The Quaternary paleo-lacustrine deposits of Bamako and their significance for the development of the Niger River course

Os depósitos paleolacustres quaternários de Bamaco e seu significado para o desenvolvimento do curso do Rio Níger

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Abstract

Sills play a crucial role in shaping river courses. They are typically natural dams that obstruct water flow and create lakes along the river. This study examines the case of the Sotuba sill in the Niger River's development in West Africa. It discusses four Quaternary outcrops in Bamako, the Niger Valley, composed of lacustrine deposits covered by fluviatile sediments, indicating a change in depositional environment. The Quaternary outcrops were mapped in the field; their azimuthal directions were recorded using GPS and a geological compass; their structures were described. Samples were collected from two outcrops for OSL dating, and a stratigraphical correlation was established. Their significance for the Quaternary development of the Niger River course was assessed. The results suggest that the Sotuba sill was a natural dam that blocked the Niger River's flow from the upper course, leading to the formation of lacustrine deposits. It was only after about 176 ka that the flows managed to cross the dam and connect the two independent rivers, forming the current unified Niger course. The contact between the laminated lacustrine and fluvial sediments indicates that the lithofacies change was abrupt and catastrophic. Since seismic events commonly trigger this change and seismic structures (seismites) are widespread in the studied Quaternary sediments, this change likely reflects neotectonic events in the area.

Keywords: Niger River, Quaternary, sill, river capture, neotectonic.

Resumo

Soleiras (sills) desempenham um papel crucial na modelagem do curso de rios. Elas são tipicamente barragens naturais que obstruem o fluxo de água e criam lagos ao longo do rio. Este estudo examina o caso da soleira de Sotuba no desenvolvimento do Rio Níger, na África Ocidental. Discutem-se quatro afloramentos do Quaternário em Bamaco, no Vale do Níger, compostos por depósitos lacustres cobertos por sedimentos fluviais, indicando uma mudança no ambiente deposicional. Os afloramentos quaternários foram mapeados em campo; suas direções azimutais foram registradas utilizando GPS e bússola geológica; suas estruturas foram descritas. Amostras foram coletadas em dois afloramentos para datação por LOE (Luminescência Opticamente Estimulada), e estabeleceu-se uma correlação estratigráfica. Avaliou-se o seu significado para o desenvolvimento do curso do Rio Níger no Quaternário. Os resultados sugerem que a soleira de Sotuba foi uma barragem natural que bloqueou o fluxo do alto curso do Rio Níger, levando à formação de depósitos lacustres. Foi somente após cerca de 176 ka que os fluxos conseguiram ultrapassar a barragem e conectar os dois rios independentes, formando o atual curso unificado do Níger. O contato entre os sedimentos lacustres laminados e os sedimentos fluviais indica que a mudança de litofácies foi abrupta e catastrófica. Como eventos sísmicos comumente engatilham essa mudança e estruturas sísmicas (sismitos) estão amplamente distribuídas nos sedimentos quaternários estudados, essa mudança provavelmente reflete eventos neotectônicos na área.

Palavras-chave: Rio Níger, Quaternário, sill, captura de drenagem, neotectônica.

1. Introduction

River networks initiate, grow, and disappear (Glock 1931, Schumm 1956, Schumm, Mosley, and Weaver 1987, Pelletier 2003). This pattern of river development has been well documented across different regions of the world under various climatic and geological settings. The development of rivers such as the Yangtze (Fan & Li 2008, Zheng 2015, Fan, Kong et al. 2021), the Nile (Wolmanet al. 2022, Woodward et al. 2022), the Zambezi (Goudie 2005, Moore et al. 2022), and the Congo (Runge 2022), has been extensively studied since the early twentieth century. Across different river growth patterns, rainfall and slope are essential to river initiation, but river piracy is a key factor influencing the extension of the river network (Crosby 1937, Calvache & Viseras 1997, Mikesell et al. 2010, Shugar et al. 2017). River piracy is a notable factor in shaping the present-day Yangtze River (Fan & Li 2008, Fan et al. 2021). The Niger River, the longest in West Africa

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and the third longest on the African continent, exemplifies this pattern of river evolution. Research indicates that the current Niger River is the result of multiple river piracy events, believed to have occurred in the northern section between Timbuktu and Bourem at a place called Taoussa, and a second in present-day Niger (Beaudet 1977, Goudie 2005, Chardon et al. 2016). It is thought that the present Niger, originating in the Futa Jalon Mountains of the Republic of Guinea and passing through southern Mali, was originally an endorheic drainage system feeding certain lake systems in the Arawane region north of Timbuktu. This endorheic river was later captured by the Tilemsi River, flowing down the Adrar des Iforas Mountains in northeastern Mali (Gaussen 1988). Chudeau (1919) hypothesised a second capture of the Niger River by the Taffassasset, a river system draining the Hoggar Mountains. The curve in the Niger's course after Timbuktu, called the "boucle du Niger" (the Ring of the Niger), is believed to result from this first river capture. Drainage pattern evidence appears to support this hypothesis; however, the timing of the river piracy remains debated, with both a Holocene and an earlier capture event proposed.

An essential condition for the river capture at the site of Taoussa is the presence of a dolerite sill. The lithological conditions observed at Taoussa are also found at Bamako along the upper Niger River. At Sotuba, the Niger River crosses a dolerite sill known as the "Seuil de Sotuba" (Sotuba sill), also referred to as Sotuba rapids, where Bamako's third bridge is constructed, along with the dam bearing the same name, the "Sotuba dam." The discovery of lacustrine sediments upstream of Bamako, above the Sotuba sill, offers new evidence for the evolution of the Niger River. Upstream of this sill, significant lacustrine profiles buried beneath fluvial sediments suggest a revised understanding of the Niger River's course development. Could river capture at the Taoussa sill also have occurred at the Sotuba sill in Bamako? Might the Niger River have crossed the Sotuba sill during that period? Under what drainage conditions were the lacustrine sediments deposited, and what insights can be drawn from their presence? The main objective of this research is to decipher the Quaternary evolution of the Niger River's upper course by analyzing Quaternary deposits along the river at Bamako. It focuses on determining the type of Quaternary sediments found, their stratigraphical disposition, their synsedimentary and post-sedimentary structures, and their age, and the significance of their presence in understanding the present-day course of the Niger River. This research is highly significant, as the evolution of the Niger River is poorly known and very few Quaternary studies have been undertaken in the area. Therefore, this research appears to be a pioneering work on the Niger Upper River region.

2. Materials and methods

Construction workers digging for building materials uncovered Quaternary outcrops in Bamako. These outcrops are scattered along both banks of the Niger River upstream of the Sotuba Sill, particularly in its vicinity. They can be seen in the districts of Missabougou, Dianeguela, Daoudabougou, Badalabougou, Kalabankoro, Kabala, and Tiebani on the right bank and at Bankoni Razel and Sangarebougou on the left bank (Fig. 1). After the discovery of the outcrops, different studies have been undertaken:

- The outcrops were visited during multiple field sessions, during which their geographic coordinates were recorded. The different sedimentary layers have been identified, and their respective widths were measured. The type of contact between the layers was also identified and described; the visible sedimentary structures, including synsedimentary and post-sedimentary, were also identified and described. The direction of the sedimentary structures, especially the soft-sediment deformation structures, was measured using a geological compass. Their texture and lithology were examined.
- Three samples were collected from the outcrop at Dianeguela, where the lacustrine sediments were well preserved, visible, and accessible. The three samples from Dianeguela were taken at 10, 27, and 33 meters above the base rocks. A fourth sample was taken at the base of the Bankoni Razel outcrop, the city's most comprehensive Quaternary outcrop for OSL dating. The Bankoni Razel sample was collected at the profile's base, approximately 65 metres from the land surface.
- These samples were sent to the Three Gorges Research Centre for Geohazards at China University of Geosciences in Wuhan, Hubei Province, China for OSL dating.

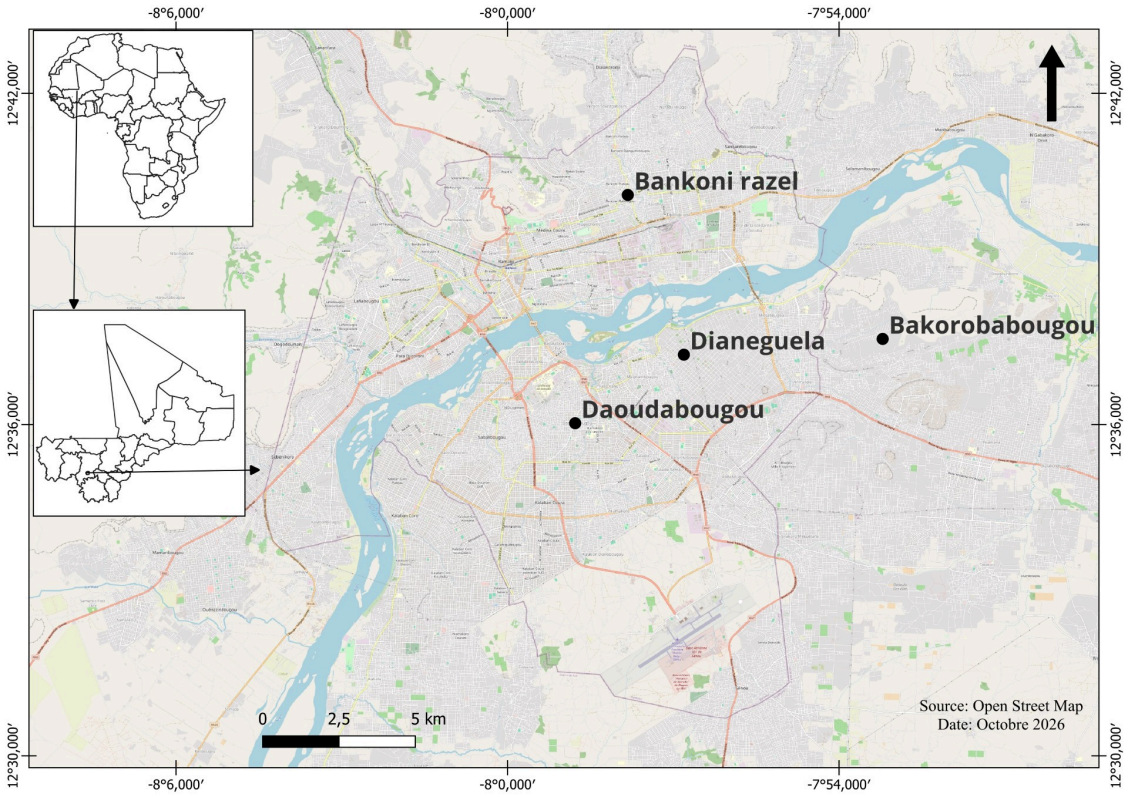


Figure 1: Location of the Quaternary outcrops at Bamako.

3. Geological and geomorphological settings

Bamako is situated on the northeastern edge of the Manding Plateau at 12°N and 8°W. This plateau extends eastward from the Futa Jalon Mountains. The city's elevation varies from 580 metres to 300 meters above the surface of the Niger River. In Bamako, four principal geological units are present: the crystalline basement at the southwestern edge of the city, three Paleozoic sandstone formations—the Sotuba, Koulouba, and Kati formations—Dolerite intrusions at the sill of Sotuba and nearby Dianeguela, and Quaternary alluviums comprising two layers: a laminated lacustrine layer topped by a cross-bedded fluviatile sand layer. The Quaternary layers are observable through quartzite pebbles at specific locations. The sandstone formations are the most prevalent lithology in the city, as illustrated in Figure 4.

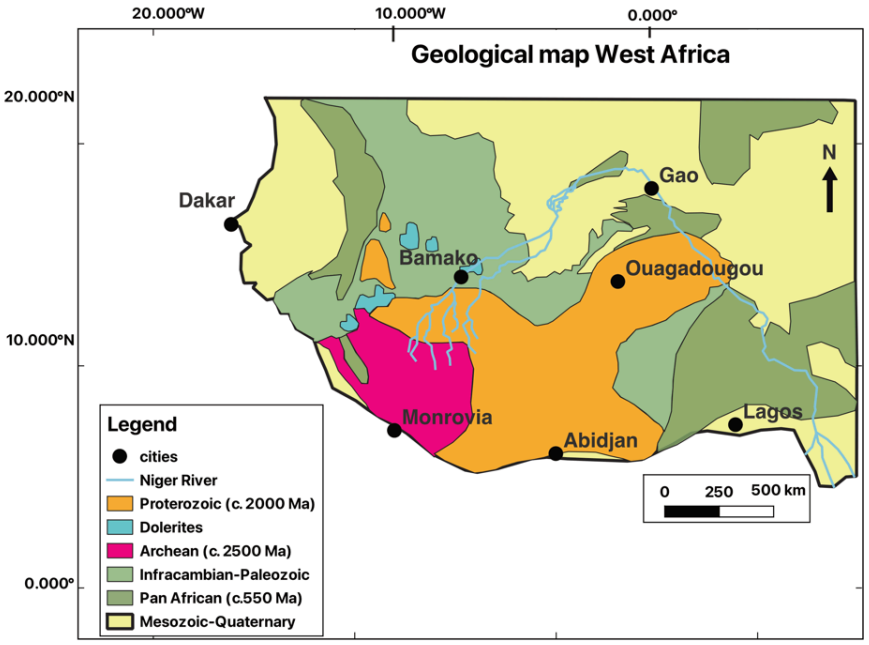


Figure 2: Geological map of West Africa (modified after Wright (Wright 1985)).

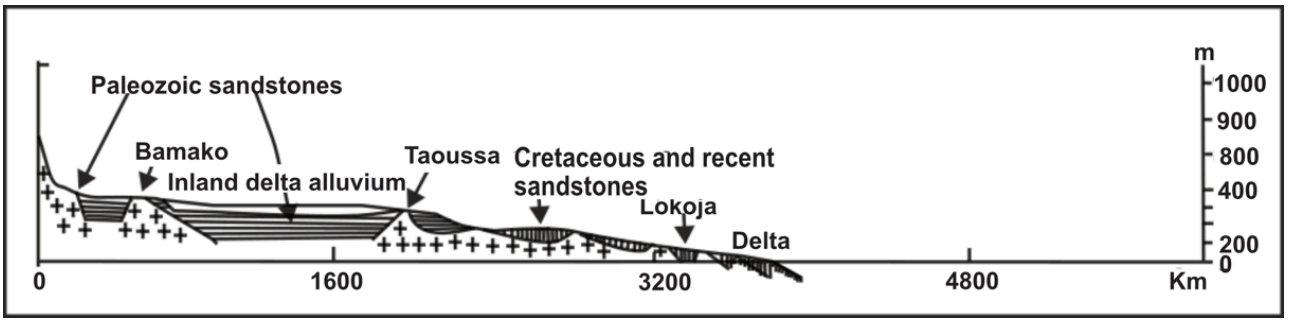


Figure 3: Longitudinal profile of the Niger River (modified after Faniran and Ojo (Faniran & Ojo 1980)).

The landforms of Bamako are primarily shaped by fluvial processes associated with the Niger River and its tributaries. The Niger River crosses the city from east to west, while the tributaries, mainly formed over Quaternary alluviums, flow from north to south. The Niger River valley is bordered by sandstone cliffs that connect the terraces and the alluvial plain via high, steep slopes. These cliffs include sandstone hills running along the Niger River from east to west, such as Lassa Kulu, Kuluba, and Point G Kulu. Within the valley, hills created by the dissection of the Niger River terraces are common, known locally as "kulubileni" (red hills) because of the duricrust caps that cover them. These hills are found along the Niger at Badalabougou, Magnambougou, Dianeguela, Bankoni Razel, and Badalabougou. A considerable part of the city lies within the Niger River floodplain, which experiences annual flooding. Some buttes and pinnacles, such as Kuluniyelege, result from differential erosion of flat sandstone formations. The tabular sandstone is highly fractured, displaying multiple, multidirectional lineaments.

Regionally, the Niger River flows from Guinea to Mali through ancient terranes and rocks dating from the Pan-African, Proterozoic, Archean, and Palaeozoic eras. These basement rocks exhibit dolerite intrusions at Taoussa in northern Mali and Sotuba in Bamako. They are illustrated in Fig. 2, which shows the different lithologies and their chronological order in West Africa, particularly within the Niger River basin. Fig. 2 also shows the longitudinal cross-section of the Niger River from its source in the Republic of Guinea to its estuary in the Atlantic Ocean off the coast of Nigeria.

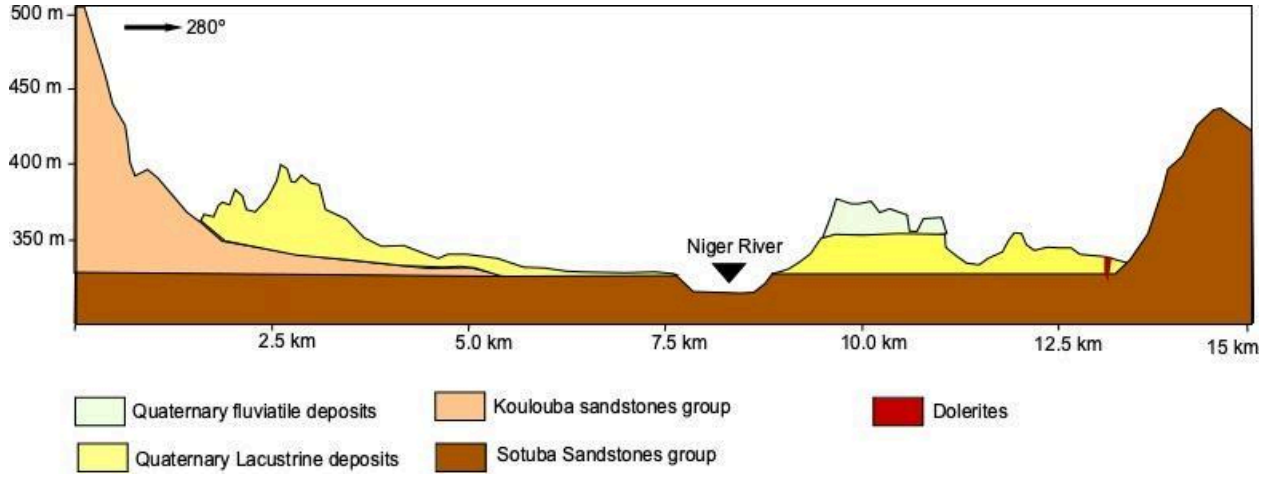


Figure 4: Geological cross-section of Bamako.

4. Results

4.1. The Quaternary outcrops of Dianeguela and Daoudabougou

At Dianeguela, the quaternary outcrops consist of two layers: a laminated silt layer overlain by fluviatile sand deposits. The lacustrine layer, 40 meters wide, lies on the Sotuba sandstone in disconformity. Its laminated features suggest an annual sequence. The fluvial sediments are made up of cross-bedded fluvial sand and rest discontinuously over the lacustrine deposits without any transitional layer. Fig. 5a & 5b show the stratigraphic profile of Dianeguela outcrops. The dark lacustrine deposits are covered by the reddish fluviatile deposits. Fig. 5c & 5d depict, respectively, the sedimentary structures of the fluviatile sediments composed of cross-bedded sands and the laminated lacustrine sediments.

The lacustrine deposits display soft-sediment deformation features, including clastic dikes, soft-sediment faults, microfaults, folds, and ball-and-pillow structures, indicating post-sedimentary seismic deformation. These are shown in Fig. 6. Figures 6a and 6b depict the same clastic dike from tangential and profile perspectives. Fig. 6c illustrates folds in the laminated lacustrine sediments, while Fig.

6d shows a micro-fault recorded within the same lacustrine deposits. Three clastic dikes with similar structure and texture were identified in the Dianeguela and Daoudabougou sediments (Dembele et al. 2016a, Dembele et al. 2016b).

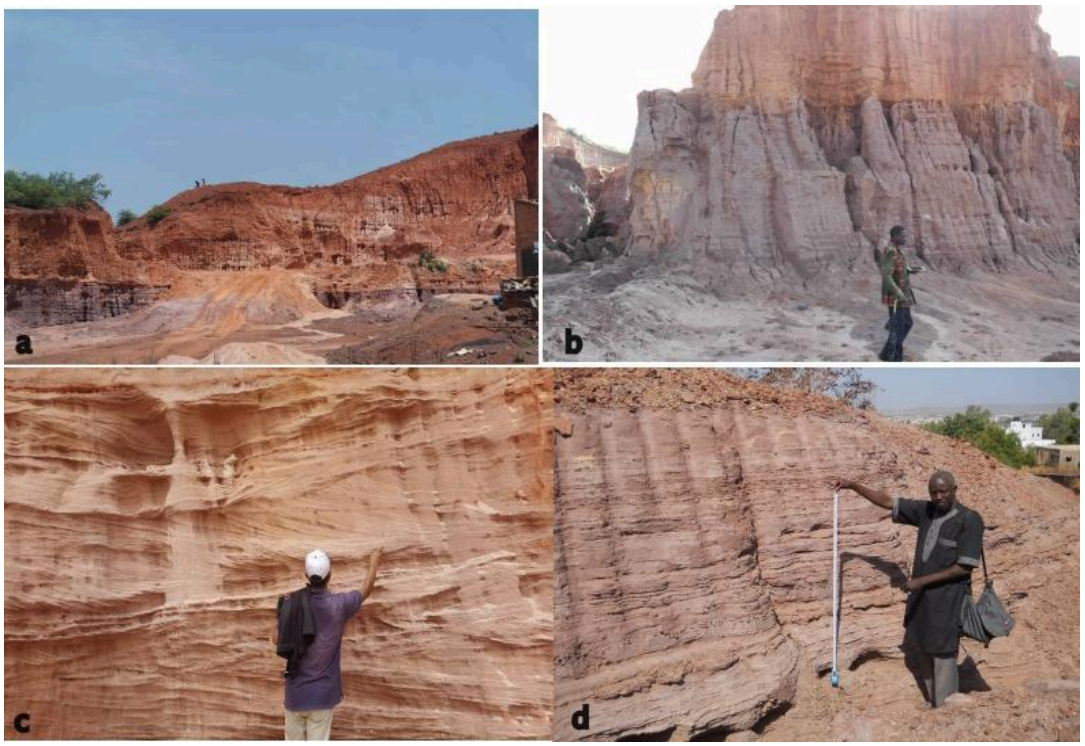


Figure 5: Quaternary outcrops of Dianeguela and Badalabougou a. Lacustrine laminated layer covered by fluvial sands; b. The lacustrine layer at the bottom is covered by fluvial sand. The sharp contact between the two layers can be observed; c. closer view of the cross-bedded fluvial sand; d. A closer view of the laminated lacustrine deposits.

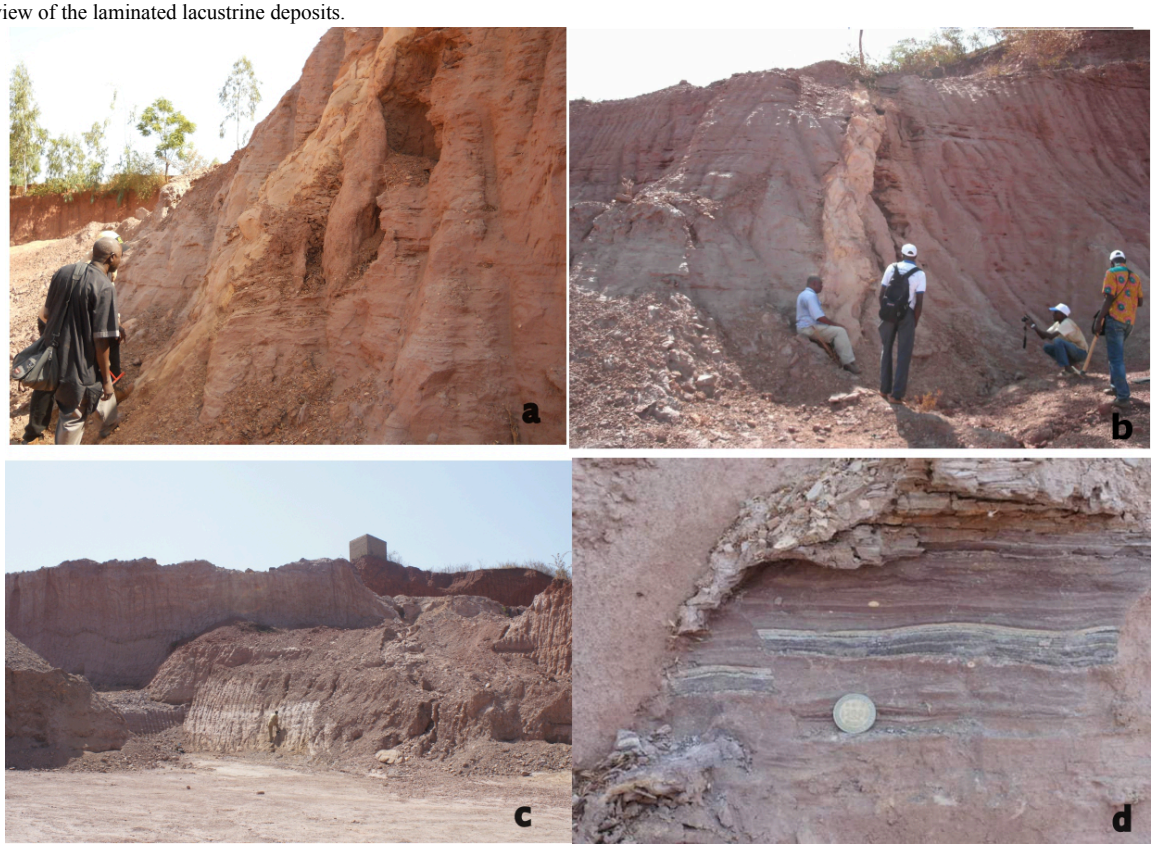


Figure 6: Soft sediment deformation in the Quaternary sediments a and b: Clastic dike in laminated lacustrine deposits; c. folds; d. inverse microfaultss.

4.2. The fluviatile outcrops of Bakorobabougou

Near the dolerite sills on the city's eastern edge, the Quaternary deposits of Bamako consist of cross-bedded fluvial sand deposits. The flow directions, indicated by the shape of the cross beds, are east-west, which contrasts with the Niger River's course. They sit above the Koulouba sandstone.

Soft sediment deformation structures are also observed in these fluviatile deposits. They include fault lines and fractures (Fig. 7b).



Figure 7: Fluviatile deposits at Bakorobabougou a. fluviatile outcrops; b. Faults in the fluviatile sediments.

4.3. The Bakarobabougou pebble layer

At the base of the fluviatile deposits and laterally against the Koulouba sandstone lies a layer of platy sandstone pebbles. Dembele (2016a) has studied them. They are aligned to form a paleoshoreline, indicating the presence of a paleolake. The sandstone layer next to the pebble shows evidence of water erosion creating notches characteristic of a lacustrine shoreline. The pebbles are arranged in a line at the footslope, as seen in Figs. 8a and 8b.



Figure 8: Pebble layers at Bakorobabougou in context a. on foot of the slope b. probable lacustrine shoreline.

4.4. The Bankoni Quaternary profile

The Bankoni Razel outcrop is situated on the left bank of the Niger River and consists of two alluvial hills. It is a substantial outcrop approximately 70 meters high, composed of silt, sand, and peat layers topped by a duricrust cap. Unlike the Quaternary deposits on the right bank, the Bankoni outcrop displays interbedded peat layers about 20 cm thick. These peat layers tend to be cyclical and separated by sand or silt layers 2 to 3 metres thick.

This type of profile is typical of river mouths. The outcrop belongs to a river that once fed a paleo lake. The peat layers probably formed during lacustrine transgressions, while the fine sand and silts result from lacustrine regression. During periods of transgression, the river and lake seasonally caused flooding in the area, leading to the anaerobic decay of organic matter that accumulates during the dry season. It is important to note that the area's climate is tropical, with two alternating seasons: dry and wet. Fig. 9a shows the high outcrop of Bankoni Razel left by construction workers, and Figures 9b and 9c display the peat layers they bear.

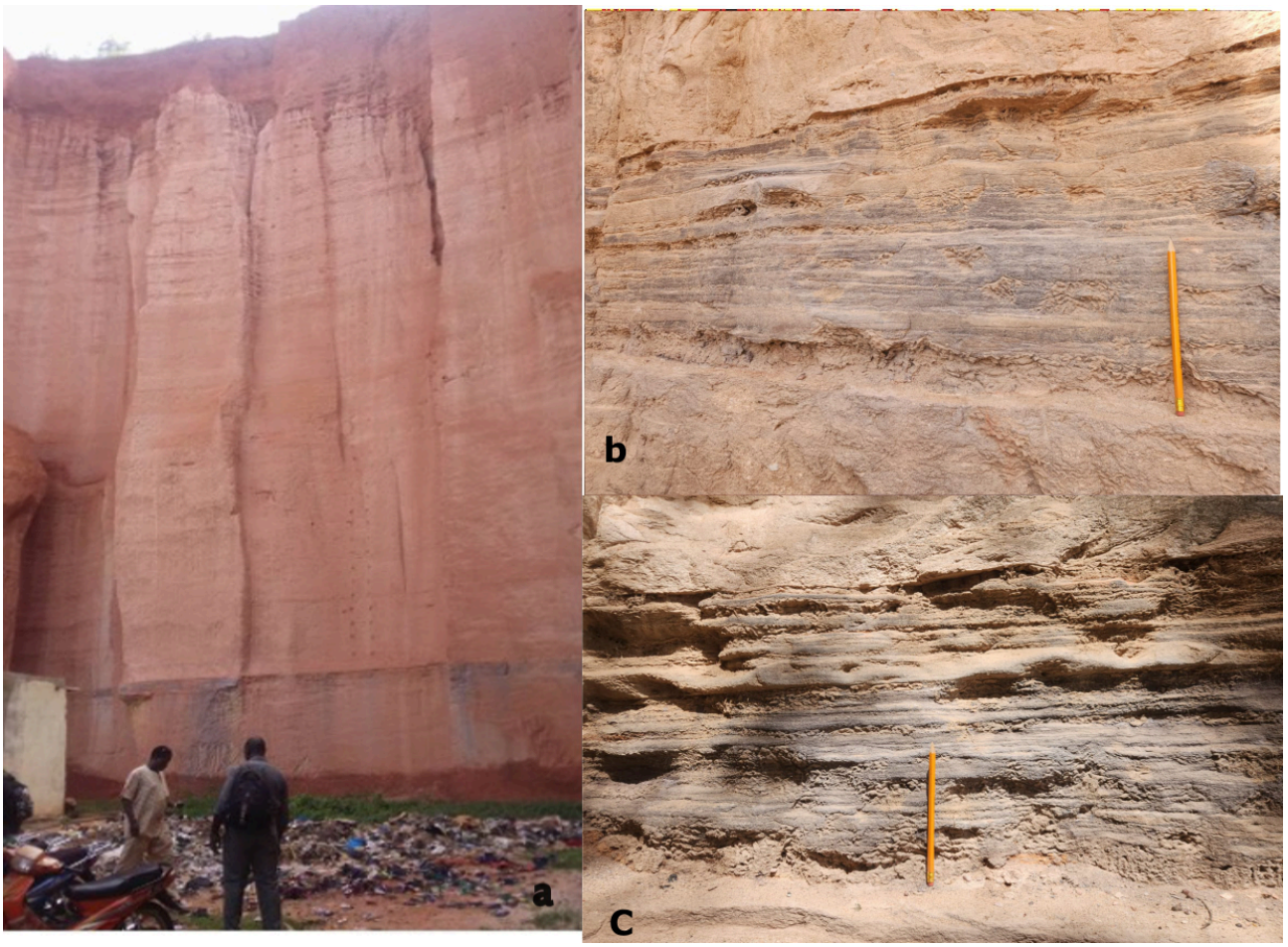


Figure 9: The Bankoni Razel profile a. the biggest Quaternary outcrops of Bamako, b and c. peat layers inside the Quaternary profile.

4.5. The age of the Quaternary deposits

Although it is critical, the OSL dating in this research provides a chronology for the Quaternary deposits. The outcrop of Bankoni Razel has been dated to 1.2 Ma using OSL. This age should be viewed with caution, as OSL dating is unreliable above 300 Ka. The samples taken from Dianeguela on the right bank of the Niger River yielded three age estimates, as shown in tab 1. The base was dated to 310 Ka, the middle to 280 Ka, and the top of the lacustrine layer—which marks the abrupt contact between the lacustrine deposits and the overlying fluviatile sand layer—to 176 ka. The deposits should be regarded as spanning from 1.2 Ma to 176 ka. Further dating is needed to establish a more precise chronology for these deposits. The same samples were sent for ESR dating, but results are still pending. When available, ESR dates will help confirm and refine the ages of the different outcrops, especially the Bankoni outcrop base, which appears much older.

Table 1: OSL dates of the Quaternary deposits.

Sample ID	Depth(m)	K(%)	U(ppm)	Th(ppm)	Water	No.of aliquots	Dose rate(Gy/ka)	Final De(Gy)	OSL Age(ka)
Sample 3	33	0.327±0.012	2.12±0.086	4.90±0.171	0.22±0.005	6[a]+12[b]	1.01±0.03	279±17.25	310.2±21.9
Sample 2	27	0.310±0.011	1.58±0.074	5.16±0.175	0.13±0.005	6[a]+12[b]	0.92±0.03	267.64±10.20	283.6±14.4
Sample 1	10	0.251±0.009	1.93±0.082	15.1±0.392	0.06±0.005	6[a]+12[b]	1.66±0.06	320.66±18.49	176.0±14.4
Clastic dike	27	0.359±0.012	1.30±0.063	5.60±0.190	0.12±0.005	6[a]+12[b]	0.94±0.03	236.02±7.45	252.4±11.9

[a] Number of aliquots by SAR, and [b] number of aliquots by SGC

5. Discussions

5.1. Correlation of the profiles

Comparing the Quaternary profiles can help make some assumptions about the Quaternary stratigraphy of Bamako.

The base rock consists of sandstone and, in certain locations, dolerite. Above the sandstone are laminated lacustrine layers, as seen at Bakorobabougou and Daoudabougou (Fig. 10a). Bakorobabougou's fluviatile layers are laid directly on top of the Koulouba sandstone (Figs 10c & 10d), which indicates it lacks the laminated fluviatile layer. It is important to highlight that Bakorobabougou is located downstream of Sotuba, while Daoudabougou and Dianeguela are situated upstream. Therefore, the lake formed upstream of the sill that initially acted as a natural dam. The Bankoni Razel profile is particularly notable because it alternates between fluviatile and lacustrine deposits, separated by peat layers (Fig. 10b). This deposit pattern is typical of a river mouth draining into a lake that recedes due to periodic fluctuations in lake levels.

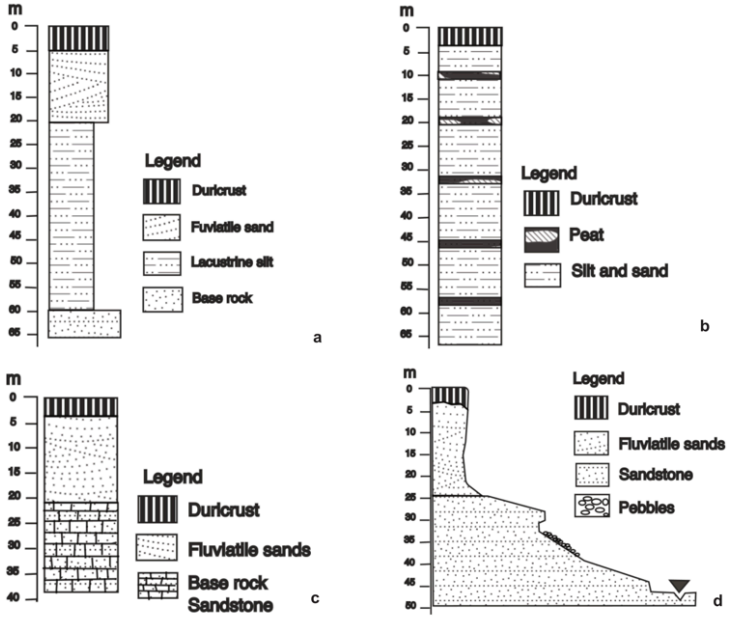


Figure 10: Quaternary profiles of Bamako a. Profile of Dianeguela, b. Profile of Bankoni Razel, c. Profile of Bakorobabougou, d. Pebble layer of Bakorobabougou.

5.2. Significance of Quaternary deposits to the evolution of the Niger river

Three critical findings must be emphasized from the results presented and the analyses of the different outcrops.

- The extensive presence of laminated lacustrine deposits across the city, upstream of the Sotuba sills, offers sedimentary evidence for a paleolake that existed prior to 176 ka.
- The sudden contact between the lacustrine deposits and the fluvial sediments indicates a rapid facies change. It seems clear that the paleolake abruptly drained into a river system.
- Soft-sediment deformation structures are present in the lacustrine deposits. Suggest the occurrence of seismic events in the area that they have recorded. It is, hence, possible to link the lake's catastrophic extinction to such seismic events that can trigger the opening of the waterway.

From these findings, it is possible to hypothesize that the Niger River, before 176 Ka, flowing from the Futa Jalon Mountains, fed a paleolake at Bamako upstream of the Sotuba sills, which has long acted as a natural dam, blocking its waters. Thus, the sill was higher than it is today, and the Niger River could not cross it. This type of lake overspill is documented

(Heidarzadeh et al. 2017, Huang et al. 2022). Around 176 ka, a significant geological event occurred, and the Niger River began to flow over the sill, as evidenced by the fluvial sediments. The presence of platy pebbles, a characteristic feature of shorelines, provides evidence for such a hypothesis (Cheng et al. 2008, Strasser et al. 2008, Heidarzadeh et al. 2017, Bacon et al. 2020, Liu et al. 2022, Sabatier et al. 2022).

Overall, the results suggest that the current Niger River is the product of the convergence of independent reaches during its evolution. A first reach originating from Guinea stopped at the sills of Sotuba, forming the Bamako palaeolake. A second reach, beginning downstream of the Sotuba sills, used to flow towards the area of Timbuktu, while the last reach extended from the Taousa sill to the Atlantic Ocean off the coast of Nigeria. The two reaches, downstream and upstream of the Sotuba sills, connected around 176 Ka ago, thereby unifying the upper Niger reaches. Therefore, the present Niger River appears to be the result of the joining of three independent rivers that merged during the Quaternary period.

6. Conclusions

The evolution of the Niger River in West Africa remains poorly understood. Few studies have examined this aspect of the river. Previous research has shown that the current Niger River was once the junction of two reaches: the upper reaches that were captured by the Tilemsi River through the Taousa sill. The discovery of lacustrine sediments covered by fluviatile sediments at Bamako, just upstream of the Sotuba Sills, sheds new light on the river's evolution. It appears that the Niger River flowed from Guinea to a paleolake at the site of Bamako until 176 ka. Therefore, after this period, the river began to flow over the Sotuba sill, connecting to the downstream reaches. It is evident that the Niger River has undergone river capture in this area, most likely triggered by an earthquake that opened the sill. Beyond the sedimentary evidence presented in this paper, the investigation should continue to examine geomorphological features upstream of the Sotuba in Bamako that could support the river capture hypothesis. These include research on paleoshorelines, fossil valleys, and river terraces.

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Credit author statement

Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation,Visualization, Writing: original draft, review & editing.

References

BACON, S.N., Jayko. A.S., Owen, L.A., Lindvall, S.C., Rhodes, E.J. Schumer, R.A., Decker, D.L. 2020. A 50,000-year record of lake-level variations and overflow from Owens Lake, eastern California, USA. Quaternary Science Reviews 238: 106312. https://doi.org/10.1016/j.quascirev.2020.106312

BEAUDET, G., COQUE, R., MICHEL, P., ROGNON, P. 1977. Y a-t-il eu capture du Niger? Bull. Assoc. Géogr. Franç., Paris 445-446: 215-222. https://doi.org/10.3406/bagf.1977.4977

CALVACHE, M.L., VISERAS, C. 1997. Long-term Control Mechanisms of Stream Piracy Processes in Southeast Spain. Earth Surface Processes and Landforms 22(2): 93-105. https://doi.org/10.1002/(SICI)1096-9837(199702)22:2%3C93::AID-ESP673%3E3.0.CO;2-W

CHARDON, D., GRIMAUD, J-L, ROUBY, D., BEAUVAIS, A., CHRISTOPHOUL, F. 2016. Stabilization of large drainage basins over geological time scales: Cenozoic West Africa, hot spot swell growth, and the Niger River. Geochemistry, Geophysics, Geosystems 17(3): 1164-1181. https://doi.org/10.1002/2015GC006169

CHENG, G., WANG, X., HE, X., FAN, J., FAN J. 2008. Outburst risk of barrier lakes in Sichuan, China. Journal of Mountain Science 5(3): 189-193. https://doi.org/10.1007/s11629-008-0208-7

CHUDEAU, R. 1919. La capture du Niger par le Taffassasset. Annales de Géographie 28(151): 52-60. https://doi.org/10.3406/geo.1919.9372

CROSBY, I.B. 1937. Methods of Stream Piracy. The Journal of Geology 45(5): 465-486. https://doi.org/10.1086/624559

DEMBELE, N.J., KEITA, D., TESSOUGUE M.M. 2016. Signification paléoenvironnementale des galets du profil stratigraphique de la rive droite du fleuve Niger à Bamako, Mali. Cahiers du CBRST 10: 19-33.

DEMBELE, N.J., KEITA, D., TESSOUGUE, M.M., CISSE, Y., DIALLO, B.A. 2016. Les structures de déformation des sédiments meubles dans les alluvions de la rive droite du fleuve Niger à Bamako, au Mali, et leur importance paléosismologique. Annales de la Faculté des Lettres, Arts et Sciences Humaines 1(22): 188-199.

FAN, D., LI,C. 2008. Timing of the Yangtze initiation draining the Tibetan Plateau throughout to the East China Sea: a review. Frontiers of Earth Science in China 2(3): 302-313. https://doi.org/10.1007/s11707-008-0018-9

FAN, N., KONG, P., ROBL, J.C., ZHOU, H., WANG, X., JIN, Z., LIU, X. 2021. Timing of river capture in major Yangtze River tributaries: Insights from sediment provenance and morphometric indices. Geomorphology 392: 107915. https://doi.org/10.1016/j.geomorph.2021.107915

FANIRAN, A., OJO, O. 1980. Man's physical environment: An intermediate physical geography. London: Heinemann Educational Books Ltd. https://api.semanticscholar.org/CorpusID:127062450

GAUSSEN, J., GAUSSEN, M. 1988. Le Tilemsi préhistorique et ses abords: Sahara et Sahel malien. Cahiers du Quaternaire 11: 1-25.

GLOCK, W.S. 1931. The Development of Drainage Systems: A Synoptic View. Geographical Review 21(3): 475-482. https://doi.org/10.2307/209434

GOUDIE, A.S. 2005. The drainage of Africa since the Cretaceous. Geomorphology 67(3): 437-456. https://doi.org/10.1016/j.geomorph.2004.11.008

HEIDARZADEH, G., BALLATO, P., HASSANZADEH, J., GHASSEMI, M.R., STRECKER, M.R. 2017. Lake overspill and onset of fluvial incision in the Iranian Plateau: Insights from the Mianeh Basin. Earth and Planetary Science Letters 469: 135-147. https://doi.org/10.1016/j.epsl.2017.04.019

HUANG, X., BALLATO, P., HASSANZADEH, J., GHASSEMI, M.R., STRECKER, M.R. 2022. Late Pleistocene lake overspill

and drainage reversal in the source area of the Yellow River in the Tibetan Plateau. Earth and Planetary Science Letters 589: 117554. https://doi.org/10.1016/j.epsl.2017.04.019

LIU, J., WANG, P., CHEN, X., SHI, W., SONG, L., HU, J. 2022. The Changes in Drainage Systems of Weihe Basin and Sanmenxia Basin Since Late Pliocene Give New Insights Into the Evolution of the Yellow River. Frontiers in Earth Science 9. https://doi.org/10.3389/feart.2021.820674

MIKESELL, L.R., WEISSMANN, G.S., KARACHEWSKI, J.A. 2010. Stream capture and piracy recorded by provenance in fluvial fan strata. Geomorphology 115(3): 267-277. https://doi.org/10.1016/j.geomorph.2009.04.025

MOORE, A.E., COTTERILL, F.P.D. 2022. The Zambezi: Origins and Legacies of Earth's Oldest River System. Large Rivers: 457-487. https://doi.org/10.1002/9781119412632.ch16

PELLETIER, J.D. 2003. Drainage basin evolution in the Rainfall Erosion Facility: dependence on initial conditions. Geomorphology 53(1): 183-196. https://doi.org/10.1016/S0169-555X(02)00353-7

RUNGE, J. 2022. The Congo River, Central Africa. Large Rivers: 433-456. https://doi.org/10.1002/9781119412632.ch15

SABATIER, P., MOERNAUT, J., BERTRAND, S., VAN DAELE, M., KREMER, K., CHAUMILLON, E., ARNAUD, F. 2022. A review of event deposits in lake sediments. QUATERNARY, 5(3). https://doi.org/10.3390/quat5030034

SCHUMM, S. A. 1956. "Evolution of drainage systems and slopes in badlands at Perth Amboy , New Jersey . " GSA Bulletin 67(5): 597-646. https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

SCHUMM, S.A., MOSLEY, M.P., WEAVER, W. 1987. Experimental fluvial geomorphology.1987. Experimental fluvial geomorphology. United States, John Wiley and Sons, Inc., New York, NY. https://doi.org/10.1002/jqs.3390060110

SHUGAR, D.H., CLAGUE, J.J., BEST, J.L., SCHOOF, C., WILLIS, M.J., COPLAND, L., ROE, G.H. 2017. River piracy and drainage basin reorganization led by climate-driven glacier retreat. Nature Geoscience, 10(5), 370-375. https://doi.org/10.1038/ngeo2932

STRASSER, M., SCHINDLER, C., ANSELMETTI, F.S. 2008. Late Pleistocene earthquake-triggered moraine dam failure and outburst of Lake Zurich, Switzerland. Journal of Geophysical Research: Earth Surface 113(F2). https://doi.org/10.1029/2007JF000802

WOLMAN, M.G., LE MEUR, C., GIEGENGACK, R.F. 2022. The Nile River: Geology, Hydrology, Hydraulic Society. Large Rivers: 704-736. https://doi.org/10.1002/9781119412632.ch24

WOODWARD, J.C., MACKLIN, M.G., KROM, M.D., WILLIAMS, M.A.J. 2022. The River Nile: Evolution and Environment. Large Rivers: 388-432. https://doi.org/10.1002/9781119412632.ch14

WRIGHT, J.B., HASTINGS, D.A., JONES, W.B., WILLIAMS, H.R. 1985. Geology and mineral resources of West Africa. London: George Allen & Unwin (Publishers) Ltd. https://doi.org/10.1007/978-94-015-3932-6

ZHENG, H. 2015. Birth of the Yangtze River: age and tectonic-geomorphic implications. National Science Review 2(4): 438-453. https://doi.org/10.1093/nsr/nwv063

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