ceremony, 04 scientific sessions, business meetings, and workshop summary/resolution) followed by two days field trip in Southern Cameroon.

First results were published in peer-reviewed journals concerning: the application of Anisotropy of magnetic susceptibility (AMS) supported by field and microstructural work to identify the sequence and character of Pan-African structures in gneissic rocks and late-tectonic granitoids in a part of the Central Africa Shear Zone (CASZ) system in Central Cameroon (Kankeu et al., 2012a), the geological and tectonic history of western central Africa since the Paleozoic (Kankeu et al., 2012b), the existence of a unique magmatic event along the entire Pan-African fold belt in Cameroon through geochemical and geochronological studies on leucosomes of the Yaounde series with the aim to identify the magma sources and to indicate their production periods and emplacement (Ngnotué et al., 2012).

2013-IGCP/SIDA 616Y Meeting and Workshop in Cameroon

The second IGCP/Sida 616Y annual meeting and workshop was organized in Yaounde/Kribi, Cameroon (08–12th October 2013), with 56 participants, from 06 countries. 36 abstracts were accepted for presentation or posters during the scientific session. New results presented improved the knowledge on the sources of minerals (such as Au, Fe, Al, etc.) and understanding their formation processes, on the pollution of surface and subsurface waters, distribution and management of groundwater and on natural and/or anthropic factors responsible for the occurrence of geohazards/natural hazards such as flood and landslides. It was followed by two days of field trip organized by the local organizing committee (B. Kankeu, J. Bassahak, M. Tchindjang and S. Ganno) which brought together graduate and post-graduate students with young and senior scientist, thus facilitating collaboration between scientists from different countries and institutions. Selected high-quality outcrops provided a good illustration of the main lithology and structures of the Pan-African Yaounde unit, ranging from the high-grade gneissic to low grade-schist.

In 2013, two field schools were also organized. The Kribi field school in southern Cameroon (09–11th June) involved 26 participants from Cameroon, Central Africa Republic and Germany. The interdisciplinary training and research activities focused on field geoscience methods, interpretation of the lithology and structure of Paleoproterozoic and Pan-African units and structures, using image processing and field control of satellite imagery, advanced geophysical technology (AMS) and the development of computerized geoscience database. The program included data collection at 10 stops (field site) including artisanal mining, weathering profile, Lake Ossa, Sanaga and Lobe River, steep mylonitic foliation along the Kribi Campo Shear Zone (KCSZ), waterfall, geomorphic features and topography. The field experience was then followed by data analysis and interpretations. At every locality, after careful observation, systematic recording procedures were adopted. Participants selected samples to be collected, measured and recorded the structural/lithological elements associated with the samples and outcrop and learned how to always draw a sketch of the area or structures being photographed and include an easily recognized scale. Discussions focused on contrasting models proposed for the evolution of stepped macro-relief at the transitional zone between coastal area and hinterland, environmental modifications and relationships between neotectonic movements and pre-existing faults/shear structures. The second field training around Ebolowa, in the northern border of the Archean Congo craton (11–14th December 2013) included 26 participants from Nigeria, Cameroon and Central Africa Republic.

Papers on various topics were published in peer-reviewed journals concerning the Paleoproterozoic synkinematic magnesian high-K magmatism from the Tamkoro-Bossangoa massif, along the Bossangoa-Bossemele Shear zone in North-western Central African Republic (Danguene et al., 2014), on the implication for gold and LREE exploration of stream sediment geochemical survey of Gouap-Nkollo prospect in southern Cameroon (Soh Tamehe et al., 2014).

2015-IGCP-646 Launching Meeting and Workshop in Yaoundé, Cameroon

The launching meeting took place in Yaoundé, Cameroon (17–21 November 2015), organized by B. Kankeu (IRGM, Yaoundé) and I.M. Akaegbobi (University of Ibadan), with 69 participants from Five (05) countries (Fig. 2). The program included two days of scientific sessions (23 presentations, 02 keynote speakers and 07 posters) and three days field trip to provide an overview through the continental basement geology of west African countries, spatial relationship between early formed Pan-African structures and zone of potentially high geological risk both for people and for infrastructure (neotectonics), mineral and hydrocarbon exploration, hydrology and climate fluctuation/change in Cameroon (Fig. 2), all of which are critical important to



Figure 2. (a-d) 2015, IGCP 646 Launching field meeting and workshop in Yaoundé. (a) group photo taken in front of the Center for German African Scientific Cooperation. (b-d) post meeting field trip in Kribi. (b) Group photo of about 12 students from St Monica university (SMY), a private Cameroon/UK Institute taken in front of the hotel. (c) B. Kankeu providing a pre-knowledge of the different features visited. (d) group picture of participants at Kribi deep sea port in front of a high-quality outcrop providing/showing a vertical section from top soil to Precambrian basement rock with the presence of fractures through which percolating water favors weathering.

developing countries and none more so than those in parts of west African where population pressures are on the rise.

First results were published in quality peer-reviewed publications and were mostly related to the characterization of gold mineralization in the Paleoproterozoic formations of southern Cameroon with a focus on the depositional setting (Fuanya et al., 2015) and on the presence of oldest volcanic activity (51 My old) with mantle source outside the Mt. Cameroon on mafic rocks from the Bamoun area, in the central part of the Cameroon volcanic Line (Atouba et al., 2016).

2016- IGCP-646 Field Workshop and Training in Center and Southern Cameroon

During this year, a field workshop was organized in Kribi, Cameroon (09–11th June 2016) by Kankeu (IRGM) and Fuanya (Pan African University, Ibadan), with a team of 27 participants from 03 countries (Fig. 3). The program included two days of field trip in the Paleoproterozoic formation of the northwestern border of the Congo along the Atlantic coast in Cameroon and one day of training at Fidelis hotel, Kribi. The first presentation by Dr. Mike Izuchukwu Akaegbobi focused on “Theoretical Approaches to Scientific Research”. The second by



Figure 3. (a-e) 2016. IGCP 646 annual field meeting in central and southern Cameroon. (a) Group photo taken in front of the Lobe water fall along the Atlantic coast in Kribi. (b) Visit at the Radio Nuclei station N°13: Photo taken in front of SPALAX CMX13 used to collect and analyse gas at Edéa. (c-f) data acquisition with basic modern methods and instruments. (c) Lithological mapping. (d) Use of compass. (e) Use of lens and (f) GPS tracking.

Foyet Gankam Arsène Delors, a Ph.D. candidate, introduced participants to the use of the “Zotero” software to prepare references or bibliography for different uses.

Papers on various topics were also published in international peer-reviewed journals concerned: identification of lineaments (shear zone, faults, foliation fractures) that constitute pathway for both gold mineralization fluids and groundwater circulation, through the application of combined field and remote sensing application (processing of the Landsat-7 Enhance Thematic mapper Plus (ETM+) in Ngoura Colomines area, Eastern part of Cameroon (Takoudjou Wambo et al., 2016) and the connection between complex geometry of three folding events and deformation mechanisms that controlled the tectonic evolution of the Pan-African fold belt in Kimbi area, Northwestern Cameroon (Ganno et al., 2016).

2017- IGCP-646 Pre-conference Field Trip in Nigeria, Training Session and Annual Meeting in Yaoundé, Cameroon

During this year, a two day training session (07–08th July 2017), with 12 participants was proposed by two GIS experts (Nguemefils, MS and Dr. Okomo Line Carole) at the IRGM Scientific Complex in Nkolbison, Yaounde (Fig. 4). Applicants came from Cameroon, Nigeria, Democratic Republic of Congo, Tunisia, Burundi, Morocco and Ethiopia). The training was centered on the use of geographic information systems (GIS) with focus on the use of Quantum GIS also known as QGIS.



Figure 4. (a-b) 2017. Preconference field trip in the Ameki Group (Middle Eocene) of Nigeria. (a) M. Akaegbobi (passed away) at the Orsumughu open pit (Artisanal exploitation of sandstone, gravel and clay). (b) Panoramic view of the Umuya section showing the characteristic lithology and sedimentary structures of the Nanka formation. (c-d) IGCP-646 training in Yaoundé. (e-f) 2017, IGCP-646 annual meeting at the IRGM scientific complex in Yaoundé.

A Six days pre-conference field trip (11–16th September 2017), organized by I.M. Akaegbobi (Nigeria) and C. Fuanya (PAU, Nigeria), with 5 five participants was organized in the Niger Delta Basin, one of the tertiary hydrocarbon-bearing deltas in the world, situated on the southern domain of Nigeria extending into the Gulf of Guinea. Selected high-quality outcrops (10 stops: Alluvial landforms/bars and channel form, indurated sandstones and conglomerates, quarry section in dark grey shales and mudstones enclosed in sandstones) provided an overview through the sedimentary fill of the Imo Formation, Ameki Formation (Middle Eocene) and Ogwashi Asaba Formation in the northern Delta which extends southward in the sub-surface into the petroliferous Niger Delta succession. Detailed characteristic lithology and sedimentary structures were observed and link with the environments of deposition. The vertical arrangement of depositional environments that existed side-by-side along the Enugu-Onitsha Expressway was illustrated by several examples.

The second Annual workshop and field meeting which was scheduled to hold in Ibadan at the Scripture Union Training and Conference Centre (TTC) from 11–16th September 2017 was postponed/cancelled as result of the passing away of Dr. Akaegbobi Mike (project co-leader and head of local organizing committee) on the 10th September 2017 (Just one day before the start of the conference). The wake keep was on October 30 at Ibadan and burial on the 1st and 2nd of November at Orsumughu (Eastern Nigeria). The second IGCP-646 meeting, finally took place in Yaoundé, Cameroon (16–17th November 2017), organized by B. Kankeu (IRGM) and C. Fuanya (PAU, Ibadan), with 40 interdisciplinary applicants from Cameroon (03 states universities and 01 Private University/SMU), Nigeria, Central Africa Republic (CAR), Republic of Congo, Ghana and Rwanda. During the scientific sessions, 10 oral presentations, 01 keynote speech was given and 05 posters were presented.

This year, papers were published in peer-reviewed journals concerning banded iron formations (BIFs) hosted in dominantly metasedimentary formations, metamorphosed into greenschist to granulite facies, Palaeoproterozoic Nyong series in the northwestern margin of the Congo craton, in Cameroon (Ganno et al., 2017), in order to identify its facies (oxide facies characterized by magnetite and/or hematite rich beds alternating with quartz-rich beds), mineralogy and chemical signatures (controlled by Fe and Si, with incorporation of minor detrital material) and geochemical signature (chemical elements such as Fe and Si were precipitated from a mixture of seawater and low-temperature hydrothermal fluid), on the application of field, microstructural, anisotropy of magnetic susceptibility, reflected light microscopy and thermomagnetic studies (Kankeu et al., 2018) to assess the Pan-African deformational history and strain geometry at the southern margin of the Central African Fold Belt (CAFB) against the older, cratonic basement of the Congo Shield (CS) and to report and document a debris flow (Ntchantcho et al., 2017) that occurred on the 1st of August 2012 in Kakpenyi in the Southern Region of Cameroon where inappropriate land use acted as a remote cause to predispose the steep slope, while heavy rainfall triggered the flow.

2018- IGCP-646 Annual Meeting and Training Session in Yaoundé, Cameroon

During the third year, a training session (Fig. 5) was proposed at the



Figure 5. (a-b) 2018. IGCP-646 training (capacity building) in Yaoundé, Cameroon. (c-d) pre-conference field trip focusing on the newly discovered gold district of Eséka in the Paleoproterozoic Nyong unit along the northern border of Congo craton, southern Cameroon, B. Kankeu (P. leader), C. Moudioh and C. Fuanya. (e) 2018, IGCP-646 meeting in Yaoundé, conference photo taken in Laboratoire de Traitement des Minerais (Institute for geological and Mining research).

Complexe Scientifique de l'IRGM in Yaoundé, Cameroon (13–14th July 2018) by two GIS experts (Fomene Nodem Rodrigue, MS and Foyem, MS) with 18 participants (8 females and 10 males). It was centered on the use of Geographic Information System (GIS) with focus on Quantum GIS also known as QGIS.

The third IGCP-646 meeting was held in Yaoundé, Cameroon (Fig. 5), organized by B. Kankeu, J. Bassahak and J.V. Hell (16–17th November 2018), with 35 interdisciplinary participants in the domain of geosciences from Cameroon (04 states Universities and 01 private University/Angela Academic), Nigeria, Central Africa Republic (CAR), and Chad. During the scientific session, 13 oral presentations, 01 keynote speech was given and 05 posters were presented. The scientific presentations during the meeting covered the fields of mineral exploration and the environment. Scientific results presented improved the knowledge on the geology of sedimentary basins and related oil, gas and mineral resources, on natural and /or anthropogenic factors responsible for the soils and air contamination.

Papers on various topics were also published in international peer-reviewed journals concerning the use of geostatistic linear ordinary kriging (Ok) and Geographical Information System (GIS) techniques to investigate the spatial distribution of alluvial gold content, mineralized and gangue layers thicknesses at the Pan-African Ngoura-Colomines area (eastern Cameroon) and show that this area is located in a large scale shear zone compatible with the Riedel fault system where

Rand R' fractures could have contributed significantly to the establishment of the gold mineralization (Takoudjou wambo et al., 2018). The petrography, lithology and major element geochemistry of Mesoproterozoic metamorphosed banded iron formation-hosted Nkout iron ore deposit, within the Ntem complex in the northwestern margin of the Congo craton which revealed that the BIF units was probably deposited in an iron-rich environment of reduced Fe³⁺ rich hydrothermal fluid in chemically stratified ocean, similar to other Superior-type BIFs in Congo Craton and in Quadrilateroferifero in Brazil (Ndime et al., 2018). The K-Ar feldspar age (Triassic ages of 231.1±4.8 Ma and 224.8±4.7 Ma) of mafic dykes that intrude late Pan-African quartz monzonite in the NE border of lake Nyos, in Cameroon was performed and compared with radio-isotopic age data available over the last 48 years for the Cameroon Line magmatism and it observed that the studied dykes intruded the basement rocks in Nyos about 150 Ma before the earliest intrusive ring complex in Cameroon, and about 80 Ma before the lower Cretaceous continental rifting and break up and separation of west Africa from Brazil and the opening of the equatorial Atlantic domain (Aka et al., 2018) and thus they might document magmatic and/or tectonic activity accompanying the still poorly known rifting and break up of west-Gondwana. The level of pollution in soils by heavy metals was also evaluated (using enrichment factors, contamination factors, degrees of contamination, pollution load index and geoaccumulation index) in gold mining sites of Betare-Oya and Batouri, Cameroon, indicating that metal contamination (As, Pb, Mn, Zr and Fe) originated from anthropogenic sources (Dallou et al., 2018).

New results of fieldwork carried out during the duration of the project has also been published in early 2019 in international peer-reviewed journals concerning the Eruption history and petrogenesis of rocks from Nyos volcano, NW Cameroon (an infamous volcano which exploded in 1986, releasing CO₂ gas that killed 1746 people and over 3000 cattle) that enabled to confirm its phreatomagmatic (maar) origin and suggest that magmas were produced by small degree partial melting of garnet-bearing ocean island basalt (OIB)-like asthenospheric mantle source, and reactivation of the fault system in lake Nyos area could have played a role in the formation of the maar (Hasegawa et al., 2019). Also, CO₂ currently venting into Lake Nyos is probably a result of geochemical processes taking place in the underlying mantle today implying complex interactions between lithospheric and surface processes. In the Palaeoproterozoic Nyong series, in southwestern Cameroon (at the northwestern margin of the Congo craton), the morphological and chemical assessment of alluvial gold grains from Ako'ozam and Njabilobe showed a restricted length of transportation of gold grains and hence their proximity to potential host rocks from which they were liberated and their liberation (over 80%) makes them suitable to be recovered via physical means which are environmentally friendly unlike chemical techniques (Fuanya et al., 2019a). It finally suggested that a gold-bearing magmatic rock was metamorphosed into amphibole and metadolerite with the subsequent partitioning of Fe-oxide, rutile and Fe-rich biotite inclusions in the gold grains during mobilization of gold grains from the basic rocks by hydrothermal fluids (Fuanya et al., 2019b).

Social and Educational Results

The original idea of IGCP-616Y and 646 projects was to investi-

gate the continental basement geology with neotectonics, mineral and hydrocarbon exploration, hydrology and climate change, especially in several West African countries. Modern geotechnical techniques were to be deployed (AMS, GIS positioning, Remote Sensing) that have the potential to treat large volumes of quantitative and semi-quantitative geoscientific data. The aim was to strengthen capacity building, create opportunities for young scientists to undertake higher degrees, knowledge transfer and training, geoscientific networking in developing central Africa. In line with the UN SDGs 4 and 12, the project used geodata to identify potential minerals resources and provided good quality education to young African geoscientists. In this respect, the projects IGCP-616Y (2012–2014) and IGCP-646 (2015–2018) supported the training of young geoscientists, addressed knowledge gaps in the geology of central and West Africa, delivered upgraded geosciences training focusing highly technical methods and also facilitated networking amongst the young geoscientists.

Conclusion

During the 3 years of the earlier SIDA-funded "pilot project" (IGCP-616Y) and 4 years of IGCP-646, 6 meetings and 5 field trips were organized. Papers on various topics were published in international peer-reviewed journals. Several MSc and PhD students, as well as postdoctoral fellows, have been involved in activities. Numerous training activities were also organized to network and equip the next generation of African earth scientists (students and other locally-based geoscientist) with the necessary innovative tools to solving the challenges of geological field mapping and environmental management (such as climate change adaptation and prevention of natural hazards).

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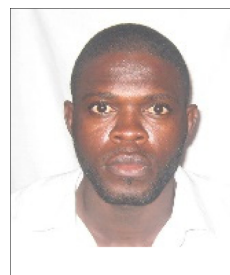
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