tions in the lower mantle, if they occur, could produce horizontal variations in the properties of the core-mantle interface. Vertical displacement velocities of parts of this interface relative to other parts might amount to 1 km in 10^5 or 10^6 years if the speed of lower-mantle motions is between 10^{-1} and 1 cm/year (3×10^{-9} to 3×10^{-8} cm/sec).

Doell and Cox (*11*) have adduced paleomagnetic evidence that the secular variation over the Pacific hemisphere has been systematically weaker than elsewhere on the earth's surface for the past 10^6 years, and I have attempted to account for this and related observations by invoking the interaction of core motions with hypothetical "topographical features" of the core-mantle interface (*1*). If such interactions are important, then a typical interval of time, τ, over which nonaxisymmetric features of the geomagnetic field can safely be assumed to average out to zero at a point on the earth's surface will be governed not by the secular variation—time-scale, years to centuries—as has often been assumed in the interpretation of paleomagnetic data (*12*), but by the dynamical processes affecting the core-mantle interface—time-scale, 10^5 to 10^6 years (?). The observational and theoretical bases for taking τ as low as 10^3 years should, therefore, be reexamined. Further tests of Doell and Cox's conclusions concerning the geomagnetic secular variation over the Pacific hemisphere, and the careful study of the relationship, if any, between features of the earth's magnetic field and features of its gravitational field, will be particularly important.

Because only minor variations in core motions are required to reverse the sign of the dipole field (*7, 13*), it would not be surprising to find that "reversals" are correlated to some extent with other phenomena that may be affected by motions in the mantle, such as tectonic activity (mountain building, ocean-floor spreading, continental drift, and so forth) and the movement of the earth's poles of rotation relative to the earth's surface ("polar wandering") (*9*). The search for such correlations might, therefore, lead to results of direct theoretical importance.

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14. My interest in mechanisms that might possibly give rise to correlations between geomagnetic and geological phenomena was aroused by a paper presented by Professor P. M. S. Blackett at the N.A.T.O. Advanced Study Institute on "Planetary Magnetic Fields" held at Newcastle in April 1965 [see *Magnetism and the Cosmos*, Hindmarsh, Lowes, Roberts, and Runcorn, Eds. (Oliver and Boyd, Edinburgh, 1967)]. Owing to lack of detailed information about the properties of the core and lower mantle, the subsequent suggestion, namely, that mantle motions might affect conditions both at the earth's surface, where geological events occur, and at the core-mantle interface, where effects on the geomagnetic field may arise, must, of course, be regarded as speculative. The favorable reaction of Dr. D. W. Strangway and Dr. E. Irving convinced me that the suggestion might not be entirely farfetched and was at least worth bringing to the attention of other paleomagnetic workers (*9*). The work of the Geophysical Fluid Dynamics Laboratory, Department of Geology and Geophysics, M.I.T., is supported by NSF (Atmospheric Sciences Program) under grant No. GP5053. This is Paper No. 25 of that laboratory.

23 March 1967

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Romeriscus, the Oldest Known Reptile

Abstract. *The description of* Romeriscus, *a new genus of limnoscelid reptile, is based on a partial skeleton from the Early Pennsylvanian (Westphalian A) of Nova Scotia. Although it is the earliest and most primitive reptile yet known, it is probably already too late and too specialized to be ancestral to the more advanced Carboniferous and Permian captorhinomorphs and pelycosaurs.*

The most primitive described genus that is also unquestionably reptilian is *Limnoscelis* (*1, 2*) from the Lower Permian of Texas. Both Romer (*2*) and Watson (*3*) have indicated that, morphologically, *Limnoscelis* is more or less intermediate between anthracosaur amphibians and typical captorhinomorph reptiles and not far from the ancestry of pelycosaurs. Two other genera of the family Limnoscelidae are known from the Lower Permian (*4*). A somewhat earlier genus, based on very incomplete material from the Middle Pennsylvanian of Nova Scotia, is being described elsewhere (*5*).

Numerous other reptiles are known from the Pennsylvanian (*6*), the earliest being two romeriid captorhinomorphs and one pelycosaur from the Lower Pennsylvanian of Joggins, Nova Scotia (*7*). All of these forms are more advanced in their morphology than is *Limnoscelis* and show little evidence of affinity with anthracosaurs. This indicates that forms related to *Limnoscelis* must have been living throughout the Pennsylvanian and possibly even in the late Mississippian.

A single specimen that evidently represents an early member of the limnosceloid lineage is described here. It was found in 1959 by D. Baird and W. F. Take near Port Hood on the northwest shore of Cape Breton Island, Nova Scotia, Canada. Its source horizon lies near the middle of the Port Hood Formation, part of the coarse fluvial facies of Belt (*8*) and the Riversdalean Stage of earlier authors. On the basis of nonmarine crustaceans (*9*), plants (*10*), and microspores (*8*) the age of the Port Hood Formation is Early Pennsylvanian and equivalent to the Westphalian A of Europe. This is earlier than any deposit from which reptiles have been described.

Although no other fossils have been found in the sandstone layer that produced the reptile skeleton, other sandstone beds in the same cove have yielded scales of the crossopterygian fish *Rhizodopsis* (Princeton University Museum of Natural History No. 17206), *Baropezia*-like footprints of large temnospondylous amphibians, and vertebrae of a large embolomerous amphibian (*11*; specimen in the Nova Scotia Museum).

Unfortunately, the reptile specimen is very poorly preserved, with much of the limb and girdle material remaining only as a dark film which fades into the matrix. Enough of the skull and vertebral column is preserved to establish its taxonomic position, and its generic identity with subsequently discovered specimens should be possible to determine. There are difficulties due to poor preservation, but because of the age of this specimen even an incomplete description of its morphology is of value in determining the phylogeny of early reptiles.

Class Reptilia
Order Cotylosauria
Suborder Captorhinomorpha
Family Limnoscelidae
Romeriscus, new genus

Type: *Romeriscus periallus*, new species. Diagnosis: Limnoscelid reptile having paired postparietals and probably retaining an open otic notch. Neural arches are not swollen. The generic name honors Dr. Alfred S. Romer, who in 1956 renewed the search for Carboniferous tetrapods in Nova Scotia.

Romeriscus periallus, new species;

Figs. 1 and 2B

Type: Princeton University Museum of Natural History No. 16982. Skull roof and anterior postcranial skeleton preserved in a single block of sandstone.

Source: Small lentil in 1.2-m bed of buff sandstone between Ten Inch and Four Inch Coal seams, middle Port Hood Formation, Lower Pennsylvanian (*12*). Cove northeast of Cape Linzee, north-northwest of Port Hood, Inverness County, Nova Scotia.

Diagnosis: As for the genus. The specific name is from the Greek *periallos*, "before all others."

The skull is exposed ventrally, with much of the palate, braincase, and ventral margin missing. External surfaces of the dermal bones are nowhere exposed, but where these bones have exfoliated a fairly deep sculpturing can be seen. There is no evidence for or against the presence of lateral line canals.

Only the posterior portion of the skull table and the right cheek are articulated. The configuration of the parietals, postparietals, tabulars, and left supratemporal can be determined with reasonable assurance, but the interpretation of the remainder of the skull is subject to varying degrees of uncertainty. The parietals, if their anterior margins are correctly determined, are short wide bones resembling those in *Limnoscelis*. The parietal foramen is of normal size for Paleozoic tetra-

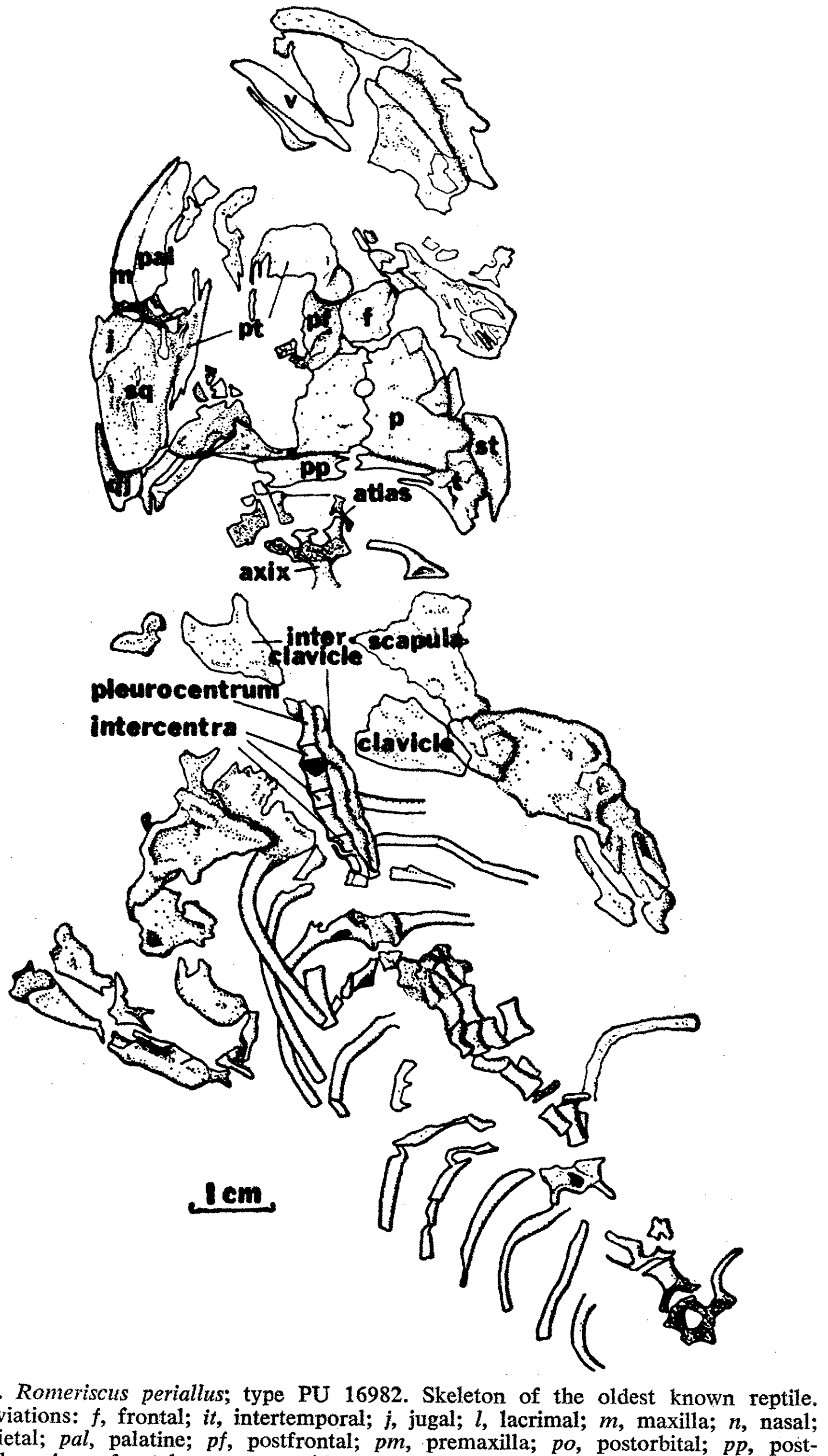

Fig. 1. *Romeriscus periallus*; type PU 16982. Skeleton of the oldest known reptile. Abbreviations: *f*, frontal; *it*, intertemporal; *j*, jugal; *l*, lacrimal; *m*, maxilla; *n*, nasal; *p*, parietal; *pal*, palatine; *pf*, postfrontal; *pm*, premaxilla; *po*, postorbital; *pp*, postparietal; *prf*, prefrontal; *pt*, pterygoid; *qj*, quadratojugal; *sq*, squamosal; *st*, supratemporal; *t*, tabular; and *v*, vomer.

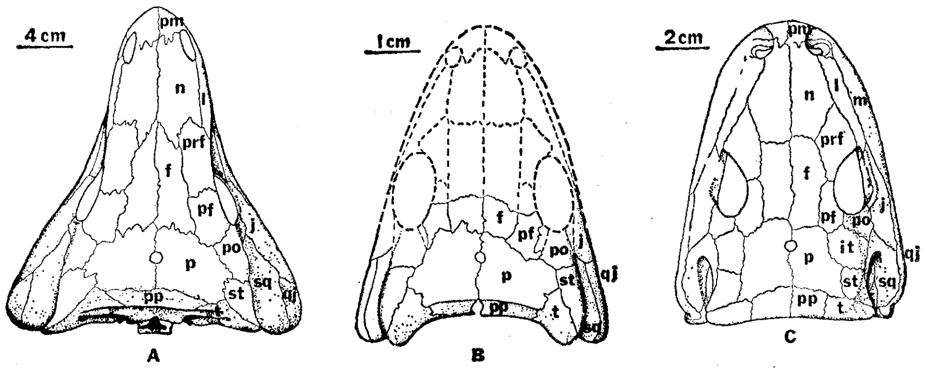

Fig. 2. Comparable restorations of the skull roof of (A) *Limnoscelis*, (B) *Romeriscus*, and (C) *Seymouria*.

pods. The postparietals are entirely occipital in position and are paired as in most Paleozoic tetrapods, in contrast to the single median postparietal of *Limnoscelis*. There appears to be a narrow natural gap between the postparietals that would have been occupied by a dorsal process of the supraoccipital.

The tabulars are large bones, exposed on both the skull roof and the occipital surface. Ventrally they are recessed and have a rugose surface, possibly to support the paroccipital process of the opisthotic. Laterally they extend posteriorly beyond the postparietals, as in *Limnoscelis*. The supratemporal is large and extends around the lateral surface of the tabular as in *Seymouria* and *Limnoscelis* (Fig. 2, A and C).

Anterior to the parietals are two bones that may be interpreted as the right frontal and postfrontal, displaced to the right as viewed ventrally. Only small fragments remain in the area between the supratemporal and postfrontal. This position is occupied in *Limnoscelis* by a dorsal extension of the postorbital and in *Seymouria* (*13*) and other anthracosaurs by the intertemporal. There is little real evidence for interpreting this area in *Romeriscus*, but judging from the configuration of the other elements in the skull table a single bone, the postorbital, may be restored here.

The anterior extremity of the postfrontal and frontal and all of the more anterior roofing elements are lost. The squamosal, jugal, and quadratojugal are preserved on the right side, but the loss of their ventral margins precludes determination of the height of the skull table. The posterior margins of the squamosal and quadratojugal extend anterodorsally, rather than directly dorsally, which indicates the presence of an open otic notch. This feature cannot, however, be established conclusively.

Of the palate, several fragments of the pterygoid are present in the area of the right squamosal, but the presence or absence of a transverse flange cannot be determined. Anterior to the right squamosal lies a lateral element that may be the palatal surface of the maxilla (no teeth are preserved) and, more medially, the palatine or ectopterygoid, or both. Further forward is a long narrow bone resembling the vomer of early reptiles and anthracosaurs.

A few tiny fragments of a massive well-ossified bone, below and just anterior to the right frontal, may be the remains of the anterior region of the braincase. Although many other bone fragments are present in the cranial region, none can be identified with any assurance.

Remains of about 16 vertebrae are exposed in ventral view. The most anterior two lie more or less in their natural position behind the occiput. The centrum of the atlas is lost, leaving the paired halves of the neural arch.

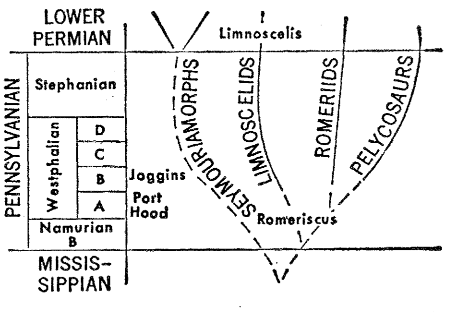

Fig. 3. Simplified phylogeny of Pennsylvanian and Permian reptiles and seymouriamorphs. Solid lines, known lineage; broken lines, probable lineage.

The axis has a pleurocentrum the same size as those of the more posterior vertebrae; no cervical intercentra are visible. The configuration of the anterior cervicals is of the level of development reported in *Limnoscelis* and other captorhinomorphs and is advanced over the condition in *Seymouria*, in which the pleurocentrum of the axis is a small wedge-shaped structure.

Beneath the dermal shoulder girdle is a gap that would have been occupied by two more vertebrae. The succeeding four vertebrae are exposed and show small, presumably crescentic, intercentra between large pleurocentra. The last vertebra preserved (approximately the 19th presacral) is exposed in section at the margin of the block. Its neural arch, unlike those of *Limnoscelis*, is not swollen.

A single rib lies lateral to the axis vertebra. It has a short cylindrical shaft and is clearly, although not exaggeratedly, double-headed. Ribs from the region posterior to the level of the sixth trunk vertebra have cylindrical shafts. The seventh, eighth, and ninth ribs appear to have widely expanded heads, as in *Limnoscelis* and *Seymouria*. Ribs of the posterior vertebrae are short and sharply curved, indicating their nearness to the sacrum.

The ventral plates of the clavicles are broad and coarsely sculptured; the interclavicle has a long stem. Evidently the endochondral shoulder girdle and most of both forelimbs were in place when the animal was buried, but their preservation is such that only the most general proportions can now be determined. The humerus, radius, and ulna were apparently robust; both the manus are missing except for a few phalanges or metacarpals, or both, scattered along the vertebral column. No trace of the pelvic girdle or hind limbs is preserved, and no scales are evident in the block.

The proportions of the skull, vertebral column, and forelimbs of *Romeriscus* are what would be expected in a fairly active terrestrial animal and quite different from those of the evidently aquatic tetrapods that are so characteristic of the Carboniferous faunas.

From what is known of reptiles and their close relatives in the late Pennsylvanian and early Permian, there are at least four groups to which *Romeriscus* might belong: (i) the lineage ancestral to *Seymouria* and *Discosauris*-

cus, (ii) the romeriid-pelycosaur assemblage, (iii) the Limnoscelidae, and (iv) the Diadectomorpha (*14*) (Fig. 3). Despite the presence of an otic notch in the Port Hood specimen, the proportions of its skull table and the configuration of the atlas and axis vertebrae show closest resemblance to the Limnoscelidae. *Romeriscus* differs from the later (and larger) members of this family in lacking swollen neural arches. Expanded arches, however, are a functional adaptation to be expected in large forms and could easily have evolved from the condition seen in *Romeriscus*. The configuration of the otic region in *Limnoscelis* suggests that the notch had only recently been closed and might well have been open in early Pennsylvanian predecessors.

In having nonswollen neural arches and paired postparietals, *Romeriscus* is more similar to other early captorhinomorphs than are the later limnoscelids. Despite these similarities, it is unlikely that *Romeriscus* itself could have been ancestral to the other captorhinomorph families, the Romeriidae and the Captorhinidae. At least one morphological peculiarity of the limnoscelids, the considerable expansion of the rib heads, is already evident in *Romeriscus*, which indicates some specialization away from the presumably primitive pattern that is retained in the other captorhinomorph families.

By Westphalian B time, not only romeriid captorhinomorphs but also pelycosaurs had evolved. These two groups show close affinities and in all probability the features in which they are advanced over limnoscelids had been achieved by an immediate common ancestor that was already distinct from *Romeriscus*. We must therefore assume that limnoscelids and more advanced captorhinomorphs had a yet earlier common ancestor. Such an ancestral form, of late Mississippian or earliest Pennsylvanian age, may have been similar to *Romeriscus* in its general morphology.

The precise relationship of this postulated reptile-ancestor to the amphibians is still not clear. Retention of an otic notch by *Romeriscus* points to an ancestry among the anthracosaurian labyrinthodonts. There are, however, no anthracosaurs—either contemporary with *Romeriscus* or from earlier beds—that appear to be at all close to the ancestry of reptiles. The seymouriamorphs are usually considered as relicts of such a group, but the Permian genera (none are definitely known from the Carboniferous) are too specialized and too late in time to contribute much to our understanding of reptile-ancestors that must have existed in the Mississippian.

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21 April 1967

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High-Pressure Dissociation of Carbonic and Boric Acids in Seawater

Abstract. *The apparent dissociation constants of carbonic and boric acids were determined for pressures up to 654 atmospheres in seawater of 34.8 per mille salinity at 22°C. Our values for the ratios of the apparent dissociation constants at 654 atmospheres to the constants at 1 atmosphere are 1.84 1.48, and 1.94 for* K'_1, K'_2, *and* K'_B, *respectively. At this pressure the commonly accepted values of Buch and Gripenberg for these ratios are 2.03 and 1.30 for* K'_1 *and* K'_2, *respectively.*

The apparent dissociation constants of carbonic and boric acids at high pressures are needed to determine the effect of pressure on the *p*H and on the distribution of carbonate species in seawater.

Lyman (*1*) defined these constants as $K'_1 = a_H(HCO_3^-)/(H_2CO_3)$, $K'_2 = a_H(CO_3^=)/(HCO_3^-)$, and $K'_B = a_H(H_2BO_3^-)/(H_3BO_3)$, where the parentheses represent molal concentrations, and (H_2CO_3) is the sum of the concentrations of carbon dioxide and carbonic acid.

Brander (*2*) determined the first dissociation constant of carbonic acid and the dissociation constant of acetic acid as a function of pressure in distilled water at 20°C. To calculate the effect of pressure on the *p*H and on the distribution of carbonate species in seawater, Buch and Gripenberg (*3*) applied Brander's (*2*) pressure coefficient for carbonic acid to K'_1, and his coefficient for acetic acid to K'_2. Pytkowicz (*4*) suggested the need to verify these pressure coefficients, because they depend on ion-pair formation and on partial molal volumes, both of which vary with the pressure, temperature, and composition of the medium. Further, in their calculation of the effect of pressure on *p*H, Buch and Gripenberg (*3*) did not consider the effect of boric acid. Disteche and Disteche (*5*) recently reported values for the pressure coefficients of the apparent dissociation constants of carbonic acid in seawater at 1000 atm and 22°C.

Our determination of the effect of pressure on K'_1, K'_2, and K'_B was based on *p*H measurements at high pressures. The following cell, which is essentially that of Disteche (*6*), was used to measure *p*H:

$$\text{Ag; AgCl, SW}_e \parallel \text{Glass} \parallel \text{SW}_i\text{, AgCl; Ag} \qquad (1)$$

The seawater in the external compartment, SW_e, had a salinity of 34.8 per mille and was prepared by the formula of Lyman and Fleming (*7*), with the following exceptions: KCl was substituted for KBr; boric acid was omitted in the determination of the effect of pressure on K'_1 and K'_2; and in the boric acid experiments the total boron was increased to 3 mmole/liter, $NaHCO_3$ was omitted, and 1.25 mmole of Na_2CO_3 per liter was added. The