The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States— Alaska

By J. THOMAS DUTRO, JR.

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-DD

Prepared in cooperation with the
State of Alaska Department of Natural Resources,
Division of Geological and Geophysical Surveys

Historical review and summary of
areal, stratigraphic, structural,
and economic geology of Mississippian
and Pennsylvanian rocks in Alaska

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

CONTENTS

ILLUSTRATIONS

THE MISSISSIPPIAN AND PENNSYLVANIAN (CARBONIFEROUS) SYSTEMS IN THE UNITED STATES—ALASKA

By J. THOMAS DUTRO, JR.

ABSTRACT

The Carboniferous rocks of Alaska are more widely distributed than those of any other Paleozoic system. The Lisburne Group of northern Alaska contains a great variety of carbonate facies, predominantly shallow-water deposits, but including some outer shelf and slope deposits. In east-central Alaska, the deep-water Ford Lake Shale is succeeded by the Calico Bluff Formation, which was probably deposited in a slope environment. Scattered throughout central and southwestern Alaska are remnants of deep-water laminated chert and argillite deposits containing a few carbonate members that may be of shelf-margin or upper slope origin. In southeastern Alaska, Carboniferous deposition began with deep-water chert and volcaniclastic rocks, but most of the sequence reflects upward-shoaling shallow-water carbonate deposition, perhaps in an island archipelago.

Correlations among the various sequences in Alaska and adjacent areas are based mainly on the foraminiferal zonation of B. L. Mamet and on other fossils, among which the cephalopods are most significant. Corals, brachiopods, echinoderms, and mollusks are regionally important guides in certain parts of the section, and fusulinids are quite useful in the upper Carboniferous deposits. Fossil plants, although minor elements of the total biota, are important in the Lower Mississippian clastic sequences and have provided a spectacular breakthrough in the recognition of terrestrial Upper Pennsylvanian strata in the western Alaska Range.

The most important economic factor in the Carboniferous deposits of the State is the oil and gas potential of the Lisburne Group in the subsurface of northern Alaska. The abundance of carbonate rocks for potential industrial uses is an untapped resource for possible future development.

INTRODUCTION

Rocks of Carboniferous age are widely distributed in Alaska (fig. 1), representing more outcrop area than those of any other Paleozoic system. Carbonate rocks of the Lisburne Group compose most of the thrust sheets and folded structures in the central and northern Brooks Range. This sequence in northern Alaska was deposited by the sea onlapping older terranes, the first rocks in the sequence are shore and nearshore clastic rocks. The succeeding Mississippian and Lower Pennsylvanian carbonate strata were deposited in a complex of predominantly shallow-water marine environments. Similar carbonate sections are also present at the western tip of the Seward Peninsula and on St. Lawrence Island in the Bering Sea. The Carboniferous of east-central Alaska begins with deep-water dark chert and shale of the Ford Lake Shale; the Ford Lake is overlain by slope deposits of limestone and shale, the Calico Bluff Formation, part of which is as young as Early Pennsylvanian. Although the Carboniferous is sparsely represented in central, southern, and southwestern Alaska, deep-water clastic and volcaniclastic rocks are present in the Alaska Range, and bedded chert and argillite are present in the Medfra quadrangle. Recently discovered terrestrial plant-bearing conglomerates of Pennsylvanian agė crop out on Mt. Dall in the Talkeetna quadrangle, southwest of Mt. McKinley. This is the first positive evidence of nonmarine late Carboniferous deposits in Alaska. In southeastern Alaska, an essentially carbonate sequence of Mississippian and Lower Pennsylvanian rocks is represented by the Iyoukeen Formation at Freshwater Bay and by the Peratrovich and Klawak Formations and the Ladrones Limestone in the Prince of Wales Island area. In addition, the Saginaw Bay Formation, which contains a lower volcanic member, a black chert member, a chert and limestone member, and an upper silty limestone member, is present in the northern part of Kuiu Island and on the Keku Islets. The Saginaw Bay Formation appears to include correlatives of the Peratrovich, Ladrones, and Klawak.

Most of the exposures in northern Alaska are north of the tree line and, consequently, are magnificent. Except where covered by deposits of mountain glaciers and recent talus cones and colluvium, Carboniferous strata are totally exposed, and opportunities for unravelling the stratigraphy, structure, and geologic history of the region are unexcelled. Much of the lowland region of central and southern Alaska is tree covered, and exposures are limited to

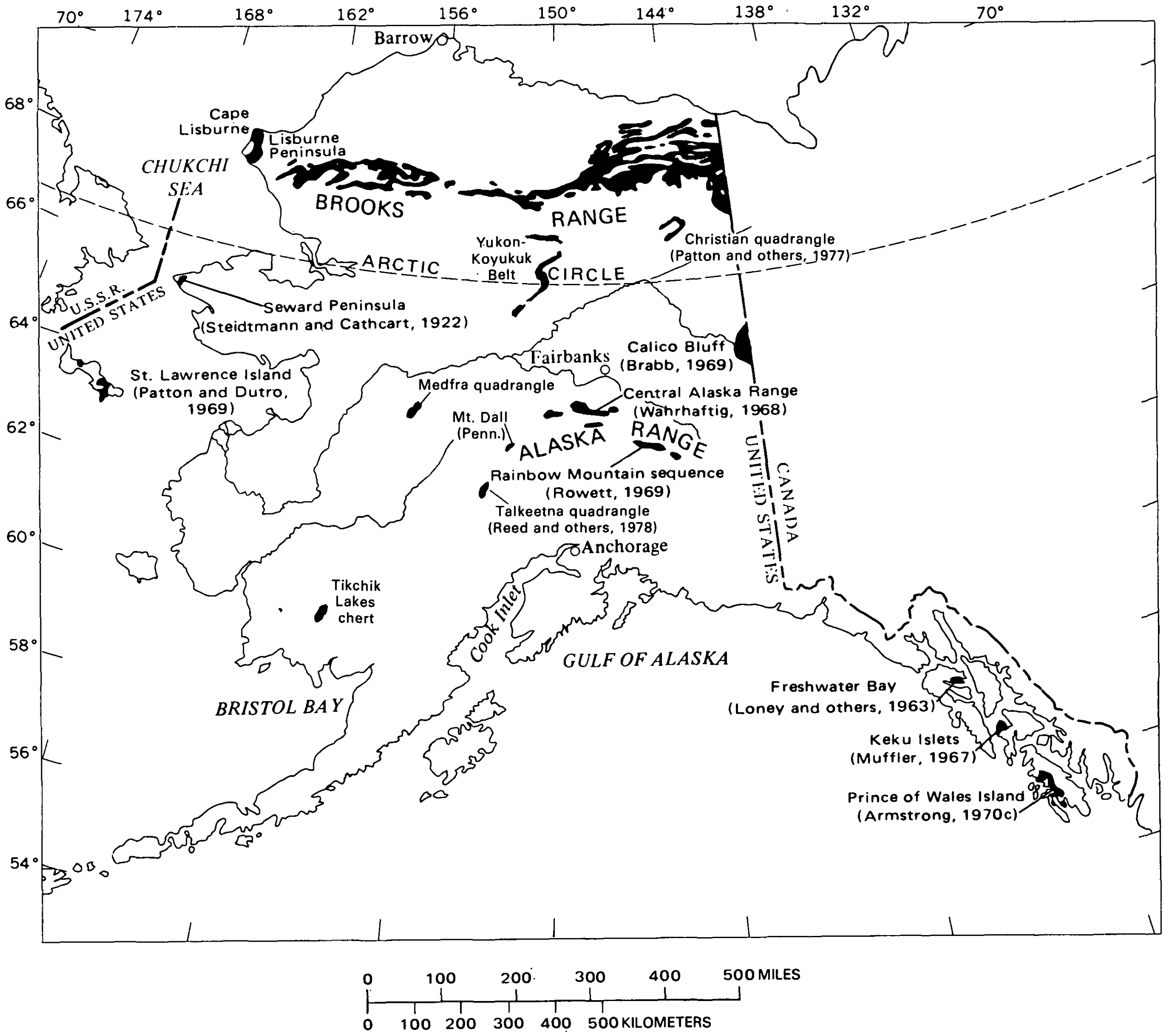


FIGURE 1.—Map showing distribution of Carboniferous rocks (shaded areas) in Alaska. Modified from Armstrong (1975).

river bluffs and isolated hilltop outcrops. Some Carboniferous strata crop out above the timberline in the Alaska Range, and exposures in southeastern Alaska are superb along the island coastlines where the great tidal range provides hectares of fine outcrop from low tide to midtide.

The stratigraphic nomenclature used in this paper has not been reviewed by the Geologic Names Committee of the U.S. Geological Survey. The nomenclature used here conforms with the current usage of the State of Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys.

ACKNOWLEDGMENTS

I am indebted to many people who by their instruction, guidance, assistance, and forbearance have made this paper possible. My first work on the Lisburne Group in 1949 was with A. L. Bowsher, who furnished a never-to-be-forgotten introduction to the subtleties of Carboniferous strata and fossils. Through the years, I have had the good fortune to be associated in Alaskan field projects with W. P. Brosgé, H. N. Reiser, R. L. Detterman, W. W. Patton, Jr., I. L. Tailleur, M. Churkin, Jr., E. G. Sable, M. D. Mangus, D. H. Richter, R. M. Chapman, B. L. Reed, C. L. Sainsbury, R. A. Loney, W. H. Condon,

M. C. Lachenbruch, A. H. Lachenbruch, and many others. All these men, through stimulating discussions about the geologic interpretation of innumerable puzzling field relationships, provided the continuing incentive to pursue my studies of the Paleozoic of Alaska.

G. Arthur Cooper, Carl O. Dunbar, James Steele Williams, Helen M. Duncan, and Edwin M. Kirk, through their dedicated pursuit of taxonomic and biostratigraphic problems, set a high standard which has guided my own paleontologic work.

I am especially indebted to A. K. Armstrong, Bernard L. Mamet, Mackenzie Gordon, Jr., Raymond C. Douglass, I. G. Sohn, S. H. Mamay, and E. L. Yochelson for their expertise, freely shared, on the groups of fossils that are their specialties.

In addition, the work of K. J. Bird and C. F. Jordan has been relied on, in large part, for the analysis of the oil and gas potential of the Lisburne Group in northern Alaska.

Finally, I am grateful to a group of supervisors who had the vision and faith in our work to support projects, at times rather esoteric, which permitted all of us to explore together the fascinating Carboniferous geology of Alaska. These farsighted chiefs include George Gryc, Preston E. Cloud, Jr., Wilmot H. Bradley, George L. Gates, Ralph L. Miller, Charles L. Anderson, and Thomas G. Ovenshine.

HISTORY

The first report of Carboniferous rocks from Alaska is probably that of Capt. F. W. Beechey (1831) who, along with other early coastal explorers, was awed by the spectacular cliff exposures near Cape Lisburne. The first mention of Carboniferous fossils is by W. Buckland (1839, p. 171) who reported that fossils collected from Cape Lisburne by the Beechey party are indistinguishable from those of the Derbyshire Limestone and listed "producta Martini, other productae, lithostrotion, flustrae and trilobites." In the latter half of the 19th century, several other writers referred to the occurrence of Carboniferous fossils in Alaska, most of them relying on Buckland's earlier statement. By the end of the century, scattered information on Paleozoic fossils, including those of the Carboniferous, was summarized by Charles Schuchert, W. H. Dall, and F. H. Knowlton (*in* Dall, 1896, p. 864–865, 876–906) in the 17th Annual Report of the U.S. Geological Survey.

During the first decade of this century, geologic exploration related to the search for gold and other mineral deposits added substantial knowledge concerning the distribution of Carboniferous rocks in Alaska. The Lisburne formation was named by F. C. Schrader (1902), who provisionally assigned it to the Devonian. By 1906, however, G. H. Girty and David White (*in* Collier, 1906) had correctly assigned the Lisburne fossils to the early Carboniferous.

Carboniferous rocks were found during the geological reconnaissance conducted in conjunction with the work of the International Boundary Survey in 1911 and 1912. The part of the boundary between the Yukon and Porcupine Rivers was studied by the Geological Survey of Canada (Cairnes, 1914). The part from the Porcupine River northward to the Arctic Coast was examined by the U.S. Geological Survey (Maddren, 1912). Cairnes recognized three major rock units—a shale group, a limestone-chert group, and the Nation River Formation. Subsequent work has shown that the Nation River is Upper Devonian and that much of the shale group is lower Paleozoic, but the limestone-chert group is probably what is now recognized as the Calico Bluff Formation. G. H. Girty of the U.S. Geological Survey identified many fossil collections and showed that these rocks are, indeed, of Carboniferous age, although many subsequent refinements in the ages and correlations have been made. North of the Porcupine River, Maddren (1912) found large areas of Carboniferous limestone when he crossed the Brooks Range. He reported that these rocks stretch for nearly 64 km north of Ammerman Mountain and that they contain Carboniferous fossils. Unfortunately, Maddren's maps and complete report were never published, but much of the information has been incorporated into later U.S. Geological Survey maps and papers.

A flurry of activity in the 1920's related to the exploration of Naval Petroleum Reserve (NPR) No. 4 greatly increased the understanding of the geologic history of northern Alaska. Specific details of Carboniferous geology and an excellent summary of all earlier exploration were given by Smith and Mertie (1930). During the same decade, detailed exploration in southeastern Alaska resulted in the first regional geologic synthesis of the panhandle by Buddington and Chapin (1929). The Yukon-Tanana region, a third major area of Carboniferous rocks, was examined primarily by J. B. Mertie, Jr., in the 1920's and early 1930's. Mertie's conclusions regarding the stratigraphy, structure, and general geology of this vast region were presented in two major papers (1930 and 1937). The general state of geologic knowledge of Alaska before World War II was summarized by P. S. Smith (1939), who discussed the Carboniferous deposits in each region and presented a very generalized correlation chart.

Until World War II, practically all the paleontologic and biostratigraphic information on the Carboniferous of Alaska was the result of the work of G. H. Girty, who provided the extensive faunal lists, age designations, and correlations that appeared in the reports of the U.S. Geological Survey during the first four decades of the century.

Work in NPR No. 4 was renewed during the latter years of World War II. From 1944 to 1953, more than 300 man-months of geologic fieldwork greatly increased the knowledge of the geology of Carboniferous deposits in about 54,390 km^2 in northern Alaska and culminated in a series of regional papers and maps (Reed, 1958).

Modern stratigraphic and paleontologic studies began with the work related to the exploration of NPR No. 4. New formational units were named, and a preliminary biostratigraphic zonation was established (Bowsher and Dutro, 1957). Several groups of fossils were described in some detail (Gordon, 1957; Yochelson and Dutro, 1960; Sohn, 1971).

In the early 1960's, major oil companies instituted massive regional studies and examined the possibility that the widespread Carboniferous carbonate rocks in northern Alaska would become oil and gas producers. Detailed regional, stratigraphic, facies, petrographic, and depositional analyses were made. A. K. Armstrong, now with the U.S. Geological Survey, contributed significant papers on coral biostratigraphy, carbonate petrography, and environmental reconstructions of the Lisburne rocks (1970a, b, c; 1972a, b; 1975).

Major advances in understanding the Carboniferous of southeastern Alaska resulted from detailed mapping and stratigraphic work of U.S. Geological Survey parties during the past 20 years. The Peratrovich and Klawak Formations and the Ladrones Limestone on Prince of Wales Island were described by Eberlein and Churkin (1970); and the Iyoukeen Formation of Freshwater Bay was named by Loney, Condon and Dutro (1963). Fusulinids from the Ladrones and Klawak indicate that they are early Middle Pennsylvanian (Douglass, 1971), Mississippian corals and biostratigraphy of the Peratrovich were described by Armstrong (1970c). Muffler (1967) described the Saginaw Bay Formation in the Keku Islets and nearby northern Kuiu Island; the Saginaw Bay Formation contains fossils of Mississippian and Pennsylvanian ages.

A recent summary of the Carboniferous of most of Alaska, except the southeastern panhandle, was prepared by Brosgé and Dutro (1973). Biostratigraphic studies emphasizing the calcareous microfossils have been an important part of all recent work in the Carboniferous. Microfaunal zonations established by B. L. Mamet are used for general correlations in Alaska as well as in most other parts of North America (fig. 2). Papers documenting this zonation include those by Armstrong, Mamet, and Dutro (1970, 1971), Mamet and Armstrong (1972), and Armstrong and Mamet (1975, 1977).

GEOLOGIC SETTING

Although in several areas no break in deposition is apparent between Lower Mississippian rocks and uppermost Devonian strata, at most places the Carboniferous rocks lie unconformably on older rocks (Churkin, 1973). In parts of the western and central Brooks Range, no structural break separates rocks as old as Mamet's Foraminifera Zone 6 from the underlying marine Devonian beds of Famennian age. In the central Brooks Range, where the highest Devonian unit is nonmarine, a basal Mississippian littoral sandstone lies disconformably on the upper Kanayut clastic sequence. In the eastern Brooks Range, Mississippian strata are regionally unconformable on rocks as old as Precambrian. Broad anticlinoria characterize the eastern Brooks Range and extend as far west as the Doonerak anticlinorium in the northeastern Wiseman quadrangle, where the Carboniferous rests with angular unconformity on rocks as old as Ordovician (Grybeck and others, 1977). In the extreme northeastern part of the State, Mississippian beds were deposited across a varied older terrane that ranges in age from Precambrian through early Middle Devonian (Reiser, 1970).

In east-central Alaska, where all the Upper Devonian and Carboniferous strata were deposited in relatively deep water, no depositional break is apparent at the boundary. In southeastern Alaska, the Mississippian marine shale and carbonate rocks are disconformable on Upper Devonian marine volcanic sequences, but the precise amount of time that is not represented by rocks is unknown.

The geology of pre-Carboniferous rocks is best shown in northern Alaska where Precambrian through lower Middle Devonian strata show the effects of at least three orogenic episodes. The older Precambrian is a sequence of quartz-mica schist and related metamorphic rocks that is succeeded by weakly metamorphosed marine deposits of late Precambrian, Cambrian, and Ordovician age. Middle Devonian clastic rocks lie with angular unconformity on the Ordovician in the southwestern part of the Demarcation Point quadrangle. The onlapping Carboniferous deposits cover all older structures. Granitic intrusive bodies in the Mt. Michelson–Jago River area are of two ages, 430 m.y. (million years) and 360 m.y., and volcanic rocks of similar ages have been dated from the core of the Doonerak anticlinorium (430 m.y. and 370 m.y.–380 m.y.). Equivalents of both the Taconic and Acadian mountain-building episodes of eastern North America clearly are a part of the early history of northern Alaska.

In most regions, Carboniferous rocks are overlain unconformably by Permian or younger sequences. An exception is the east-central Alaska Range where volcaniclastic rocks of the Pennsylvanian Slana Spur Formation grade upward into limestone and sandy volcaniclastic limestone of the Wolfcampian Eagle Creek Formation.

Carboniferous and early Mesozoic strata were subsequently folded and faulted beginning in Late Jurassic time. In northern Alaska, deformation is most intense in the core of the Brooks Range where long-distance thrust faulting and imbricate thrust patterns are ubiquitous. Further north, as seen in the northeastern part of the range, tectonic style tends to more open folds and high-angle reverse faulting. Broadly folded Neogene strata at the Arctic Coast near Barter Island indicate that tectonism continued until relatively recent times.

LITHOSTRATIGRAPHY

Most of the major stratigraphic units in the Alaskan Carboniferous rocks have been examined in at least a broad reconnaissance way, and most units examined have been given formal names.

In northern Alaska, the Lisburne Group is composed of predominantly carbonate rocks of Mississippian and Early Pennsylvanian age. Various formation and informal member names are applied to major mapped units, most of which reflect regional facies variations (Bowsher and Dutro, 1957; Sable and Dutro, 1961). Figure 2 shows the correlation of the Lisburne Group in sections whose locations are shown on figure 3.

Lower Mississippian clastic rocks, including the Kayak Shale, Kekiktuk Conglomerate, and Itkilyariak Formation (Mull and Mangus, 1972), have been mapped on small-scale regional maps, together with Devonian clastic units, as the Endicott Group. This is a convenient expedient because of the onlapping nature of the deposition from the Late Devonian into the Middle Mississippian.

In east-central Alaska, the Upper Devonian and Lower Mississippian Ford Lake Shale apparently grades upward into the Calico Bluff Formation of Late Mississippian and Early Pennsylvanian age.

Throughout a broad belt in central and southwestern Alaska, fragments of a deep-water argillite-chert-volcanic rock terrane have recently yielded radiolarians and conodonts of Carboniferous age. In the past, some of these outcrops have been mapped as Circle Volcanics, Rampart Group, or Livengood Chert. Although the type Livengood Chert has subsequently been shown to be of Ordovician and, perhaps, Silurian age, some exposures in the Medfra, Ruby, and Kantishna quadrangles have yielded Carboniferous fossils (Patton and others, 1977).

In the western Alaska Range (Talkeetna quadrangle), pods of limestone in deep-water graywacke-argillite sequences have yielded both Chesterian and Atokan Foraminifera (Reed and others, 1978). In the east-central Alaska Range, the Rainbow Mountain sequence is known to be of Middle or Late Pennsylvanian age (Rowett, 1969). Further to the east, Atokan and younger volcaniclastic strata containing thin limestone beds are included in the Slana Spur Formation. This formation is underlain by the Tetelna Volcanics, a thick pile of marine flows and associated volcanic rocks that may be of Early Pennsylvanian or Mississippian age (Richter and Dutro, 1975; Richter, 1976).

Although Carboniferous rocks are found in only a few places in southeastern Alaska, they are very fossiliferous and are predominantly shallow-water carbonates. The Peratrovich Formation, which is more than 300 m thick, includes relatively deep water slope deposits of shale, chert, and volcanic rocks at its base and grades upward through shelf limestones to shoal-water carbonates near its top (Armstrong, 1970c). The Peratrovich is disconformably overlain by two formations, both probably of Early or early Middle Pennsylvanian age. The Klawak Formation is composed of 150–300 m of calcareous sandstone and siltstone and minor beds of limestone and chert-pebble conglomerate. The Ladrones Limestone, on the other hand, is nearly pure massive-bedded lime mudstone containing some dolomitic beds and is as much as 300 m thick. No great time gap existed between deposition of the Peratrovich and deposition of the overlying Pennsylvanian strata as all Mamet's Foraminifera Zones

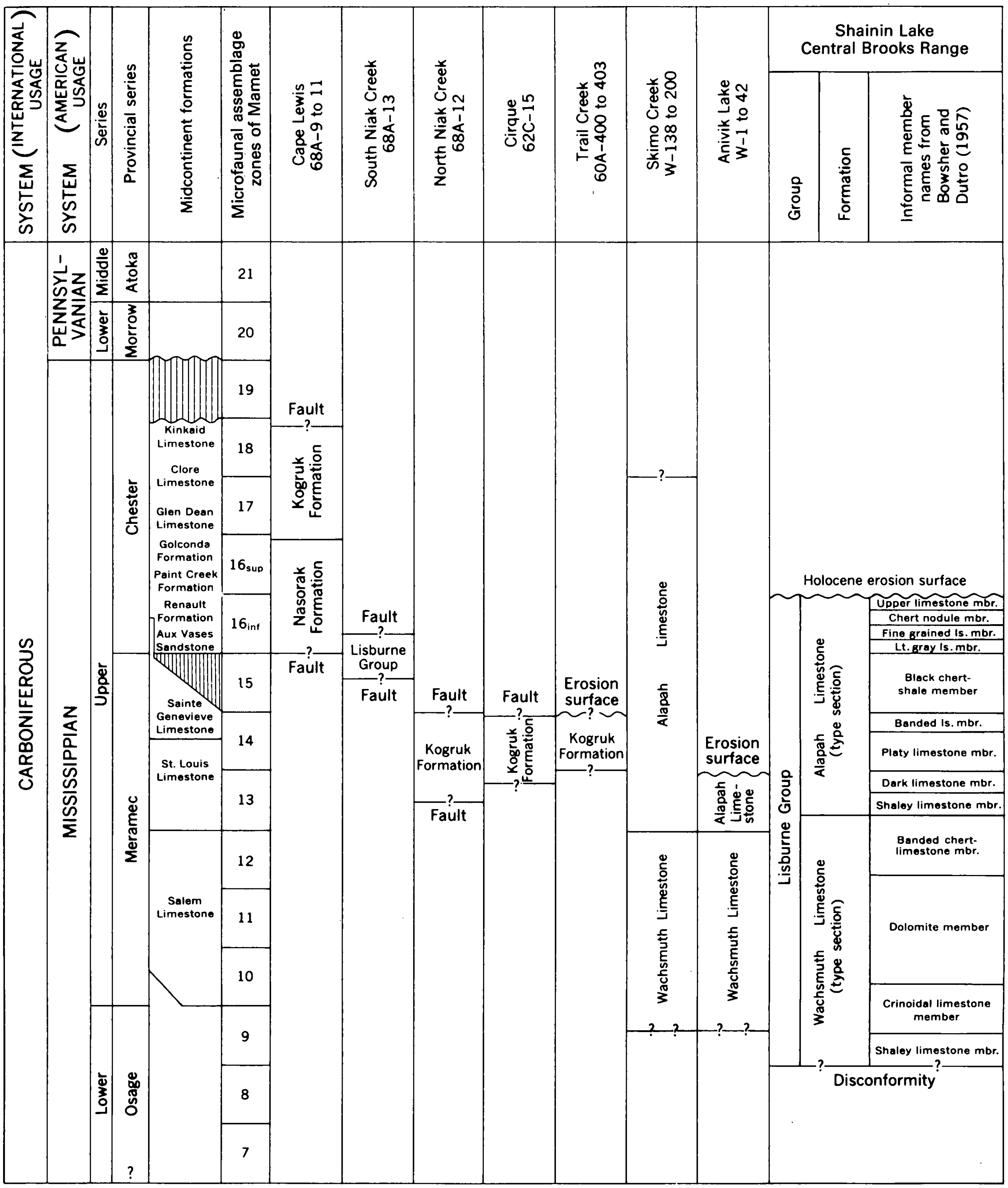
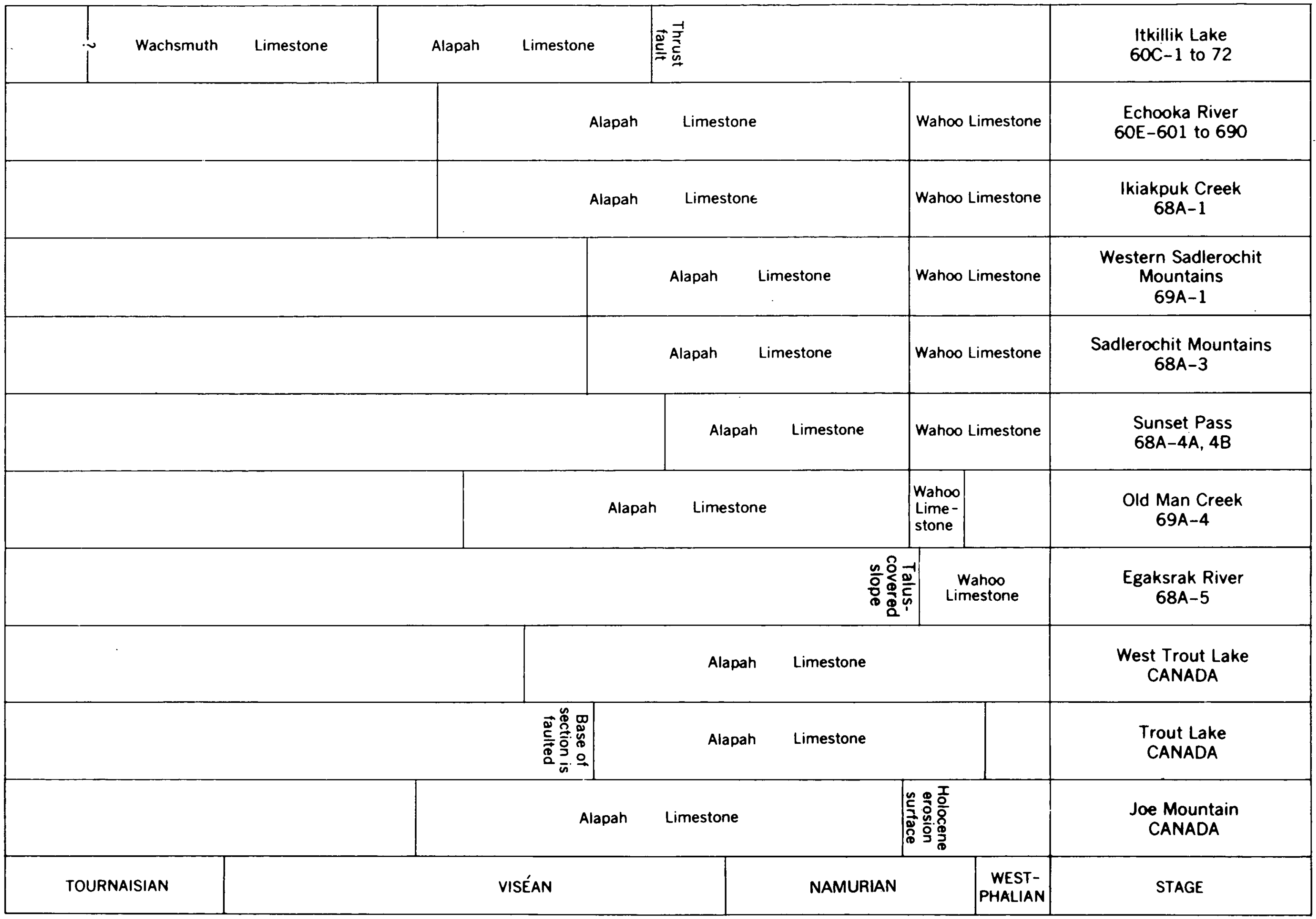


FIGURE 2.—Regional stratigraphic correlation chart of the Lisburne Group, northern Alaska and adjacent Canada.



Locations of sections are shown on figure 3. Modified from Armstrong and Mamet (1977, fig. 3).

are present, including Zone 19, which is the highest Mississippian zone in the Mamet classification.

ENVIRONMENTS OF DEPOSITION

The Carboniferous of northern Alaska was a time of northward and eastward onlap across an older complex geological terrane. Initial deposits are now littoral sandstone and shallow-water shale and shaly carbonate rock. Although many fluctuations are represented in the thick carbonate sequence, the general picture is one of regional shallow-water deposition throughout the Mississippian. In Meramecian time, platform carbonates graded southward into deeper water dark limestone and chert in some areas. In the northeast, nearly continuous deposition across the Mississippian-Pennsylvanian boundary extended the regionally shallowing pattern into the early Middle Pennsylvanian rocks of Atokan age (Wood and Armstrong, 1975).

Throughout most of the rest of the State, the Mississippian deposits were laid down on the outer shelf or upper slope. In a few places, limestones probably of shelf-edge origin contain shallow-water fossils that can be correlated with shallow-shelf deposits elsewhere.

Several of the deeper water Carboniferous deposits have been interpreted recently as parts of an extensive ophiolite terrane in the central and southwestern parts of the State (Patton and others, 1977). Although the mafic belts are thought to have been emplaced in the Jurassic, associated laminated cherts and volcaniclastic rocks have yielded Mississippian, Pennsylvanian, and Permian fossils in at least five places.

The upward-shoaling sequence in southeastern Alaska, because of its regional setting and local distribution, may well represent carbonate deposition in a volcanic archipelago (Churkin and Eberlein, 1977).

BIOSTRATIGRAPHY

All correlations of the Carboniferous of Alaska are integrated by using the scheme of foraminiferal zones proposed by B. L. Mamet (Mamet and Skipp, 1970; Sando and others, 1969). In this numbered sequence of zones, 6 through 9 are Tournaisian, 10 through 16 are Viséan, 17 through 20 are Namurian, and 21 is early Westphalian. The Mississippian-Pennsylvanian boundary is about at the boundary between Zones 19 and 20. In terms of midcontinent stratigraphy, the Chesterian-Meramecian boundary lies at about the boundary between Zones 16_{inf} and 15, and the Meramecian-Osagean boundary is approximately at the boundary between Zones 10 and 9. Beds of Zone 6 and pre-7 ages are equivalent to the Kinderhookian, but the Kinderhookian-Osagean boundary has not been precisely set.

The first generalized sequence of megafossil zones was discussed by Bowsher and Dutro (1957, p. 5–6) and was later slightly modified by Yochelson and Dutro (1960, p. 114–115). These assemblage zones are most useful for identifying informal subdivisions of the Wachsmuth and Alapah Limestones in the central Brooks Range.

Cephalopods from the Carboniferous of Alaska were described by Gordon (1957), who placed the several occurrences of nautiloids and goniatites in the general zonal scheme that he had devised for North America. Correlations with the worldwide zones were also shown.

Gastropods were described by Yochelson and Dutro (1960), and their relationship to the megafaunal zonation was indicated. The systematic descriptions of corals that have been published during the last decade by Armstrong (1970c; 1972a, b) were related by that author (1975) to the biostratigraphic scheme for the Lisburne Group, and a coral zonation was established. New ostracodes were described by Sohn (1971), and, although they appear to be of limited biostratigraphic use, they provide valuable paleontologic documentation for the Mississippian fossil assemblages in Alaska.

Few Pennsylvanian megafossils have been described, but calcareous Foraminifera were described by Armstrong and Mamet (1977), and Pennsylvanian fusulinids of southeastern Alaska were described by Douglass (1971).

Mississippian biostratigraphic zonations and occurrences of the several invertebrate groups that have been studied in more detail are shown on figure 4. As a result of discussion with Mackenzie Gordon, Jr., and A. K. Armstrong (oral communs., 1978), positions of some of the cephalopod and coral zones are adjusted slightly from those originally published.

Fossil plants are not abundant in the Carboniferous of Alaska, and no coal beds of any significance are known. Nevertheless, plant fragments are present in the dark shales near the base of the Mississippian sequence throughout the Brooks Range. Many of these collections have been studied by S. H. Mamay during the past two decades. A combined list of this Mississippian floral assemblage includes *Lepidodendropsis* sp., *Calamites* sp., *Stigmaria* cf. *S. ficoides* Sternberg, *Lepidodendron* cf. *L. veltheimii*

Sternberg, *Lepidophyllum* sp., *Lepidostrobus* sp., *Rhodea vespertina* Read, and *Triphyllopteris* sp. According to Mamay (written commun., 1970), this assemblage represents Floral Zone 2 of Read and Mamay (1964).

Plants were collected years ago from carbonaceous shale in the exposures along the sea coast south of Cape Lisburne (David White, *in* Collier, 1906, p. 22). In a review of these floras, Mamay (written commun., 1964) identified several forms among new collections that permitted him to recognize both Zones 2 and 3 of Read and Mamay (1964). The oldest marine fossils from beds lying above the plant-bearing strata are now known to be assignable to Mamet's Microfaunal Assemblage Zone 13 (middle Meramecian); thus, the Early Mississippian age traditionally assigned to Floral Zones 1 and 2 of Read and Mamay (1964) seems to be justified, and Floral Zone 3 must begin as early as Meramecian.

Until very recently, no known fossils of Pennsylvanian plants had been reported from Alaska or, for that matter, from any part of the western Cordillera north of Washington. In 1976, however, Bruce Reed of the U.S. Geological Survey collected an assemblage of plants that S. H. Mamay (written commun., 1977) reported to be "Middle Pennsylvanian, probably no lower than Alleghenian * * * possibly Floral Zone 10 of Read and Mamay, 1964." The assemblage includes *Cordaites* sp., ?*Calamites* sp., *Neuropteris scheuchzeri* Hoffman, *Pecopteris* cf. *P. arborescens* Schlotheim, and *Pecopteris unita* Brongniart. These plants come from the upper half of the Mt. Dall Conglomerate in the Talkeetna C–5 quadrangle, about 5.23 km N. 76°E. from Mt. Dall (Reed and others, 1978).

IGNEOUS AND METAMORPHIC ROCKS

Igneous and metamorphic rocks of Carboniferous age are found in only a few places in Alaska. In northern Alaska, mafic dikes and sills are found within the Lisburne Group in the northeastern part of the Philip Smith Mountains quadrangle. Just to the north, in the southeastern Sagavanirktok quadrangle, volcaniclastic rocks and associated andesitic flows are present in about the same stratigraphic position. Fossils in the enclosing rocks suggest that these volcanic rocks are Late Mississippian in age.

In the east-central Alaska Range, the Mankomen Group is underlain by a predominantly mafic marine volcanic sequence, the Tetelna Volcanics of probable Carboniferous age. As the oldest fossils in the overlying dominantly volcaniclastic Slana Spur Formation are of Atokan age, the Tetelna must be Early Pennsylvanian or older.

In southeastern Alaska, both intrusive igneous rocks and volcanic rocks are known. In the Kuiu-Kupreanof Islands area, Muffler (1967) reported basaltic to andesitic pyroclastic rocks and pillow lavas, apparently of Early Mississippian age, in the lower part of the Saginaw Bay Formation. On Prince of Wales Island, granitic rocks about 280 m.y. old intrude the Klawak Formation of Early and Middle Pennsylvanian age (Eberlein and Churkin, 1970). In the Nabesna quadrangle, the Ahtel pluton is also of latest Pennsylvanian age. Richter (1976) reported its age to be about 280 m.y. With the exception of these very late Pennsylvanian intrusive rocks, no plutonic rocks of Carboniferous age are known in Alaska.

Metamorphic rocks of Carboniferous age are very poorly known; the only possible candidate is the Totatlanika Schist of the central Brooks Range. Wahrhaftig (1968) reported that fossils of probable Mississippian age are found in this terrane which occupies a northeast-trending belt in which Permian rocks lie unconformably on early Paleozoic or older rocks. Significantly, this belt also includes the only known nonmarine Carboniferous plant-bearing strata in the State.

ECONOMIC PRODUCTS

The major commodities in the Carboniferous of Alaska are oil and gas. The carbonate rocks of the Lisburne Group in the subsurface of northern Alaska provide one of the main reservoir zones for storage of hydrocarbons. In the Prudhoe Bay field, porosity zones in the upper Lisburne are primary targets for drilling. Facies trends indicate that Chesterian (upper Alapah Formation) strata contain good to excellent dolomite porosities in a broad band that extends generally west from the Prudhoe area to the northwestern Arctic Coast in the vicinity of Wainwright (Armstrong and Mamet, 1970). Unfortunately, most of the part of this band that is west of the Colville River is probably too deep for exploration. However, in the region east of the Colville, from the foothills north to the coast, good possibilities exist for reaching the Lisburne in a number of structural settings.

An analysis of the discovery well in the Prudhoe field, Prudhoe Bay State 1, by Armstrong and Mamet (1974) indicates that the Lisburne Group is 540 m thick and ranges in age from Mamet's Foraminifera Zone 16_{sup} to Zone 21. The Alapah Limestone is

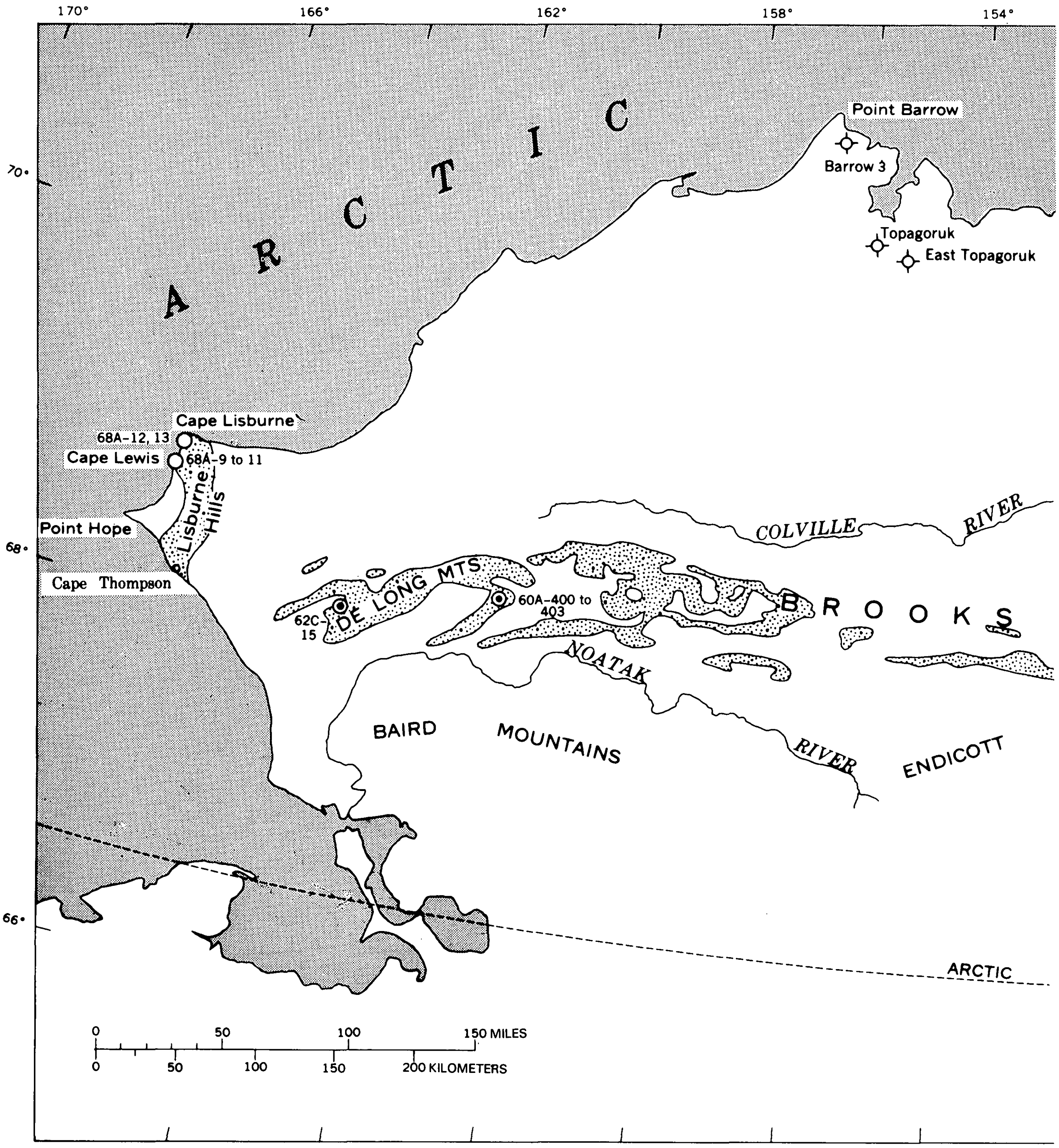
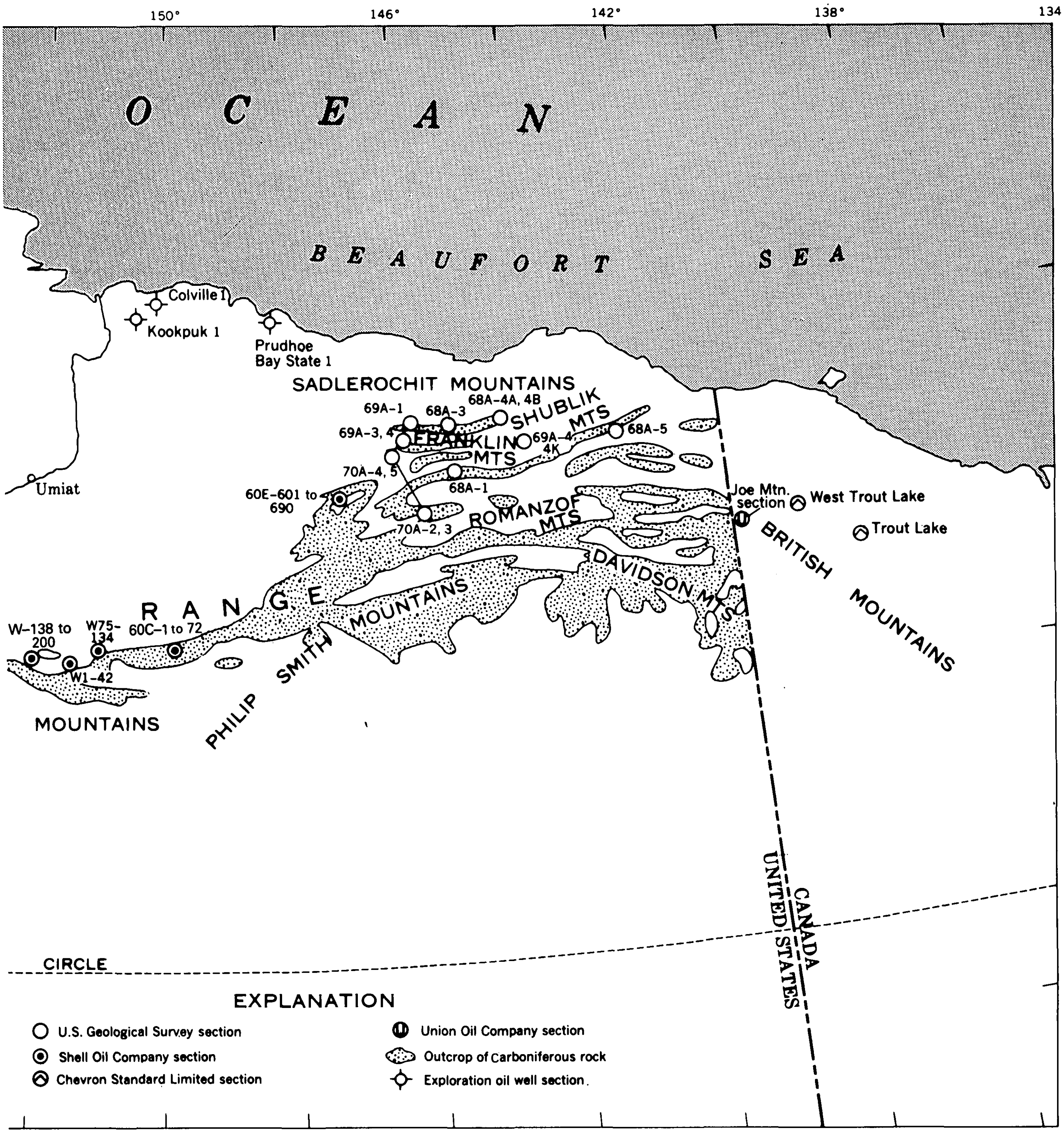


FIGURE 3.—Index map of arctic Alaska and adjacent Canada showing locations of outcrops of Carboniferous rock in Alaska

320 m thick and is composed of arenaceous packstone and wackestone, lime mudstone, and gypsiferous microdolomite. The Alapah is entirely Chesterian in age, ranging from Zone 16_{sup} through Zone 18. The overlying Wahoo Limestone, 219 m thick, is a series of cycles composed of packstone and wackestone capped by lime mudstone and arenaceous microdolomite. These deposits were interpreted by Armstrong and Mamet (1974) to represent tidal-flat lime muds directly above ooid tidal bars. The



and locations of sections, some of which contain the Lisburne Group (fig. 2). From Armstrong and Mamet (1977, fig. 1).

Wahoo Limestone is entirely Pennsylvanian (Foraminifera Zones 20 and 21). The Alapah Limestone is more arenaceous and dolomitic in the Prudhoe Bay State 1 well than are its outcrop equivalents in the Franklin and Sadlerochit Mountains. On the other hand, the Wahoo Limestone is very similar to outcrop sections in the Sadlerochits and represents a similar depositional environment.

The oil and gas potential of the Lisburne Limestone in the subsurface of northern Alaska was re-

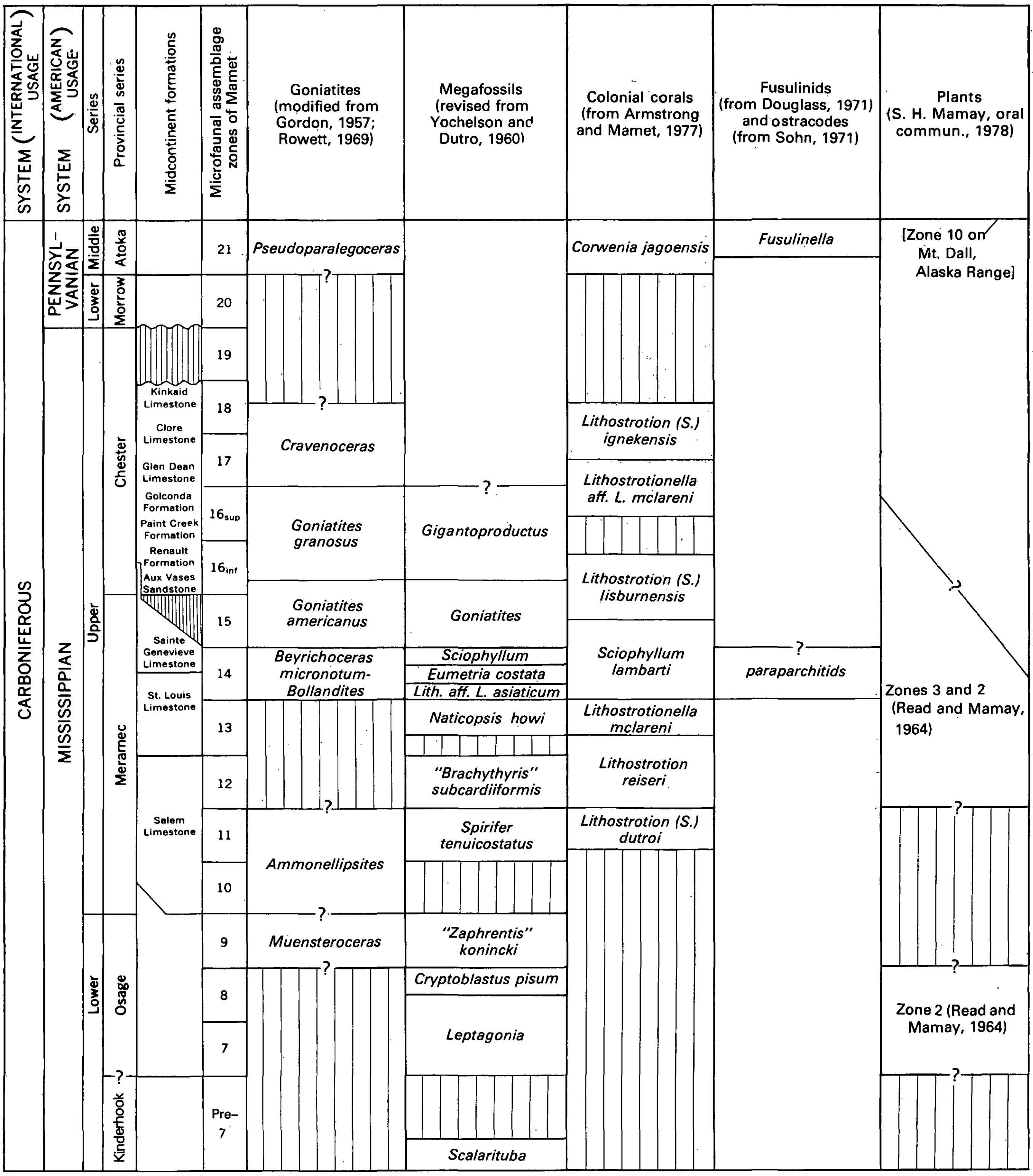


FIGURE 4.—Biostratigraphic zonations in the Carboniferous deposits of Alaska.

cently analyzed by Bird and Jordan (1977) who reviewed the regional setting and reservoir potential of the Lisburne Group. According to Bird and Jordan, although the Lisburne had been considered a probable petroleum reservoir for many years, these carbonate rocks were not penetrated by drilling until 1966. In that year, both the Union Kookpuk No. 1 and the Sinclair Colville No. 1 reached the

Lisburne; both wells had porosity and oil shows. The Arco-Humble Prudhoe Bay No. 1, discovery well for the Prudhoe field in 1968, also penetrated the entire Carboniferous section. Records and samples from 46 wells reaching the Lisburne are now available to the public and were used in the Bird and Jordan study.

An isopach map of the Lisburne in the eastern part of the Arctic Coastal Plain (fig. 5) shows that the thickest section is near the front of the Brooks Range where more than 1,200 m (4,000 ft) of strata are present. These carbonate deposits thin northwestward to less than 150 m (500 ft) over a broad northwest-trending arch that is a major subsurface structural feature. To the northeast, near the mouth of the Canning River, the top of the Lisburne has been truncated below the ground surface, and the Carboniferous carbonate deposits are completely absent near the Arctic Coast.

Porosity in the Lisburne strata is of three kinds. Microdolomite has porosity values as high as 23 percent from laboratory measurements and 27 percent as calculated from well logs. This is mostly intergranular porosity, but, in addition, the presence of vugs and small vertical fractures enhances primary porosity. The fractures, more importantly, also provide increased permeability. Bird and Jordan (1977) suggested that an average porosity of at least 10 percent may be expected in the subsurface.

Oolitic grainstones are common in the Lisburne, and, although the open-framework packing has nearly always been found filled with secondary calcite, this facies must be considered for its potential contribution to the overall porosity of the carbonate deposits.

Although the extent of these strata is unknown, sandstone porosity may be important in offshore wells in the Beaufort Sea. The dolomite thicknesses and the possible distribution of sandstone in the Lisburne Group are shown in figure 6.

Hydrocarbons have been reported from the Lisburne in three wells of the Prudhoe Bay field and from another well southeast of the field. Other wells have yielded saltwater from the Lisburne part of the column. Oil and gas flow rates from the Lisburne have not been disclosed as yet; the saltwater flow

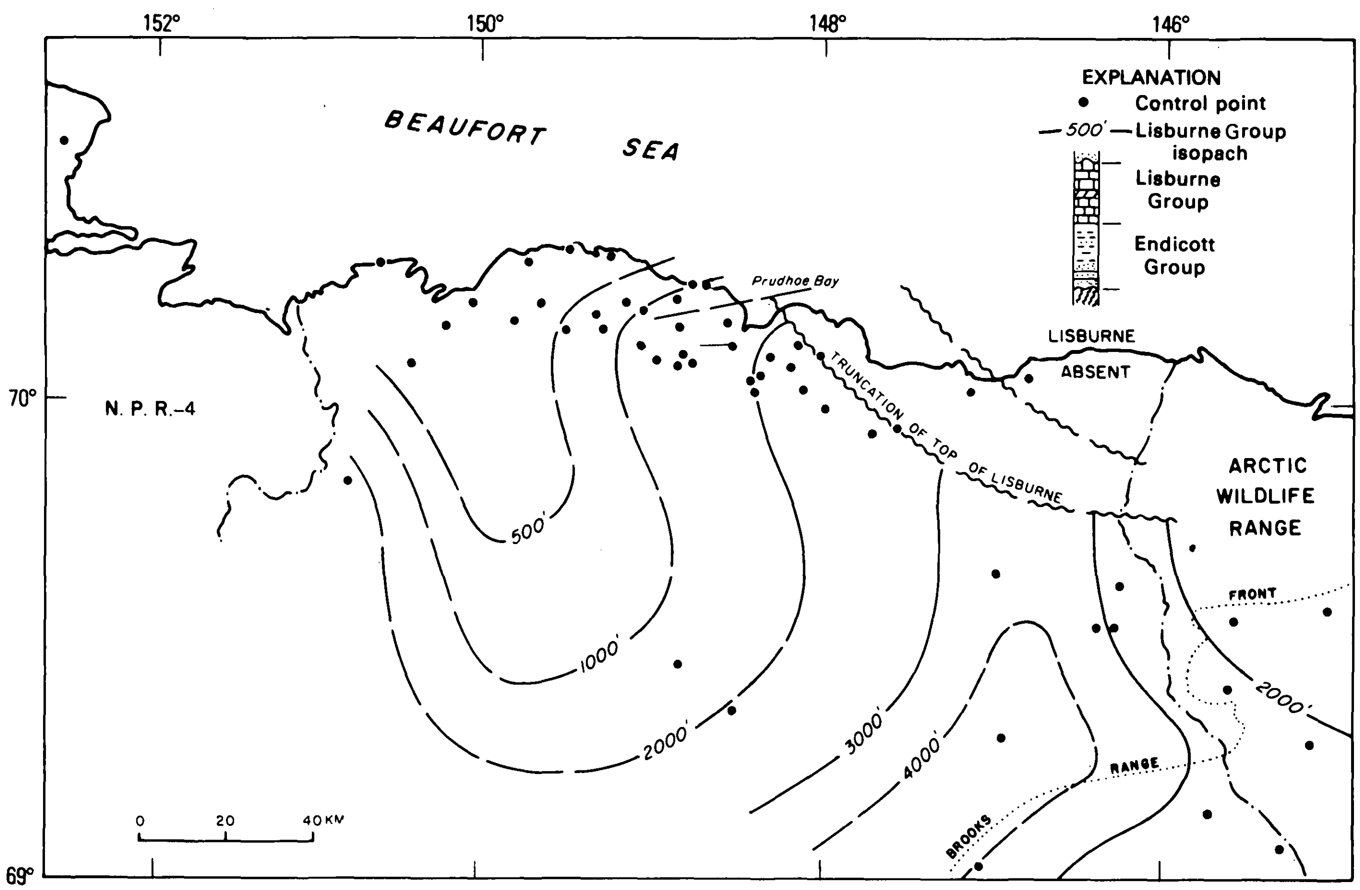


FIGURE 5.—Isopach map of Lisburne Group in the subsurface of the eastern Arctic Slope, Alaska. Modified from Bird and Jordan (1977).

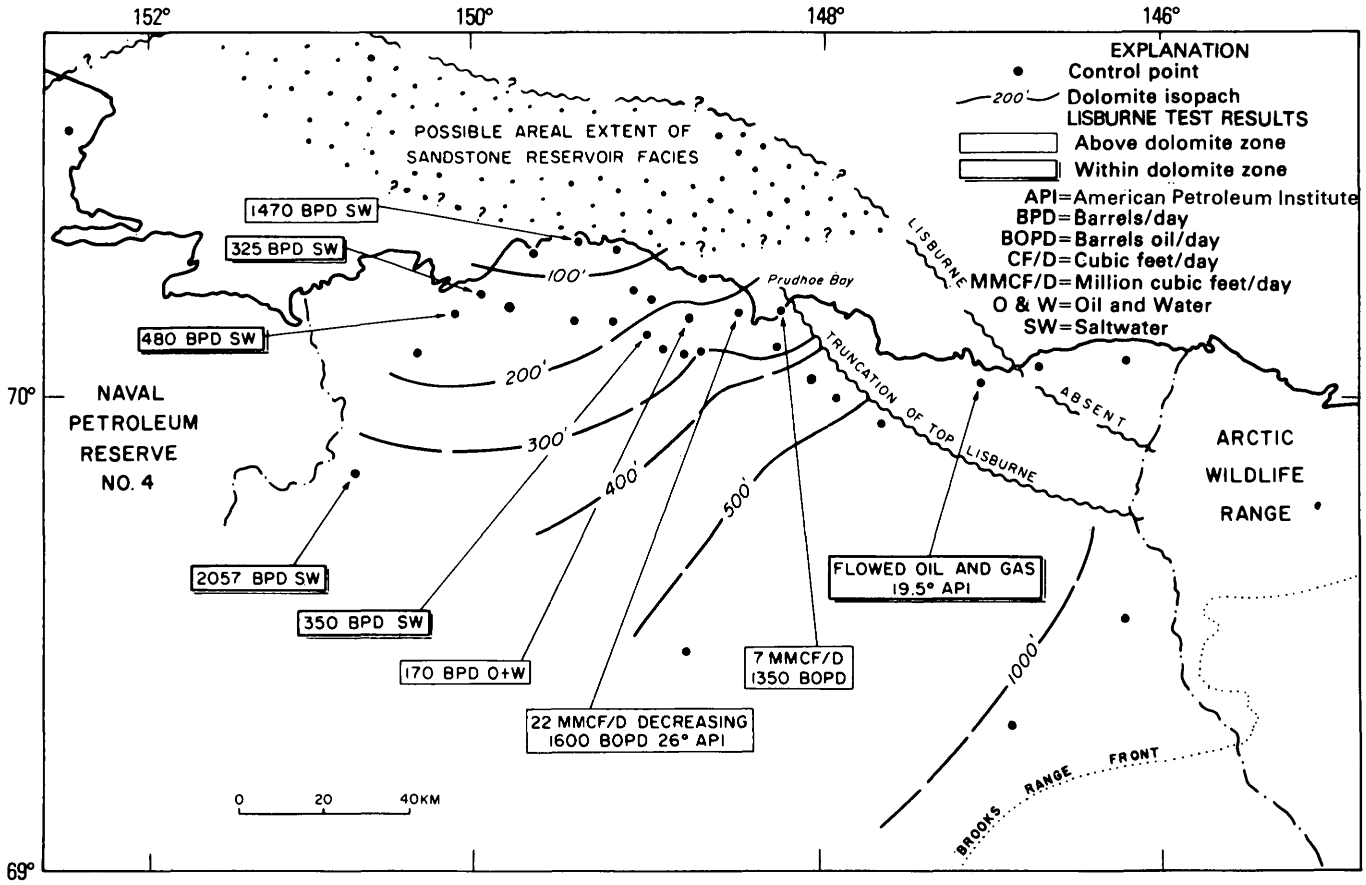


FIGURE 6.—Reservoir data summary for the Lisburne Group in the subsurface of the eastern Arctic Slope, Alaska. Modified from Bird and Jordan (1977).

rate from the dolomite in Mobil Mikkelson Bay No. 1 is 2,057 BPD (barrels per day) and from sandstone in the same well is 1,470 BPD.

Bird and Jordan (1977) suggested that, although the most likely source beds are Jurassic and Cretaceous shale, shale within the Lisburne Group and the Kayak Shale are possible contributors as well. They also indicated that coal in the basal Kekiktuk Conglomerate may be a source for dry gas in the Lisburne. Various estimates indicate that, although this coal in the Prudhoe Bay area has not been buried deep enough or for a long enough period to generate gas, downdip correlatives to the south may have generated gas.

Several formations provide adequate sealing beds at the top of the Lisburne Group throughout the subsurface area. Stratigraphic and structural traps and combinations of both are present in northern Alaska. Along the Barrow arch, traps of the Prudhoe Bay type may be expected. In the Prudhoe Bay field, the Sadlerochit pool was shown by Rickwood (1970) and Morgridge and Smith (1972) to be on a west-plunging anticlinal nose, faulted on both the north and south, and truncated and sealed by an unconformity to the east. The Lisburne pool, presumably, is similarly trapped.

Although nowhere commercially developed, the Carboniferous carbonate rocks of Alaska provide an immense potential resource for various industrial uses of limestone. In northern Alaska alone, thousands of cubic kilometers of limestone are exposed in the Brooks Range, either at the surface or within a hundred meters of the surface. No detailed chemical analyses have been made on these limestones, but the various carbonate facies that have been examined during field mapping and stratigraphic studies indicate a full range of shelf-carbonate types, ranging from pure chemical-grade lime mudstone through argillaceous and dolomitic limestone to pure dolomite. If industrial limestone is needed and if economic factors are favorable, the Carboniferous limestones of Alaska may become an invaluable asset.

REFERENCES CITED

Armstrong, A. K., 1970a, Carbonate facies and the lithostrotionid corals of the Mississippian Kogruk Formation, DeLong Mountains, northwestern Alaska: U.S. Geol. Survey Prof. Paper 664, 38 p., 14 pls., 37 figs.

———1970b, Mississippian dolomites from Lisburne Group, Killik River, Mount Bupto region, Brooks Range, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 54, no. 2, p. 251–264, 10 figs.

———1970c, Mississippian rugose corals, Peratrovich Formation, west coast, Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Prof. Paper 534, 44 p., 13 pls., 30 figs.

———1972a, Biostratigraphy of Mississippian lithostrotionoid corals, Lisburne Group, Arctic Alaska: U.S. Geol. Survey Prof. Paper 743–A, 28 p., 9 pls., 25 figs.

———1972b, Pennsylvanian carbonates, paleoecology, and rugose colonial corals, north flank, eastern Brooks Range, Arctic Alaska: U.S. Geol. Survey Prof. Paper 747, 21 p., 8 pls., 16 figs.

———1975, Stratigraphy and paleoecology of Carboniferous corals, Lisburne Group, Brooks Range, Arctic Alaska: Bulls. Am. Paleontology, v. 67, no. 287, p. 17–31, 5 figs.

Armstrong, A. K., and Mamet, B. L., 1970, Biostratigraphy and dolomite porosity trends of the Lisburne Group, *in* Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, Am. Assoc. Petroleum Geologists, Pacific, Sec., p. N1–N16, 12 figs.

———1974, Carboniferous biostratigraphy, Prudhoe Bay State 1, to northeastern Brooks Range, Arctic Alaska: Am. Assoc. Petroleum Geologists Bull., v. 58, no. 4, p. 646–660, 9 figs.

———1975, Carboniferous biostratigraphy, northeastern Brooks Range, Arctic Alaska: U.S. Geol. Survey Prof. Paper 884, 29 p., 16 figs.

———1977 [1978], Carboniferous microfacies, microfossils, and corals, Lisburne Group, Arctic Alaska: U.S. Geol. Survey Prof. Paper 849, 144 p., 47 pls., 19 figs.

Armstrong, A. K., Mamet, B. L., and Dutro, J. T., Jr., 1970, Foraminiferal zonation and carbonate facies of Carboniferous (Mississippian and Pennsylvanian) Lisburne Group, central and eastern Brooks Range, Arctic Alaska: Am. Assoc. Petroleum Geologists Bull., v. 54, no. 5, p. 687–698, 4 figs.

———1971, Lisburne Group, Cape Lewis–Niak Creek, northwestern Alaska: U.S. Geol. Survey Prof. Paper 750–B, p. B23–B34, 9 figs.

Beechey, F. W., 1831, Narrative of a voyage to the Pacific and Beering's Strait * * * 1825, 26, 27, 28: London, Henry Colburn and Richard Bentley, 2 v.

Bird, K. J., and Jordan, C. F., 1977, Lisburne Group (Mississippian and Pennsylvanian), potential major hydrocarbon objective of Arctic Slope, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 61, no. 9, p. 1493–1512, 11 figs.

Bowsher, A. L., and Dutro, J. T., Jr., 1957, The Paleozoic section in the Shainin Lake area, central Brooks Range, Alaska: U.S. Geol. Survey Prof. Paper 303–A, 39 p., 6 pls., 4 figs.

Brabb, E. E., 1969, Six new Paleozoic and Mesozoic formations in east-central Alaska: U.S. Geol. Survey Bull. 1274–I, 26 p., 10 figs.

Brosgé, W. P., and Dutro, J. T., Jr., 1973, Paleozoic rocks of northern and central Alaska, *in* Pitcher, M. G., ed., Arctic geology: Am. Assoc. Petroleum Geol. Mem. 19, p. 361–375, 15 figs.

Buckland, William, 1839, Geology, *in* Beechey, F. W., and others, The zoology of Captain Beechey's voyage * * * 1825, 26, 27, 28: London, H. G. Bohn, p. 157–180.

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U.S. Geol. Survey Bull. 800, 398 p., 22 pls. 3 figs.

Cairnes, D. D., 1914, The Yukon-Alaska International Boundary, between Porcupine and Yukon Rivers: Canada Geol. Survey Mem. 67, 161 p., 16 pls., 2 figs., 2 maps.

Churkin, Michael, Jr., 1973, Paleozoic and Precambrian rocks of Alaska and their role in its structural evolution: U.S. Geol. Survey Prof. Paper 740, 64 p., 24 figs.

Churkin, Michael, Jr., and Eberlein, G. D., 1977, Ancient borderland terranes of the North American Cordillera; Correlation and microplate tectonics: Geol. Soc. America Bull., v. 88, no. 6, p. 769–786, 6 figs.

Collier, A. J., 1906, Geology and coal resources of the Cape Lisburne region, Alaska: U.S. Geol. Survey Bull. 278, 54 p., 9 pls., 8 figs.

Dall, W. H., 1896, Report on coal and lignite of Alaska: U.S. Geol. Survey 17th Ann. Rept., 1895–96, pt. 1, p. 763–908. (See especially p. 864–865; Knowlton, F. H., Appendix I—Report on the fossil plants collected in Alaska in 1895* * *, p. 876–897; and Schuchert, Charles, Appendix II—Report on Paleozoic fossils from Alaska, p. 898–906.)

Douglass, R. C., 1971, Pennsylvanian fusulinids from southeastern Alaska: U.S. Geol. Survey Prof. Paper 706, 21 p., 7 pls., 9 figs.

Eberlein, G. D., and Churkin, Michael, Jr., 1970, Paleozoic stratigraphy in the northwest coastal area of Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Bull. 1284, 67 p., 2 pls., 31 figs.

Gordon, Mackenzie, Jr., 1957, Mississippian cephalopods of northern and eastern Alaska: U.S. Geol. Survey Prof. Paper 283, 61 p., 6 pls., 26 figs.

Grybeck, Donald, Beikman, H. M., Brosgé, W. P., Tailleur, I. L., and Mull, C. G., 1977, Geologic map of the Brooks Range, Alaska: U.S. Geol. Survey Open-File Map 77–166–B, 2 sheets, scale 1:1,000,000.

Loney, R. A., Condon, W. H., and Dutro, J. T., Jr., 1963, Geology of the Freshwater Bay area, Chichagof Island, Alaska: U.S. Geol. Survey Bull. 1108–C, 54 p., 2 pls., 1 fig.

Maddren, A. G., 1912, Geologic investigations along the Canada-Alaska boundary: U.S. Geol. Survey Bull. 520–K, p. K297–K314.

Mamet, B. L., and Armstrong, A. K., 1972, Lisburne Group, Franklin and Romanzof Mountains, northeastern Alaska: U.S. Geol. Survey Prof. Paper 800–C, p. C127–C144, 10 figs.

Mamet, B. L., and Skipp, Betty, 1970, Lower Carboniferous calcareous Foraminifera; preliminary zonation and stratigraphic implications for the Mississippian of North America:Cong. Internat. Stratigraphie Géologie Carbonifère, 6th, Sheffield, 1967, Compte rendu, v. 3, p. 1129–1146.

Mertie, J. B., Jr., 1930, Geology of the Eagle-Circle district, Alaska: U.S. Geol. Survey Bull. 816, 168 p., 12 pls., 6 figs.

———1937, The Yukon-Tanana region, Alaska: U.S. Geol. Survey Bull. 872, 276 p., 15 pls., 2 figs.

Morgridge, D. L., and Smith, W. B., Jr., 1972, Geology and discovery of Prudhoe Bay field, eastern Arctic Slope, Alaska, *in* King, R. E., ed., Stratigraphic oil and gas fields; classification, exploration methods, and case histories: Am. Assoc. Petroleum Geologists Mem. 16, p. 489–501.

Muffler, L. J. P., 1967, Stratigraphy of the Keku Islets and neighboring parts of Kuiu and Kupreanof Islands, southeastern Alaska: U.S. Geol. Survey Bull. 1241–C, 52 p., 1 pl., 15 figs.

Mull, C. G., and Mangus, M. D., 1972, Itkilyariak Formation; New Mississippian Formation of Endicott Group, Arctic Slope of Alaska: Am. Assoc. Petroleum Geologists Bull., v. 56, no. 8, p. 1364–1369, 6 figs.

Patton, W. W., Jr., and Dutro, J. T., Jr., 1969, Preliminary report on the Paleozoic and Mesozoic sedimentary sequence on St. Lawrence Island, Alaska: U.S. Geol. Survey Prof. Paper 650–D, p. D138–D143, 5 figs.

Patton, W. W., Jr., Tailleur, I. L., Brosgé, W. P., and Lanphere, M. A., 1977, Preliminary report on the ophiolites of northern and western Alaska, *in* Coleman, R. G., and Irwin, W. P., eds., North American ophiolites: Oregon Dept. Geology and Mineral Industries Bull. 95, p. 51–57.

Read, C. B., and Mamay, S. H., 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geol. Survey Prof. Paper 454–K, 35 p., 19 pls.

Reed, B. L., Nelson, S. W., Curtin, G. C., and Singer, D. A., 1978, Mineral resources map of the Talkeetna quadrangle, Alaska: U.S. Geol. Survey Misc. Field Studies Map MF–870–D, scale 1:250,000.

Reed, J. C., 1958, Exploration of Naval Petroleum Reserve No. 4 and adjacent areas, northern Alaska, 1944–53. pt. 1, History of the exploration: U.S. Geol. Survey Prof. Paper 301, 192 p., 3 pls., 101 figs.

Reiser, H. N., 1970, Northeastern Brooks Range—A surface expression of the Prudhoe Bay section, *in* Adkison, W. L., and Brosgé, M. M., eds., Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, Am. Assoc. Petroleum Geologists, Pacific Sec., p. K1–K14, 6 figs.

Richter, D. H., 1976, Geologic map of the Nabesna quadrangle, Alaska: U.S. Geol. Survey Misc. Inv. Map I–932, scale 1:250,000.

Richter, D. H., and Dutro, J. T., Jr., 1975, Revision of the type Mankomen Formation (Pennsylvanian and Permian), Eagle Creek area, eastern Alaska Range, Alaska: U.S. Geol. Survey Bull. 1395–B, 25 p., 8 figs.

Rickwood, F. K., 1970, The Prudhoe Bay field, *in* Adkison, W. L., and Brosgé, M. M., Proceedings of the geological seminar on the North Slope of Alaska: Los Angeles, Am. Assoc. Petroleum Geologists, Pacific Sec., p. L1–L11, 9 figs.

Rowett, C. L., 1969, Upper Palaeozoic stratigraphy and corals from the east-central Alaska Range, Alaska: Arctic Inst. North America Tech. Paper 23, 120 p., 13 pls., 20 figs.

Sable, E. G., and Dutro, J. T., Jr., 1961, New Devonian and Mississippian Formations in DeLong Mountains, northern Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 585–593, 4 figs.

Sando, W. J., Mamet, B. L., and Dutro, J. T., Jr., 1969, Carboniferous megafaunal and microfaunal zonation in the northern Cordillera of the United States: U.S. Geol. Survey Prof. Paper 613–E, 29 p., 1 pl., 7 figs.

Schrader, F. C., 1902, Geological section of the Rocky Mountains in northern Alaska: Geol. Soc. America Bull., v. 13, p. 233–252, pls. 40–43.

Smith, P. S., 1939, Areal geology of Alaska: U.S. Geol. Survey Prof. Paper 192, 100 p., 18 pls.

Smith, P. S., and Mertie, J. B., Jr., 1930, Geology and mineral resources of northwestern Alaska: U.S. Geol. Survey Bull. 815, 351 p., 34 pls., 22 figs.

Sohn, I. G., 1971, New Late Mississippian ostracode genera and species from northern Alaska: U.S. Geol. Survey Prof. Paper 711–A, 24 p., 9 pls., 3 figs.

Steidtmann, Edward, and Cathcart, S. H., 1922, Geology of the York tin deposits, Alaska: U.S. Geol. Survey Bull. 733, 130 p., 12 pls., 23 figs.

Wahrhaftig, Clyde, 1968, Schists of the central Alaska Range: U.S. Geol. Survey Bull. 1254–E, 22 p., 5 figs.

Wood, G. V., and Armstrong, A. K., 1975, Diagenesis and stratigraphy of the Lisburne Group limestones of the Sadlerochit Mountains and adjacent areas, northeastern Alaska: U.S. Geol. Survey Prof. Paper 857, 47 p., 12 pls., 25 figs.

Yochelson, E. L., and Dutro, J. T., Jr., 1960, Late Paleozoic Gastropoda from northern Alaska: U.S. Geol. Survey Prof. Paper 334–D, p. D111–D147, 3 pls., 7 figs.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1980 O— 311-344/88

2001

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110–M–DD

ON THE COVER

Swamp-forest landscape at time of coal formation: lepidodendrons (left), sigillarias (in the center), calamites, and cordaites (right), in addition to tree ferns and other ferns. Near the base of the largest *Lepidodendron* (left) is a large dragonfly (70-cm wingspread). (Reproduced from frontispiece in Kukuk, Paul (1938), "Geologie des Niederrheinisch-Westfälischen Steinkohlengebietes" by permission of Springer-Verlag, New York, Inc.)

The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—

M. Iowa, by Matthew J. Avcin and Donald L. Koch
N. Missouri, by Thomas L. Thompson
O. Arkansas, by Boyd R. Haley, Ernest E. Glick, William M. Caplan, Drew F. Holbrook, and Charles G. Stone
P. Nebraska, by R. R. Burchett
Q. Kansas, by William J. Ebanks, Jr., Lawrence L. Brady, Philip H. Heckel, Howard G. O'Connor, George A. Sanderson, Ronald R. West, and Frank W. Wilson
R. Oklahoma, by Robert O. Fay, S. A. Friedman, Kenneth S. Johnson, John F. Roberts, William D. Rose, and Patrick K. Sutherland
S. Texas, by R. S. Kier, L. F. Brown, Jr., and E. F. McBride
T. South Dakota, by Robert A. Schoon
U. Wyoming, by David R. Lageson, Edwin K. Maughan, and William J. Sando
V. Colorado, by John Chronic
W. New Mexico, by Augustus K. Armstrong, Frank E. Kottlowski, Wendell J. Stewart, Bernard L. Mamet, Elmer H. Baltz, Jr., W. Terry Siemers, and Sam Thompson III
X. Montana, by Donald L. Smith and Ernest H. Gilmour
Y. Utah, by John E. Welsh and Harold J. Bissell
Z. Arizona, by H. Wesley Peirce
AA. Idaho, by Betty Skipp, W. J. Sando, and W. E. Hall
BB. Nevada, by E. R. Larson and Ralph L. Langenheim, Jr., *with a section on* Paleontology, by Joseph Lintz, Jr.
CC. California, Oregon, and Washington, by Richard B. Saul, Oliver E. Bowen, Calvin H. Stevens, George C. Dunne, Richard G. Randall, Ronald W. Kistler, Warren J. Nokleberg, Jad A. D'Allura, Eldridge M. Moores, Rodney Watkins, Ewart M. Baldwin, Ernest H. Gilmour, and Wilbert R. Danner
DD. Alaska, by J. Thomas Dutro, Jr.

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1110-M-DD

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

FOREWORD

The year 1979 is not only the Centennial of the U.S. Geological Survey—it is also the year for the quadrennial meeting of the International Congress on Carboniferous Stratigraphy and Geology, which meets in the United States for its ninth session. This session is the first time that the major international congress, first organized in 1927, has met outside Europe. For this reason it is particularly appropriate that the Carboniferous Congress closely consider the Mississippian and Pennsylvanian Systems; American usage of these terms does not conform with the more traditional European usage of the term "Carboniferous."

In the spring of 1976, shortly after accepting the invitation to meet in the United States, the Permanent Committee for the Congress requested that a summary of American Carboniferous geology be prepared. The Geological Survey had already prepared Professional Paper 853, "Paleotectonic Investigations of the Pennsylvanian System in the United States," and was preparing Professional Paper 1010, "Paleotectonic Investigations of the Mississippian System in the United States." These major works emphasize geologic structures and draw heavily on subsurface data. The Permanent Committee also hoped for a report that would emphasize surface outcrops and provide more information on historical development, economic products, and other matters not considered in detail in Professional Papers 853 and 1010.

Because the U.S. Geological Survey did not possess all the information necessary to prepare such a work, the Chief Geologist turned to the Association of American State Geologists. An enthusiastic agreement was reached that those States in which Mississippian or Pennsylvanian rocks are exposed would provide the requested summaries; each State Geologist would be responsible for the preparation of the chapter on his State. In some States, the State Geologist himself became the sole author or wrote in conjunction with his colleagues; in others, the work was done by those in academic or commercial fields. A few State Geologists invited individuals within the U.S. Geological Survey to prepare the summaries for their States.

Although the authors followed guidelines closely, a diversity in outlook and approach may be found among these papers, for each has its own unique geographic view. In general, the papers conform to U.S. Geological Survey format. Most geologists have given measurements in metric units, following current practice; several authors, however, have used both metric and inch-pound measurements in indicating thickness of strata, isopach intervals, and similar data.

FOREWORD

This series of contributions differs from typical U.S. Geological Survey stratigraphic studies in that these manuscripts have not been examined by the Geologic Names Committee of the Survey. This committee is charged with insuring consistent usage of formational and other stratigraphic names in U.S. Geological Survey publications. Because the names in these papers on the Carboniferous are those used by the State agencies, it would have been inappropriate for the Geologic Names Committee to take any action.

The Geological Survey has had a long tradition of warm cooperation with the State geological agencies. Cooperative projects are well known and mutually appreciated. The Carboniferous Congress has provided yet another opportunity for State and Federal scientific cooperation. This series of reports has incorporated much new geologic information and for many years will aid man's wise utilization of the resources of the Earth.

H. William Menard

H. William Menard
Director, U.S. Geological Survey

CONTENTS