Late Quaternary vegetation history of Quebrada de Chaco (25°30'S, 2650-3450m) in the hyperarid transitional zone between summer and winter rainfall regimes, Atacama Desert, Chile

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Vegetation histories are being developed from fossil rodent middens collected along a 1500-km transect (16-28°S) in the Atacama Desert to discriminate wet and dry episodes that can be linked to long-term changes in the tropical and extratropical rainfall belts. In North American deserts, packrat middens have been the primary method for reconstructing vegetation (Betancourt et al. 1990). Several kinds of rodents (*Lagidium*, *Abrocoma*, *Phyllotis*, and *Octodontomys*) produce analogous deposits in South America, including Bolivia, Peru, Argentina and Chile. Having the consistency of a strongly-cemented adobe brick, rodent middens include plant macrofossils, pollen, rodent feces, bones and insects imbedded in crystallized urine. Rodent middens are preserved in rock crevices, shelters and caves (e.g., the hyperaridity of the Atacama Desert affords preservation of Pleistocene-age middens even underneath well-exposed boulders on hillslopes). The advantage of rodent middens is that plant macrofossil assemblages can be resolved to species, and the source area is known to be within 100 m of the midden. Radiocarbon dates are obtained either from a bulk sample of fecal pellets or fragments of a key plant species. The main disadvantage is that middens do not represent continuous nor stratigraphic deposition, but rather snapshots of local vegetation in rocky terrain over a few years to a few decades. Time series are constructed from middens of different ages collected from the same locality and elevation. Replicability is feasible by developing numerous midden chronologies from several localities at the same or different elevations. The ability to document exact elevational and latitudinal displacements of key plant species permits quantitative estimates of temperature and precipitation, which vary systematically with elevation. Species departures from midden chronologies are particularly suited to record abrupt changes in climate, specifically desiccation.

Fig. 1. Lowest (2650m) midden site in Quebrada de Chaco produced several full glacial and infinite age middens with *Stipa frigida*, a grass generally found above 3450 m.

Most of the several hundred middens collected and dated along the Atacama transect are from dry hillslopes with no access to wetlands. We focused primarily on the elevational transition from Prepuna to

Absolute Desert, where temperature effects can be ignored and vegetation changes can be attributed unequivocally to variations in seasonal precipitation. At their lower limits in the Atacama, plants are being constrained by lack of precipitation rather than heat load. Proof of this is the fact that lower limits of plants tend to decrease to the north, with increasing temperature and precipitation at equivalent altitudes. The season of the precipitation increases can be discerned from the flowering time of both annuals and perennials encountered in the middens, as well as the latitudinal direction of species displacements—i.e., summer (winter) precipitation can be inferred from summer (winter) annuals, summer (winter)-flowering perennials, or southerly (northerly) expansion of a northern (southern) species. In an earlier study of the Calama/San Pedro de Atacama Basins (22-24°S), we attributed grass invasions into Absolute Desert to intensification of monsoonal precipitation, particularly between 13.5-9 ^{14}C kyr B.P. (Betancourt et al. 2000; Latorre et al., Submitted).

We are presently analyzing pollen and macrofossil assemblages in 40 dated middens collected in April 2000 from Quebrada de Chaco (25°30'S, 2650-3450 m), within what is arguably the driest sector in the Atacama Desert. Quebrada de Chaco is part of a large transverse valley that drains the west slope of the Cordillera Domeyko and eventually reaches the Pacific by way of Quebrada Taltal, a total distance of 150 km. There are no weather stations in the immediate vicinity or altitudes of the midden sites; the nearest station (Estacion Refresco; 25°19'S; 69°52'W, 1850 m) receives mean annual precipitation of 9mm, two-thirds of it in winter. The flora of the region is poorly known, not very diverse, and restricted primarily to cliff areas, washes and canyon bottoms below 4000 m. Elevations below 2500 m generally do not support vascular plants. Arroyo et al. (1998) studied the flora on the flanks of Volcan Llullaillaco overlooking Salar de Punta Negra,100 km north of Quebrada de Chaco. They found 27 species that are northern Andean elements, 23 southern Andean elements, and 40 distributed in both sectors. Most of the northern Andean elements reach their southern limit in Llullaillaco National Park, and do not occur at Quebrada de Chaco.

The Quebrada de Chaco middens were collected from two elevational belts, 2650-3200m and 3450-3500 m. Fig. 2 reports grass point occurrence in these two sets of middens. The lowest site, 2650 m, consists of a low limestone cliff on the edge of a barren valley (Fig. 1). This site yielded several full glacial and infinite age middens full of grasses (mostly *Stipa frigida*) and other species that today have lower limits above 3450 m. One of the full glacial and two of the infinite age middens have low abundance of grasses. The Holocene middens from the lower elevational belt come mostly from 2800-3200m. The upper elevation site, 3450-3500 m, consists of a shallow, dry canyon with ignimbrite walls. At this site, middens that date between 14.2 and 9 ^{14}C kyr B.P. are also full of grasses. One midden of infinite age contains abundant grasses, while the other is full of grasses. Holocene grass abundances at these higher sites are relatively low. At both the lower and higher sites, the probability of finding a midden older than 9 ^{14}C kyr B.P. is greater than that of finding a Holocene midden; the number (8) of middens of infinite age at this site is unusual for both North and South America.

It appears that the lower site is registering only the most extreme wet events, evident in full-glacial (19.4-15.1 ^{14}C kyr B.P.) expansion of *Stipa frigida* and other high-elevation shrubs >800 m downslope into the Absolute Desert. The higher site registers another, perhaps lesser, pluvial event between 14.2 and 9.0 ^{14}C kyr B.P. evident in a 100m or more elevational displacement of *Stipa frigida*. As a first cut an interpreation, the full glacial pluvial (perhaps due to a northward expansion of the westerlies and more winter precipitation) recorded at the lower Quebrada de Chaco site did not produce wholesale expansion of steppe grasses only 200-300 km to the north in the Salar de Atacama/Calama Basins. Conversely, the late glacial/early Holocene summer pluvial which produced up to 1000 m expansion of steppe grasses in Salar de Atacama/Calama Basins produced a lesser expansion recorded only at the higher Quebrada de Chaco site. These questions may be resolved with ongoing pollen and macrofossil analysis of these middens, and continued midden work in the southern Atacama.

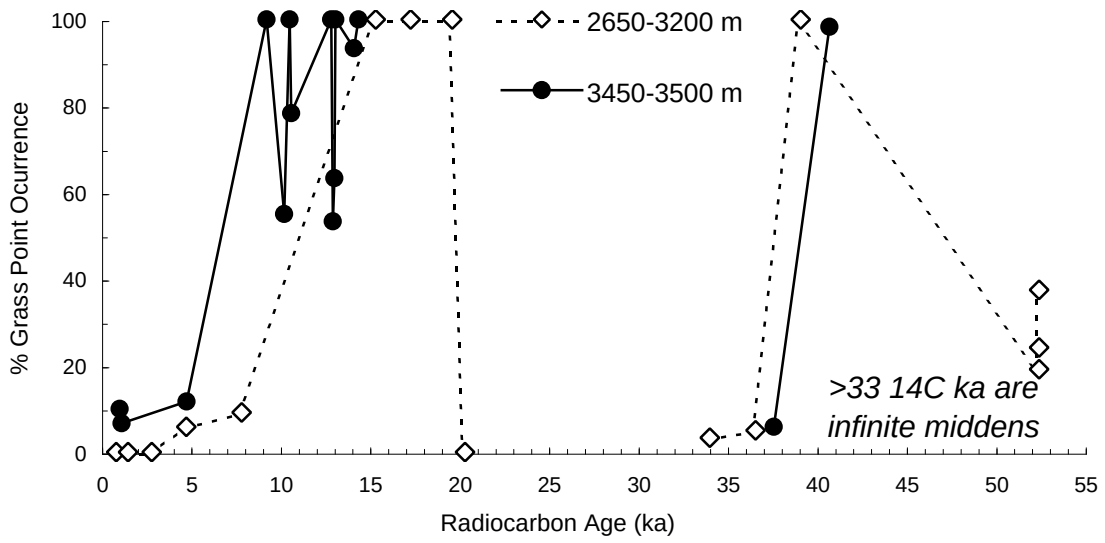

Fig. 2. Grass point occurrence in Quebrada de Chaco middens from two elevational zones 3450-3500 m and 3200-2650 m. Grass abundance was measured as point occurrence on a 120-cell rectangular grid (each cell is 6.45 cm^2) overlain on a sorting tray. A sediment matrix spitter was used to randomly segregate 100 ml of plant debris from each midden. Midden debris was spread uniformly across the grid, and grass abundance was measured as point occurrence (the number of cells out of 120 where grass blades, florets, or seeds were identified).

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