Enclosure 9: Literature, in Sherwood, K.W., and Amoco Oil Co., 1977 geologic field investigations, Point Lay area, North Slope, Alaska

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GMC DATA REPORT 445F

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Floral Zones and Correlations of Cretaceous Kukpowruk and Corwin Formations, Northwestern Alaska[1]

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Abstract Cretaceous fossils, mainly plant megafossils, were collected from 140 localities in the Kukpowruk River–Corwin Bluff areas of northwestern Alaska. Mollusks, from 13 marine interbeds in the Kukpowruk Formation of the Kukpowruk River area, correlate with middle to late? Albian faunas of the Chandler-Colville area about 300 mi east. Correlations by plant megafossil zones suggest an early Albian to possibly Cenomanian age for the Kukpowruk and Corwin Formations of northwestern Alaska.

Floral records in the type section of the Corwin Formation show three sequential stages: (1) an oldest stage, equivalent largely to the widespread marine Torok Formation; (2) a middle stage, found also in the Kukpowruk Formation and the lower part of the Corwin Formation in the Kukpowruk River area, and in the Tuktu Formation of the Chandler-Colville areas; (3) a youngest stage in the bentonitic clay member of the Corwin type section, correlative with medial Corwin units in the Kukpowruk River area, and with a floral zone in the lower part of the Killik Tongue (Chandler Formation) in the Chandler-Colville areas.

Plants in upper Corwin beds along Kukpowruk River represent a floral zone younger than the zones in the type section at Corwin Bluff. The floral zone in Chapman and Sable's upper sandstone member in the Corwin type section repeats a zone found in older beds of the type section. The upper sandstone member of the Corwin type section is thus a duplication of older beds, rather than a younger unit containing a later and continuing stage of floral development.

Introduction

The Cretaceous Kukpowruk and Corwin Formations of northwestern Alaska were described by Chapman and Sable (1960) from sections exposed along the Kukpowruk River (Fig. 1, area 4; Fig. 2) and near Corwin Bluff east of Cape Lisburne (Fig. 1, area 7; Fig. 3).

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Earlier reports in which plant megafossils are mentioned are those of Schrader (1904), Collier (1906), Knowlton (1914), and Smith and Mertie (1930). Plant remains are noted at a few levels in the measured sections of Chapman and Sable (1960, p. 88–90, 106–121), and small sample collections from these units later were identified by Brown (*in* Chapman and Sable, 1960). Plant megafossils otherwise were not collected and studied on a stratigraphic basis in the area until the current project was extended westward into the western part of the Arctic Slope.

The present study of Cretaceous floras began in 1956 in the southern Kuk River area (Langenheim *et al.*, 1960). In 1961 the project was continued northward to Wainwright, completing the Kuk River sequence of floral zones (Smiley, 1966). There (Fig. 1, area 3) a sequence of 40 florules, representing five major floral zones, was collected. Marine fossils from Kaolak No. 1 test well indicate that the overlying plant-bearing section lies on Albian strata. However, criteria for more precise dating of the younger nonmarine units were not available.

In 1964 the project was extended southeastward to the Chandler-Colville region (Fig. 1, areas 1, 2) where fossiliferous marine units were known to intertongue with coal- and plant-bearing nonmarine beds (Detterman *et al.*, 1963). Plant collections from 55 localities provided rich floral records and interbedded molluscan faunas through about 9,800 ft of section (Smiley, 1969). On the basis of the marine faunal records, the Chandler-Colville floras appear to represent all Cretaceous stages from middle Albian to Maestrichtian. A sequence of seven floral zones, including the five recognized earlier in the Kuk River area, is found in the Chandler-Colville section. With the biostratigraphy thus established in the Chandler-Colville and Kuk River areas, the project was extended in 1965 and 1966 westward to the Kukpowruk River and Cape Lisburne areas (Fig. 1, shaded areas 4–7).

The Kukpowruk River (area 4) was selected for study because it contains the measured type

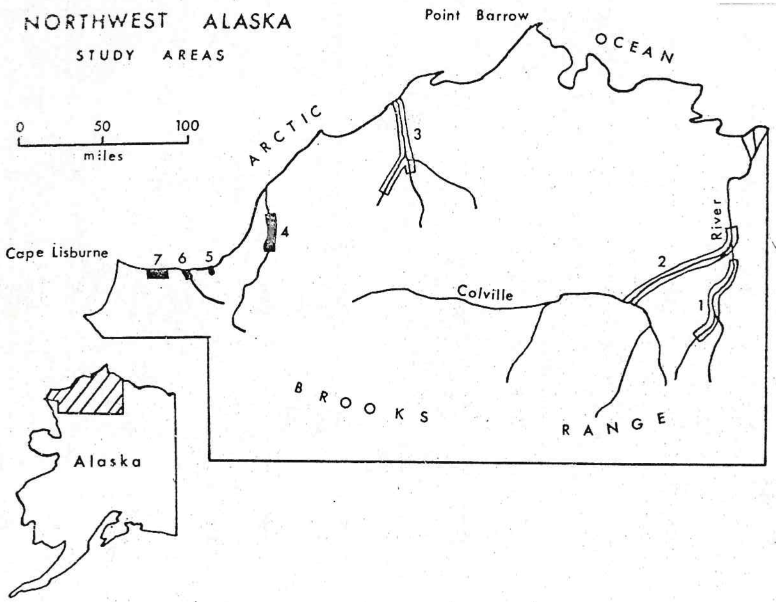


FIG. 1.—Map of northwestern Alaska study areas. *1,* Chandler River (Smiley, 1969); *2,* Colville River (Smiley, 1969); *3,* Kuk River (Smiley, 1966); *4,* Kukpowruk River; *5,* Punak Creek; *6,* Pitmegea River; *7,* Corwin Bluff.

section of the partly marine Kukpowruk Formation and the gradationally overlying nonmarine beds referred by Chapman and Sable to the Corwin Formation. The Corwin Bluff area (area 7) was selected for study because it contains the measured type section of the nonmarine Corwin Formation. Punak Creek (area 5) and Pitmegea River (area 6) were examined during stops en route to the Corwin Bluff exposures.

The Kukpowruk River area (Fig. 2), a river traverse about 25 mi long, is between 69° 15′ and 69° 30′ N lat., and along about 162° 40′ W long. The southern part is within the northern foothills section of the Arctic Foothills province, and the northern part is in the Arctic coastal plain. The river traverse follows a general northerly course across east-west fold axes. Fresh exposures are confined mainly to river cutbanks and tributary gullies.

The Corwin Bluff area (Fig. 3) consists of the 10 mi of sea cliffs between Thetis Creek on the east and Risky Creek on the west (about 68° 55′ N lat. and 165° 00′ W long.). Corwin Bluff (Fig. 3, *B*) is near the center of the area. The steep cliffs cut across regional structures, and exposures are almost continuous.

Geologic Setting

The Kukpowruk River traverse (Fig. 2) crosses two adjacent anticline-syncline pairs that strike almost due east-west and contain nearly duplicate stratigraphic successions (Chapman and Sable, 1960, p. 88–89, Pl. 11). The southern pair contains the Archimedes Ridge anticline–Howard syncline section (about 7,300 ft thick), which includes the type section of the Kukpowruk Formation in the lower part. The northern pair contains the Snowbank anticline–Barabara syncline section (about 10,250 ft thick) that consists of Kukpowruk units in the lower part and the youngest known Corwin beds in the upper part. Strata dip 55–70° near anticlinal axes and less than 10° in the vicinity of synclinal axes. No major faults were noted; but beds are crumpled near the axis of Archimedes Ridge anticline, with apparent but undetermined duplication in the lower part of the Kukpowruk type section ("covered" interval of Chapman and Sable).

The Pitmegea River (Figs. 3, 4) has truncated a homoclinal structure dipping 28–30° southwest. No major faults, crumpled zones, or unconformities are present. The 1,500-ft section can be correlated by lithologic and floral evidence with units in the Corwin type section that is exposed about 10 mi west.

The Corwin Bluffs cut a section that strikes generally northwest and dips 35–65° southwest. The section is bounded by major faults on both the east (near Thetis Creek) and the west (near Risky Creek). A third ...

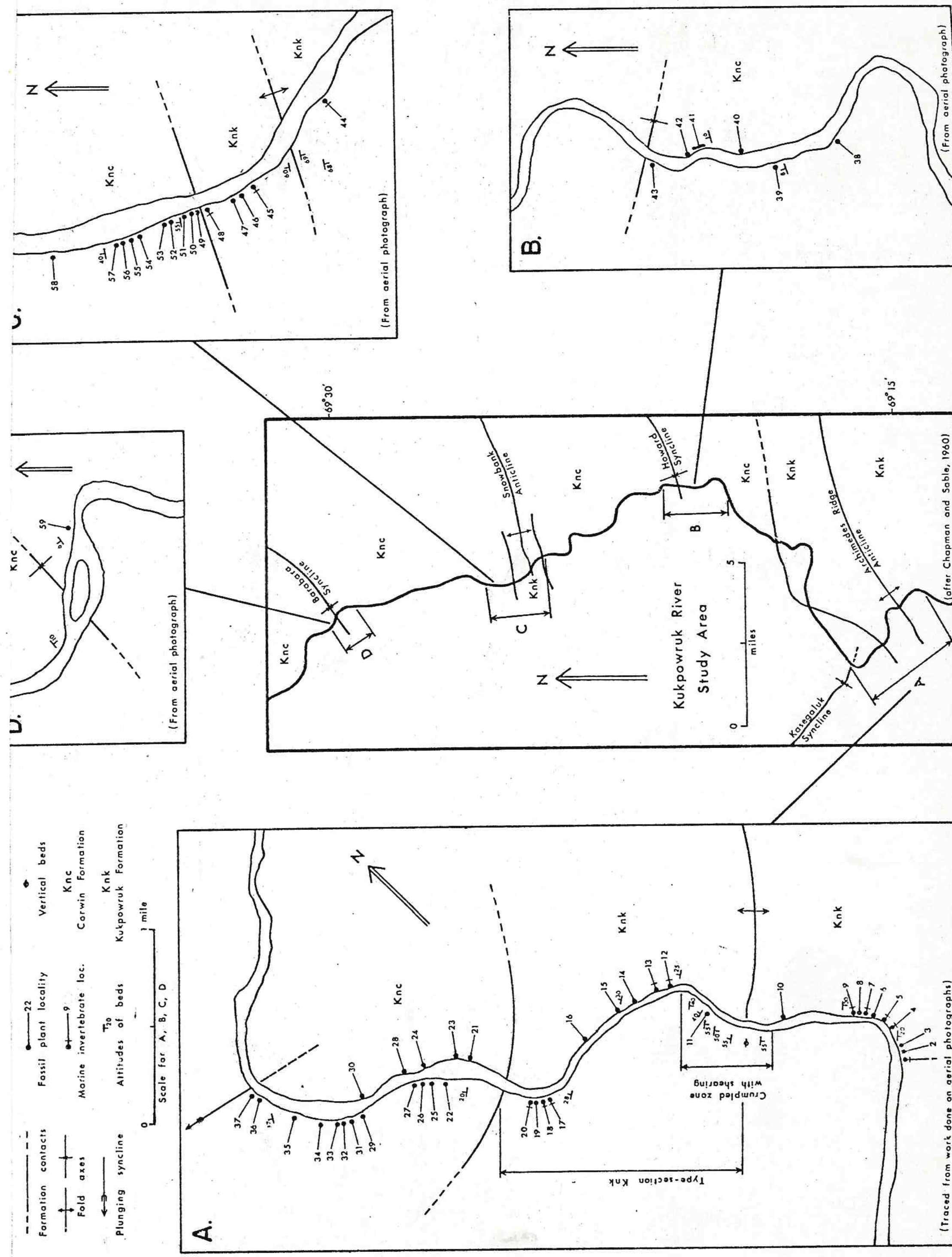
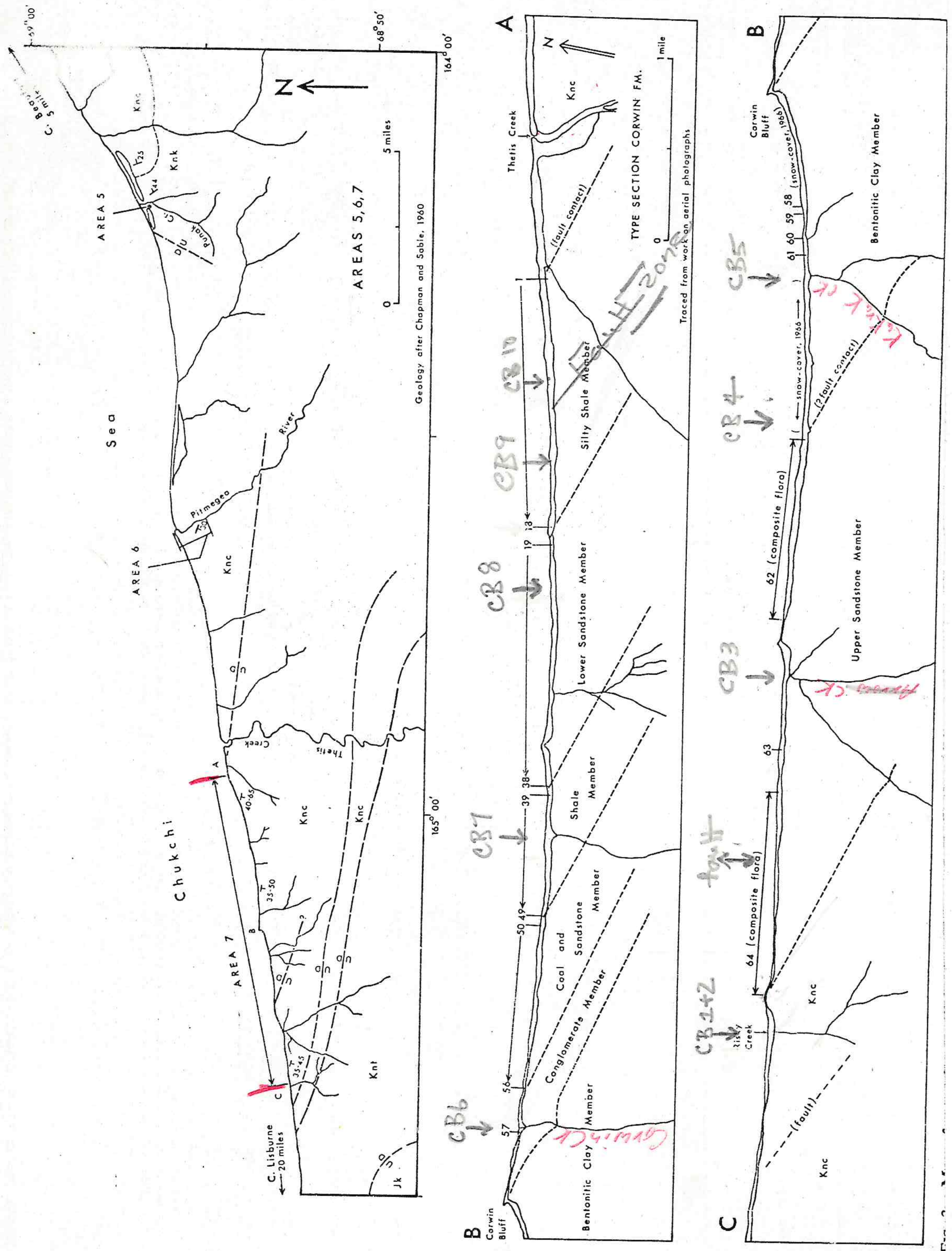


FIG. 2.—Maps of Kukpowruk River study area showing fossil localities and geology. Cross-bars designate marine localities.



appears to be present about 3 mi east of Risky Creek, at the contact between Sable's bentonitic clay member and his upper sandstone member. A few crumpled zones are present elsewhere in the area, but no other appreciable duplication of beds or break in the stratigraphic sequence is indicated by either lithologic or floral evidence.

Lithologic Units

Two plant-bearing formations were described in the region by Chapman and Sable: (1) the Kukpowruk Formation, the type section of which represents the lowermost rocks examined in the Kukpowruk River study area; and (2) the Corwin Formation, the type section of which is represented by the Corwin Bluff sequence. The Kukpowruk Formation is composed of interbedded marine and nonmarine units; the Corwin Formation is nonmarine. The Corwin floral zones in the Kukpowruk River area are only partly correlative with ones in the type section of the Corwin Formation at Corwin Bluff (Fig. 5).

In the Kukpowruk River area, the Kukpowruk Formation consists of plant-bearing sandstone and siltstone with fossiliferous marine interbeds of sandstone, siltstone, and shale. The lower 1,100 ft of the 2,865-ft type section is poorly exposed because of erosion and tundra cover, but in outcrops near low-water level in the river bed it is a markedly crumpled zone. Although the lower contact of the formation is not apparent there, elsewhere in the region the Kukpowruk lies on marine shale of the Torok Formation. The contact with the overlying Corwin Formation is gradational. The Corwin is distinguished from the Kukpowruk by entirely nonmarine strata which are coarser in texture, contain numerous beds of coal, and become progressively more bentonitic higher in the section.

A florule was found near the mouth of Punak Creek (Fig. 3) during a stop enroute to the Corwin Bluff area. Chapman and Sable mapped the Punak Creek beds as Kukpowruk Formation, and an estimate from prevailing dips in the area places the florule about 2,000 ft below the top of the formation. The gray and greenish-gray sandstones and siltstone beds at this locality are typical of the Kukpowruk. However, large fronds of the cycadophyte *Nilssonia magnifolia* with the fern *Cladophlebis huttoni* appear to correlate with basal Corwin florules in the Kukpowruk River section.

Plant-bearing beds in the Pitmegea River section are present in rocks that are correlated lithologically with the shale, coal and sandstone, and conglomerate units of the Corwin type section about 10 mi west (Fig. 3). This lithologic correlation is corroborated by sequential floral records in the two sections.

In the Corwin Bluff area the type section of the Corwin Formation is about 15,500 ft thick according to Chapman and Sable (1960, p. 105). Their informally designated members, based on predominant lithology, are from base to top (Fig. 5): the silty shale; lower sandstone; shale; coal and sandstone; conglomerate; bentonitic clay; and upper sandstone. They considered these units to be conformable and to represent essentially continuous deposition. However, the floral records in their upper sandstone member were found to be the same (Floral Zone I) as those present in their lower sandstone, shale, and coal and sandstone members, rather than those of Zone III, which elsewhere succeeds Zone II present in their bentonitic clay member (Fig. 5).

Other lines of evidence suggest also that the upper sandstone member of the type section represents a duplication of beds rather than a conformable continuation of deposits: (1) evidence of a contorted zone at the contact between the bentonitic clay member and the upper sandstone member suggests a possible fault contact (see also geologic map of Chapman and Sable); (2) the upper sandstone member is lithologically similar to parts of the lower sandstone, the shale, and the coal and sandstone members on the east (Fig. 3); (3) in other study areas of northern Alaska, bentonite becomes more conspicuous at progressively

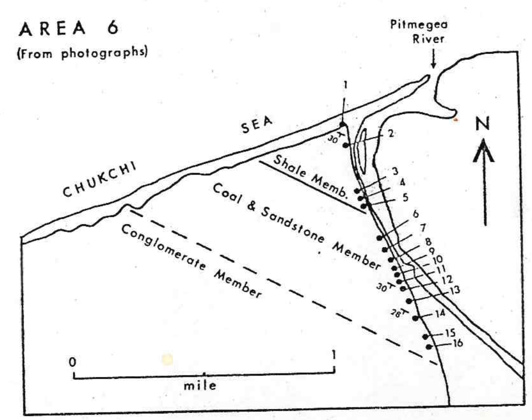


FIG. 4.—Map of Pitmegea River study area (Figs. 1, 3), showing floral localities by dots. Relation of localities to structure shows oldest florules near coast and progressively younger florules southward. Rock units

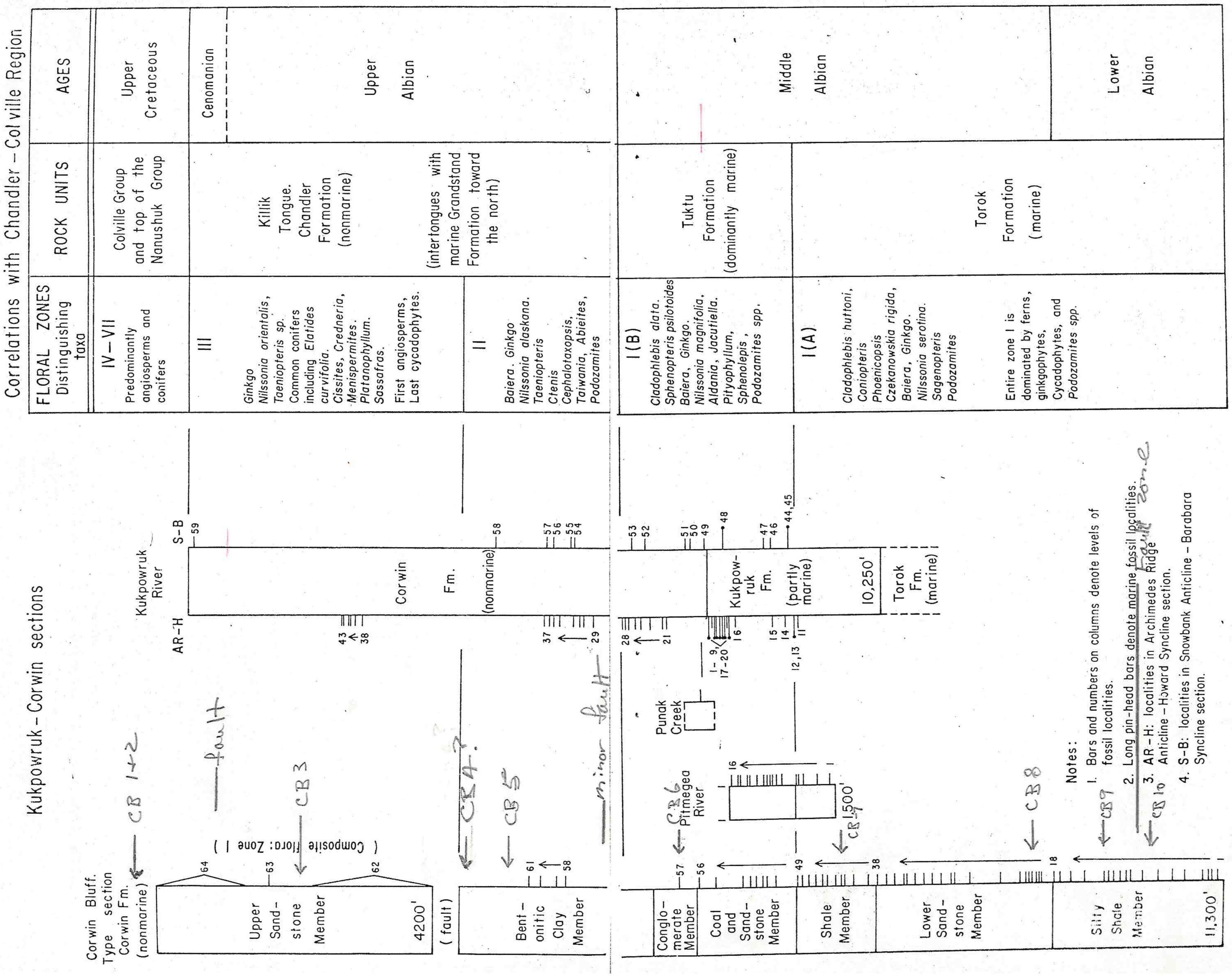


FIG. 5.—Correlation of Kukpowruk-Corwin and Chandler-Colville areas by plant-megafossil zones.

higher levels; in the Corwin type section bentonite is present in the bentonitic clay member but not in the presumably overlying upper sandstone member.

Stratigraphic Data for Fossil Localities

Fossils, mainly plant megafossils, were collected from 140 localities in the western study areas of the Arctic Slope. Thirteen localities provided faunas from marine interbeds in the Kukpowruk Formation. All others are plant-megafossil localities (florules).

Kukpowruk River area (Table 1).—Fossils were collected from 59 localities along the Kukpowruk River traverse, mainly across two adjacent homoclinal sections: from the axial area of Archimedes Ridge anticline to the axis of Howard syncline (Fig. 2, *A*, *B*), and from the axial area of Snowbank anticline to the axis of Barabara syncline (Fig. 2, *C*, *D*). The relative ages of localities were determined by clear-cut superposition in both sections. The two sections, correlated by lithologic and floral comparisons, are sufficiently alike to be represented by a single column, as in Figure 5.

Stratigraphic data for Kukpowruk River localities are given in Table 1. Localities of the Kukpowruk Formation were referred to numbered units in the sections of Chapman and Sable (1960, p. 88–90); those in the overlying Corwin Formation were referred to units in their stratigraphic columns (their Pl. II).

Pitmegea River area (Table 2).—Plant megafossils were collected from 16 beds distributed stratigraphically through a 1,500-ft section near the mouth of the river (Fig. 3, area 6; Fig. 4). Beds near the coast (lower part of the section) resemble the shale member in the Corwin type section at Corwin Bluff (Fig. 3, area 7). Beds farther upstream (upper part of the section) resemble the coal and sandstone member of the type-section, and also contain the first evidence of a conglomeratic sandstone similar to Chapman and Sable's unit 13 of this member. Conglomeratic beds exposed along the coast west of the river mouth (Fig. 4) appear to be conformable on the local plant-bearing section and to be correlative with the conglomerate member of the Corwin type section. The sequence of Pitmegea florules shows a floral change found also in the shale to coal and sandstone part of the type section—from presence of cycadophytes in older florules to their absence in younger ones.

Corwin Bluff area (Table 3).—Plant megafossils were collected from 64 localities along the Corwin Bluff coastal traverse (Fig. 3). An apparently continuous section is represented by the silty shale, lower sandstone, shale, coal and sandstone, conglomerate, and bentonitic clay members of the Corwin type section. As noted previously, the upper sandstone member appears to duplicate older beds that are exposed in the cliffs east of Corwin Bluff (Fig. 3*B*). The stratigraphic position of each florule in the Corwin type section is given in Table 3, in reference to numbered units in the section of Chapman and Sable (1960, p. 106–121).

Correlations of Kukpowruk and Corwin Formations

Faunal records.—Faunal remains were found by the 1965 field party in marine interbeds of the Kukpowruk Formation, and were reported also by Chapman and Sable (1960, p. 98–101) in the upper part of the underlying Torok Formation. Molluscan correlations by Imlay (*in* Chapman and Sable, 1960) indicates a middle to late? Albian age, and collections made in 1965 contain elements of this faunal zone (Table 1, Fig. 5). Microfossils identified by Bergquist (*in* Chapman and Sable, 1960; Detterman *et al.*, 1963) represent the *Verneuilinoides borealis* zone that is present in the upper part of the Torok, Tuktu, and Grandstand Formations of the Chandler-Colville region.

Floral zones.—Seven plant-megafossil zones have been distinguished in the Chandler-Colville areas, where they are in stratigraphic succession (Smiley, 1969). Five of these zones are present in the Kuk River area (Smiley, 1966), three in the Kukpowruk River area, one (with two subzones) in the Pitmegea River section, and two in the type section of the Corwin Formation near Cape Lisburne. The inferred correlations of the western sections (areas 4–7) are shown on Figure 5.

Floral Zone I in northern Alaska is dominated by species of ferns, ginkgophytes, and cycadophytes. Conifers are few and are represented by isolated shoots or cones. Angiosperms (dicotyledons) have not been discovered at this level in any of the study areas of northern Alaska. Zone I plants found commonly in the Kukpowruk-Corwin sections include the fern *Cladophlebis* cf. *huttoni*, the ginkgophytes *Baiera* (or *Sphenobaiera* vide Samylina) and *Ginkgo*, and species of *Podozamites*. On the basis of records in the Corwin type section, Floral Zone I can be further subdivided into an older subzone IA and a younger subzone IB, as shown in Figure 5.

Subzone IA is distinguished by the additional

Table 1. Stratigraphic Data for Kukpowruk River Localities

(Units containing marine fossils indicated by asterisk)

ARCHIMEDES RIDGE ANTICLINE–HOWARD SYNCLINE SECTION

Kukpowruk Formation (locs. 1–20)

1.* South limb Archimedes Ridge anticline, equated with base of unit 5 on north limb, about 100 ft from top of formation and about 20 ft below loc. 2 (coral).
2. South limb Archimedes Ridge anticline, equated with top of unit 5 on north limb (cycadophyte, *Pityophyllum*).
3. South limb Archimedes Ridge anticline, equated with unit 6 on north limb, about 10 ft below loc. 2 (*Pityophyllum*).
4.* South limb Archimedes Ridge anticline, equated with unit 10 on north limb, about 50 ft below loc. 3 (ferns, conifer, pelecypods).
5.* South limb Archimedes Ridge anticline, equated with unit 15 on north limb, about 60 ft below loc. 4 (?*Panope*).
6. South limb Archimedes Ridge anticline, equated with unit 18 on north limb, about 15 ft below loc. 5 (ginkgophytes, cycadophyte).
7.* South limb Archimedes Ridge anticline, equated with unit 20 on north limb, about 15 ft below loc. 6 (*Entolium*, *Tancredia* cf. *kurupana*, *Solecurtus* cf. *chapmani*).
8. South limb Archimedes Ridge anticline, equated with unit 22 on north limb, about 25 ft below loc. 7 (cycadophyte).
9.* South limb Archimedes Ridge anticline, equated with unit 26 on north limb, about 35 ft below loc. 8 (?*Aucella*, *Entolium*).
10. Gravel bar float a few hundred feet downstream from loc. 9 (frond of cycadophyte found at locs. 6 and 8).
11. In crumpled axial area of Archimedes Ridge anticline, similar to unit 46 on north limb (plant fragments).
12.* Type section Kukpowruk Formation, float from units 50 and 51, and about 227–247 ft above 1,100-ft "covered" interval (ferns, ginkgophytes, *Pityophyllum*, ?*Aucella* cf. *A. sublaevis*).
13.* Type section Kukpowruk Formation, unit 49, a 2–3 ft sandstone bed overlying loc. 12 (ferns, ginkgophytes, ?*Panope*, ?*Aucella* cf. *A. sublaevis*).
14. Type section Kukpowruk Formation, unit 45, about 165 ft above loc. 13 (*Ginkgo*).
15. Type section Kukpowruk Formation, top of unit 36 or base of unit 35, about 200 ft above loc. 14 (ferns, *Ginkgo*).
16. Type section Kukpowruk Formation, unit 31, about 550 ft above loc. 15 (ferns, cycadophyte).
17.* Type section Kukpowruk Formation, unit 20 (pelecypods as at loc. 7).
18.* Type section Kukpowruk Formation, unit 18, about 40 ft above loc. 17, and about equivalent to loc. 6 (13-in.-diameter ammonite mold).
19. Type section Kukpowruk Formation, unit 13, about 70 ft above loc. 18 (ferns, *Ginkgo*).
20.* Type section Kukpowruk Formation, until 11, about 15 ft above loc. 19 (?*Aucella*).

Corwin Formation (locs. 21–43)

21. North limb Archimedes Ridge anticline, about 600 ft above base of formation (?*Unio*).
22. North limb Archimedes Ridge anticline, about 75 ft above loc. 21 (ferns, ginkgophytes, conifers).
23. Unit containing loc. 21, east side of river (ginkgophytes).
24. North limb Archimedes Ridge anticline, east side of river, about 100–200 ft above loc. 23 (composite flora from several beds: ferns, *Ginkgo*, conifers).
25. North limb Archimedes Ridge anticline, west side of river, lower part of loc. 24 sequence (ferns, ginkgophyte).
26. North limb Archimedes Ridge anticline, about 100 ft above loc. 25 (ferns).
27. North limb Archimedes Ridge anticline, about 50 ft above loc. 26 (ferns, ginkgophytes).
28. North limb Archimedes Ridge anticline, about 50 ft above loc. 27 (fern, ginkgophytes, *Pityophyllum*).
29. North limb Archimedes Ridge anticline, about 200 ft above loc. 28 (ferns, *Ginkgo*, conifers).
30. North limb Archimedes Ridge anticline, east side of river, same level as loc. 31 (*Ginkgo*).
31. North limb Archimedes Ridge anticline, west side of river, about 150 ft above loc. 29 (ferns, *Ginkgo*, conifers).

Table 1 (*Continued*)

32. North limb Archimedes Ridge anticline, about 75 ft above loc. 31 (ferns, ginkgophytes, cycadophytes, conifers).
33. North limb Archimedes Ridge anticline, about 100 ft above loc. 32 (fern, ginkgophytes, cycadophytes, *Pityophyllum*).
34. North limb Archimedes Ridge anticline, about 225 ft above loc. 33 (ferns, ginkgophytes, cycadophytes, *Pityophyllum*).
35. North limb Archimedes Ridge anticline, about 100 ft above loc. 34 (fern, ginkgophytes).
36. North limb Archimedes Ridge anticline, about 125 ft above loc. 35 (ferns, ginkgophytes, cycadophytes, *Pityophyllum*).
37. North limb Archimedes Ridge anticline, near axis of Kasegaluk syncline, about 50 ft above loc. 36 (ferns, ginkgophytes, conifers)
38. Near axis of Howard syncline, in bentonite-bearing beds estimated about 2,650 ft above loc. 37, and about 550 ft below top of section (ferns, ginkgophytes, cycadophytes, *Pityophyllum*).
39. Near axis of Howard syncline, about 30 ft above loc. 38 (ferns, *Ginkgo*, FIRST DICOTYLEDONS).
40. Near axis of Howard syncline, about 150 ft above loc. 39 (ferns, *Ginkgo*, conifers).
41. Near axis of Howard syncline, about 35 ft above loc. 40 (ferns, ginkgophytes, conifers, dicotyledons).
42. Near axis of Howard syncline, about 40 ft above loc. 41 (fern, ginkgophytes, conifers).
43. Near axis of Howard syncline, about 60 ft above loc. 42, and about 200 ft below top of section (ferns, ginkgophytes, ?*Unio*).

SNOWBANK ANTICLINE–BARBARA SYNCLINE SECTION

Kukpowruk Formation (locs. 44–48)

44.* South limb Snowbank anticline, near axis, equated with unit 20 on north limb (*Entolium*, ?*Panope*).
45. North limb Snowbank anticline, unit 20, approximately equivalent to loc. 14 (pelecypods as at loc. 44).
46. North limb Snowbank anticline, about 50 ft above base of unit 15, and about 250 ft above loc. 45; approximately equivalent to loc. 15 (fern, ginkgophytes, *Pitylophyllum*).
47. North limb Snowbank anticline, unit 15, about 100 ft above loc. 46 (Ginkgo, *Pityophyllum*).
48.* North limb Snowbank anticline, unit 6, about 600 ft above loc. 47, and about 250 ft below top of formation; approximately equivalent to locs. 5–7 and 17–20 (*Entolium*, small gastropods and pelecypods).

Corwin Formation (locs. 49–59)

49. North limb Snowbank anticline, about 15 ft above base of formation, and about 250 ft above loc. 48 (ferns, ginkgophytes, cycadophytes, *Pityophyllum*).
50. North limb Snowbank anticline, about 200 ft above loc. 49 (ferns).
51. North limb Snowbank anticline, about 75 ft above loc. 50 (ferns).

Locs. 49–51 are equivalent to barren beds between locs. 20 and 21.

52. North limb Snowbank anticline, about 600 ft above loc. 51; approximately equivalent to locs. 24–26 (ferns, *Ginkgo*).
53. North limb Snowbank anticline, about 200 ft above loc. 52; approximately equivalent to locs. 27–28 (ferns, *Ginkgo*).
54. North limb Snowbank anticline, about 800 ft above loc. 53; approximately equivalent to loc. 33 (fern, *Ginkgo*, *Pityophyllum*).
55. North limb Snowbank anticline, about 75 ft above loc. 54 (ferns).
56. North limb Snowbank anticline, about 250 ft above loc. 55; approximately equivalent to loc. 35 (ginkgophytes).
57. North limb Snowbank anticline, about 100 ft above loc. 56; approximately equivalent to locs. 36–37 (*Ginkgo*, *Pityophyllum*).
58. North limb Snowbank anticline, about 750 ft above loc. 57; approximately equivalent to lower part of unfossiliferous section between locs. 37 and 38 (ferns).

Locs. 38–43 are intermediate between locs. 58 and 59.

59. Near axis of Barabara syncline, about 10,000 ft above base of section, and about 4,500 ft above loc. 58; about 2,200 ft above loc. 43 (ferns, *Ginkgo*, conifers, dicotyledons).

Table 2. Stratigraphic Data for Pitmegea River Localities

Shale member of Corwin Formation

1. Base of section at river mouth (ferns, ginkgophytes, cycadophytes).
2. About 180 ft above loc. 1 (ferns).
3. About 280 ft above loc. 2 (ginkgophytes, cycadophytes).
4. About 40 ft above loc. 3 (ferns ginkgophytes).
5. About 30 ft above loc. 4 (ferns, cycadophytes).

Coal and sandstone member of Corwin Formation

6. About 250 ft above loc. 5 (ginkgophytes).
7. About 100 ft above loc. 6 (ferns, ginkgophytes, *Pityophyllum*).
8. About 80 ft above loc. 7 (ferns, ginkgophytes).
9. About 20 ft above loc. 8 (ferns, ginkgophytes).
10. About 20 ft above loc. 9 (ferns, ginkgophytes).
11. About 20 ft above loc. 10 (ferns, ginkgophytes).

Between locs. 11 and 12 is first evidence of conglomeratic sandstone unit, comparable to Chapman and Sable's unit 13 in coal and sandstone member of type section.

12. About 100 ft above loc. 11 (ferns).
13. About 60 ft above loc. 12 (ginkgophytes, *Pityophyllum*).
14. About 90 ft above loc. 13 (ginkgophytes).
15. About 60 ft above loc. 14 (ferns, ginkgophytes).
16. Top of section, about 1,500 ft above base, and about 150 ft above loc. 15 (ferns, ginkgophytes, *Pityophyllum*).

common presence of the ferns *?Dicksonia* and *Coniopteris*, by the ginkgophytes *Phoenicopsis* and *Czekanowskia*, by cycadophyte fronds resembling *Nilssonia serotina*, and by a very few leaves of *Sagenopteris*. Some of these taxa may be present as uncommon or scarce specimens at higher levels. Figure 5 shows this subzone to be present in the three lowest members of the Corwin type section, and in the lower part of the Pitmegea River section. It seems to be correlative with the marine Torok Formation and the lower (covered) part of the Kukpowruk Formation.

Subzone IB is distinguished by the additional common presence of the ferns *Cladophlebis* cf. *alata* and *Sphenopteris* (*?Onychiopsis*) *psilotoides*, by species of *Baiera* (*Sphenobaiera*) and *Ginkgo* different from ones in subzone IA, by the cycadophytes *Nilssonia magnifolia* and *Aldania* (*?Taeniopteris*) sp., and by the conifers *Pityophyllum* cf. *nordenskioldii* and *Sphenolepis* cf. *sternbergiana*. Some of these taxa may be present as uncommon specimens in subjacent or superjacent beds. Figure 5 shows this subzone to be present in the coal and sandstone and the conglomerate members of the Corwin type section, the upper part of the Pitmegea River section, Punak Creek, upper Kukpowruk and lower Corwin of the Kukpowruk River area, and the Tuktu Formation in the Chandler-Colville areas.

Floral Zone II is distinguished in northern Alaska by a variety of ferns including species of *Cladophlebis*, *Coniopteris*, *?Dicksonia*, and *Sphenopteris*, by species of *Baiera* (*Sphenobaiera*) and *Ginkgo*, by the cycadophytes *Nilssonia* cf. *alaskana*, *Ctenis*, and *Taeniopteris*, and by the first abundant and varied records of conifers including species of *Abieites*, *Cephalotaxopsis*, *Pityophyllum*, *Podozamites*, *?Sphenolepis*, and *?Taiwania*. Figure 5 shows this zone to be present in the bentonitic clay member of the Corwin type-section, in the middle part of the Kukpowruk River section (part of the Corwin Formation), and in the lower part of the Killik Tongue, Chandler Formation, in the Chandler-Colville areas.

Floral Zone III, found only in the upper part of the Kukpowruk River section of the western region (Fig. 5), is distinguished by relatively few ferns including species of *Cladophlebis* and *Sphenopteris*, by species of *Ginkgo* including *G.* cf. *concinna*, by *Nilssonia* cf. *orientalis* and *Taeniopteris*, by a variety of conifers including species of *Amentotaxus*, *Cephalotaxus*, *Elatides* (*Araucarites*) *curvifolia*, *?Juniperites*, *Podozamites*, *Sequoia*, and *Torreya*. The oldest records of angiosperms (dicotyledons) appear in this zone, including species of *Cissites*, *Credneria*, *Dombeyopsis*, *Dryophyllum*, *Laurophyllum*, *Menispermites*, *Platanophyllum*, *Sassafras*, *Sterculia*, and *Zizyphus*. In the Chandler-Colville areas, this zone is present in the Killik Tongue of the Chandler Formation, where it overlies Zone II as in the Kukpowruk River area.

Sedimentary sequences.—The temporal facies changes represented by the Torok-Kukpowruk-Corwin sequence in the Kukpowruk River area appear comparable with the Torok-Tuktu-Chandler sequence in the Chandler-Colville region. Chapman and Sable note (p. 73) that "The Torok Formation is defined to include the predominantly shale sequence that underlies the Nanushuk group in the Arctic foothills province of northern Alaska," and that "The upper part of the formation can be traced westward from the type locality [Chandler River area] into the Utukok-Corwin region." Regional correlations by floral zones (Fig. 5) suggest that the sequence from marine to transitional to nonmarine facies is not strictly synchronous, but appears to be time transgressive in an easterly direction.

The Kukpowruk Formation, which overlies the Torok shale in the western region, is composed mainly of coarser, interbedded marine and nonmarine clastic rocks. Gradationally overlying the Kukpowruk Formation is the

Table 3. Stratigraphic Data for Fossil-Plant Localities in Corwin Type Section

Silty shale member (locs. 1–18)

1. Unit 115, about 50 ft above base of member (*Algites*).
2. Unit 112, lower part, about 100 ft above loc. 1 (ferns, ginkgophytes).
3. Unit 112, middle part, about 50 ft above loc. 2 (ferns, ginkgophytes, cycadophytes).
4. Unit 112, upper part, about 75 ft above loc. 3 (ferns, ginkgophytes, cycadophytes).
5. Unit 105, about 250 ft above loc. 4 (ferns).
6. Unit 95, about 150 ft above loc. 5 (ginkgophytes, cycadophytes).
7. Unit 78, about 175 ft above loc. 6 (ferns, ginkgophytes).
8. Unit 59, about 265 ft above loc. 7 (ferns).
9. Unit 53, middle part, about 235 ft above loc. 8 (cycadophytes).
10. Unit 53, upper part, about 40 ft above loc. 9 (ferns, ginkgophytes).
11. Unit 48, about 100 ft above loc. 10 (ferns, ginkgophytes).
12. Unit 44, about 100 ft above loc. 11 (ferns, cycadophytes).
13. Unit 43, near base, about 50 ft above loc. 12 (ferns ginkgophytes, cycadophytes).
14. Talus cone at base of cliffs containing units 40–42, 75–150 ft above loc. 13 (ferns, ginkgophytes).
15. Talus cone at base of cliffs containing units 16–19, 235–335 ft above loc. 14 (ginkgophytes).
16. Unit 10, lower part, about 75 ft above loc. 15 (ferns, ginkgophytes).
17. Unit 10, upper part, about 125 ft above loc. 16 (ferns, ginkgophytes, cycadophytes).
18. Unit 5, near top of member, about 135 ft above loc. 17 (ferns, ginkgophytes, cycadophytes).

Lower sandstone member (locs. 19–38)

19. Unit 179, about 65 ft above base of member, and about 110 ft above loc. 18 (ferns, ginkgophytes, cycadophytes).
20. Unit 171, about 90 ft above loc. 19 (ferns, ginkgophytes, cycadophytes).
21. Unit 167, about 40 ft above loc. 20 (ginkgophytes, cycadophytes).
22. Unit 161, about 65 ft above loc. 21 (ferns, ginkgophytes, cycadophytes).
23. Units 154 and 155, about 15 ft above loc. 22 (ferns, ginkgophytes).
24. Units 148–150, about 15 ft above loc. 23 (ferns, ginkgophytes).
25. Units 138–140, about 100 ft above loc. 24 (ferns, ginkgophytes).
26. Units 114–116, about 275 ft above loc. 25 (ferns, ginkgophytes).
27. Unit 83, about 435 ft above loc. 26 (ferns, ginkgophytes, cycadophytes).
28. Unit 70, about 200 ft above loc. 27 (ferns, ginkgophytes).
29. Units 66–69, about 25 ft above loc. 28 (ferns, ginkgophytes).
30. Talus cone at base of cliffs containing units 50–57, about 115 ft above loc. 29 (ferns, ginkgophytes).
31. Talus cone at base of cliffs containing units 41 (lower part) to 45 (upper part), and 75–110 ft above loc. 30 (ferns, ginkgophytes, cycadophytes).
32. Unit 31, about 90 ft above loc. 31 (ferns, ginkgophytes).
33. Talus cone at base of cliffs containing units 21–23, about 100 ft above loc. 32 (ferns, ginkgophytes).
34. Unit 19, about 75 ft above loc. 33 (ferns).
35. Talus cone at base of cliffs containing units 13–17, about 15 ft above loc. 34 (ferns, ginkgophytes).
36. Unit 11, upper part, about 125 ft above loc. 35 (ferns, ginkgophytes).
37. Unit 5, lower part, and unit 6, about 75–100 ft above loc. 36 (ferns, ginkgophytes).
38. Unit 1, near top of member, about 200 ft above loc. 37 (ferns).

Shale member (locs. 39–49)

39. Unit 21, about 80 ft above base of member, and about 100 ft above loc. 38 (ginkgophytes, cycadophytes).
40. Unit 20, upper part, about 200 ft above loc. 39 (ferns, ginkgophytes).

Table 3 (*Continued*)

41. Unit 18, upper part, about 125 ft above loc. 40 (ferns, ginkgophytes).
42. Unit 16, lower part, about 25 ft above loc. 41 (ferns, ginkgophytes, cycadophytes).
43. Unit 16, middle part, about 100 ft above loc. 42 (ferns, ginkgophytes).
44. Unit 16, upper part, to unit 14, lower part, about 75 ft above loc. 43 (ferns, ginkgophytes).
45. Unit 14, middle part, about 75 ft above loc. 44 (ferns, ginkgophytes).
46. Unit 14, upper part, to unit 11, lower part, about 75–100 ft above loc. 45 (ferns, ginkgophytes).
47. Unit 6, about 175 ft above loc. 46 (ferns, ginkgophytes).
48. Unit 5, about 30 ft above loc. 47 (ferns, ginkgophytes).
49. Unit 1, near top of member, about 75 ft above loc. 48 (ferns, ginkgophytes).

Coal and sandstone member (locs. 50–56)

50. Talus cone at base of cliffs containing units 49–52, about 275 ft above base of member, and about 300 ft above loc. 49 (ferns, ginkgophytes).
51. Unit 47, upper part, about 125 ft above loc. 50 (ferns, ginkgophytes).
52. Talus cone at base of cliffs containing units 44–46, about 25–50 ft above loc. 51 (ferns, ginkgophytes).
53. Talus cone at base of cliffs containing units 38–40, about 75 ft above loc. 52 (ferns, ginkgophytes).
54. Units 29–32, about 55 ft above loc. 53 (ferns).
55. Talus cone at base of cliffs containing units 24–27, about 50 ft above loc. 54 (ferns).
56. Talus cone at base of cliffs containing units 4–10, about 175 ft below top of member, and about 375 ft above loc. 55 (ferns, ginkgophytes).

Conglomerate member (loc. 57)

57. Units 9–12, about middle of member, and about 475 ft above loc. 56 (ferns, ginkgophytes).

Bentonitic clay member (locs. 58–61)

Lower part of member, units 116–263, largely snow covered.

58. Units 112–114, about 1,220 ft above base of member, and about 1,530 ft above loc. 57 (ferns, ginkgophytes).
59. Unit 101, about 55 ft above loc. 58 (ferns, ginkgophytes, cycadophytes, conifers).
60. Units 84–86, about 225 ft above loc. 59 (ferns, ginkgophytes).
61. Unit 70, upper part, about 150 ft above loc. 60, and about 1,025 ft below top of member (ferns, ginkgophytes, conifers).

Upper part of member, units 1–69, largely snow covered.

Upper sandstone member (duplicated section)

62. Units 147–210, composite flora from large talus blocks at base of snow-covered cliffs (ferns, ginkgophytes).
63. Unit 104, about 2,400 ft above base of member (ferns, ginkgophytes).
64. Units 1–102, composite flora from large talus blocks at base of snow-covered cliffs (ferns, ginkgophytes).

nonmarine Corwin Formation. In the Chandler River area the Tuktu type section, which overlies the Torok type section, is composed of coarser clastic sedimentary rocks containing molluscan fossils and locally abundant molds and casts of large wood fragments. Conformably overlying the Tuktu type section are nonmarine beds of the Chandler Formation (lower part of the Killik Tongue). Farther north the lower part of the Chandler Formation intertongues with the marine Grandstand Formation and the upper part with the marine Ninuluk

Formation. The intertonguing of marine and nonmarine units toward the north indicates that marine conditions persisted longer in areas more distant from the rising Brooks Range source area (Detterman *et al.*, 1963; Smiley, 1969). Figure 5 shows that the changes from Kukpowruk to Corwin deposition and from Tuktu to Chandler deposition are not exactly synchronous but are rather time transgressive in an easterly direction.

Apparently, the type sections of the Kukpowruk and Tuktu Formations, in proximity to the rising Brooks Range landmass, represent transitional stages between the marine Torok shale below and the nonmarine Corwin and Chandler Formations above. Both transitional units contain marine fossils of middle to perhaps late Albian age. Grandstand intertongues in the lower part of the Chandler Formation contain marine faunas indicating a probable late Albian age, and faunas from Ninuluk intertongues in the upper part of the Chandler Formation indicate a probable early Cenomanian age. Floral Zones II and III are found in the Killik Tongue of the Chandler Formation, and also in the Corwin Formation of the Kukpowruk River area. The youngest floral records in the Corwin type section near Cape Lisburne are those of Zone II (late Albian). Older florules of Zones IA and IB hold a stratigraphic position comparable to that of the marine Torok Formation, which is widely distributed on the east, and are probably of early to middle Albian age.

The time transgression of facies in a northeasterly or easterly direction, inferred by Chapman and Sable from regional mapping, is corroborated by the regional correlations of sequential floral zones (Fig. 5). Such time transgression is particularly evident in widely separated study areas, as between the Corwin Bluff and Kukpowruk River areas or between the Kukpowruk River and Chandler-Colville areas. Where sections are in proximity, however, the factor of time transgression of facies is not so readily apparent, as between the Pitmegea River and Corwin Bluff sections or between the two Kukpowruk River sections. If the seas were retreating northeast or east during Kukpowruk-Corwin deposition, the western shoreline may have trended generally north-south in the Kukpowruk River area. The lithologic and floral similarities between the two Kukpowruk River sections show little if any north-south time transgression, and the north-south study traverse may have been following such an Albian shoreline.

Bentonite records.—The oldest records of bentonite in sufficient quantity or purity to be readily identifiable in exposures do not appear to be synchronous across northern Alaska. Records in the Corwin Bluff area are found in the bentonitic clay member of the Corwin type section that contains Floral Zone II; farther east Zone II outcrops lack discrete bentonite beds. About 75 mi east of Corwin Bluff, in the Kukpowruk River area, bentonite may be present in poorly exposed units between outcrops containing Floral Zone II below and Zone III above; it is not apparent in rocks below this covered interval, but is a common constituent of rocks above.

In the Kuk River area about 100 mi northeast of the Kukpowruk area, bentonite is first observable in rocks containing Zone III, and is a common constituent in rocks containing younger floral zones. In the Chandler-Colville region about 350 mi east of Corwin Bluff, bentonite is first apparent in exposures containing Zone IV, and is most characteristic of the overlying Colville Group that contains Zones V to VII. Correlations by early bentonite records observable in outcrop thus may not be reliable, as such records appear to be time transgressive in an easterly direction (Albian in the west to Cenomanian farther east).

Modification of Corwin type section.—Supplemental floral records in the type section of the Corwin Formation, and in rocks of the Kukpowruk River area that are referred to the Corwin Formation, show that the type section at Corwin Bluff should be modified as follows (see Fig. 5).

1. The bentonitic clay member is the stratigraphic top of the Corwin type section, rather than the upper sandstone member as proposed by Chapman and Sable. The bentonitic clay member contains Floral Zone II, which is found also in the lower half of the Corwin Formation in the Kukpowruk River section.

2. The upper sandstone member of Chapman and Sable is not floristically correlative with the upper part of the Corwin Formation in the Kukpowruk River area. Rather, the composite flora from their topmost unit is a repetition of a floral stage (Zone I) present in older members of the type section, and not a continuation to Zone III as in other study areas.

3. The Corwin type section, exclusive of the upper sandstone member, totals about 11,300 ft in thickness. About 4,000 ft of Corwin strata in the upper part of the Kukpowruk River section contains a younger floral zone (Zone III) than is found in the type section. It is probable that at least part of the younger Corwin strata was

eliminated in the Corwin Bluff area by fault truncation of the top of the succession.

Conclusions

Feasibility of Correlation by Plant-Megafossil Zones

Across the northern margin of Alaska during Cretaceous time the surface of sedimentary accumulation was an extensive coastal plain or the floor of a shallow sea. The coastal-plain vegetation, insofar as represented by fossils, was of generally uniform composition during any particular stage of this period. During the Cretaceous the vegetation changed, partly at least, as the result of changing climates. Successive records of the developing vegetation were preserved wherever sediments accumulated and became a part of the stratigraphic sequence.

Detailed stratigraphic collection of plant megafossils in seven study areas has resulted in many fossil data relating to the sequential floral stages (an estimated 10,000 specimens from 250 localities). The fossil sequences, ranging in age from early Albian to Maestrichtian, provide evidence of a slow but cumulatively striking change in the regional flora during this time interval.

The nearly continuous record is divided arbitrarily into seven major stages of development (floral zones), all of which are present in the Chandler-Colville region. Similar stages in similar successions can be found in other study areas, although not all zones may be represented in a particular section. Wherever two or more zones are in superposition, they are in the same sequential relation as found in the Chandler-Colville region. Wherever marine fossils are available, the floral correlations correspond with those of the marine faunas. Thus the use of plant-megafossil records for correlation of nonmarine rocks in northern Alaska appears to be both reliable and accurate.

Inferences on Regional Geology

Coal-bearing clastic rocks rich in plant fossils were accumulating in the Cape Lisburne (Corwin Bluff) region while the marine shale of the Torok Formation was being deposited in other northern Alaska areas. Regional uplift may have followed, resulting in the nearshore, strandline, and interbedded marine-nonmarine beds of the Tuktu and Kukpowruk Formations; this event is reflected in the Corwin Bluff section by the change from mainly shale, to coal-bearing siltstone and sandstone, to coarse sandstone and thick conglomerate beds. Coarse pebbly sandstone beds were deposited as far north as the Kuk River area (unit 2 of Smiley, 1966), probably during this time interval. In northwestern Alaska, coastal-plain conditions may have persisted throughout later Cretaceous time, as younger rocks are coal-bearing clastic sedimentary beds rich in plant megafossils. Local marine transgressions continued until about Maestrichtian time, however, in the easternmost Chandler-Colville region.

The volcanic ash and bentonite indicate that eruptive volcanism may have been associated with the Cretaceous Brooks Range uplift. Where present in marine units, bentonite or ash is disseminated as a matrix of coarser clastic detritus. The mixing of finer ash with coarser detrital material probably resulted from the action of waves, tides, or currents in shallow nearshore or offshore environments. Where such marine deposits intertongue with coastal-plain beds, bentonite or ash commonly is found in the nonmarine facies as fairly pure and discrete beds resembling Neogene ashfall deposits of western United States.

An easterly time transgression of bentonite deposition has been noted, insofar as the records are observable in outcropping rocks. Albian exposures in the Cape Lisburne region contain discrete beds of bentonite, whereas comparable beds did not form in the Chandler-Colville area until Cenomanian time. However, the numerous "stringers" of bentonite reported by Collins and Robinson (1956–1961) in Chandler-Colville test cores of this age suggest that ashfalls were common but perhaps thinner in the east than in the west during Albian time. After the inception of discrete ashfall deposition, bentonite or ash became an important constituent in later Cretaceous deposits; this facies change is noted in all study areas of northern Alaska.

An earlier start of volcanic activity in the western part of the Brooks Range area, and perhaps in northeastern Siberia, may account for the thicker ash beds in the Albian of the Cape Lisburne region and thinner stringers on the east at sites more distant from the source. An eastward extension of volcanic activity during later Albian and early Cenomanian time could account for the easterly time transgression of rich ash or bentonite records noted in northern Alaska.

Inferences on Local and Regional Climates

Close similarities among contemporaneous floras in the several study areas of northern Alaska suggest that Cretaceous climates were essentially uniform across the region. Albian floras in the Kukpowruk-Corwin areas are similar to ones of the Chandler-Colville areas more than 300 mi east. Cenomanian and younger floras of the Kuk River area resemble those of equivalent age in the Chandler-Colville areas more than 200 mi southeast. Notable also is the uniformity of floral changes in the study areas, which suggests that climatic changes were similarly of regional scope.

Samylina (1964) reported a sequence of floras, ranging in age from Late Jurassic to late Albian, from the Kolyma River area of the Soviet Arctic, about 1,500 mi west of the Alaska sites. The temporal changes noted in such plant groups as ferns, ginkgophytes, and cycadophytes were interpreted to indicate a warming of climates there from the Late Jurassic to medial Cretaceous. Vakhrameev (1964, 1966) compiled floral data from numerous areas across Eurasia, extending from near-equatorial to Arctic regions, and ranging in age from Early Jurassic to Albian. His data show essentially parallel vegetation zones for the five intervals designated, and with a general northward shift of the topical-climate zone until the middle of the Cretaceous. Such evidence of warming climates conforms to the local changes noted by Samylina in the Kolyma River area. The inferred Mesozoic floral zones across Eurasia parallel the Eocene zones shown by Chaney (1940) and present-day climatic zones.

The floral records in northern Alaska overlap in time (Albian) those of the Kolyma River area, and continue until near the end of the Cretaceous Period. The Siberian record of cycadophytes (warm-climate indicators) shows an increase in abundance and in variety of taxa to a maximum in the Albian. In northern Alaska maxima are recorded in upper Albian rocks, with a subsequent decline to local extinction in the Cenomanian. Conifer records from Alaska show a predominance of warmer-climate taxa in Albian floras, and a predominance of cooler-temperate-climate taxa in rocks of later Cretaceous age. Late Albian and early Cenomanian dicotyledons are referred mainly to taxa of warmer-temperate-climate affinities, whereas angiosperm-dominated floras of later Cretaceous age are of cooler-temperature-climate character. Leaf forms of angiosperms also show temporal changes by which climatic trends can be inferred: from a higher proportion of entire-margined forms (warm-climate indicators) in late Albian floras (about 30 percent) to lower proportions in Maestrichtian floras (about 10 percent). The Early Jurassic to medial Cretaceous records of Vakhrameev, the Late Jurassic to Albian sequence in the Kolyma and Lena Rivers areas, and the Albian to Maestrichtian sequence in the northern Alaska region indicate that world climates were warming to a maximum in the late Albian (humid warm temperate in the Arctic) then underwent a general cooling trend to about the end of the Cretaceous Period.

Along the west coast of North America from northern Alaska southward to Vancouver Island, Senonian floras differ at different latitudes. Santonian-Campanian floras of northern Alaska are of distinctly temperate-climate character, and lack such warm-climate indicators as cycadophytes. Floras of Campanian age in the Chignik area of south coastal Alaska (Hollick, 1930) contain a larger proportion of warmer-climate angiosperms, and two species of cycadophytes are present. Farther south on Vancouver Island (Bell, 1957) are warm-temperate to subtropical angiosperm floras of Santonian-Campanian age, containing five species of cycadophytes. In all three areas the floral records are from coal-bearing sections with fossiliferous marine interbeds that indicate humid coastal-plain (near sea level) conditions. Thus, the floral differences seem attributable to latitude, rather than to differences in elevation or proximity to marine bodies.

The later Mesozoic floral records of Eurasia and North America thus show significant latitudinal differences in contemporaneous vegetation: from warmer temperate to tropical floras toward the present equator to cooler temperate floras toward the present geographic pole. The application of such evidence to concepts of drifting continents and wandering poles has been discussed (Smiley, 1967). The evidence shows also that correlations of fossil floras from significantly different latitudes may be in error if such latitudinal differences are not taken into account.

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DELTAS:

PROCESSES OF DEPOSITION & MODELS FOR EXPLORATION

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Northern Alaska coal investigations, western Naval Petroleum Reserve No. 4
By James E. Callahan

Approximately 46 mi^2 in the Oxbow and Lookout Ridge synclinal basins (fig. 2 (6)) were mapped geologically, with composite stratigraphic sections measured along Kokolik River across the Oxbow syncline. Nineteen coal samples were taken from outcrops on Kokolik River and Elusive Creek and along two large tributaries of Avingak Creek. Analyses of the samples by the Bureau of Mines indicate a fairly consistent rank of high volatile B or C bituminous coal in the Oxbow-Lookout Ridge synclinal trend (the two synclines have an echelon relation separated by a small syncline). Analyses of samples taken farther north, along the south flank of the Norseman anticline, suggest a northward decrease in rank. Relation between weathered and unweathered samples from equivalent coals farther west indicate that weathering has a significant effect on coking properties in these coals. It is expected that unweathered samples from many of the oxidized beds sampled in 1975 would exhibit coking properties as well as a significant increase in rank over the surface samples.

Hydrological studies for the Alaskan Air Command
By R. J. Madison

Results of geophysical surveys made in August 1975 at Cape Lisburne (fig. 2 (7)) indicate that the area beneath the water-collection gallery has thawed to a depth of between 40 and 50 feet. This area is suggested as the best potential for future water supply development at the Cape Lisburne facility.

Interpretation of depositional environments in the Fortress Mountain Formation, central Arctic Slope
By R. E. Hunter and J. E. Fox

Middle Cretaceous clastic rocks shed northward from the Brooks Range orogenic belt may contain a substantial amount of the hydrocarbon potential of Naval Petroleum Reserve No. 4 (NPR–4) and adjacent areas of the Arctic Slope and Chukchi Sea. Effective exploration of this potential may depend strongly on assessing environments of deposition and distribution of potential reservoir facies in terms of modern concepts of clastic sedimentation. In order to begin this type of assessment, J. E. Fox, of the Reservoir Studies Group, Branch of Oil and Gas Resources, and R. E. Hunter, of the Coastal Processes Group, Office of Marine Geology, joined I. L. Tailleur and C. G. Mull on the North Slope Petroleum field party for 2 weeks in late July 1975. A number of exposures of the Fortress Mountain Formation and related rocks were examined, and a preliminary reconnaissance was made of representative exposures of other middle Cretaceous rocks on the central and western Arctic Slope.

The Fortress Mountain Formation of Albian age crops out extensively on Ekakevik Mountain (fig. 2 (8)) very close to the source area, the Brooks Range orogenic belt. A detailed stratigraphic section was not measured, but three distinctly different clastic facies were recognized.

The uppermost part of the formation at Ekakevik Mountain is less than 35 m thick and is dominantly medium- to coarse-grained sandstone. Conglomerate beds make up less than 10 percent of the unit. The depositional environment of the uppermost part of the formation is probably shallow marine and wave-worked. This interpretation is based on the predominant low-angle, gently lenticular cross-bedding (Imbrie and Buchanan, 1965; Goldring and Bridges, 1973; Harms, 1975, p. 87–88), high degree of pebble segregation (Clifton, 1973), and presence of marine pelecypods. A fluvial origin seems unlikely because of the marine pelecypods and the absence of steeply dipping cross-bedding. A turbidite origin seems unlikely because of the absence of grading or other evidence of rapid deposition by waning currents of high density.

The middle part of the formation at Ekakevik Mountain makes up the bulk of the formation and consists largely of conglomerate; sandstone and pebbly sandstone make up less than 10 percent of the exposed rocks. The clasts of the conglomerates range from pebble to cobble size; some beds contain boulders. The beds are relatively tabular and are mostly less than 1 m thick. This main part of the formation was deposited by currents containing sediment moved largely by traction, probably in a braided stream or alluvial fan environment. This interpretation is based on the thinness of the conglomerate beds and the steepness of the crossbedding that occurs in many of the sandstone beds. A meandering stream origin seems unlikely because of the absence of extensive channeling or fining-upwards sequences and because of the overall coarseness of the deposit. The segregation of clasts of different sizes into discrete beds is not distinct enough to suggest a wave-worked environment (Clifton, 1973). Evidence for deposition by turbidity currents or by other kinds of sediment gravity flows is lacking. None of the types of internal organization typical of "resedimented" conglomerate beds (Walker, 1975) were noted, and resedimented conglomerate beds are generally thicker than beds in this outcrop.

The lower part of the formation is exposed on the north side of Ekakevik Mountain. Only the most resistant units, forming about half of the total section, are exposed. These units are composed of conglomerate, are tabular in form, and range in thickness from about 3 to 6 m. The conglomerate units differ from those higher in the sequence on the south side of the mountain (stratigraphic interpretation of Tailleur) by the poorer development of bedding within the lower units, by their coarser clast size, and by their poorer sorting. These conglomerates have characteristics approaching those of Walker's (1975) disorganized-bed model. The chaotic nature of disorganized-bed deposits suggests very rapid deposition from a dense sediment gravity flow, such as a debris flow. As debris flows occur on alluvial fans and on submarine slopes, the environmental implications of such deposits are not very restrictive.

In summary, the Fortress Mountain Formation at Ekakevik Mountain is interpreted as representing initial very rapid deposition of gravels in an unknown environment, followed by the deposition of braided stream and (or) alluvial fan gravels and sands, followed in turn by a transgression of the sea and deposition of nearshore marine sands. In this area the formation as a whole fines upward.

Characteristics of the sandstones in the upper part of the Fortress Mountain Formation exposed on Castle Mountain (fig. 2 (10)) indicate slow deposition in a dominantly fluvial or shallow marine environment, whereas on the East Fork of the Etivluk River (fig. 2 (9)), the exposed Fortress Mountain Formation consists of graded conglomerate beds deposited by turbidity currents.

The occurrence in close geographic proximity of facies of one formation ranging from undoubted turbidites to a facies that is either shallow marine or nonmarine is not surprising in an active tectonic setting. Similar juxtapositions of facies are common in Upper Cretaceous deposits along the California and Oregon coasts (see, for example, Lowe, 1972). Changes in depositional environment in such settings can come about by tectonic movements, by large-scale slumping, by rapid infilling of basins, or by rapid progradation of shelves.

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Metamorphism in the southwestern Brooks Range
By C. F. Mayfield

Preliminary results of a continuing examination of field and petrologic data from rocks collected in the Baird Mountains and Ambler River quadrangles (fig. 3 (8)) indicate a belt of sedimentary, volcanic, and plutonic rocks along the south edge of the Brooks Range (Alaska Division of Geological and Geophysical Surveys, 1973, p. 6–8) as much as 40 km wide that has been regionally metamorphosed to the greenschist facies. Typical pelitic schists contain quartz, muscovite, albite, chlorite, ±chloritoid, ±calcite, ±tourmaline, ±magnetite, ±carbon. Metamafic rocks most commonly contain albite, chlorite, sphene, ±amphibole, ±epidote, ±quartz, ±pyrite, or magnetite. Granitic orthogneisses contain quartz, potassium feldspar, albite, muscovite, ±biotite, ±zircon, ±pyrite, or magnetite. Garnet-bearing zones occur discontinuously in the southeastern Ambler River and northeastern and central Baird Mountains

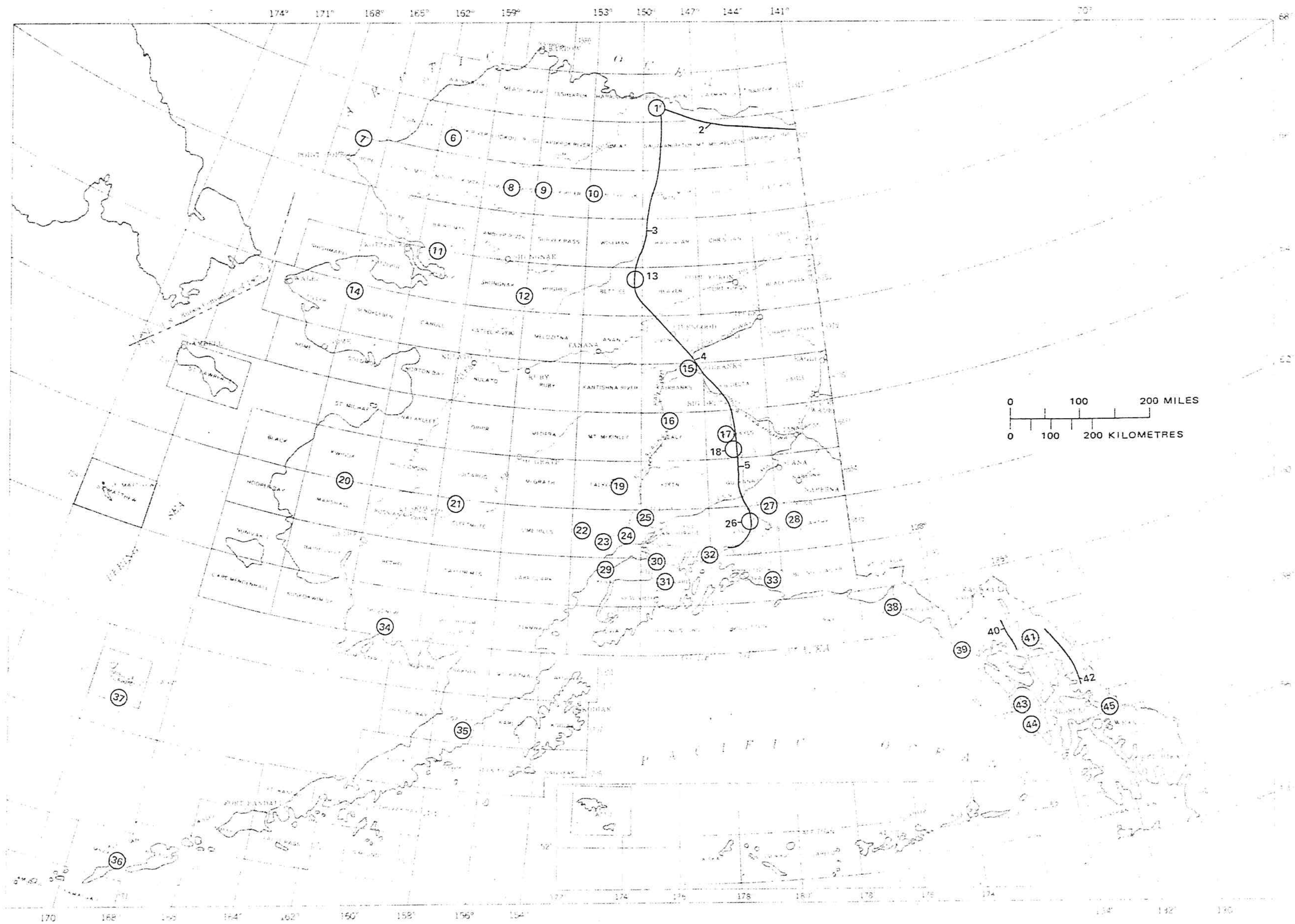

FIGURE 2.—Location of studies discussed in summary of important results, 1975 (see also fig. 3). Numbers key to project discussions in text.