Naturwissenschaften Kurze Originalmitteilungen

Naturwissenschaften 76, 518–520 (1989)

Natural Rain Forest Fires in Eastern Borneo During the Pleistocene and Holocene

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Lowland tropical rain forests have been generally regarded as ecosystems in which disturbance by natural fires was excluded due to fuel characteristics and moist climatic conditions [1]. However, recent findings demonstrate that climatic conditions during the past six millennia have favored the occurrence and spread of fires in the Amazon rain forest [2]. We are now able to show that natural fires have repeatedly occurred in the lowland dipterocarp rain forest of East Borneo since the late Pleistocene.

Interannual climatic variability, associated with the "El Niño-Southern Oscillation" (ENSO) phenomenon, leads to periodic droughts within great parts of Indo-Malesia. A distinct and well documented ENSO event occurred in 1982–83 and caused an extreme dry spell in the equatorial zone of insular South-East Asia [3]. A similar strong event was recorded and reported in Indonesia in 1877–78 [4]. In Balikpapan (East Kalimantan) the rainfall between July 1982 and April 1983 was only one-third of the annual mean; the rainfall deficit was similar in other coastal areas of Borneo. The drought stress of the lowland rain forest vegetation led to the drying of vines and shedding of leaves by evergreen species, and the turf-like accumulation of organic matter in the peat swamp forests was desiccated up to 2 m. In that period numerous fires set by slash-and-burn cultivators and other forest conversion purposes went completely out of control. At the end of the drought an area totalling 5×10^6 ha of forested land in east and northeast Borneo was affected by fire or severe drought stress [5, 6].

Palynological records and paleoclimatological models show that during the last glaciation in the Pleistocene and at the Pleistocene/Holocene transition the tropics were for the most part cooler and drier than today. In the highlands of equatorial Malesia the Quaternary climate most different from that of the present was during the period c. 18000 to c. 15000 BP [7]. Radiometric and pollen data from the lowlands covering that period are very sparse. However, evidence of a widespread savannah climate during the last glaciation within some regions of tropical Africa and America, where modern rain forests are now growing [8], suggests that similar conditions were found in today's lowlands of equatorial Asia and on the formerly exposed Sunda shelf [9].

The impact of the 1982–83 ENSO event on drought stress and flammability of the lowland rain forest biome led to the assumption that both the more seasonal climate at the end of the Pleistocene and the oscillations of the modern rain forest climate must have favored the occurrence of wildfires.

This hypothesis was supported by the permanent presence of a potential fire source. Burning coal seams extending to or near the surface are found at about 30 locations in East Kalimantan (Fig. 1). During average wet years the burning edges of the coal seams slowly progress through the rain forest with-

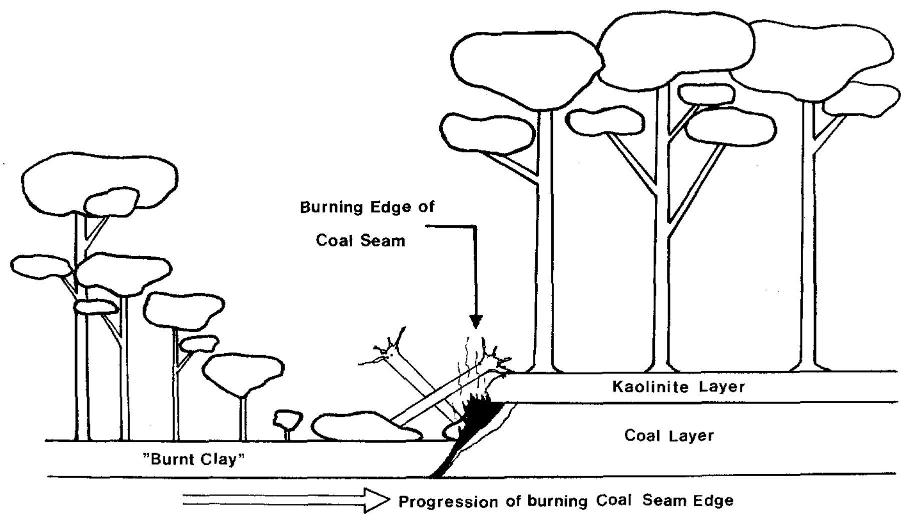

Fig. 1. Model of progression of burning subsurface coal seam edge

Fig. 2. Primary rain forest along the Sangkulirang – Muara Wahau Road, East Kalimantan, affected by the 1982–83 drought and wildfires (photo taken in September 1987). Almost all standing trees were killed and were successively covered by climbers. The successional and regeneration patterns of the burned forest are the subject of several investigations [6] (Photo: J. G. Goldammer)

out igniting the forest fuels. During the 1987 drought it was witnessed by the authors that the lowered fuel moisture content and the availability of surface fuels led to the buildup and spread of a wildfire starting from a burning coal seam in Bukit Soeharto National Park.

In a field study in East Kalimantan in early 1989 the theory was tested whether the coincidence of periodic flammability of the rain forest ecosystem and the presence of obviously long-lasting fire sources would have triggered long-return interval forest fires.

The project was carried out along the new road between Sangkulirang and Muara Wahau (Fig. 2) which served as a transect between the coast (Strait of Makassar) and about 75 km inland. In the vicinity of active coal fires an old burnt coal seam was investigated. Thermoluminescence analysis of the burnt clay (kaolinite) on top of the extinguished fire provided evidence that this coal seam had burned between c. 13200 and c. 15300 BP. Charcoal was sampled in primary rain forest in an upslope terrain in order to avoid dislocation effects by sedimentation. ^{14}C-ages of charcoal along the transect yielded dates between 350 and 17510 BP (Table 1). A sample from a sedimented charcoal layer in Kutai National Park provided through the project of Shimokawa [10] yielded an age of c. 1040 BP.

These first findings on old rain forest fires and fire sources in Borneo are far from being complete. However, they reveal that coal fires were active during the last glaciation and that forest fires occurred at that time and later on. The case study may also add new considerations to the controversial debate whether evolutionary diversification of rain forest species took place in an ageless, undisturbed and stable environment, or whether it was stimulated by disturbances [11].

It seems likely that during the last glaciation a pronounced moisture gradient between the highlands and the drier Sunda shelf and today's remnant lowlands have created a wet rain forest refugium in the uplands and a drier ecotone in the lowlands. In the lowlands the vegetation had to cope with frequent droughts and fires. Forest die back due to these disturbances can be seen as a great evolutionary chance because it created gaps and accelerated regeneration dynamics. Thus it has prevented the take-over of a few dominant species which would lead to forest communities poor in species.

Table 1. Location of radiocarbon-dated soil charcoal in primary rain forest, East Kalimantan (Borneo)

Sample No.	Location[a]	^{14}C-age [years BP]	Laboratory No.
1	km 30.0	10560 ± 110	HAM 2755
2	km 141.5	350 ± 60	HAM 2752
3	km 153.0	1280 ± 70	HAM 2753
4	km 153.5	17510 ± 310	HAM 2754
5	km 45.0	1040 ± 70	HAM 2756

[a] Locations of samples 1 to 4 refer to the Sangkulirang – Muara Wahau Road. Location of sample 5 refers to the logging road network in Kutai National Park

We thank B. Zentgraf for his basic and constructive ideas and his field support, R. Andi Abdoerrachman for logistic and technical support and E. Shimokawa, Kagoshima University, for providing a charcoal sample from Kutai National Park. We thank P. Becker-Heidmann, Isotope Dating Laboratory, University of Hamburg, for his immediate ^{14}C-dating by Liquid Scintillation Counting, and Chr. Goedicke, Rathgen Research Laboratory, Staatliche Museen Preussischer Kulturbesitz Berlin, for immediate TL dating. M. A. Gill, C.S.I.R.O. Canberra, has critically reviewed this paper. This research was sponsored by the Volkswagen Foundation.

Received September 13, 1989

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Naturwissenschaften 76, 520 – 521 (1989)

Occurrence of Krypton and Xenon in the Bakreswar Thermal Spring Gases

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The purpose of the present study was to determine the relative abundance of the noble gases in the emanations released from the Bakreswar thermal springs (23.9°N, 87.4°E). The natural gas released from the three principal thermal springs at Bakreswar contain 1.8 % helium and 2.3 % argon. Recently, a field laboratory was set up at Bakreswar in order to recover helium from the emanating gases on a regular basis. Chatterjee et al. [1] have shown that the argon component has a non-atmospheric isotopic abundance. The natural outflow of significant quantities of helium can possibly be attributed to the leakage of primordial mantle gas through a hydrothermal reservoir, or it could possibly connote the presence of higher concentrations of radioactive minerals spread over a large volume which lie embedded within the circulatory paths of the thermal spring waters. Because a reservoir containing radioactive minerals might also contain the heavier noble gases krypton and xenon derived through various nuclear processes, it was thought worthwhile to measure and compare the relative abundances of these two elemental gases in the thermal spring emanations. Nitrogen and other similarly active constituents in the sample gases were removed by circulating the gas repeatedly over hot titanium in a glass manifold system. The enriched gas was analyzed with a gas chromatograph. Helium was used as a carrier gas. At room temperature both krypton and xenon are strongly adsorbed. The temperature of the column containing molecular sieve 5A was therefore raised to 140 °C which permitted the elution of both gases. Identification of the peaks was established by injecting 5 μl of krypton and xenon separately.

Table 1. Abundance of krypton and xenon

Source	Kr [%]	Xe [%]	Kr/Xe	
Bakreswar	1.34×10^{-3}	5.12×10^{-3}	0.262	
Atmosphere	1×10^{-4}	0.09×10^{-4}	11.1	
Spontaneous and neutron-induced fission of uranium in pitchblende	4.91	28.46	0.172	[3]
Spontaneous fission of ^{235}U			0.261	[4]

The terrestrial noble gases may be considered as having a primordial component along with a component arising from their secondary production through well-known nuclear processes. The production of helium from the disintegration of radioactive minerals is fairly large and widespread. Because helium has a high mobility together with a comparatively lower retentivity in minerals, the radiogenic component (He_{rad}) intermingles rapidly with the primordial component (He_{prim}). Thus, terrestrial helium can always be considered as a combination of both as suggested by Tolstikhin [2].

$$He_{terr} = He_{rad} + He_{prim}$$

The relative amounts of krypton and xenon from the Bakreswar thermal springs as obtained by us is shown in Table 1 along with a comparison of the ratio Kr/Xe obtained from other sources.

The ratio Kr/Xe obtained from Bakreswar indicates that it significantly differs from the value obtained from atmospheric air, but closely resembles that derived from fissionogenic materials. This leads us to suggest that the primordial component of the two heavy noble gases which must have contributed to their composition in the atmospheric air is absent in gases derived from significant terrestrial depths. This suggests the possibility that both xenon as well as krypton have been removed to a large extent from their free states under the influence of high temperature and pressures existing within the terrestrial mantle, thus enabling them to combine with highly electronegative elements such as fluorine to form the clathrate compounds XeF_2 and KrF_2 to-

