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CARBONIFEROUS LISBURNE GROUP OF THE ARCTIC NATIONAL WILDLIFE REFUGE, BROOKS RANGE, NORTHEASTERN ALASKA

PROGRESS REPORT SUMMARIZING INITIAL RESULTS OF 1988 RESEARCH

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ABSTRACT

The Lisburne Group of the northeastern Brooks Range is a major hydrocarbon target in the Arctic National Wildlife Refuge (ANWR). During the 1988 field season, we made a number of significant discoveries and have continued to expand our understanding of the stratigraphic framework, paleogeography and depositional history of the Lisburne Group and underlying Endicott Group. Specific results include :

1) recognition and analysis of widespread sandy limestones and fossiliferous sandstones at the base of the Lisburne Group (above the Kayak shale, possibly the Itkilyariak Formation). Continued studies will allow us to determine their distribution and paleogeography, allowing interpretation of the provenance of the sands and their regional significance.

2) recognition and documentation of the "Egaksrak Grainstones" (new informal unit) - a sequence of repeated intervals of cross-stratified bioclastic grainstone which formed as barrier shoals south of widespread lagoonal to supratidal dolomites of the age-equivalent Alapah Formation.

3) information on the Wahoo Formation - New age and microfacies information is now available for the upper 50m of the type section, indicating significant lateral facies changes in the upper Wahoo over a short distance (40 km). Detailed sections of the Wahoo Limestone were measured at Leffingwell Ridge and the Aichilik River ("the Wall"), focusing on cyclic stratigraphy and paleogeography.

4) conodont biostratigraphy and CAIs - Anita Harris (U.S. Geological Survey, Reston) has analyzed conodonts extracted from a number of our samples, providing age data, conodont alteration indices, and paleoenvironmental interpretations. Andrea Krumhardt (1989) has begun systematic biostratigraphic research on conodonts collected from a reference section of the Carboniferous Wahoo Formation in the eastern Sadlerochit Mountains.

In a general sense, the Lisburne Group lies transgressively over the Endicott Group with the contact being locally marked by an influx of quartzose sands, the Itkilyariak Formation. Corals locally developed very small build-ups over these sands but then pass upward into dark-colored lagoonal limestone and supratidal dolomite of the Alapah Formation, the best potential reservoir rock in the sequence. Locally, high-energy bioclastic shoals developed repeatedly in the Egaksrak region, forming a barrier to relatively stagnant lagoons farther to the north. Massive crinoidal limestones of the lower Wahoo formed in open-marine conditions signifying a major transgression in Late Mississippian time. Numerous lithologic cycles in the Pennsylvanian upper Wahoo developed due to fluctuations in relative sea-level and associated migrations of ooid shoals across a gently south-dipping carbonate ramp. Variable amounts of the upper Wahoo Formation have been removed due to erosion beneath the pre-Echooka unconformity, a major break in the geologic record.

INTRODUCTION

The Carboniferous Lisburne Group is a major potential hydrocarbon reservoir unit in the Arctic National Wildlife Refuge (ANWR; Bird and Jordan, 1977; Bird et al., 1987). Lisburne Group limestones and associated rocks extend across the Brooks Range from the Lisburne Peninsula eastward into Canada (700 km; Fig. 1; Armstrong and Mamet, 1977, 1978). These rocks formed as an extensive carbonate platform that was later deformed as part of the Brooks Range orogenic belt. A northern continental landmass shed clastic sediments of the Ellesmerian sequence southward onto this platform which have may represented a passive continental margin from Mississippian to Jurassic time.

Researchers at the University of Alaska Fairbanks have focused upon the Lisburne Group of the northeastern Brooks Range in the Arctic National Wildlife Refuge (ANWR), where moderately deformed parautochthonous rocks are remarkably similar to limestones of the Lisburne field at Prudhoe Bay (Fig. 2; Reiser, 1970; Armstrong and Mamet, 1974; Okland et al., 1987). Basically, our long-term goals involve determining the paleogeography and evolution of these rocks. Our paleogeographic reconstructions are being integrated with structural reconstructions by Wallace and others to better define the tectonic evolution of the Brooks Range and its relationship to the circumarctic region.

Over the last three years, Watts and his students have established a solid foundation of understanding of the Lisburne Group adjacent to the ANWR coastal plain (Fig. 3). The research was supported petroleum industry sponsors and done in cooperation with the Alaska Division of Geological and Geophysical Surveys and U.S. Geological Survey. We have examined and sampled more than 20 stratigraphic sections that help to define the anatomy, depositional environments, depositional history, and paleogeography of the Lisburne Group in this economically important area (Fig. 3). In 1988, we addressed a number of important problems and made some unexpected discoveries. Specific results include work on the:

1) "Itkilyariak Formation" (expanded definition) - Widespread sandy limestones and fossiliferous sandstones at the transition between the Endicott and Lisburne Groups were described and sampled at a number of localities (Figs. 3, 4 & 6).

2). "Egaksrak Grainstones" (new unit) - a sequence of repeated intervals of cross-stratified bioclastic grainstone formed as barrier shoals south of widespread lagoonal to supratidal dolomites of the age-equivalent upper Alapah Formation (Figs. 3, 4 & 7).

3) Wahoo Formation - New age and microfacies information are now available for the upper 50m of the type section (Figs. 3, 4, 8 & 9). Detailed sections of the Wahoo Limestone were measured and sampled at Leffingwell Ridge and the Aichilik River ("the Wall").

4) Conodont biostratigraphy and CAIs - Anita Harris has analyzed conodonts extracted from a number of our samples, providing age data, paleoenvironmental interpretations, and conodont alteration indices (Fig. 10). Masters student, Andrea Krumhardt, has begun systematic biostratigraphic research on conodonts from the Carboniferous Wahoo Formation of the eastern Sadlerochit Mountains.

In the near term, we plan to continue our research in the northeastern Brooks Range, completing microscopic and biostratigraphic analyses of our present collections of samples. The M.S. thesis studies of the Lisburne Group of Teresa Imm (western Sadlerochit and Shublik Mountains) and Paul Gruzlovic (north-south facies changes along the Canning River transect) are nearing completion (Fig. 3).

We are lucky to have experts on biostratigraphy of the Lisburne Group involved in our research program. Dr. Bernard Mamet, who established the zonation for foraminifera and algae in Lisburne Group, has determined the biostratigraphy of many of our thin sections. Anita Harris, best known for her work in establishing the Conodont Alteration Index (a means of geothermometry), has analyzed conodonts extracted from our samples and is co-supervising the thesis research of Andrea Krumhardt, one of Watts' students.

Students working under Watts' supervision are each addressing specific geologic problems critical to understanding the nature and origin of the Lisburne Group in ANWR. In addition to his own topical studies, Watts is integrating the findings of all the researchers into a regional paleogeographic framework. Such studies will hopefully continue in the future as we extend our understanding to encompass other parts of the Brooks Range. Our plans for continued research are outlined in our 1989 proposal.

INITIAL RESULTS OF SPECIFIC TOPICAL RESEARCH CONDUCTED IN 1988

"ITKILYARIAK FORMATION" - FOSSILIFEROUS SANDSTONES AND SANDY LIMESTONES, EASTERN ANWR.

Sandy limestone and fossiliferous quartzose sandstone were discovered in the basal Lisburne Group near the Okpilak batholith in our 1986 research program. In our 1988 research, we found that fine-grained quartz sandstone is locally (near the Okpilak batholith) the dominant lithology the transition between the Endicott and Lisburne Groups. These sands overlie the typical Endicott Group (Kekiktuk Formation and Kayak Shale) and may be equivalent to the Itkilyariak Formation of Mull and Mangus (1972) which occurs in the Prudhoe Bay area (Figs. 2, 3 & 4). These marine sands occur to the north and east of the Okpilak Batholith. In 1988, a number of stratigraphic sections of the unit were measured between the Jago and Aichilik Rivers, documenting significant lateral facies changes (Figs. 3 & 6).

<u>Lithofacies</u>

<u>Crinoidal limestone with very coarse quartz sand</u>

Fossiliferous grainstone containing very coarse-grained to granular, subangular, clear, quartz sand is perhaps the most distinctive lithology in the "Itkilyariak Formation". These coarse-grained sediments contain pelmatazoans (crinoids) and other coarse-grained fossils in addition to the quartz sand. Channelized beds, cross-stratification and plane lamination indicate high-energy conditions.

<u>Fossiliferous sandstone and sandy limestone</u>

Very fine to fine grained, well-sorted, quartzose sandstone is the dominant lithology north of the Okpilak batholith and is common at other localities. These sandstones contain variable amounts of bioclastic carbonate sediment grading into sandy bioclastic limestone. Most sandstones are thin-bedded (10-20 cm) or massive but some thicker (25-100 cm) lenticular beds of fossiliferous sandstone are intercalated with siltstone and silty bryozoan wackestone.

Silty bryozoan wackestone/bafflestone and siltstone

Dolomitic siltstone containing variable amounts of carbonate (primarily bryozoans) is commonly interbedded with fossiliferous sandstone and sandy limestone. Silty bryozoan wackestone typically contains intact fronds of fenestrate bryozoans, some in growth position being silty bafflestones. It is unclear how bryozoans were able to thrive in such a silty environment, but future petrographic analyses may yield some insights.

Coralline boundstone/limestone

In a number of sections, abundant corals occur immediately above the sandy limestones. Some corals, including rugose, syringoporid, favositid and other forms, are in growth position (boundstone) whereas others are slightly displaced. The best developed interval of coralline boundstone is at Leffingwell Ridge, forming a discrete sequence bounded by black shales of the Kayak Shale. The lack of lateral continuity suggests that these formed as a coral bioherm or small buildup of limited lateral extent.

Lateral Facies Changes - Localities

Okpilak batholith

The Lisburne Group immediately north of the Okpilak batholith is overturned and highly attenuated due to the strain of the batholith being thrust northward over it. However, quartzose sands mark the base of the unit. At the westernmost fork of McCall Creek, a window of relatively unstrained Itkilyariak Formation and Endicott Group is well preserved beneath the structurally higher, overturned sequence. Channelized beds of granular sandy limestone indicate that the sequence is upright. Fine-grained, very well-sorted, calcareous, quartzose sandstone is the dominant lithology and contains variable amounts of marine fossils. Time did not allow us to measure or describe the section in detail, thicknesses and stratigraphy shown on figure 4 are approximate estimates.

"The Wall"

A series of stratigraphic sections of the "Itkilyariak Formation" were described and measured along "the Wall" (the next belt of Ellesmerian rocks south of Leffingwell Ridge) between the Aichilik and Jago Rivers (Figs. 3 & 6; Bader and Bird, 1986). Significant lateral facies changes suggest that the sands were derived from near the Okpilak batholith but more sections must be measured to fully understand facies relationships.

Jago Stock

Over the Jago Stock, the Endicott Group (Kayak Shale) passes upward into limestones of the Lisburne Group without intervening quartzose sandstones of the "Itkilyariak Formation". The Kekiktuk Formation here consists of only 5m of thin to medium bedded (5-20 cm), coarse to very coarse- grained, quartzose sandstones which passes upward into an equally thin interval of Kayak Shale (<5 m). The Kayak Shale is poorly exposed but includes black, calcareous shale and passes upward into dark-colored, bioturbated, peloidal lime mudstone and dolomite, typical of the lower Alapah Formation (Lisburne Group). The Lisburne Group which overlies the Jago Stock is deformed and shows evidence of detachment faulting and folding and northward displacement. The amount of displacement is unknown. If the displacement is small, the lack of the "Itkilyariak Formation" indicates either nondeposition or erosion, possibly suggesting that the Jago stock was a paleotopographic high.

Jago

Along the northern flank of "the wall" near the divide between the Jago and Aichilik Rivers (2 km east of the Jago Stock), the "Itilyariak Formation" is very well exposed on a cliff adjacent to the saddle formed by the Kayak Shale (Fig. 3 & 6; section 88E). Thick (up to 490 cm), lenticular intervals of fossiliferous sandstone show channelization, cross-stratification and indistinct plane lamination. The thicker intervals of sandstone show coarsening-upward trends from fine-grained to very coarse-grained. Beds of sandstone are separated by dolomitic silty bryozoan wackestone with large fenestrate bryozoan fronds. The top of the unit is poorly exposed and rubble covered but passes upward into sandy coralline dolomite with other fossils. The underlying Kayak Shale is poorly exposed but apparently thick (95 m estimated, possibly structurally thickened) and the Kekiktuk Formation is thin and difficult to distinguish from underlying pre-Mississippian quartzite.

Upper Aichilik

An interesting section is exposed near the ridgetop of "the Wall" of the upper Aichilik River (section 88KW15, Figs. 3 & 6). The sequence passes from very coarse, well-sorted quartzose sandstones of the Kekiktuk Formation into black siltstone and very fine to fine sandstone of the Kayak Shale. This is overlain by a sequence of fossiliferous sandstones and siltstones, typical of the "Itkilyariak Formation", which pass upward into limestone. The limestones show a succession from crinoidal packstone to bryozoan wackestone and coralline boundstone, similar to the limestones in the Kayak Shale at Leffingwell Ridge. The corals include a variety of rugose and colonial corals such as *Syringopora*.

Aichilik

Just west of the main Aichilik River (section 88D, Fig. 3 & 6), a well-exposed section of "Itkilyariak Formation" seems to be distal relative to coarser-grained sandstones near the Okpilak batholith. Intervals of sandstone are thinner (50-210 cm) and finer grained (typically very fine to fine grained). The dominant lithology is dolomitic siltstone and silty bryozoan wackestone and bafflestone with large bryozoan fronds. Rugose corals occur in fossiliferous limestone at the top of the unit.

Egaksrak

The "Itkilyariak Formation" is partially exposed at the base of section 88C between the Aichilik and Egaksrak Rivers (Figs. 3, 6 & 7). The unit consist of thick-bedded (55 cm), very fine to fine grained, well-sorted, fossiliferous sandstone. The upper part is rubbly but is coarser grained (fine to medium) and locally shows plane lamination. Moldic porosity after bioclastic grains (crinoids and brachiopods) is evident at base of unit. Although incompletely exposed, sandstones here are thicker and coarser than those at the Aichilik River (section 88D, Fig. 3 & 6). The fining-eastward trend between the Jago and Aichilik Rivers must have changed, coarsening significantly at the Egaksrak section. Thus, the paleogeography and patterns of sediment distribution for the "Itkilyariak Formation" are not yet completely understood.

Leffingwell

On the south side of Leffingwell Ridge (section 86Y, Figs. 3 & 6), an interval of limestone is bounded above and below by black shale of the Kayak Formation. The unit is similar to the "Itkilyariak Formation" in some respects but differs in that it is overlain by black shale rather than passing gradationally upward into limestone of the Lisburne Group. The interval begins with bioturbated sandy limestone and crinoidal limestones and passes upward into bryozoan wackestone which are overlain by coralline boundstone. The corals show an upward increase in diversity and include rugose, favositid, and tabulate forms. The boundstone is overlain sharply by black shale and a single bed of black peloidal limestone. The stratigraphic relationship between this limestone interval and the "Itkilyariak Formation" are uncertain, requiring further study.

Interpretation - Initiation of Carbonate Sedimentation

A major influx of quartzose sand preceded the development of the Lisburne carbonate platform. Fine-grained sandstones tend to be very well-sorted and contain variable amounts of marine fossils suggesting that they represent near-shore marine sands. Periodic channelized beds of crinoidal grainstone containing subangular quartz granules are relatively high-energy deposits derived in-part from a source of coarse crystalline quartz and mixed with normal marine fossils. The fossiliferous sands apparently formed on the flanks of a source of coarse quartzose terrigenous sands, possibly the Okpilak batholith. In the proximal deposition environments, fine-grained fossiliferous sands were cut by channels filled with the granular limestones, possibly representing storm deposits. In distal environments, calcareous silts were stabilized by fenestrate bryozoans which alternate with finer grained sands, storm deposits. Problems exist with this model; particularly identifying the source of terrigenous sediments and increased thicknesses of sands farther to the east (section 88C).

Proposed Future Research

We would like to continue our analyses of the "Itkilyariak Formation" sandstones, addressing the following questions:

1) How extensive are these sands and what is the significance of lateral facies changes in the unit? Do the geometry and compositional variations in the unit help to constrain environmental interpretation or help in determining source area?

2) Were the sands derived from erosion of the Okpilak batholith? If so, why aren't there any feldspars? Perhaps heavy minerals extracted from insoluble residues will provide some clues about provenance.

3) Are the sands age equivalent to the Itkilyariak Formation at Prudhoe Bay? Do the sands reflect a low-stand of eustatic sea level or tectonic uplift of some source of quartzose sands?

4) What is the stratigraphic relationship of the sands to the Lisburne Group proper? Did the sands provide a relatively stable substrate for the establishment of the Lisburne carbonate platform in this area?

5) What is the petroleum reservoir potential of these sands?

EGAKSRAK GRAINSTONE

Watts discovered and documented an interval of repeated sequences of cross-stratified bioclastic grainstone are a lateral equivalent of widespread dark-colored lime mudstone, dolomite and lesser evaporites of the Alapah Formation. These grainstones formed as barrier shoals along the southern margin of the extensive lagoons and arid tidal flats of the Alapah Formation (Fig. 4; Armstrong, 1974; Armstrong and Bird, 1976). These distinctive deposits are informally termed the Egaksrak Grainstone after a well-exposed section between the Egaksrak and Aichilik Rivers on the north flank of "the wall" (section 88C, Figs 4 & 7). The grainstones appear to be localized, thinning westward beyond the Aichilik River; their eastward extent has not been determined.

At the base of the Lisburne Group, fossiliferous sandstone and sandy limestone of the "Itkilyariak (?) Formation" (see above) form a distinct mappable horizon characterized by its yellow to orange coloration. Unfortunately, large accumulations of limestone talus obscure most of the lower part of the Lisburne Group. Above this covered interval (90 m), dark-grey to black, peloidal limestones of the Alapah Formation contain oncolites, gastropods, and other fossils which indicate a lagoonal environment. Dark-colored, laminated, pyritiferous intervals alternate with highly bioturbated, fossiliferous limestones, commonly containing in-situ articulated brachiopods. Stagnant lagoonal conditions alternated with periods of better water circulation which became dominant upsection where bioturbated, fossiliferous limestones alternate with grainstones of the Egaksrak Grainstone.

The Egaksrak Grainstone begins with the first interval of cross-stratified, bioclastic grainstone and is comprised of 6-7 thick intervals grainstone, stacked shoal deposits, alternating with muddy, fossiliferous limestone. The intervening muddy limestones contain a variety of fossils including pelmatazoans (crinoids), bryozoans, and brachiopods which indicate normal marine salinities. Large fronds of fenestrate bryozoans locally occur in growth position (bafflestones) suggesting quiet water conditions, either below wave-base or in quiet lagoons. Petrographic analyses may help to distinguish lagoonal from open-marine deposits, in order to better define the local sea-level curve for the section (Fig. 5).

Conodont biostratigraphy indicates a middle Meramecian to Chesterian age (Late Mississippian and possibly younger; A. Harris, written comm., 1988). These preliminary age data indicates that the Egaksrak Grainstone is age-equivalent to the Alapah Formation farther to the north and northwest. CAI values for the rocks range from 5.0-6.0 indicating temperatures of at least 300°C, among the highest seen in ANWR (Fig. 10). More precise age dating will probably be obtained following biostratigraphic zonation of foraminifera and algae by Mamet.

WAHOO LIMESTONE

Wahoo Type Locality - Redefined

Conodont biostratigraphy has also shed light on the age of the Wahoo Formation at the type locality in southwest Mt. Michelson quad (section 87Z, Figs. 3, 8 & 9). The upper 50m of the Wahoo Limestone is Morrowan to Early

Atokan in age (Early Pennsylvanian; Anita Harris, written comm., 1988), rather than Permian as suggested by earlier workers (Brosge et al., 1962). It consists of dark-colored argillaceous, spicular limestones with lesser fossiliferous limestone and thin black shale and calcareous shale intervals, suggesting a relatively deep-marine environment (Fig. 9; Watts et al., in press). The majority of the Wahoo is a massive, cliff-forming unit composed of fossiliferous (crinoidal) limestone ranging in age from Mississippian (Chesterian) to Pennsylvanian (Morrowan; Anita Harris, written comm., 1988).

As previously stated (Watts, 1988), the former "upper Wahoo Formation" (Brosge et al., 1962) is actually a calcareous facies of the Echooka Formation characterized by sandy, argillaceous limestone and lesser calcareous shale, all with distinctive pyrite nodules. This is overlain by "normal" Echooka Formation comprised of glauconitic sandstone with chert-pebble and shell lag deposits at the bases of repeated graded beds having strongly bioturbated tops. Characteristic *Zoophycus* trace fossils occur in both the calcareous and glauconitic facies of the unit.

Major stratigraphic differences exist between the Wahoo Formation at the type section and that of the Sadlerochit Mountains, Shublik Mountains, Fourth Range and Plunge Creek (Gruzlovic, 1988). These stratigraphic changes appear to be due to paleogeographic changes from ooid shoals in the north to deep-marine deposits farther to the southwest. The ooid shoals formed on a gently sloping, southward-sloping ramp but the nature of the transition into the deep-marine deposits is unknown, requiring analyses of the Lisburne Group exposed in the intervening region.

Northern Aichilik Transect - Leffingwell and Aichilik ("the wall") sections

In 1986 and 1987, Watts began work on a well-exposed section along Leffingwell Ridge west of the Aichilik River. In 1988, Julie Dumoulin of the U.S. Geologic Survey completed measuring and sampling (at 0.5 m) the Pennsylvanian Wahoo Formation as part of her Ph.D. studies at the University of California, Santa Cruz*. She worked directly with Watts on this project and assisted with studies north of the Okpilak batholith.

An excellent section of the entire Lisburne Group is exposed along the east bank of the Aichilik River where it cuts across "the wall". Watts measured, described and sampled (at 0.5m intervals) the upper part (130m) of the section. Numerous carbonate lithologic cycles characterize the unit and include oolitic grainstone similar to those in the upper Wahoo Formation. Unfortunately most of these carbonates are badly strained, having elliptical ooids and flatten crinoid ossicles. Future petrographic studies of the samples may provide information on microfacies and foram age determinations, but the original depositional textures may been obliterated by the strain.

LISBURNE GROUP OF THE OKPILAK BATHOLITH

The Lisburne Group immediately north of the Okpilak batholith occur as part of an overturned sequence of Ellesmerian rocks which have been overthrust by rocks of the Okpilak Batholith. The Lisburne Group here is highly attenuated, being only 90 m thick, a fraction of its normal thickness. A strong bedding parallel shear fabric shows pervasive slickensides and is nearly a mylonite. Intense deformation is apparent in intervals having early diagenetic chert bands.

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* The U.S. Geological funded Dumoulin's work so a preliminary report on her work will not be provided to our industrial sponsors.

Conodont biostratigraphy of the Wahoo Formation, eastern Sadlerochit Mountains

Andrea Krumhardt (M.S. student at UAF) is doing a detailed study on the conodont biostratigraphy of the Wahoo Formation at the "Sunset Pass" section in the eastern Sadlerochit Mountains (Wood and Armstrong, 1975). Krumhardt is working with Anita Harris at the U.S.G.S. in Reston from February to April 1989, processing her samples and learning techniques of conodont biostratigraphy. The "Sunset Pass" section is the thickest known section of the Pennsylvanian upper Wahoo, is remarkably similar to the Wahoo Formation occurring in the Lisburne Field at Prudhoe Bay, and is a good hypostratotype section for the unit (cf., Hedberg, 1976).

A goal of the study is to independently determine the age of the lower and upper Wahoo subunits, particular the contact between the units. The Mississippian-Pennsylvanian boundary in this section is apparently conformable (Mamet and Armstrong, 1984) and worthy of more detailed biostratigraphic study. The upper Wahoo Formation includes well-developed lithologic cycles typically containing oolitic grainstones, a cyclic stratigraphy possibly useful in correlation (Carlson, 1987; Carlson and Watts, 1987). Conodont biostratigraphy will provide an independent means of biostratigraphic correlation that might be traceable into deeper water facies where forams and algae are typically lacking. Conodonts will also provide paleoenvironmental information that might be closely tied to particular lithologies. Ultimately, we hope to integrate our conodont biostratigraphy data with existing information on lithologic cycles and the biostratigraphy of forams and algae in order to enhance our correlations between different sections.

The general stratigraphic sequence has been maintained with sandy limestones at the stratigraphic base passing upward into bryozoan wackestone and dolomite. Crinoidal packstone and grainstone at the top of the unit may represent the lower Wahoo Formation. The amount of shearing decreases rapidly away from the batholith. A window of upright Itkilyariak Formation structurally beneath this overturned limb is essentially undeformed. Another exposure of the Lisburne Group farther to the north at the mountain front is relatively undeformed. In 1989, we would like to measure a well-exposed section at the mountain front (cf. Sable, 1977; Bader and Bird, 1987), contrasting the degrees of deformation and depositional history of the Lisburne Group with that of adjacent areas.

CONODONT ANALYSES

Anita Harris has provided us with useful biostratigraphic ages, conodont alteration indices (CAIs, indicators of thermal maturation) and paleoenvironmental interpretations for samples collected from a number of localities. Some of these results are discussed above along with discussions of specific areas and other material is presently under analysis. Present results on geothermometry include a compilation of CAI values across ANWR (Fig. 10) and age data from reconnaissance studies of the Bathtub Ridge are summarized below.

Geothermometry - Conodont Alteration Indices

Figure 10 summarizes the CAI values obtained as of February 1989. Some interesting trends are apparent and may be related to variations in the structural development and tectonic burial history of the northeastern Brooks Range in ANWR. The range front region has the lowest CAI values, particularly the Sadlerochit Mountains which has CAI's of 3.5 to 4.0 (200°C, slightly overmature). CAIs increase progressively southward across the Shublik Mountains to the Fourth Range. Leffingwell Ridge also has relatively low CAIs of 4.0-4.5 (200-250°C). The Lisburne Group of "the wall" has high CAI values (5.5 to 6.0; >300°C) suggesting significant burial (tectonic?) and associated heating. The Wahoo Lake area shows similar high CAI values, suggesting similar depths of tectonic burial. Variations in CAI values within individual sections suggests that the heat may have been transmitted by hydrothermal fluids. The Bathtub Ridge area has lower CAI values, 4.0-4.5 (200-250°C) possibly continuing to decline into the higher thrust sheets (3.5-4.5; >145-180°C; i.e. the Kongakut thrust sheet of Wallace et al., 1988).

Ages of the Lisburne Group of Bathtub Ridge

In 1987, Watts conducted reconnaissance studies of a number of relatively complete and well-exposed stratigraphic sections near Bathtub Ridge, collecting samples for conodont analyses. At Cottonwood Creek (northeast of Bathtub Ridge), a very thick, complete section of the Lisburne Group is comprised of three mappable lithologic units. The upper part of the unit is a thick interval of massive fossiliferous limestone which is lithologically similar to the lower Wahoo Limestone (mostly upper Mississippian) of northern ANWR, but conodonts indicate a Morrowan to Atokan (Early to Middle Pennsylvanian) age for the top of the unit (Anita Harris, pers. comm., 1988). This is similar to the Atokan age dates (foram zone 21) for a section northwest of Bathtub Ridge (Armstrong and Mamet, 1975). The Lisburne is unconformably overlain by shale and slate of the Echooka Formation which includes fossiliferous limestones farther upsection.

On the south flank of Bathtub Ridge, the Lisburne Group of the Drain Creek Duplex (Wallace et al., 1988) is lithologically similar to that described above but the contact with the Kayak Shale is not exposed due to structural detachment at a higher stratigraphic level. Watts collected conodont samples from the contacts of the major mapping units within the Lisburne Group. Conodonts indicate a middle Meramecian to late, but not latest, Chesterian age (Late Mississippian) for the top of the unit, much older than that of Cottonwood Creek (Anita Harris, written comm., 1988). We located a number of well-exposed incomplete sections which could be measured as a v section, but have yet to find a single representative section of the unit, particularly lacking its contact with the underlying Kayak Shale.

Farther south, the Kongakut thrust sheet of Wallace and others (1988) has a relatively complete stratigraphic succession including the Endicott, Lisburne and Sadlerochit Groups. The lower part of the Lisburne Group consists of dark-colored, fossiliferous limestone, locally argillaceous and is apparently younger than middle to late Meramecian (Late Mississippian; Harris, pers. comm., 1988). Thin intervals of black bedded chert form discrete marker beds in the unit. The upper part of the Kongakut thrust sheet was not observed in my studies but apparent occurs farther to the east at Armstrong's Kongakut section. Mamet and Armstrong (1975) indicate that the top of the Lisburne Group in the Kongakut River section is Late Mississippian (Chesterian, zone 18) with at least 200m of Wahoo Limestone missing beneath the pre-Echooka unconformity (compared to that north of Bathtub Ridge along the Aichilik River and at Cottonwood Creek). A Mississippian age of the top of the Lisburne Group indicates either pre-Echooka erosion and/or nondeposition. This suggests an affinity to Lisburne Group rocks of the Endicott Allochthon which are typically Mississippian at the top (Armstrong and Mamet, 1977, 1978). Variations in the age of the uppermost Lisburne Group farther south in the Arctic quadrangle may also have structural significance (Brosge', pers. comm., 1989.

The conodont data and reconnaissance field studies provide a solid foundation for continued research in the Bathtub ridge region. In the future, detailed stratigraphic studies will provide information on age and microfacies required to develop paleogeographic models and to unravel the depositional history and structure of this part of the northeastern Brooks Range.

SUMMARY

Our research during the 1988 field season focused on the eastern part of ANWR and has resulted in a better understanding of the paleogeography and depositional history of the area. We are tentatively proposing some new stratigraphic units that should help us to focus on some unresolved problems in our continued research program. Conodont data provided by Anita Harris is helping us to determine the ages, stratigraphic relationships and thermal history of the Lisburne Group across ANWR. Our research provides a regional stratigraphic and paleogeographic framework that can be extrapolated northward to predict the nature of the Lisburne Group in the subsurface of the ANWR coastal plain.

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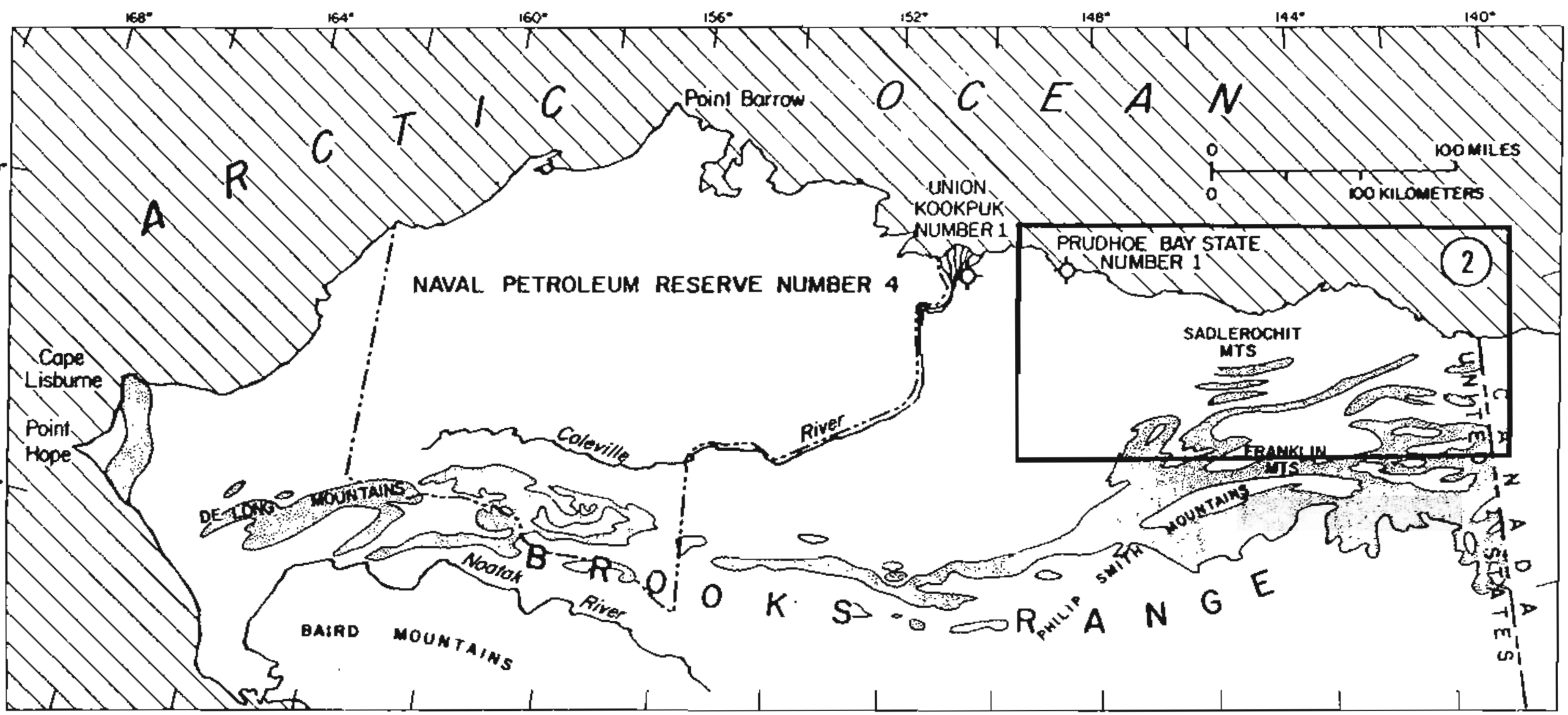

Figure 1 - Map shows the distribution of the Lisburne Group across the Brooks Range (modified after Armstrong and Mamet, 1977).

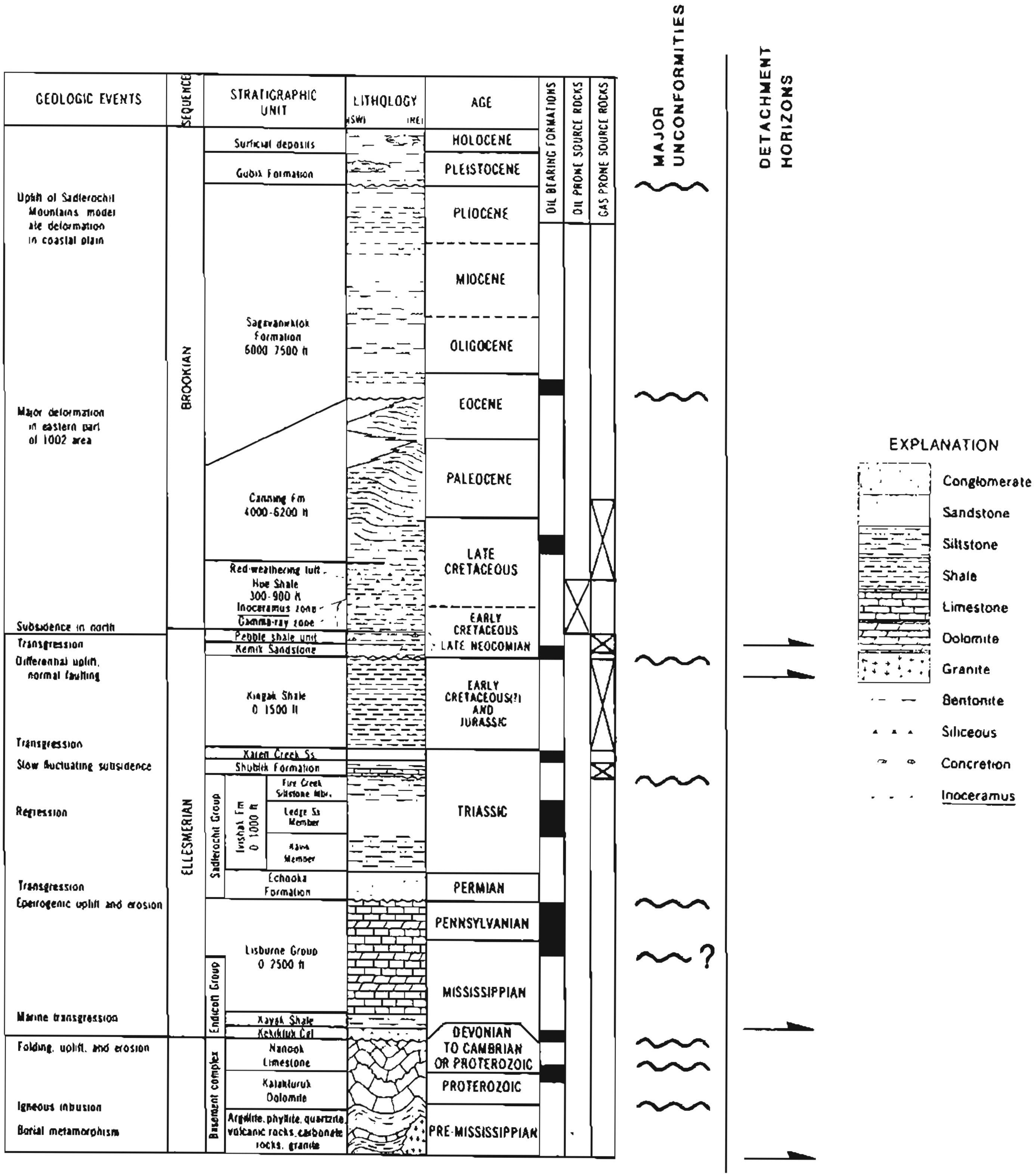

Figure 2 - Stratigraphic column for the northeastern Brooks Range/ANWR shows position of Endicott and Lisburne Groups in lower Ellesmerian sequence (modified after Bird and Molenaar,1987).

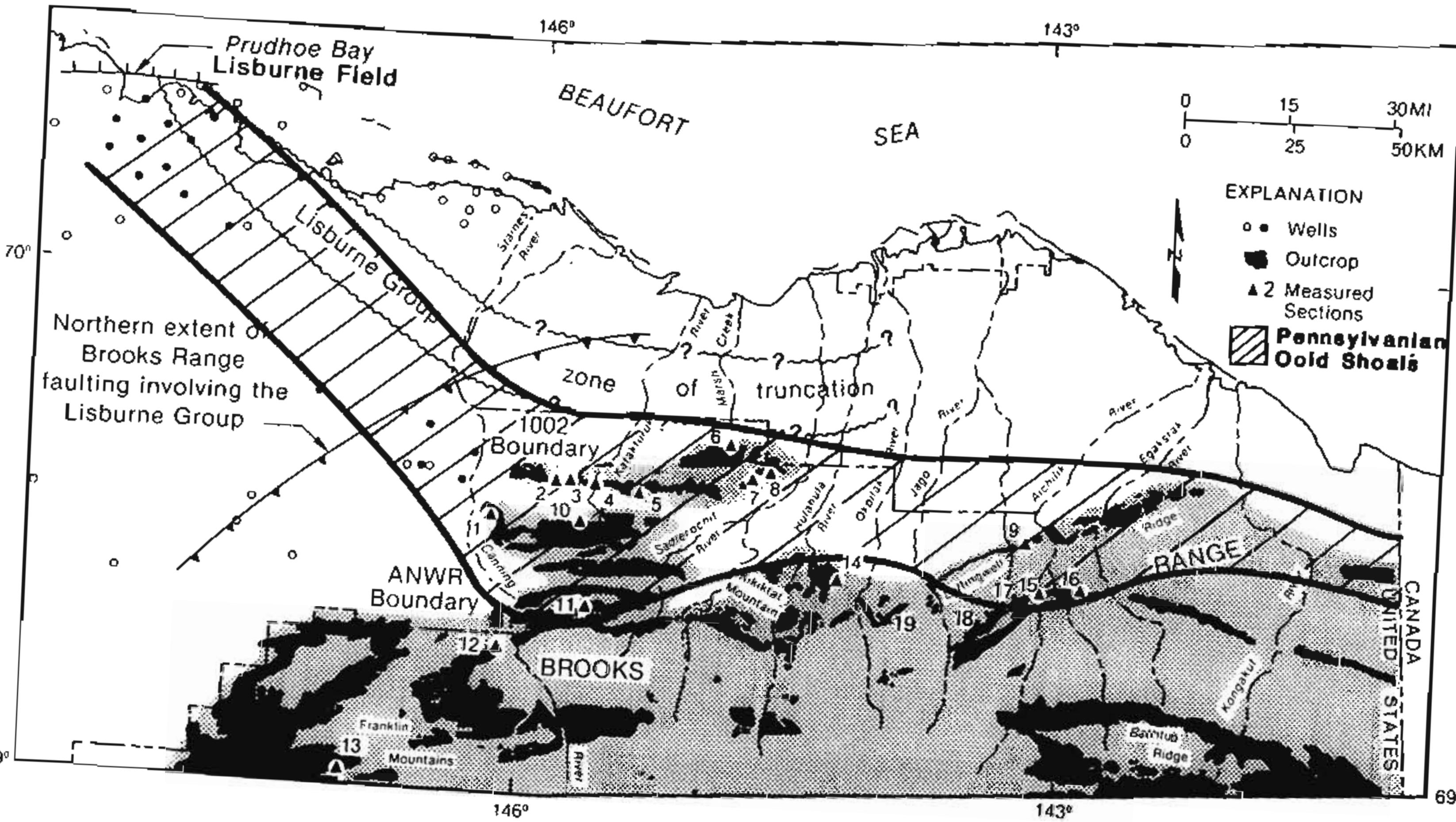

Figure 3 - Map shows distribution of Lisburne Group exposures in ANWR and location of sections measured by University of Alaska researchers (modified after Bird and Molenaar, 1987)

LISBURNE GROUP STRATIGRAPHIC SECTIONS

MEASURED BY UNIVERSITY OF ALASKA GEOLOGISTS

1 - Western Shublik Mountains [1],	section 86 O&P
2 - Western Sadlerochit Mountains [1],	section 86 M
3 - Western Sadlerochit Mountains [1],	section 86 N
4 - Katakturuk Canyon [1],	section 86 I-L
5 - Central Sadlerochit Mountains [2],	section 86 Z
6 - Marsh Creek [3],	section 86 D
7 - Ledge Creek [3],	section 86 C
8 - Sunset Pass [3],	section 86 A
" " [5],	section 88 A
9 - Leffingwell Ridge [6],	section 86 X&Y, 87V
10 - Central Shublik Mountains [4],	section 87 A-C
11 - Fourth Range [4],	section 87 D&E
12 - Plunge Creek [4],	section 87 F&G
13 - Wahoo Lake type section [2],	section 87 Z&Y
14 - Old Man Creek [2],	section 87 X
15 - Aichilik (Wahoo section) [2],	section 88 F
16 - Egaksrak [2],	section 88 C
17 - Aichilik (Itkilyariak section) [2],	section 88 D
18 - Upper Aichilik [2],	section 88 E
19 - Okpilak [2],	section 88KW10

1 - sections measured by Teresa Imm
2 - " " " Keith Watts
3 - " " " Randall Carlson
4 - " " " Paul Gruzlovic
5 - " " " Andrea Krumhardt
6 - " " " Jullie Dumoulin and Keith Watts

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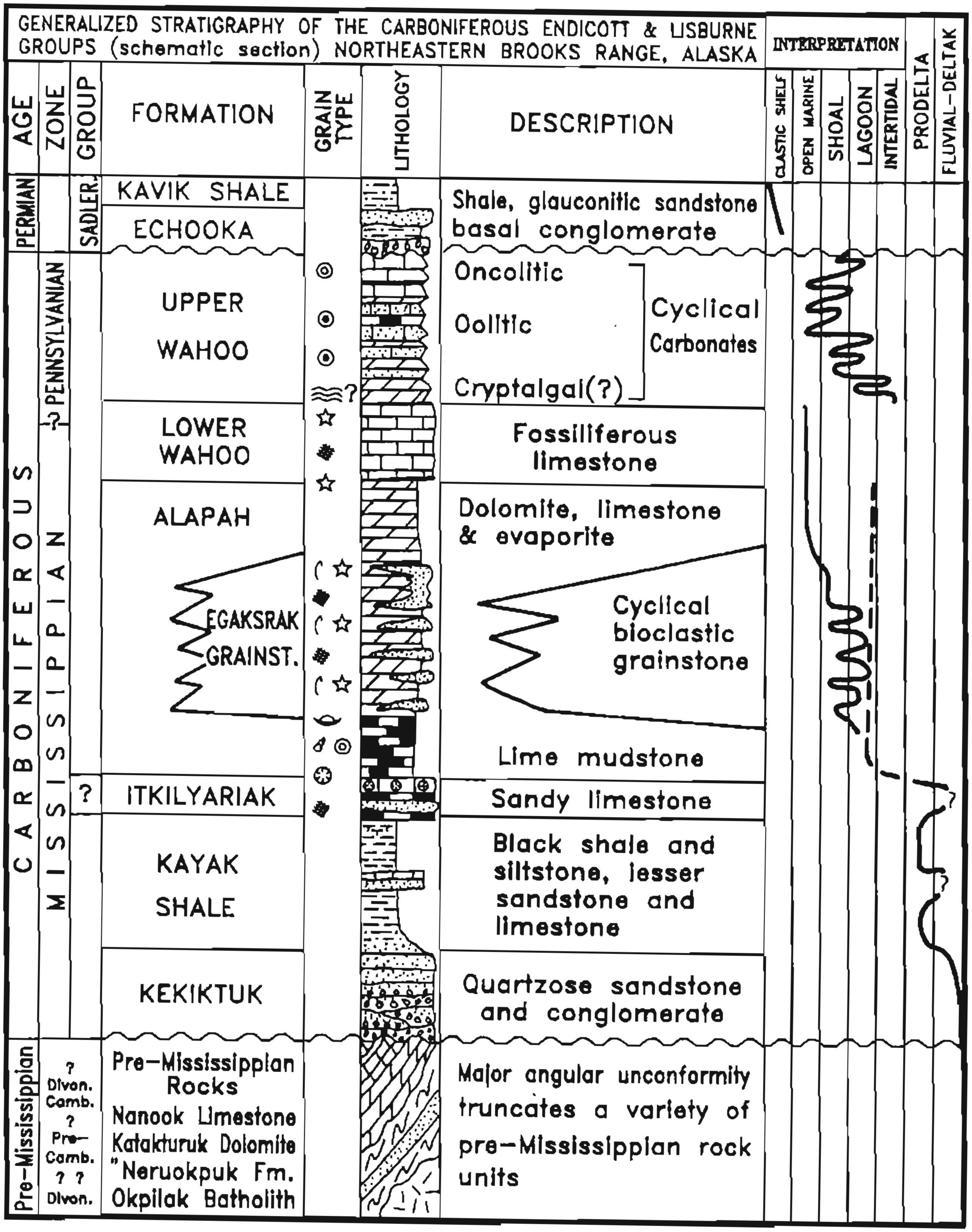


Figure 4 - Generalized stratigraphy of the Endicott and Lisburne Groups in the northeastern Brooks Range and ANWR (schematic). See figure 5 for key to symbols.

LITHOLOGIES

- Grainstone
- Packstone
- Wackestone
- Lime Mudstone
- Dolomite
- Dolomite Limestone
- Calcareous Dolomite
- Mudstone, Shale
- Siltstone
- Sandstone
- Sandy Limestone
- Silty Limestone
- Breccia
- Conglomerate

DIAGENETIC FEATURES

- chert nodules
- geoids filled with quartz and/or calcite
- stylolites

py = pyrite
gl = glauconite
fluor = fluorite
bit = bitumen
D = dolomitized

SEDIMENTARY STRUCTURES

- fine lamination
- coarse lamination
- cross-lamination
- gradded bedding
- scour
- bioturbation
- horizontal trace fossils

BIOGENIC STRUCTURES

- cryptalgal laminite
- articulated crinoids
- large bryozoan fronds
- corals in growth position
- articulated brachiopods

GRAIN TYPES

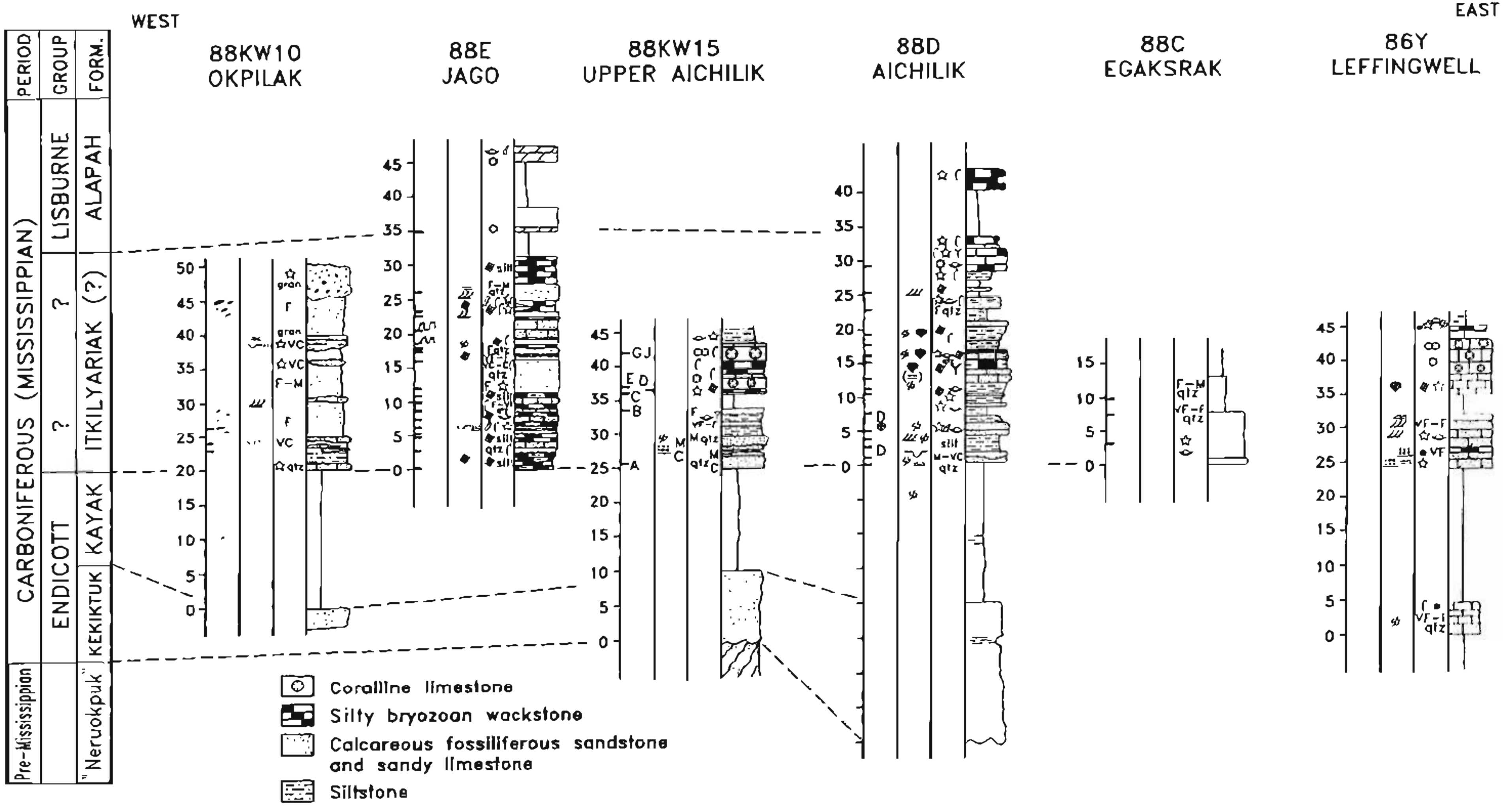
- ooid
- superficial ooid
- oncolite
- intraclast
- peloid
- skeletal grain (undiff.)
- crinoid
- bryozoan (undiff.)
- bryozoan fronds
- stick bryozoans
- brachiopods
- solitary coral
- colonial coral
- gastropods
- bivalves

GRAIN TYPES (cont'd)

- sponge spicules
- foraminifera
- trilobite
- ostracod
- algae (undiff.)
- Osagin
- Donazella
- Asphaltina
- Calcispheres

OTHER

( ) rare
? questionable
! ! abundant



ITKILYARIAK FORMATION – QUARTZOSE SANDS IN THE BASAL LISBURNE GROUP (?)

EASTERN ANWR – NORTHEASTERN BROOKS RANGE

Figure 6 - Measured sections of the "Itkilyraiak Formation" east of the Okpilak batholith. The Okpilak section was not described in detail, thicknesses estimated. See figure 5 for key to symbols.

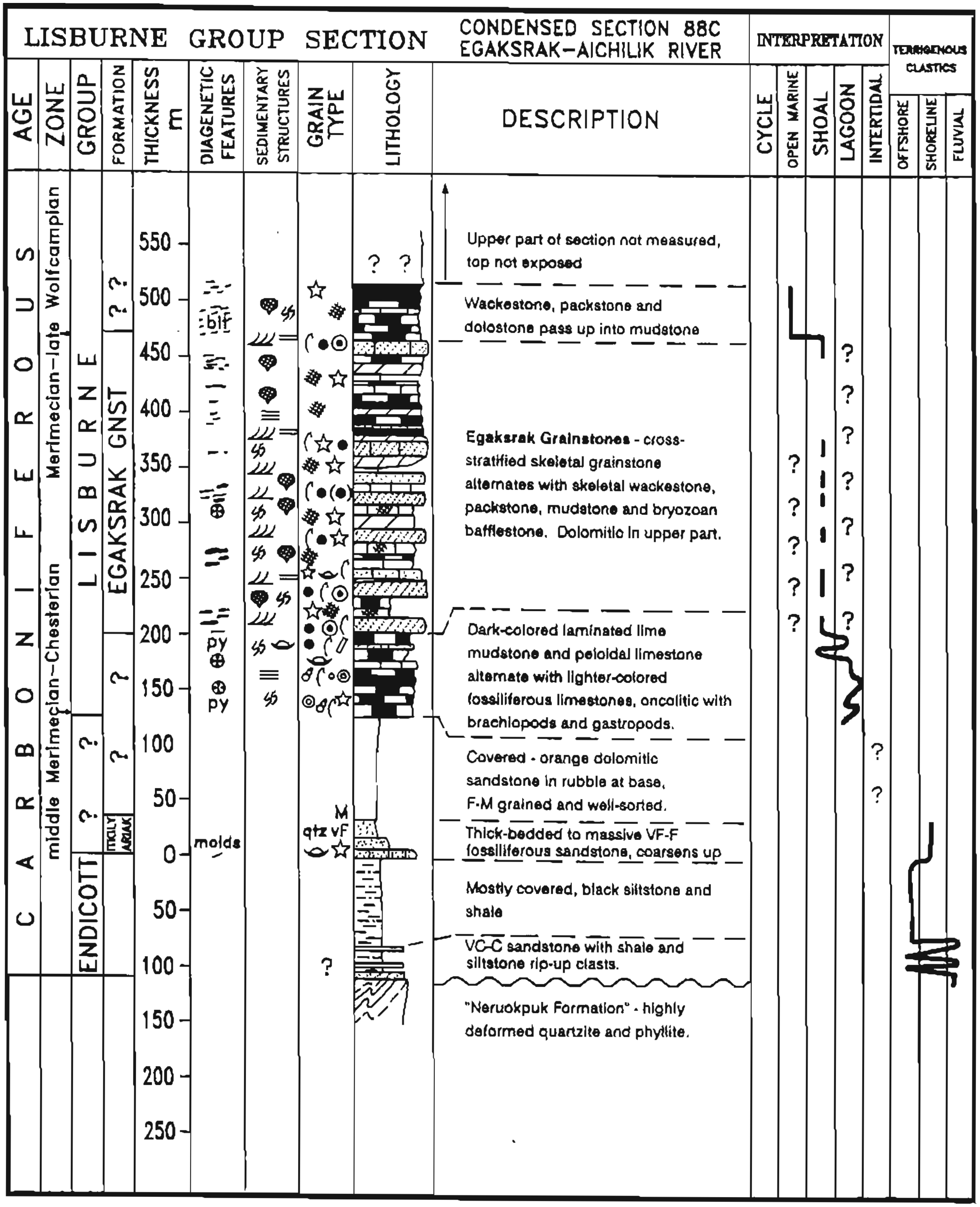


Figure 7 - Condensed stratigraphic section for the Egaksrak River section (section 88C) shows repeated intervals of cross-stratified, bioclastic grainstones of the Egaksrak Grainstone, a lateral equivalent of the Alapah Formation. See figure 5 for key to symbols.

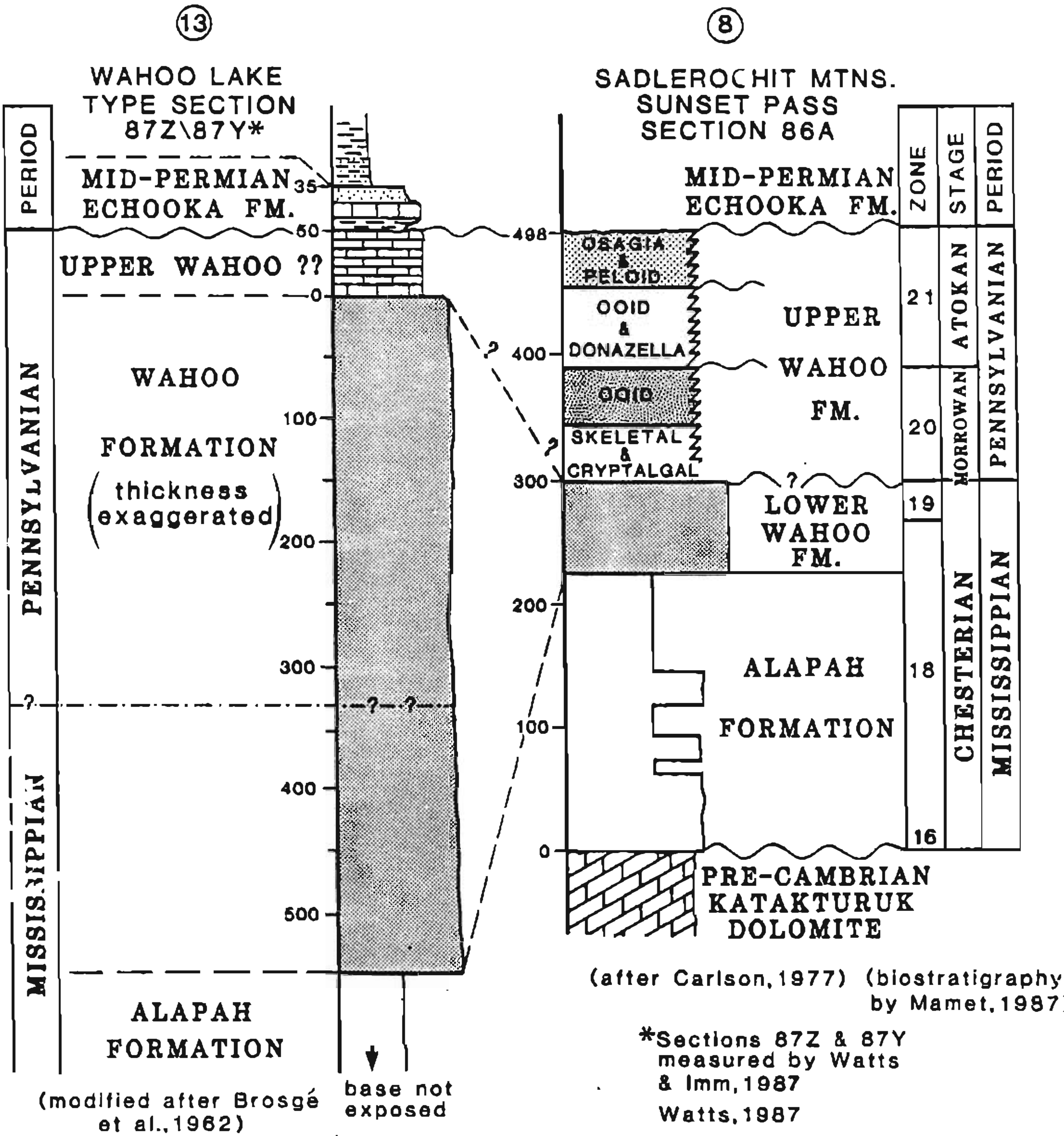


Figure 8 - The type section of the Wahoo Formation is signifcantly different from that of the Sadlerochit Mountains. See figure 5 for key to symbols.

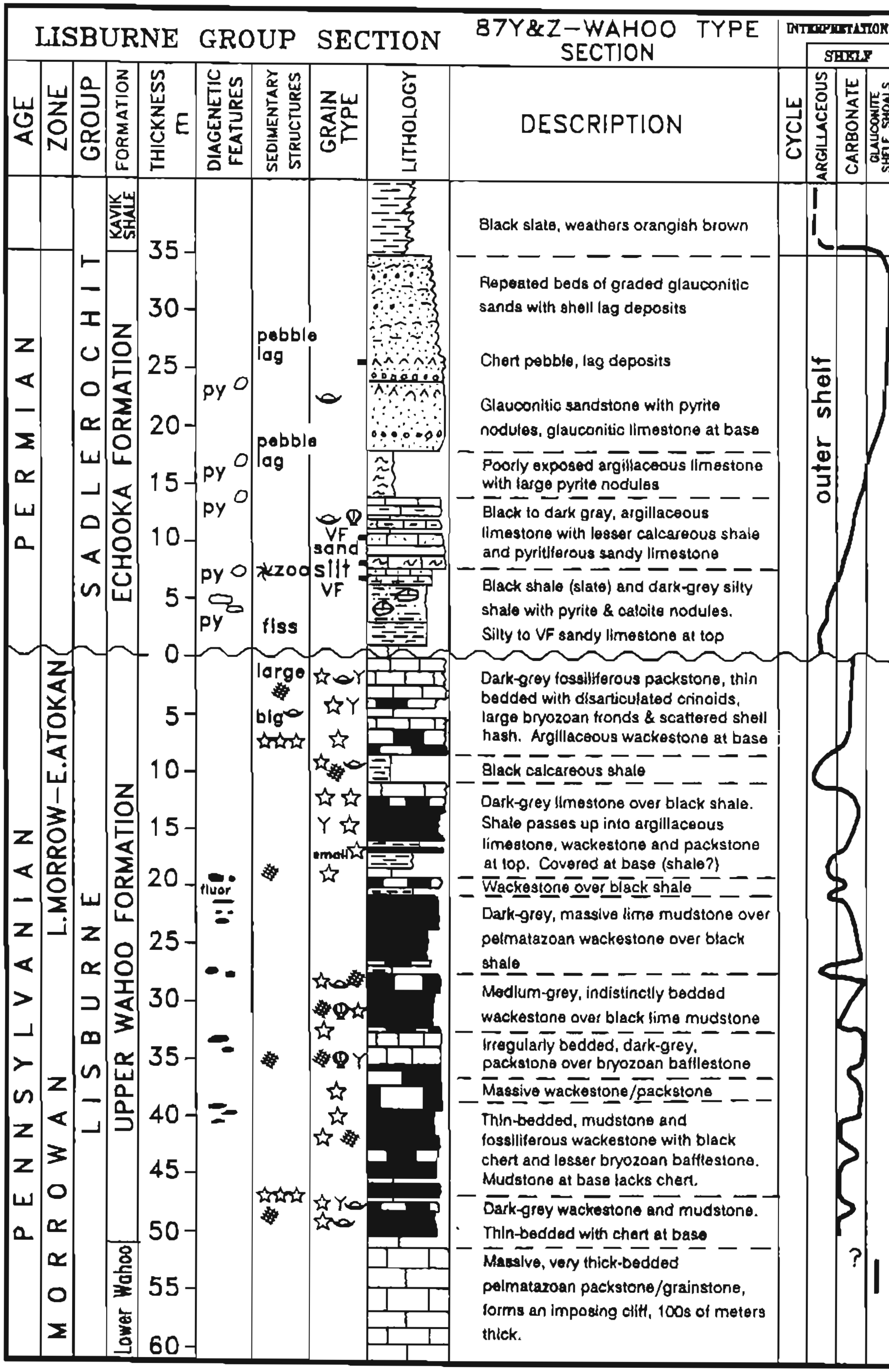


Figure 9 - Detailed section of the upper Wahoo Formation and Echooka Formation at the type section of the Wahoo Formation. See figure 5 for key to symbols.

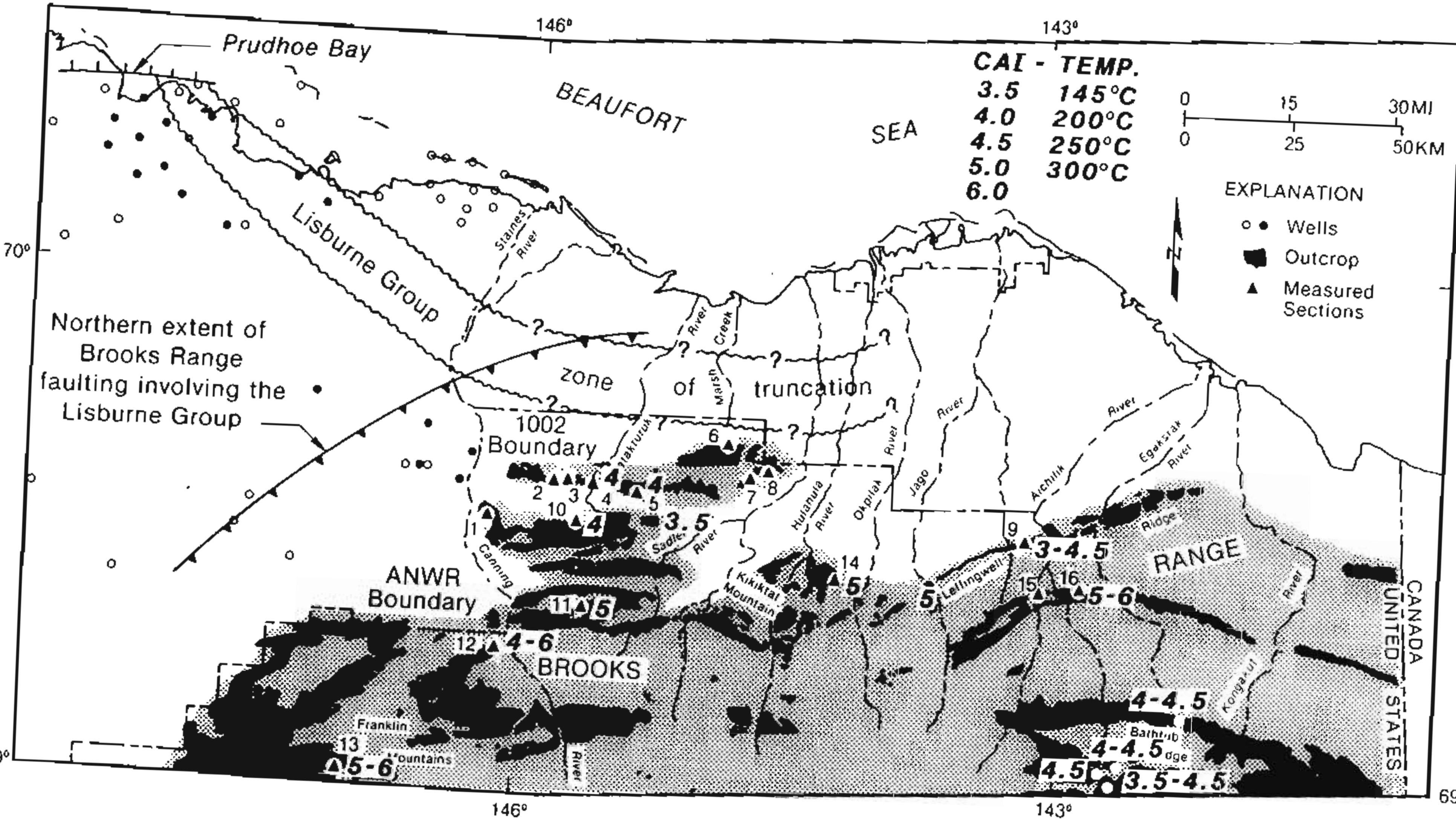


Figure 10 - Preliminary map shows conodont alteration indices (CAIs) for samples collected by University of Alaska researchers.