Time and Faunas

History implies time, and time is usually thought of as implying dates. At the beginning of a historical account time obviously must be considered, and it enters into this particular history in more than one way. For clarity of the verbal account there are also various terms referring to time that must be used. Those absolutely necessary will be given here at the outset.

The classical approach to geological time, which is still in universal use by paleontologists and other geologists and which has already been used in a limited way in this book, does not in fact involve dates as such or in the ordinary sense. It involves only sequence. It indicates which rocks, which fossils, which faunas are older and which younger than others, but not directly how much older or younger. One of its main bases is the order in which rocks were formed. That order can be perturbed by crustal movements, but it is usually quite simple for a geologist to determine in any one region. For example, if molten rock has intruded into what were fissures in another kind of rock and there solidified, that solidification clearly happened later than the formation of the rock around the intrusion. More important to paleontologists, rocks deposited as sediments—and they are the only ones in which fossils usually occur—are normally laid down one after another. Thus, the strata higher in any undisturbed sequence are always younger.

By studying such sequences in different regions and correlating relative ages from one to another, usually by means of similarities in fossils, a sequential time scale for the whole earth was slowly built up and is now everywhere in use. It divides geological time

into eras, periods (subdivisions of eras), and epochs (subdivisions of periods). Those involved in the present history are shown in table 1. Eras earlier than the Mesozoic, Mesozoic periods earlier than the Cretaceous, and Cretaceous epochs earlier than the Senonian are not involved in the history of known South American mammals. Earlier eras are not involved because there were no true mammals before the Mesozoic, and earlier periods and epochs are not involved because, although mammals did exist then and doubtless occurred also in South America, none have yet been found in South America.

For many purposes the sequential time scale is still adequate, but geologists do also want to have a scale of dates in years. Such dates are inherently interesting, and they are also necessary for the study of rates of geological processes and of evolutionary changes. Many attempts to determine such dates, and especially to estimate, at least, the age of the earth, were made in the nineteenth century, but the methods then tried were all extremely inaccurate,

Table 1

Worldwide system of sequential geological time units relevant to this history

Eras	*Periods*	*Epochs*	*Approximate time (millions of years before present)*
Cenozoic	Quaternary	Recent or Holocene	
			0.01
		Pleistocene	
			2
	Tertiary	Pliocene	
			5
		Miocene	
			22
		Oligocene	
			37
		Eocene	
			55
		Paleocene	
			65
Mesozoic	Cretaceous	Late Senonian or Maastrichtian	

and it is now known that almost all the results obtained by these were grossly incorrect.

In the present century a number of different, new methods for determining such dates have been discovered and applied. None is yet accurate to within less than a few percentage points, but their combined application has become increasingly definite, and at very worst they produce a certain order of magnitude. Most of these methods depend on radioactivity, paleomagnetism, or both.

Radioactive elements tend spontaneously to break down or "decay" into other elements at determinable and constant rates, rates usually measured in "half-lives," which are the times for the transformation into another element of one-half of the atoms of the radioactive element originally present. When the ratio of a radioactive element in a mineral to a product of its radioactive decay is obtained, the time since the mineral was formed can be calculated from the relevant half-life. The rates of radioactive change can also be estimated in several other ways, notably by the tracks left in a mineral by radioactive fission. Numerous radioactive elements and their products can be used for dating, but for geological purposes the most widely used have been two radioactive isotopes (forms of an element with different masses) of uranium and their respective end results as isotopes of lead: uranium-lead dating. Another widely used method involves radioactive potassium and its end-result argon.

The so-called carbon-14 clock has been more widely publicized because of its applications to human history, but its half-life, less than 8,000 years, is too short for it to be useful for most paleontological purposes. Forms of uranium have more geologically relevant half-lives, up to about 4.5 billion years, but those ratios have lately been found less often obtainable for fossil deposits than potassium-argon, KA, K/A, or K-A, ratios. Potassium-argon dates have recently been obtained for a number of South American mammalian faunas, and this work is continuing. The approximate dates of beginnings of Cenozoic epochs in table 1 are based on the potassium-argon method, which, however, is not so precise that everyone agrees exactly on its results. There is also debate as to just where the epoch boundaries, which are essentially arbitrary, should be drawn. Such dates are sometimes symbolized by Ma, signifying millions of years before the present. By agreement, "present" in this sense is fixed as A.D. 1950, a slightly silly refinement as no known method of geological dating before the Recent could possibly distinguish between years before 1950 and, say, 1980.

A still more recent dating method now being actively pursued in connection with South American fossil mammals involves what is called paleomagnetism. It has been found that many rocks, often including sediments in which remains of ancient mammals were buried, contain minerals that were to some extent magnetized by the earth's magnetic field at the time when the rocks were formed. There are as usual difficulties and complications, but by appropriate methods the direction of that original magnetization can often be determined. Surprisingly enough, as these methods were developed it was found that from time to time the earth's magnetic poles have reversed their positions. That is, at times in the past the end of a compass needle that now points to near the earth's north pole of rotation would have pointed to near the earth's south pole of rotation. Times when the magnetic poles were as they are today are called "normal," and times when they were reversed are called "reversed," which seems logical enough except for the fact that in the past reversal seems to have been more normal, in the sense of usual, than what this usage labels normal. In fact, the times when paleomagnetism was "normal" are technically called anomalies.

There is a big, fairly obvious catch in using paleomagnetism for dating. It does not really measure time. At any past time the magnetic poles were either "normal" or "reversed," and in itself a "normal" 50 million years ago, for example, does not differ from a "normal" 50 years ago. The paleomagnetic episodes become useful for dating only when they are tied in with some independent dating either by radioactivity methods or by fossil sequence or preferably by both. Then a characteristic sequence of magnetic events, usually studied in the form of a pattern of anomalies (times of normal earth magnetism) may be observed, and its anomalies can be numbered and recognized widely, eventually all over the earth. When that stage of dating by the combination of three different methods is reached, the inclusion of paleomagnetism in those methods has great advantages. The changes between normal and reversed surely affected the magnetism of the earth everywhere at once. Thus, when a paleomagnetic anomaly found in South American rocks can be identified as the same as one found in European rocks, the onset of that anomaly can be taken as simultaneous on the two continents. That will permit a correlation of times, rocks, and ages of faunas with precision often quite impossible by faunal methods alone, the faunas of the two continents being too different for that, and sometimes also by radioactivity, appropriate radioactive minerals being absent in one place or another for considerable spans of time. This result has as yet been obtained only for the later fossil mammal–bearing rocks of South America, but work now well started gives promise that is will eventually be extended to earlier rocks and faunas.

Now we must turn to still another system of dating, one devised especially for use in studies of mammalian history like this one. This system is primarily sequential, but in South America it is now in the course of being tied with K-A year dating in Ma's and with correlation of paleomagnetic anomalies. It comprises a sequence of named ages defined by mammalian faunas. In South America it was started by the Ameghinos (see chapter 2), who designated a long sequence of mammalian faunas by a mixed nomenclature. Some of the ages, most of the earlier ones, were called by the names of genera of fossil mammals that lived at those times. Most of the later ages were given adjectival names of localities or regions where fossil-bearing rocks of the given ages occur. A modification and a refinement of the latter system have been developed through the years by combined efforts of South and North American paleontologists.

Regional or provincial "land mammal ages" are defined by their mammalian faunas and are given geographic names ending in -an or -ian in English (*-ense* in Spanish). The same names are used for the faunas that define them, for the ages thus defined, and for the rocks that were deposited in those ages. (Technically the rocks belong to "stages" rather than to "ages.") There is some slight disagreement as to just which ages should be listed, but the system is now used by all paleontologists dealing with South American fossil mammals. The sequence adopted for the present book and a quite provisional assignment of these ages into epochs (originally named in Europe) are given in table 2. The geographic parts of the names should be pronounced as in Spanish. For example, Lujanian is nearly loo-ha′-nee-an, and Uquian is oo-kee′-an.

The three hiatuses noted are ages for which the South American mammalian fauna is inadequately known or completely unknown at present. It can be expected that further exploration, especially outside of Argentina, will fill in these gaps in knowledge. All the geographic features referred to in these ages are in Argentina, those of the earlier ages in Patagonia and of the others farther

Table 2

South American land mammal ages and their tentative assignment to epochs adopted here

Epoch	*Land Mammal Age*
Pleistocene	Lujanian Ensenadan Uquian
Pliocene	Chapadmalalan Montehermosan Huayquerian
Miocene	Chasicoan Friasian Santacrucian
Oligocene	Colhuehuapian (Hiatus) Deseadan
Eocene	(Hiatus) Mustersan Casamayoran
Paleocene	Riochican (Hiatus)

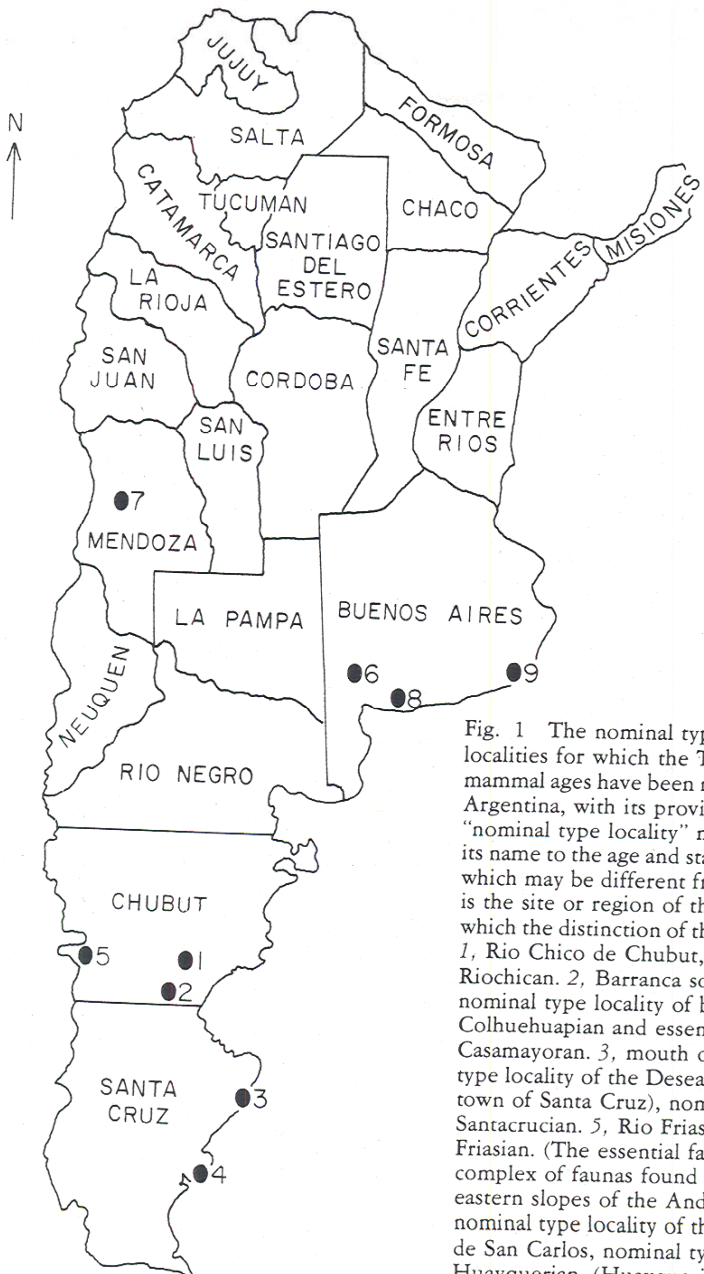

Fig. 1 The nominal type localities or essential faunal localities for which the Tertiary South American land mammal ages have been named. The map includes all of Argentina, with its provinces outlined and named. A "nominal type locality" means the site or region giving its name to the age and stage. "Essential faunal locality," which may be different from the nominal type locality, is the site or region of the fauna of land mammals on which the distinction of the age or stage was established. *1,* Rio Chico de Chubut, nominal type locality of the Riochican. *2,* Barranca south of Lake Colhué-Huapí, nominal type locality of both the Mustersan and the Colhuehuapian and essential faunal locality of the Casamayoran. *3,* mouth of the Rio Deseado, nominal type locality of the Deseadan. *4,* Monte León (near the town of Santa Cruz), nominal type locality of the Santacrucian. *5,* Rio Frias, nominal type locality of the Friasian. (The essential fauna of the Friasian was a complex of faunas found at various localities along the eastern slopes of the Andes.) *6,* Arroyo Chasicó, nominal type locality of the Chasicoan. 7, Huayquerías de San Carlos, nominal type locality of the Huayquerian. (Huayquerian faunas are better known from the province of Catamarca, which might be considered the essential faunal region.) *8,* Monte Hermoso, nominal type locality of the Montehermosan. *9,* Arroyo Chapadmalal, nominal type locality of the Chapadmalalan. (The Pleistocene ages, Uquian

north. Exploration for fossil mammals in other South American countries has not yet been so intensive, but what has been done, notably in Colombia, Bolivia, and Brazil, indicates that fossil mammalian faunas throughout the continent can readily be placed within the same system. An entirely different set of land mammal ages is used in North America. Until toward the end of the history, approximately from the Montehermosan onward, it is almost impossible to establish equivalences between South American and North American ages by their mammalian faunas alone, but this is now being accomplished by tying in the faunas on each continent with radioactivity Ma's and with numbered paleomagnetic anomalies.

Each age of this system has an appreciable length in geological time. When the hiatuses are filled in, the number of South American Cenozoic ages recognized and separately named will probably be about eighteen to twenty. The time involved is about 65 million years, so the average length of an age will probably be somewhere between 3¼ and 3¾ million years. The length of an age in such a system is somewhat arbitrary; the beginnings and endings of an age are rarely marked by definite geological or evolutionary events. There is some tendency to recognize shorter ages in the later part of the sequence where the amount of information available is usually greater. For example, the three Pleistocene ages in the sequence adopted for this book probably average only about two-thirds of a million years in length, while the two Eocene ages currently recognized may have averaged about 5 million years.

A fauna in terms of these ages is not a single, static thing. There were successive faunas within each age. When the fossil collections are adequate and include earlier and later faunas within one designated age, those faunas generally are distinguishably different in detail even though there is an overall resemblance characteristic of the age as a whole. Early collectors rarely were able to make field records precise enough to serve as a basis for examination of detailed changes within one designated age, but with more modern methods and instrumentation this is becoming increasingly possible. When faunas of about the same age are known from widely separate geographic regions, for example Argentina and

Colombia, there are evident differences in the faunas, just as there are in the now living faunas of different regions in South America. In spite of such local differences, the present fauna of the continent as a whole does have a distinctive overall composition. There is increasing evidence that this has been true of South American faunas throughout the Cenozoic era, Age of Mammals.

References

For general background see the references to Simpson 1969 and to Patterson and Pascual 1972 following chapter 1. The following shorter and more technical papers are examples of results in the current campaign to improve the dating of South American mammalian faunas.

Marshall, L. G.; R. Pascual; G. H. Curtis; and R. E. Drake. 1977. South American geochronology: Radiometric time scale for middle to late Tertiary mammal-bearing horizons in Patagonia. *Science,* 195: 1325–1328.

Marshall, L. G.; R. F. Butler; R. E. Drake; G. H. Curtis; and R. H. Tedford. 1979. Calibration of the Great American Interchange. *Science,* 204: 272–279.