formed in an orbit interior to $a/R_\oplus = 34.2$ its primordial spin decayed rapidly and its spin axis drifted into state 1 (*14*) on a time scale of order (a few) × 10^6 years at $(a/R_\oplus) = 30$ or (a few) × 10^5 years at $(a/R_\oplus) = 20$ (assuming an initial rotation period of $2\pi/\dot{\psi} = 10$ hours). Following this event, state 1 begins to slowly drift away from the orbit normal, carrying the spin axis with it as the orbit expands. The solid angle traced out by the precession of the spin axis about the Cassini state behaves as an adiabatic invariant: that is, although not exactly constant, it remains nearly so provided the drift rate, $\dot{\theta}$, is slow enough (*3*, *15*). In particular, if the spin axis is initially in the direction of a Cassini state, it remains very nearly so.

As the semimajor axis approaches 34.2 earth radii states 1 and 4 merge, and the spin axis, which now has an obliquity of −26°, begins to move on a trajectory surrounding state 2. Figure 1, c and d, shows a succession of trajectories converging on state 2 through which the tides drive the spin axis. (These are obtained from the Hamiltonian, Eq. 2.) A maximum obliquity of 77° is reached while traversing the initial trajectory following loss of state 1 stability. Then, as the tides change the value of H, the parabolic cylinder slides along its axis until it is tangent to the unit sphere at state 2. Equation 7 with $\Delta\dot{\psi} \sim n$ and $a/R_\oplus = 34.2$ yields $\tau_{\text{tidal}} \sim$ (a few) × 10^5 years before the spin axis settles into state 2 with an obliquity of 49° (*16*). Thereafter, the obliquity continues to decrease as the orbit expands and state 2 drifts toward the normal to the invariable plane. At $a/R_\oplus = 60.3$, the present value of 6.7° is achieved.

Although a simplified model of the lunar orbit has been discussed here, a more accurate treatment of earth-moon dynamics has actually been employed in the analysis leading to Fig. 2 (*17*). It appears that in addition to drastically altering the lunar orbit, the tides have resulted in a complex history for the lunar spin axis characterized by very large excursions of this axis from the lunar orbit normal during the early history of the earth-moon system.

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11. E. J. Öpik, *Irish Astron. J.* **10**, 190 (1972). The advantage of this procedure is that the spin axis of the earth can be regarded as fixed (aside from a very slow precession due to the solar torque on the figure of the earth).
12. The lunar spin axis precesses about the normal to the Laplacian plane, **k**. Although **k** is nearly coincident with the normal to the ecliptic today, it was not always so. A decrease in the semimajor axis causes a rotation of the Laplacian plane toward the equator plane of the earth. However, the inclination, I, of the lunar orbit to the Laplacian plane behaves as an adiabatic invariant (*15*) during the process of orbit expansion and is not significantly changed by this rotation. The inclination has, however, been somewhat altered by direct tidal decay (*1*).
13. Even for an initial spin period of 10 hours and a ratio $[(Q/k_T)_{☽}/(Q/k_T)_\oplus]$ of order 10^3, one finds τ_{spin} to be at least an order of magnitude less than τ_{orbit} for $a/R_\oplus \geq 5$.
14. Peale has shown that when state 1 is near the orbit normal, it is the most probable end point of spin down (*3*). During this initial event, the Cassini states will undergo some drift, since a more general form of Eq. 1 shows that they are a function of $\dot{\psi}$ also.
15. P. Goldreich and A. Toomre, *J. Geophys. Res.* **74**, 2555 (1969). For the problem at hand, sufficiently slow can be taken to mean $\omega_i \gg \dot{\theta}$, where ω_i is the frequency for spin axis precession about Cassini state i. The constancy of the solid angle about the Cassini state can be appreciated if one imagines the spin axis alternately leading and then trailing the drifting state position. Decreases in the angular separation between the spin axis and Cassini state that occur when the spin axis is leading are very nearly canceled by increases when **s** is trailing if the precession is rapid.
16. Since the spin is already synchronous, changing the obliquity involves changing components of **s** by amounts of order $\Delta\dot{\psi} \sim n$.
17. In constructing Fig. 2 we have included the finite mass of the moon in the analysis of the past orbit, the changes in J for both the earth and the moon, and the tidal decay of the inclination, I, of the lunar orbit to the Laplacian plane. Past positions of the Laplacian plane and the obliquity of the earth have also been found. A more detailed account of this analysis will be presented elsewhere (*18*).
18. W. R. Ward, in preparation.
19. Several valuable suggestions from F. Franklin, H. Mitler, M. Lecar, and A. G. W. Cameron have greatly improved the clarity of the manuscript. Supported by NASA NGR 22-007-269 and NSF GP-40776 at the Harvard College Observatory.

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Catagonus, an "Extinct" Peccary, Alive in Paraguay

Abstract. *A third species of peccary, discovered in the Chaco of Paraguay, is added to the living members of family Tayassuidae. It is assigned to the genus* Catagonus *Ameghino, heretofore considered confined to the Pleistocene. The new peccary is conspecific with* Catagonus wagneri *(Rusconi), a species placed in the related extinct genus* Platygonus *LeConte when it was described from pre-Hispanic archeological deposits of Argentina.*

Organic remains of extinct mammals, such as hides and dung of ground sloths and frozen carcasses of woolly rhinoceroses and mammoths, have been noteworthy findings in the history of mammalogy. There have also been several genera of mammals discovered as fossils and later found to be still living (*1*). We are pleased to announce an addition to this group. A living peccary, related to the genus *Platygonus* LeConte of the upper Pliocene to early postglacial times and to the genus *Catagonus* Ameghino of the Pleistocene, has been found in South America. Twenty-nine specimens were obtained in recent fieldwork (*2*) in the Chaco of western Paraguay.

Peccaries are members of the family Tayassuidae, New World relatives of the pigs or Suidae. Until now, only two species were known to have survived to the present (*3*): the collared peccary or javelina *Dicotyles tajacu* (L.), distributed from the southwestern United States to Argentina, and the white-lipped peccary *Tayassu pecari* (Link) which occurs from southern Mexico to Argentina. But large portions of South America, particularly the thorn forests of the Gran Chaco, extending from southeastern Bolivia through western Paraguay to northern Argentina, remain relatively unstudied. Earlier investigations in Paraguay (*4*) were biased toward the more accessible eastern third of that nation. It is possible that specimens of the third peccary are concealed in some of the

Table 1. Comparison of specimens from Paraguay with *C. wagneri* (holotype and No. 6, pre-Hispanic) and *C. carlesi* (holotype, Pleistocene) (*9*). For specimens from Paraguay, the mean ± standard deviation of the sample and (in parentheses) the observed range and number in sample are given. Abbreviations: C^1, upper canine; PM^2, first upper premolar; M^{1-3}, first to third upper molars; and M^1, first upper molar.

Specimen	Measurement (mm)					
	Condylobasal length	Width across canines	C^1–PM^2 diastema	M^{1-3} length	M^1 length	M^1 width
Paraguay	266.7 ± 7.7 (255–278) (N = 16)	61.2 ± 1.8 (58.4–63.6) (N = 13)	23.4 ± 3.5 (18.8–28.7) (N = 16)	58.5 ± 2.6 (54.1–64.9) (N = 13)	16.8 ± 0.9 (15.0–18.7) (N = 26)	15.4 ± 0.6 (14.3–16.4) (N = 26)
C. wagneri	—, 265	61, 60	20, 20	57, 54	17, 15	15.5, 16
C. carlesi	287	70	32	51	12.3	14

collections of the world under various synonyms of the other two species. The existence of only two species of living peccaries has been so long accepted that we suspect Recent peccary skulls often receive cursory examination. In periods of short funds for museum space, skulls as large as those of peccaries are usually viewed as a storage rather than an intellectual problem. Certainly most studies in the past two decades on the evolution and zoogeography of peccaries have been by paleontologists.

The new peccary is far more different from the other two living species than *D. tajacu* and *T. pecari* are from each other. Unlike those species, the specimens from Paraguay have long, inflated sinuses extending posteriorly below the orbits and dorsolaterally to the pterygoid processes. As compared to *D. tajacu* and *T. pecari* skulls, the cranium of the new peccary has high-crowned teeth, a long rostrum distinctly convex in lateral profile, a proportionally smaller braincase, extreme posterior basicranial flexure, orbits more dorsally positioned and well posterior to the maxillary tooth row, and greater depth of the zygomatic bar, and it lacks the pronounced articular fossa on the anterior face of the zygoma.

These characteristics are shared by specimens of *Platygonus* examined from the upper Pliocene and Pleistocene of North America (*5*). Long, inflated sinuses are found in well-preserved skulls of *Platygonus compressus* LeConte from Welsh Cave, Kentucky (*6*). Although our specimens have three pairs of lower incisors and lack the keeled mandibular symphysis of *P. cumberlandensis* Gidley and *P. compressus* of the middle and upper Pleistocene, these differences are not uniform for earlier specimens of *Platygonus*. The keel is lacking in *Platygonus* from the upper Pliocene of North America, and the third pair of lower incisors, present in many of the Pliocene specimens, almost disappears from *P. cumberlandensis* to *P. compressus*.

Despite these similarities, the Paraguayan specimens differ from *Platygonus* in having larger teeth, longer tooth rows, and shorter diastemas. The large, molariform last premolar is nearly as large as the first molar and, like the molar, has four cusps rather than the two cusps on the much smaller, more compressed last premolar of *Platygonus*. The last upper molar is more quadrangular, lacking the pronounced constriction of the posterior half shown in both *P. compressus* and *P. cumberlandensis*. In addition to the four molar cusps as in North American *Platygonus*, the molars and premolars of our sample show a more bunodont pattern with many minor cuspules.

With the caveat that some of the specimens reported by Ameghino (*7*) and Rusconi (*8*) are incomplete, the Paraguayan peccary shares its differences from North American *Platygonus* with the following extinct taxa of Argentina: *Catagonus bonaerensis* (Ameghino), Bonaerense, Pleistocene, Buenos Aires, based on isolated, worn teeth; *Catagonus metropolitanus* Ameghino, Ensenadense, Pleistocene, Buenos Aires, based on a palate in two fragments and lacking the second and third upper molars; *Platygonus carlesi* Rusconi, Bonaerense, Pleistocene, Santiago del Estero; *Platygonus carlesi wagneri* Rusconi (*8*) or *Platygonus wagneri* Rusconi (*9*), pre-Hispanic Recent, Santiago del Estero. In Fig. 1, the last upper premolars of our specimens and the fossil specimens from Argentina are contrasted with those of North American *Platygonus*. Because of these differences between North American *Platygonus* and the South American specimens, our specimens from Paraguay and Rusconi's species *Platygonus carlesi* and *P. wagneri* are assigned to the genus *Catagonus* Ameghino.

As Rusconi's plates and measurements (*8, 9*) of *C. carlesi* and *C. wagneri* are from complete or nearly complete skulls, they permit adequate comparisons with the *Catagonus* from Paraguay. The Paraguayan specimens and *C. wagneri* differ from *C. carlesi* in having a smaller, less massive skull; the width across the upper canines of *C. carlesi* is the same as that of *C. metropolitanus*. These differences could represent merely a size gradient within a single species from the Pleistocene to a Recent subspecies *wagneri*, whether the species be called *C. bonaerensis, C. metropolitanus*, or *C. carlesi*. We consider this unlikely as Rusconi's two skulls of *C. wagneri* and the skulls of our specimens differ distinctly from *C. carlesi* (Table 1) as well as from *C. bonaerensis* in having larger upper molars, and from *C. carlesi* and *C. metropolitanus* in having a smaller maxillary postcanine diastema. We provisionally consider our specimens to be conspecific with *Catagonus wagneri* (Rusconi).

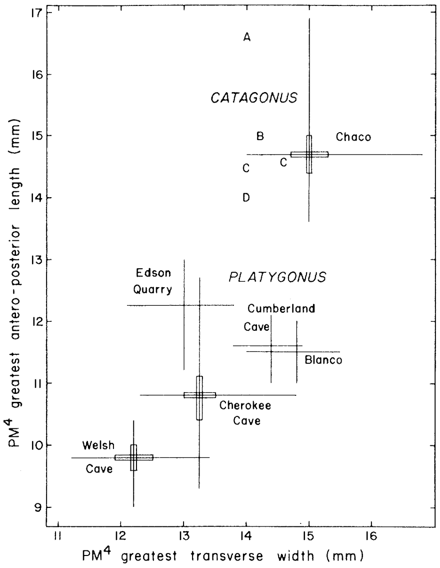

Fig. 1. Comparison of the Chaco peccary (N = 20) with related fossil species. Measurements of the last upper premolar are from this study and from the literature. A single line represents the observed range; a bar represents 2 standard errors of the mean of the sample. (A) *Catagonus metropolitanus* and (B) *C. bonaerensis*, holotypes, Pleistocene, Argentina (*8*). (C) *Platygonus wagneri*, holotype and topotype, pre-Hispanic, and (D) *P. carlesi*, holotype, Pleistocene, Argentina (*9*). *Platygonus compressus*, Welsh Cave, Kentucky (*6*), and Cherokee Cave, Missouri (*10*); *P. cumberlandensis*, holotype and paratypes (N = 5), Cumberland Cave, Maryland; *P. bicalcaratus*, Blanco beds, Texas (*11*); *Platygonus* sp. (N = 4), Edson Quarry, Kansas. Because of the similarities of *P. wagneri* and *P. carlesi* to the genus *Catagonus*, they, as well as the Chaco peccary, are assigned to that genus.

Catagonus wagneri has survived in a scrub-thorn and grass refugium, the Chaco, along with the fossorial armadillo *Burmeisteria retusa*, the cricetid rodent *Pseudoryzomys wavrini*, and the mara *Dolichotis salinicola*. It is probable that *C. wagneri*, one of the major mammalian species hunted for food in western Paraguay, occurs in most or all of the Gran Chaco. One cannot be optimistic about the future of this relict or of most other wildlife of the Paraguayan Chaco. All-weather surfacing of the Trans-Chaco Highway is now in progress. With increased accessibility will come greater pressure from sportsmen, hunters, hide buyers, and increased land clearance for ranching.

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Locomotory Adaptations in a Free-Lying Brachiopod

Abstract. Magadina cumingi *inhabits an environment of high current energy and mobile sediments by using its pedicle in Pogo-stick fashion as an elevating device. This type of progression is associated with pedicle musculature different from that of attached and other free-lying forms, and some diagnostic differences in muscle attachment areas are evident in preservable hard parts.*

Brachiopods are known to be attached to the substrate (by pedicle or cementation) or to be free-lying (with a reduced or atrophied pedicle) and with other various stabilizing and tethering devices, such as differential weighting or spines (*1*). *Magadina cumingi* (Davidson 1852), the only known Recent member of the terebratellid subfamily Magadinae, is free-lying but possesses a pedicle which is not used as a means of permanent attachment to the substrate. The pedicle is long and retractile so that when it is fully withdrawn into the body cavity its anterior end lies close to the intestine; posteriorly it bears four to six fingerlike processes (Fig. 1). The histological structure of the pedicle of *M. cumingi* does not differ from that described for other articulate, attached brachiopods and, since the processes are extensions of the main shaft of the pedicle, they contain no muscular or nervous tissue. Two pairs of muscles, the dorsal and ventral adjustors, act antagonistically to extend and retract the pedicle. The ventral adjustors have small tendonous attachments to the pedicle and wide fibrous attachments to the ventral valve; the dorsal adjustors are fibrous for their full lengths, their attachments to the pedicle forming a cradle-like structure around its antero-ventral segment.

Observations with scuba equipment in the tide race (surface velocities up to 250 cm sec^{-1}) of Backstairs Passage, South Australia, at a depth of 40 m showed that most animals lie obliquely (ventral valve uppermost) partially buried in the substrate so that only their anterior halves are visible; other living animals were observed lying on the substrate surface. The substrate consists of a planed-off surface of bedrock covered with a thin layer of sediment made up of coarse sand, small flat pebbles, and biogenic carbonates. These sediments form drifts in the lee of the sparse reef outcrops or of any small obstructions and contain the highest population densities observed (20 to 80 m^{-2}) of *M. cumingi*. Between one tide and another sediments in given areas in Backstairs Passage may vary in depth by several centimeters.

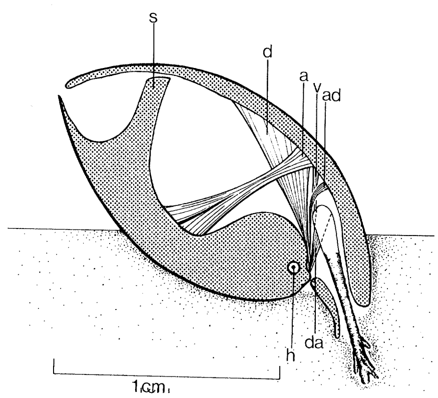

Fig. 1. *Magadina cumingi*. Semidiagrammatic sagittal section to show the extended pedicle and muscles of the left-hand side, ventral valve uppermost; *a*, adductor muscle; *ad*, accessory diductor muscle; *d*, diductor muscle; *da*, dorsal adjustor muscle; *h*, hinge axis; *s*, septal pillar; *v*, ventral adjustor muscle.

The shell of *M. cumingi* is differentially weighted and the accessory diductor muscles lie alongside the anterior section of the retracted pedicle so that their contraction is always accompanied by an elevation of the animal on the pedicle. These morphological features together with the nature of the pedicle and its musculature thus provide a picture of an animal which can automatically right itself if shifted by current action, in which opening of the valves is accompanied by an extension of the pedicle, and in which the more powerful activation of the pedicle by the adjustor muscles (together with added frictional resistance to the substrate provided by the processes of the pedicle) can lift the animal to or nearer to the surface of the substrate. Elevation of the animal seems to be the principal function of the pedicle. It is doubtful if the pedicle could serve any direct anchoring function since its posterior processes provide considerable resistance to penetration of a layer of sediment. It is possible, however, that an extended pedicle could function effectively, for animals lying in different positions on the surface of the substrate, as a stabilizer or as a lever.

The morphological characters contingent upon such a relationship between *M. cumingi* and its substrate in a high-energy environment are:

1) The absence of median pedicle muscles attaching the pedicle to the valve permits the pedicle to be fully retractile.

2) The attachments of the dorsal adjustor muscles are sited more posteriorly than is the case in attached or other known free-lying brachiopods—that is, flanking the cardinal process instead of lying anterior to it on hinge plates or on the valve floor. In this position the dorsal adjustors lie more nearly parallel to the pedicle so that a greater component of the total muscle force is available to move the pedicle in and out.

3) The diductor muscles are of greater size than those of attached species. The angle of insertion of the diductors is governed by the length of the pedicle, a long pedicle and a small angle of insertion requiring large ventral attachments for the muscles to operate efficiently.

4) Differential thickening governs the correct orientation of the shell and holds it in a stable position. The valves of *M. cumingi* are heavily thickened and, since the dorsal adjustor muscles are attached posteriorly, the greater part of the massive platform formed by the fused cardinalia has no function other than to provide weight. This extensive thickening combined with the large area occupied by the diductors reduces the size of the mantle