this strong field can orient several layers of water molecules at the interface to yield the enhanced spectrum. No free OH peak is discernible. These observations indicate that water molecules must have surrounded the hydrophobic chains. The partly wettable surface then corresponds to a situation in which the bulk water contacts a surface covered partly by water (hydrophilic) and partly by hydrocarbon (hydrophobic).

We can now describe a hydrophobic interface at the molecular level as follows: The surface water molecules do not interact strongly with the opposing surface. They form a hydrogen-bonding network, with dangling OH bonds on one-fourth of them. This large number of dangling OH bonds gives rise to a large interfacial surface energy (*18*). In this respect, air or vapor (or gas) is hydrophobic and also forms a hydrophobic interface with water. The hydrogen-bonding network of the surface layer can be more or less ordered, depending on the opposing hydrophobic surface. For a solid surface, the restriction of packing surface water molecules against the rigid wall forces the molecular arrangement into a more ordered, ice-like structure. For air-water and oil-water interfaces, no such packing restriction exists, and the interface water layer is less ordered. In the case of a partly wettable substrate prepared by surface coverage with a monolayer of loosely packed alkyl chains, water molecules appear to penetrate into the surfactant layer and induce a straightening of the alkyl chains.

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A Crested Theropod Dinosaur from Antarctica

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Jurassic fossil vertebrates collected from the Falla Formation in the Central Transantarctic Mountains included a partial skull and postcranial elements of a crested theropod, *Cryolophosaurus ellioti* gen. nov. sp. nov. The theropod bears some resemblance to the large tetanurans of the Middle to Late Jurassic but also has primitive ceratosaurian features. Elements from a prosauropod, teeth from scavenging theropods, a pterosaur humerus, and a tritylodont molar were also recovered. The presence of this fauna suggests that a mild climate existed at high paleolatitude in this area of Gondwana during the Early Jurassic.

A number of high-latitude Cretaceous dinosaurs have been found recently, which indicates that these animals were not restricted to tropical or subtropical areas (*1*, *2*). Few high-latitude dinosaurs are known from the Jurassic, particularly from the early part of the period before the breakup of Pangea. We describe an assemblage of Early Jurassic tetrapods collected from Mount Kirkpatrick near the Beardmore Glacier in the Transantarctic Mountains, Antarctica, approximately 650 km from the geographic South Pole (Fig. 1). The existence of this assemblage, which is similar to Early Jurassic assemblages from other continents, indicates that there were no geographic or climatic barriers to prevent dinosaurs from populating high southern latitudes during the Jurassic.

The fossils occur in a tuffaceous siltstone high in the Falla Formation (*3*) at an elevation of over 4000 m. All but three of the numerous bones collected were concentrated within a single meter stratigraphically and 5 m laterally. At least four dinosaurs (including a new theropod) and two non-dinosaurian taxa make up the fauna. The theropod is one of only a few reasonably complete Jurassic carnivorous dinosaurs known from any of the Gondwana continents; thus, it provides important information about the earlier stages of evolution of the large theropods. The specimen has a mixture of primitive and derived features and shows that Early Jurassic large theropods had diverged considerably from their Triassic ancestors.

The fossils include a partial skull with articulated mandibles and postcranial elements of a large crested theropod, *Cryolophosaurus ellioti* gen. nov. sp. nov. (*4*). The deep narrow skull is approximately 65 cm long. The nasals extend posteriorly as high ridges that join with a large furrowed lacrimal crest (Figs. 2 and 3, A and B). Above the orbits, the crest runs approximately perpendicular to the length of the skull and curves anteriorly as it rises. Although the top of the crest is broken, its furrowed

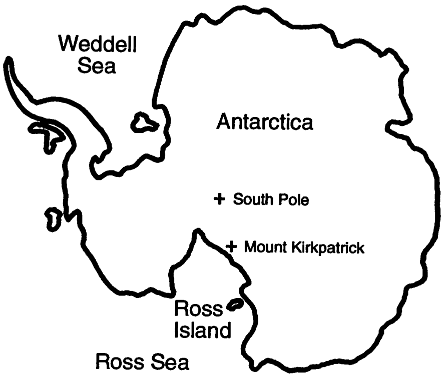

Fig. 1. Map showing location of Mount Kirkpatrick where Antarctic Jurassic fauna was discovered.

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surface appears to separate into what would be small vertical projections along the dorsal surface. An orbital horn is fused to the crest on each side. In the postorbital region, the jugal crosses the lower lateral temporal opening and sutures with the squamosal, splitting the opening into two parts.

The front of the skull, including the maxillae, had been glacially eroded out of a cliff face. However, some broken teeth and a few pieces of the maxilla were recovered from the base of the exposure, near the skull. The right side is generally better preserved than the left; however, the postorbital-jugal bar that separates the orbit and the lateral temporal opening is missing on the right. The tongue-and-groove suturing of the jugal and squamosal across this opening is preserved on the left side. The large frontal display crest is well preserved, except that it is broken where it thins distally. The orbital horn cores adjacent to the crest are broken on both sides.

Cryolophosaurus has a deep narrow skull with a large antorbital fenestra, as do the large, late Middle to Late Jurassic tetanurans from other parts of the world, such as the North American carnosaur *Allosaurus* and the megalosaurid-grade theropods, such as the Chinese *Yangchuanosaurus* (5). However, although it has a pneumatic lacrimal like that of tetanurans, it lacks the large lacrimal opening and deep surangular that are typical of the larger carnosaurian tetanurans. The only large Jurassic tetanuran from a Gondwana continent is the South American *Piatnitzkysaurus* (6). The single specimen that represents this taxon has little cranial material; however, some of the derived postcranial features of *Piatnitzkysaurus* indicate that it is not congeneric with *Cryolophosaurus*.

Other material found associated with the skull of *Cryolophosaurus* includes a femur, ilium, ischium, pubis, tibiotarsus, fibula, and two articulated metatarsals. In addition, some of the more than 30 unidentified vertebrae collected that are still in matrix may pertain to *Cryolophosaurus*. The skull shows derived features, but some of the associated postcranial elements have more primitive characteristics. The femur has features that are typical of more primitive theropods, including ceratosaurs such as *Dilophosaurus*: a highly bowed shaft, a declined head from the greater trochanter, and the lack of a deep extensor groove (7, 8). The trochanteric shelf region is not preserved. The tibia, astragalus, and calcaneum appear to be fused as they are in most ceratosaurs and abelisaurs. It is possible that these elements may not go with the skull, but they are clearly theropod and are the right size. Although the postcranial elements mentioned above show some primitive ceratosaurian features, the pelvis is not at all like that of ceratosaurs but is very similar to that of megalosaurid-grade theropods such as *Gasosaurus*, *Monolophosaurus*, and *Yangchuanosaurus*.

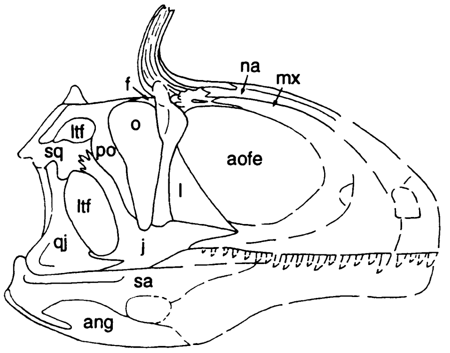

Fig. 2. Composite reconstruction of the right lateral view of *Cryolophosaurus ellioti* skull; na, nasal; l, lacrimal; mx, maxilla; aofe, antorbital fenestra; o, orbit; f, frontal; j, jugal; po, postorbital; sq, squamosal; qj, quadratojugal; ltf, lateral temporal fenestra; sa, surangular; and ang, angular. Skull length, 65 cm.

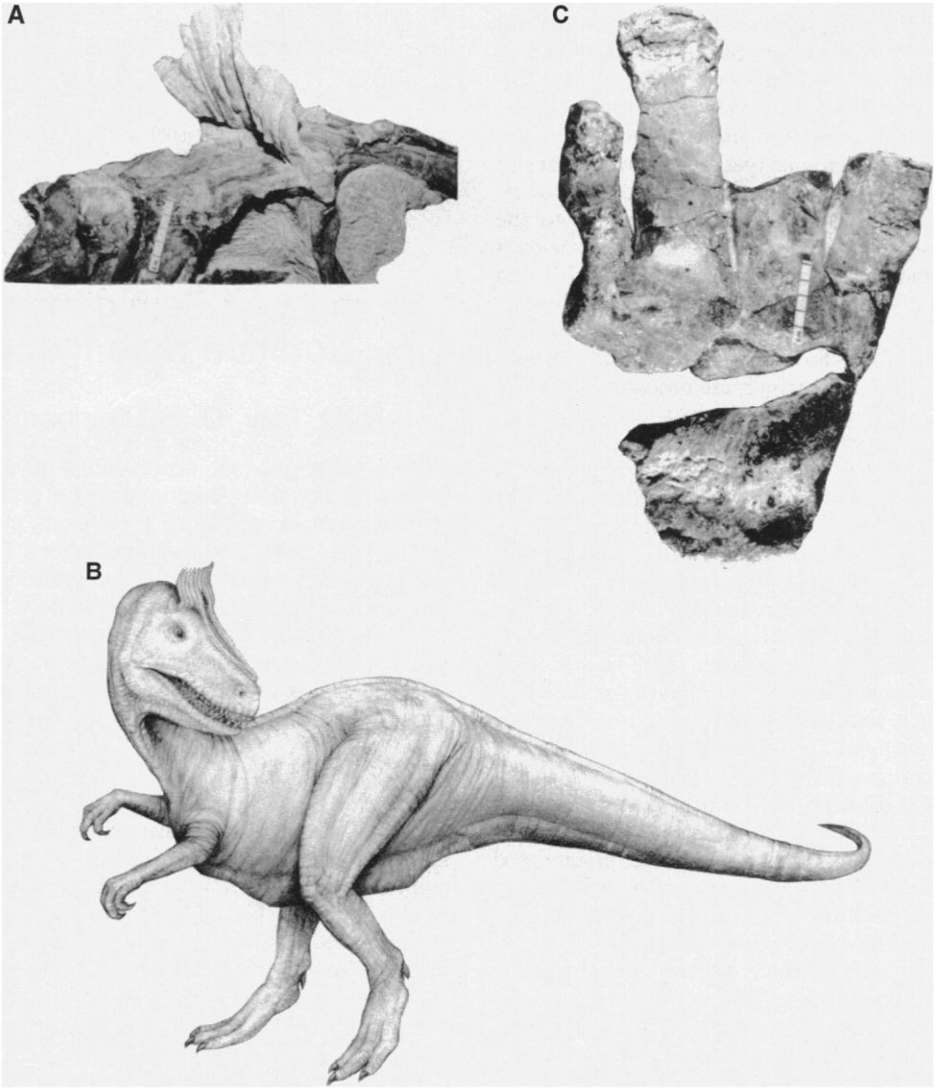

Fig. 3. (**A**) Posterior view of the dorsal surface of *Cryolophosaurus ellioti* skull, showing the furrowed crest. (**B**) Reconstruction of *Cryolophosaurus ellioti*. (**C**) Dorsal view of large prosauropod pes, showing astragalus and metatarsals I through IV.

If the postcranial material does go with the skull, *Cryolophosaurus* exhibits an unusual mixture of characteristics. Because the tetanurans and ceratosaurs had to diverge before the Carnian (7), *Cryolophosaurus* could be a ceratosaur with features convergent with those of some of the large tetanurans, an earlier large tetanuran that has some primitive features, or an early abelisaur. Regardless of the animal's affinities, its highly derived cranial features indicate that by the Early Jurassic theropods inhabiting Gondwana had diverged considerably from the smaller basal theropods of the Triassic.

Specimens occurring with *Cryolophosaurus* that represent other taxa include broken teeth of at least two additional taxa of scavenging theropods found a few centimeters from the gnawed end of the ischium. Two other broken theropod teeth were found near the shaft of a limb bone. A partial maxilla with teeth may represent another theropod or perhaps another individual of *Cryolophosaurus*.

Non-theropod specimens include a partial articulated left pes of a large prosauropod with the astragalus and metatarsals I through IV (Fig. 3C). This specimen shows the distinctive metatarsal articulation pattern found only in prosauropods (*9*). The distal end of a large prosauropod left femur that was recovered may belong to the same individual. Two articulated, plano-concave cervical vertebrae also appear to be prosauropod. A series of long cervical ribs run parallel to these vertebrae along their ventral side. The preserved portion of the longest of these is 50 cm, and the actual length of the ribs must have been even longer, perhaps as much as 60 cm. Even though these vertebrae were associated with the *Cryolophosaurus* skull, the ribs are several times longer than the cervical ribs of theropods, and the vertebrae lack the pleurocoels that are typical of all theropods.

The collection also contains the humerus of a pterosaur (perhaps dimorphodontid) and a single molar from a large tritylodont. This synapsid is equivalent in size to the largest of the tritylodonts, *Bienotheroides* from the Early Jurassic of China (*10*) and *Tritylodon maximus* from the Early Jurassic of Africa. Thus, the Antarctic fauna from the Falla Formation includes at least six taxa, four of which are dinosaurs.

The age of the fauna is constrained by radiometric and biostratigraphic data. Diabase that is comagmatic with the Kirkpatrick Basalt (177 ± 2 million years ago) (*11*) and intrudes into the upper Falla Formation indicates that the fossils are older than early Middle Jurassic. A *Dicroidium* flora occurs approximately 300 m lower in the section, which constrains the age to Late Triassic or younger (*12*). The fact that prosauropods are restricted to the Late Triassic and Early Jurassic on all of the other continents, along with the considerable stratigraphic distance between *Dicroidium* and the dinosaur locality, suggests that this fauna is most likely Early Jurassic in age. However, because the large prosauropod material appears to be similar to *Plateosaurus* from the latest Triassic, the fauna could conceivably be of that age, although *Cryolophosaurus* is more derived than any of the Triassic theropods.

During the Early Jurassic (Pliensbachian), the approximate paleolatitude of this region of Antarctica could have been as high as 65° to 70° south and was at least 60° (*13*). The large prosauropods and theropods and the pterosaur may have migrated away from harsher winter temperatures; smaller animals such as the tritylodont may have hibernated through a cold season. However, the existence of this fauna suggests that conditions were at least seasonally mild at high latitudes during the early part of the Jurassic.

In addition to the animals found in the Falla Formation, there are tree trunks preserved approximately 4 m above the bones in this section, which indicates the presence of forested areas (*14*). Recent general circulation model (GCM) simulations for the Early Jurassic (*13*) suggest that at high latitudes inland areas experienced climate extremes while coastal areas had milder conditions with seasonal average temperatures never dropping below freezing. Because the Beardmore Glacier region of Antarctica appears to have been near the southern coast of Gondwana during the Jurassic, the existence of this fauna at high latitudes during the Early Jurassic is not in conflict with this model.

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Diurnal and Semidiurnal Variations in the Earth's Rotation Rate Induced by Oceanic Tides

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Recent space-geodetic observations have revealed daily and subdaily variations in the Earth's rotation rate. Although spectral analysis suggests that the variations are primarily of tidal origin, comparisons to previous theoretical predictions based on various ocean models have been less than satisfactory. This disagreement is partly caused by deficiencies in physical modeling. Rotation predictions based on a reliable tidal-height model, with corresponding tidal currents inferred from a modified form of Laplace's momentum equations, yield predictions of tidal variations in Universal Time that agree with very long baseline interferometer observations to 2 microseconds. This agreement resolves a major discrepancy between theory and observation and establishes the dominant role of oceanic tides for inducing variation in the Earth's rotation at these frequencies.

The last several years have witnessed a remarkable development in our ability to monitor high-frequency variations in the Earth's rotation. The observations rely on modern methods of space geodesy: very long baseline interferometry (VLBI), satellite laser ranging (SLR), and the Global Positioning System (GPS). All three measure Earth rotation by determining the three-dimensional orientation of networks of ground observatories relative either to extragalactic radio sources (VLBI) or to the orbital planes of artificial satellites (GPS and SLR). With such technology, special observation campaigns have demonstrated evident daily and subdaily variations in Earth rotation (*1*). In terms of rotation rate, the magnitude of the variations is such that a point on the equator leads and then

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