A 5200-year history of Amazon rain forest

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ABSTRACT. The explosion crater (maar) Lake Kumpak* in the western Amazon basin of Ecuador has yielded an 18.6 m sediment core spanning 5200 radiocarbon years. Sedimentary stratigraphy and pollen analysis provide the first record of rain forest climate and vegetation at a site undisturbed by riverine process. Deeper sediments were deposited very rapidly, apparently as a result of a 500-year episode of drier climate that led to massive slumping or rapid erosion about 4000 years ago. A complex history of local storms is preserved through the upper part of the record as textural banding. A three-zone pollen history is recognized, with boundaries at 3300 and 900 years BP. All three pollen zones are taken to represent facies of intact tropical rain forest. A large influx of pollen of the colonizing trees is present at all intervals, but the remaining pollen is of a diverse array of rain forest trees. About 350 pollen taxa are recognized, but only about 100 can be named. Changes in the pollen diagram synchronous with the postulated flooding event of northern Ecuadorian Amazonia 1300–800 years ago are apparent, but the palaeoecological significance of the changes cannot be assessed satisfactorily with the present data. It is possible that the regime of high precipitation in northern Ecuador was contemporaneous with a drier climate at Kumpak*, suggesting that the two sites may be on opposite sides of a climatic divide. The pollen record demonstrates that a complex history of Amazonian rain forest is preserved in lake sediments, despite the prevailing animal pollination mechanisms.

Key words. Tropical rain forest, Amazon Basin, Holocene, palaeoecology, pollen record.

Introduction

We report a pollen and sedimentary record from the western Amazon basin spanning more than 5000 years. The record is the first from undisturbed sediments of a volcanic crater lake in the Amazon and the first to describe the history of terra firme forest at a site free from riverine disturbance.

The Amazon basin supports the largest and the most diverse tropical rain forest, yet the Quaternary history of the Amazonian rain forest
is poorly understood. Few palynological studies have been conducted in the lowland rain forests of Amazonia. Poor accessibility, high floristic diversity, and the prevalence of zoophilous plants are some of the obvious factors that have discouraged palynological investigations in this region. Another problem arises from the difficulty in finding ancient lake basins in which long and continuous pollen and sediment records can be preserved (Colinvaux et al., 1985). Hitherto lakes in the Amazon lowlands have been thought all to be the varzea type that are created and obliterated by flooding and meander shifting in relatively short time, and are therefore unlikely to yield pollen records spanning more than a few millennia. The few previous pollen records from the Brazilian Amazon have been derived from seasonally drained and flooded varzea lakes of this type, where a more pronounced dry season lets the lake sediment be sampled by trenching the exposed lake beds or coring over shallow water (Absy, 1979, 1985). A pollen diagram from a single undated river cut of uncertain age is available from a strongly seasonal portion of Rondonia (Absy & van der Hammen, 1976). The varzea pollen diagrams are strongly influenced by pollen of grasses and other herbs or shrubs of the seasonally dry surface, by floating mat vegetation, or by repeated cycles of recolonization of flood-denuded river banks and flats.

Autonomous riverine lakes in the western Amazon lowlands of Ecuador are not subject to the flood cycles of varzeas and have yielded pollen diagrams free from flood-cycle disturbance, but the records are relatively short (late-Holocene), the local vegetation is riverain forest, and the vegetational histories are dominated by successional changes following major hydraulic disturbances on millennial time-scales (Frost, 1988; Colinvaux et al., 1988a).

No other pollen records that are directly relevant to Amazon prehistory are available, although a few pollen studies have been published of tropical American vegetation more or less remote from the Amazon basin. From high elevations in the Andes of Colombia, Peru, Bolivia and Ecuador are the studies of van der Hammen (1974, 1982), van der Hammen & Gonzalez (1960a, b, 1964, 1965), Hansen, Wright & Bradbury (1984), Graf (1981) and Colinvaux, Olson & Liu (1988b); from northern Venezuela are the studies at Lake Valencia (Bradbury et al., 1981; Salgado-Labouriau, 1980; Leyden, 1985); and from British Guiana comes the tropical savanna history of Wijmstra & van der Hammen (1966) and the mangrove swamp history of Wijmstra (1969) and van der Hammen (1963). These sections are generally so remote from the Amazon basin as to be within different climatic systems, as for instance the Lake Valencia and British Guiana records that are separated from the Amazon basin by subcontinental distances, mountain ranges, and the Intertropical Convergence Zone (ITCZ).

Our record is from Lake Kumpak, an autonomous, permanent deep lake in the Amazon lowland of Ecuador. The data show not only that pollen records of undisturbed lake sediments can be obtained from the Amazon lowlands, but also that the Amazonian rain forest leaves a pollen record of more detail than had been supposed.

The study site

Lake Kumpak (3°2′ S, 77°49′ W) is situated close to the foothills of the Andes at 700 m elevation in the Oriente region of Ecuador (Fig. 1). The lake can be reached by a 5–10 km foot trail from the Salesian mission at Yaupi. The region has an annual mean temperature of 24°C and receives about 2000–3000 mm of precipitation per year (Naranjo, 1981; Pourrut et al., 1983). There is no dry season, although precipitation decreases slightly between December and February. A region with much higher precipitation (3000–5000 mm year−1) occurs north of Lake Kumpak along the Andean foothills of central and northern Ecuador (Fig. 2). Precipitation decreases westward with increasing altitude up the Andean mountain slopes.

The vegetation in the Lake Kumpak region is tropical lowland rainforest of high species diversity (Harling, 1979; Grubb et al., 1963). The region is poorly explored botanically, but Myristicaceae, Moraceae, Meliaceae, Bombacaceae, Leguminosae, Rubiaceae, Melastomataceae and Flacourtiaceae are important tree families (Brandis & Azanza, 1982; Harling, 1979). The basin slopes around Kumpak largely support terra firme or upland forests. Cecropia Loeff., an heliophyte, grows along water courses and in more open sites. Palm communities, similar to those found elsewhere in varzea forests
and swamps (Moore, 1973), are present but infrequent; a fact compatible with the prevalence of sloping, upland habitats in the region. Much of the forest around the lake has been disturbed recently for agriculture and supports more open vegetation now (Fig. 3); otherwise the forest canopy is closed.

Lake Kumpak\(^{a}\) is roughly circular, 1 km across, and has a bottom that shelves gently to 19.5 m at the centre (Fig. 4). The lake basin is a small part of a much larger explosion crater or maar (Colinvaux \textit{et al.}, 1985). The lake has no outlet, suggesting that water level should change in response to changes in precipitation. Narrow tributary streams drain the crater rim on all sides and deliver sediment-laden water to the lake following tropical storms. Soils of the basin slopes are of sticky clay and apparently poorly consolidated, since runoff becomes rapidly charged with sediment.

Principal characteristics of Lake Kumpak\(^{a}\) are given in Colinvaux \textit{et al.} (1985) and de Oliveira \textit{et al.} (1986). Below 1 m the water is essentially anoxic and a 3\(^{\circ}\)C temperature gradient from top to bottom suggests some stability of thermal stratification. The lake regime may best be described as warm, discontinuously polymictic. Estimated productivity of between 0.48 and
2.19 g C m⁻¹ day⁻¹ is comparable with that for riverine black-water lakes of Ecuadorian Amazonia (Miller, Steinitz-Kannan & Colinaux, 1984). The lake is probably well supplied with nutrients carried in as fine sediments, or by regeneration from the extensive shallows, but light-occlusion in the turbid water probably limits productivity below levels that might be allowed by the nutrient supply. The most abundant phytoplankton we observed were Cyanophyta of the genus *Microcystis* Kuetz. and diatoms of the genus *Cyclotella stelligera* Cl. & Grun. Small fish were abundant in the surface water. Broad shallows supported water lilies (*Nymphaea* L.) and a population of caymen.

**Materials and Methods**

Lake Kumpak¹ is not shown on the 1:100,000 Ecuadorian topographic maps. It was first reported to us by Ecuadorian pilots who sighted ‘a lake above the rivers’ during flights over the region. Following an air reconnaissance of the region, we reached the lake in July 1982 and raised a 9.7 m core (core A) from the deepest part. In June 1983 another core 18.6 m long (core B) was raised from an adjacent spot. The cores were raised with a Livingstone piston sampler equipped with steel cutting shoes and a 10 pound sliding hammer to aid penetration of stiff sediments. The core tubes were 3.8 cm
(1.5 in) in diameter. Cores were raised in 1 m sections, corked and sealed in the field and returned unopened to the laboratory. The sediments were so sticky and stiff that continuous hammering was necessary below about 9 m, but penetration was steady until the last metre when the old hole collapsed and we could not regain the bottom of the 18.6 m hole. It seems certain that the bottom of the deposit was not reached.

Sediment stratigraphy was recorded by X-radiography of all core sections by irradiating cores from above with an overhead Norelco MG-150 X-ray machine. Core sections were opened by slitting the aluminium alloy tubes with a router. The core surface was cleaned with a spatula and the core was logged by comparing its visual appearance with the X-radiographs. Colours were described using a Munsell Soil Colour Chart. Both cores were sampled at intervals of 10 cm or less for measurement of water content, loss on ignition at 550°C, and at 1000°C as described by Dean (1974). Seven samples, including three from core A and four from the bottom 9 m of core B, were submitted to Teledyne Isotopes or Beta Analytic for radiocarbon dating.

Subsamples for pollen analysis of known volume were taken by packing sediment into special stainless steel dispensers which deliver 0.5 ml pellets. Pollen subsamples were taken at every 30–40 cm in core A (top 9.7 m), and at every 60–100 cm in the bottom 9 m of core B (9.7–18.6 m) where radiocarbon dating suggested that sedimentation rates were much higher. Pollen extraction followed Faegri & Iversen (1975), using HCl, KOH, HF and acetylation solution. *Eucalyptus* pollen was used as the standard for calculating pollen concentration (Stockmarr, 1971). Pollen identifications are based on a reference collection of about 3000 tropical American taxa first put together for Galapagos palynology (Colinvaux & Schofield, 1976), then increased to include representatives of other taxa appearing in published pollen diagrams from tropical America. Also consulted were pollen keys and photographs available for adjacent regions of South America (e.g. Absy, 1979; van der Hammen & Gonzalez, 1960; Heussler, 1971; Markgraf & D’Antoni, 1978; Salgado-Labouriau, 1978). Numbers were assigned to all unknown taxa found in small quantities. These were identified by drawings

FIG. 3. Aerial view of Lake Kumpak and its watershed. Photograph was taken on 28 June 1983.
and written descriptions, sometimes supplemented with photomicrographs. It was deemed impracticable to attempt positive identification of these minor elements in a local Ecuadorian flora in excess of 20,000 taxa (Dodson & Gentry, 1978). A pollen sum of 250 pollen grains and fern spores was counted at each level. A computer program originally developed by J. H. McAndrews and others in the Botany Department of the Royal Ontario Museum was used to calculate pollen percentage, concentration, and influx, and to plot pollen diagrams.

**Sediment stratigraphy and radiocarbon chronology**

The sediment is largely allochthonous clay-sized mineral particles, typically very dark grey (5Y3/1) in colour, with a loss on ignition of 10–15% by dry weight (Fig. 5). Impressions or fragments of leaves are prominent, suggesting that much of the organic content of the core is allochthonous also. Small streaks and concretions of vivianite occur at intervals. Fine laminations are visible in most parts of the core, both to the naked eye and on the X-radiographs (Fig. 6). They are especially distinct in the upper 9 m and the lower 2 m of the core, though they seem to be less regular in thickness in the latter section. These laminations consist of alternating pale and dark layers of organic clay. In addition, at intervals are broader bands, from 0.1 cm to 12 cm wide, of lighter coloured (10YR5/1, 5Y5/1 or 5Y4/1), clay-sized minerals. X-ray diffraction analysis shows that they are largely composed of detrital quartz, with sharp reflectivity peaks at 20.8° and 26.66°, but contain little or no clay minerals. No clear sedimentary structures are apparent in these mineral bands. Their mineralogy is consistent with geomorphic evidence that the Kumpak catchment is composed of young, easily erodible volcanic material. We interpret these mineral bands as products of intensified erosion, each following an intense tropical storm. We witnessed the effect of one tropical

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**FIG. 4.** Bathymetric map of Lake Kumpak showing inlet streams (lines), *Nymphaea* mats (stippled), and coring sites (indicated by X). Depth contours in metres. The 3 m depth contour is inserted for the southern end of the lake to indicate steep basin slope there.
storm following which the otherwise clear water of inlet streams became turbid and fans of suspended sediments were distributed over the lake. Large fragments of poorly decomposed leaves were found at the base of many of these bands, reinforcing our interpretation that these bands suggest increased stream transport of terrigenous or littoral materials. Intense storms would be needed to deposit the wider bands by this mechanism.

These mineral bands provide very good stratigraphic markers for cross-correlating between core A (9.7 m) and core B (18.6 m). Particularly, a series of distinct bands occurring at 715.0 cm, 717.8 cm, 720.6 cm and 725.5 cm in core A could be cross-correlated with those occurring at 752.5 cm, 754.0 cm, 756.0 cm and 760.0 cm in core B, respectively; so does another set occurring at 415.0 cm, 416.3 cm, 418.0 cm and 419.2 cm in core A and at 479.0 cm, 480.5 cm, 482.4 cm and 483.7 cm in core B, respectively (Fig. 6). This permits us to fit the pollen analyses and stratigraphies of the two cores into one continuous sequence (Fig. 7).

The sedimentology of the section between c. 843.0 cm and 1430.5 cm is highly unusual and interesting. Within this section the mineral bands are more frequent and noticeably thicker than in other sections of the core, many of them over 1 cm thick and one being 12 cm thick (983.0–995.0 cm) (Fig. 7). More significantly, various degrees of tilting, contortion and convolution are clearly visible in several laminated segments and some mineral bands, both to the naked eye and on the X-radiographs. These disturbed sediments are not an artefact of the coring operation, because they occur in different parts of a core segment and they are interbedded with horizontally laminated sediments. Convolved laminations were found in 1100.0–1109.5 cm and 1355.0–1385.0 cm (Fig. 8). Laminations, including some mineral bands, are tilted at an angle of 20°–25° in 1050.0–1057.5 cm and 1109.5–1133.3 cm (Fig. 9). Two mineral bands of fine sand, light brownish grey (10YR6/2) and grey (5Y6/1), occur at 1280.2–1281.5 cm and at 1409.0–1409.8 cm, respectively. The latter is tilted and is vertically displaced 1.5 cm apart by a small fault. We are not sure if these sandy layers are air-fall tephra or reworked pyroclastic material brought in by streams. Moreover, evidence of disturbance, either from bioturbation or mechanical mixing, was found in 843.5–873.5 cm, 881.0–887.0 cm, 968.0–983.0 cm and 1074.5–1082.5 cm (Fig. 9). The continued presence of vivianite in this section seems to suggest anoxic conditions at the lake bottom, thus making bioturbation unlikely. Many segments in this section appear massive or only indistinctly laminated.

The seven radiocarbon dates obtained on both cores are given in Table 1 and Fig. 10. Three dates of sediment between 952 cm in core A and 1276 cm in core B overlap completely and are essentially the same age (4090±100, 3840±220, 4040±130 BP). They suggest extremely rapid

### TABLE 1. Radiocarbon dates from Lake Kumpak sediments

<table>
<thead>
<tr>
<th>Core</th>
<th>Depth (cm)</th>
<th>C-14 date</th>
<th>Lab. number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>461–476</td>
<td>1900±140</td>
<td>I-13,380</td>
</tr>
<tr>
<td>A</td>
<td>821–839</td>
<td>3340±80</td>
<td>Beta-9729</td>
</tr>
<tr>
<td>A</td>
<td>952–965</td>
<td>4090±100</td>
<td>I-12,886</td>
</tr>
<tr>
<td>B</td>
<td>968–982</td>
<td>3840±220</td>
<td>I-13,436</td>
</tr>
<tr>
<td>B</td>
<td>1264–1276</td>
<td>4040±130</td>
<td>I-13,381</td>
</tr>
<tr>
<td>B</td>
<td>1665–1680</td>
<td>4280±110</td>
<td>Beta-9730</td>
</tr>
<tr>
<td>B</td>
<td>1846–1860</td>
<td>5120±100</td>
<td>I-13,305</td>
</tr>
</tbody>
</table>
FIG. 6. X-radiographs of the Lake Kumpak cores showing the fine laminations. Mineral bands occurring at 415.0 cm, 416.3 cm, 418.0 cm and 419.2 cm in core A are cross-correlated with those at 479.0 cm, 480.5 cm, 482.4 cm and 483.7 cm in core B, respectively.
deposition over this section of the core, a suggestion that is reinforced by the date of $4280 \pm 110$ BP at 1665–1680 cm. The sedimentation rate between 952 cm and 1680 cm reaches 1.48–1.68 cm/year, roughly 5 times the sedimentation rates of sediments both above and below this section (Fig. 10).

The five-fold increase in sedimentation rate between c. 3840 BP and 4280 BP cannot be explained by sediment focusing resulting from changes in lake bottom bathymetry (Lehman, 1975), because this explanation is inconsistent with the slow sedimentation in the underlying section of the core. One possible mechanism is massive slumping of slightly older sediments from the littoral slopes of the lake to the deepest basin. Such occurrence would be difficult to detect from un laminated sediments cored from the centre of a lake, but would be readily detectable in laminated sediments by the occurrence of tilted, faulted, or contorted laminations in the slumped block (Bennett, 1986). Coherent slumping has been reported from the late-glacial clays of Lake Windermere (Mackereth, 1965) and more recently from the Holocene sediments of Hall Lake in Ontario (Bennett, 1986). The occurrence of tilted, convoluted and faulted laminations in this section of the Lake Kumpak core suggests that massive slumping might have contributed to the high sedimentation rates by redeposition of older, littoral materials. This could also have resulted in the virtual overlapping C-14 dates for this section.

The high sedimentation rate is also partly due to the incorporation of many thick mineral bands in this section. If these mineral bands are produced by intensified slopewash and stream dissection following intense tropical storms, as we have suggested, the increased sedimentation rate between 3840 BP and 4280 BP probably records environmental change that led to massive slumping of littoral sediments within the lake, as well as greater erosion of the young volcanic materials around the lake basin.

In summary, the Lake Kumpak sediments record a long and complex history of storm cycles and erosion in the catchment. The most notable episode led to rapid sedimentation, including massive slumping, lasting about 500 years some 4000 years ago.

The pollen record

Fig. 11 is a pollen percentage diagram from Lake Kumpak, and Fig. 12 shows the total pollen concentration and pollen influx values. A total of 346 recognizable pollen taxa was found, so that some lumping has been necessary to display them in the pollen diagram. Of these, about 100 are given taxonomic names. All but one of the remaining 246 unknown taxa are given identifying names and are included in the category ‘other unknowns’ at the right of the pollen dia-
FIG. 8. X-radiography of convoluted laminations in the 1355.0–1385.0 cm section.

FIG. 9. X-radiography of tilted and disturbed laminations in the 1050.0–1082.5 cm section.
FIG. 10. Depth-age curve for the Lake Kumpak§ stratigraphy. Sedimentation rates are calculated by linear interpolation between C-14 dates. The 4000 ± 100 yr date is ignored in the calculation because it overlaps with the date below it.

gram. Unknown 131, a four-porate, psilate to scabrate pollen grain with protruding pores like Acalypha L., is plotted separately from other unknowns because of its greater abundance. In addition, the category Moraceae–Urticaceae includes all diporate and triporate grains with psilate to granulate–scabrate exine that are characteristic of these two families, including Pilea Lindl., Urtica L., Brosimum Sw., and those that cannot be identified to genus. Cecropia and Ficus L., however, are plotted separately. The taxon Melastomataceae also includes Miconia Ruiz & Pav., which has a smaller size than other pollen members of this family.

Roughly three ecological groupings of forest trees can be discerned. Trees of mature forest are suggested by some members of the taxa Ficus, Celtis L., Piper L., Melastomataceae, Leguminosae, Euphorbiaceae and Moraceae–Urticaceae (Dodson & Gentry, 1978). Disturbed forest is represented by Cecropia. Wetter sites are suggested by the principal palm taxa, Iriartea Ruiz & Pav. and Mauritia L.

Both pollen concentration and pollen diversity are high. Pollen concentration typically is about 100,000 grains cm⁻³, suggesting pollen influx rates of about 25,000 grains cm⁻² year⁻¹ over the last millennium or so. These figures are comparable to typical values for temperate vegetation in the American Midwest (Davis, Brubaker & Webb, 1973). They are surprising in view of the general expectation that entomophily of the Amazonian flora should lead to low pollen production and limited dispersal. Nor is the pollen rain dominated by wind-pollinated herbs such as grasses. The only anemophilous taxon that is obviously over-represented is Cecropia. Diversity of taxa appearing in low concentrations, presumably of entomophilous plants, is high; thirty-nine to seventy-five taxa are present in each of our counts of 250 grains.

Pollen assemblages at Lake Kumpak§ are quite different from those reported by Ahsy (1979, 1985) from the central Amazon lowlands of Brazil. Some part of this difference doubtless is due to the fact that Ahsy’s varzea lakes yield records of riverain forest whereas the catchment of Lake Kumpak§ supports terra firme forest. Then again Ahsy’s lakes, spanning as they do 1000 km traverses both east and west and north and south, are located in a series of different Amazonian watersheds, including the strongly seasonal or ecotonal northern and southern watersheds as well as the wet western watershed from the Andes (Colinvaux, 1987). But the result is clearly distinctive pollen assemblages for the different watersheds of Amazonia. Apart from obvious varzea influences in Ahsy’s pollen spectra such as Gramineae pollen, or the presence of Compositae and Brysonima Rich. ex Kunth. in her samples from the semi-arid northern watershed, her persistent high percentages of Alchornea Sw., Symmeria Hook. and Myrtaceae are striking, when compared with the low importance, or absence, of these taxa from Lake Kumpak§. Myrtaceae would be masked in our routine preparations because we used Eucalyptus as our exotic pollen, but we did not add exotic pollen to our surface samples from either Lake Kumpak§ or the riverine lakes (Colinvaux et al., in press) and can confirm that Myrtaceae is not important in the modern pollen rain of the western Amazon as it is in Ahsy’s forest samples. These differences probably reflect the spatial heterogeneity in the floristic composition of the vast Amazon rain forest.

The data suggest that pollen analysis is still a useful palaeoecological tool in the tropical rain forest of Amazonia. A floristic record is preserved that may represent a proportion of the total flora not very different from that preserved in pollen records elsewhere in the world. It must be admitted, however, that reading the details of
FIG. 11. Pollen percentage diagram for Lake Kumpak. Pollen percentages are calculated based on a pollen sum including all pollen and spores counted.
this floral history will require a mastery of the Amazon pollen flora that may take decades to achieve.

The pollen diagram is divided into three pollen assemblage zones based on pollen percentage, concentration, and influx data.

1. Zone 1 (819–1860 cm) spans 5200–3300 BP. It is characterized by moderately high pollen percentages of Moraceae–Urticaceae (12–29%) and *Ficus* (1–9%), relatively low percentages of *Cecropia* (22–34%), and the virtual absence of *Iriartea* pollen. *Podocarpus* L. Hérit. ex Pers. pollen (up to 0.8%) is present in two consecutive levels near the top of this pollen zone. Two subzones are delineated based on pollen concentration and pollen influx data. Subzone 1a (1680–1860 cm) has relatively high pollen concentration (98–261×10^3 grains cm^-3) but relatively low pollen influx values (21–57×10^3 grains cm^-2 yr^-1), apparently a result of slow sedimentation between 4300 and 5200 BP. Subzone 1b (819–1680 cm) encompasses the interval of rapid sedimentation and spans 3300–4300 BP. It has extremely high pollen influx values (156–306×10^3 grains cm^-2 yr^-1) that are probably an artefact of including pollen redeposited in slumped sediment, but pollen concentrations (106–195×10^3 grains cm^-3) are similar to the subzone below.

2. Zone 2 (448–819 cm) contains maximum frequencies of *Cecropia* pollen (21–55%) and has high pollen concentrations (up to 360×10^3 grains cm^-3). Moraceae–Urticaceae and *Ficus* percentages have declined but are fluctuating. Pollen influx has decreased to less than 50×10^3 grains cm^-2 yr^-1. Sedimentation rate has restored to about 0.25 cm year^-1, a figure characteristic of the upper 9 m of the core. This zone spans from about 3300 to 900 BP.

3. Zone 3 (0–448 cm) encompasses two prominent peaks of *Iriartea* pollen (up to 16%), separated by an interval in which this taxon is absent. *Mauritia* pollen also seems to increase slightly. The abundance of *Cecropia* declines but remains variable. Both pollen concentration and pollen influx have declined to low but stable levels, as does sedimentation rate.

Interpretation of the Lake Kumpak pollen diagram is facilitated by comparison with our surface sample network from Ecuador (Liu & Colinvaux, 1985) and those from Brazil (Absy, 1979) and Colombia (Grabandt, 1980). The predominance of *Cecropia*, *Ficus* and Moraceae–Urticaceae in this pollen stratigraphy suggests that tropical rain forest has prevailed around Lake Kumpak throughout the last 5200 years. Even so, the pollen data do demonstrate a number of local events within the forest.

The prominent peak in pollen influx in subzone 1b is most striking. It is surprising that the increase in sedimentation rate over this interval is not accompanied by a corresponding decline in pollen concentration, as one might expect from dilution by an increase in sediment input if the pollen influx remains constant. Instead, the pollen influx increases 5 times to 156–306×10^3 grains cm^-2 yr^-1, a figure unrealistically high. This reinforces our interpretation based on sedimentological grounds that the increased sedimentation rate is not caused by a steadily increased supply of sediment, but by the incorporation of many instantaneously deposited mineral bands and slumped sediments. In effect, the apparent increase in pollen influx in subzone 1b is an artefact of the way pollen influx values are calculated. The real pollen influx from the vegetation to the lake probably remained cons-
tant, as the constant pollen concentration values suggest.

The pollen of *Iriartea* is present in small percentages in subzone 1a but completely disappears in subzone 1b, only to occur again in zone 2. This taxon, like many other palm species of the Neotropics, is tolerant of poor drainage and is characteristic of wetlands in the rain forest (Moore, 1973). Its absence in subzone 1b could have been caused by a lowered water table resulting from a drier climate, thereby eliminating the habitats for *Iriartea* around Lake Kumpak*. Alternatively, improved soil drainage due to greater stream dissection and drainage development would have the same effect.

The occurrence of two *Podocarpus* grains (0.8%) at 1130 cm and one (0.4%) at 1013 cm is intriguing. In Ecuador, *Podocarpus* is a typical tree of the Andean forest above an elevation of 1800 m (Harling, 1979; Liu & Colinvaux, 1985; Colinvaux & Liu, 1987), although other species of *Podocarpus* have been reported to occur locally on white sand soils near Iquitos in the lowland (A. Gentry, personal communication, 1985). The occurrence of the *Podocarpus* pollen may not necessarily indicate that this tree was locally present around Lake Kumpak* 3900 years ago. The grains are degraded (one is broken), and the samples containing them have an unusually high amount of fungal hyphae and organic debris that suggest a terrigenous origin (Cushing, 1964). It is likely that the *Podocarpus* grains were redeposited from older deposits eroded by streams. This happened at a time when the sedimentary history of the lake was most turbulent, as witnessed by the frequent occurrence of thick mineral bands and slumped materials. Alternatively, the vesiculate pollen might have been blown in by wind descending from higher elevations in the Andes. This would have required an increase in the strength or frequency of Pacific air streams from the west relative to the prevailing easterly air streams from the Amazon basin. This would be consistent with the scenario of a drier climate postulated below.

The increase in pollen concentration at the bottom of pollen zone 2 is probably due to a change in sedimentation rate that is undetected from the resolution of the radiocarbon chronology. The calculated pollen influx value of $90 \times 10^3$ grains cm$^{-2}$ year$^{-1}$ is still too high even by the standard of temperate regions. The greater variability displayed by the *Cecropia* pollen curve is partly due to the closer sampling intervals in the upper 9 m of the core, but because of much lower sedimentation rates the time span between two sampling levels is actually longer here than in subzone 1b. Nevertheless, these continual fluctuations in the frequencies of the gap colonizer *Cecropia* and in Melastomataceae over the last 3300 years are consistent with the endless flux of change required if rain forest diversity is thought of as the result of ceaseless succession in gaps (Connell, 1978; Hubbell, 1979) and in habitat mosaics on shifting floodplain networks (Salo *et al*., 1986; Räsänen, Salo & Kalliola, 1987).

The two prominent peaks in *Iriartea* pollen in pollen zone 3 are dated at 1900–1500 BP and 800–0 BP respectively. The cause for the abrupt expansion and demise of this taxon is not clear. The two peaks may suggest wetter climatic episodes that resulted in a higher water table and an increase in wetland habitats. By the same token, the total disappearance of *Iriartea* between 1500 BP and 800 BP might have been caused by a drier climate with a lowered water table. It is tempting to relate this latter episode to the increased precipitation and flooding event documented between 1300 and 800 BP in lakes along the Napo and Aguarico drainage systems about 350 km north of Lake Kumpak* (Colinvaux *et al*., 1985).

A common climatic origin for the two events would imply that precipitation changes between the Napo region and the Lake Kumpak* region were out of phase or directly opposite. This is perfectly possible, but a confident interpretation of the pollen history of *Iriartea* must await a better understanding of the ecology of this taxon.

The abundance of Gramineae pollen increases slightly to 2–3% between 348 cm and 548 cm across the zones 2 and 3 boundary. A large grass pollen grain measuring 102 µm in diameter, probably *Zea* L. or other cereal, was found at 384 cm. While evidence from a single grain is admittedly inconclusive, it might suggest cereal cultivation in the western Amazon lowland around 1550 BP. The greater abundance of grass pollen between 1500 and 2200 BP is consistent with forest clearance and agriculture.

**Paleoenvironmental reconstruction**

The pollen and sedimentary records from Lake Kumpak* suggest a continually perturbed
environment in the rain forest of the western Amazon lowland. The most dramatic event occurred about 4300–3800 years ago, when sedimentation rate increased five-fold as a result of massive slumping within the lake and intensified erosion around the lake basin. The most likely mechanism involves a change in the precipitation regime. We postulate that a drier climate with more seasonal rainfall prevailed in the Kumpak\(^a\) region between 4300 and 3800 BP, resulting in a shallower lake. This would have exposed the sediments resting on the steeper slopes of the now littoral zone to stronger wave action and circulation, thereby triggering block slumping and greater erosion. The intensity of summer storms tends to increase in a more seasonal climate, such as that of the tropical savannas peripheral to the rain forest. An increase in seasonality and rainfall intensity could have accelerated the fluvial erosion of the young volcanic soils on the basin slopes and deposited the thick mineral bands observed in the core. It has been established that sediment yield, hence erosion rates, are higher in a seasonal climate than in the perennially wet tropics (Fournier, 1960; Corbel, 1964; Kirby, 1975; Jansson, 1982).

This scenario of a drier, more seasonal climate around 4000 BP is consistent with evidence from fossil diatoms recovered from the Lake Kumpak\(^a\) core. Planktonic diatom species predominate in the upper 850 cm (corresponding to pollen zones 2 and 3) but are completely replaced by periphytic species characteristic of shallow waters in the rest of the core (corresponding to pollen zone 1) (de Oliveira \textit{et al.}, 1986). Thus the diatom data suggest shallow water at the same time as sediment stratigraphy suggests slumping, reworking of sediments, or strong seasonality.

Geomorphological and pollen evidence for a drier climate around 4000 BP has been documented from several sites in Colombia and elsewhere on the periphery of the Amazon Basin (Wijmstra, 1967; van der Hammen, 1982; Soubiès, 1979). On the other hand, stratigraphic evidence from the Amazon lowlands of Bolivia suggests a relatively moist period between 5000 and 3400 BP (Servant \textit{et al.}, 1981). This apparent contradiction runs parallel to our finding a wet episode between 1300 and 800 BP in northeastern Ecuadorean Oriente while the Kumpak\(^a\) data suggest comparative dryness. In a vast region like the Amazon basin, climatic change caused by shifting wind belts and storm tracks should be manifested in both spatial and seasonal redistribution of precipitation, resulting in wetter conditions in some places but drier conditions in others (Servant & Villarroel, 1979). A well-documented example from the periphery of the Amazon basin is in the incidence of strong El Niño–Southern Oscillation events, which brought increased precipitation to the Pacific coast of Peru and Ecuador but were correlated with reduced annual snow accumulation on the Quelccaya Ice Cap in the eastern side of the Peruvian Andes, where the moisture source is from the Amazon Basin (Thompson, Mosley-Thompson & Armas, 1984; Thompson \textit{et al.}, 1985). Absy (1979) attempts to correlate various evidence of past dry periods in her dispersed \textit{varzea} records from central Brazil with the 4000 BP Andean dry episode of Wijmstra (1967) but in our opinion this correlation is not warranted without more precise dating of the sections. As mentioned earlier, Absy’s \textit{varzea} lakes record climatic histories in very different Amazon watersheds across which in-phase synchronicity is inherently unlikely.

The Kumpak\(^a\) region, like the Quelccaya Ice Cap, derives its precipitation from the Amazon basin to the east, but its location at the eastern foothills of the Andes still makes it susceptible to climatic influences from the Pacific. At the same time its position south of the geographic equator places it further away from the ITCZ than the riverine lakes of the flooding episode, and it receives less precipitation than the region of those lakes in the modern climate. Its climatic controls are different from those for sites in other parts of the Amazon basin. Thus the records of Holocene climatic change in different regions of Amazonia may be synchronous but may not carry the same signs.

Two hypotheses can be put forward to explain the sedimentological and palynological changes around 4000 BP as alternatives to the seasonal dry climate hypothesis favoured here. These are the wet climate hypothesis and the non-climatic control hypothesis.

The wet climate hypothesis rests on the possibility that increased heavy rains, with accompanying prolonged saturation of surface soils, could have triggered landslides (So, 1971), increased runoff and stream dissection, and enhanced splash erosion by the increased
throughfall (Faniran & Jeje, 1983). These combined effects might then have increased the rate of sedimentation overall and introduced episodes of flash floods to account for the thicker mineral bands. However, much current work suggests reduced, rather than increased, sediment yield with increasing precipitation in humid to subhumid regions (Jansson, 1982), although it must be admitted that few empirical data exist on erosion rates in the seasonless wet tropics with more than 4000 mm of rain per year, such as in the region just less than 100 km north of Lake Kumpak* (see Fig. 2). It is, however, hard to see how the slumping and reworking of pollen-rich sediments from the lake sides can be reconciled with the deeper lake implied by the wet climate hypothesis. Neither can this necessarily deeper lake be reconciled with the diatom data. Thus this hypothesis can reasonably be rejected.

Non-climatic factors could account for the sedimentation record if they worked to devegetate the catchment or to destabilize the landscape. Forest clearance by human activities could have exposed the young volcanic soil around Lake Kumpak* to rapid erosion. However, although sparse archaeological evidence suggests that human inhabitation of the southern part of the Amazon basin might have begun as early as 12,500 years ago (Meggers, 1985), no such early sites have been reported from the Amazon lowlands of Ecuador. More importantly, no evidence of agriculture or forest clearance is found in the Kumpak* pollen record until a thousand years after the episode of rapid sedimentation. Deforestation by fire of the kind reported by Sanford et al. (1985) should have left a charcoal record in the sediments, of which we found no trace. In addition, we should expect to find pollen evidence for clearing of any kind, but there is none. It is certainly possible that slumping of sediments was triggered by earthquakes associated with volcanic activity in the adjacent Andes, but there is no evidence of widespread volcanic activity throughout the interval of rapid deposition such as would suggest an unstable, or deforested catchment. The two coarse mineral bands at 1280 cm and 1409 cm may be tephra, but their relatively small thickness (8–13 mm) suggest a distant source. Thus the hypothesis of non-climatic causes has to be rejected for want of evidence.

In the 5000 years spanned by the Lake Kumpak* record there have been at least two significant episodes of climatic change. The greater of these was a 500 year interval of more seasonal and drier climate from 4300 to 3800 BP. The lesser was a second relatively dry climate from 1500 to 800 BP, which was not sufficient to have altered the sedimentary regime but which probably lowered lake level sufficiently to reduce local populations of wetlands palms. Since this second dry interval was out of phase with increased precipitation a few hundred kilometres to the north it should be very interesting to know if the earlier interval also was out of phase with climate of the northern sites along the Equator. The position of Lake Kumpak* at just south of the summer position of the ITCZ and close to the conjunction of Atlantic and Pacific air masses makes it likely that it should be sensitive to shifts in air mass patterns.

Despite these climatic events, terra firme rain forest has occupied the Lake Kumpak* watershed continuously for the last 5200 years, without any interruption by more open vegetation in the more seasonal centuries. It has left a remarkably detailed pollen record, thus demonstrating that the antiquity and stability of Amazonian rain forests can be investigated by pollen analysis. The pollen and sedimentary records from Lake Kumpak* reveal a history of perturbations and local turnover in the Amazonian rain forest that is required to maintain high species diversity according to the intermediate disturbance hypothesis (Connell, 1978).

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