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Identification of a fossil wood specimen in the Red Sandstone Group of southwestern Tanzania: stratigraphical and tectonic implications

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Abstract—A piece of silicified fossil wood was found in the middle part of the Red Sandstone Group of the Songwe-Kiwira area, north of Lake Malawi (Nyasa) in the Western Branch of the East African Rift System. It is identified as *Pahudioxylon* Chowdhury *et al.*, 1960. Until now, *Pahudioxylon* has been strictly restricted to the Cenozoic. The occurrence of *Pahudioxylon* in the Red Beds Formation supports a Cenozoic (Miocene) age rather than a Mesozoic age for this formation. Comparison with a collection of modern species gives information about the environmental conditions of deposition of the Red Sandstone Group. A discussion follows on the significance of the Red Sandstone Group during the Rukwa-Malawi Rift development. © *1998 Elsevier Science Limited.*

Résumé—Un échantillon de fois fossile silicifié a été découvert dans la partie moyenne du "Red Sandstone Group" de la région de Songwe-Kiwira, au nord du Lac Malawi (Nyasa), dans la branche ouest du rift est-africain. Il est identifié comme *Pahudioxylon* Chowdhury *et al.*, 1960. Jusqu'à présent, tous les *Pahudioxylon* ont été découverts dans des sédiments cénozoïques. La présence de ce *Pahudioxylon* au sein du "Red Sandstone Group" est donc un argument en faveur d'un âge cénozoïque (Miocène) plutôt que mésozoïque pour cette Formation. La comparaison avec une collection d'espèces modernes suggère des informations sur les conditions environnementales du dépôt du "Red Sandstone Group". La signification du "Red Sandstone Group" dans le développement du rift de Malawi-Rukwa est discutée. © *1998 Elsevier Science Limited.*

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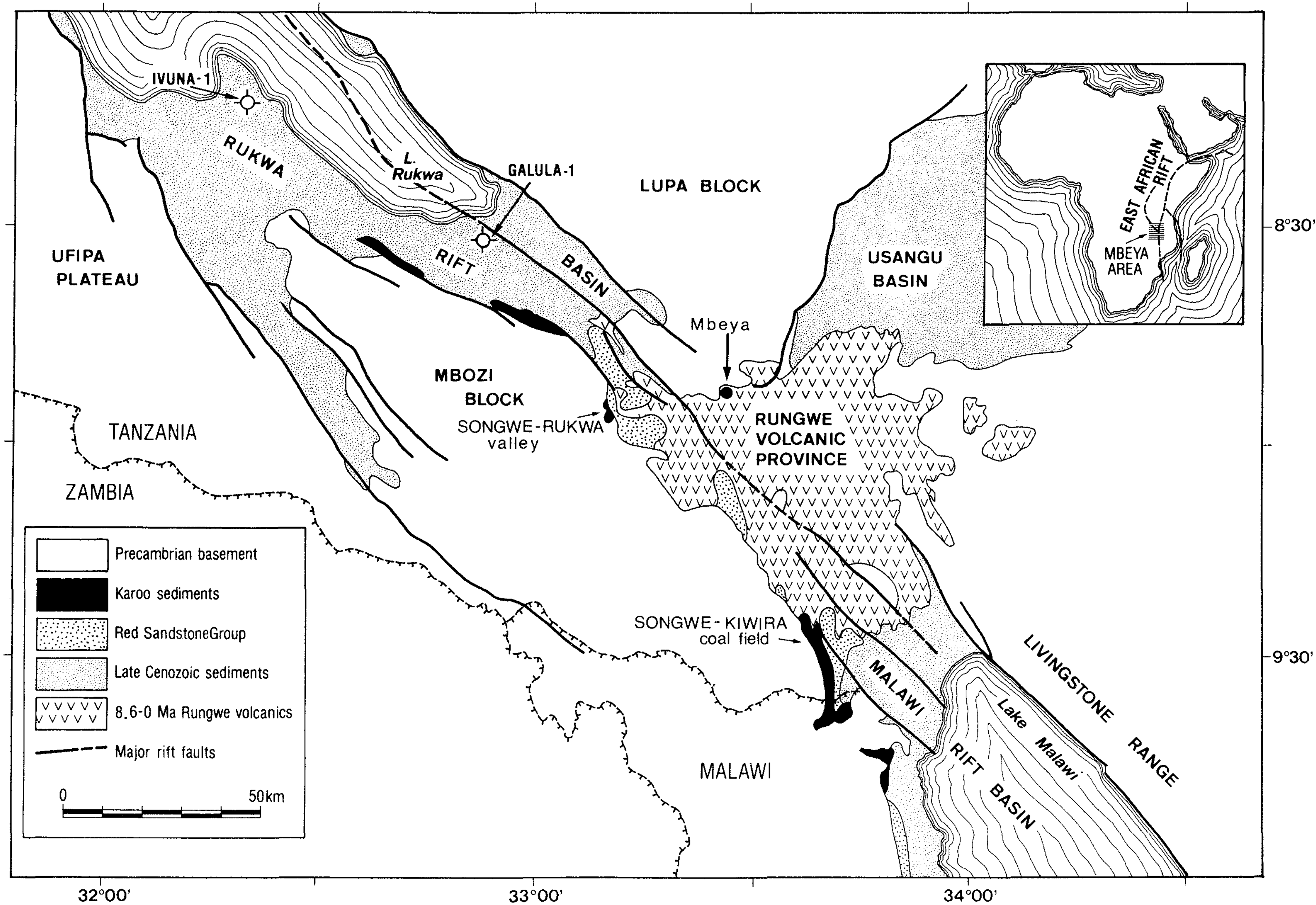
INTRODUCTION

Discussions about Middle Jurassic-Cretaceous sedimentation and tectonic activity in the Rukwa-Malawi Rift segment (Fig. 1), in relation to post-Karoo alkaline volcanism has been put forward by many authors (Dypvik *et al.*, 1990; Castaing, 1991; Delvaux *et al.*, 1992; Mbede, 1993; Ebinger *et al.*, 1993; van der Beek *et al.*, 1998). Red beds are found in Karoo (K3), Jurassic and Cretaceous rocks, as well as Tertiary, and there are several units which appear similar. This is a stratigraphical problem which demands serious mapping to clearify the problems, particularly in the Rift Valley.

For a long time, the red sandstones and mudstones ("Red Beds") of the Red Sandstone Group in southwest Tanzania have been considered as Cretaceous, on the basis of long distance lithological correlation with the Dinosaur


IVUNA-1
RUKWA
L. Rukwa
GALULA-1
RIFT
BASIN
LUPA BLOCK
UFIPA PLATEAU
USANGU BASIN
EAST AFRICAN RIFT
MBEYA AREA
Mbeya
MBOZI BLOCK
SONGWE-RUKWA valley
RUNGWE VOLCANIC PROVINCE
TANZANIA
ZAMBIA
SONGWE-KIWIRA coal field
MALAWI
RIFT BASIN
Lake Malawi
LIVINGSTONE RANGE
MALAWI
Precambrian basement
Karoo sediments
Red SandstoneGroup
Late Cenozoic sediments
8.6-0 Ma Rungwe volcanics
Major rift faults
0
50km
8°30'
9°30'
32°00'
33°00'
34°00'

Beds in north Malawi (Dixey, 1928; McConnell, 1972; Spence, 1954; Jacobs *et al.*, 1990). The discovery of fossil dinosaur eggs in the Red Beds in the Songwe-Rukwa Valley (Fig. 1) by W. G. Aitken of the Geological Survey of Tanganyika (Grantham *et al.*, 1958) strengthens this view, but more recent workers have not been able to re-locate the discovery site. Later, Biyashev and Pentel'kov (1974) found relics of mollusc and reptile fauna in so-called "Cretaceous Red Beds" in Usevia, northwest of Lake Rukwa. However, these fossils were dated late Middle Jurassic (Callovian; Smirnov *et al.*, 1974). Near Mbeya, the Red Beds are intruded by carbonatite bodies, radiometrically dated between Late Jurassic and Late Cretaceous (Pentel'kov and Voronovskiy, 1977). The stratigraphical relation between rift-typical carbonatites and sediments of the Red Sandstone Group is an important argument for a Late Jurassic-Cretaceous phase of continental rifting in East Africa.

Renewed discussions on the age of the Red Sandstone Group arose from new biostratigraphical data obtained on the Ivuna-1 and Galula-1 exploration wells drilled in the Rukwa Rift Basin (Fig. 1) (Wescott *et al.*, 1991). Microfaunal assemblages suggest that the Red Sandstone Group is of Neogene age, not older than Miocene. This interpretation is based on a limited diatom assemblage of diatom *Melosira* (*Aulacoseira*), *granulata* and/or *agassizii* found in the cuttings of the wells (Wescott *et al.*, 1991). Both species are known since the early Late Miocene in Africa (Fourtanier, 1987). Morley *et al.* (1992) consider the Red Sandstone Group as Upper Miocene and suggest that these Miocene Red Beds also occur in the other basins of the Western Rift Branch. However, Kilembe and Rosendahl (1992) report the finding of *Classopollis classoides* and *C. dampieri* in three out of four cutting samples of the Red Sandstone Group in the Ivuna-1 well between 1615 and 1860 m deep. These were identified by palynologists from the Tanzanian Petroleum Development Corporation and indicate a Middle Jurassic-Middle Cretaceous age (Srivastava, 1988). A possible pollution by drilling mud is ruled out by Kilembe and Rosendahl (1992) since no such pollen was found in the rest of the well. This observation contradicts the age scheme of Wescott *et al.* (1991) and instead favours a Late Mesozoic age for the Red Sandstone Group. A possible reworking of Jurassic/Cretaceous fauna during Upper Miocene time is invoked by Mbede (1993) to explain the coexistence of both Cretaceous and Tertiary fauna. In conclusion, the age of the Red Sandstone Group is still controversial.

The discovery of a fragment of silicified tree in the Red Sandstone Group in the Songwe-Kiwira sector of the northern Malawi Rift in Tanzania provides a new opportunity to better constrain the age of these sediments. This paper describes the palaeontological analyses and identification of the wood sample and discusses the implications of this new biostratigraphical data in terms of stratigraphy and tectonic evolution.

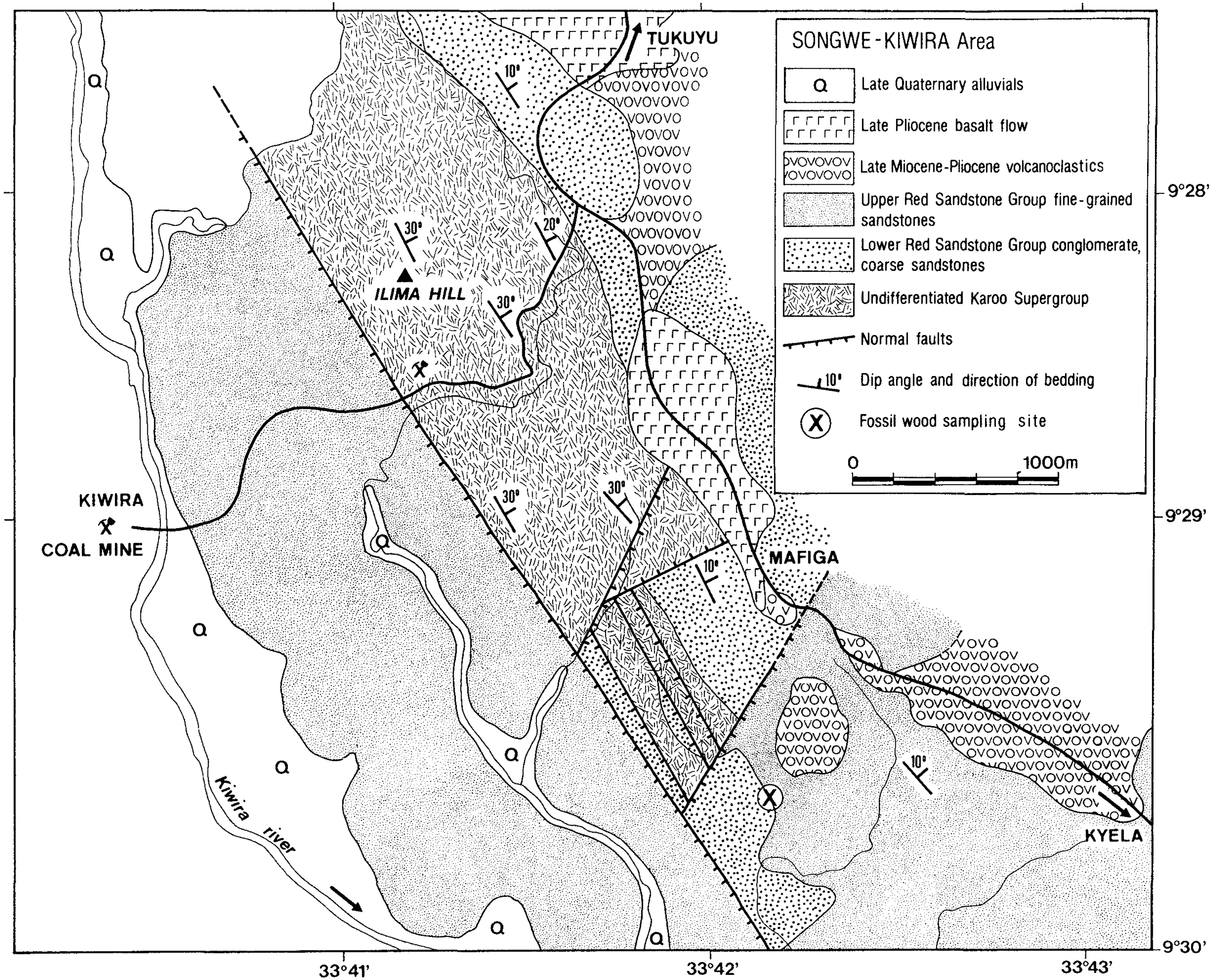
TECTONIC SETTING

The Western Branch of the East African Rift (Fig. 1) developed into a sigmoidal shape on Proterozoic mobile belts which surround the Tanzanian Archean Craton (McConnell, 1972; Delvaux, 1991). The central part of the Western Branch follows the general northwest-southeast orientation of the Ubendian Belt (Theunissen *et al.*, 1992, 1996) and is occupied by the Tanganyika, Rukwa and Malawi (Nyasa) Rift Valleys.

The northwest trending south Rukwa and north Malawi Rift segments cut the northeast trending Usangu Basin in the Mbeya area (Fig. 1). Together, they form a triple junction which is characterised at its centre by the Rungwe Volcanic Province (Harkin, 1960; Delvaux and Hanon, 1993). Sediments of the Karoo (Permo-Triassic) and Red Sandstone Groups are exposed along the western side of the Rukwa Basin and the northern Malawi Basin (Grantham *et al.*, 1958; Harkin and Harpum, 1957). More than 900 m of the Red Sandstone Group and 700 m of the Karoo were drilled in the Rukwa Basin (Wescott *et al.*, 1991; Mliga, 1994).

The Red Sandstone Group was deposited in an alluvial-fan, fan-delta and fluvial-deltaic environment (Dypvik *et al.*, 1990; Mliga, 1994). The period of deposition of the Red Sandstone Formation is characterised by high surface temperature, increased humidity and weathering and the formation of palaeogenetic minerals (Dypvik and Nesteby, 1992). Possible signs of syn-sedimentary tectonic activity are observed

Figure 1. *Simplified geological and structural map of the Mbeya triple junction in the Western Branch of the east African Rift System. (basement, Karoo, Red Sandstone Group, Late Cenozoic lacustrine sediments and volcanics, position of the Galula and Ivuna wells).*


SONGWE-KIWIRA Area
Q
Late Quaternary alluvials
Late Pliocene basalt flow
Late Miocene-Pliocene volcanoclastics
Upper Red Sandstone Group fine-grained sandstones
Lower Red Sandstone Group conglomerate, coarse sandstones
Undifferentiated Karoo Supergroup
Normal faults
10°
Dip angle and direction of bedding
Fossil wood sampling site
0
1000m
TUKUYU
ILIMA HILL
KIWIRA
COAL MINE
MAFIGA
KYELA
Kiwira river
30°
20°
9°28'
9°29'
9°30'
33°41'
33°42'
33°43'

in the Red Sandstone Group of the Songwe-Kiwira coal field (Dypvik *et al.*, 1997) and along the Songwe-Rukwa Valley near the Mbeya-Tunduma road.

Near Mbeya, palaeostress investigations on minor faults in the Red Sandstone Group documents that deposition of the Red Sandstone Group occurred in a pure extensional stress field, with a northeast-southwest trending direction of horizontal principal extension (Delvaux *et al.*, 1992). In the northeast trending Usangu Basin, sedimentation is apparently limited only to the Plio-Pleistocene (Ebinger *et al.*, 1989; Stone *et al.*, *in press*).

RED SANDSTONE GROUP IN SONGWE-KIWIRA

The differentiation between the Red Beds of the Karoo and the Red Sandstone Group may in several cases be very difficult, due to similar lithologies. Systematic field mapping is needed to sort out the complex Red Bed setting.

The Songwe-Kiwira area is part of the northern end of the Malawi Rift Basin (Fig. 1). It is well known for its important coal deposit in the Karoo series. The Red Sandstone Group overlies the latter. The Red Beds are exposed along the Tukuyu-Kyela road, in the Ilima Hill and in the badlands on the western side of the road (Fig. 2). Besides sandstones, the Red Beds comprise also mudstones and marls. The sediments either rest directly on the basement, or overly Karoo sediments with a major angular unconformity of 10-30° (Dypvik *et al.*, 1990). This indicates that a tectonic episode occurred between the deposition of the Karoo series and the Red Beds. The Red Beds attain a thickness of about 600 m (McKinlay, 1965). They are unconformably covered by Late Cenozoic volcano-sedimentary deposits (Ebinger *et al.*, 1989). The pyroclastics and lavas have erupted from the Rungwe volcanic centres since 8.60 Ma (Ebinger *et al.*, 1993). In Ilima, the base of the Neogene is conglomeratic with pebbles of weathered basalt. Both the Red Beds and the Karoo series are cut by northwest to north-northeast trending faults, which also seem to affect the Neogene deposits (Harkin, 1955, 1960).

The Red Sandstone Group is subdivided in two units on the basis of lithological characteristics (Dixey, 1928; Dypvik *et al.*, 1990; Back, 1994). The lower Red Beds unit consists of fining upwards sequences of medium- to coarse-grained sandstones, with pebble rich conglomerate layers along the erosional bases. Sedimentary facies and structures like crossbedding and ripple marks indicate fluviatile deposition. The silicified fossil tree was discovered in the uppermost conglomeratic horizon of this unit (sample location: 09°29′25″S, 33°42′10″E). The upper Red Beds comprises fine-grained sandstones interbedded with silt- and claystone. In the sandstones, crossbedding structures, parallel laminations and ripples occur in places; palaeochannels are observed. This indicates an alluvial fan/fluviatile environment of deposition. Palaeocurrent direction measurements on crossbedding structures indicate an unimodal transportation to the east-northeast, across the trend of the basin towards its centre (Dypvik *et al.*, 1990; Back, 1994).

IDENTIFICATION OF A FOSSIL WOOD SAMPLE FROM THE RED BEDS FORMATION

The fossil material consists of two blocks of dense rock, brown-dark red coloured with dimensions reaching 15 × 10 × 10 cm. Several polished sections were realised: transversal, tangential and radial.

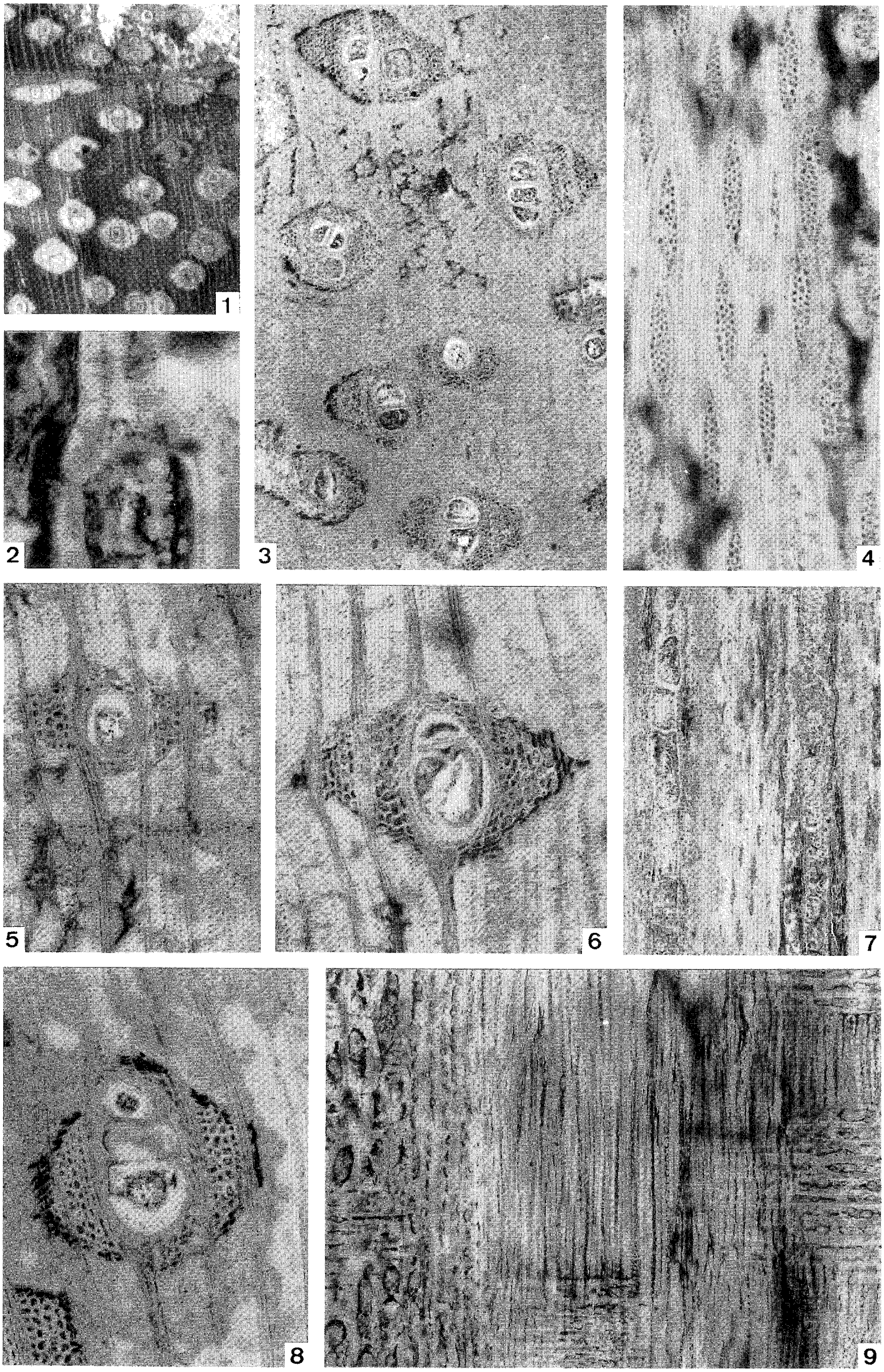
Dicotyledonae
Family: Caesalpiniaceae
Genus: *Pahudioxylon* Chowdhury *et al.* 1960

Description

Transverse section (Fig. 3: 1, 3, 5, 6, 8).
The wood structure is heteroxylous with growth rings marked by terminal parenchyma (Fig. 3: 5), most often 4-5 cells thick, and by widening of the rays. The radial parenchyma consists of 1 to 4 rows of cells. The ray density is 8-10 per horizontal mm (Fig. 3: 1). The lozenge-aliform parenchyma is locally confluent around 1-2-3 pores or groups of pores (Fig. 3: 5, 6, 8). The vessels are circular to oval, with a diameter of 110 to 260 μm and a density of 2-3 per mm^2. Most vessels are isolated, but radial groups of 2-3 vessels are not exceptional. The fibres are thick-walled (Fig. 3: 5, 6).

Tangential section (Fig. 3: 4, 7).
The rays are multiseriate and homogeneous to weakly heterogeneous, (2)-3-4-(5) cells wide and 10-20 cells high (Fig. 3: 4). The mean ray width is 50 μm and their height, between 240 and 350 μm. Some uniseriate rays of 10 cells high

Figure 2. *Geological setting of the Songwe-Kiwira area with the sampling sites marked.*



are present. The ray density is 8-9 per mm and they have a tendency towards a storeyed arrangement. The studied material does not show septate fibres. Fibre length is difficult to measure exactly. Vessel elements are between 200 and 300 μm long (Fig. 3: 7) and present simple perforations. The height of the parenchyma cells varies between 70 and 160 μm and their width between 20 and 25 μm. Some (chambered?) parenchyma of fibre cells, containing a file of prismatic crystals, accompany the rays. Other crystal cells are restricted to the perimeter of the paratracheal parenchyma.

Radial section (Fig. 3: 2, 9).

The rays are mainly formed by elongate procumbent cells. Exceptionally some square cells contribute to a weak heterogeneous character. Figure 3 (2) shows alternate to subopposite polygonal vestured pits of the vessels.

Synthetic description

The wood structure is diffuse-porous, with vessels isolated or in radial files of 2-3 vessels. The vessel elements are short, with simple perforations. They have a shape of alternate vestured and polygonal pits. The axial parenchyma is lozenge-aliform. The confluent parenchyma is sometimes tangentially wrapping 2-3 pores or groups of pores. The terminal parenchyma marks the tree ring borders, where the rays widen. Rays are grouped in series of 3-5, homogeneous with weak tendency, towards heterogeneity and reaching 20 cells in height. There is a tendency towards a storeyed structure. Prismatic crystals are in paratracheal parenchyma. The fibres are thick-walled.

Identification

The preceding description fits with the anatomical structure of the *Caesalpiniaceae*. According to the key provided by Müller-Stoll and Mädel (1967, pp164-165) for the woods of those plants, the specimen of this study conforms to the characters of *Pahudioxylon* Chowdhury *et al.*, 1960 (subfamily *Caesalpinioideae*). The main characters of the genus are: vessels regularly spaced, isolated or in short radial groups (2-4 cells), with simple perforation plates and alternate small pits; intervascular pits identical to ray/vessel pits; libriform fibres non-septate; paratracheal parenchyma aliform or aliform-confluent; presence of initial and terminal parenchyma; rays homogenous, 1-4 cells wide (Müller-Stoll and Mädel, 1967). Today, the genus *Pahudioxylon* includes 18 species (Vozenin-Serra, 1981). According to Guleria (1984) and Vozenin-Serra and Privé-Gill (1991), a revision of the 18 species assigned to the genus *Pahudioxylon* should be undertaken, as most of them are distinguished on the basis of characters that might be intraspecific variability. Furthermore, it has not been possible to compare our specimen with all the previously described species. Therefore, the specimen of this study is preferably identified as *Pahudioxylon* sp.

The genus *Pahudioxylon* has been established by Chowdhury *et al.* (1960) for fossil woods close to that of the living *Pahudia* Miq. The present day genus *Pahudia* was used for Asian specimens very close to *Afzelia* Smith, which was considered to be restricted to Africa. The only difference between the two genera was the partly fused filaments of *Pahudia*. This character has however been proved to be variable. Consequently, *Pahudia* is a later synonym of *Afzelia* (Leonard, 1950; Soerianegara and Lemmens, 1993) and all those taxa are now called *Afzelia*. In other respects, Louvet (1966) created the genus *Afzelioxylon* for fossil woods close to the wood of the living *Afzelia*. Since *Pahudia* is identical to *Afzelia*, and because *Pahudioxylon* has priority to *Afzelioxylon* (Prakash *et al.*, 1967), all the fossil woods of both *Pahudia*- and *Afzelia*-types are to be called *Pahudioxylon.* Moreover, as *Afzelia* and *Intsia* Thouars are very close or even indistinguishable

Figure 3. Pahudioxylon *Chowdhury* et al. *1960, anatomical features. Red Sandstone Group (southwest Tanzania). The specimens are housed in the Royal Institute of Natural Sciences, specimen n° IRSNB - b 3404. 1. Transverse section x10. Gross view showing pores wrapped in aliform axial parenchyma and a growth ring marked by marginal parenchyma. The lozenge-aliform parenchyma is locally confluent. 2. Longitudinal radial section x240. Slide n° 1: Detail of a vessel element showing the alterante or subopposite polygonal pits. 3. Transverse section x30. Slide n° 2: Groups of pores wrapped in aliform axial parenchyma crossed by rays. One row of marginal parenchyma is visible in the middle of the picture. 4. Longitudinal tangential section x75. Slide n° 3: Multi-(2-3-4)seriate rays in tangential section; rays are homogenous to weakly heterogenous and show a tendency to be storeyed. 5. Transverse section x60. Slide n° 4: Vessel surronded by aliform parenchyma; note the multiseriate rays and the growth ring marked by 3-4 rows of marginal parenchyma. 6. Transverse section x60. Slide n° 5: Two vessels wrapped in aliform parenchyma crossed by multiseriate rays. 7. Longitudinal tangential section x30. Slide n° 6: Two vessels showing the vessel elements short length and their surrounding axial parenchyma. Note the approximately horizontal end walls. 8. Transverse section x60. Slide n° 7: Three vessels wrapped in aliform parenchyma crossed by multiseriate rays. 9. Longitudinal radial section x150. Slide n° 8: Section showing homogenous rays with procumbent cells, wide, thin-walled cells of axial parenchyma and thick walled fibres.*

anatomically (Guleria, 1984; Soerianegara and Lemmens, 1993), *Pahudioxylon* also comprises woods of *Intsia*-type. Due to the small size and state of conservation of the speciment, it is not possible to provide a more specific determination, and to test if it is a new species. Also, it is not possible to state if the *Afzelioxylon* species described by Louvet (1966) is identical.

Pahudioxylon is known from various localities from Africa (Algeria, Ethiopia, Chad), Asia (Borneo, Cambodia, India, Vietnam) and Europe (Hungary) (Vozenin-Serra, 1981). All those records of *Pahudioxylon* are strictly restricted to the Tertiary (Early Eocene to Pliocene; Vozenin-Serra, 1981) or the Pleistocene (Vozenin-Serra and Privé-Gill, 1991). Although no definitive stratigraphical conclusions can be drawn on the occurrence of *Pahudioxylon* in the Red Sandstone Formation, it nevertheless supports a Cenozoic (Miocene) rather than Mesozoic age for these beds.

Comparison with present-day material

After comparison with 260 specimens from the collections of the Royal Museum for Central Africa belonging to the groups *Caesalpiniaceae* and *Mimosaceae*, it appears that the sample is closer to the modern *Afzelia*, and particularly with *Afzelia pachyloba* Harms, *A. bipindensis* Harms and *A. africana* Smith. The qualitative and quantitative differentiation of the *Afzelia* group with regards to *Acacia* and *Albizia* is based mainly on the vessel diameters, the shape of the axial parenchyma, by the regular presence of terminal parenchyma where the rays widen, the tendency of the rays towards a storeyed structure and by the density and consistency in the ray shape.

Present-day ecology

The group *Afzelia* Smith is typically palaeotropical, of which at least two species (*Afzelia pachyloba* and *Afzelia bipindensis*) are largely distributed in the Cameroon-Gabon and Congo forest domains and are submitted to intense forest exploitation (Aubreville, 1968).

The species *Afzelia bipindensis* Harms is a 15-40 m high tree with a 10-140 cm diameter, living in the dense rain forests of medium altitude. The mean annual rain fall is between 1450 and 1750 mm, and the dry season is 1-2 months long. These are trees of hard ground, present in the gallery forests (Letouzey, 1968).The species *Afzelia pachyloba* Harms reaches 35 m in height, and 80 cm in diameter. It is encountered mainly in dense rain forest of low to medium altitude, as in secondary forests (Leonard, 1952).The species *Afzelia africana* Smith ex Pers, is a tree of hard ground Sudano-Guinean forests, favouring forested savannah and gallery forests in savannah (Aubreville, 1968, Leonard, 1952).

STRATIGRAPHICAL AND TECTONIC IMPLICATIONS

There is no doubt that the Dinosaur Beds in north Malawi are of Cretaceous age (Dixey, 1928; Jacobs *et al.*, 1990), but their correlation with the Red Sandstone Group in Malawi is still questionable. The Red Sandstone Group is older than the Rungwe volcanics (starting at 8.6 Ma) and the Older Lake Beds (Late Miocene-Pliocene-Pleistocene). In the Rukwa area, the Red Beds might be either Miocene (Wescott *et al.*, 1991), or Jurassic-Cretaceous (Kilembe and Rosendahl, 1992). In the Songwe-Kiwira area, the identification of the fossil wood sample as *Afzelioxylon* Louvet 1966 suggests that the middle part of the Red Sandstone Group cannot be older than Eocene, and most probably Miocene. Since this new dating is based only on one sample, this conclusion cannot be considered definitive and it does not rule out both Karoo or Mesozoic age for at least part of the Red Sandstone Group.

Based on apatite fission track (AFT) thermochronology, van der Beek *et al.* (1998) reported three phases of accelerated cooling and denudation in the north Malawi-Rukwa Rift area. The oldest and more widespread event is recorded during the Triassic-Early Jurassic. A Late Jurassic-Early Cretaceous event is recorded only in the western flanks of the north Malawi (Songwe-Kiwira area) and Rukwa Rift. These are precisely the areas of deposition of the Red Sandstone Group. The latest event started in the Early Tertiary (40-50 Ma), with more than half of the denudation occuring during the last 20 Ma. These cooling events can be correlated to continental-scale tectonic events and major phases of plate reorganisation (Foster and Gleadow, 1993). In the present geological context, the deposition of the Red Sandstone Group might be related to both the Late Jurassic-Early Cretaceous and Early Triassic denudation events. However, the stratigraphical occurrence of *Afzelioxylon* Louvet 1966 apparently suggests that the Red Sandstone Group might correspond to the Early Tertiary event. As pointed out by van der Beek *et al.* (1998), this event is coeval with a major plate reorganisation in the Indian Ocean, while the Late Jurassic-Early Mesozoic event is coeveal with the intitiation of rifting in the South Atlantic (Foster and Gleadow, 1993; Janssen *et al.*, 1995).

Volcanism in the Western Branch of the East African Rift is generally used as an indicator of the onset of Late Cenozoic rifting. Volcanic products can be easily dated and provide a good reference for estimating the relative age of sedimentation and faulting. Volcanism and faulting started at *ca* 12 Ma in the Kivu Rift to the north, and at *ca* 8.6 Ma in the Rungwe area to the south (Ebinger *et al.*, 1997; Kampunzu *et al.*, 1998). This difference is interpreted as evidence for along-axis propagation of lithospheric extension. A Tertiary age for the Red Sandstone Group of Songwe-Kiwira would imply the existence of an earlier phase of rifting during the Tertiary. As mentioned above, the deposition of the Red Sandstone Group occurred only in northwest trending basins in a pure extensional stress field with a northeast-southwest direction of principal extension. This phase differs markedly from the Late Tertiary one, characterised by basaltic volcanism in the junction of both northwest trending and northeast trending basins under a near-radial extensional stress field (Delvaux *et al.*, 1992).

CONCLUSION

Despite the preponderance of arguments in favour of a Late Jurassic-Cretaceous age for the Red Sandstone Group in southwestern Tanzania, the limited diatom assemblage found in the Galula and Ivuna wells (Wescott *et al.*, 1991) supports for the first time a Miocene age. The presence of *Pahudioxylon* in the Red Sandstone Group of Songwe-Kiwira is a further indication that the age of the beds might be Cenozoic rather than Mesozoic. In addition, it gives some indications concerning the ecology and climate during the time of deposition. It also suggests the existence of an Early Tertiary phase of rifting in the north Malawi-Rukwa Rift, coeval to a cooling stage evidenced by AFT data and controlled by a major plate tectonic reorganisation in the Indian Ocean.

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