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# Deglaciation and Holocene climate change in the western Peruvian Andes

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**Abstract**

Pollen, charcoal, magnetic susceptibility, and bulk density data provide the first paleoecological record spanning the last 33,000 years from the western cordillera of the Peruvian Andes. Sparse super-puna vegetation existed before 30,000 cal yr B.P. around Lake Compuerta (3950 m elevation), prior to a sedimentary hiatus that lasted until c. 16,200 cal yr B.P. When sedimentation resumed, a glacial foreland or super-puna flora is represented in which *Polylepis* was a significant element. Glacial outwash, marked by high sedimentary magnetic susceptibility, increased from c.16,200 cal yr B.P. and reached a peak at c. 13,200 cal yr B.P. Between c. 12,500 cal yr B.P. and 10,000 cal yr B.P., magnetic susceptibility was reduced. Vegetation shifts suggest a cool dry time, consistent with regional descriptions of the Younger Dryas event. Deglaciation resumes by 10,000 cal yr B.P. and the last ice is lost from the catchment at ~7500 cal yr B.P. During the early Holocene warm and dry period between 10,000 and 5500 cal yr B.P., *Alnus* expanded in downslope forests. *Alnus* declined in abundance at 5500 cal yr B.P. when wetter and cooler conditions returned and human activity intensified. Maize (*Zea mays*) pollen first occurred in the core at ~2600 cal yr B.P., indicating a minimum age for local agriculture. An increase in *Alnus* pollen abundance at ~1000 cal yr B.P. could be due to human activity or perhaps due to a regional climate change associated with cultural turnover elsewhere in the Andes at this time.


*Keywords:* Charcoal; Fire; Paleoclimatology; Paleoecology; Pollen analysis; *Polylepis*; Holocene; Pleistocene; Last glacial maximum; Glacier; Younger Dryas; South America

## Introduction

Steep environmental gradients in the Andes, and the short spatial distances over which communities change, make this region particularly sensitive to climatic change. While the most complete paleoclimatic records for the central Andes come from the Altiplano (e.g., Abbott et al., 1997; Baker et al., 2001a; Fornari et al., 2001; Paduano et al., 2003; Tapia et al., 2003), deglacial records from other parts of Bolivia, northern Peru, and southern Ecuador have added detail to the regional image (e.g., Clapperton, 1993; Hansen and Rodbell, 1995; Colinvaux et al., 1997; Abbott et al., 2000; Seltzer et al., 2000; Hansen et al., 2003). Although there are broad similarities with the northern hemispheric ice age, the details of glacial maxima and deglaciation are somewhat different from those of northern latitudes. The greatest glacial extent in the high Andes may have preceded that of the northern hemisphere. Klein et al. (1998) suggested maximum glacier extent earlier than 24,000 cal yr B.P. in the central Andes, and Smith et al. (2005) dated terminal moraines at their lowest elevation in Bolivia to ~34,000 cal yr B.P. (Smith et al., 2005). The last glacial maximum (LGM), which we define as 26,000–22,000 cal yr B.P., in the Titicaca region was wetter and about 5°–8°C colder than today (Abbott et al., 2000; Baker et al., 2001b; Paduano et al., 2003), and deglaciation

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began between 21,000 and 19,000 cal yr B.P. (Seltzer et al., 2002; Smith et al., 2005).

Progressively, the climate warmed, with a transition from glacial foreland to puna taking place in many high montane locations between c. 17,000 and 15,000 years ago depending on elevation, precipitation, aspect, proximity of ice mass, and other local variables (Seltzer et al., 2002; Paduano et al., 2003; Bush et al., 2005).

At Lake Titicaca, pronounced warming between 13,000 and 12,000 cal yr B.P. established near-modern temperatures (Ybert, 1992; Paduano et al., 2003). No clear evidence of the Younger Dryas event can be seen in that record, although at Sajama, Bolivia, Junin, and perhaps at Chochos, Peru, a dry oscillation is attributed to this event.

During the Holocene, a time-transgressive drought occurred (Abbott et al., 2003) in which lake levels closest to the equator fell earliest and progressively later with increasing latitude to the south. The peak of this event, at c. 7000 cal yr B.P., resulted in a widespread lowstand affecting sites from 7° to 20°S (Abbott et al., 2003). These low lake stands partly reflect the pattern of increasing Holocene insolation and a thermal optimum that enhanced evaporation. Considerable disagreement exists in the interpretation of isotopic data for the region, with some seeing ratios primarily determined by precipitation (e.g., Seltzer et al., 2000; Baker et al., 2001b), whereas others see the record indicating temperature changes (e.g., Thompson et al., 2000). Thus, the common pattern of $\delta^{18}O$ values in Holocene lake and ice records are taken to reflect progressively wetter or cooler conditions.

The only palynological studies from northern Peru that span the deglacial period are from Lagunas Baja (Hansen and Rodbell, 1995) and Chochos (Bush et al., 2005). Neither of these records spans the LGM, and both are on the eastern flank of the Andes, in a climatically distinct zone from the site reported here.

A long record of human occupation is evident in the high Andes, although the Altiplano may have been abandoned during the worst droughts of the mid-Holocene (Núñez et al., 2002). As the droughts abated c. 4500 cal yr B.P., archaeological evidence indicates persistent human presence, and by 3200 cal yr B.P. agriculture was widespread (Núñez et al., 2002). Subsequent climate change was associated with the rise and decline of the Chiripa and Tiwanaku cultures around Lake Titicaca (Binford et al., 1997; Kolata, 2000). In northern Peru, even though many archaeological sites have been found in coastal valleys (Dillehay, 2002), evidence of early human occupation from adjacent highland regions is less extensive (Lavallee, 2000).

In this paper, we report the first long palynological record spanning the last glacial maximum from the western flank of the northern Peruvian Andes.

## Study area

The study area is located on a high plain amid wet puna grasslands on the west slope of the Andes in northern Peru (Fig. 1). Elevation generally decreases from north-northeast to south-southwest (Fig. 2). The surrounding summits are about 4600 m high. Annual precipitation, which is derived from both Amazonia and the Pacific Ocean, is variable, ranging between 800 mm and >1500 mm annually. Although the treeline is at ca. 3300 m elevation, shrubs of the sub-puna and patches of Andean forest protected from frost and fire are found as high as 3800 m elevation. Trees and shrubs of these patches include *Alnus*, *Baccharis*, *Berberis*, *Brachyotum*, *Chuquiraga*, *Clethra*, *Escallonia*, *Gynoxys*, *Miconia*, *Myrsine,* and *Weinmannia*. In ungrazed and unburned areas, *Polylepis* woodlands exist from 3600 m to more than 4400 m elevation (Young and Leon, 1995; Kessler, 2002). Above 4000 m, Poaceae and wetland plants such as *Distichia muscoides*, *Plantago rigida* and *Gentiana*, *Hypsela*, *Isoetes*, *Lilaeopsis*, *Ourisia*, *Oxychloe*, and *Scirpus* are important landscape components (Davis et al., 1997).

Highland montane forests in the region are heavily modified by human activity and increasingly threatened by logging for timber species such as podocarps (*Podocarpus* and *Prumnopitys*; Young and Leon, 1995; Davis et al., 1997). Crop fields are found in sheltered intermontane valleys. The nearest modern crop field identified from a satellite image is about 27 km away from our study site.

The study site, Laguna La Compuerta (7°30′S, 78°36′W, 3950 m elevation), lies within a high-elevation lake district and was selected for its relatively large size (ca. 750 m × 450 m; Fig. 2). Water depth across the main body of the lake was between 6 m and 7 m and was 6.2 m at the coring site. The lake was oligotrophic, with a Secchi depth greater than its depth.

## Methods

A 3.7-m sediment core was raised on August 16, 2000. The uppermost 0.70 m of the profile was collected using a 3″ OD corer designed to collect unconsolidated sediments (Fisher et al., 1992). This core was extruded in a vertical position to maintain stratigraphy and sampled into Whirl-pak bags. Deep sediments between depths of 0.50–3.70 m were collected using a Livingstone piston corer and shipped unopened in their polycarbonate coring tubes to the University of Florida, where they were stored at 4°C until studied.

Physical properties (magnetic susceptibility and bulk sediment density) were measured using a Geotek Multi-Sensor Core Logger at the University of Florida using a Bartington SI2 loop sensor and by gamma ray attenuation, respectively. Unconsolidated sediments above 0.50 m were not measured for physical properties.

Samples of 0.5-$cm^3$ volume were taken at 5–20 cm depth intervals for pollen analysis. The samples were treated with standard palynological procedures (Faegri and Iversen, 1989) and a spike of exotic *Lycopodium clavatum* spores was added to calculate pollen concentration (Stockmarr, 1971). Identifications were based on published atlases and keys (Heusser, 1971; Markgraf and D'Antoni, 1978; Hooghiemstra, 1984; Roubik and Moreno, 1991; Colinvaux et al., 1999) and the pollen reference collection at the Florida Institute of Technology. A computerized key was used in assisting pollen identification (http://research.fit.edu/bushlab/pollen_db.htm). At least 300 terrestrial pollen grains were counted at each level. Pollen percentages were calculated based on the total of terrestrial pollen grains. Charcoal fragments <180 μm were counted in pollen samples. CONISS analysis was used to zone the palynological data based on pollen percentage data (Grimm, 1992).


Figure 1. Map of the study site and its relative location to other paleoecological study sites in the text. Other sites: (a) Chorreras; (b) Surucucho; (c) Chocho; (d) Baja; (e) Junin; (f) Paca; (g) Pomacocha; (h) Jeronimo; (i) Marcacocha; (j) Titicaca.

Radiocarbon dates of bulk sediment were determined by AMS at Lawrence Livermore National Laboratories and Woods Hole Oceanographic Institute and were calibrated using CALIB 4.3 (Stuiver and Reimer, 1993) or, for older samples, the linear equation in Bard (1998).

## Results

### *Chronology and sedimentation*

The chronology was based on seven AMS radiocarbon dates (Table 1). The basal age of the core was estimated to be >50,000 cal yr B.P. Pollen was only obtained from the top 200 cm of the core, yielding a c. 33,000-year pollen record.

A discontinuity in the sedimentation is evident between c. 30,000 and 16,200 cal yr year B.P., which coincides with a major stratigraphic transition (Table 2). As the 30,000-year age dates the top of the more consolidated sediment, this is taken as being the age of the onset of the hiatus. To determine the resumption of sedimentation, the rate of accumulation in the overlying gyttja was projected down to the consolidated sediment boundary, yielding an extrapolated age of 16,200 cal yr B.P. (Fig. 3).

A further period of slow sediment accumulation takes place between c. 120 and 130 cm and is bounded by dates of 9490 and 12,870 cal yr B.P. While this rate of deposition is not impossible, given that this is seen as being a dry event within the record (below), it is more likely that sediment only accumulated intermittently during this interval.

### *Magnetic susceptibility and bulk density*

Magnetic susceptibility (MS) reveals three striking peaks of iron-rich sediment at between 205 to 185 cm (c. 33,500–31,000 cal yr B.P.), between 157 and 127 cm (c. 14,700–11,900 cal yr B.P.) and again between 120 and 108 cm (c. 9500–8300 cal yr B.P.). Bulk density gradually decreases between 240 and 175 cm. Between 175 and 0 cm, density is constant with the exception of an increase between c. 120 and 123 cm (Fig. 4).

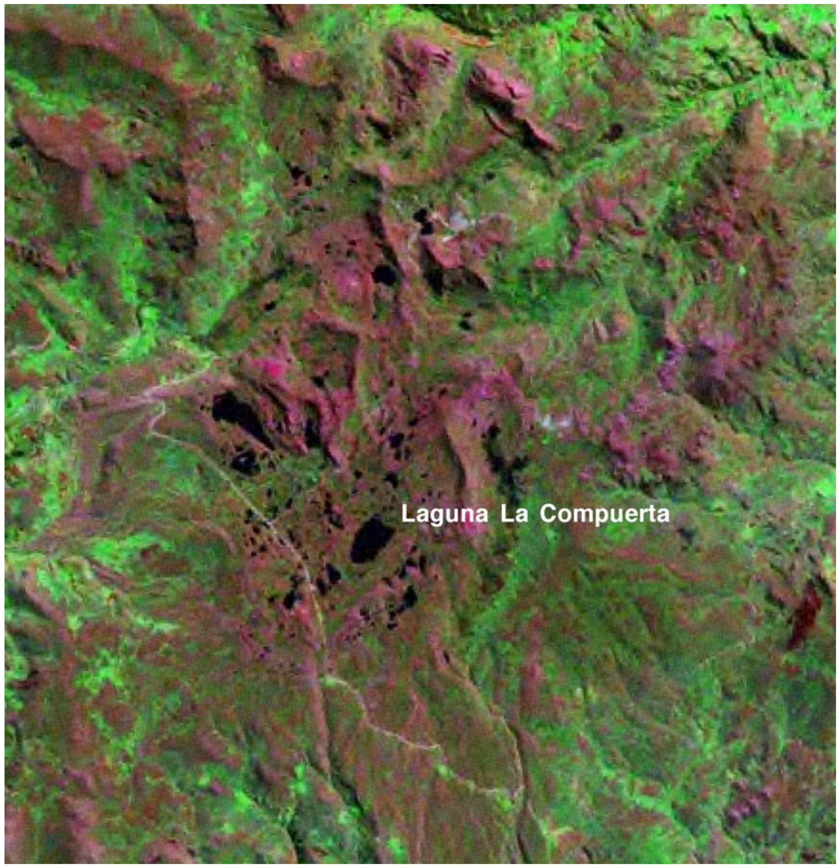


Figure 2. Satellite image of the study area and Laguna La Compuerta.

*Pollen analysis*

The CONISS analysis of the pollen diagram yielded four zones (Fig. 4).

*Zone 1 (200–132 cm, ~33,000–13,000 cal yr B.P.)*

Very abundant *Polylepis/Acaena* (~20%) pollen was the most striking characteristic of this zone. Ericaceae, *Acalypha*, *Plantago,* and *Myrsine* were the other abundant taxa. Poaceae pollen abundance was low compared with other portions of the core, even though it was ~25% of the pollen sum in this zone. Pollen concentration was very low at <100,000 grains/cm$^3$ (Fig. 5). The relative abundance of fern spores was highest in this zone, but *Isoetes* spores were rare.

Two subzones were divided above and below a depth of 168 cm (~15,500 cal yr B.P.). The lower subzone contained higher percentages of Poaceae, *Plantago*, and *Podocarpus* pollen and *Polypodium* and Trilete spores than the upper one. Very few *Isoetes* spores were found in the lower subzone. The upper subzone contained more pollen and spores of *Polylepis/Acaena*, *Ambrosia*, Ericaceae, *Lycopodium*, and *Isoetes* than the lower subzone. The division also coincides with the bulk density decline at ~170 cm (Fig. 4).

Table 1
AMS radiocarbon dates and calibrated dates for Laguna La Compuerta

| Depth (cm) | Lab no. | Materials | $^{14}$C age | Calibrated age (age range) |
|---|---|---|---|---|
| 25–26 | 83744 [a] | sediment | 1585 ± 40 | 1516, 1425 (1553–1354) |
| 80–81 | 83745 [a] | sediment | 4720 ± 40 | 5468 (5586–5320) |
| 120–121 | 83746 [a] | sediment | 8455 ± 40 | 9487 (9531–9331) |
| 130–131 | 83747 [a] | sediment | 10,760 ± 40 | 12,876 (12,979–12,631) |
| 154–155 | 40565 [b] | sediment | 12,450 ± 80 | 14,500 (14,144–15,434) |
| 179–180 | 83719 [a] | sediment | 25,720 ± 200 | 30,041 (29,807–30,274) |
| 375–376 | 83720 [a] | sediment | 47,900 ± 1700 | 55,947 (53,961–57,933) |

Calibration followed Stuiver and Reimer (1993) using CALIB 4.3. For dates >21,000 14C yr B.P., calibrated ages were calculated using the linear regression equation of Bard (1998).

[a] By Lawrence Livermore National Laboratories (LLNL).

[b] By National Ocean Science Accelerator Mass Spectrometry Facility (NOSAM).

Table 2
Descriptions of the sediment for the core from Laguna La Compuerta

| Depth (cm) | Sediment |
|---|---|
| 0–110 | grey gyttja |
| 110–120 | stratified yellow-grey clayey gyttja |
| 120–122 | yellow clayey gyttja |
| 122–130 | stratified brown clayey gyttja |
| 130–135 | stratified brown-orange clayey gyttja |
| 135–154 | stratified bright brown clayey gyttja |
| 154–179 | bright brown stratified clayey gyttja |
| >179 | grey-green clay |

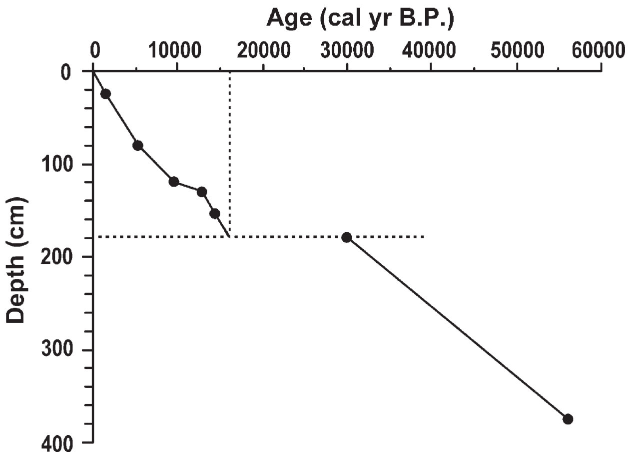


Figure 3. Age-depth curve of the Laguna La Compuerta core.

*Zone 2 (132–82 cm, ~13,000–5600 cal yr B.P.)*

This zone begins with a sudden drop in abundance of *Polylepis/Acaena* pollen. *Polylepis/Acaena* pollen was <5% and in most levels was <2%. Meanwhile, Poaceae pollen increased to become the most dominant type (~50%) in the zone. *Alnus* pollen was another important type that increased from ~5% to ~20% in upper portions of the zone. *Podocarpus*, *Thalictrum,* and Urticaceae/Moraceae (with 3 pores) all increased in abundance. *Isoetes* spores attained their highest peak of abundance (>250% of total terrestrial pollen sum) at the beginning of the zone. Percentages of *Ambrosia* pollen were very low. This zone contained the highest pollen concentration (>300,000 grains/cm$^3$) of the entire core.

*Zone 3 (82–20 cm, 5600–c. 1150 cal yr B.P.)*

Poaceae was still the most dominant pollen type (~50%). However, concentration data show its steady decline throughout the zone. *Alnus* dropped to <10% in the first part of the zone and then started to recover in the upper part of the zone. Abundances of pollen of *Ambrosia* and Chenopodiaceae/Amaranthaceae increased almost simultaneously in this zone, whereas *Podocarpus* decreased slightly. *Isoetes* spores were generally abundant (mostly >50% of total terrestrial pollen). An overall pattern of declining pollen concentrations is evident in this zone, falling from 350,000 to 150,000 grains/cm$^3$ (Fig. 5).

Two subzones were divided at the depth of ~53 cm (3500 cal yr B.P.). The lower subzone contains lower *Alnus* and higher Poaceae and *Podocarpus* pollen percentages. Concentrations of *Isoetes* spores and total pollen were much higher in the lower subzone than in the upper. Maize pollen was found in the upper subzone at a depth of 40 cm (~2600 cal yr B.P.).

*Zone 4 (20–0 cm, 1150–0 cal yr B.P.)*

Poaceae decreased in this zone, both in percentage and concentration (between 100,000 and 130,000 grains/cm$^3$). *Alnus*, *Dodonae*, and *Myrsine* pollen increased in abundance, as did spores of filicales and *Isoetes*, whereas *Ambrosia* and *Podocarpus* pollen decreased slightly from zone 3.

### *Charcoal*

Charcoal was rare below 120 cm (9500 cal yr B.P.). Above 120 cm, charcoal concentrations increased dramatically with reaching peak abundances between 105 cm (8000 cal yr B.P.) and 120 cm. Generally, charcoal remained at high levels in the rest of zone 2 and most of zone 3. Charcoal concentrations were highest in zone 3 but decreased in zone 4 (Fig. 5).

## Discussion

### *Deglaciation*

The bottom sediments (373 to 225 cm) in the core were composed of glacial flour, indicating that the site was very close to the lowest extent of the alpine glacier. Increased magnetic susceptibility (MS) between c. 34,000 and 32,000 cal yr B.P. indicate increased influx of glacial rock flour. This observation could be consistent with the assessment of Smith et al. (2005) that there was a deglacial event within the Andes at c. 32,000 yr B.P. Given the dating uncertainties in both records, the rock flour pulse to La Compuerta and the retreat from moraines in Bolivia could represent the same event.

At La Compuerta, the period between c. 32,000 and 15,000 cal yr B.P. has low values of rock flour input, consistent with a landscape covered by ice. Within this period is a depositional hiatus that is flanked by samples that contain pollen consistent with glacial forelands. Low pollen concentrations and the presence of puna taxa, such as *Polylepis* (below) and Poaceae, and rare grains updrafted from downslope forests, e.g., *Podocarpus*, *Alnus*, and Urticaceae/Moraceae, are typical of such unproductive systems (Hansen et al., 2003; Bush, 2000).

The next wave of deglaciation is marked by high MS values that indicate a high influx of rock flour from retreating glaciers. The steady increase in MS between 160 cm and 130 cm (c. 14,900 and 12,900 cal yr B.P.) is consistent with a steadily warming landscape and closely parallels other regional records (Thompson et al., 1995; Seltzer et al., 2002; Paduano et al., 2003; Ramirez et al., 2003; Bush et al., 2005).

An abrupt decrease in MS, an increase in sediment density, relatively low pollen concentrations, and a low lake stand indicated by a peak of *Isoetes* spores, all occurring between 13,000 and 11,000 cal yr B.P., suggest a return of glacial conditions. Reduced meltwater input and cold, dry conditions are consistent with other regional estimates for a Younger Dryas cooling.

### *A note on Polylepis/Acaena pollen*

Today, more than a dozen species of *Polylepis* are found in Peru and they include species that grow from the upper cloud forest and some that are the highest elevation woody plants, growing as high as 5000 m elevation in the Peruvian and Bolivian Andes (Kessler, 1995, 2002). In Peru, the palynologically indistinguishable *Acaena* is restricted to moist valleys and habitats within the cloud forest. While we are very conscious that communities change through time, the ecophysiological niche of a species is

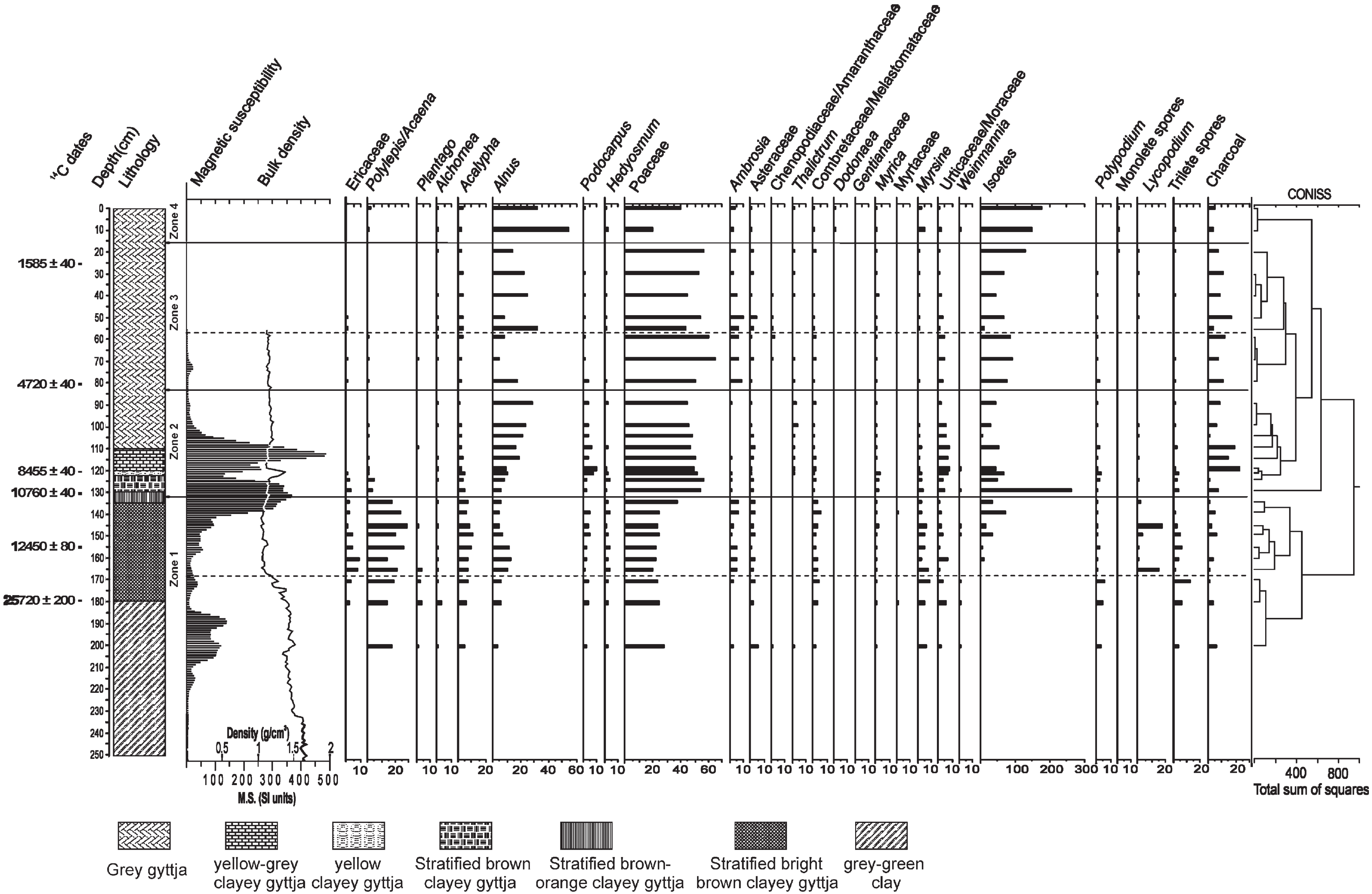


Figure 4. Pollen percentage diagram of the Laguna La Compuerta core. AMS $^{14}C$ dates, lithology, magnetic susceptibility, bulk density and the CONISS diagram are also shown.

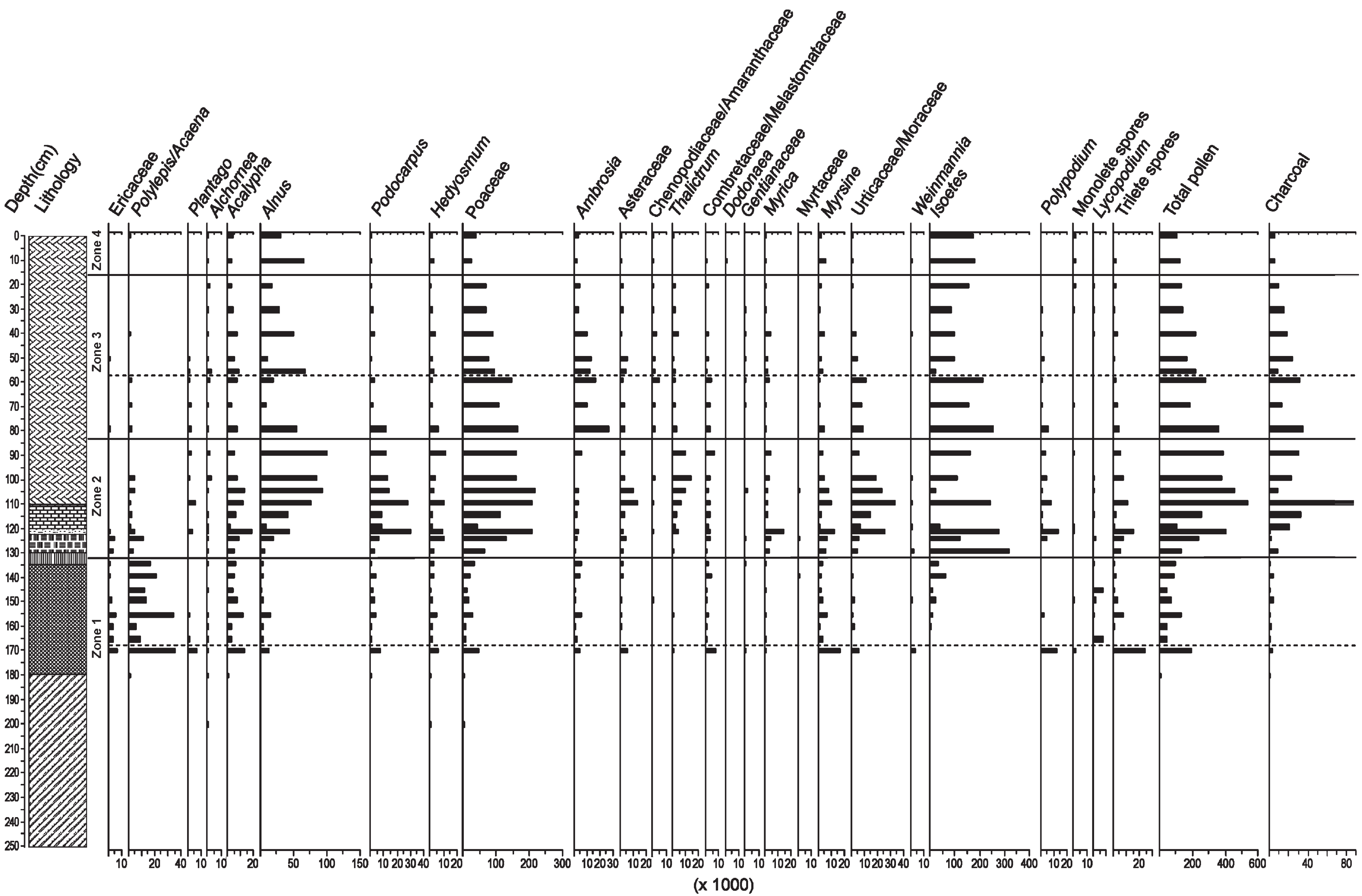


Figure 5. Pollen concentration diagram of the Laguna La Compuerta core. Also shown is the lithology of the core.

probably conservative. Therefore, in this record where we find the grains of *Polylepis*/*Acaena* uniquely associated with a super-puna environment, we are confident that they are *Polylepis* and not *Acaena*. Consequently we refer to them as *Polylepis*.

The 20% abundances of *Polylepis* found in this study have not been replicated in studies of modern pollen rain (Hansen and Rodbell, 1995; Weng et al., 2004a). However, similar proportions of *Polylepis* have been described during relatively dry events in records from Surucucha (Colinvaux et al., 1997), Chochos (Bush et al., 2005), Junin (Hansen et al., 1984), and Titicaca (Paduano et al., 2003). That the Andes supported a *Polylepis*-rich woodland prior to human occupation has been suggested (Ellenberg, 1979). Rather than assuming a dense forest of *Polylepis*, it is perhaps more plausible (given the cold at this time) to postulate a super-puna with extensive bare ground and scattered *Polylepis*, perhaps growing best in the moderated microclimate near the lake.

The decline of *Polylepis* occurs after the first incidence of charcoal in the core but is broadly coincident with the transition to a fire-dominated grassy puna. Kessler (2002) suggested that the decline of *Polylepis/Acaena* pollen was due to human-induced burning of *Polylepis*. Our field observations are that *Polylepis* can survive periodic fire but is slow to resprout and would probably be eliminated by regular fire, as suggested by Kessler (2002). Thus, more frequent fires, coupled with warming following the Younger Dryas event, probably caused the decline of *Polylepis* while promoting an assemblage approximating that of modern puna.

### *Holocene climate change*

Records from ice cores and the Altiplano indicate that the central Andes experienced a time-transgressive drought that progressed southward. Lake sites at 7°S experienced a lowstand between c. 9500 and 7300 cal yr B.P. (Hansen and Rodbell, 1995; Bush et al., 2005). At Laguna La Compuerta the record appears to be somewhat different. The *Polylepis* phase was probably drier than that of the early Holocene, which appeared to be warm and mesic. Forest components such as Urticaceae/Moraceae, *Podocarpus,* and *Myrica* reached their peak abundance, while *Isoetes* was much less abundant than during the Younger Dryas event or the present. This warming event appeared to peak about 8500 cal yr B.P. and coincided with the maximum MS input as glaciers receded from the catchment. By 7500 cal yr B.P., the glacial inputs were negligible, suggesting an ice-free catchment.

The more mesic floral elements gave way to *Alnus*, which can tolerate drier conditions, and a gradual lowering of lake level is suggested by increasing abundances of *Isoetes.* The early- to mid-Holocene peak of *Alnus* representation (~25%) suggests *Alnus* growing closer to, though probably not actually at, the sampling site. This site at 3950 m altitude is well above the treeline and it is probable that *Alnus*, *Hedyosmum*, *Myrica*, and *Podocarpus* were not locally present. However, a mid-Holocene temperature optimum (Thompson et al., 1995; Ramirez et al., 2003) may have led to an upslope expansion of these genera closer to the site (Weng et al., 2004b).

While our inference that the early Holocene was relatively wet prior to 8500 cal yr B.P. does not match records from sites at this latitude on the eastern cordillera, a different precipitation history on the western slopes from their eastern Andean counterparts has been noted by Betancourt et al. (2000) and Placzek et al. (2001).

At ~5500 cal yr B.P., forests of *Alnus*, *Hedyosmum*, and *Podocarpus* declined and were replaced by Poaceae and weedy species, such as *Ambrosia* and Chenopodiaceae/Amaranthaceae. The decline of *Alnus* at approximately the same time has been observed in all studied sites from the highland Ecuador and Peru, suggesting a regional phenomenon (Weng et al., 2004b). A cooling event starting at ~5500 cal yr B.P. and the onset of intensive land management by humans may have been responsible for the change (Weng et al., 2004b; also see below).

As at other locations (e.g., Hansen et al., 1984, 1994; Hansen and Rodbell, 1995; Chepstow-Lusty et al., 1998; Weng et al., 2004b), pollen of *Alnus* increased to its highest values in the last millennium. At Marcacocha, Chepstow-Lusty and Winfield (2000) suggested pre-Incan cultivation of *Alnus*. At La Compuerta, coincident increases of *Isoetes* and *Alnus* are consistent with progressively warmer and drier conditions from about 1150 to 600 cal yr B.P. influencing the site (Chepstow-Lusty et al., 2003); a decline in charcoal abundance suggests that this was not a period of intensified human activity.

### *Human activities*

Humans probably arrived in northern Peru by 11,000 cal yr B.P. (Dillehay, 2000; Núñez et al., 2002). No indisputable evidence of early human occupation has been demonstrated in the immediate vicinity of Laguna La Compuerta, and therefore we do not know whether the charcoal increase in our site at about 10,000 cal yr B.P. was anthropogenic or natural in origin. However, the presence of rock shelters and caves with cultural deposits (e.g., lithic tool debitage, ceramics, anthropogenic charcoal deposits) located ~1 km from the lake suggests a long human presence in the area.

At La Compuerta, the increase of the herbaceous weeds *Ambrosia* and Chenopodiaceae/Amaranthaceae in both percentage and concentration pollen data at 5500 cal yr B.P. matches a decrease of *Alnus*, *Hedyosmum,* and *Podocarpus*. These records probably reflect spatially disparate but related events. Downslope intensification of land clearance may have reduced forest cover, while the local manifestation of land use increased weed species growing close to the lake. In Baja, Chorreras, Chochos, and Surucucho, a similar response is evident at ~5000 cal yr B.P. (Colinvaux et al., 1988; Hansen and Rodbell, 1995; Hansen et al., 2003; Bush et al., 2005).

*Ambrosia* is often introduced by disturbance, especially after human disturbance as it was deliberately planted to stabilize earthen terraces (Chepstow-Lusty and Winfield, 2000). Chenopodiaceae/Amaranthaceae could be crops, weeds or marshland plants. Quinoa (*Chenopodium quinoa*) is a traditional food crop in the Andes. Unfortunately, the pollen of *C. quinoa* pollen is inseparable from that of other Chenopodiaceae/Amaranthaceae. Further evidence that the disturbance may be human-related is the high relative abundance of charcoal during this period. Moreover, in Laguna La Compuerta, the appearance of maize (*Zea mays*) pollen at the depth of 40 cm (2600 cal yr B.P.) is a strong signal of human occupation and cultivation of an important food crop.

These data suggest that human occupation could have occurred in the high central and northern Peruvian Andes by 9000 years ago and most likely at least by 5500 years ago as the climate became moist and more suitable for human activities. It is possible that after 5500 years ago, hunting was supplemented by lakeside agriculture as reported in other regions (Bonavia, 1991; Dillehay, 2000). Our conclusions regarding land use are tentative, however, and further investigations are needed to elicit the timing and nature of early Andean hunting and gathering, agriculture, and land management.

## Conclusions

The analysis of Laguna La Compuerta provided a c. 33,000-year record of climate and vegetation change in the western Andes of Northern Peru. Two phases of deglaciation, at c. 34,000–32,000 yr B.P. and at 16,200 yr B.P., were separated by a period of no sediment accumulation. During this time a glacial episode is suggested to have covered the landscape in ice. Deglaciation was interrupted by a dry cold event coincident with the Younger Dryas event.

An early Holocene thermal optimum is suggested between c. 11,000 and 5500 cal yr B.P. The precipitation signature in this record is not particularly distinct, but tentatively we suggest the early Holocene to have been relatively mesic, with a general trend to somewhat drier conditions around 5000 years ago, a wetter oscillation centered on 2600 cal yr B.P. when evidence of maize agriculture is found, followed by a relatively dry last millennium. This precipitation pattern is almost the inverse of that observed in lakes in the eastern cordillera at the same latitude, suggesting a primarily Pacific control, though not necessarily a Pacific moisture source, for the precipitation at this site.

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