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Hydrogeologic influences on the preservation of *Orestias ascotanensis* (Teleostei: Cyprinodontidae), in Salar de Ascotán, northern Chile

Influencias hidrogeológicas en la preservación de *Orestias ascotanensis* (Teleostei: Cyprinodontidae), en el Salar de Ascotán, norte de Chile

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ABSTRACT

Orestias ascotanensis Parenti 1984, is a small native fish found in isolated freshwater pools at Salar de Ascotán. Other *Orestias* are found in freshwater lakes in the Altiplano to the north, separated by hundreds of kilometers of desert. The distribution of fish in the Salar is limited by freshwater availability and thus the populations are located within very short extension (less than 1 000 m) on each spring and pool. The fish apparently arrived at Ascotán during a high stand at the last glacial maximum (LGM, ~17 ka) of Lake Minchin, which filled the internal drainage of the Altiplano. During Holocene time, with drier climate, the Ascotán pools have been maintained by groundwater flow which includes recharge from the Ascotán topographic basin and from recharge in Pastos Grandes Caldera, a Miocene-Pliocene ignimbrite center at higher elevation to the east. Such hydrogeologic features create a permanent water supply allowing the preservation of a unique landscape and biota including the small and very isolated populations of Orestias.

Key words: *Orestias*, Ascotán, salar, Andean killifish

RESUMEN

Orestias ascotanensis Parenti 1984, es un pequeño pez nativo de *lagunitas* aisladas de agua dulce en el Salar de Ascotán. Existen especies de *Orestias* en lagos de agua dulce en el Altiplano más al norte, separados por cientos de kilómetros de desierto. En Ascotán, los peces se encuentran restringidos a la disponibilidad de agua dulce, lo cual sólo permite que la población de cada vertiente y laguna se concentre en una extensión muy corta (no superior a los 1000 m) desde el nacimiento de las vertientes. Aparentemente, los peces llegaron a Ascotán durante el último máximo glacial (LGM, ~17 ka) del Lago Minchin, el cual llenaba la cuenca endorréica del Altiplano. Durante el Holoceno, con clima más seco, las lagunitas de Ascotán se mantuvieron y se mantienen por caudales de agua subterránea provenientes de recargas desde la cuenca Ascotán y tambien de recargas desde la Caldera Pastos Grandes, un centro ignimbrítico del Mioceno-Plioceno de cota más alta al este. Tales características hidrogeológicas generan un abastecimiento mínimo permanente de agua dulce, lo cual permite mantener un ambiente y biota únicas, incluyendo las pequeñas y aisladas poblaciones de *Orestias*.

Palabras clave: *Orestias*, Ascotán, salar, pez andino

INTRODUCTION

The development of large new mining ventures in norhern Chile has spurred a search for new water resources. At the same time, a heightened environmental consciousness has prompted the performance of baseline studies to establish potential environmental impact associated with development of the water resources. One such study at Salar de Ascotán, performed by Geotecnica Consultores for

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CODELCO, Division Chuquicamata, documented the presence of a freshwater fish, *Orestias ascotanensis* Parenti 1984, in various spring-fed pools on the margins of the salar (Jara et al. 1995).

Salar de Ascotán is located at 21.5° S latitude at approximately 3720 msl (meters relative to mean sea level) elevation (Fig. 1) in the modern high Andes volcanic chain. At present time, this Salar is part of an endorheic basin and as such, surface water is restricted to the margins of the salar, where it is fed by springs, and to stream channels and lagoons within the salar dry lake surface, while most of this surface is covered by evaporite deposits.

In the springs, a fish of the genus *Orestias* (Andean killifish) has been

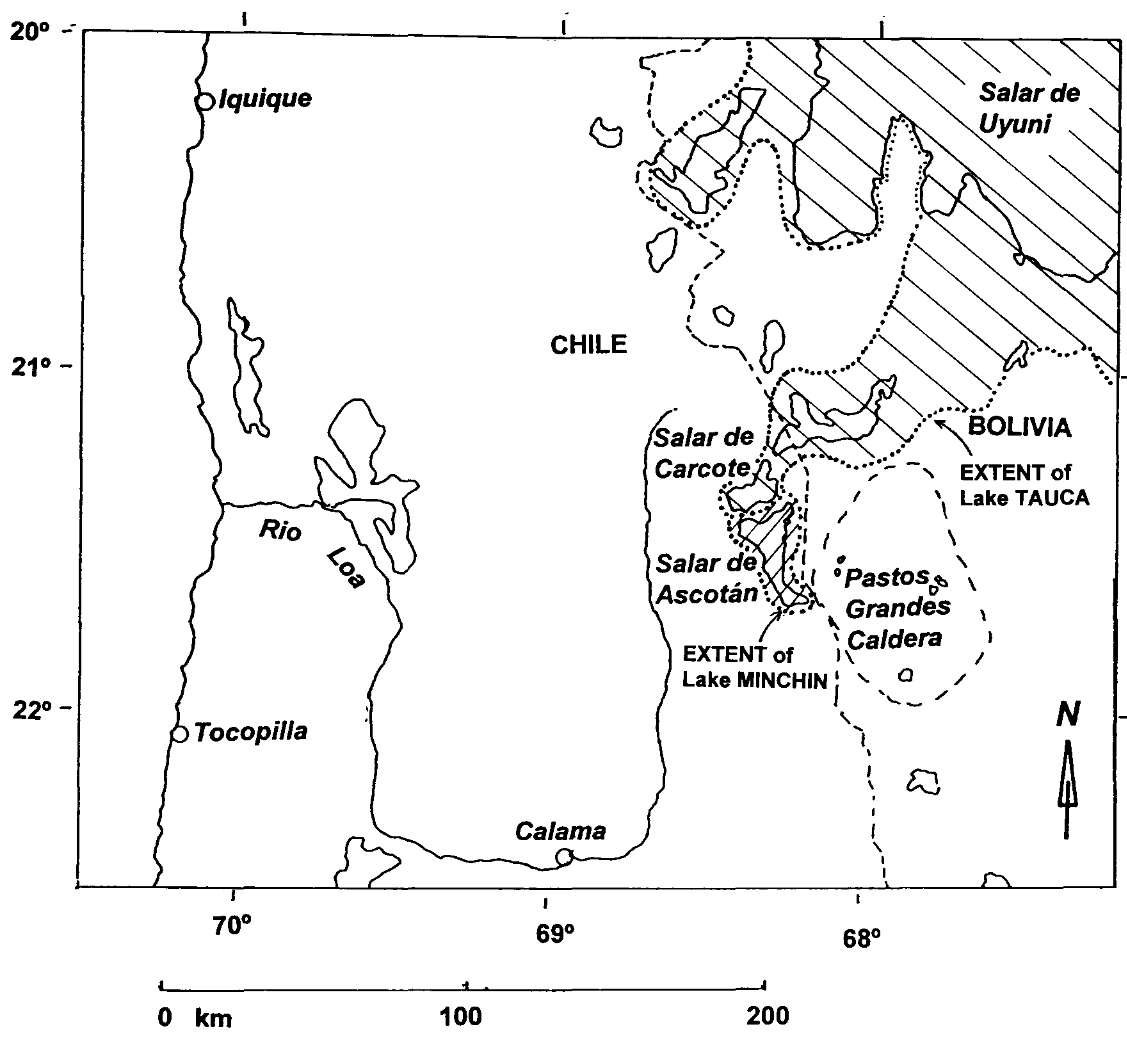

Fig. 1: Location of Salar de Ascotán. Indicated by dotted lines are the approximate extents of Pleistocene Lake Minchin and Lake Tauca. The southern extent of Lake Minchin included Salar de Ascotán, while the southern extent of Lake Tauca included only Salar de Carcote. The closed dashed line surrounding Pastos Grandes Caldera is the approximate outline of the caldera. The north-south dashed line is the international border.

Ubicación del Salar de Ascotán. La línea de puntos indica la extensión aproximada de los Lagos Pleistocénicos Minchin y Tauca. El extremo sur del Lago Minchin incluía el Salar de Ascotán, mientras la región sur del Lago Tauca sólo incluía el Salar de Carcote. La línea cortada que forma un círculo cerrado alrededor de la Caldera de Pastos Grandes indica su extensión actual aproximada. La línea discontínua de norte a sur indica la frontera entre Chile y Bolivia.

reported. The genus *Orestias* belongs to a complex species group restricted to Altiplano lakes and ponds (Parenti 1984), with an apparent high degree of speciation and/or morphological variability. As *O. ascotanensis* at Salar de Ascotán could be a unique species (Parenti 1984), and freshwater being a scarce and needed resource for mining activities, it is necessary to study the remaining populations and its habitat. Also it is necessary to understand the mechanisms which maintain these very isolated, small water bodies, through time. The evaluation of the present fish populations and interpretation of how this fish came to Salar de Ascotán and how it has survived during late Pleistocene and Holocene climate changes involves understanding of the geologic setting, the regional hydrogeologic regime, and the history of glacial lakes in the Altiplano.

MATERIALS AND METHODS

The aquatic environments at Salar de Ascotán were visited and sampled during April 1992, March 1994 and June 1995. In every field trip, the whole perimeter of the salar was surveyed and water samples for basic chemistry were collected at the springs, in a sequence from the source towards the center of the lake. On site we measured T° and conductivity with a Jenway conductivity meter and three water samples were taken along transects at each spring. As we did not want to damage the small and isolated populations, during the field seasons of April 1994 and June 1995 only qualitative fish samples were collected at each spring by pulling a fence net along the stream. The only quantitative fish sampling was performed in march 1994 when each netting episode lasted 10 minutes and covered roughly 10 m along the stream. Most information on the fish biology and population characteristics will be reported elsewhere.

During the same field trips, geological sampling and observations were carried out through the Ascotán and Carcote basins and at the upper part of the Rio Loa basin (Fig. 1). The geological effort also included evaluation of aerial photographs spanning approximately the past 50 years and of Landsat satellite images representing the past two decades.

An important part of the hydrogeologic interpretation is based on visual observation and photographic documentation of temporal changes in surface water flow with the salar.

RESULTS AND DISCUSSION

Climatic characteristics of Salar de Ascotán are typical of altiplanic environments, very dry, windy, with large temperature fluctuations between day and night, with these differences being extreme in winter (less than -20°C at night and 12 to 13°C during the day in June or July). Direct precipitation to the salar is unusual and generally occurs only during austral summer due to tropical storms coming from the Atlantic. A sixteen year average precipitation reported for Cebollar, on the west side of the salar is 49.2 mm/year (DGA, 1992 - Listado de Datos Estaciones Meteorológicas de Chile).

Freshwater Pools

Several isolated springs are present all along the east side of the salar (Fig. 2). Each spring produces a freshwater stream which runs into the salar for several hundred meters generating a marsh with terrestrial and aquatic vegetation. In most cases each stream ends in a shallow saline lagoon (less than 5 cm depth), these springs are issuing from bedrock fractures in Plio-Pleistocene volcanic rocks. While at the spring head, water conductivity was lower than 4,000 µS cm^{-1}, as the water flows in channels across the dry lake bed, conductivity increases

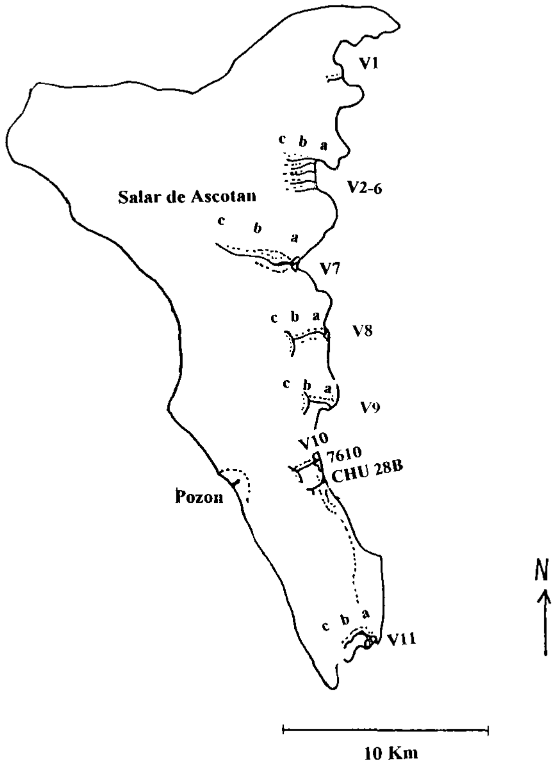

Fig. 2: Salar de Ascotán schematic view. Spring and stream locations and relative length are indicated. Names V1 to V11 indicate individual springs and a, b, c represent sampling locations. CHU28B is an artesian well while Pozon represents an isolated natural pool.

Vista esquemática del Salar de Ascotán. Se indica la ubicación de las vertientes y canales y su extensión relativa. Los nombres V1 a V11 indican vertientes individuales mientras a, b y c representan estaciones de muestreo. CHU28B es un pozón artesiano en tanto Pozón representa un pozo aislado natural.

rapidly, reaching values of more than 10 000 $\mu S\ cm^{-1}$ within 100 m from the spring head (Fig. 3). Fish and abundant aquatic insects are mostly found in areas designated as "a", "b", and "c" (Fig. 2). In each case, the spring head itself is designated as "a", with sites "b" and "c" being farther toward the interior of the salar, with correspondingly higher salinity. (Fig. 3). There was very little variation in conductivity among years for every site, and the coefficient of variation for the mean was in every case lower than 5%, indicating a rather stable situation in time.

The fresh water pools, with a varied aquatic flora and fauna, are separated from each other by expanses of dry evaporite surface ranging from hundreds of meters to several kilometers. Most of the pools are on the east side or south end of the salar (Fig. 2), with surface flow toward the northwest part of the salar, which is at lower elevation. This flow direction within the salar is consistent with a northwestward tilt of the Altiplano observed farther north (Bills et al. 1994). Although the perimeter of the salar is not flat, having internal relief of 20 meters or more, all springs occur at the local elevation of the evaporite surface, suggesting that the fresh water may be forced to the surface by a density contrast with the saline aquifer within the salar. Similar type of freshwater/brackish groundwater interface has been described at Mono lake in California (Rogers & Dreiss 1995).

Fish

The freshwater fish genus *Orestias* is restricted to high altitude lakes and ponds in the Altiplano from Ancash, Peru, in the north, to Salar de Ascotán, in the south (Jara et al. 1995). The largest species diversity and abundance is found in Lake Titicaca (Parenti 1984).

Orestias ascotanensis, the ecotype found in the pools of Salar de Ascotán, grows to reach between 6 and 7 cm in total length, is sexually dimorphic, with females larger than males (Jara et al. 1995). Populations in each spring are small (few thousand of individuals), and population sizes of *Orestias* in most of the streams seem to be related to salinity. In all the springs the largest fish densities were found near the head of the stream in sector identified as "a" (Fig. 3). Also the highest fish densities were found in sites V7 and V11, the springs and marshes with lowest conductivity (Fig. 3). The optimal conductivity where the fish develop larger populations seems to be

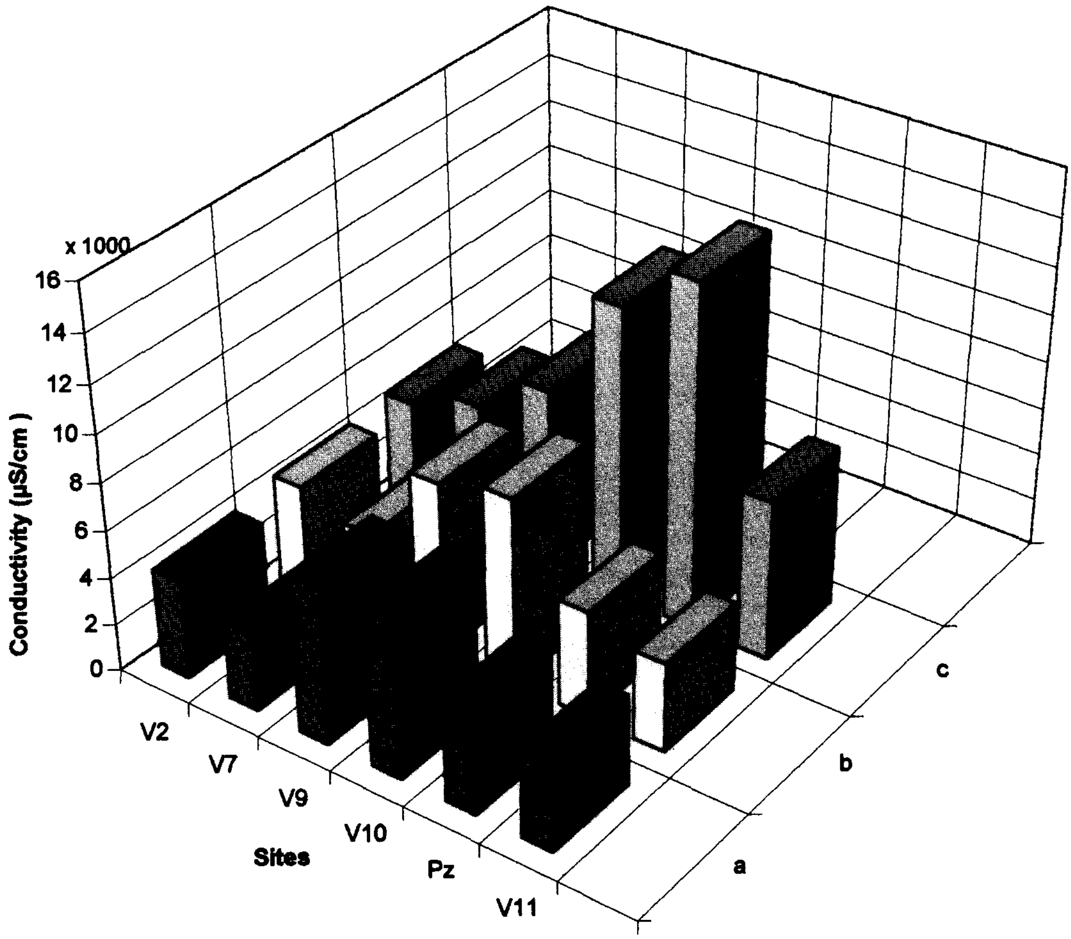

Fig. 3: Average Conductivity for each sampling site in µS cm^{-1} x 1 000. Site names for each spring are as indicated in Fig. 2. Pz represent Pozón. In the Z axis are the sampling sites within each spring, going from the spring head (a) to the Salar center (see Fig. 2).

Conductividad promedio para cada sitio de muestreo en µS cm^{-1} x 1 000. Los nombres de los sitios son aquellos indicados en la Fig. 2. Pz indica Pozón. En el eje Z están los sitios de muestreo dentro de cada vertiente, desde la cabecera de la vertiente hacia el centro del Salar.

between 3 000 and 4 000 µS cm^{-1} (Fig. 4), values corresponding to a range between 2 and 4 g l^{-1} of Total Dissolved Solids, that is in most cases still in the range considered as freshwater, therefore the fish are restricted to freshwater.

Orestias ascotanensis has in the past been described as a unique, endemic species only found at Ascotán, however, recent evidence suggests that breeding with other *Orestias* could be possible, so the designation as a separate species may not be warranted (Villwock & Sienknecht 1995, 1996). In Chile, *Orestias parinacotensis, O. chungarensis* and *O. laucaensis* are found in the area of Parque Nacional Lauca (18° 14´S), where they are listed as endangered (Glade 1988). However, this issue needs further revision if they all turn out to be just one species.

The modern population of *Orestias ascotanensis* in the pools of Salar de Ascotán are totally or partially isolated from each other in the individual streams or pools, and are isolated from other *Orestias* by many kilometers of extremely arid desert. There is little evidence of large changes in the water level of the salar since

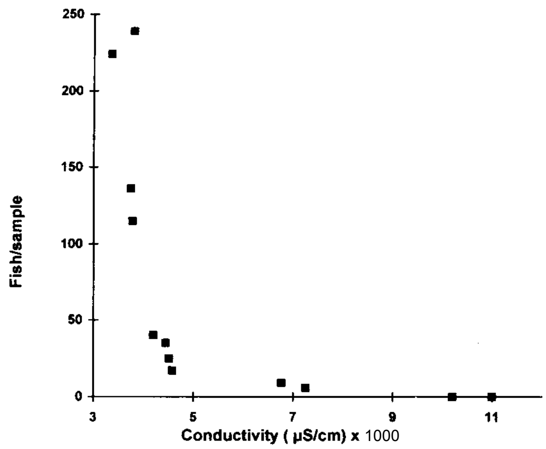

Fig. 4: Fish relative abundance (N° of fish per sample) in March 1994 as it relates to conductivity (µS cm^{-1} x 1000) for each site.

Abundancia relativa de los peces (N° de peces por muestra) en marzo de 1994, en relación a la conductividad (µS cm^{-1} x 1000) en cada sitio.

12, ka (thousands of years before present) so it is likely that the populations at each stream have remained mostly isolated through the same period. It is then surprising that such reduced populations have been maintained in each stream for thousands of years, and thus it is likely that water supply and general environmental conditions have remained with little variation during this time.

The suggested explanation of their presence in Salar de Ascotán involves the existence of large glacial era lakes and a permanent water supply until today.

Pleistocene Lakes

The interior drainage area of the Altiplano held large late Pleistocene lakes, which extended from north of Lake Titicaca to Ascotán Basin (Fig. 1). The highest fossil shoreline, at about 3800 m elevation, is called the Lake Minchin shoreline, and includes Ascotán as its southernmost extent. This fossil shoreline is observed in the western (railroad) pass between Salar de Ascotán and Salar de Carcote. Regionally, the age of the highest shoreline is about 17 ka (Bills et al., 1994), which apparently corresponds to the last glacial maximum (LGM) as indicated in ice cores and deep sea sediment cores. A lower fossil shoreline at about 3720 m, called the Lake Tauca shoreline, has been dated at about 12 ka (Servant & Fontes 1978), apparently corresponding to the mid-deglacial Younger Dryas cooling and ice-growth interval (Ruddiman 1987, Vostok Project Members 1995, Thompson et al. 1995). This shoreline is observed near the modern edge of Salar de Carcote, northeast side of Ascotán (Fig. 1), in Salar de Carcote, a completely dry area, fossil *Orestias* have been found (Villwock & Sienknecht 1995) which demonstrate their former presence in the whole basin.

The named glacial stages are best defined in the northern hemisphere, but interpretation of ice core records from Huascaran, Peru (Thompson et al. 1995), indicates that they also apply to southern hemisphere features. Lake Tauca did not fill Ascotán Basin, but the observed presence of fossil shorelines indicates that a smaller lake occupied the area of the present-day salar. These shorelines have not been dated, but are interpreted to represent the same 12 ka Younger Dyras wet period. During Holocene time (the period between the 11 ka end of the Younger Dryas wet period and the present time), the driest period was at about 6 ka (COHMAP Members 1988). A GPS survey of the Lake Minchin shoreline (Bills et al. 1994) shows that the entire Altiplano area has tilted down to the northwest by about 8.5 cm km^{-1} (about 0.003°) during the past 17 000 years, a very rapid tectonic motion. The history of the glacial lakes suggests that *Orestias* may have arrived in Ascotán Basin with the LGM Lake Minchin advance at about 17 ka and has been isolated there during subsequent climate shifts. During this period *Orestias ascotanensis* developed as a separate ecotype, a process which clearly required the continual existence of fresh water bodies. This suggested mechanism for the presence of fish in isolated water bodies assumes that the fish arrived with the water body; discarding the possibility of some other mechanisms for transport of fish between separate water bodies (e.g., human actions). As previously mentioned, Villwock & Sienknecht (1996) suggested that all the *Orestias* species found in Chile, including *O. ascotanensis* are really one species, *Orestias agassii* which is distributed in isolated pockets originated by the ancient lake Minchin.

Regional hydrogeology

Within a few hundred kilometers of the Ascotán Basin, there are two large physiographic features which are apparently related to the large scale hydrologic regime. These are the Pastos Grandes Caldera, a Miocene - Pliocene ignimbrite center located east of Salar de Ascotán, and Salar de Uyuni, the largest salar within the internal drainage area of the Altiplano, located about 100 km to the north-northeast (Fig. 1). It is suggested herein that some of the hydrologic recharge of Ascotán Basin is by underflow from Pastos Grandes Caldera in Bolivia. Salar de Uyuni is the topographic low point of the system of large Pleistocene lakes, and may be the ultimate end of a groundwater flow system which originates in Pastos Grandes Caldera and passes through Salar de Ascotán, where it is locally expressed as surface water flow. On the basis of field observations and analysis of the regional geomorphology, it appears that the Salar de Ascotán springs are fed by groundwater flow recharged both by infiltration in Pastos Grandes Caldera, and on the stratovolcanos bordering the Ascotán Basin (Fig. 5), although the relative contributions are not well quantified.

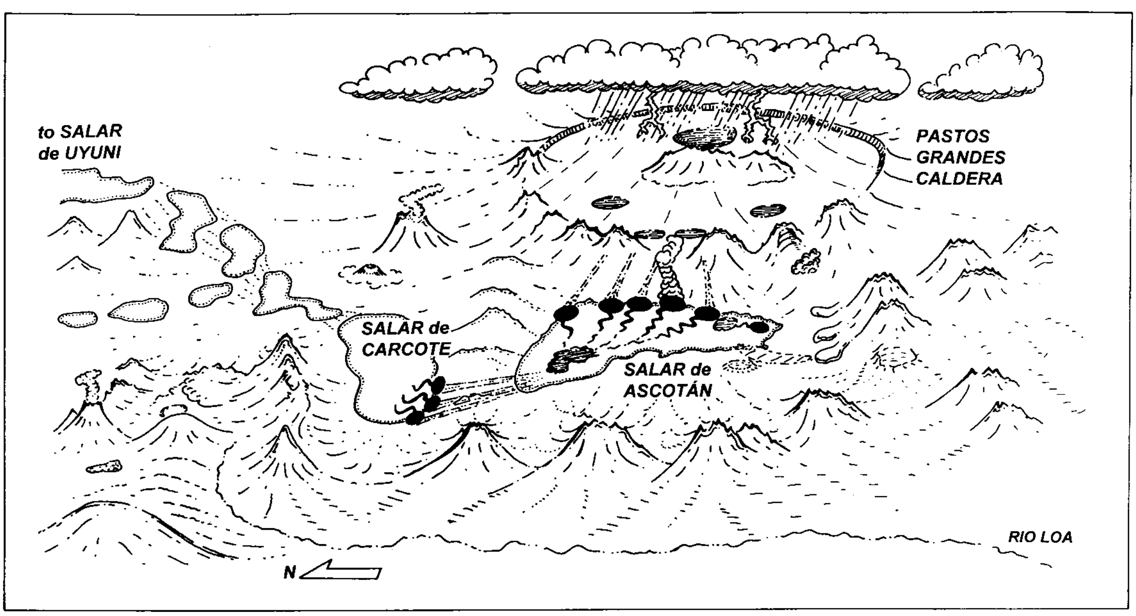

Fig. 5: Schematic interpretation of the hydrogeologic regime at Salar de Ascotán. Most of the water which feeds the east side freshwater pools is meteorically recharged in Pastos Grandes Caldera. It flows in the subsurface to springs at the salar, then as surface flow across the salar. It infiltrates again in the northwest part of the salar and flows as groundwater to Salar de Carcote. The ultimate downgradient end of the system is probably Salar de Uyuni.

Interpretación esquemática del régimen hidrogeológico del Salar de Ascotán. La mayor parte del agua que alimenta las vertientes del lado oeste del mismo, es recargada meteóricamente en la Caldera de Pastos Grandes. El agua fluye subsuperficialmente a las vertientes del salar y luego como flujo superficial a través del salar, luego se infiltra de nuevo en la parte noroeste del mismo y fluye como agua subterránea hacia el Salar de Carcote. Posiblemente el límite final del sistema hídrico alcanza al Salar de Uyuni.

Pastos Grandes Caldera is at about 4 600 meters msl elevation, with peaks reaching 5947 meters msl. The caldera floor has a westward tilt, consistent with the modern tectonic tilting of the Altiplano, as observed in the Pleistocene lake shorelines. Its location on the east side of the high Andes is favorable for receipt of Atlantic ocean moisture during the austral summer, a phenomenon known as "Invierno Altiplánico" (altiplanic winter).

The hydrologic relation of Salar de Ascotán to Pastos Grandes Caldera may have been of primary importance in maintaining freshwater pools during the dry Holocene period. Pastos Grandes Caldera is a collapsed eruptive center which was the source of ignimbrite sheets with ages from approximately 3 to 8 ma (millions of years before present, De Silva & Francis 1991). The Pastos Grandes ignimbrites span the entire width of the high Andes volcanic belt, about 100 kilometers, overlying pre-Neogene rocks on the west, west of Río Loa, and on the east, in the Grande de Lipez drainage. The caldera is about 50 kilometers by 30 kilometers in diameter, with caldera scarps on the eastern side and a ring of younger stratovolcanos apparently marking the west side. Numerous rhyolitic domes within and near the caldera show activity younger than 1 ma, some perhaps Holocene. At Laguna Pastos Grandes, on the east side of the caldera depression, is a large area of hot springs. It is suggested that this, and possibly other hot areas within Pastos Grandes Caldera, may cause enhanced melting of snowfall, resulting in higher recharge to groundwater than in colder areas. Within the caldera depression, on the west side, closest to Ascotán Basin, are permanent lakes. At least one of these lakes abuts a post-ignimbrite caldera rim lava flow which flowed both eastward into the caldera depression and westward into Ascotán Basin. One of the east side springs at Salar de Ascotán (V8 -, Fig. 2) issues from the toe of this lava flow.

Ascotán Basin, a structural depression in which Salar de Ascotán is located, is on the western flank of Pastos Grandes Caldera. The Ascotán Basin has some Miocene volcanic rocks which are older than the Pastos Grandes ignimbrites and areas of apparently-uplifted blocks of Pastos Grandes ignimbrite (Ramirez & Huete 1981), suggesting both a pre-caldera topographic high and post-ignimbrite structural disruption. Surface water flow originating at certain of the Salar de Ascotán springs on the northeast side is at times substantial. The flow occurs in stream channels within the central part of the salar lake bed, flowing to the northwest. In the northwest part of the salar, some of the surface water flow apparently infiltrates to groundwater, based on field observation of flows into ponds with no outlet, at times of limited evaporation. Groundwater flows northward from the northwest part of Salar de Ascotán to Salar de Carcote, as documented by a groundwater study by the Chilean Dirección General de Aguas (DGA 1992). Presumably it eventually flows northwestward in the subsurface to Salar de Uyuni, the remnant low point of the Pleistocene lakes.

During the field study, one recharge event demonstrating the link of surface water in Salar Ascotán to Pastos Grandes Caldera was observed, in June 1992. A notable rapid increase in surface water flow was seen within Salar de Ascotán, with channelized flow in the northwest part of the salar increasing by an estimated hundreds of liters second-1 within weeks. This was associated with an austral winter storm which deposited snow in Pastos Grandes Caldera. Snow was also deposited on the volcanoes surrounding Ascotán Basin, but it was observed to be extremely dry, and subject to sublimation rather than infiltration. The flow rate at several of the east side springs increased greatly, with no evidence of surface water flow between Pastos Grandes Caldera and the edge of the salar, and no precipitation at the salar itself.

No corresponding increase in flow was observed at springs farther from Pastos Grandes Caldera, which are presumably recharged from the local volcanoes. This rapid recharge phenomenon from an apparently distant source suggests that the fresh water springs represent the base flow condition of a spatially intermittent, but temporally continuous surface/subsurface flow system, whose temporal continuity through deglacial and Holocene time has allowed the survival of aquatic life, including the fish *Orestias ascotanensis*. An important part of the water is apparently recharged in Pastos Grandes Caldera.

CONCLUSIONS

Environmental parameters in the Chilean Altiplano, such as the existence of a native fish species, are receiving careful attention in the search for water resources for the mining industry. It is interpreted that the arrival of *Orestias ascotanensis* at Salar de Ascotán is associated with the existence of Pleistocene Lake Minchin, which filled Ascotán Basin. The subsequent survival of the fish appears to be supported by a hydrogeologic regime which includes recharge from the Pastos Grandes Caldera. A combination of factors including late Pleistocene and Holocene climate changes and the regional hydrogeology of the modern volcanic arc are important in the existence of environmental values, such as flora and fauna, which are the subject of current environmental studies. These studies are particularly relevant when mining activities need to obtain freshwater from an area where, to prevent loses of endemic fish habitats it is necessary to understand the water system, its supply and recharge.

The very particular water supply system seems to guarantee the permanence of these very unique and isolated small populations of *Orestias ascotanensis,* which gives an excellent opportunity for genetic, evolutionary and ecological studies. Even though the species may not be a truly species (Villwock & Sienknecht 1995, 1996), the uniqueness of its location, isolation and population sizes make this populations really worth to preserve and to care for.

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LITERATURE CITED

BILLS BG, SL DE SILVA, DR CURREY, RS EMENGER, KD LILLQUIST, A DONNNELLAN & B WORDEN (1994) Hydro-isostatic deflection and tectonic tilting in the central Andes: Initial results of a GPS survey of Lake Minchin shorelines. Geophysical Research Letters 21: 293-296.

COHMAP MEMBERS (1988) Climatic changes of the last 18,000 years: Observations and model simulations. Science 241:1043-1052

DE SILVA SL & PW FRANCIS (1991) Volcanoes of the central Andes. Springer-Verlag. New York. 216 pp.

DIRECCION GENERAL DE AGUAS (1992) Listado de Datos Estaciones Meteorológicas de Chile. Ministerio de Obras Públicas, Chile.

GLADE A (1988) Libro rojo de los vertebrados terrestres de Chile. Corporación Nacional Forestal Chile, Santiago Chile. 65 pp.

JARA F, D SOTO & R PALMA (1995) Reproduction in captivity of the endangered killifish *Orestias ascotanensis*, (Teleostei:Cyprinodontidae). Copeia 1995: 226-228.

PARENTI L (1984) A taxonomic revision of the Andean killifish genus *Orestias* (Cyprinodontiformes, Cyprinodontidae). Bulletin of the American Museum of Natural History 178: 107-214.

RAMIREZ C & C HUETE (1981) Carta Geológica de Chile, Hoja Ollagüe. Instituto de Investigaciones Geológicas, Santiago, Chile.

ROGERS DB & SJ DREISS (1995) Saline groundwater in Mono Basin, California, 1, Distribution. Water Resources Research. 31: 3131 - 3150.

RUDDIMAN WF (1987) Synthesis; the ocean/ice sheet record. In: Ruddiman WF & HE Wright Jr (eds) North America and adjacent oceans during the last deglaciation. The geology of North America. v K-3. Geological Society of America. pp 463 - 478.

SERVANT M & JC FONTES (1978) Les lacs quaternaires des hauts plateaux des Andes Boliviennes: Premieres interpretations paleoclimatiques. Cahiers O.R.S.T.O.M., Series Geologie, X: 9 - 23.

THOMPSON LG, E MOSLEY-THOMPSON, ME DAVIS, PN LIN, KA HENDERSON, J COLE-DAI, JF BOLZAN & KB LIU (1995) Late glacial stage and Holocene tropical ice core records from Huascaran, Peru. Science 269: 46-50.

VILLWOCK W & U SIENKNECHT (1995) Intraspezifische Variabilität im Genus *Orestias* Valenciennes, 1939 (Teleostei:Cyprinodontidae) und zum Problem der Artidentität. Mittelagungen Hamburg zoologisches. Institut und Museum 92: 381-398.

VILLWOCK W & U SIENKNECHT (1996) Contribución al conocimiento e historia de los peces chilenos. Los Cyprinodontidos del género *Orestias* Val. 1839 (Teleostei: Cyprinodontidae) del Altiplano Chileno. Medio Ambiente (Chile) 13: 119-126.

VOSTOK PROJECT MEMBERS (1995) International Effort Helps Decipher Mysteries of Paleoclimate From Antarctic Ice Cores. Earth and Ocean Science 76: 169-179.