Project Summary

The interaction between the uplift of the earth's surface and climate change has been a topic of considerable interest in recent years. The Central Andean Plateau was largely ignored in this discussion, even though it is the second highest and largest emergent plateau on earth. The lack of attention stemmed from two factors. Firstly, the steepness and narrowness of the Andes made them difficult to resolve in most computer models of global climate, and secondly, the paleotopography and paleoenvironmental conditions of the Plateau and its environs were less well documented than those for western North America, particularly in the english-language literature.

However, the uplift history of the Andes is critical to our understanding of the earth's climate history. The Central Andean Plateau has a profound affect on the climate of South America, and also affects global circulation, especially in terms of the paths of mean planetary waves and of the transportation of water vapor. Along with the rest of the Andean Cordillera, it forms the only barrier to circulation in the southern hemisphere. And as perhaps the youngest of the three major plateaus, the Central Andes could have played an important role in the late Cenozoic climate deterioration.

Advances in computer modeling and recent studies of the geology and paleontology of the Central Andes have significantly reduced the obstacles to study of the interactions between of uplift and climate. We propose to investigate this topic by conducting the following research:

- We will predict the climatic effects of Andean uplift, particularly the effects on the distribution of precipitation, using a high-resolution climate model of the Central Andes, which will be embedded in a lower-resolution general circulation model.
- We will test the climate model results by compiling existing data and collecting additional faunal data on the Neogene paleoenvironmental conditions of the Central Andes.

For the modeling portion of the study, we will first run an atmospheric general circulation model (AGCM) for three time slices: mid-uplift, pre-mid Miocene cooling (20 Ma), mid-uplift post-mid Miocene (10 Ma), and post-uplift, pre-Ice Age (3 Ma). For each time slice, we will model three topographies based on the existing paleoelevation data set of Gregory-Wodzicki (2000), average estimated elevation, average elevation – error, and average elevation + error. These global model integrations will provide distributions of precipitation, temperature, and other biotically significant climate variables for South America.

Using these global GCM boundary conditions, we will embed more detailed regional or mesoscale topographic histories for two areas: the Bolivian altiplano, and western and northwestern Argentina. The climatologies of these two embedding experiments will summarize patterns of regional climate resulting from different topographies for the three time slices at a scale more commensurate with the geographic and temporal resolution of the fossil record.

Time Slice	SST Scenario	Uplift scenarios
20 Ma	Miocene warm	No mountain – 25% mountain – 60% mountain
10 Ma	Miocene cold	No mountain – 35% mountain – 70% mountain
3 Ma	Miocene	35% mountain – 100% mountain

For the data collection component of the project, we will develop a data set of Miocene-Pliocene paleoenvironmental conditions for the central Andes by the following research: 1. We will analyze the ecological morphology and community structure of paleofaunas from Argentina and Bolivia in order to estimate paleoprecipitation. 2. We will measure the stable isotopic composition of mammal teeth in order to estimate paleoprecipitation. 3. We will compile existing paleotemperature and paleoprecipitation estimates from fossil floras and 4. We will compile paleoenvironmental data from other sources, such as sedimentology or geomorphology. Using statistical tests of geographic goodness of fit, we will compare the paleoclimate estimates from the

fossil faunas and floras, along with other geological evidence, to the GCM output, to evaluate the results of the climate modeling. **(Originally, I was saying that we were doing all this to evaluate the validity of the uplift history, but I think ESH would be happier if our focus was on evaluating the validity of the climate models (of which uplift history is an important boundary condition, of course))**

This research fits the goals of the Earth Systems History program, because it involves 1) an analysis of the sensitivity of climate to changes in forcing mechanisms, namely uplift of the Central Andean Plateau and 2) the systematic compilation of a high quality biological paleorecord, namely the floral and faunal based record of temperature and precipitation for the Central Andes. These data will be used to evaluate the results of the climate modeling. This modeling will not only improve our understanding of the role of Andean uplift, but it will improve our understanding of the causes of climate change during the middle Miocene warm period. **(Note: this discussion must be specific to the areas of emphasis defined in the program announcement).**

In terms of broader impacts, it will foster communication, cooperation, and we hope lasting research partnerships between researches from the US, Chile, and Argentina.

Results from Previous Funding

Project Description: Climatic Implications of the Cenozoic Uplift of the Central Andean Plateau

Kathryn M. Gregory-Wodzicki, Maisa Rojas *Lamont-Doherty Earth Observatory of Columbia University*
Rick Madden, *Duke University*
Kerry Cook? *Cornell University*

1. Introduction

The North and South American Cordilleras along with the Tibetan Plateau define a modern orography unusually high and massive compared to that of the previous 570 million years. All these ranges have mostly uplifted since the Cretacous, and their uplift undoubtedly had an important effect on the climate history of the Cenozoic. Mountains change patterns of precipitation and seasonal heating, act as a barrier to atmospheric circulation, affect upper atmosphere flow patterns, and can perhaps increase rates of chemical weathering.

Most investigation into the topic of the effect of uplit on global climate has focused on the Tibetan Plateau because it is the largest emergent plateau on earth and has a large influence on global circulation due to the monsoonal circulation to which it gives rise. In contrast, the second higest plateau on earth, the Central Andean Plateau (Fig 1) has received very little attention, mainly due to two factors. First of all, the low spatial resolution of GCM's results in topographic smoothing, where Andean orography is reduced to a broad rounded dome, limiting the questions that climate modeling can address to the consequences of broad plataeu uplift. This limitation is compounded if the spatial resolution of the baseline climate and/or modern climate-bioproxy datasets have a topographic texture of higher resolution than the GCM. The greater the resolution mis-match, the more the analysis is forced toward validating large regions of uniform climate far-removed from the high topography (Ruddiman et al., 1997).

Secondly, though there exists a wealth of floral and faunal data from the Central Andes, the record has been less well studied than the record of North America, and no one has yet attempted a compilation of the existing data. **(I thought it would be nicely symmetrical if we could also use a data argument for why the time is now ripe for this sort of study, but maybe we should just focus on the modeling advances?)**

Yet the sensitivity of climate to the uplift of the Central Andean Plateau is also an important topic to study. Andean uplift may not have had quite the global impact of the Tibetan Plateau, but it had a large influence on the climate of South America, particularly in terms of the distribution of precipitation. Low resolution, mountain-no mountain studies suggest that the presence of the Central Andean Plateau increases precipitation along the eastern slopes and reduces precipitation in Argentina, Paraguay, Uruguay, and southern Brazil. A higher-resolution model of Tanajura suggests that not only do the Andes cause topographic convection, but they also have an important role in moisture advection and the organization of the low level convergence.

We believe that advances in climate modeling and in study of the fossil record now allow the sensitivity of both South American and global climate to Andean uplift to be investigated. (Sentences here about regional models, the mammal record, and the paleoelevation data set).

In this study we propose to do the following:

- We will predict the climatic effects of Andean uplift, particularly the effects on the distribution of precipitation, using a high-resolution climate model of the Central Andes, which will be embedded in a lower-resolution general circulation model.

- We will test the climate model results by compiling existing floral and faunal data and collecting additional faunal data on the Neogene paleoenvironmental conditions of the Central Andes.

In the following pages, we will describe this project in more detail. First, we will discuss the climate and uplift history of the Cental Andes and previous modeling studies. We will then discuss the new modeling techniques and data that we propose to bring to bear on the problem, and will then discuss our methodologies and a detailed work plan.

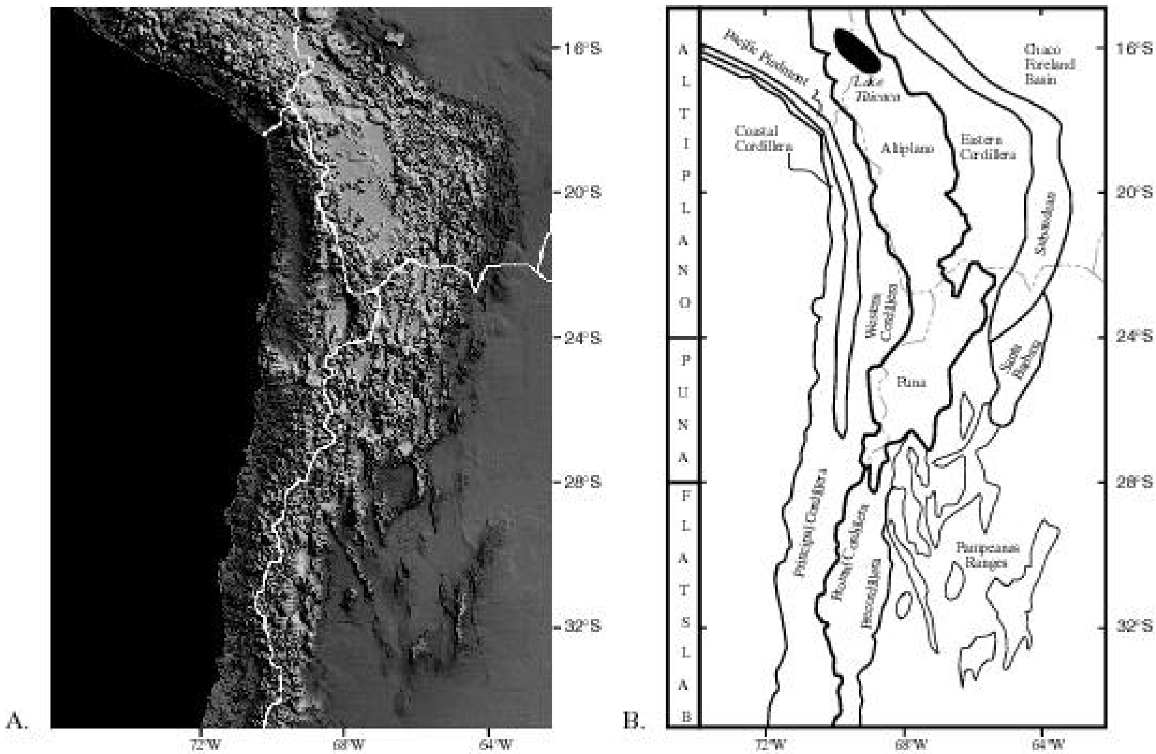

Fig 1

2. The Uplift and Climate History of the Central Andes

First, we would like to give some background on the uplift history and climate history of the Central Andes, along with a summary of previous modeling studies.

2.1 Andean Orogeny

The Andean orogeny is related to the subduction of the oceanic Nazca plate beneath the South American plate. Subduction began in the Precambrian-early Paleozoic along the western margin of South America, with the first evidence of major, cordillera-wide orogenesis in the upper plate appearing in the late Cretaceous (Megard, 1984; Coney and Evenchick, 1994; Sempere et al., 1997). Traditionally, compression was thought to have occurred in up to six short pulses separated by periods of extension (i.e. Mégard et al., 1984; Sébrier et al., 1988). More recent studies suggest that deformation took place fairly continuously, creating a fold-thrust belt and foreland basin system that migrated eastward (Jordan et al., 1983, 1997; Sempere, 1995; Horton and DeCelles, 1997; Sempere et al., 1997).

In the Central Andes, Eocene deformation, termed Incaic deformation, affected the Western Cordillera and some local regions of the foreland basin (Sempere et al., 1997, Lamb and Hoke, 1997; Jordan et al., 1997) (Fig. 1). The locus of thrusting then shifted to the east. In the Altiplano subdomain, compression in the Altiplano-Eastern Cordillera began in the late Oligocene, between 25 and 29 Ma and continued until about 10-6 Ma (Sempere et al., 1990; Allmendinger et al., 1997; Jordan et al., 1997; Lamb et al., 1997), and the foreland shifted east to the Subandean area. Then around 10-6 Ma, deformation again shifted to the east, this time to the Subandean zone, and the foreland basin shifted to its present location in the Chaco Basin.

In general, the timing of deformation is similar in the Puna subdomain to the south (Fig. 1), with some exceptions. Eocene compression occurred only in the region west of the Western Cordillera, and deformation began later in the central part of the orogen; it began between 13-17 Ma in the Puna and Eastern Cordillera and continued until around 2-3 Ma, contemporaneous with deformation in the Santa Bárbara system to the east (Jordan et al., 1997).

The paleoelevation data in the compilation of Gregory-Wodzicki (2000a) come from a variety of indicators, including amounts of upper crustal shortening, the occurrence of marine facies, the analysis of climate indicators, such as fossil floras, and the reconstruction of erosion surfaces. Studies of fission track data and supergene enrichment suggest that both the Western and Eastern Cordillera were uplifted in the late Oligocene and Early Miocene. Amounts of crustal shortening and studies of landscape development suggest that the Western Cordillera of the Altiplano subdomain reached no more than half its present height by 18 Ma (Fig. 2), while paleobotanical evidence suggests that the Altiplano-Puna had attained no more than a third of its modern elevation of 3700 m by 20 Ma, and no more than half its modern elevation by 10.7 Ma (Fig. 2); these data imply surface uplift on the order of 2300-3400 m since the late Miocene at uplift rates of 0.2-0.3 mm/yr. Paleobotanical and geomorphological data suggest a similar uplift history for the Eastern Cordillera, namely no more than half the modern elevation present by 10 Ma (Fig. 2). If taken at face value, these data suggest that the Central Andes are fairly young.

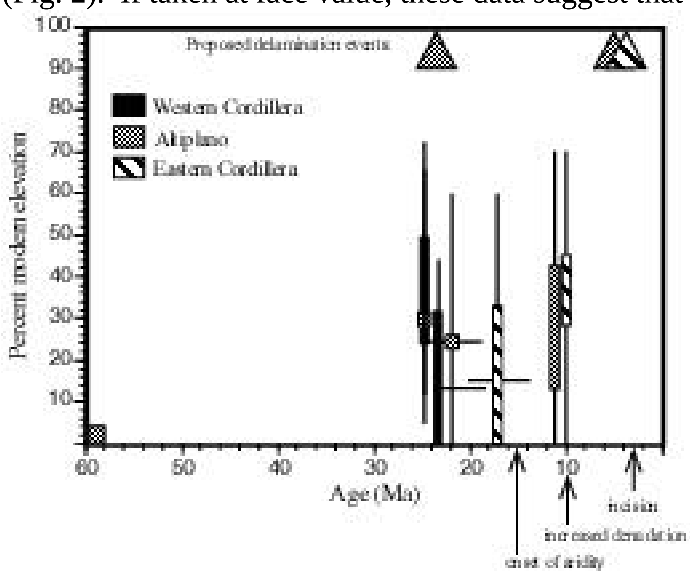

Fig 2

2.2 Neogene Climate Evolution in South America

At the same time as the Andes were uplifting, important changes were occuring in the climate of South America. In the early Miocene, the circum-Antarctic current began to isolate Antarctica in a polar cold zone due to the opening the Drake Passage between South America and Antarctica from the middle Oligocene to the Oligocene-Miocene boundary, Thereafter, a general process of global cooling was established, interrupted by the middle Miocene warm interval (between 17.5 and 13.3 Ma), a period of high biological productivity in the oceans and strong coastal upwelling resulting from strong zonal winds. A sharp decline in global temperatures and the build-up of the permanent East Antarctic ice cap between 12-14 Ma (Savin 1977) produced an increase in the pole-to equator surface temperature gradient during the middle Miocene from 6 to 12 degrees C through cooling of high-latitude surface water and slight warming of low-latitude water temperature (Miller, Fairbanks & Mountain, 1987).

On land, the Altiplano and Atacama Desert became significantly drier around 15 Ma, as suggested by studies of supergene enrichment and by deposition of evaporites. Fission-track data suggests that at about the same time, 10-15 Ma, denudation rates increased in the Eastern Cordillera, and at 10 Ma, terrigenous flux to the Amazon fan began increasing.

Thereafter, the East Antarctic ice cap expanded between 6.2 and 5.7 Ma (Shackleton & Kennett, 1975; Miller & Hsu, 1987) with pulses of glacial expansion at 5.2 Ma, 4.8 Ma, that reached a peak at 3.59Ma with Patagonian glaciation (Mercer, 1983). Following a brief early Pliocene (3.5-2.4 Ma) warming of 2-3 degrees in mid-latitude of the Southern oceans, climate deterioration resumed in the late Pliocene with northward migration of polar front and the further intensification of glaciation.

2.3 Previous GCM modeling of Andean uplift

Most models of Andean uplift have been fairly low resolution. In general, they show that the uplift of the Andes caused Argentina to be drier and

The only study that we are aware of to use a regional model to study South American climate is Tanajura (1996). He used the National Centers for Environmental Prediction Eta model nested in the Center for Ocean-Land-Atmosphere studies general circulation model to study the mechanisms which produce the observed summer climate of South America. In order to study the importance of the Andes to the summer climate, he ran a mountain/no mountain experiment. He found that the Andes are very important in organizing the low level convergence and precipitation. Without the Andes, no precipitation was produced in the southern part of the continent, and no moisture was transported from the Amazon to higher latitudes. This suggests that the Andes and the southward florw along their eastern side are crucial to the precipitation over northern Argentina. No large remote effect was discerned, which is consistent with Walsh (1994).

3. New Approaches in this Project

In this study, we would like to improve our understanding of the effects of uplift through the follwing innovations:

3.1 Use of nested model to simulate climate

As discussed in the introduction, the steepness and narrowness of the Andes made them difficult to resolve in most computer models of global climate. Thus, we propose to use a nested model of the Central Andean area in order to get around the problem of model-data resolution mis-match that has previously limited study of the Andes…..

3.2 Modeling of global climate during uplift

Most models of the effect of Andean climate have compared mountain-no mountain runs for the modern climate. Yet perhaps as much as half the Andean uplift took place during a very different global climate regime, that is, the middle Miocene warm interval. Thus, in order to accurately investigate the effects of uplift, we need to model global climate at the time of uplift. We plan to test climate sensitivity to uplift for three different time-slices: mid-uplift, pre-mid Miocene cooling (20 Ma), mid-uplift post-mid Miocene (10 Ma), and post-uplift, pre-Ice Age (3 Ma), using marine isotope data to constrain SSTs **(Maisa - are these available, or will we have to just make do with some sensitivity experiments to different pole-equator gradients and with and without the Humbolt current?**)

3.3 Use of realistic uplift model

We will use the paleoelevation data set of Gregory-Wodzicki (2000) to constrain possible uplift histories. These data are useful in that they give us a broad idea of when uplift occurred, but note that they have large error bars. For example, if we take the leaf and geomorphic surface data at face value, it would suggest that at 10 Ma the Altiplano and Eastern Cordillera were at 30-40% of their modern elevation (Fig. 2). However, when we factor in the error bars, they could have been from 0-70%. Also, we need to model the across strike variation in uplift, which migrated from west to east. Thus in this project, for each time slice we will model three topographies based on the existing paleoelevation data set of Gregory-Wodzicki (2000), the face value, face value – error, and face value + error.

Table X. Summary of modeling scenarios.

Time Slice	SST Scenario	Uplift scenarios
20 Ma	Miocene warm	No mountain – 25% mountain – 60% mountain

10 Ma	Miocene cold	No mountain – 35% mountain – 70% mountain
3 Ma	Miocene	35% mountain – 100% mountain

3.4 Verification of results with paleoclimate data

No model of Andean Uplift has attempted to verify its simulations with paleoclimate data. We propose to use both floral and faunal data to verify the simulations of the models. We will restrict validation tests to stratigraphic sequences spanning the temporal range of late Cenozoic uplift from geographically restricted portions of the orogen, rather than attempt to validate the full geographic extent of uplift-induced change. This last is both a limitation imposed by the geographic bias of the fossil record, and its principal strength.

4. Methods

Before discussing our detailed work plan, we will first briefly review both the modeling methods and paleoclimate proxies that we propose to use in this study.

4.1 Modeling (MAISA)

A. The GCM. The GCM that will be used to generate the paleo-climate scenario is model X. As is the case for all GCM's, the model is based on the primitive equations of large-scale atmospheric motion, and simulates four-dimensional (latitude, longitude, height, and time) fields of atmospheric temperature, horizontal wind (2 components), vertical velocity, pressure and density. A seventh governing equation, based on conservation of water mass, provides for the simulation of the atmospheric moisture content. Other imporatnt processes for determining climate, such as long and short wave radiative fluxes and precipitation, are treated with physical parameterizations.

We would use the model with the so-called R30 resolution, which is equivalent to a horizonal resolution of about 2.25 degrees of latitude and 3.75 degress of longitude. There will be 14, or possible 22, vertical layers in the atmosphere. These settings for the model resolution have proved adequate for simulating the large-scale structure of the South American precipitation climatology in summer, while still being computationally efficient for additional integrations to explore the dependence on various boundary conditions (Lenters and Cook, 1995, 1997).

The model is initialized as a dry, isothermal atmosphere at rest. About 200 days of integration insures that the model has "spun up" from these initial conditions and established a climate that is consistent with the prescribed boundary conditions (such as topography) within the constraints of the governing equations and physical parameterizations. The model is then integrated for several years or more of model time, and the time-dependent fields (which have variability similar to that observed) averaged to form a climatology. Although GCM's are essentially the same models used by the National Weather Service to predict the weather, they solve a different problem. Weather prediction consists of using a model to evolve a realistic initial state through a few days, while climate modeling involves finding an atmospheric state that is consistent with a given set of boundary conditions, independent of the initial state.

B. High resolution model

4.2 Paleoenvironmental Proxies

In order to test the simulations of the model, we need a dataset of paleotemperature and rainfall. We propose to derive that from mammalian species richness and community structure, the stable isotope composition of mammal teeth, and from the leaf morphology of fossil floras.

A. Mammal species richness and community structure. (RICK)

For the South American Neogene, the mammalian fossil record is one of the most complete archives of the continental biota and offers a potential source of biotic proxies for understanding natural variability in the earth system.

Characteristics of mammal communities vary predictably with altitude and rainfall. Mammalian species richness and the composition or guild structure of mammalian communities vary along environmental gradients in ways that are analagous to how leaf form varies with mean annual temperature (Givnish, Wolfe et al.) and how characteristics of plants that relate to plant-animal interaction (e.g. stem to leaf ratio, fruit type and size) vary along the same environmental gradients

(). In living mammals, absolute richness within guilds, the relative richness among guilds, and the number and composition of guilds vary along elevation and rainfall gradients, probably in response to variation in primary productivity, the pattern of allocation of assimilates by plants, and the architecture of the spatial distribution of food resources for mammals.

For 555 non-volant mammal species occurring in 82 faunal inventories from all latitudes in South America, observations about their diets are available for 49%, substrate preference for 44% and body mass for 68%. Where unknown, species can be assigned to broad diet and substrate preference categories by reference to general patterns within the genus. For the 82 inventories, latitude (LAT), median altitude (ALT), relief, sampling area, mean annual precipitation (MAP), temperature (MAT) and relative humidity, amplitude of mean monthly temperatures (seasonality), potential evapotranspiration (PET), and summertine (January) rainfall rate, are also known or reasonably estimated. In addition, measures of primary productivity (litterfall) and tree species richness are available over precipitation and elevation gradients for 29 sites and 78 floral inventories in South America.

Using the data from living mammals, significant correlations between mammalian species richness and single climate variables revealed by rank correlation are used in linear regression and PCA to estimate the same climate variable. Using stepwise multiple regression, subsets of richness measures that singly or together explain variation in richness along particular environmental gradients can be identified. Canonical community ordination summarizes more complex relationships among multiple variables and serves to calibrate samples (modern inventories and paleofaunal lists) for which the value of the explanatory variable is missing (e.g. fossil faunas of unknown climate).

Results show that mammalian species richness is significantly correlated with PET, MAP, LAT and ALT. PET is more strongly correlated with mammalian species richness along Andean altitudinal gradients whereas MAP is more strongly correlated with richness in the tropical lowlands. Both the absolute number of species and the proportion of total species are variably correlated with LAT, MAP, PET and/or ALT in 29 different categories of trophic level, diet, locomotor preference, and body mass. Along eastern Andean altitudinal gradients, 35 measures of absolute and relative species richness within adaptive categories are significantly correlated with ALT. In lowland Amazonia, 39 measures of richness are correlated with MAP at values between 500 and 4000mm. Using all 40 tropical inventories, 46 measures of species richness are significantly correlated with PET. Jackknife simulations using sampling with replacement permit an estimate of the robusticity of this method of estimating MAP and ALT from modern faunas.

Mammalian species richness within functional guilds has several desirable features as a tool in paleoclimatology: 1) The approach is non-taxonomic and relies as much as possible on the morphological adaptations of species, not their phylogenetic affinities. As such it is less subject toinfluence by taxonomic turnover events (e.g, the Great American Biotic Interchange, the immigration of Homo sapiens). 2) The assignment of fossil species to adaptive categories or guilds is based where feasible on falsifiable laws of animal design. If a structure in a living species has a clear function in all living species having the same structure, then it can be safely inferred that the presence of the structure in a fossil species implies the same function (the falsifiable comparative method). 3) The method yields a quantitative estimate of a climatic variables with well-understood relationships to primary productivity (for example, MAP, MAT, potential evapotranspiration, seasonal temperature amplitude, dry season intensity, and altitude). 4) The method is statisticaly robust and allows a confidence interval to be placed on the estimated climate parameter. 5) Finally, the method is comprehensive, it uses all significant correlations between species richness and climate simultaneously (in multivariate approaches) and/or as individual correlations which permit the identification of potential biases or for preferential weighing. Such a comprehensive multivariate approach is naturally preferred over the use of single mammalian indicator species.

B. Stable Isotopes of Mammal Teeth (MATT)

C. Leaf morphology of fossil floras The foliar morphologic method of climate analysis is based on the observation that the leaf morphology of woody dicotyledons varies with climate. For example, the percentage of entire, that is, smooth-margined, species tends to increase with the mean annual temperature (Fig. 4) and leaf size tends to increase with precipitation (Bailey and Sinnott 1915; Wolfe 1979, 1993, 1995; Givnish 1987; Chaloner and Creber, 1990; Wilf, 1997; Wilf et al., 1998). These relationships between leaf morphology and climate exist because leaves influence heat exchange with the atmosphere, transpiration, photosynthesis, and nutrient supply (Taylor, 1975; Givnish, 1979, 1984, 1987). Thus the leaf morphology of a plant affects its efficiency in a given environment.

In order to quantify these relationships, a number of data sets of leaf morphology have been collected, most notably the Climate-Leaf Analysis Multivariate Program (CLAMP) data set of J.A. Wolfe, which includes 31 different leaf morphology variables versus climate for 173 sites, mostly from North America and Japan. Gregory-Wodzicki (2000b) collected a data set of 12 modern foliage sites from Bolivia, which, along with the CLAMP data set, can be used to estimate the mean annual temperature of Bolivian floras within 1-2 °C and mean annual precipitation to within 400 mm (for additional discussion of these Bolivian sites please see "results for prior funding").

Subalpine sites have significantly higher percentages of entire-margined species for a given mean annual temperature than other cool-temperate sites (Fig. 3). However, Miocene vegetation from Bolivia is clearly not subalpine, based on both floristic and morphologic analysis (subalpine sites plot in a distinct region of multivariate space from the other CLAMP samples). Thus, these outlier sites can be excluded from the data set (Wolfe, 1993, 1995).

5. Proposed work Plan

In detail, we propose the following research program:

5.1 GCM Modeling-Experimental Design

For the modeling portion of the study, Rojas and Cook will first run an atmospheric general circulation model (AGCM) for three time slices: mid-uplift, pre-mid Miocene cooling (20 Ma), and mid-uplift post-mid Miocene (10 Ma), and post-uplift, pre-Ice Age (3 Ma).

For each time slice, we will model three topographies based on the existing paleoelevation data set of Gregory-Wodzicki (2000), the face value, face value – error, and face value + error.

Rojas will develop regional model.

5.2 Collection and Compilation of Paleoenvironmental Data

A. Mammal Record (RICK)

The specific faunas that we propose to study are the following:

Bolivia. The oldest fossil mammals of the Neogene sedimentary sequence in Bolivia are from the Salla redbeds. The base of the Salla beds at 29Ma is taken to represent the age of initiation of uplift. The main fossil-bearing portion of the section yielding a Deseadan fauna has been dated to between 25 and 26Ma (Kay et al., 1998). There follows a significant temporal hiatus in the fossil mammal record of the Bolivian altiplano until the middle Miocene.

North Argentina. The oldest fossil mammals of Neogene age in Mendoza occur at Malargüe, a Deseadan fauna (). There occurs a significant temporal hiatus in the fossil mammal record of this part of Argentina until the middle Miocene Chinches Formation (Carlini et al., 1996). In the late Miocene, an important faunal change is conventionally attributed to the geographic reorganization of sediment deposition and aridification associated with Andean uplift (Ortiz & Pascual, 1990) occurs at the base of the faunal sequence in the valley of Santa Maria (Catamarca) in the Chasicoan and more extensively in structural valleys east of the Andes during the Huayquerian (Ortiz & Pascual, 1990).

B. Stable Isotopes (MATT)

C. Paleoflora data set

We do not propose to collect any new floras for this proposal, as the collection of this data is being proposed in two sister proposals **(Note: I will probably be submitting another proposal to ESH to collect Miocene floras from the Chilean coast. If I do, I won't ask for money to collect in this proposal, because I don't imagine they will fund two of my projects).** The only work that needs to be done in conjunction with this project is to compile and communicate, and to help with the experimental design.

Preliminary compilation of paleoclimate and paleoelevation estimates for Miocene fossil floras from the Central Andes

Flora	Lat.	Long.	Age (Ma)	Method	MAT (°C)	MAP (mm)	PaleoZ (m)	Refs
1. Los Litres	33.30	70.55	21.2-26.6	M	subtrop.	700-800	--	1.
2. Chucal	18.9	68.9	21	A	temperate	dry	1000	2, 3
3. Potosí	19.61	65.74	~14	M	21.6 ±2.1	500 ±400	0-1300	4, 5
4. Goterones	33.96	71.87	19-10	M	15	1500+	0	1, 6
4. Boca Pupuya	33.96	71.87	19-10	M	21	humid	0	1, 6
5. Upper Jakokkota	17.17	69.17	10.66 ±0.06	M				
5. Lower Jakokkota	17.17	69.17	~10.4	M	21.5 ±2.5	550 ± 180	550-1600	4, 7, 8
6. Pislepampa	17.18	66.03	7-6	A, M	~20	1000-1500	1200-1400	9, 10

Numbers denote the location of the floras on Figure 1. Method = Method used to estimate paleoclimate and paleoelevation, A = modern analog, M = leaf morphology. MAT = mean annual temperature. MAP = mean annual precipitation. PaleoZ = Paleoelevation. Refs = References. 1. Hinojosa and Villagran, 1997. 2. Charrier, Muñoz, and Palma-Heldt, 1994. 3. Muñoz and Charrier, 1996. 4. Gregory-Wodzicki et al., 1998. 5. Berry, 1939. 6. Troncoso, 1991. 7. Berry, 1922a. 8. This study. 9. Berry, 1922b. 10. Graham et al. (in review).

5.3 Validation of model results

Using statistical tests of geographic goodness of fit, we will compare the paleoclimate estimates from the fossil faunas and floras, along with other geological evidence, to the GCM output, to evaluate the results of the climate modeling.

5.4 Timetable

The time table for this work will be the following:

Year	Action	Researchers
Year 1	Run GCM simulations	Rojas, Cook
	Develop embedded models	Rojas, Cook
	Run embedded models	Rojas, Cook
	Revise taxonomy of mammal collections	Madden
	Collect mammal teeth	Madden, Kohn
	Analyze stable isotopes	Kohn
	Compile floral data	Gregory-Wodzicki
	Write up results	

6. *Relevance of study to Earth Systems History Objectives*

(Note: this discussion must be specific to the areas of emphasis defined in the program announcement). The project is relevant to the follwing areas of special emphasis of the Earth System History Program:

3. Extreme Warm conditions. This proposal will try to explain changes during the middle Miocene, one of the periods of global warmth

6. Modeling of Past Change. This project is relevent to this program goal because it involves the analysis of the sensitivity of climate to changes in forcing mechanisms, specifically the uplift of the Central Andean Plateau, through modeling studies. This has not been previously done.

The project also involves the collection and compilation of a high-quality biological paleorecord of climate change, specifically, the fossil flora and fauna record of temperature and precipitation. This data will be used to evaluate the predicted responses of the climate modeling.

7. Quantification and development of biotic, physical, and geochemical proxy indicators for past Earth System processes. Can we say that we are developing the mammal record of paleoclimate?

The broader impacts of this study are that it will foster communication, cooperation, and we hope a lasting partnership between researchers at Columbia University and the Universidad de Chile.

Selected Bibliography

Lenters, J. D., and Cook, K. H., 1995, Simulation and diagnosis of the regional summertime precipitation climatology of South America, Journal of Climate, v. 8, p. 2988-3005.

Lenters, J. D., and Cook, K. H., 1995, Comments on "On the influence of the Andes on the general circulation of the Southern Hemisphere": Journal of Climate, v. 8, p. 2113-2115.

Tanajura, C.A.S., 1996, Modling and analysis of the South American summer climate: unpublished PhD thesis, University of Maryland, 164 p.

Walsh, K., 1994, On the influence of the Andes on the general circulation of the Southern Hemisphere: J of Climate, v. 7, p. 1019-1025.

Budget

BUDGET:	**9/1/01-8/31/02**	**9/1/02-8/31/03**	**9/1/03-8/31/04**
A. Senior Personel			
Kathryn M. Gregory-Wodzicki	0.5	0.5	1 mo.
Rick Madden	?	?	?
Maisa Rojas	12 mo.	12 mo.	12 mo.
Kerry Cook	1 mo.		
Matt Kohn			
B. Other Personel			
Secretarial Staff			
C. Fringe Benefits			
D. Permanent Equipment			
E. Foreign Travel			
F. Participant support costs			
Fieldwork in Argentina?			
G. Other Direct Costs			
1. Miscellaneous office and computer supplies			
2. Publications:			
3. Consultant services:			
4. Computer LDEO Sun Network System			
6. Other:			
Communications and Shipping			

Budget Justification