Reports

Paleozoic Sedimentary Rocks in Oaxaca, Mexico

Abstract. *Fossiliferous Cambrian, Ordovician, Mississippian, and Pennsylvanian rocks, never before found in southern Mexico, have been discovered in the Nochixtlán region. Superjacent unfossiliferous sedimentary rocks may be Permian in age. Early Paleozoic and late Paleozoic intervals of marine sedimentation were bounded by intervals of positive tectonism and erosion.*

Practically nothing has been known concerning the Paleozoic history of southern Mexico. Published geologic maps (*1*) of that part of the country indicate occurrence of the following stratigraphic succession: basal metamorphic rocks of Precambrian or questionable Paleozoic age; sedimentary rocks of Mesozoic age; and sedimentary and volcanic rocks of Cenozoic age. Rocks of unquestioned Paleozoic age previously have been reported only in Chiapas (*2*) where only the Permian System is represented by a belt of deformed rocks.

One of us (J.P.-A.) recently discovered fossiliferous sedimentary rocks of Paleozoic age in the Nochixtlán region of Oaxaca. The composite stratigraphic sequence is about 800 m thick and includes rocks of early and late Paleozoic age separated by an unconformity. Several recent analyses (*3*) of pegmatite dikes in the underlying metamorphic complex consistently indicate ages of approximately 1 billion years. Therefore, the metamorphic complex of southern Mexico is Precambrian rather than Paleozoic in age. Furthermore, on the basis of evidence presented here, it now can be determined that erosion of Precambrian rocks in the Nochixtlán region was followed during the Paleozoic by at least two long intervals of marine sedimentation and at least one intermediate interval of erosion.

Sedimentary rocks of Paleozoic age crop out in two areas in the Nochixtlán region (Fig. 1). One small area, about 200 by 500 m, is approximately 9 km south-southeast of Nochixtlán and is crossed by an unimproved road that connects the village of Tiñu with Federal Highway 190 (International Highway). Only lower Paleozoic rocks are present at that locality, and they occur in a graben-type fault block in Precambrian gneiss. Within the fault block, lower Paleozoic rocks lie nonconformably on Precambrian gneiss and are overlain disconformably by lower or middle Tertiary sandstone and conglomerate.

In the larger area rocks of both early and late Paleozoic age crop out for about 7 km in a north-south band along the west wall of the Barranca de Santiago Ixtaltepec. The southern tip of the outcrop is about 14 km east-northeast of Nochixtlán. Paleozoic rocks lie nonconformably on Precambrian gneiss and are overlain disconformably by Lower Cretaceous conglomerate. A complete stratigraphic section has been measured just north of Santiago Ixtaltepec near the north end of the outcrop (Fig. 2), and a lower Paleozoic section has been measured in Arroyo Totoyac near the south end of the outcrop.

In the Nochixtlán region the oldest known interval of Paleozoic sedimentation is represented by an unnamed formation of limestone, shale, and sandstone. Mostly as a result of post-depositional erosion, thickness of the unit ranges from 23 to about 200 m. A lower member averages about 15 m in thickness and characteristically is composed of interbedded thin- to medium-bedded dark fossiliferous limestone and thin to medium beds of light, generally unfossiliferous shale.

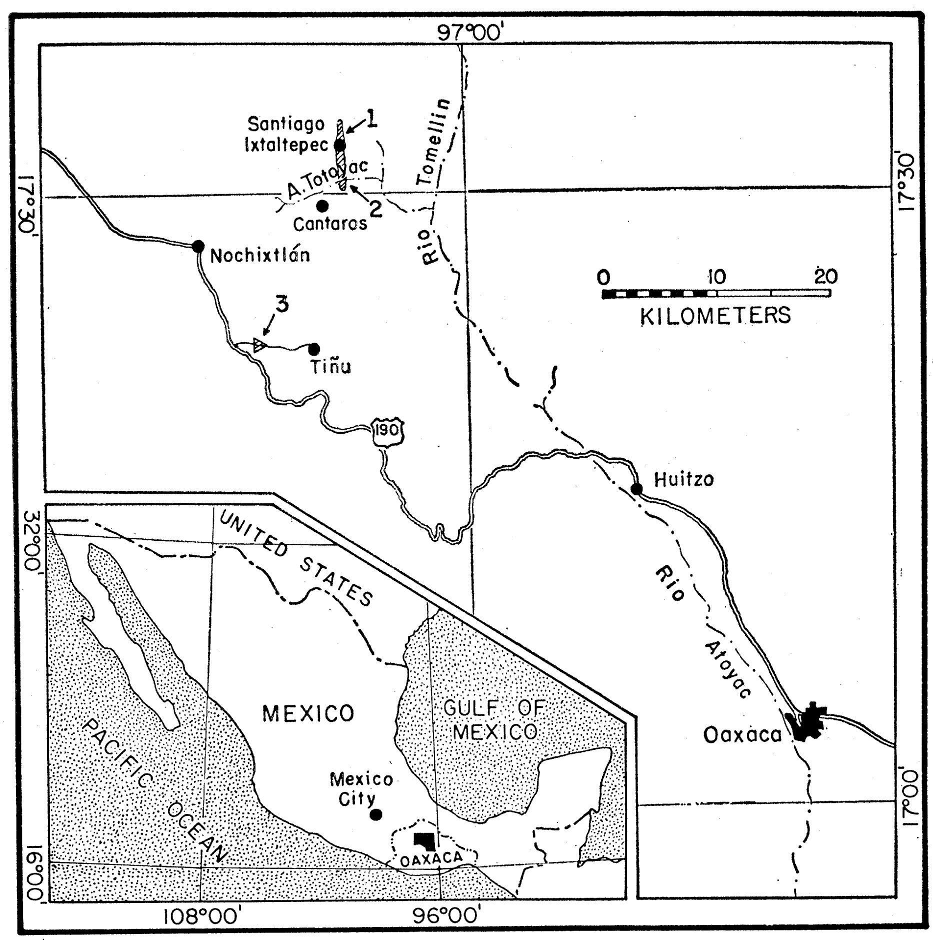

Fig. 1. Index maps of Mexico and the Nochixtlán region of the State of Oaxaca. Outcrops of Paleozoic rocks are cross-hatched. Measured stratigraphic sections (numbers and arrows) are: (1) Santiago Ixtaltepec, (2) Arroyo Totoyac, and (3) Tiñu.

An upper member is 12 to 22 m thick in the Barranca de Santiago Ixtaltepec and mostly consists of noncalcareous fissile shale. The same member is about 180 m thick near Tiñu where it includes shale, siltstone, sandstone, and fine conglomerate.

An abundant fauna in the basal Paleozoic formation includes trilobites, brachiopods, echinoderms, mollusks, conodonts, sponges, ostracodes, and other organisms that cannot be readily identified. Fossils that have been identified are listed in Table 1. Of the trilobites, *Koldinioidia, Richardsonella*, and *Saukia* are found in the lower part of the basal member, and previously have been reported only from the Trempealeauan stage in the United States and its equivalents in eastern Asia. All of the other trilobites occur in the Tremadocian stage of Argentina, Newfoundland, Britain, and Scandinavia. An upward succession of conodont species in the basal member correlates with a similar succession of species in the Trempealeauan and Canadian stages of the western United States (*4*). Other significant genera are *Rioceras*, a cephalopod from the lower part of the upper member and previously known only from the middle and upper Canadian (*5*), and *Macrocystella*, an echinoderm previously reported only from the Tremadocian of Europe.

Table 1. Fossils from the basil Paleozoic formation of the Nochixtlán region. Trilobites and the echinoderms were identified by R. A. Robison, conodonts by D. L. Clark, cephalopods by R. H. Flower, and gastropods by E. L. Yochelson. Several genera of brachiopods are present but have not been identified.

Trilobites

Asaphellus n. spp.
Angelina hyeronimi (Kayser)
Angelina n. sp.
Bienvillia n. sp.
Geragnostus n. spp.
Koldinioidia n. sp.
Leptoplastides marianus (Hoek)
Onychopyge n. sp.
Parabolina cf. *P. argentina* (Kayser)
Parabolinella argentinensis Kobayashi
Parabolinella n. spp.
Peltocare norvegicum (Moberg and Möller)
Pharostomina n. sp.
Pseudagnostus sp.
Richardsonella n. sp.
Saukia n. sp.
Shumardia n. spp.
Triarthrus tetragonalis (Harrington)
Five new tribolite genera

Conodonts

Cordylodus angulatus Pander
Cordylodus oklahomensis Müller
Cordylodus proavus Müller
Cyrtoniodus sp.
Hertzina sp.
Oneotodus simplex Furnish
Oneotodus tenuis Müller
New genera? cf. *Gothodus*

Cephalopods

Rioceras n. spp.

Gastropods

Eobucania n. sp.
Undetermined pelagiellids

Echinoderms

Macrocystella sp.

An analysis of the fauna documents the correlation of at least the upper Trempealeauan and the lower and middle Canadian stages of North America with the Tremadocian stage of Europe. Systemic age assignment of the fauna is complicated, however, because many British geologists assign the Tremadocian to the Cambrian, whereas many other geologists assign it to the Ordovician. We follow the generally accepted North American usage and term the Trempealeauan part of the basal formation Cambrian and the Canadian part Ordovician. The Trempealeauan-Canadian boundary occurs near the top of the basal carbonate member, but does not coincide with a distinct interruption in faunal continuity.

Rocks of late Paleozoic age are known only in the Barranca de Santiago Ixtaltepec where they rest with angular unconformity on rocks of early Paleozoic age. A section measured at the Santiago Ixtaltepec locality consists of approximately 625 m of mostly shale, sandstone, and limestone. The stratigraphic distribution of rock types is graphically shown by Fig. 2.

The basal 25 m of the upper Paleozoic section is mostly limestone, but the lower 4 m is conglomeratic with quartz pebbles up to 2 cm in diameter, and the upper beds grade into calcareous sandstone. Fossils from the upper part of this unit include the following brachiopods identified by G. A. Cooper: *Acanthospirifer* cf. *A. keokuk* (Hall) or *A. pellaensis* (Weller), *Kitakamithyris* sp., *Rotaia* sp., and *Tylothyris* sp. According to Cooper (*6*), the presence of *Kitakamithyris* and *Rotaia* indicates a Mississippian age, probably about Keokuk equivalence.

The interval from the top of the basal limestone of Mississippian age to the top of the highest Paleozoic limestone bed is about 275 m thick and consists mostly of shale and sandstone with a few intercalated beds of limestone. Brachiopods from shaly beds approximately 25 m below the top of

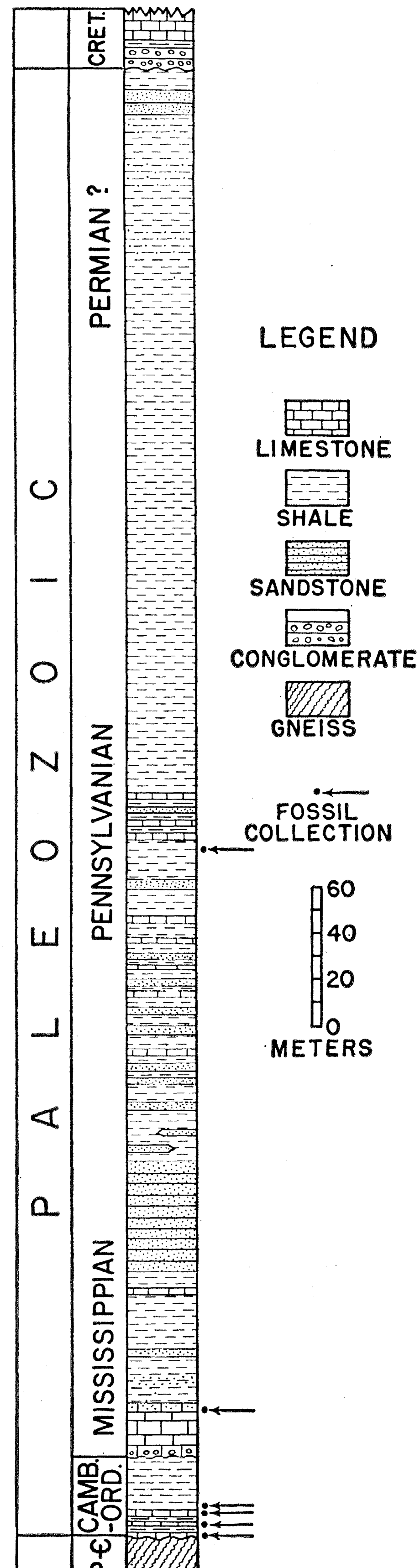

Fig. 2. Generalized stratigraphic section of Paleozoic rocks near Santiago Ixtaltepec (see Fig. 1, locality 1).

the interval were identified by G. A. Cooper (*6*), who concluded that the large productoids and spirifers suggest an Early to Middle Pennsylvanian age. The brachiopods include: *Anthracospirifer occiduus* (Sadlick), *Crurithyris* sp., *Inflatia*-like productoids, *Neochonetes* sp., *Reticulatia* sp., and *Rynchopora* sp.

Approximately 325 m of unfossiliferous shale, siltstone, and fine-grained sandstone occur between the highest Paleozoic limestone and an unconformity that is overlain by Lower Cretaceous conglomerate. Shale in the lower 80 m of the interval is variegated, whereas rocks in the upper 245 m commonly are light to medium greenish brown. Because of lack of evidence to indicate a significant interruption of depositional processes, and because of the thickness of strata, it seems likely that at least the upper part of the sequence may be Late Pennsylvanian or Permian in age. At this time, lack of paleontological control prevents the precise location of the Mississippian-Pennsylvanian and possible Pennsylvanian-Permian boundaries in the upper Paleozoic sequence.

Structural relationships between rock units in the Nochixtlán region indicate that block faulting, intrusion, and erosion occurred between the end of the final cycle of Paleozoic sedimentation and the resumption of marine sedimentation in the Early Cretaceous. Remnants of Paleozoic rocks are preserved in greatly displaced fault blocks formed during that interval. Several dikes and sills intrude Paleozoic rocks in the Barranca de Santiago Ixtaltepec and indicate intrusive activity that probably was concomitant with the block faulting.

In conclusion, the Paleozoic and related rock record now known in the Nochixtlán region of Oaxaca indicates the following sequence of historical events:

1) Metamorphism and intrusion of sedimentary rocks of Precambrian age approximately 1 billion years ago.

2) Uplift and deep erosion of Precambrian rocks.

3) Subsidence and accumulation of at least 200 m of marine sediment during the Late Cambrian and Early Ordovician (Tremadocian).

4) Uplift, tilting, and erosion between Early Ordovician and Early Mississippian time. Erosion, at least locally, appears to have removed as much as 180 m of Tremadocian strata.

5) Subsidence and accumulation of at least 625 m of mostly, if not all, marine sediment during the Mississippian, Pennsylvanian, and possibly Permian.

6) Block faulting, intrusion, and erosion between the Pennsylvanian and Early Cretaceous.

7) Subsidence and accumulations of marine sediment commencing at least by Early Cretaceous time.

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Fossiliferous Bauxite in Glacial Drift, Martha's Vineyard, Massachusetts

Abstract. *Pebbles of pisolitic bauxite occur in Pleistocene drift on Martha's Vineyard. The bauxite contains plant remains and relict quartz and was derived from plant-bearing sediments, probably from the preglacial coastal plain of New England. The preservation of plant tissue suggests that bauxitization took place beneath, rather than above, the water table, as generally believed. This occurrence of bauxite is the northernmost known in eastern North America and suggests the possible existence of undiscovered deposits in the northern coastal plain.*

Four pebbles of pisolitic bauxite have been found in Pleistocene drift on Martha's Vineyard, an island 6.4 km south of Woods Hole, at the southwestern tip of Cape Cod (Fig. 1). The pebbles undoubtedly came from a bauxite deposit that was part of the preglacial regolith of southern New England and were transported by glacial ice from their place of origin to their present position. All four specimens came from the same drift, tentatively considered to be Kansan in age (*1*). Three of the specimens were found in Gay Head, the sea cliff at the western tip of the island. A fourth pebble was discovered in till in the interior of the island.

The pebbles vary from one that is hard, with a light-gray matrix (Fig. 2), to one that is somewhat friable and iron-stained. Megascopically they closely resemble "birdseye" ore from Arkansas (*2*). The pisolites are ellipsoidal to spherical, attaining a maximum diameter of 20 mm. They are of a wide variety of colors within the range black, brown, red, and white. Most have a laminated outer shell that may be darker or lighter than the core. Some pisolites are compounded of several cores wrapped together into ellipsoidal, or bean-shaped, masses by the outer shell. In thin-section, some of the black to deep-red pisolites are opaque and consist dominantly of iron oxide, presumably hematite. Others consist of aggregates of minute gibbsite spherulites or large book-shaped crystals of gibbsite in a fine-grained iron oxide matrix. All pisolites are broken by radial shrinkage cracks that are filled with a clear slightly yellowish amorphous material, possibly allophane.

The matrix of the bauxite is mainly cryptocrystalline gibbsite organized into oölitic shapes and peppered with mi-

Table 1. Chemical analysis of ferruginous bauxite cobble, Gay Head, Massachusetts.

Oxide	Weight (%)	Oxide	Weight (%)
SiO_2	21.0	H_2O^-	2.9
Al_2O_3	41.2	H_2O^+	12.9
Fe_2O_3	13.7	TiO_2	1.5
FeO	1.9	P_2O_5	0.83
MgO	0.03	MnO	.01
CaO	.02	CO_2	$<$.05
Na_2O	.07	Total S *	.15
K_2O	.05	Organic matter †	1.5

*As SO_3. † By ignition loss.