Chronologic implications of new Miocene mammals from the Cura-Mallín and Trapa Trapa formations, Laguna del Laja area, south central Chile

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A B S T R A C T

Recent work in the central Andean Main Range of Chile near Laguna del Laja (~37.5°S, 71°W) has produced the first mammal fossils for the region. Fossils, locally abundant and well preserved, occur patchily across a wide area southeast of the lake. Mammalian remains are derived from generally strongly folded (kilometer-scale) exposures of the locally ~1.8 km thick, early to middle Miocene Cura-Mallín Formation; two identifiable specimens have been recovered from the overlying Trapa Trapa Formation as well. Both formations consist primarily of well-stratified (1–5 m thick layers) volcaniclastic and volcanic strata, deposited predominantly in fluviatile systems. The Cura-Mallín Formation is possibly the southern continuation of (or lateral equivalent to) the richly fossiliferous Abanico Formation mapped between ~32°S and 36°S. Intensive sampling in a series of localities east and south of Laguna del Laja has yielded diverse faunas, in addition to radioisotopically dateable horizons. The new fossil mammal faunas represent as many as six South American Land Mammal "Ages" (SALMAs). Fossils, together with preliminary $^{40}Ar/^{39}Ar$ radioisotopic dates, ranging from ~9 to 20 Ma across the exposed thickness of the Cura-Mallín Formation and into the overlying Trapa Trapa Formation, provide a robust geochronological framework for middle Cenozoic strata in the Laguna del Laja region. The sequence of directly superposed mammalian assemblages at Laguna del Laja is one of the longest in all of South America, rivaled only by the classic Gran Barranca section of Patagonian Argentina. These data illuminate the geological history of the area and its record of mammalian evolution. The potential to isotopically date these diverse faunas with high precision (error ± 0.5 Ma) presents a rare opportunity to calibrate related portions of the SALMA sequence.

1. Introduction

Fossil mammals of the central Chilean Andes, first discovered near ~35°S in volcaniclastic sediments currently assigned to the Abanico (=Coya-Machalí) Formation, have played a key role in refining the geochronology of post-Neocomian strata in the region (Novacek et al., 1989; Wyss et al., 1990; Charrier et al., 1990; Flynn and Wyss, 1990; Flynn et al., 1991). The thick volcanic, volcaniclastic, and sedimentary deposits making up this geographically widespread unit in the Andean Main Range were traditionally regarded as Late Cretaceous to early Cenozoic in age (Klohn, 1957, 1960), a conclusion seemingly consistent with early ^{40}K–^{40}Ar analyses (Vergara and Drake, 1979; Drake et al., 1982). The recovery of abundant mammal fossils from this formation (between ~33.5°S and 35.15°S), later complemented by $^{40}Ar/^{39}Ar$ analyses, have now securely established that much (if not all) of the unit spans late Eocene through middle Miocene time (Wyss et al., 1990, 1992, 1994, 1996; Charrier et al., 1994, 1996, 2002, 2005; Godoy and Lara, 1994; Flynn et al., 1995, 2003; Gana and Wall, 1997; Hitz et al., 2000; Fuentes et al., 2002; Croft et al., 2003b; Reguero et al., 2003; Flynn and Wyss, 2004; Vergara et al., 2004).

Similarly, between ~37°S and 39°S in the Main Range, the age and tectonic history of units roughly equivalent to the more northern Abanico and Farellones formations, have only recently been clarified. With the discovery of abundant mammals in the Cura-Mallín Formation (CMF) reported here, a second, enormously thick, geographically widespread lithostratigraphic unit in the central Andean Main Range is now recognized for its paleontological significance. Herein we present preliminary results of paleontological and associated geological investigations southeast of Laguna del Laja (LdL) – within the northeast corner of Bío Bío province, Chile (Fig. 1), and a consideration of their implications for the area's geologic history.

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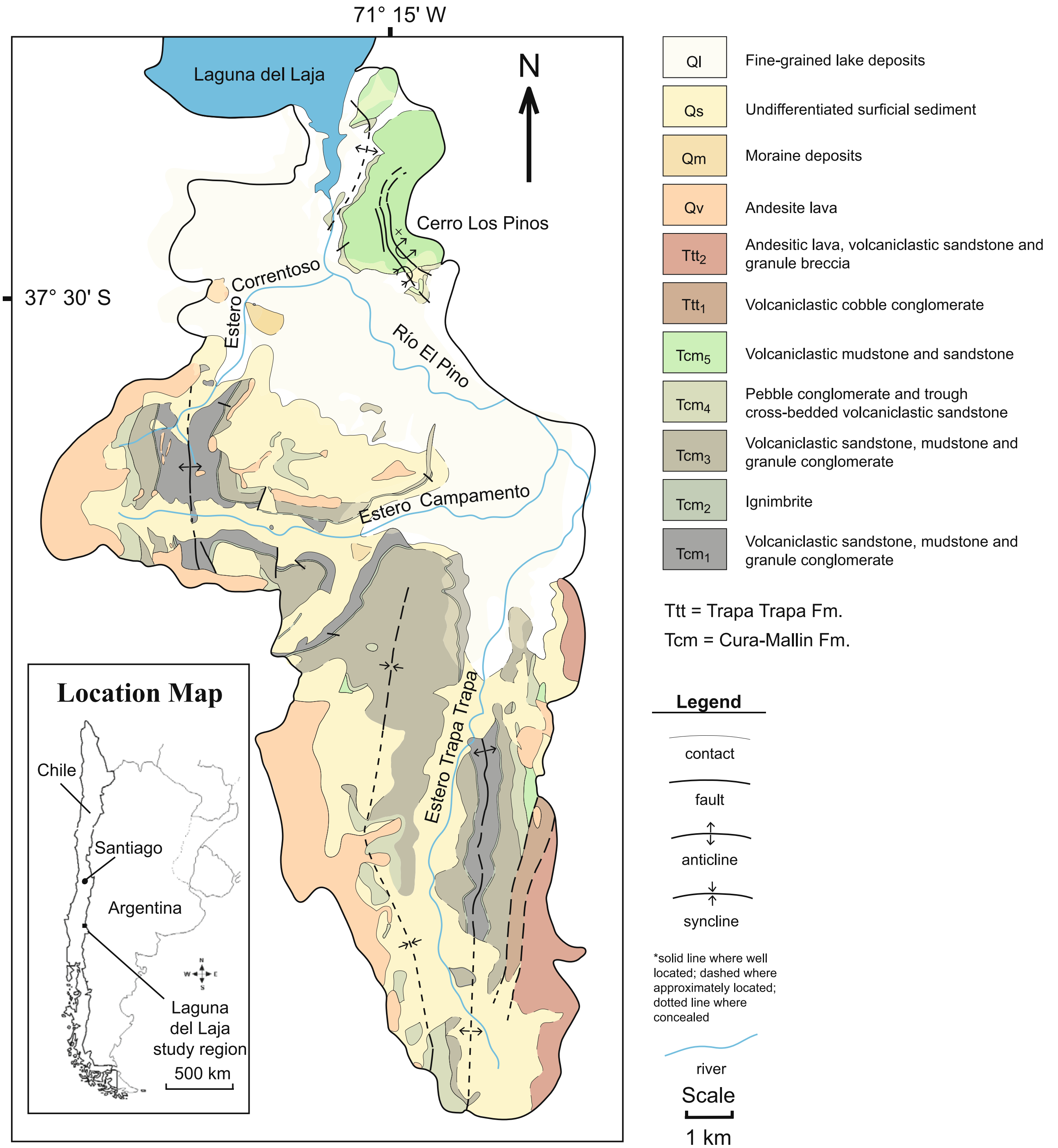

Fig. 1. Map of the Laguna del Laja study area. Generalized geologic map, showing stratigraphic units and major geographic and structural features discussed in the text (after Herriott et al., 2006. Inset shows the location of the study area within Chile.

The study area, first reconnoitered for fossils during March 2001, was comprehensively studied over the four subsequent summers. We initially targeted the LdL region because of its excellent exposures of the CMF, the sparse occurrence of mammal fossils in this unit ~150 km to the south (Lonquimay area: Marshall et al., 1990; Suárez et al., 1990; Croft et al., 2003a), and the remarkable mammal faunas contained in the roughly correlative Abanico Formation farther north. Fossil mammals occur in units mapped previously (Niemeyer and Muñoz, 1983) as the Malla Malla and Río Queuco members of the CMF, as well as the overlying Trapa Trapa Formation (TTF), none of which were recognized as containing terrestrial fossils until now (Table 1). Indeed, this is the first report of age diagnostic vertebrate fossils from the northern of the two recognized Cura-Mallín sub-basins (Radic et al., 2000, 2002). Below we provide a preliminary assessment of these fossils and the initial results of $^{40}Ar/^{39}Ar$ work being undertaken throughout the fossiliferous section (Wertheim et al., 2003, 2004, 2005; Wyss et al., 2003, 2004; Herriott, 2006; Herriott et al., 2006).

The Cura-Mallín Formation is a north–south oriented swath of volcano-sedimentary deposits between ~36°S and 39°S along what

Table 1
Laguna del Laja preliminary faunal lists

CERRO LOS PINOS (Tcm_4–Tcm_5)
Low "red bed" sequence
Xenarthra
  Dasypodidae, unident.
Notoungulata
  Typotheria, unident.
Rodentia
  Chinchillidae
    Lagostominae
      Prolagostomus sp. (Santacrucian–Laventan)

Green "middle" beds (Locs. C-01-3; C-02-4)
Rodentia
  Chinchillidae
    Lagostominae
      Prolagostomus sp. nov. (Santacrucian–Laventan)
      Prolagostomus sp. and unident. (Santacrucian–Laventan)
  Echimyidae
    Heteropsomyinae
      Gen. et sp. nov. (aff. Acarechimys) (Colhuehuapian–Laventan)
  Indet. large, enigmatic rodent (teeth)

Upper beds
Rodentia
  Dasyproctidae
    Dasyproctinae
      Gen. et sp. nov. (aff. Alloiomys) (Friasian–Colloncuran)
  Caviomorpha, unident.
ESTERO TRAPA TRAPA EAST (Tcm_1–Ttt_2)

Undifferentiated
Xenarthra
  Dasypodidae, unident.
Notoungulata
  Interatheriidae
    Interatheriinae, unident.
  Hegetotheriidae, unident.
  Toxodontidae, unident.

Low beds (Tcm_1, <100m below Tcm_2)
Notoungulata
  Interatheriidae
    Interatheriinae
      cf. Protypotherium sp. (Colhuehuapian–Chapadmalalan, possibly to Montehermosan)
Rodentia
  Dasyproctidae
    Dasyproctinae
      ?Neoreomys sp. (Santacrucian–Laventan)
  Echimyidae
      Gen. et sp. nov, cf. Maruchito (Colloncuran)

Mid-High beds (Tcm_3, <100 m above Tcm_2)
Notoungulata
  Hegetotheriidae
    Hegetotheriinae
      ?Hegetotherium
  Interatheriidae
    Interatheriinae
        New taxon cf. Protypotherium sp. (Colhuehuapian–Chapadmalalan, possibly to Montehermosan)
    Interatheriinae, unident.
  Typotheria, unident.
Rodentia
  Echimyidae
      Maruchito sp. nov. (Colloncuran)
      Protacaremys sp. nov. (Colhuehuapian–Colloncuran)
      cf. Protacaremys sp. nov. (Colhuehuapian–Colloncuran)
    Adelphomyinae
      Prostichomys sp. nov. I (Santacrucian)
      Prostichomys sp. nov. II (Santacrucian)
  Eocardiidae
      Luantus sp. nov. (Colhuehuapian–"Pinturan")
      ?Luantus sp. nov. (Colhuehuapian–"Pinturan")
  Octodontidae
    Acaremyinae
      Acarechimys sp. nov. (Colhuehuapian–Laventan)
Marsupialia
  Sparassodonta
      Sipalocyon (Colhuehuapian–Friasian)

Table 1 (*continued*)

Upper beds (Tcm_3, >100 m above Tcm_2)
Rodentia
      Gen. et sp. nov. (aff. Incamys) (Deseadan)
      Gen. et sp. nov. (aff. Alloiomys) (Friasian–Colloncuran)
    Dasyproctidae
      Luantus sp. nov (Colhuehuapian–"Pinturan")

TRAPA TRAPA FORMATION
Typotheria
  Interatheriidae
      cf. Interatherium sp. (Santacrucian–Friasian)

ESTERO TRAPA TRAPA WEST (Tcm_1–Tcm_3)
Undifferentiated
Notoungulata
  Hegetotheriidae
    Hegetotheriinae, unident.
Astrapotheria, unident.

Low beds (Tcm_3, ~250 m above Tcm_2)
Marsupialia
  Caenolestoidea
    Abderitidae, unident.
Notoungulata
  Hegetotheriidae, unident.
Rodentia
  Eocardiidae
      Luantus sp. nov. (Colhuehuapian–"Pinturan")

Middle beds (Tcm_3, ~300–400 m above Tcm_2)
Notoungulata
  Interatheriidae
    Interatheriinae, unident.
  Hegethotheriidae
    Pachyrukhinae
      Paedotherium minor [Paedotherium is Chapadmalalan–Uquian]
  Toxodontidae, unident.
  Typotheria, unident.
Astrapotheriidae, unident.
Rodentia
  Caviomorpha, unident.
  Dinomyidae
    Potamarchinae
      Scleromys sp. nov. (Santacrucian)
  Echimyidae
      Gen. et sp. nov. (aff. Prostichomys) (Santacrucian)
      Gen. et sp. nov. (aff. Protacaremys) (Colhuehuapian–Colloncuran)
      Gen. et sp. nov. (aff. Prospaniomys) (Colhuehuapian)

High beds (Tcm_3, ~470 m above Tcm_2)
Xenarthra
  Dasypodidae, unident.
Notoungulata
  Interatheriidae
    Interatheriinae, unident.
  Hegetotheriidae
    Pachyrukhinae, unident.
  Toxodontidae, unident.
Rodentia
  Echimyidae
    Heteropsomyinae
      Acarechimys sp. nov. (Colhuehuapian–Laventan)
  Chinchillidae
    Lagostominae
      Prolagostomus sp. nov. and unident. (Santacrucian–Laventan)
Eocardiidae
      ?Luantus sp. (Colhuehuapian–"Pinturan")
      Eocardiidae, unident.

ESTERO/CERRO CAMPAMENTO (Tcm_1–Tcm_2)
Middle
Notoungulata
  Hegetotheriidae, unident.
Rodentia
  Chinchillidae
      Lagostominae

PIEDRA DEL INDIO
Sparassodonta, unident.

ESTERO CORRENTOSO (Tcm_1–Tcm_2)
Xenarthra

Table 1 (*continued*)

Phyllophaga			
	Mylodontidae		
		Nematherium cf. N. angulatum or sp. nov. (Santacrucian)	
Notoungulata			
Interatheriidae			
	Interatheriinae		
		Protypotherium sp. and unident. (Colhuehuapian–Chapadmalalan, possibly to Montehermosan)	
Hegetotheriidae, unident.			
Typotheria, unident.			
Leontoniidae, unident.			
Rodentia			
Chinchillidae			
	Lagostominae, unident. (Santacrucian–Laventan)		

Temporal ranges for taxa from Marshall et al. (1983), Pascual et al. (1996), and McKenna and Bell (1997), as well as more detailed information in Vucetich (1977, 1984), Vucetich et al. (1993), Kramarz (2002, 2004, 2006a, b) and Croft (2007) for the rodents. Unless indicated otherwise, all taxa are from the Cura-Mallín Formation.

is now the eastern border of south-central Chile and adjacent western Argentina (Niemeyer and Muñoz, 1983; Muñoz and Niemeyer, 1984; Carpinelli, 2000; Jordan et al., 2001; Radic et al., 2000, 2002; Burns, 2002; Burns et al., 2006; Melnick et al., 2006). Initially considered Mesozoic in age, sparse whole rock ^{40}K–^{40}Ar analyses and inconclusive non-vertebrate paleontological evidence were subsequently interpreted as indicating an Eocene–Oligocene or Eocene–Miocene age for this unit (Niemeyer and Muñoz, 1983; Muñoz, 1984; Muñoz and Niemeyer, 1984). Possible correlative units in Argentina include the Estratos del Arroyo Tábanos and Estratos del Arroyo Carbón (Sarris, 1984; Burns, 2002). Within Chile the CMF has been correlated with the Farellones Formation (Davidson and Vicente 1973; Vergara and Drake, 1979; Thiele, 1980), and more recently to the Abanico (=Coya-Machalí) Formation (Charrier et al., 2002). Radic et al. (2002) have suggested that the CMF was deposited in two related half-graben sub-basins, which are mirror images of one another structurally. The southern sub-basin (south of 38°S) is bounded to the west by east-dipping normal faults; it is separated from the northern sub-basin (bounded to the east by west-dipping normal faults) by a tectonic accommodation zone formed through late Miocene tectonic inversion and Pliocene volcanic activity (Burns and Jordan, 1999; Carpinelli, 2000; Radic et al., 2000, 2002). Although the sedimentary fill of the northern and southern sub-basins is of similar maximum thickness, deposition of the CMF is considered to span a much shorter interval in the north (~22–26 Ma) than in the south (~8–22 Ma) (Suárez and Emparán, 1995, 1997; Jordan et al., 2001; Radic et al., 2000, 2002). Our results, however, suggest that the CMF at LdL is significantly younger than the proposed age range for this unit elsewhere in the northern sub-basin.

2. Paleontology

We have recovered fossil mammals from five stratigraphic sequences southeast of LdL, each containing multiple fossiliferous horizons. Cropping out roughly from NW to SE, these have been informally named the Cerro Los Pinos, Estero Correntoso, Estero Campamento, Estero Trapa Trapa West, and Estero Trapa Trapa East collecting areas (Fig. 1). Recent detailed stratigraphic and structural studies (Contreras, 2003; Herriott, 2006; Herriott et al., 2006) provide a reliable framework for determining the relative stratigraphic intervals and temporal positions of these five main local sequences (Fig. 2): (1) Cerro Los Pinos (Tcm_4–Tcm_5); (2) Estero Correntoso (Tcm_1–Tcm_2); (3) Estero Campamento (Tcm_1–Tcm_2); (4) Estero Trapa Trapa West (Tcm_1–Tcm_3); and (5) Estero Trapa Trapa East (Tcm_1–Ttt_1). Below we provide a preliminary accounting of the key taxa identified from these sequences to date, and their temporal implications. To facilitate correlations to standard SALMAs (Fig. 3), we provide the temporal ranges of these taxa (or their closest relatives) occurring elsewhere in South America, derived from Marshall et al. (1983), Pascual et al. (1996), and McKenna and Bell (1997), as well as more detailed information in Vucetich (1977, 1984), Vucetich et al. (1993), Kramarz (2002, 2004, 2006a,b), and Croft (2007) for the rodents. Various taxa co-occurring in certain stratigraphic intervals at LdL do not appear together elsewhere in South America, indicating that some LdL taxon records represent range extensions relative to previously known assemblages. One of us (JAW) is undertaking a dissertation study of the taxonomy, biochronology, and biogeography of the rodents from these sequences, and more detailed analyses of other taxa are in progress by other authors. Photographs of representative specimens collected from the CMF in the LdL area (Fig. 4), give a sense of the taxonomic diversity and preservation quality of these fossils.

At Cerro Los Pinos, where LdL fossil vertebrates were initially discovered, mammals occur at three levels across nearly 500 m of stratigraphic section, the upper two-thirds of which form a spectacular, west-verging anticline–syncline fold pair (González and Vergara, 1962 – photo 29 therein – see below). This sequence includes the stratigraphically highest portion of the CMF exposed southeast of LdL, spanning the uppermost part of Tcm_4 and Tcm_5 (Fig. 2). Ironically, Cerro Los Pinos has since proven to be the least fossiliferous (and faunally most imbalanced) of the five sequences we have worked. Caviomorph rodents are the most common fossils from Cerro Los Pinos, complemented by a small number of other taxa (e.g., dasypodids and typotheres). Notable rodent occurrences include partial crania, jaws, and teeth of the lagostomine chinchillid *Prolagostomus* (the most abundant taxon at Cerro Los Pinos), a new genus and species of echimyid closely resembling *Acarechimys*, and a new, hypsodont, dasyproctid genus and species near *Alloiomys*. Elsewhere in South America *Prolagostomus* ranges from the Colhuehuapian to the Laventan, while the new echimyid and dasyproctid taxa appear to be closely related to forms occurring elsewhere in the Colhuehuapian–Laventan and Friasian–Colloncuran, respectively (Vucetich, 1984; Kramarz, 2002, 2004). The middle "green" beds contain most of the age-diagnostic rodents; the SALMA represented by this horizon lies somewhere between the Colhuehuapian and Laventan, most likely toward the younger end of that span within the mid-late Miocene. *Prolagostomus* occurs in both that level and the underlying red beds, suggesting that both may pertain to the same SALMA. Although abundant in this sequence, *Prolagostomus* is rare elsewhere at LdL. Age-diagnostic taxa have not yet been identified for the upper fossiliferous interval at Cerro Los Pinos, so it remains uncertain whether more than one SALMA is recorded in this sequence.

The easternmost fossils in the LdL area are derived from a tight anticline (apical angles ⩾65°) on the east side of the Estero Trapa Trapa (TTE). From across a ~1100 m thick interval, the thickest and most complete exposures of the CMF and TTF examined in this study, we recovered several notoungulate skulls and jaws, numerous rodents (a new species of *Maruchito* [the genus is Colloncuran elsewhere], a new species of *Luantus* [Colhuehuapian–"Pinturan"]), plus several other taxa, including dasypodids. The lowest strata at TTE occur within the core of the anticline in unit Tcm_1, <100 m *below* the marker ignimbrite (Tcm_2). These strata have yielded an interatheriine notoungulate resembling *Protypotherium* (Colhuehuapian–Chapadmalalan to possibly Montehermosan), a dasyproctid possibly referable to *Neoreomys* ("Pinturan"–Laventan), and a new echimyid genus and species resembling *Maruchito* (Colloncuran), suggesting an age somewhere between the Colhuehuapian and Colloncuran. The dasyproctid appears to derive from lower horizons than the other specimens, indicating a possible Colhuehuapian age for the lowest beds here, with "Pinturan"/Santacru-

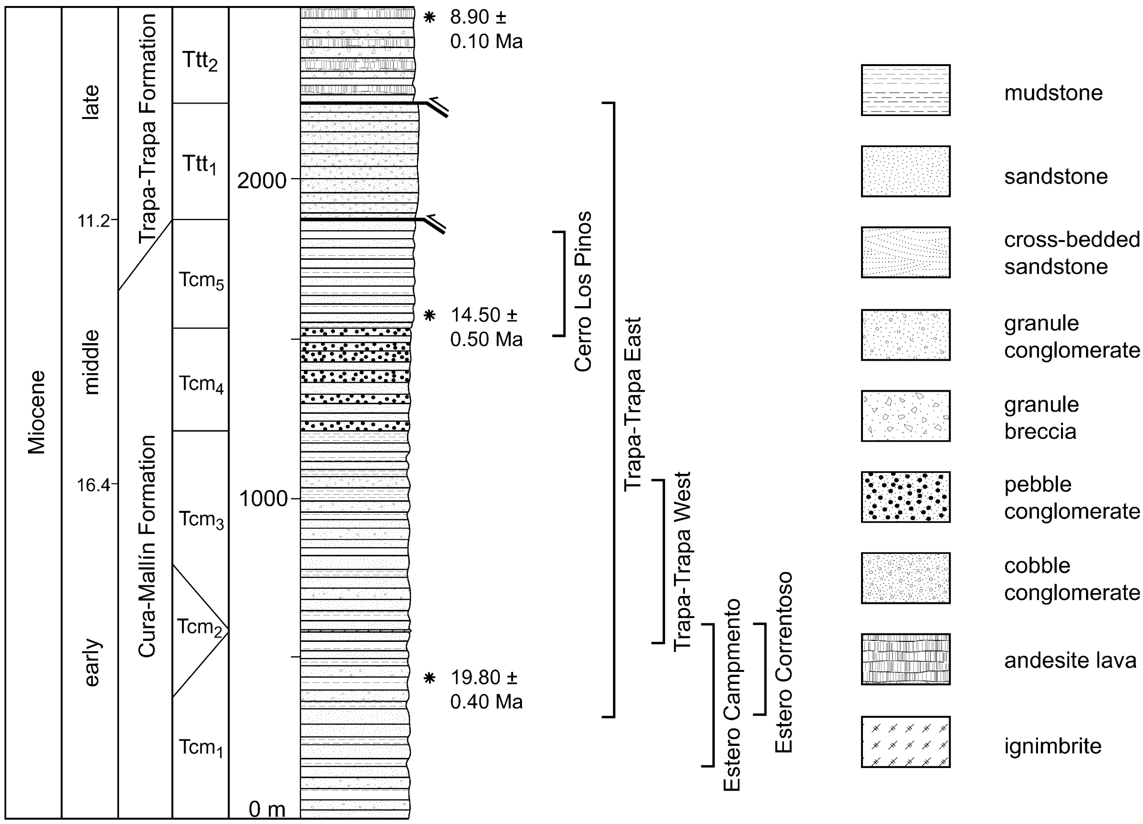

Fig. 2. Composite stratigraphic section for the Cura-Mallín and Trapa Trapa formations, and its informal lithostratigraphic subdivisions, exposed southeast of Laguna del Laja. Included are a generalized composite lithostratigraphy (lithologic key on far right), representative $^{40}Ar/^{39}Ar$ dates bracketing the fossiliferous intervals, and approximate stratigraphic spans of the fossilferous portions of each of the five main sequences examined. The bracketed stratigraphic intervals are those over which fossils have been recovered. We emphasize that this column is a synthetic composite and that no single section in the region exposes all 1875 m of section. The thicknesses of Tcm_1 and Tcm_3 were determined at Estero Campamento; of Tcm_4 and Tcm_5 at Estero Trapa-Trapa East; and the 10 m thickness of Tcm_2, an ignimbrite marker bed, at Estero Campamento, Estero Correntoso, and Estero Trapa-Trapa.

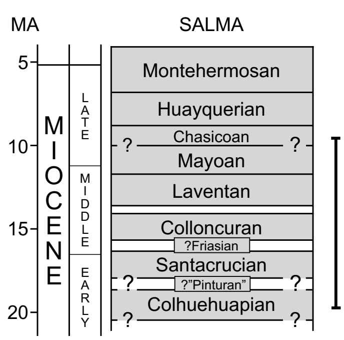

Fig. 3. Geochronology with standard South American Land Mammal "Ages" (SALMAs). Vertical bar indicates available data on the temporal span of the Cura-Mallín and Trapa Trapa formations exposed in the study area. Modified from Flynn and Swisher (1995).

cian above. Fossiliferous localities from higher in the CMF at TTE occur on both the east and west flanks of the anticline, all lying <100 m *above* the ignimbrite, and thus within Tcm_3. These sites have yielded a sparassodont marsupial resembling *Sipalocyon* (Colhuehuapian–Friasian), several notoungulates (including a hegetotheriid possibly referable to *Hegetotherium* [Colhuehuapian–Friasian] and a new interatheriine resembling *Protypotherium* [Colhuehuapian–Chapadmalalan to possibly Montehermosan]) and a diverse assemblage of rodents (including a new species of *Maruchito* [Colloncuran], one new echimyid species referable to *Protacaremys* [Colhuehuapian–Colloncuran], two new species of the echimyid *Prostichomys* ["Pinturan"], at least one new eocardiid species resembling *Luantus* [Colhuehuapian–"Pinturan"], and a new species of *Acarechimys* [Colhuehuapian–Laventan]). The biostratigraphic ranges of these taxa suggest a late early to middle Miocene age, most likely representing the Santacrucian SALMA. Still higher in the CMF at TTE (>100 m above Tcm_2) occur a new genus and species resembling *Incamys* [Deseadan], and a new genus and species resembling *Alloiomys* [Friasian–Colloncuran]. In the overlying TTF we have recovered a jaw of an interatheriid, cf. *Interatherium* sp. (Santacrucian–Friasian) with procumbent, splayed anterior teeth, and lower teeth of a new, very large dasyproctid rodent resembling – yet twice the size of – *Alloiomys* (Colloncuran to Friasian), but differing significantly in morphology from Huayquerian and younger taxa to which the LdL specimen is similar in size. The TTF fossil-bearing horizon is thus difficult to correlate precisely, but appears to be mid-late Miocene, possibly Colloncuran or Mayoan, in age. In sum, the TTE sequence preserves faunas that seem assignable to at least three distinct early–late Miocene SALMAs, from as old as Colhuehuapian or Santacrucian to at least as young as Friasian or Mayoan.

On the west side of Estero Trapa Trapa we have recovered mammals from several horizons in the middle and upper parts of a sequence (Fig. 2) of gently west dipping strata of the CMF exposed on the east and north flanks of Cerro Campamento (Trapa Trapa West localities, TTW). These fossiliferous horizons occur predominantly in Tcm_3, extending down across the ignimbrite of Tcm_2 into upper Tcm_1. The lowest fossiliferous levels outcropping in the northern part of TTW appear to be slightly higher stratigraphically than the lowest beds on the east side of Estero Trapa Trapa (TTE). The

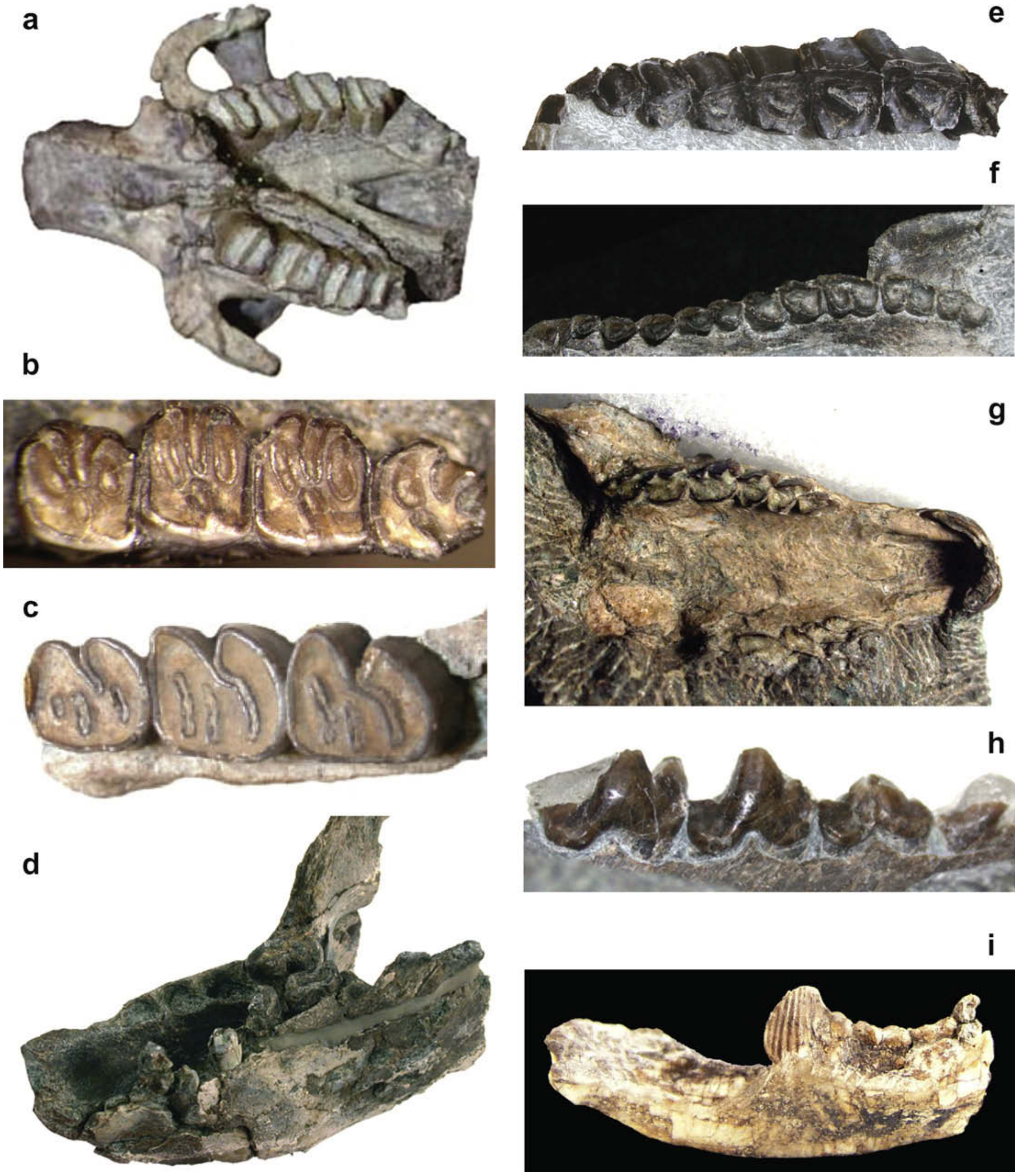

Fig. 4. Representative photographs of fossil mammal specimens from the Cura-Mallín Formation of the Laguna del Laja area (to differing scales): (a) Rodentia, Chinchillidae, *Prolagostomus* sp. nov. palate (SGOPV 3790); (b) Rodentia, Echimyidae, *Protacaremys* sp. nov. right maxillary definition (SGOPV 3901); (c) Rodentia, Dasyproctidae, *Neoreomys* sp. nov, right mandible (SGOPV 3834); (d) Xenarthra, Mylodontidae, *Nematherium* cf. *N. angulatum* or sp. nov. pair of lower jaws (SGOPV5560); (e) Notoungulata, Leontoniidae, nearly complete left upper dentition of a rostrum (SGOPV5704); (f) Notoungulata, Interatheriidae, *Protypotherium* sp., left maxillary toothrow of nearly complete skull (SGOPV 3941); (g) Notoungulata, Hegetotheriidae, *Paedotherium minor,* palatal view of skull (SGOPV 3805); (h) Marsupialia, Sparassodonta, *Sipalocyon*, right lower jaw (SGOPV 3812); (i) Marsupialia, Caenolestoidea, Abderitidae indet., left lower jaw (SGOPV 5710).

lowest levels at TTW have yielded an abderitid marsupial, a hegetotheriid, and a new species of the temporally short-lived eocardiid rodent *Luantus* (Colhuehuapian–''Pinturan''). The middle beds of the northern TTW lie about 50–150 m higher and produce an especially rich assemblage, including specimens of an astrapotheriid, various notoungulates (interatheriine, the pachyrukhine hegetotheriid *Paedotherium minor* [the genus ranges from Chapadmalalan–Uquian], and a toxodontid), and a diverse array of rodents (a new species of the dinomyid *Scleromys* [Santacrucian], the eocardiid *Luantus* [Colhuehuapian–''Pinturan'' – a species indistinguishable from the one from lower in the section at TTW], three new echimyid genera and species resembling *Prostichomys* [Santacrucian], *Protacaremys* [Colhuehuapian–Colloncuran], and *Prospaniomys* [Colhuehuapian], and a new species of the chinchillid *Prolagostomus*). The ranges of these taxa suggest a Santacrucian SALMA for the high northern TTW fossil-producing levels. If correct, this represents a temporal range extension of at least 10 million years for *Paedotherium*. It is more difficult to correlate the fauna from the highest part of the TTW sequence to a specific SALMA, although it may be as young as Laventan based on the occurrences of a dasypodid, various notoungulates (interatheriine, pachyrukhine hegetotheriid, toxodontid), and diverse rodents (echimyid [new species of *Acarechimys* (Colhuehuapian–Laventan)], chinchillid [new species of *Prolagostomus* (Santacrucian–Laventan)], and eocardiids [one possibly referable to *Luantus* sp. (Colhuehuapian–''Pinturan'')]).

We have recovered numerous specimens from between Cerro Los Pinos and Estero Trapa Trapa, including from the south side of Estero Campamento (to the west of Cerro Campamento) and in several horizons in Estero Correntoso (from the main drainage, the faulted anticline at its southern reaches, and crossing the divide into the Estero Campamento drainage to the south). Strata forming the core of the Estero Correntoso anticline represent the stratigraphically lowest levels of the CMF (Tcm_1 to the ignimbrite marker of Tcm_2) in the LdL area. Well-preserved, but only moderately abundant, material has been recovered from Estero Campamento (Tcm_1 to the ignimbrite marker of Tcm_2) – the few specimens prepared to date include a hegetotheriid and a lagostomine. Although Estero Correntoso localities are quite rich and have produced some exceptionally well-preserved specimens, few have yet been prepared sufficiently to permit precise identification, as these are the most recently discovered LdL sites. Preliminary identifications include interatheriines (including *Protypotherium* sp. [Colhuehuapian–Chapadmalalan, possibly to Montehermosan]), a hegetotheriid, toxodontians (including a leontoniid), a mylodontid sloth (*Nematherium* cf. *N. angulatum* or sp. nov. [Santacrucian]), and the lagostomine *Prolagostomus* sp. (Santacrucian–Laventan).

Smaller numbers of specimens have been recovered from sites in the CMF in intervening areas at LdL, including the slopes southwest of the Piedra del Indio (west of Estero Campamento, paralleling the east-west flowing drainage of the Río Pino) and on the southeast flank of Cerro Los Pinos, near the core of the huge west-vergent fold pair forming its southeastern face. A sparassodont marsupial mandible has been recovered from the former site, while the latter has yielded one of the few non-mammalian vertebrates recovered from volcaniclastic strata of the central Chilean Andes, a squamate jaw. Other strata in this area were prospected (e.g., the highest levels of Cerro Campamento; the west flank of the Cordillera Pichicoyahue along the Estero Mallín de las Yeguas), but they yielded no vertebrate fossils.

The extra-Patagonian location of these deposits is reflected in the strong dissimilarity of their fossil rodents relative to roughly contemporaneous Patagonian caviomorph assemblages, with the exception of the geographically proximal Colloncuran (middle Miocene) Cañadon del Tordillo Fauna of Neuquén, Argentina. While many LdL rodents have affinities to Patagonian taxa at the genus level, most represent new species and a few, new genera. Equally surprising, some rodents typically found in great abundance in the Santacrucian of Patagonia (e.g. *Neoreomys* and *Perimys*) are absent at LdL – except one specimen representing a new species of *Neoreomys* which occurs in older beds at TTE. The distinctiveness of the LdL rodents relative to Patagonian contemporaries is notable given the geographic proximity of LdL to the northern edge of modern Patagonia. Similarly, many of the species or genera represented at LdL differ from those occurring in penecontemporaneous faunas from 2° to 4° farther north in the Andean Main Range within the basin(s) of the Abanico Formation. Endemism of the LdL mammals relative to those from Patagonia and the Abanico Formation undoubtedly reflect a combination of factors, including differences in age (by sampling "snapshots" or subintervals within a SALMA, or intervals within temporal gaps between currently recognized SALMAs), geography, paleoenvironment, and depositional setting. Nevertheless, resemblance of some LdL rodents to those from Cañadon del Tordillo demonstrates that these factors did not completely isolate the LdL area from neighboring biogeographic provinces, with some lineages having persisted across the region for extended periods of time.

3. Geologic and tectonic overview

Paralleling the story for the Abanico Formation, age interpretations for the Cura-Mallín Formation and overlying Trapa Trapa Formation have changed dramatically over the last two decades. Even with recently improved age control in the southern sub-basin of Chile (Suárez and Emparán, 1995) and western Argentina (Jordan et al., 2001), numerous geochronologic uncertainties persist (Fig. 6). These unresolved issues have important ramifications relative to the pattern and timing of extension, as well as the timing of subsequent compressional deformation in the region.

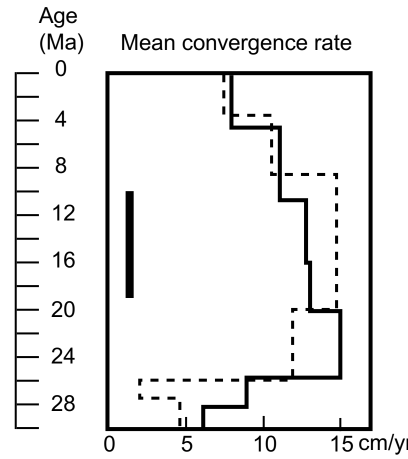

Fig. 5. Trench normal South America-Nazca plate convergence rates for the Andean margin. Dashed line from Pilger (1984); solid line from Somoza (1998) – both for 30°S, i.e., approximately 7° of latitude north of Laguna del Laja (LdL). Thick vertical bar indicates temporal span of the Cura-Mallín and Trapa Trapa formations exposed in the study area, an interval characterized by little variation in convergence rates. The most salient feature in both curves is the near tripling of the convergence rate between 26 and 28 Ma. Basin subsidence and deposition of the Cura-Mallín and Trapa Trapa formations in our study area cannot be ascribed to this spike, however, as deposition did not commence at LdL until considerably later.

Recent $^{40}Ar/^{39}Ar$ geochronological results from the CMF in the Andacollo area immediately east of LdL in Argentina (Jordan et al., 2001) bear directly on the current study. The base of the lower pyroclastic series of the CMF in Argentina has yielded a $^{40}Ar/^{39}Ar$ age of 24.6 ± 1.8 Ma while the top of an upper sedimentary-dominated sequence has produced a date of 22.8 ± 0.7 Ma (Jordan et al., 2001) (Fig. 6). These authors also reported a $^{40}Ar/^{39}Ar$ age of 16.2 ± 0.2 Ma for the overlying Trapa Trapa Formation in the Andacollo region (and a possible range from ~13 to 20 Ma for the TTF, Jordan et al., 2001, fig. 3 therein). More recent studies integrating previously published geochronological data with new field observations suggest that the TTF in the northern area ranges from 14.7–18.2 Ma (Radic et al., 2002) to 12–20 Ma (Melnick et al., 2006).

Prior to the work of Jordan et al. (2001), just a single radioisotopic date was available for the Cura-Mallín Formation in the northern sub-basin, a 14.5 ± 1.4 Ma $^{40}K–^{40}Ar$ analysis (Drake, 1976), coincidentally from the Laguna del Laja area. This date was difficult to reconcile with views about the age of the formation prevailing then. For example, Niemeyer and Muñoz (1983) concluded that the CMF was Eocene to middle Miocene in age, even while citing Drake's (1976) $^{40}K–^{40}Ar$ age of 14.5 Ma from the top of the Río Queuco Member (the lower of their two recognized members: see below).

In the northern sub-basin the CMF varies greatly along strike, ranging from a volcanic and volcaniclastic sequence (Río Queuco Member) interbedded with 500 m of sediments (Malla Malla Member) in the south, to a 2.8 km thick, primarily volcanic sequence (with sparse sedimentary interbeds) towards its northern limit (Muñoz and Niemeyer, 1984; Jordan et al., 2001; Radic et al., 2002). The Malla Malla Member is composed mainly of fluvial sandstones, lacustrine mudstones, and limestones. The most detailed previous geological investigations in the study area were by Niemeyer and Muñoz (1983), complemented by more recent unpublished work by Carpinelli (2000), Radic et al. (2000), and

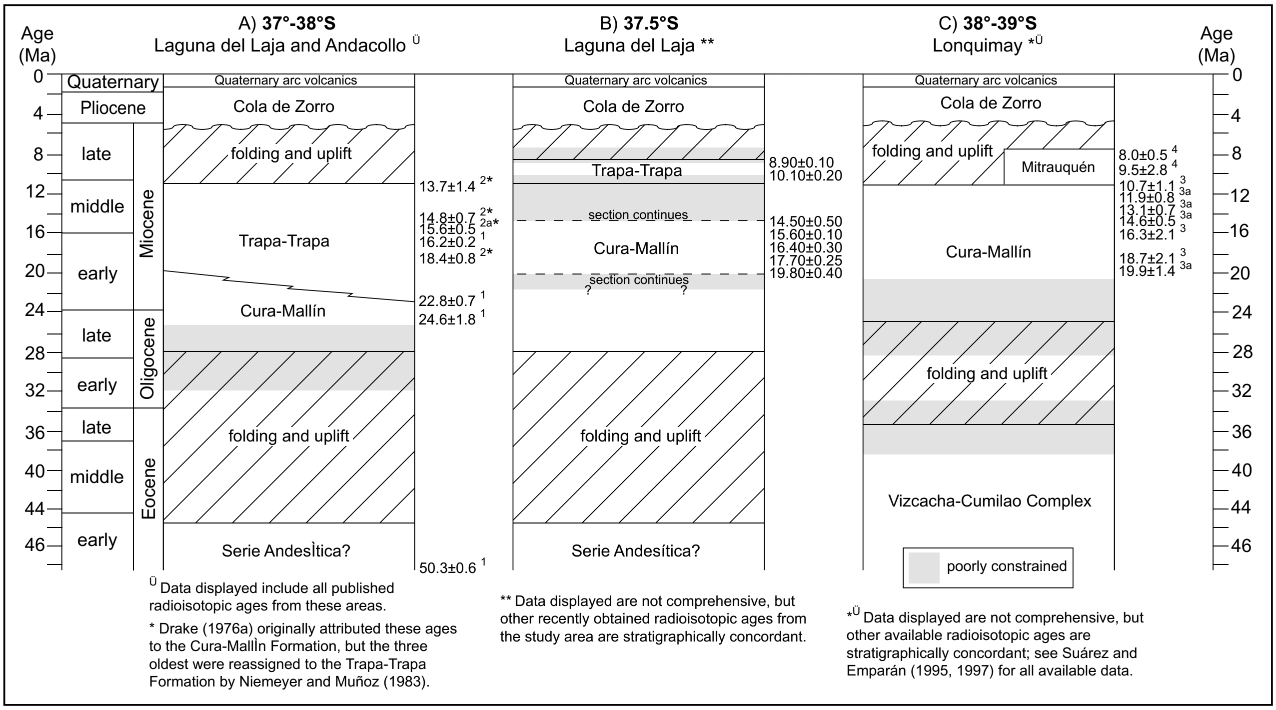

Fig. 6. Summary of the local stratigraphies for the Cura-Mallín and Trapa Trapa formations, including previously published isotopic ages, and results of the current study. (A) and (C) modified after Melnick et al. (2006, fig. 2 therein); (B) summarizes chronologic data reported here superimposed on the framework of (A). The lack of overlap between the age of the Cura-Mallín Formation exposed near Laguna del Laja (B), and this formation in the Andacollo region of Argentina (A), is noteworthy. North of 38°S the Trapa Trapa Formation overlies the Cura-Mallín Formation, with the former portrayed in previous studies (Niemeyer and Muñoz, 1983, fig. 5 therein; Jordan et al., 2001, fig. 3 therein; Melnick et al., 2006, fig. 2 therein) as having been deposited prior to folding (A); nonetheless, the temporal coincidence of the litho-stratigraphically similar Trapa Trapa and Matrauquén formations in (B) and (C) is striking. [1]Jordan et al., 2001 (^{40}Ar/^{39}Ar: hornblende). [2]Drake, 1976 (^{40}K–^{40}Ar: plagioclase[2] and whole rock[2a]). [3]Suárez and Emparán, 1995 (^{40}K–^{40}Ar: plagioclase[3] and whole rock [3a]). [4]Suárez and Emparán, 1997 (^{40}K–^{40}Ar: biotite).

Contreras (2003). Our analyses indicate that the exposed thickness of the CMF southeast of LdL exceeds 1800 m, consisting of interbedded predominantly-fluviatile volcaniclastics (within which the vertebrate fossils occur most commonly), with minor facies possibly indicative of short-lived lacustrine phases (Contreras, 2003; Herriott, 2006; Herriott et al., 2006). In contrast, shallow to deep water carbonate and detrital lacustrine sediments are abundant and laterally widespread (individual beds can be traced >10 km) in the CMF in both Argentina and elsewhere in Chile (Suárez and Emparán, 1995; Jordan et al., 2001).

In the southern sub-basin (Radic et al., 2002) of the Lonquimay or Alto Bío Bío area, ~150 km south of Laguna del Laja, the CMF has been divided into a lower volcaniclastic member (Guapitrío Member; Suárez and Emparán, 1995, 1997) that underlies and interfingers with (i.e., is partly coeval with) a more sedimentary unit (Río Pedregoso Member). These units have lithologies and superpositional relationships mimicking those of the Río Queuco and Malla Malla members of the northern sub-basin, suggesting similar basin histories (whether or not the units are direct lateral equivalents). Near its base, volcanic facies of the CMF (Guapitrio Member) have been ^{40}K–^{40}Ar dated at 20.3 ± 4.0 Ma, 19.9 ± 1.4 Ma and 19.1 ± 2.8 Ma, with other ages as young as 10.7 ± 1.1 Ma near the top of the member (Suárez and Emparán, 1995, 1997). A small vertebrate fauna is known from the Río Pedregoso Member near Lonquimay (Suárez et al., 1990; Wall et al., 1991; Rubilar, 1994; Azpelicueta and Rubilar, 1998), including osteichthyan fishes, birds, and mammals (glyptodontid, a questionable rodent, macraucheniid litoptern, notoungulates [*Protypotherium* and a possible mesotheriid], and *Astrapotherium*), as have isolated elements along the Río Quepuca in the Lonquimay area (*Astrapotherium*, Marshall et al. 1990; strata not assigned to a formal unit, but considered similar to sedimentary facies along the Río Guapitrio [Guapitrio Member]). An age-diagnostic notoungulate, *Nesodon conspurcatus*, was recently recovered from the area (Croft et al., 2003a), indicating a Santacrucian SALMA assignment (16–17.5 Ma; Flynn and Swisher, 1995) for at least part of the Río Pedregoso Member. ^{40}K–^{40}Ar dates (Suárez and Emparán, 1995, 1997) of 13.0 ± 1.6 and 17.5 ± 0.6 Ma from a volcanic-rich lacustrine unit within the Río Pedregoso Member immediately overlying the *Nesodon* specimen are consistent with this age assignment.

Collectively, fossils and radioisotopic dates obtained from these central Main Range volcaniclastic sequences are elucidating various aspects of South American mammalian evolution. Most SALMAs have been based on moderately to densely sampled but geographically restricted faunas from the high latitudes, or more sparsely sampled localities from elsewhere on the continent; many of these remain poorly constrained radioisotopically (Flynn and Swisher, 1995; Fig. 3). The Oligocene to Miocene interval likely encompassed by the Cura-Mallín Formation from various sub-basins in Argentina and Chile (Jordan et al. 2001; Radic et al., 2000, 2002; Melnick et al., 2006; herein) spans an important interval in South American land mammal history, such as the continuing evolution of more diverse and specialized herbivores, and the expansion of grassland and woodland savanna biomes (e.g., Janis, 1989; Wyss et al., 1994; Flynn and Wyss, 1998; Flynn et al., 2003). As the first mammals known from this area, the fossils of the Cura-Mallín and Trapa Trapa formations at Laguna del Laja represent an important opportunity to clarify some of these influential events, aid in biogeographic and temporal comparisons to Chilean assemblages at other latitudes, as well as to nearby faunas east of the Andean divide in Argentina. Integrating biochronologic information with well-constrained radioisotopic dates from numerous superposed fossiliferous horizons at LdL provides one of the best opportunities to further constrain SALMA chronology.

In 2004 we traversed a several thousand-km^2 swath of the central Main Range by helicopter, permitting rapid survey of large areas of outcrop of the Abanico and Cura-Mallín formations in more remote regions. Among the series of new fossil mammal-bearing localities discovered on that expedition were sites from two areas immediately north of Laguna del Laja (Wyss et al., 2004). The first of these areas lies immediately north of the lake near 37°10′S, some 40 km NNW of the LdL localities discussed above from southeast of the lake. Fossils north of the lake were recovered from several different volcaniclastic and fluviatile horizons in east-facing, cliff-forming exposures of the CMF. A second set of localities was discovered ~15 km NE of the first, near Laguna Béjar, in exposures originally mapped as the Plan de Los Yeuques Formation (González and Vergara, 1962), but which currently are regarded as pertaining to the CMF (Muñoz and Niemeyer, 1984; see also Melnick et al., 2006). Preliminary faunal evidence (xenarthrans, notoungulates, rodents) suggests that fossil bearing strata of these two regions are roughly temporally correlative (middle Miocene) with some of the better sampled faunas described above from SE of Laguna del Laja.

4. Subduction parameters, arc and basin tectonics

Our findings at LdL bear on recent discussions concerning the relationship between subduction parameters and the Cenozoic history of subsidence of intra-arc basins (ubiquitous throughout the central Andes) and the foreland basins of Argentina. Interest in this question stems partly from the economic importance of oil-bearing marine sediments, and the lack of an obvious cause for subsidence (Uliana and Biddle, 1988). One interpretation based primarily on late Mesozoic sequences (and the now superceded view that the Abanico-like sequences were of that age), linked foreland basin subsidence in Argentina to increased convergence rates. This increase was considered to have triggered an eastward migrating thrust belt (Uliana and Biddle, 1988; Somoza, 1998), the growing mass of which caused isostatic depression. As for subsidence in the arc itself, Charrier et al. (1996, p. 417) suggested that this might reflect weak coupling between the subducting slab and overriding plate "during periods of slow convergence and/or steep slab subduction." Charrier et al. (2002) noted the temporal coincidence between (1) decreasing convergence rates and basin extension, and (2) increasing convergence rates and basin contraction or inversion (see Charrier et al., 2007).

Near LdL, crustal thinning, borehole, gravity, and field data suggest that north–south striking faults developed during late Oligocene-early or middle Miocene extension and that these were later reversed during late Miocene compression (Legarreta et al., 1990; Jordan et al., 2001; Melnick et al., 2006). Jordan et al. (2001) suggested that basin-forming extension was related to a convergence rate increase between 26 and 28 Ma (Fig. 5). It should not be overlooked, however, that the thick Abanico Formation (north of LdL) began to be deposited well in advance of this event, suggesting that increased plate convergence rate and extension do not necessarily occur in step (although compression and basin inversion may be roughly coeval in the two regions). While the age of the base and top of the equally voluminous CMF remain uncertain, it is clear that this unit was deposited over a span of highly variable convergence rates – using either the reconstruction of Pilger (1984) for these latitudes, or Somoza (1998) for northern Chile and Perú (see Fig. 5). By clarifying the timing of arc volcanism, basin subsidence, and subsequent compression and uplift, improved dating of the CMF will help select among these competing models – assuming that a discernable pattern emerges.

5. Preliminary $^{40}Ar/^{39}Ar$ geochronological data and geological interpretations

As mentioned, the only prior radioisotopic dates from Tertiary strata from the area surrounding LdL in Chile are those of Drake (1976; see also Niemeyer and Muñoz, 1983). The TTF yielded three ^{40}K–^{40}Ar ages from clastic material in one level south of LdL: 18.2 ± 0.8 (plagioclase), 15.4 ± 0.5 (whole-rock) and 14.7 ± 0.7 (plagioclase) Ma, suggesting a middle Miocene age for this unit. The CMF of this area yielded a ^{40}K–^{40}Ar date of 14.5 ± 1.4 Ma (plagioclase; Drake, 1976) from the upper part of the lower (Río Queuco) member (Niemeyer and Muñoz, 1983). This date, in conjunction with freshwater macroinvertebrates correlated to the Eocene and ostracodes correlated to the middle Miocene, led to an Eocene to middle Miocene age assignment for the Malla Malla Member of the CMF. The inverted age estimates for the Cura-Mallín and Trapa Trapa formations (relative to known stratigraphic superposition), as well as for the Malla Malla and Río Queuco members of the CMF, make the incompatibilities of the invertebrate biostratigraphic indicators and/or the initial ^{40}K–^{40}Ar dates all too evident.

Our preliminary, stratigraphically consistent $^{40}Ar/^{39}Ar$ dates from multiple sections at LdL indicate that the fossil-bearing strata of the Cura-Mallín and Trapa Trapa formations might span more than 10 million years, from ~9 to 20 Ma, and up to as many as six SALMAs (using the calibrations of Flynn and Swisher, 1995), consistent with the biochronological data highlighted above (taxa with ranges spanning Colhuehuapian to Colloncuran or Laventan in the CMF and undifferentiated Friasian–Mayoan in the TTF; see also Wertheim et al., 2005). $^{40}Ar/^{39}Ar$ data from the CMF at LdL indicate that the exposed part of the formation spans at least 5 million years, from ~14.5 to 19.8 Ma (Herriott, 2006; Herriott et al., 2006). Ongoing analysis of these data and the processing of additional samples will further refine the numerical geochronology. Results to date indicate that: (1) previous ^{40}K–^{40}Ar and invertebrate biochronologic ages for the Cura-Mallín and Trapa Trapa formations in the LdL area are incongruent; (2) the Cura-Mallín and Trapa Trapa formations in this area span less time than previously believed (entirely within the Miocene, rather than Eocene to Miocene); (3) new $^{40}Ar/^{39}Ar$ dates from the TTF southeast of LdL are much younger than prior ^{40}K–^{40}Ar dates from the same unit in this same area (on the west margin of LdL; Drake, 1976); (4) the CMF sampled in Chile is younger than exposures of the same unit in Argentina (~14–20 Ma vs ~23–25 Ma); (5) the biochronologic age estimates and radioisotopic dates from the CMF at LdL overlap with or are younger than radioisotopic dates reported for the overlying TTF in Argentina (~14–20 Ma vs 16.2 [14.7–18.2 or ~13–20] Ma); and (6) the TTF at LdL is significantly younger (at least in part) than the previously reported ages for this formation in Argentina (9 Ma vs 16.2 [14.7–18.2 or ~13–20] Ma). The youngest exposed levels of the CMF in the LdL region are folded (west vergent), and there is no structural evidence of syndepositional contraction in the formation. Sedimentological analyses of the CMF at Cerro Los Pinos and the west side of Estero Trapa Trapa indicate several phases of progradational-retrogradational facies shifts, possibly in response to basin margin tectonics or shifts in volcanic sediment supply (Contreras, 2003). Extensional basins thus seem to have persisted in this region of the Andes until at least ~14 Ma, followed by E–W shortening (Herriott, 2006; Herriott et al., 2006). Despite the apparently marked age difference between the Cura-Mallín and Trapa Trapa formations between Chilean and Argentine sub-basins, compressional deformation does not appear to have begun at these latitudes prior to the middle Miocene (Jordan et al., 2001; Herriott et al., 2006).

New geochronologic data of Cenozoic units in the central Andes between ~33°S and 37°S have brought into focus questions about large-scale tectonic models relating convergence rates and obliquity of subduction with arc volcanism, styles of deformation, and patterns of basin subsidence. Interpreting the volcanic arc's original stratigraphy and tectonic depositional setting is complicated by strong Miocene to Recent structural overprinting (Mpodozis and Ramos, 1989). A widely favored model (Malumián and Ramos, 1984; Ramos, 1988) envisions initial arc deposition as having occurred within a subduction-related compressional regime – although this was seen as a much older event given the Cretaceous age of the arc sediments (Abanico, Cura-Mallín, etc.) accepted at that time. More recent studies invoke a similar model – albeit within a much younger time frame – as all pertinent arc deposits are now known to be Cenozoic in age (e.g., Wyss et al., 1992, 1994; Charrier et al., 1994, 1996, 2002, 2005; Godoy and Lara, 1994; Godoy et al., 1999; Flynn et al., 2005; Fock et al., 2005). Additionally, recent studies of the Abanico (e.g., Godoy et al., 1999; Charrier et al., 2002, 2005; Fock et al., 2005) and Cura-Mallín formations – and related units in neighboring basins (e.g., Jordan et al., 2001; Radic et al., 2002; Nystrom et al., 1993, 2003) – indicate considerable extension prior to pervasive middle to late Miocene compression, at which point extensional structures became inverted.

As noted, an enormous asymmetric syncline–anticline fold pair makes up the south face of Cerro Los Pinos. Divergence of the anticline's single axial surface is indicative of a fault propogation style of folding (Suppe and Medwedeff, 1990), consistent with Carpinelli's (2000) interpretation. The east-northeast dipping backlimb of this structure likely parallels the underlying fault that facilitated the fold's growth. Trishear modeling (Erslev, 1991) yields estimates of ~900 m of displacement and 40% shortening across the structure. If a reverse fault is indeed implicated in this folding, it might well have originated as a normal fault during initial basin subsidence, becoming inverted during post middle Miocene compression – a pattern potentially repeated by other folds in the region.

6. Conclusions

A large (~200 km^2), new, paleontologically significant area in the Andean Main Range has produced nearly 300 fossil mammal specimens to date. Fossils occur in volcaniclastic deposits of the Cura-Mallín and Trapa Trapa formations, extending recovery of Abanico Formation-like fossil preservation several hundred kilometers south of our previous collecting areas in the Abanico extensional basin (Charrier et al., 2005).

Fossil mammals from the Cura-Mallín Formation include a diversity of taxa, occurring across a thick composite stratigraphic section. Rodents are particularly common and diverse. There are significant faunal differences between the five main local sequences, reflecting the broad temporal range of these stratigraphically superposed faunas. Biostratigraphic data for the Cura-Mallín Formation suggest a minimal age span of at least four to five SALMAs (at least Colhuehuapian to Colloncuran or Laventan), with the Trapa Trapa Formation likely extending as young as the Mayoan (conservatively considered to be undifferentiated Friasian–Mayoan in age). There are marked taxonomic differences between the faunas of the Laguna del Laja area and those reported from nearby Argentina, indicating that LdL was once a region of pronounced local endemism. Potential explanations for this include unusual environments or elevation, topographic or other geographic barriers, and/or temporal distinctions. This series of superposed faunas from LdL, in tandem with stratigraphically-consistent high-precision radioisotopic ages currently being generated, will provide one of the longest and best constrained SALMA sequences in South America, clarifying the history and timing of faunal changes during the middle Cenozoic.

New age-diagnostic fossil mammals and radioisotopic dates indicate that the Cura-Mallín Formation exposed at LdL is highly compressed temporally (some 5 million years long) and is roughly temporally equivalent to either the base of the Farellones Formation or to the youngest known levels of the Abanico Formation in more northern regions.

Paleontological information, $^{40}Ar/^{39}Ar$ dating, and stratigraphic/tectonic studies in progress will help elucidate the duration, sedimentation rate, and precise ages of horizons in the Cura-Mallín and Trapa Trapa formations, as well as the timing of their deformation, in the Laguna del Laja area. Currently available chronologic information from LdL is not in accord with the age span suggested for other "northern" CMF sequences, agreeing more closely with the published ages for this unit in the southern sub-basin. Faunally based age estimates and preliminary isotopic dates both clearly show that the Cura-Mallín and Trapa Trapa formations at LdL are substantially younger (by more than ~10 million and ~5–10 million years, respectively) than the same formations in Argentina. This suggests either limitations of the isotopic ages reported from nearby basins, and/or a more complex pattern of basin development than currently recognized (e.g., the "northern sub-basin" may exhibit strong lateral variation in the timing of basin subsidence, sediment accumulation, and compressional deformation between the eastern [Argentina] and western [Chile, LdL] areas). If future studies confirm such diachroneity, it will underscore the inadequacy of the traditional "formation" designation for laterally discontinuous units in tectonically complex, volcanically dominated depositional basins.

How the Cura-Mallín and Trapa Trapa formations between ~36°S and 39°S correlate precisely in time, genesis, and deformation to the better studied Abanico and Farellones sequences farther north remains in doubt. Although it is uncertain when deposition of the Abanico Formation began, the process was well underway by at least the late Eocene, and it continued until at least the middle Miocene (~16 Ma). Fossil mammals recovered from the CMF at Laguna del Laja, and associated $^{40}Ar/^{39}Ar$ radioisotopic dates, fall within the younger end of the Abanico spectrum and the early phases of Farellones deposition. Conglomerates marking the onset of deposition of the Trapa Trapa Formation may reflect. inversion of the basin at that time. The TTF has no known lithostratigraphic equivalents in the Main Range between 32°30′ and 36°S, but it may correlate to syntectonic deposits in the foreland basin of Alto Tunuyán – western Argentina (Palomares, Papal, and La Pilona formations) (Giambiagi et al., 2001; Giambiagi and Ramos, 2002). Ongoing refinement of the geochronology of the Cura-Mallín and Trapa Trapa formations promises to clarify correlations to similar units elsewhere in the Main Range and permit discrimination between competing models of basin tectonics.

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