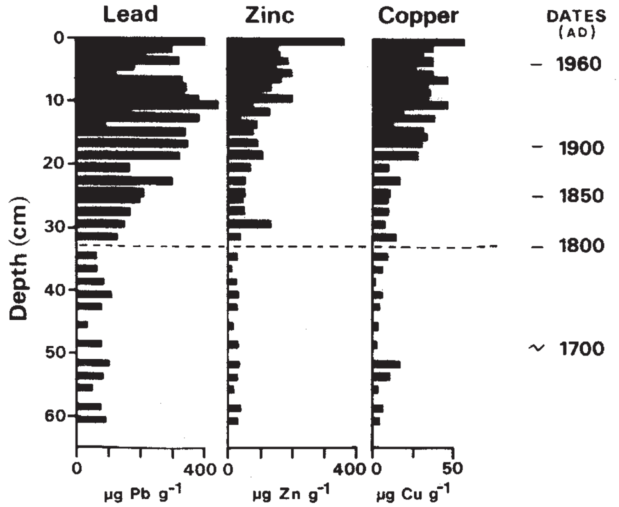

Fig. 3 Concentrations of Pb, Zn and Cu from the Loch Enoch sediment core. Dotted line signifies point of change.

digestion, the precision of the results are, respectively, 4.7, 0.9 and 3.8 $\mu g\ g^{-1}$ ($n = 14$). The background concentrations (Table 2) show that there are no geochemical anomalies in the catchment. The slightly lower Cu and Zn and somewhat higher Pb concentrations, compared with the mean for freshwater sediments[24], are a result of the granites in the catchment[25]. The increased concentrations (Fig. 3) and sedimentary fluxes (Table 1) can be accounted for by increased deposition from the atmosphere[26], a situation common in remote and rural lakes[27–29]. It has been shown that atmospheric contamination of lake waters by trace metals is correlated with acidification[30,31], and that contamination of sediments is correlated with sedimentary evidence of acidification[26,27,32]. This latter relationship holds true for Loch Enoch and all these relationships are consistent with expectations derived from the acid precipitation hypothesis.

We cannot prove that an increase in acid deposition was responsible for the acidification of Loch Enoch and similar lakes in Galloway, but we have shown that alternative hypotheses, as presently formulated, are inadequate. Land-use change may play a part in other areas, but at present it is clearly not applicable to the Galloway sites. For this hypothesis to be tested by palaeoecological means, examination of an acidified site in an area of low acid deposition, where heathland regeneration has occurred concurrently, is required.

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Sediment and pollen evidence for an early to mid-Holocene humid period in the eastern Sahara

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A major problem in the study of Holocene palaeoenvironments of the arid and wind-deflated Sahara is the low preservation potential of sediments from which a record of past climatic change can be established. Several indirect and imprecisely dated pieces of evidence have suggested humid episodes in the Holocene that may have supported more productive ecosystems and denser human populations than today. Searches for reliable proxy data on past climates, however, have failed to yield satisfactory results. We report here the discovery of buried lake muds in north-west Sudan, in the hyperarid core of the Eastern Sahara, which yield sedimentological and palynological data clearly interpretable as recording an early to mid-Holocene humid episode that supported a relatively-deep stratified lake surrounded by tropical savanna woodland vegetation.

The site lies in the Oyo Depression in NW Sudan at 19°16′N and 26°11′E, 510 ± 20 m above sea level (Fig. 1). The depression is surrounded by bedrock and contains Holocene lacustrine sediments buried by variable depths of dune sand[1]. It lies in the hyperarid core of the Sahara, with an estimated mean annual rainfall of ~5 mm (ref. 2), northerly winds with mean daily average velocity of 2–20 km h^{-1}, daily average relative humidity of 20–60% and estimated evaporation rates of ~5 m yr^{-1} (ref. 3). The area is in the zone of absolute desert vegetation whose southern limit is ~500 km south of the site[4] (Fig. 1). Vegetation is confined to oases, supported by artesian water, and to wadi channels where episodic rainstorms produce transient communities of annuals and herbaceous perennials[4].

Table 1 Radiocarbon dates from the Oyo sediments

Site and depth from surface (cm)	Material analysed	Radiocarbon laboratory number	Age (yr BP)
Hole-6, 170–180	Algal sapropel	SMU-1232	4,920 ± 200
Hole-6, 270–280	Algal sapropel	SMU-1233	5,880 ± 80
Hole-6, 310–320	Algal sapropel	SMU-1231	6,100 ± 80
Hole-6, 460–470	Algal sapropel	SMU-1230	8,490 ± 90
Hole-6, 460–470	Charcoal	AA-253	8,030 ± 280
Auger-1, 460	Charcoal	A-2826	8,900 ± 120
Auger-1, 180	Algal sapropel	A-2820	4,590 ± 140
Well-2, 200	Charcoal	A-2951	8,720 ± 170

The auger-1 site samples were collected from the basin sediments 150 m north-west of the hole-6 pit; the well-2 charcoal sample was recovered from the base of the Zone I sediments exposed in a hand-dug well 260 m west of the hole-6 pit, at a depth of 200 cm from the surface, near the margin of the basin. The analyses were conducted at the Radiocarbon Laboratory of Southern Methodist University, Texas (SMU) and at the Arizona National Science Foundation Regional Facility for Accelerator Mass Spectrometry, Tucson, Arizona (A).

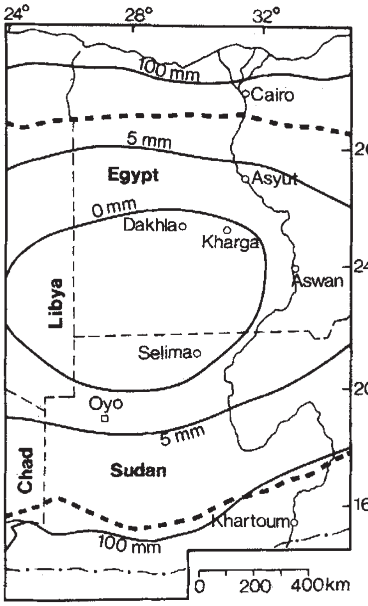

Fig. 1 Map of the Eastern Sahara region showing the location of the Oyo site, the 0, 5 and 100-mm mean annual precipitation limits (after Dubief[2]), the northern and southern limits of absolute desert (- - -) and the northern limit of the savanna (-·-·-·) (both after White[4]).

The sample site is in a small basin, ~1.0×0.5 km in size, in a 2-km wide depression open to the south-west and bounded by sandstone escarpments. The sediments were discovered in 1980 and sampled in 1982 and 1983, by hand augering and by digging a 5-m deep pit (hole-6 pit) in the centre of the basin[1]. Undisturbed overlapping 1-m lengths of sediment were recovered from the pit face in aluminium trays each 5 cm in width and depth. The lowest levels were collected by discontinuous bulk sampling because groundwater made tray sampling impossible. Four levels in hole-6 pit and three from nearby auger holes were dated by radiocarbon analysis (Fig. 2, Table 1). The radiocarbon dates of algal sapropel can be considered to be maximum values because of the possibility of error due to older carbonates. The charcoal from the 460–470-cm level in hole-6, dated by the tandem accelerator mass spectrometer (TAMS), indicates a potential discrepancy, but the large standard deviation precludes any firm conclusions about the magnitude of the carbonate error.

Sedimentological analysis suggested that the sequence can be divided into three major zones[5]. Zone 1 consists predominantly of finely laminated (0.1–1.0-mm) carbonate muds interbedded with sequences of pure white and grey laminae, dark organic bands and bioturbated horizons. The finely laminated muds are composed of green/brown and cream microcrystalline dolomite with trace amounts of clay minerals. Annual deposition of these couplets is suggested by comparing sedimentation rates estimated from ^{14}C dates (Fig. 2; 1 cm every 11–15 yr) with the counted average of 13 couplets cm^{-1}. Units of pure white and grey laminations consist predominantly of calcite with minor amounts of quartz and dolomite and are always associated with dark organic-rich bands composed of algal remains (Fig. 3).

Zone I sediments indicate carbonate deposition in a stratified lake with stagnant bottom waters[6-8]. The predominance of dolomite with an olive-green colour and absence of burrowing organisms through most of this zone suggests reducing conditions, characteristic of arid perennial lakes receiving a restricted seasonal supply of fresh water[8]. The association of white and grey laminations, organic bands and bioturbated horizons (Fig. 3) suggests that episodic increased inflow of calcium-bearing freshwater into the basin and/or temperature fluctuations are responsible for triggering calcite precipitation, algal blooms and weakening of the halocline.

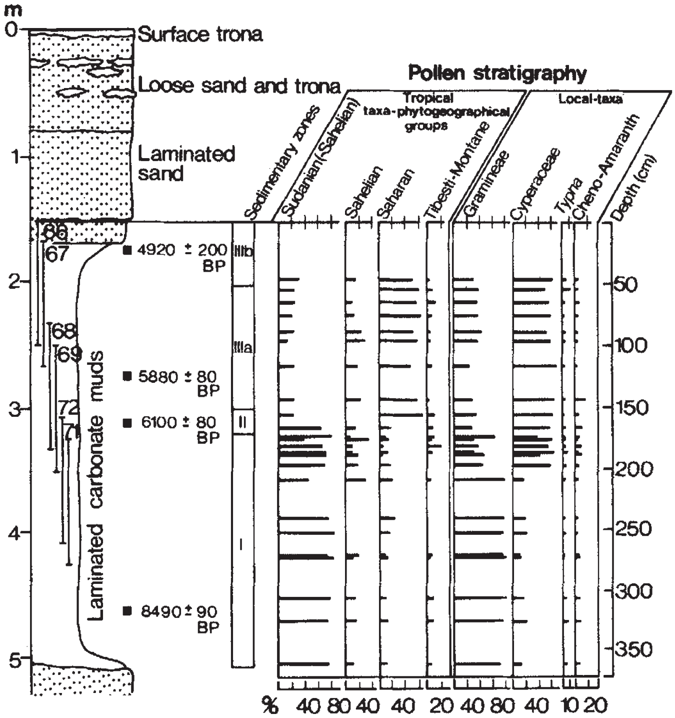

Fig. 2 A summary diagram showing the sediment stratigraphy, positions of the hole-6 1-m tray samples (numbered), positions and values of the radiocarbon age estimates and the pollen stratigraphy of the main groups. The phytogeographical pollen groups are expressed as percentages of the tropical taxa and the sum of the local taxa is the pollen total for the 'local' percentages.

Zone II sediments consist of laminated carbonate muds similar to the green/brown and cream laminations of zone I but with irregularities in thickness, abundant soft sediment deformation structures and evidence of downslope resedimentation and slumping of sediment blocks. Such increased sediment instability may have been caused by lowered lake levels.

Zone III consists of a coarsening upwards sequence of highly deformed muds and sands. The deformed and crudely bedded dolomitic muds of zone IIIa contain significant amounts of windblown sand, which may indicate shallowing of the lake body. Final desiccation is indicated by the crudely bedded and bleached aeolian sands of zone IIIb (Fig. 2).

So far, 55 pollen taxa have been recorded (by J.C.R.) in the sediments, belonging to the following phytogeographical groupings[9-12]: (1) Sudano-Sahelian taxa, found today in the tropical savannas of north-central Sudan and adjacent territories of Africa; (2) Sahelo-Saharan taxa with modern distribution in the thorn scrub and herbaceous desert belt of North Africa; (3) Saharan taxa, today confined to the Sahara and adjacent Arabian deserts. (These tropical taxa ((1)–(3) above) are listed in Table 2.) (4) Tibesti-Montane elements, so designated because the nearest pollen source is the Tibesti Massif, represented here by *Artemisia*, *Ephedra* (two types) and *Erica arborea*; (5) Mediterranean taxa, represented by rare occurrences in a few levels of *Betula*, *Picea*, *Pinus* and *Quercus*; and (6) a group of taxa of uncertain geographical affinity (Gramineae, Cyperaceae, *Typha*, Compositae-Asterae, Compositae-Fenestratae, Chenopodiaceae-Amaranthaceae, Leguminosae and *Myriophyllum*). Many of the tropical taxa are plants with low pollen productivity (for example *Piliostigma*, *Grewia*) and, in addition, several produce large (>60-μm) pollen grains with low dispersal capacity (*Acacia*, *Abutilon*, *Delonix*, *Hibiscus*, *Commicarpus*, *Grewia tenax* and *Pavonia*); thus, although they occur in low concentrations (100–500 grains ml^{-1}), their presence, in a state of excellent preservation, suggests that the source plants were close to, or in, the sedimentary basin.

Table 2 Tropical pollen taxa recovered from the sediments, grouped according to their phytogeographical affinities

Sudanian (-Sahelian)	Sahelian (Sudanian)	Saharan
Acacia cf. *sieberana*	*Abutilon*	*Aerva*
Borreria radiata	*Acacia* cf. *nilotica*	*Cleome*
Boscia	*Acacia* cf. *senegal*	*Maerua*
Cadaba	*Acacia* cf. *seyal*	*Salvadora*
Celtis integrifolia	*Acacia* cf. *raddiana*	*Tamarix*
Chlorophytum	*Atractylis*	
Commicarpus	*Balanites*	
Commiphora	*Blepharis*	
Delonix regia	*Borreria* cf. *chaetocephala*	
Grewia cf. *tenax*	*Capparis*	
Hibiscus (2 taxa)	*Cassia*	
Lannea	*Chroxophora*	
Pavonia	Combretaceae	
Piliostigma cf. *thonningii*	*Corchorus*	
Piliostigma cf. *reticulatum*	*Ottelia*	
Ruellia	*Phyllanthus maderspatensis*	
Zizyphus	*Polygala* cf. *erioptera*	

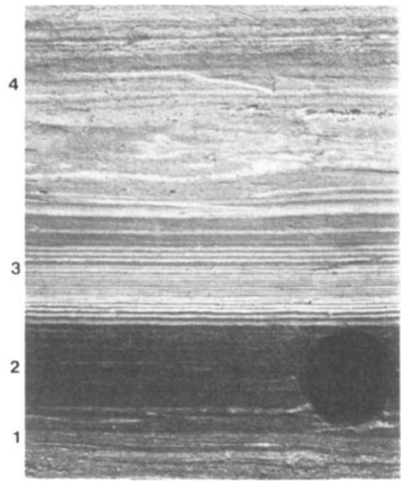

Fig. 3 Segment of Zone I (188–193 cm) sediments, showing: (1) finely laminated green/cream dolomite-rich muds; (2) finely laminated dark organic unit; (3) pure white/grey laminae, thinning upwards; (4) bioturbated laminated muds. Sample hole is 1 cm in diameter.

Gramineae and Cyperaceae, the dominant taxa in all samples, have pollen concentrations between 10,000 and 60,000 grains ml^{-1}, indicating both a regional and local component.

The pollen stratigraphy shows a close correlation with the sediment zones (Fig. 2). The lower levels, 360–170 cm, exhibit a predominance, among the tropical taxa, of Sudano-Sahelian elements of which *Grewia tenax* and *Piliostigma*, both tree taxa characteristic of the modern deciduous savanna zone, are notable. Zones II and III of the sediment column are characterized by an abrupt increase in Sahelian and Saharan elements, typical of modern Sahelian savannas and thorn scrub vegetation. A significant change in the proportions of Gramineae and Cyperaceae occurs at approximately the Zone I/II boundary (Fig. 2). This change is difficult to interpret, but the relative increase in Cyperaceae could have been caused by a lowered lake level producing a larger marginal marshy zone; alternatively, part of the increase may have been the result of an expansion of such important dune taxa as *Cyperus conglomeratus*.

The sediment, pollen and radiocarbon data from this site indicate (1) that between 8,500 and 6,100 yr BP the Oyo depression supported a relatively deep stratified lake with stagnant bottom water and annual inputs of fresh water, surrounded by a continuous deciduous savanna vegetation, similar to that found today ~500 km to the south; (2) that at about 6,000 yr BP a reduction in precipitation and/or an increase in evaporation initiated a shallowing of the lake; and (3) that between 6,000 and 4,500 yr BP the lake became still shallower and the tropical Sudano-Sahelian savannas were replaced by *Acacia*-thorn savanna and scrub-grassland. Finally, at 4,500 yr BP the lake basin dried out and was covered subsequently by aeolian sediments, whereas the vegetation, in the form of desert scrub-grasslands, disappeared from all habitats except at oases and wadis.

The Holocene lake at Oyo was probably groundwater supported, as at Merga Lake, 40 km to the south-east, today[13]. Recent isotope investigations of shallow groundwater in the region support a model of direct recharge[14-16] through the oases depressions, as opposed to subsurface flow over great distances, such as from the Enedi highlands in the case of Oyo.

The palaeoclimates suggested by the above conclusions are: for Zone I, a humid tropical climate with annual monsoonal rainfall of at least 400 mm; for Zones II and III, a progressive increase in aridity with annual precipitation declining from 300 mm at 6,000 yr BP to <100 mm at 4,500 yr BP. These reconstructions corroborate previous conclusions based on evidence from laminated lake sediments[17-20], East Mediterranean sapropels[21], geomorphology and archaeology[22,23] and Nile River flood history[24]. Our results provide the first conclusive demonstration of vegetation and climate change in the early to mid-Holocene of the eastern Sahara. They agree with tentative conclusions of Maley[25-27] for the distant Lake Chad record, with the general Holocene lake level trends for north-east Africa[28,29] and with changes in the position of the African monsoon predicted on the basis of Milankovitch orbital forcing factors[30,31]. Detailed sediment, radiocarbon and pollen analyses of the Oyo deposits will be reported elsewhere.

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A terrestrial fauna from the Scottish Lower Carboniferous

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Despite several important discoveries, extending over more than 120 years, our knowledge of early land vertebrates is still sparse. The earliest tetrapod remains are known from the Upper Devonian of East Greenland[1–3] and Australia[4–6], but the tetrapod fossil record does not become plentiful until Coal Measure times, in the Upper Carboniferous, some 50 Myr later. Finds in the Lower Carboniferous are very few indeed. Apart from two localities in West Virginia, USA[7,8], and one in Nova Scotia, Canada[9], all other Lower Carboniferous tetrapod sites are from the Viséan of Fife and the Lothian Region, Scotland[10,11]. We report here the discovery of an assemblage of terrestrial animals from a new Lower Carboniferous locality in the Lothian Region. Specimens were collected from the East Kirkton Limestone in the Brigantian stage of the Scottish Viséan, and include the first articulated amphibian skeleton to be found in the Lower Carboniferous of Europe in the twentieth century. This find is the earliest well-preserved amphibian skeleton ever discovered. The associated fauna is remarkable for the presence of myriapods, scorpions, the earliest known harvestman and several other types of amphibian. The presence of such forms, together with the striking absence of fishes, suggests that the amphibians form an integral part of a terrestrial fauna; terrestrial amphibians are otherwise unknown before the Upper Carboniferous Coal Measures.

The earliest Lower Carboniferous tetrapod sites are in the Oil Shale Group (Fig. 1), and the fauna consists of the aïstopod *Lethiscus*[12], the colosteid temnospondyl *Pholidogaster*[13] and a form of unknown affinities, *Doragnathus*[14]. There is also a series of specimens, including three incomplete skeletons, which are attributable to the Adelogyrinidae[15]. The principal amphibian find reported here is not attributable to any of these taxa. The site from which it comes is a new one in the Lothian Region. The specimen was found in the East Kirkton Limstone in sediments originating from the East Kirkton Quarry, near Bathgate, West Lothian. The limestone is very localized and separated by the Riccarton Hills Lavas from the overlying Hurlet Limestone, which marks the boundary between the Upper Oil Shale Group and the Lower Limestone Group (Fig. 1)[16]. The underlying Bankhead Tuffs separate it from the Raeburn Shell Bed, which in West Lothian probably forms the base of the Brigantian[17].

In striking contrast to other Scottish Mississippian tetrapod localities, there is a complete absence of fish remains at this horizon. The matrix in which the amphibians were found is a peculiar laminated cherty limestone[18], and initial associated discoveries suggest a unique environment of deposition. Most notable among these is what appears to be the earliest known fossil harvestman (Arachnida: Opiliones)[19] (Fig. 2). A number of myriapods and scorpions have also been found. Together with these small arthropods are several incomplete specimens

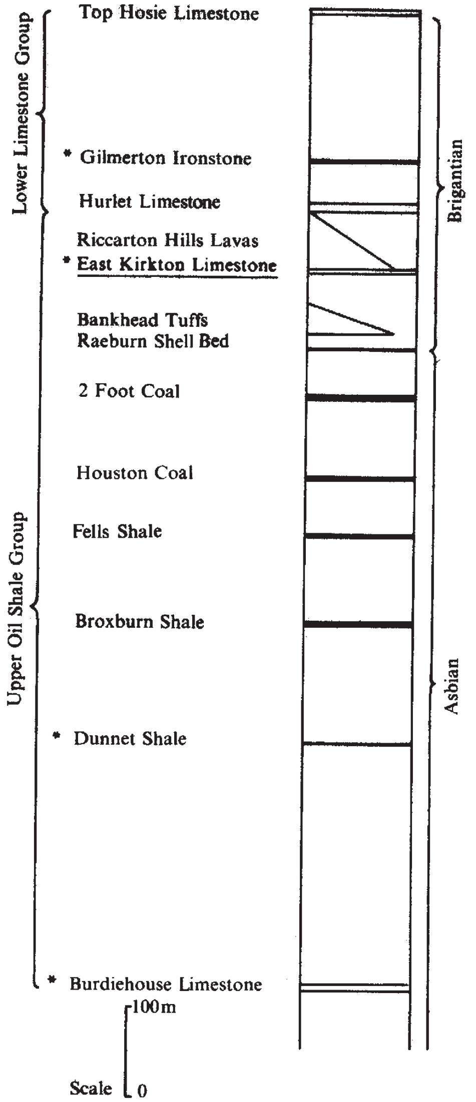

Fig. 1 Generalized section of the Upper Viséan of West Lothian, Scotland (after Geological Survey of Great Britain (Scotland), Sheet 32W). *Amphibian horizons.

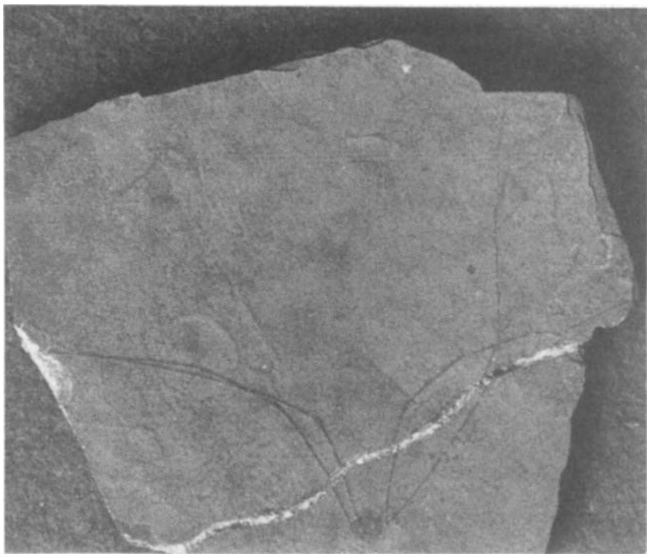

Fig. 2 Fossil harvestman (Opiliones) from the East Kirkton Limestone (SPW: G480). Natural size.