Reports

Triassic Tetrapods from Antarctica: Evidence for Continental Drift

Abstract. *During the austral summer of 1969–1970 bones of Lower Triassic vertebrates were excavated from coarse quartzose sandstones forming stream channel deposits of the Fremouw Formation at Coalsack Bluff, in the Transantarctic Mountains of Antarctica. This is the first assemblage of fossil tetrapods of significant geologic age to be found on the Antarctic Continent. The fossils include labyrinthodont amphibians, presumed thecodont reptiles, and therapsid reptiles, including the definitive genus,* Lystrosaurus. *This genus is typical of the Lower Triassic of southern Africa, and is also found in India and China.* Lystrosaurus *and associated vertebrates found in Antarctica were land-living animals: therefore their presence on the South Polar Continent would seem to indicate the contiguity of Antarctica, Africa, and India in Early Triassic times.*

Antarctica was, until 1967, the one great land mass in which no significantly ancient fossils of land-living vertebrates had been discovered. In December of that year, Peter J. Barrett discovered part of a lower jaw of a labyrinthodont amphibian at Graphite Peak in the central Transantarctic Mountains (*1*). This find was the first evidence of land-living vertebrates in the late Paleozoic-early Mesozoic Beacon rocks—the equivalents of the Karroo System of southern Africa and correlative strata in other Gondwana continents.

No closer identification could be made than that this jawbone fragment was part of a labyrinthodont amphibian. It was felt that additional material would be necessary to indicate with some degree of plausibility a possible paleontological connection between Antarctica and the other Gondwana land masses. This connection, if established, would give strong support to the idea of a former single southern continent, Gondwanaland, and to the theory of continental drift.

The Institute of Polar Studies at the Ohio State University planned a field season for 1969–70 in the central Transantarctic Mountains as part of their continuing program of geological investigations in Antarctica (*2*). Camp was established northwest of the Queen Alexandra Range near Coalsack Bluff (Fig. 1), at that time one of a group of poorly known isolated nunataks. Elliot discovered fossil bones in the lower part of the Fremouw Formation at Coalsack Bluff on 23 November, the first day of reconnaissance fieldwork. On 4 December, during routine excavation of bone specimens at Coalsack Bluff, Jensen found the first bone definitely identifiable as the genus *Lystrosaurus.* Subsequently some 450 specimens were recovered at this site, while a few additional fossils were found at adjacent localities.

In the Beardmore Glacier area of the Transantarctic Mountains (Fig. 1), Beacon rocks rest subhorizontally on a pre-Devonian erosion surface of low relief. Sedimentary rocks of the Beacon sequence are mainly continental, and range in age from Devonian (?) to Triassic-Jurassic (Table 1). They are intruded by diabase sills and overlain by basalt flows (*3*). The stratigraphy of the Beacon rocks was first described by

Table 1. Post-Ordovician stratigraphy of the Beardmore Glacier area.

Age		Formation	Description	Thickness (m)
Jurassic	Ferrar group	Kirkpatrick basalt	Tholeiitic flows, rare sedimentary interbeds with conchostracans, holostean fish. (Correlative Ferrar Dolerite sills with a cumulative thickness of about 1000 m intrude the Beacon sequence)	600+
			DISCONFORMITY	
Triassic		Prebble	Volcanic mudflow deposits, pyroclastic breccia, tuff, and tuffaceous sandstone.	3–460+
		Falla	Volcanic sandstone, shale; tuff dominates upper part; *Dicroidium.*	160–530
		Fremouw	Subarkose, volcanic sandstone, greenish gray mudstone; *Lystrosaurus* near base; logs, coal, *Dicroidium* near top.	~ 650
			DISCONFORMITY	
Permian	Beacon sequence	Buckley	Arkosic and volcanic sandstone, dark-gray shale, coal; *Glossopteris.*	~ 750
		Fairchild	Massive subarkose and arkose.	130–220
		Mackellar	Dark shale and fine-grained sandstone.	60–140
		Pagoda	Tillite, sandstone, and shale.	125–395
			DISCONFORMITY	
Devonian?		Alexandra	Quartz arenite, sandstone.	0–330
			ANGULAR UNCONFORMITY	
Ordovician–Precambrian			Basement metasedimentary complex intruded by granitic rocks.	

Grindley (*4*); more detailed discussions are given by Barrett (*5*) and Lindsay (*6*), and summarized by Barrett *et al.* (*7*).

The labyrinthodont jaw fragment (*1*) and the vertebrate fossils from Coalsack Bluff were found in a cyclic unit that forms the lower part of the Fremouw Formation. This formation, more than 600 m thick, can be divided into a lower sandstone-siltstone unit, a middle unit of grayish-green fine-grained sandstone, siltstone, and mudstone, and an upper unit of sandstone and carbonaceous shale. The prominent sandstone bluffs of the lower unit are distinctive in the field and are believed to crop out for 500 km along the Transantarctic Mountains from just north of the Lennox-King Glacier to the Nilsen Plateau (Fig. 1). Barrett (*5*) assigned the Fremouw Formation a Triassic age on paleobotanical and stratigraphic evidence. The new land-vertebrate discoveries confirm that age assignment.

Near the southern end of the northwest-facing side of Coalsack Bluff (84°14.4′S, 162°9.8′E), the Permian Buckley Formation, consisting of 220 m of thin-bedded, fine-grained sandstone, siltstone, and carbonaceous shale and coal, and containing glossopterid leaves (*8*), is overlain by a cyclic sequence 120 m thick (*A* in Fig. 2) of massive, cross-bedded, coarse sandstone that grades through grayish-green fine-grained sandstone into grayish-green noncarbonaceous siltstone and mudstone that lacks determinable fossils. This cyclic and noncarbonaceous sequence is assigned to the lower part of the Fremouw Formation on the basis of lithology and stratigraphic position. A diabase sill about 60 m thick is intruded near the top of the Buckley Formation, but southward it rises stratigraphically at a low angle; another diabase sill caps the succession. The formational contact, which is about 1 m above a thick Permian coal bed, is about 25 m above the lower sill at the well-exposed ridge toward the northern end of the outcrop (Fig. 2); at the southern end the formational contact lies below the sill. The strata dip at a low angle (about 20°) to the southeast, and, as first recognized by Breed, Coalsack Bluff is structurally a faulted monocline, and is thus more complex and deformed than most Beacon outcrops.

Less than 1 km to the northwest of the outcrops described, a small fault block contains Beacon rocks that dip steeply (about 80°) to the southeast (*B* in Fig. 2). The strata in this fault block are similar to those of the main outcrop. Only the top of the Buckley Formation is present; it is overlain by the lower unit and part of the middle unit of the Fremouw Formation. The Buckley Formation has been displaced and metamorphosed by diabase, and a concordant diabase intrusion is locally present just below the formational contact. A detailed stratigraphic study of Coalsack Bluff is in preparation (*9*).

Fossil bones have been recovered from the basal sandstones of the first three sandstone-siltstone cycles of the Fremouw Formation at the gently dipping upper outcrops (*A* in Fig. 2). However, bones are most abundant in the sandstones of the second cycle as scattered fragments and in thin pebble lenses. The basal sandstones of two of the Fremouw cycles in the fault block also yielded fossil bones, principally from the second cycle where the basal sandstones include several pebbly lenses. In these lenses the bones are associated with pebbles of quartz and pebbles and cobbles, up to 40 cm long, of black mudstone, grayish-green shale, and black phosphatic mudstone (Fig. 3).

An extensive search in the lower part of the Fremouw Formation exposed between Coalsack Bluff and Mount Sirius, 16 km to the northeast (Fig. 1), has yielded only a few vertebrate bones. Sparsely distributed fragmentary bones were found also about 10 km northeast of Mount Marshall (*10*), in erratic blocks south of The Cloudmaker (*11*), and in talus blocks west of Ludeman Glacier (*11*) (Fig. 1). The distribution of bone localities suggests that the basal Triassic sand-

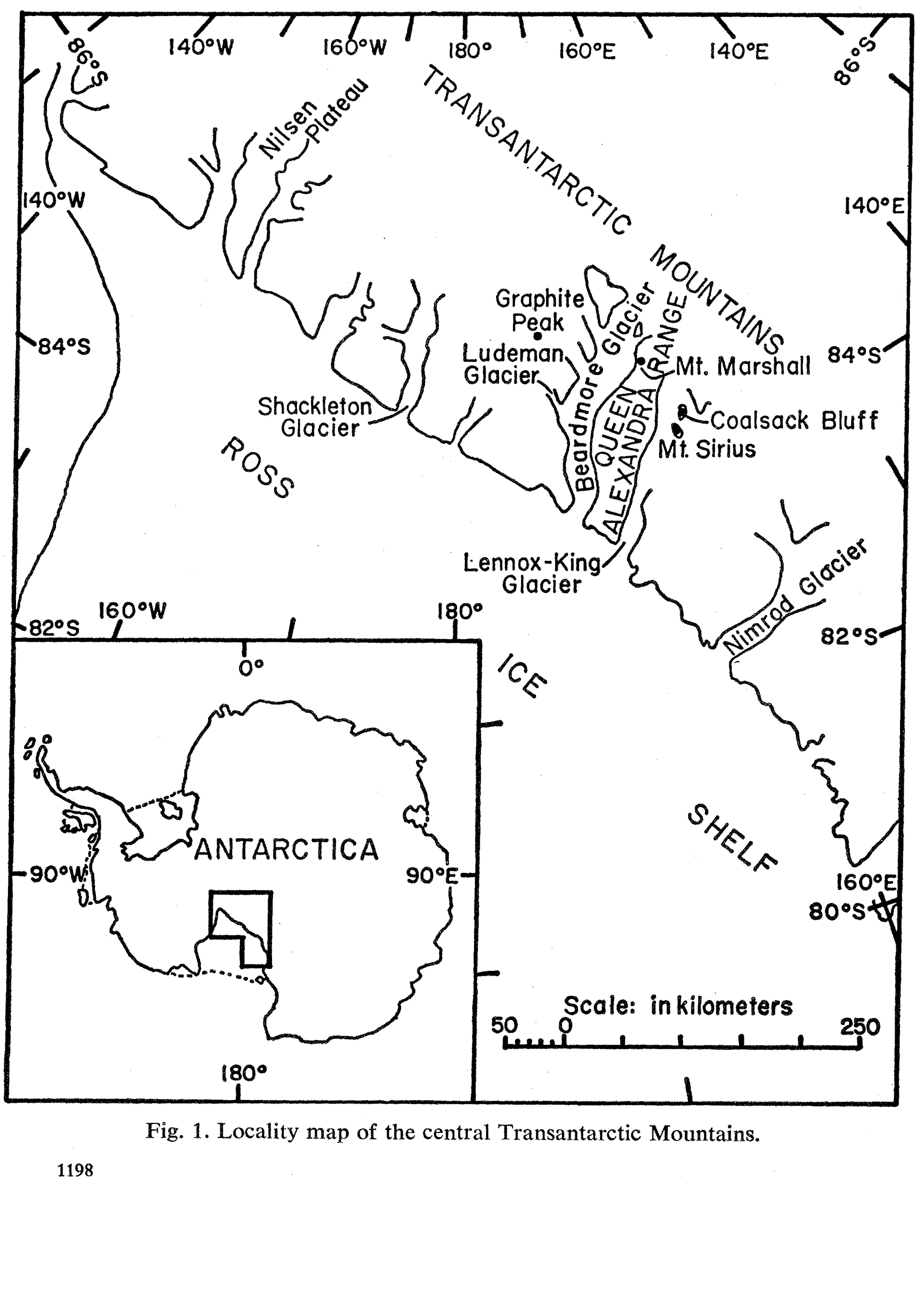
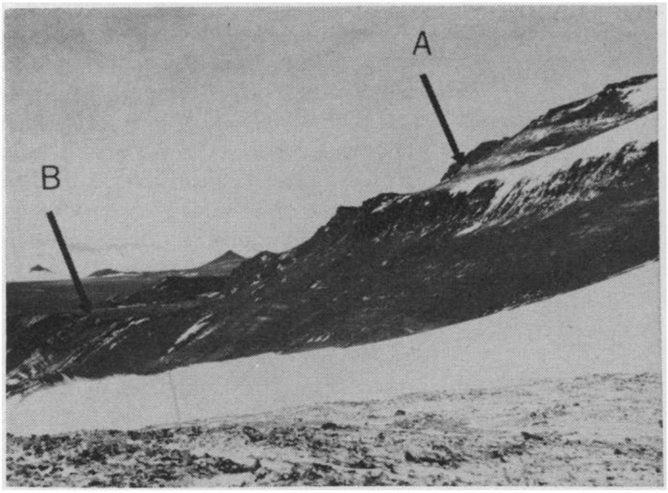


Fig. 1. Locality map of the central Transantarctic Mountains.



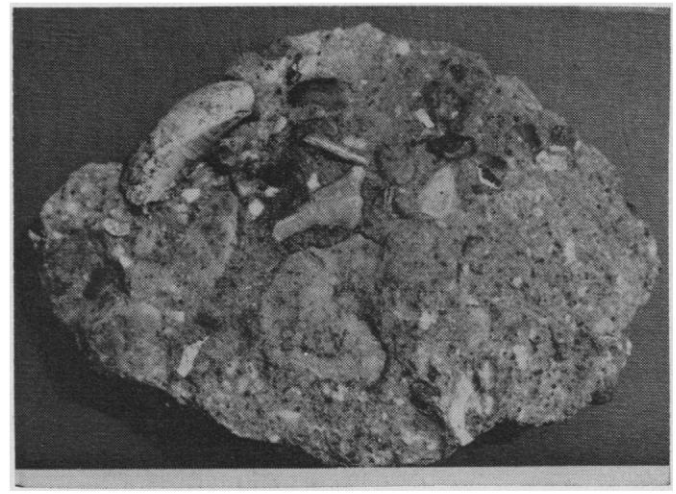
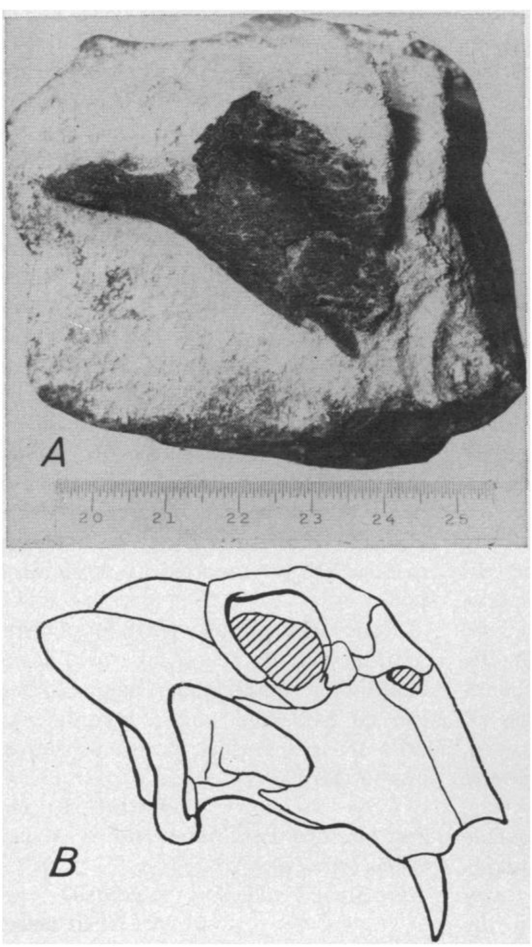


Fig. 2 (left). View from the southwest of the bone-bearing strata of Coalsack Bluff. (*A*) Sandstone bluffs of the lower cyclic unit of the Fremouw Formation which dips there at 20° to the southeast; the arrow points to the basal sandstones of the second cycle. (*B*) Near-vertical strata of the upper part of the Permian Buckley Formation and the overlying Fremouw Formation; the arrow points to the basal sandstones of the second cycle of the Fremouw Formation. Fig. 3 (right). A block of conglomeratic sandstone, including a large tooth and other fossil bones from the Lower Triassic Fremouw Formation, Coalsack Bluff, Antarctica. This shows the characteristic deposition of bone fragments in quartzose sandstone with pale mudstone and white quartz pebbles. This sandstone block is about 17.3 cm long.



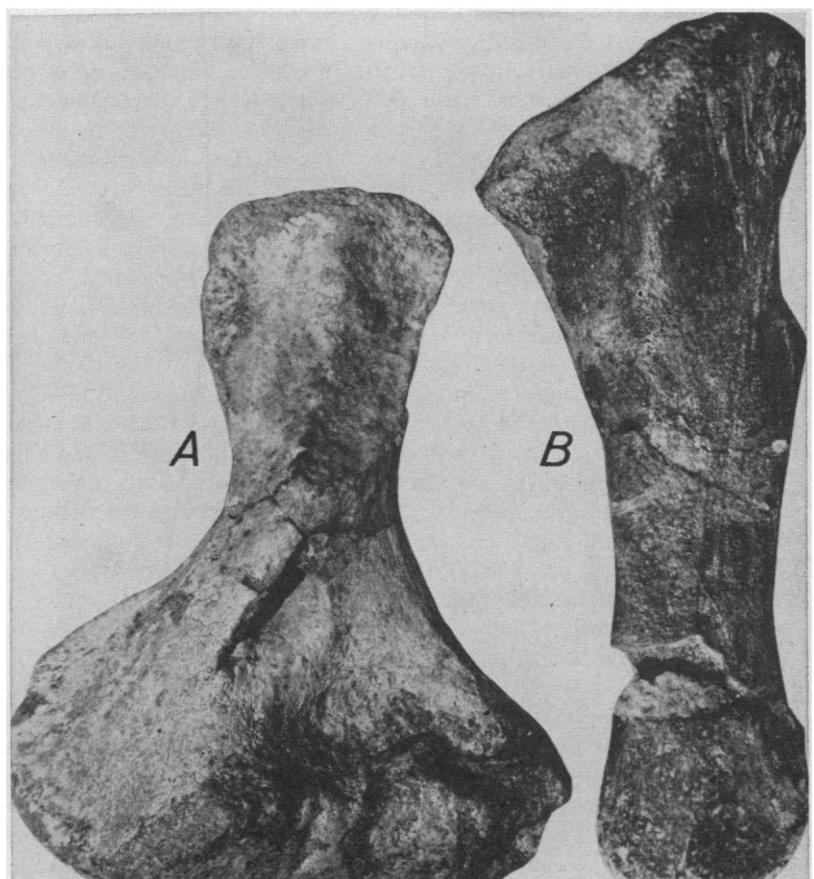


Fig. 4 (left). (A) *Lystrosaurus* sp., right maxilla of a young individual, lateral view, with the point of the tooth showing. Lower Triassic Fremouw Formation, Coalsack Bluff, Antarctica. Approximately natural size. This specimen is No. 9302 of the American Museum of Natural History, New York (A.M.N.H.). (B) Outline drawing of a skull of an adult *Lystrosaurus murrayi*, from the Lower Triassic of South Africa, for comparison. Fig. 5 (right). (A) *Lystrosaurus* sp., A.M.N.H. No. 9304, distal portion of a left humerus, ventral view. (B) *Lystrosaurus* sp., A.M.N.H. No. 9303, left ulna, found in close proximity to the maxilla shown in Fig. 4, external lateral view. Both from the Lower Triassic Fremouw Formation, Coalsack Bluff, Antarctica; both about one-fifth larger than natural size.

stones may be productive over a wide area.

It is not yet possible to present a definitive report on the vertebrate fossils collected at Coalsack Bluff. As already mentioned, the fossils occurred as scattered bones, some complete and some fragmentary, in the cross-bedded sandstones near the base of the Fremouw Formation. The majority of the fossils consist of postcranial elements. Many of them require preparation. Consequently some close and very time-consuming work and study will be required before a reasonably satisfactory analysis of the fauna can be made.

Nevertheless it is already apparent that the fossils from Coalsack Bluff represent a varied assemblage of vertebrates. Preliminary studies show that the assemblage includes possible fish remains, labyrinthodont amphibians, perhaps of capitosaur relationships, and therapsid and thecodont reptiles. The therapsids appear to dominate the collection, and among these it is possible to identify with complete certainty various bones of the genus *Lystrosaurus* (Figs. 4 and 5). Perhaps 40 or 50 specimens among the more than 400 fossils that were collected have been recognized as representing *Lystrosaurus*.

Since *Lystrosaurus* is definitely present in the Fremouw Formation of Antarctica, one would expect the fossils associated with it to show some resemblances to those fossils constituting the classic *Lystrosaurus* fauna of southern Africa. How close such resemblances may be is still a matter to be decided by subsequent studies, but certainly some general resemblances are already evident. Thus there are among the fossils from Coalsack Bluff, and in the *Lystrosaurus* fauna of South Africa, labyrinthodont amphibians, thecodonts, dicynodonts, and other therapsids.

The labyrinthodont amphibians are fairly common among the fossils collected at Coalsack Bluff. Some of the bones indicate amphibians of fairly large size. Others are quite small; they may be small labyrinthodonts, such as are found in the *Lystrosaurus* zone of Africa, or they may be young individuals of the larger labyrinthodonts (*12*).

Although the *Lystrosaurus* fauna of South Africa is characterized by two large thecodont reptiles, it seems that none is present among the antarctic fossils. Rather, such fossils as have been identified tentatively as thecodonts indicate reptiles of comparatively small size. Whether there are eosuchians in Antarctica, as there are in the *Lystrosaurus* fauna, is yet to be determined.

The African *Lystrosaurus* fauna is noteworthy because it contains a considerable variety of cynodont therapsids, including the small and very interesting mammal-like reptile *Thrinaxodon*. It will be interesting to learn just how varied the therapsids from Coalsack Bluff may be, and how many of them may be of cynodont relationships.

Whatever the precise identification of the fossils may be, there can be no doubt as to their extraordinary significance. At Coalsack Bluff there is a reasonably abundant tetrapod "fauna" of Early Triassic age which appears on first examination to be related to the characteristic Lower Triassic *Lystrosaurus* zone fauna of the Upper Beaufort beds in the Karroo sequence of southern Africa. Beyond this the relationships extend to the Panchet Formation of India, also containing *Lystrosaurus* associated with labyrinthodont amphibians and thecodont reptiles, and to the Tunghungshan beds of Sinkiang, China, characterized by the presence of therapsid reptiles, including *Lystrosaurus*, and thecodonts.

The discovery of these Lower Triassic vertebrates in Antarctica not only removes the former apparent faunal contrast between that continent and the other Gondwana land masses but proves beyond any reasonable doubt the existence of an intimate connection between the present South Polar Continent, other Southern Hemisphere land masses, and peninsular India as well. This, in turn, has a direct bearing upon the theory of continental drift.

The presence of such land-living vertebrates in Antarctica can be explained only by two hypotheses, namely (i) that there was some sort of land bridge connecting Antarctica with one or more of the other southern continents, or (ii) that the land mass of Antarctica, specifically East Antarctica, was contiguous to other southern land masses, in particular southern Africa and peninsular India. The only possible land bridge, between South America and the Antarctic Peninsula, is by way of the Scotia Arc; however, on the present distribution of the land masses in the Scotia Arc there is no way that land vertebrates could have migrated from one continent to the other.

Therefore, the presence of Lower Triassic tetrapods in Antarctica similar to those of the Karroo must be explained by assuming that the Antarctic, African, and other land masses were in fact contiguous at the beginning of Mesozoic time. Various other lines of geologic evidence have, in the past decade, pointed to this conclusion. But these other lines of evidence have often involved assumptions (as in the case of paleomagnetic studies) or mitigating considerations (as in the case of fossil plants, the seeds or spores of which conceivably might have been transported from one land mass to another by winds). In the case of terrestrial vertebrates there would seem to be no assumptions or mitigating considerations; these animals could have migrated from one land mass to another only by means of land connections.

Consequently, this discovery of Lower Triassic reptiles and amphibians in Antarctica is crucial evidence in the reconstructon of earth history. The Lower Triassic reptiles of South America, for example (among which *Lystrosaurus*, curiously enough, has not as yet been discovered—perhaps the result of accidents of preservation and of collecting), so similar to those of southern Africa, might have spread from one region to the other by a circuitous route—across Asia, the Bering Strait and the North and South American continents. For Antarctica, however, there is no "long way round." The interchange of Lower Triassic tetrapods between Africa and Antarctica could have been only by a direct ligation of the two land masses. The arrangement of those land masses during Lower Triassic time, which can be postulated from other lines of evidence, would place Antarctica to the east of southern Africa, an arrangement which is supported by these tetrapods.

Hence the present position of Antarctica, with its assemblage of Triassic land-living amphibians and reptiles, can be explained only by continental drift from a former position contiguous to Africa.

DAVID H. ELLIOT
Institute of Polar Studies and
Department of Geology,
Ohio State University, Columbus
EDWIN H. COLBERT
WILLIAM J. BREED
Museum of Northern Arizona, Flagstaff
JAMES A. JENSEN
Brigham Young University, Provo, Utah
JON S. POWELL
University of Arizona, Tucson

References and Notes

1. P. J. Barrett, R. J. Baillie, E. H. Colbert, *Science* **161**, 460 (1968).
2. E.H.C., with a team of vertebrate paleontologists (W.J.B., J.A.J., and J.S.P.), joined the Institute's field party in order to search for vertebrate material.
3. D. H. Elliot, *Proceedings of the Second Columbia River Basalt Symposium* (1970).
4. G. W. Grindley, *N.Z. J. Geol. Geophys.* **6**, 307 (1963).
5. P. J. Barrett, *Inst. of Polar Studies Rep. No. 34* (1969).
6. J. F. Lindsay, *Inst. of Polar Studies Rep. No. 33* (1969).
7. P. J. Barrett, D. H. Elliot, J. D. Gunner, J. F. Lindsay, *Antarctic J. U.S.* **3**, 102 (1968).
8. Paleobotanical evidence reviewed by J. M. Schopf.
9. J. W. Collinson, J. S. Powell, D. H. Elliot, in preparation.
10. W. J. Gealy, personal communication.
11. D. A. Coates, personal communication.
12. In a recent paper Cosgriff infers that the *Lystrosaurus* zone of South Africa lies "just below the Permo-Triassic boundary." Except for this dissent, paleontological and geological opinion is essentially unanimous in regarding the *Lystrosaurus* zone as representing the lowest phase of Triassic history in South Africa. See J. W. Cosgriff, *J. Roy. Soc. W. Australia* **52**, 86 (1969).

13. Supported by grant No. GA-12315 from NSF to the Ohio State University Research Foundation (RF 2882). U.S. Naval Task Force 43 provided logistic support for the field work. Contribution No. 168 of the Institute of Polar Studies, Ohio State University.

8 June 1970 ■

Cluster Analysis and Multidimensional Scaling of Archeological Sites in Northern Chile

Abstract. *Cluster analysis and multidimensional scaling procedures are used to test Chilean site relationships derived by traditional archeological methodologies. The results tend to confirm the intuitive evaluations but clearly indicate the value of computerized statistical analyses for this kind of comparative study.*

Archeological investigations in the Province of Tarapacá, northern Chile, resulted in the recovery of data from a number of preceramic sites. A traditional analysis of the associated artifacts (*1*) suggested the following site groupings: workshop sites (sites 9, 10, 11, and 28); seasonal campsites with some indication of vegetable food processing (sites 24, 25, 26, 29, and 31); campsites suggesting utilization of vegetable food resources and a minimum concern with hunting (sites 1, 2, 3, 4, 8, 12, 14, and 18); small campsites with distinctive knife and projectile point artifacts and some milling-stone elements (sites 2A and 14A); and a single component marked by separable projectile point types and the presence of maize (*2*).

The classification described above was fairly obvious from traditional archeological grouping procedures. However, within-group similarity tended to be based mainly on only one or two preselected diagnostic artifact classes and on such gross differences in site artifact collections as the relative abundance of scrapers and the presence or absence of thinned, bifacially flaked tools. These are valid observations, from which it was possible to make the above suggestions about intersite relationships and site groups. In order, however, to reduce possible bias in such traditional classification techniques, detailed comparative analyses that employ complete site inventories and artifact counts are planned for the future, by which groups of similar sites can hopefully be defined as polythetic units (*3*).

A careful preliminary testing of relationships, using formal statistical techniques, seemed to be in order, however, and the results of the pilot study are presented here. The preliminary analysis, it was hoped, would serve to support or refute the original intuitive, traditional classification of sites; it would provide a basis for planning and evaluating future statistical data manipulations; and it would help to determine the usefulness, generally, of studies based on partial, as opposed to complete, data inventories.

The pilot study was performed as follows. Seventy-four characters were selected for 20 preceramic sites along the lower reaches of the Arroyo Tarapacá, northern Chile. These characters were scored as present or absent for each archeological site. The characters are mainly bead and lithic artifact traits; no floral, faunal, or locational data and no midden characteristics were used, although they will enter into the final analysis planned for the future. The studied lithic artifacts account for more than 95 percent of the total artifact assemblages. In general, the characters are gross physical features of the specimens themselves and do not represent traditional artifact types. By using 74 characters, we hoped that the sample would be sufficiently large to minimize any distortion of site relationships that might follow from including possibly interdependent characters.

A Burroughs 5500 computer was used to compute a matrix of similarity scores and to carry out two different analyses of this matrix. Jaccard's coefficient of association was calculated to depict the similarity between all pairs of the 20 sites. This coefficient computes similarity on the basis of positive matches and on the basis of the characters unique to each site in a pair; characters that are absent from both members of a pair are not included in the calculation. First, the sites were clustered by using the average linkage, unweighted pair-group method (*4*), the

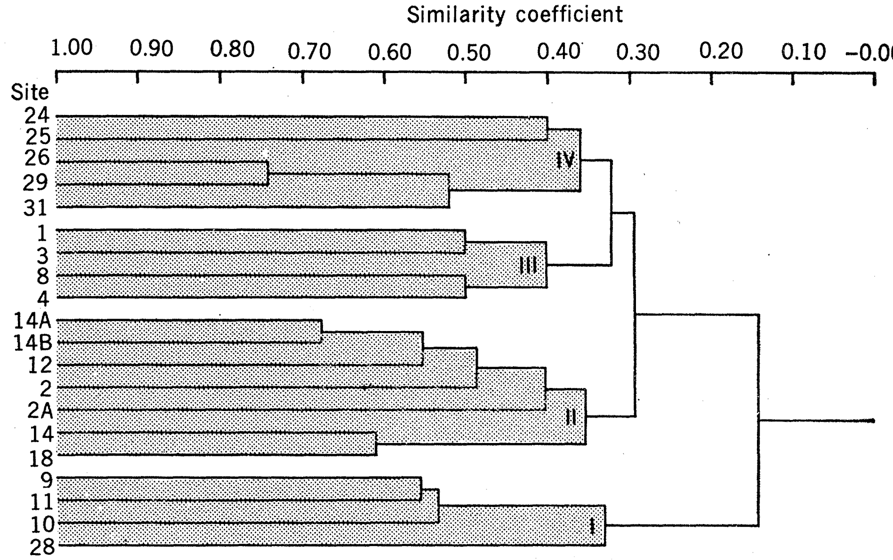


Fig. 1. Dendrogram showing arrangement of sites derived by cluster analysis.