Predictive Stratigraphic Analysis—Concept and Application

Edited by C. Blaine Cecil and N. Terence Edgar

U.S. GEOLOGICAL SURVEY BULLETIN 2110

A collection of extended abstracts of papers presented at two workshops on the title subject

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For sale by U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

Published in the Eastern Region, Reston, Va.
Manuscript approved for publication August 4, 1994.

Library of Congress Cataloging in Publication Data

Predictive stratigraphic analysis : concept and application / edited by C. Blaine Cecil and N. Terence Edgar.
p. cm. — (U.S. Geological Survey bulletin ; 2110)
Extended abstracts of papers from two workshops held April 22–24 and June 24–26, 1991.
Includes bibliographical references.
Supt. of Docs. no. : I 19.3:2110
1. Geology, Stratigraphic—Congresses. I. Cecil, C.B. II. Edgar, N. Terence. III. Series.
QE75.B9 no. 2110
[QE640]
557.3 s—dc20
[551.7] 94-24707
CIP

PREFACE

Two workshops were held to develop a Predictive Stratigraphic Analysis (PSA) research initiative. The workshop cooperators were the U.S. Geological Survey, the West Virginia Geological Survey, Morgantown, West Virginia (April 22–24, 1991), and the Kansas Geological Survey, Lawrence, Kansas (June 24–26, 1991). This volume is a compilation of extended abstracts of each of the scheduled presentations.

Larry Woodfork, State Geologist and Director of the West Virginia Geological and Economic Survey, and Lee Gerhard, State Geologist and Director of the Kansas Geological Survey, set the tone of each meeting by discussing the potential benefit of the program to the scientific community, Federal and State agencies, and the public. The need was stressed for a continental-scale program through multidisciplinary research in order to evaluate and resolve eustatic and tectonic controls on transgressive-regressive cycles and to determine paleoclimatic latitudinal gradients, orography, and paleoclimatic cycles as controls on sediment flux including organic productivity. The well-known cyclothems of the Pennsylvanian System of North America were cited as one of the most ideal records with which to evaluate global change and the effects of climate, eustasy, and tectonics on the origin of sedimentary rocks in foreland basin (Appalachian), epeiric sea (midcontinent), deep sea (Ouachita), epicontinental shelf (western United States), and lacustrine basin (Appalachian) environments. The results of PSA research on the mid-Pennsylvanian rocks of North America will have application on a global scale and for older and younger intervals of time.

C. Blaine Cecil
N. Terence Edgar
Editors

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Evidence of Climate Change in the Lower and Middle Carboniferous Shallow-Water Carbonate Rocks of Arctic Alaska, New Mexico, and Arizona

Augustus K. Armstrong and Bernard L. Mamet

An extensive shallow-water carbonate shelf developed in arctic Alaska during the Carboniferous. According to paleomagnetic data, the region was then 28 to 43° north of the equator (C.R. Scotese, University of Texas at Arlington, written commun., June 1991). Twenty-two measured sections (700–3,000 ft thick) from the Lisburne Group (Mississippian to Permian) in the Brooks Range of arctic Alaska and three from the Yukon Territory, Canada (figs. 1, 2) contain microfossil assemblages assigned to zones of late Tournaisian (Osagean) through early Westphalian (Atokan) age (Armstrong and Mamet, 1977).

Representatives of both Eurasiatic and American cratonic microfaunas permit correlation with the original Carboniferous type sections in Western Europe as well as with the standard Mississippian and Pennsylvanian sequences in the midcontinent region of North America. The carbonate petrology of the Lisburne Group is composed of predominantly bryozoan-pelmatozoan wackestones and packstones and lesser amounts of lime mudstones, diagenetic dolomites, and pelmatozoan and ooid grainstones. The Lisburne Group was deposited on a slowly subsiding shallow-water carbonate shelf. The stratigraphic succession is commonly cyclic, alternating from open marine to subtidal. A carbonate-platform depositional model for these carbonate rocks, illustrating the spatial distribution of the organic remains and microfacies to water depth and salinity, shows that the corals and foraminifers are common near the shoaling-water facies, rare in the basinal and subtidal facies, and absent in the intertidal or supratidal facies. The pelmatozoan-bryozoan wackestone packstone facies, an open-marine facies, contains a sparse foraminifer fauna.

The microfauna belong to the Alaska and Taimyr subrealms, and a temperate warm environment is indicated by low abundance, low species diversity, high genus to species ratio, high rate of cosmopolitanism, and incomplete phylogenies. Some 61 genera and 130 species of Carboniferous foraminifers and algae are recognized. Algaé are not diverse, although Palaeosiphonocladales are prolific at some levels (for example, *Donezella* bands in zone 21, Mamet and de Batz, 1989). Dasycladales, considered good indicators of tropical-equatorial waters are quite scarce (base of the Alapah Limestone and top of the Wahoo Limestone).

Lithostrotionoid corals can be identified to the species level, in part provincial to northern Canada and Alaska. The stratigraphic range of individual coral species and faunal assemblages extends throughout two to four microfossil zones. Rugose corals are rare in the Wachsmuth Limestone, zones 8 to 9 (Tournaisian). Colonial rugose corals are abundant in zones 11 through 15 (Visean) in the Alapah Limestone and disappear near the base of zone 16i (Visean). They reappear in significant numbers in the shoaling ooid sands of zone 20 to 21 (Morrowan and Atokan), Middle Carboniferous, Wahoo Limestone (Armstrong, 1972). The Tournaisian carbonate rocks contain poor faunas of foraminifers, and the sedimentary deposits are dominated by echinoderm-bryozoan fragments. Oolites are absent in these rocks. The upper Visean-Namurian rocks have red beds and evaporites that are now preserved as collapse breccias (zones 16i to 19). The microfauna and microflora are poorly diversified.

These shallow-subtidal fossils and microfacies are interpreted as representing cooler and deeper water (fig. 3) in the Tournaisian, whereas the abundance of foraminifers and robust colonial corals and patch reefs indicate warmer waters in zones 10 into 15 (Visean). A warmer and wet climate in the early Visean is supported by thin coal beds in the terrigenous Kekiktuk Conglomerate in the subsurface of the Prudhoe Bay region and in outcrops in the eastern Brooks Range (Armstrong and Mamet, 1975; Bloch and others, 1990).

In extreme northwestern Alaska on the sea cliffs south of Cape Lisburne, a thick sequence of lower Visean, terrigenous clastics rocks has 1- to 4-ft-thick coal beds (Collier, 1906). The Cape Lisburne exposures contain numerous silicified upright-standing tree stumps and trunks that extend into the overlying argillaceous-carbonaceous siltstones and sandstones. These Visean coal seams are part of the terrigenous sequence beneath the diachronous marine carbonate transgression.

The abrupt disappearance of the colonial rugose corals early in zone 16i (Visean) represents a cooling and local increase of aridity that remained through zone 18 (Namurian). The Middle Carboniferous (zones 20 and 21, upper Namurian and lower Westphalian) rocks of the Wahoo Limestone, which contains calcareous algae flora and rugose corals, reflect sedimentation in warmer water and repeated, thin, shoaling-upward cycles from oolitic sands to intertidal dolomites. This distinctive sequence of cyclic facies of shoaling-upward sequences of beds extends over a wide area in the subsurface of the North Slope from the Sadlerochit Mountains to the Prudhoe Bay oil fields.

According to paleomagnetic reconstructions, New Mexico (figs. 4, 5) was some 8° south of the paleomagnetic equator at the beginning of the Carboniferous. By Westphalian (Middle Carboniferous) time, the paleomagnetic equator crossed New Mexico from the northeast to the southwest (Habicht, 1979; C.R. Scotese, written commun., June 1991). Some 94 genera and 113 species of Early Carboniferous foraminifers and algae are recognized in these (100- to 1,400-ft-thick) cratonic carbonate rocks. This is considerably less than the Tethyan fauna and flora in which well

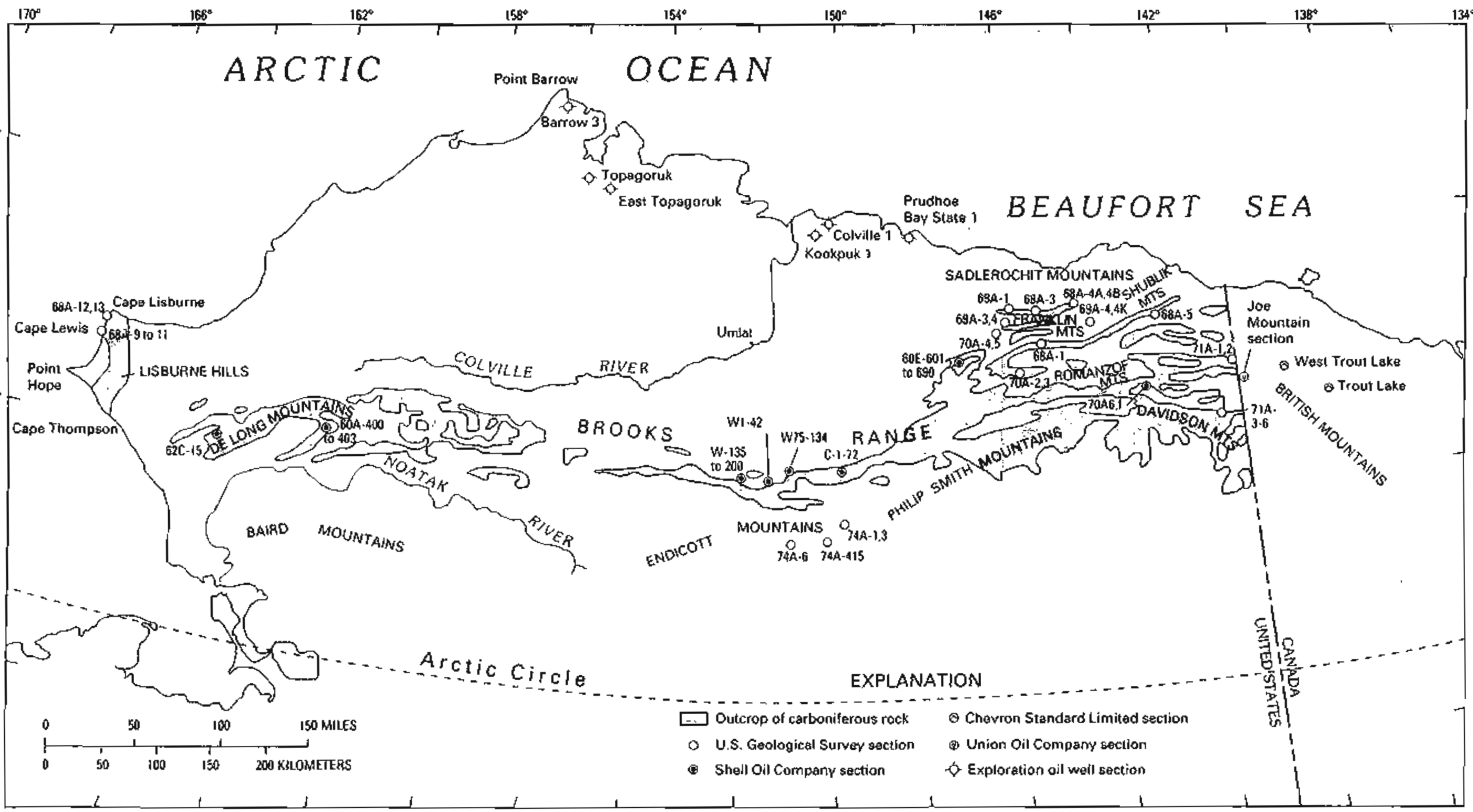

Figure 1. Index map of arctic Alaska and the Brooks Range illustrating Carboniferous outcrops and location of the measured sections described in this report (modified from Armstrong and Mamet, 1977).

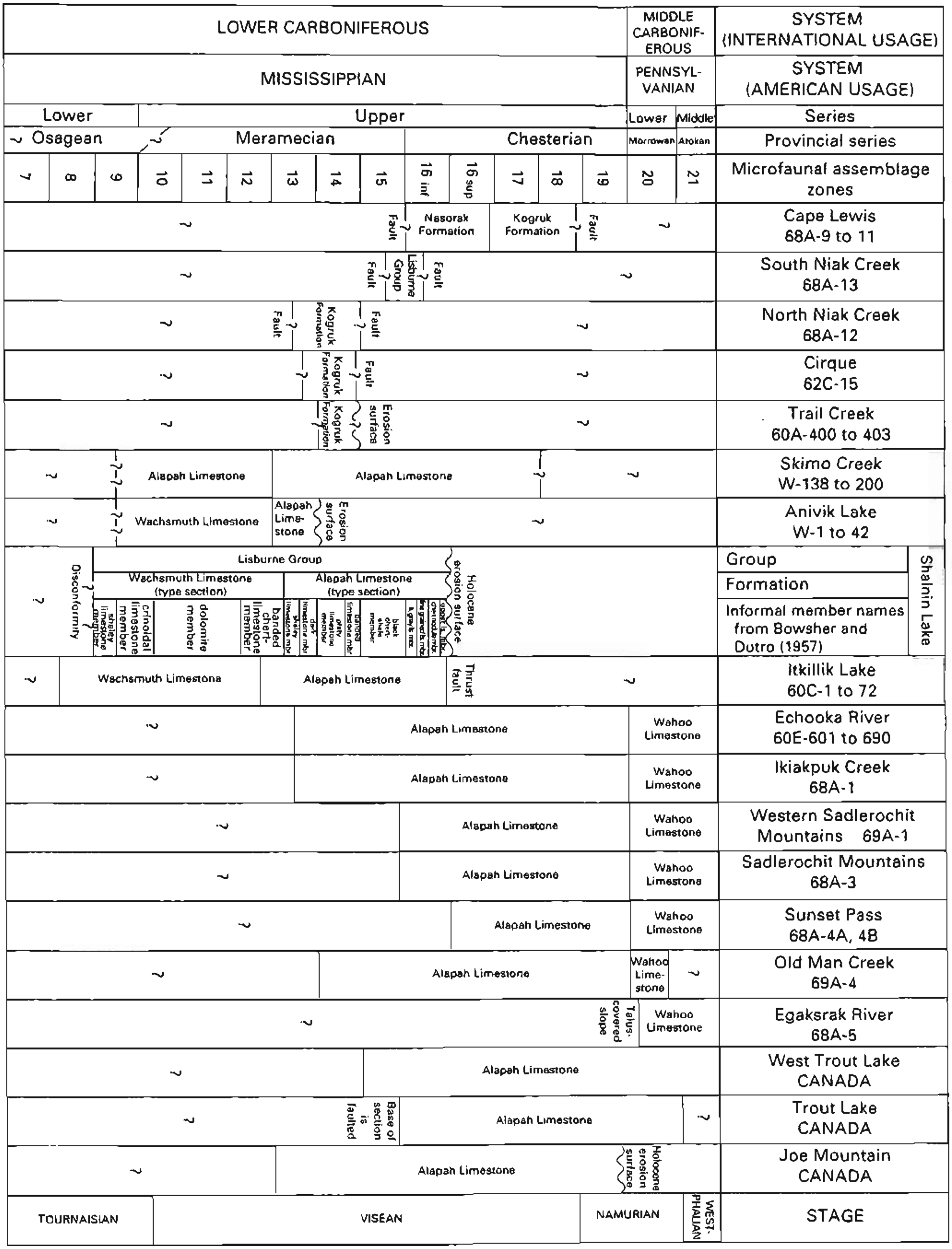

Figure 2. Regional correlation diagram for the Lisburne Group (from Armstrong and Mamet, 1977).

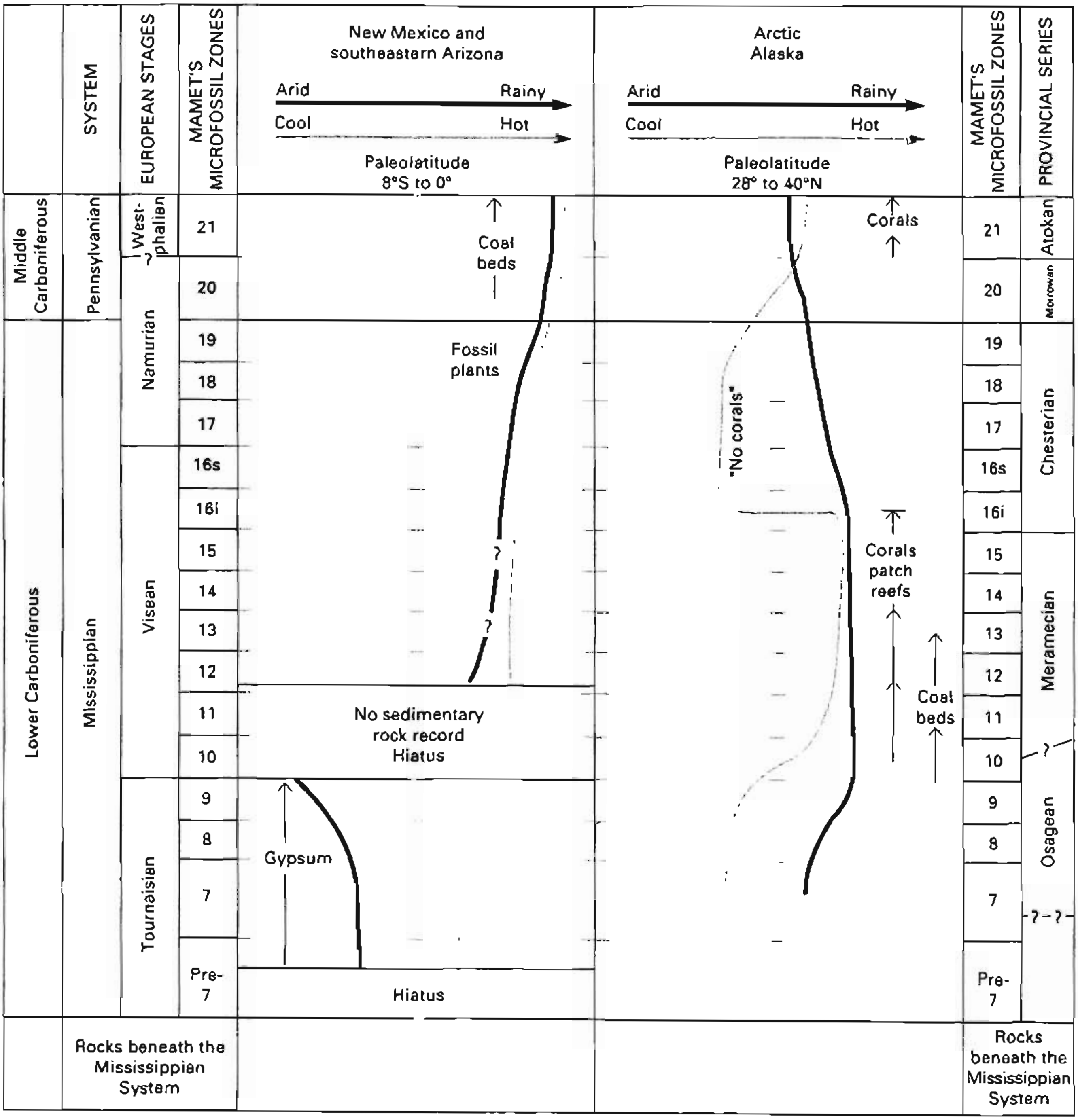

Figure 3. Model for the relative rainfall and temperature for the Early and part of the Middle Carboniferous for arctic Alaska and for New Mexico and southeastern Arizona. The model is subjective and is based on field and petrographic studies and the analysis of carbonate rock microfacies, including mineralogical composition, fossil content, and distribution.

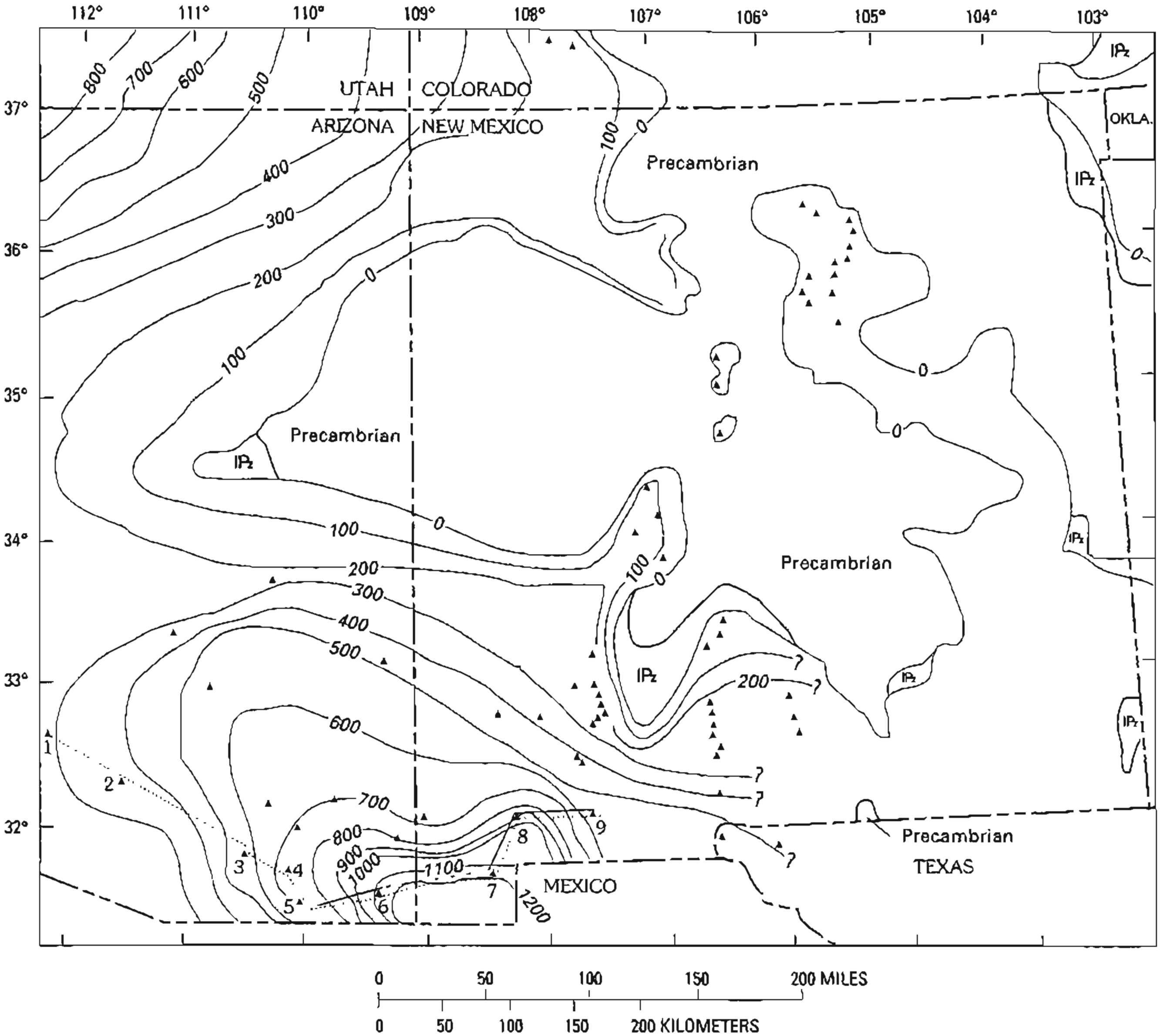

Figure 4. Index map of New Mexico and eastern Arizona showing location of outcrop sections used in this report (triangles) and isopachs (interval=100 ft) of the Lower Carboniferous (Mississippian) (from Armstrong and Mamet, 1988).

over 200 genera are recognized. Dasycladales are more abundant than those in arctic Alaska (*Alberaporella, Perkiskopora, Columbiapora*), indicating higher temperature, but again they are considerably less diverse than those in the Tethys. Thus equatorial surface temperatures should be excluded.

Rugose corals are abundant only at a specific level in the pre-7 zone and are associated with oolitic grainstones. Lithostrotionoid corals are rare in Visean carbonate rocks. During the Tournaisian and Visean, this peneplained part of the craton was fairly stable, and the region was alternately slightly emergent or submergent as a result of eustasy and (or) mild tectonism. Initial Lower Carboniferous deposits of southwestern New Mexico and southeastern Arizona (Tournaisian, pre-7 zone) are subtidal to intertidal carbonate rocks, which rest unconformably on rocks of Late Devonian age.

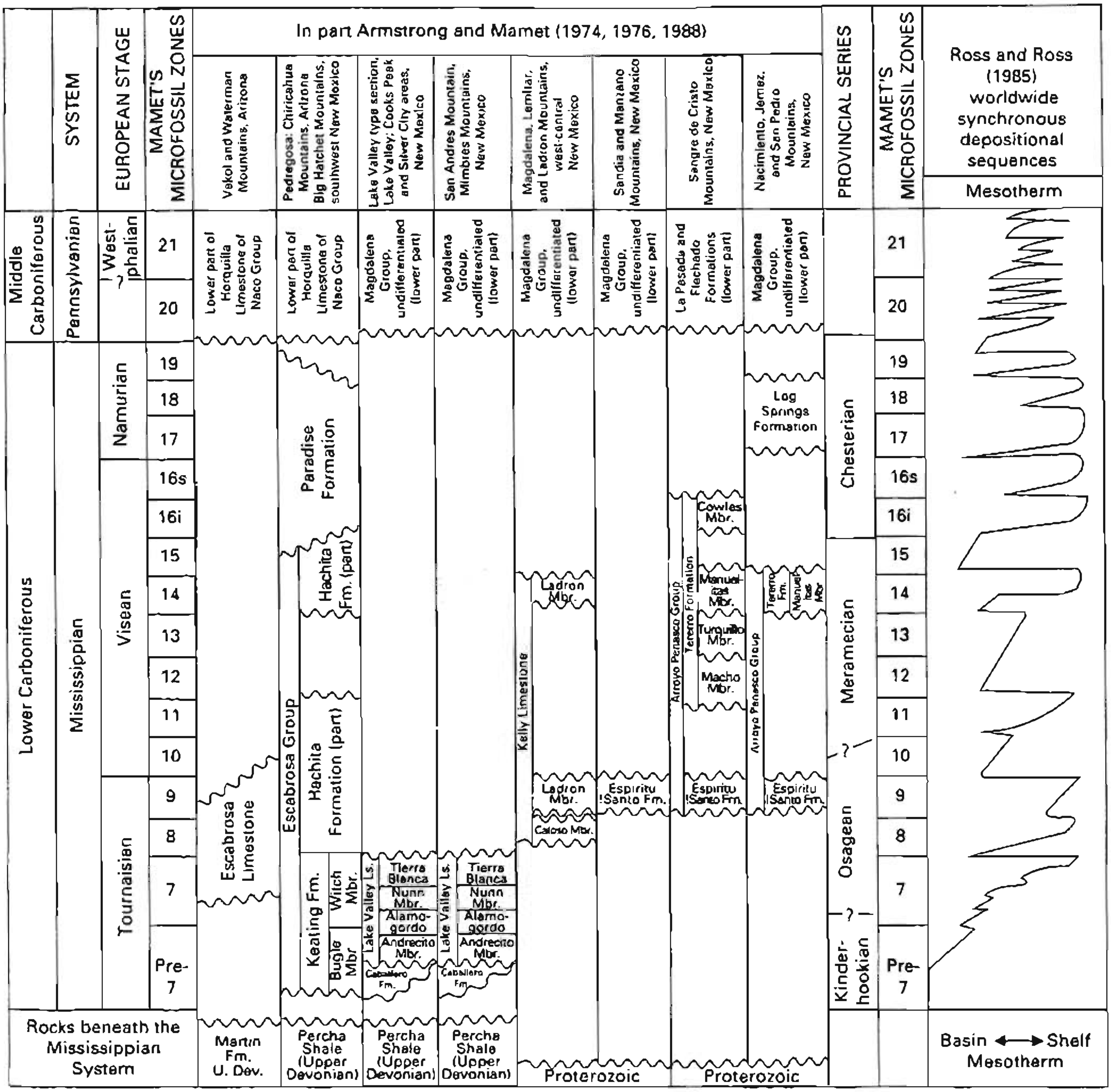

Figure 5. Correlation chart for the Lower Carboniferous (Mississippian) of New Mexico and southeastern Arizona (modified from Armstrong and Mamet, 1988). Ross and Ross (1985) diagram of mesotherms for the Lower and Middle Carboniferous are shown for comparison.

A marine transgression in the early and middle Tournaisian began in southwestern New Mexico and adjacent parts of Arizona, depositing the pelmatozoan-brachiopod packstones of the Keating Formation of the Escabrosa Group (Osagean to Meramecian). Further west in Arizona, the lower part of the Escabrosa Limestone was deposited on a shoaling subtidal to supratidal carbonate platform. Some of the pre-7 zone supratidal dolomites have zebra structures and dolomite pseudomorphs after gypsum. These indicate a hot arid climate. The Hachita Formation of the Escabrosa Group in the Pedregosa basin was deposited in shoaling water as crinoidal sand on a wide carbonate shelf. Further west in Arizona, the stratigraphic equivalent of the lower part of the Hachita Formation is the upper part of the Escabrosa Limestone, which is composed of peloid-calcareous-algal wackestone, packstones, and dolomites deposited in subtidal to supratidal environments in a hot arid climate.

By the end of late Tournaisian time, epicontinental seas had flooded much of New Mexico and Arizona. In northern New Mexico, a thin veneer of subtidal to supratidal lime mudstone and gypsum was deposited over the southern end of the Proterozoic transcontinental arch. The sedimentary record indicates that the climate in New Mexico was hot and arid in zones 8 to 9 (Tournaisian). The supratidal sedimentary deposits include an abundance of calcite pseudomorphs of gypsum and the deposition of bedded gypsum (Vaughan, 1978; Ulmer and Laury, 1984). A major regional marine regression and ensuing transgression took place during early Visean time. This event is represented by a hiatus in the upper part of massive encrinite of the Hachita Formation in southwestern New Mexico. Ross and Ross (1985) show a worldwide marine regression at the end of the Tournaisian, zone 9. The hiatus, which spans zones 11 and 13 in New Mexico, is recorded in an unconformity between shelf carbonates of the Lake Valley Limestone (Lower Mississippian) and deeper water basinal carbonate rocks of the lower part of the Rancheria Formation (Osagean to Chesterian) in south-central New Mexico. This hiatus is found in northern New Mexico in the upper part of the Arroyo Penasco Group (Osagean to Chesterian) and the Kelly Limestone (Osagean to Meramecian) of west-central New Mexico.

A major transgression occurred over the region in zone 14. In southwestern New Mexico and adjacent parts of Arizona, the cyclic, subtidal to intertidal Paradise Formation, zone 15 (Visean) through zone 19 (Namurian), contains oolitic grainstone to dolomite and interbedded plant-bearing quartz sandstones and shales. The withdrawal of marine waters off the craton in late Visean and the influx of terrigenous sediments into Pedregosa basin record the tectonism and rising highland to the north, which were the beginning of the Ouachita orogeny and the cyclic sedimentation that was to characterize the Middle Carboniferous. The lack of pseudomorphs of gypsum and the abundance of plant remains suggest a warmer and wetter climate for the latest Mississippian. The basal sandstones and shales of the Pennsylvanian in the southern Sangre de Cristo Mountains of New Mexico (zones 20 and 21) have 5-ft-thick coal beds (Gardner, 1910), which indicates a warm and humid climate during late Namurian. This is further substantiated by the reappearance of Dasycladales algae in shallow-water carbonate rocks.

These two examples of rocks taken from a rather complete geologic column and deposited on comparable carbonate platforms bordering the same continental block show how difficult it is to estimate global paleotemperatures. Local basinal variations leave paramount imprints in the record and appear to be as important as global trends.

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