Uranium And Thorium Concentration In Neoproterozoic Formations And Sediments From The Pala Region Of Mayo-Kebbi, Southwestern Chad

[1, 2] **Doumnang Mbaigané Jean Claude**, [1, 3] **Mbaguedjé Diondoh**, [1]**Siddig Ahmed Abbas**, [1] **Vicat Jean Paul**, [1] **Guidéal Roland.**

[1] Laboratory of Geology, Geomorphology and Remote sensing, Department of Geology, Faculty of Fundamental and Applied Sciences, University of N'Djamena P.O. Box 1027 N'Djamena Chad Republic.

[2] Laboratoire des Géosciences et de l'Environnement Université de Moundou

[3] Département de Géologie Université d'Abeché (Chad)

E-mail: doumnang@gmail.com

***Abstract*—The Pala region of southwestern Chad belongs to the Central Africa mobile zone. The Neoproterozoic formations of the Pala region include metavolcano-sedimentary rocks set up in a back-arc basin and granitoids intruded during the pan-African basin closure. They were affected by intense NNE-SSW deformation and greenschist facies metamorphism. Although few studies have been conducted in this area, these formations have acknowledged concentrations in gold, uranium, thorium and various other metals. Here we realized a prospecting by gamma-ray spectrophotometry and analyzed 312 samples of sediments and rocks for U and Th. U and Th content were mapped to specify the areas of interest. The result of this research is important to develop geological and mining mapping, the only way to guide research of uranium and protect the environment.**

Keywords—Neoproterozoic, sediments, uranium, thorium, Pala, Mayo-Kebbi, Chad.

Introduction

Geological formations in the Pala region of Mayo-Kebbi in southwestern Chad form part of the "mobile zone" [2] in Central Africa. This vast domain, belonging to the pan-African between 900 and 550 Ma [4, 18, 5] is the result of the collision between the cratons of Congo to the South, the craton of West Africa to the West and the Sahara metacraton to the East (Fig. 1). The Pala region lies in an intermediate position between the pan-African Trans-Saharan fold Belt thrusted westward onto the West African craton and the pan-African Central Africa Fold Belt thrusted southward onto the Congo Craton. In the Mayo-Kebbi region, pan-African convergence was accompanied by intense tectonic movements, syn- to late-tectonic granitization and NE-SW-oriented shear zones [19, 10, 34, 35, 20, 8, 18]. These processes are generally highly favorable to the production of metal concentrations, but also to their remobilization, dissemination, differentiation and concentration in usable deposits. The geological area of Pala is an excellent metallogenic province but is, until now, poorly studied. Recognized mineralizations are varied and are particularly relevant to gold, uranium, thorium, arsenic, chromium, tantalum, antimony, cobalt, tungsten and antimony [25, 30, 16, 31]. Concurrently to this wealth of metals, the search for and exploitation of these mineralizations is hampered by the complexity of the deposits resulting from successive processes of concentration and dissemination. It is difficult to know where to search for mineralizations, which may lead to unnecessary work. Consequently, uncontrolled artisanal mining (particularly gold) is thus causing environmental degradation. For the research of uranium, it is therefore important to develop geological and mining mapping, the only way to guide research and protect the environment. This work involves targeting carriers and producing the distribution map of uranium and associated thorium concentrations.

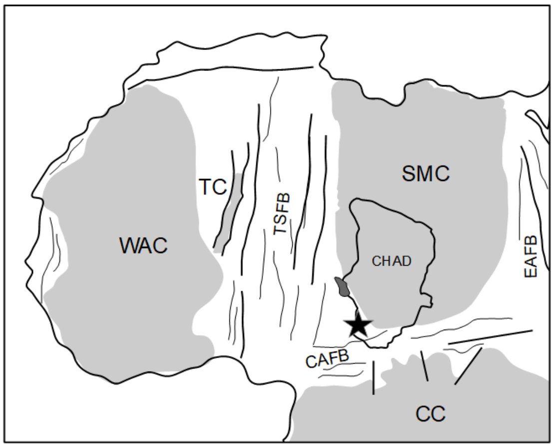

Figure 1. Location of the study area. CC: Congo Craton; SMC: Saharan metacraton ; TC, Touareg Craton; WAC, West Africa Craton. Zone mobile panafricaine: Trans-Saharian Fold Belt (TSFB) ; Central African Fold Belt (CAFB) ; East-African Fold Belt (EAFB). Black Star : area studied.

Location, physiography and geological settings

The studied area is located in the Mayo-Kebbi region, in the South-West of Chad between latitude 9°20’ to 9°35’ North and longitude 14°46’ to 15° East (Fig. 2). It belongs to the neoproterozoic basin of Goueygoudoum [22, 8] so named Pala Belt. The Pala belt-oriented SSW-NNE disappears towards the South in the Cretaceous basin of Lamé and towards the North under the mio-Holocene deposits of the Logone Chari basin.

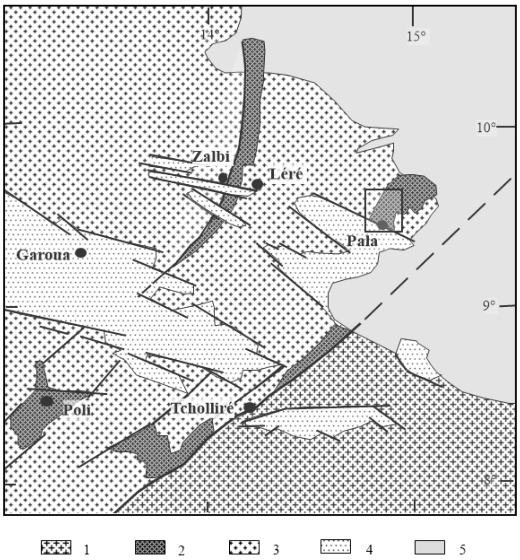

Figure 2. Geological map of Pala region. 1 : Paleo-Neoproterozoic Adamaoua-Yadé Block. 2 : Neoproterozoic volcano sedimentary basins. 3 : Undifferentiated syn to post tectonic igneous rocks 4 : Cretaceous basins. Mio-Pliocene deposits. Box: Location of the study area.

This region has a Sudano-Guinean climate according to the Aubréville Classification [1]. It is tropical semi-humid with a dry season from November to April and a wet season from May to November. The annual rainfall ranges from 900 to 1000 mm. The water system is dense with many water tributaries that feed the Mayo-Kebbi. The meandering morphology of the hydrographic netwook is imposed by faults systems that have affected the substratum. The average altitude is 380 meters above sea level. The reliefs are not much accentuated with many small hills. The climate characteristics have lead to the formation of leached tropical ferruginous soils composed of clay minerals (kaolinite, smectite, illite), iron oxides and hydroxides and quartz residual minerals and various heavy minerals). The area is covered by thick ferruginous soils and lateritic carapace and shows only few bedrock outcrops. The Pala belt outcrops between the Torrok village in the north and Pala in the south where it is covered by the Cretaceous sediments. A detailed map of the study area (Fig. 3) shows that the Pala belt is constituted of volcano-sedimentary formations similar to the green belt rocks. The Pala schists comprise clastic and epiclastic rocks, interlayered with felsic to mafic metavolcanic chloritic schists which form the majority of outcrop alternate with talcschists, metadiorites, metagabbros, metapyroxenites, and metabasalts. The dominant minerals in these low- and medium-level green rocks are amphiboles, plagioclases, chlorites, and epidotes. These metamorphic formations are massive, structured into parallel linear bands strongly deformed following high slope and horizontal elongation movements. This deformation is related to pan-African orogenesis, which affected rocks between 600 Ma and 540 Ma [8, 21, 12]. The geochemical composition of the Pala Belt metabasites is characteristic of the arc rear basins [14, 24, 12, 13]. Various granitoids intruded the volcano-sedimentary formations. The Mayo-Kebbi batholith outcrops in the NE study area. This massif described as “Concordant granite” or “Syntectonic granite” by ancient authors [36, 29], is composed of foliated tonalites, trondhjemites and granodiorites containing large xenoliths of polydeformed banded amphibolites. These granitoïds are calcoalkaline in composition with negative Nb–Ta anomalies, indicating a subduction-related magmatic arc setting [14, 9]. The deformation of the Mayo Kebbi tonalites occurred at about 639 ± 20 Ma according to the syntectonic Landou granite [23]. Undeformed massive granites appear at the SE of the study area. Their chemical composition is also consistent with an active margin context [33]. These small, circumscribed, post-tectonic, undeformed massifs range from charnockites, porphyrogranites, and diorites from 570 Ma [22] to 565 Ma [21, 8]. Their composition is calcoalkaline [22, 8]. Metamorphic rocks and granitoid are dissected by veins of quartz of NNE-SSW and NW-SE directions.

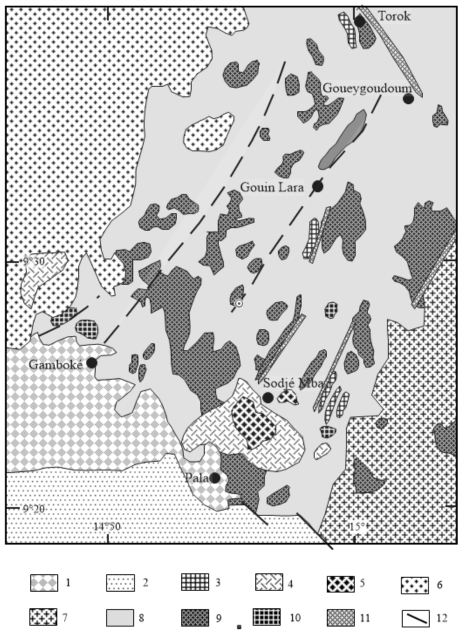

Figure 3 : Detailed geological map of Pala Belt, modified after [8] and [25]. 1 : Laterite cover. 2 : Cretaceous. 3 : Granodiorites. 4 : Porphyrogranite. 5 : Charnockites. 6 : Mayo Kebbi batholith. 7 : Granites not deformed. 8 : Metasediments. 9 : Metabasites. 10 : Metadiorites. 11 : Quartz threads. 12 : Fault.

Materials and methods

During a first phase of exploration, we used a portable Geiger counter GAMMA SCOUT model GS1 to measure the gamma radiation of outcrops and to ensure the interest of the study area. On the areas of interest recognized by the Geiger meter we then realized a gamma spectrometer mapping with a portable gamma/neutron spectrometer to discriminate exactly the type of radiation and to locate the areas containing uranium. On uranium-containing areas we collected sediment samples from wadis. Samples were taken at a depth of between 60 cm and 1 m with a hand auger. Charnockite and metabolite samples were also collected. A total of 312 samples were taken. Each sample was systematically located by a Global Positioning System (GPS) Garmin 12. Sediments were analyzed in the laboratory of the Korene Institute of Geology, Mines and Materials (KIGAM). The rocks were analyzed by ICP-MS at the Nancy Rock and Mineral Analysis Service (SARM). The software Surfer 21.2 was used to map the area from uranium and thorium levels.

Results

The results of the analyses are shown in Table 1 with a Shapiro - Wilk test of normality [28] calculated with a significance level = 99% and also the correlation coefficient between U and Th. the test was done to interpret the distribution of thoriu m and uranium.

Table 1.

Element	LD	Mean	Median	SD	Min	Max	W Statistics	p value	R
U	0,03	1,60	0,00	2,74	0,00	26,20	0,60	0,00	0,758
Th	0,06	12,21	9,25	17,82	0,00	225,00	0,40	0,00	

Tab 1 : Limit of determination, mean, median, standard deviation, minimum, maximum, W statistics and p-value of Shapiro-Wilk test and correlation coefficient regarding the distribution of U and Th of 312 samples. All concentrations are expressed in ppm.

Of the 312 samples analysed, 125 contained uranium and 187 have a concentration below the limit of determination (LD) of 0.03 ppm. Th was quantified in all samples except for one sample with a content of less than the LD (0.06 ppm). The average U content is 1.60 ppm with a standard deviation of 2.74 ppm. The average Th content is 12.21 ppm with a standard deviation of 17.82 ppm. The results of Shapiro-Wilk test show (p <0.01) that U and Th are not normally distributed. With a correlation coefficient R = 0.758, the contents of U and Th are well correlated. The box and whisker plots of U and Th show a lack of symmetry and several outliers according to the anomalous distribution of U and Th. The histograms of the U and Th contents (Fig. 5) differ greatly from the normal distribution due to the importance of very low values.

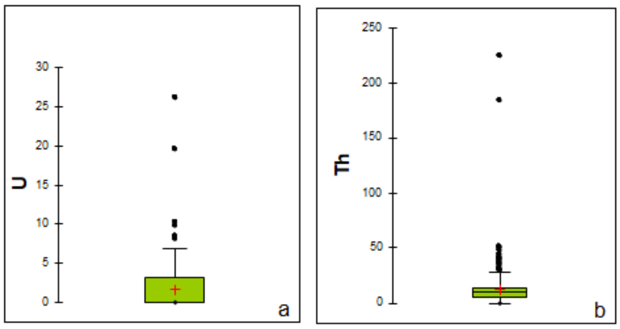

Figure 4: Box and whiskers plots of concentration in Uranium (a) and Thorium (b). Average: cross in the box. Median: horizontal bar in the box.

Where uranium or thorium is not quantified, the sample content is considered null due to low LD values.

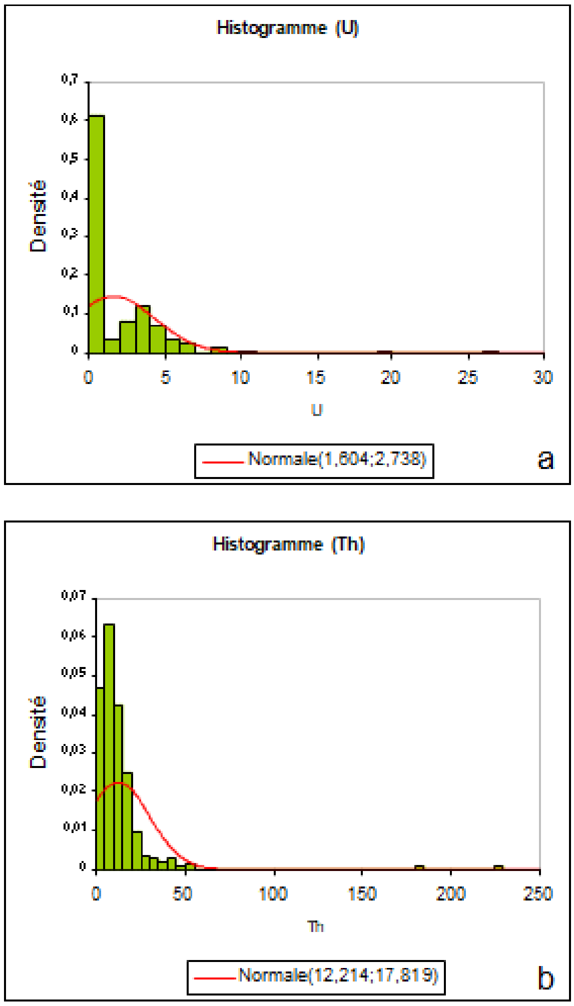

Figure 5. Histograms of Uranium (a) and Thorium (b) contents. U-Th levels do not follow normal law.

Discussion

Th and U are incompatible elements because of their large ionic radius, their concentration is thus controlled by magmatic processes and increases in residual liquids. The poor correlation between U and Th levels of the samples analysed shows the importance of postmagmatic, metamorphic and alteration phenomena in the distribution of these elements. In the continental crust, acid and basic rocks Thorium is 3 to 4 times more abundant than Uranium [6, 32].

Uranium, unlike thorium, is easily mobilized by hydrothermal and low-metamorphic phenomena affecting the Th/U ratio. Sediments containing U have an average Th/U ratio 4.2, similar to that of [27], but values vary widely from 0.7 to 10.0 and are very high for sediments with U content below the limit of determination. Charnockites have very variable mean Th/U ratios, from 3.2 to 9.38 and very high for those with U content below the limit of determination. Metatasites have very variable mean Th/U ratios, from 2.3 to 11.76, and very high for those with U content below the limit of determination. The variation in the Th/U ratio reflects U mobility during a small metamorphic episode and subsequent alterations and possible Th mobility during a more intense metamorphic episode.

In the Th vs U diagram (Fig. 6), U levels between 0.6 and 9.8 ppm and Th between 0.3 and 44.6 ppm of sediment are dispersed around the PAS content [32]. Sediment levels are similar to those of metabasites and pan-African intrusive granites [8, 33]. Relatively high levels of U (1.5 ppm to 8.5 ppm) and Th (4.7 ppm to 37.8 ppm) metabasites are not magmatic in origin because they contradict the composition of the base rocks of the arc basins with very low U and Th levels [15, 3, 26, 11]. Pan-African metamorphism was therefore important enough to remobilize the U but also the Th element much less mobile. The highest levels of U (Min Max) and Th (Min Max) were found in the charnockites analysed in this work and in previously studied charnockites and diorites [8]. These levels are similar to those of pan-African uranium granites in Egypt [7].

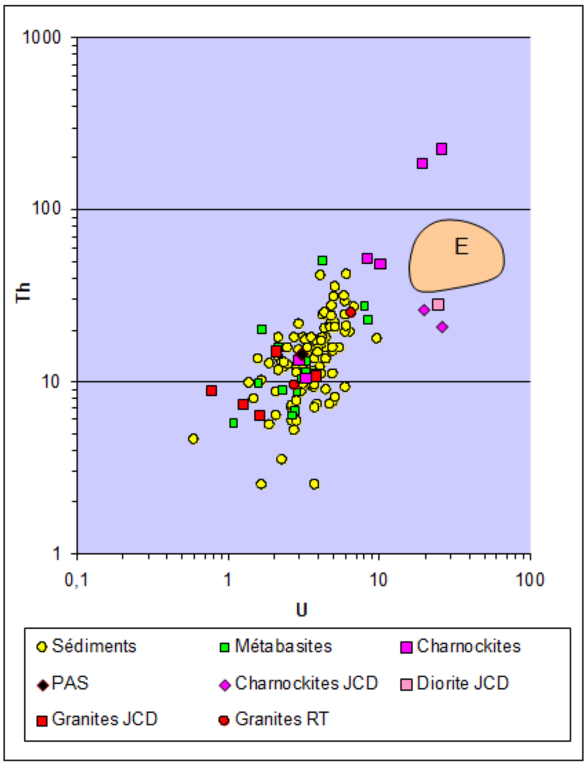

Figure 6. Diagramme U vs Th. Charnokites JCD, Diorite JCD, Granites JCD after [8]. Granites RT after after [33]. E : Uraniferous panafrican granites of Egypt after [7]. Samples with content below the limit of determination are not represented.

Cartography of U and Th levels

The mapping of uranium and thorium concentrations was done by plotting with the software surfer 9. The U-content map (Fig. 7) shows values ranging from 0.5 ppm to 10 ppm. In fine stream sediments, levels are most often below the limit of determination, with a maximum U-content value of 1.64 ppm. Values higher than 10 ppm are found only in the Sodjé Mbay area north of Pala. These high values are related to Charnockites outcrops. The highest U-value, 26.2 ppm, is found on the charnockite west of Sodjé Mbay.

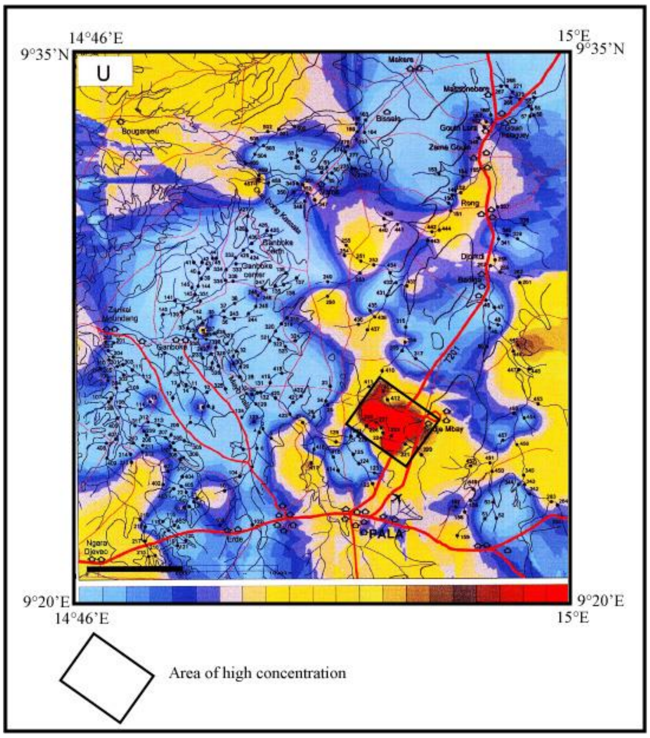

Figure 7. Map of Uranium distribution in sediment and rocks.

The Th-content map (Fig.8) shows values of thorium concentration ranging from 1.5 ppm to 49.5 ppm. Like uranium, the higher levels of Th are found in the charnockite west of the village of Sodjé Mbay.

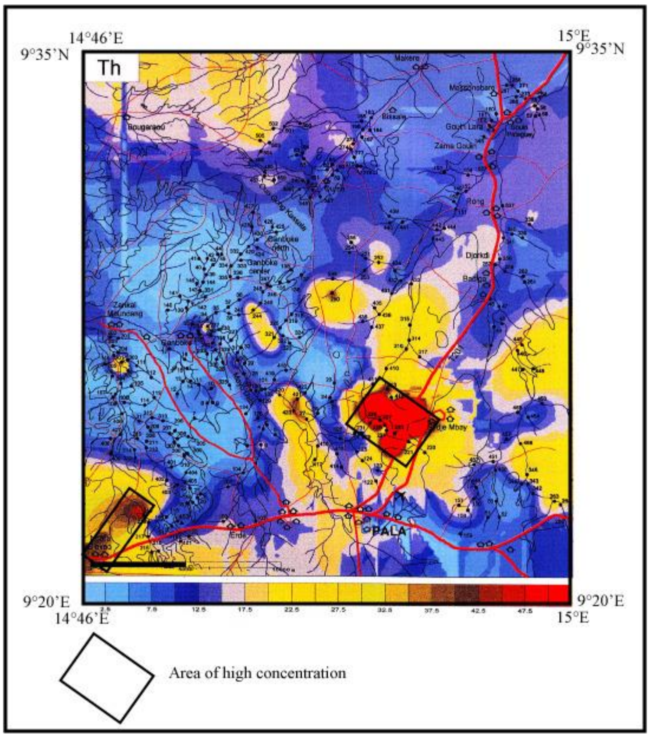

Figure 8. Map of thorium distribution in sediments and rocks.

Both maps show a similarity in the distribution of uranium and thorium in the study area. Levels are very low and variable in sediments, and high levels are related to charnockite in western Sodjé Mbay. Also, the concentration of thorium is high in the area at the west of Pala town. This work involves targeting carriers and producing the distribution map of uranium and associated thorium concentrations. It is therefore important to develop geological and mining mapping, the only way to guide research and protect the environment.

Conclusion

The distribution of uranium and thorium in the neoproterozoic formations of Pala is linked to the geodynamic context of the region. The origin of the U and Thorium is to be found in plutonic rocks, especially in charnockites. The U and Th were remobilized during pan-African metamorphism. The presence of uranium in sediments is related to pedogenesis: progressive alteration, leaching, and distribution according to topography. Leaching is favored by acidic tropical rain. The uranium and thorium anomaly maps will help to focus future work on the Sodjé Mbay area of interest and also guide studies on uranium-accompanying elements such as antimony and tantalum.

Acknowledgements We thank the Ministry of Mines and Geology of the Republic of Chad for making certain data available to us. We thank the French Cooperation, which financed the field work. Our thanks also go to the IRD, who kindly financed the stay, the CEREGE, which welcomed us and in particular Florence Sylvestre who received us in his laboratory.

Références

1. Aubréville A. 1949. Climats, forêts et désertification de l'Afrique tropicale. Société d'Editions Maritimes et Coloniales, Paris, 351 p.

2. Bessoles, B., Trompette, R., 1980. Géologie de l'Afrique. La chaîne panafricaine «zone mobile d'Afrique centrale», (partie sud) et zone soudanaise. Mémoire BRGM, Orléans, vol. 92, p. 394.

3. Bézos, A., S. Escrig, C. H. Langmuir, P. J. Michael, and P. D. Asimow (2009), Origins of chemical diversity of back-arc basin basalts: A segment-scale study of the Eastern Lau Spreading Center, J. Geophys. Res., 114, B06212, doi :10.1029/2008JB005924.

4. Black, R., Liegeois, J.-P., 1993. Cratons, mobile belts, alkaline rocks and continental lithospheric mantle: the Pan-African testimony. Journal of the Geological Society, London 150, 89–98.

5. Castaing, C., Feybesse, J.-L., Thiéblement, D., Triboulet, C., Chèvremont, P., 1994.

Paleogeographical reconstructions of the Pan-African/Brasiliano orogen: closure

of an oceanic domain or intracontinental convergence between major blocks. Precambrian Research 69, 327–344.

6. Coppens R. 1973. Sur la radioactivité des granites.in pp. 44-61. Les roches plutoniques dans leurs rapports avec les gîtes minéraux. Masson Edit., Paris, 406 p.

7. Dardier and El-Galy, 2000. Contribution to the U-Th distribution in the older and youngr granitoids along Qena-Safaga road, Central Earstern desert, Egypt.gyptian Journal of Geologie, V. 44/1, pp. 55-64.

8. Doumnang, J.C., 2006. La géologie des formations néoprotérozoïques du Mayo Kebbi, Sud-Ouest du Tchad. Thèse de Doctorat d'Université d'Orléans (France), 234p.

9. Doumnang, J.C., Pouclet, A., Vidal, M., Vicat, J.P., 2004. Lithostratigraphie des terrains panafricains du sud du Tchad (région du Lac de Léré) et signification géodynamique des formations magmatiques. In: IGCP-470 Second Annual Field Conference, Garoua, Cameroon, abstract, p. 8.

10. Ferré, E., Gleïzes, G., Caby, R., 2002. Obliquely Convergent tectonics and granite

emplacement in the trans-saharan belt of Eastern Nigeria: a synthesis. Precambrian Research 114, 199–219.

11. Gale A., Dalton C.A., Langmuir C.H., Schilling J-G., 2013. The mean composition of ocean ridge basalts Geochemistry, Geophysics, Geosystems, Vol. 14, issue 3, P. 489-518. https://doi.org/10.1029/2012GC004334

12. Isseini, M., 2011. Croissance et différenciation crustales au Néoprotérozoïque. Exemple du domaine panafricain du Mayo Kebbi au Sud-Ouest du Tchad. Thèse de doctorat de l'Université Henri Poincaré, Nancy I, 345p.

13. Isseini, M., André-Mayer, A.-S., Vanderhaeghe, O., Barbey, P., Deloule, E., 2012. A type granites from the Pan-African orogenic belt in south-western Chad constrained using geochemistry, Sr–Nd isotopes and U–Pb geochronology. Lithos 153 (2012), 39–52.

14. Kasser, M.Y., 1995. Evolution précambrienne de la region de Mayo Kebbi (Tchad), un segment de la chaîne panfricaine. Thèse de Doctorat au Muséum National d'Histoire Naturelle de Paris, 217 p.

15. Keller R.A., Fisk M.R., Smellie J.L., Strelin J.A., Lawver L.A. 2002. Geochemistry of back arc basin volcanism in Bransfield Strait, Antarctica: Subducted contributions and along-axis variations. Journal of Geophysical Research, Vol. 107, No. B8, 2171, 10.1029/2001JB000444,

16. KIGAM, (1999). Report on the Mineralisation of Gold in Mayo-Kebbi in south-west of Chad. Directorate of mines and geology, Ministry of mines, energy and petroleum, Republic of Chad.

17. Liégeois, R. Black, J. Navez and L. Latouche, Early and late PanAfrican orogenies in the Aïr assembly of terrane (Tuareg shield, Niger), Precambrian Research 67 (1994), pp. 59–88

18. Mbaguedje Diondoh (2008). Protogeneses and cartography of geological formations of Lere (Southwest of Chad). Master these, University of Dschang Cameroon.

19. Ngako, V., Jegouzo, P., Nzenti, J.P., 1992. Shortened area and cratonization of North Cameroon from Upper Proterozoic to Paleoproterozoic. Report, Scienific Academy, Paris 315-377.

20. Ngako V., Affaton P., Nnange J.M., Njanko T., 2003 Pan-African tectonic evolution in Central and Southern Cameroon: Transpression and transtension during sinistral shear movements. Journal of African Earth Sciences 36(3):207-214

DOI: 10.1016/S0899-5362(03)00023-X

21. Penaye J., Kröner A., Doumnang J. C., Toteu S. F. 2004. Reconnaissance geochronological survey of Neoproterozoic granitoids in south-western Chad using the single zircon evaporation technique. IGCP Second Annual Field Conference, Garoua, Cameroon, p. 7.

22. Penaye, J., Kröner, A., Toteu, S.F., Van Schmus, W.R., Doumnang, J.C., 2006. Evolution of the Mayo Kebbi region as revealed by zircon dating: an early (ca. 740 Ma) Pan-African magmatic arc in southwestern Chad. Journal of African Earth Sciences 44, 530–542.

23. Pinna, P., Calvez, J.Y., Abessolo, A., Angel, J.M., Mekolou Mekoulou, T., Managa, G., Vernet, Y., 1994. Neoproterozoic events in the Tcholliré area: Pan-African crustal growth and geodynamic in central-northern Cameroun (Adamawa and north Provinces). Journal of African Earth Sciences 18, 347–353.

24. Pouclet A., Vidal M., Doumnang J-C., Vicat J-P., Tchameni R., 2006. Neoproterozoic crustal evolution in Southern Chad: Pan-African ocean basin closing, arc accretion and late- to post-orogenic granitic intrusion. Journal of African Earth Sciences 44 (2006) 543–560.

25. Projet PNUD/CHD/87/010/DRGM, 1987 PNUD/Projet/CHD/87/010/DRGM, 1987. Rapport sur la prospection de l'or dans le Mayo-kebbi, 20 p. Direction des mines, ministère des mines et de l'Energie, République du Tchad.

26. Regan M.K., Ishizuka O., Stern R.J. , Kelley K.A., Ohara Y., et al. Forearc basalts and subduction initiation in the Izu-Bonin-Mariana system. Geochemistry, Geophysics, Geosystems, AGU and the Geochemical Society, 2010, 11, pp. Q03X12. 10.1029/2009GC002871. hal-00677177.

27. Rudnick, R.L., Gao, S., 2014. 4.1 - Composition of the Continental Crust A2 - Holland, Heinrich D, in: Turekian, K.K. (Ed.), Treatise on Geochemistry (Second Edition). Elsevier, Oxford, pp.

1-51, http://dx.doi.org/10.1016/B978-0-08-095975-7.00301-6.

28. Shapiro, S.S., Wilk, M.B., 1965. An analysis of variance test for normality (complete samples). *Biometrika*, Volume 52, Issue 3-4, December 1965, Pages 591–611, https://doi.org/10.1093/biomet/52.3-4.591

29. Schneider, J.-L., 1989. Géologie et hydrogéologie de la République du Tchad. Thèse

Université d'Avignon, France, 547p.

30. Schneider, J.L., Wolff, J.P., 1992. Carte géologique et cartes hydrogéologiques à 1/500.000 de la République du Tchad. Mémoire explicatif. Document du BRGM 209, 2 volumes.

31. Soo-Young et Se-Jung, 2001 Soo-Young, Se-Jung, 2001. Fluid inclusion and stable isotope studies of gold deposits in the Ganboke mineralized district, Pala area, Chad. Geosciences Journal 5 (1), 27–45.

32. Taylor S.R. , Mclennan S.M., 1985. The Continental Crust: its Composition and Evolution. Blackwell Scientific Publications, 312 p.

33. Tchameni R., Doumnang J.-C., Deudibaye M., Branquet Y., 2013. On the occurrence of gold mineralization in the Pala Neoproterozoic formations, South-Western Chad. Journal of African Earth Sciences 84 (2013) 36–46 http://dx.doi.org/10.1016/j.jafrearsci.2013.03.002

34. Toteu, S.F., Van Schmus, R.W., Penaye, J., Michard, A., 2001. New U–Pb and Sm–Nd data from north-central Cameroon and its bearing on the pre-Pan-African history of central Africa. Precambrian Research 108, 45–73.

35. Toteu, S.F., Penaye, J., Poudjom Djomani, Y.H., 2004. Geodynamic evolution of the Pan-African belt in Central Africa with special reference to Cameroon. Canadian Journal of Earth Sciences 41, 73–85.

36. Wolff, J.P., 1964. Geological map of Chad Republic on scale 1/500 000. B.R.G.M. Paris.