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Department of the Interior
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Geological Investigations
Naval Petroleum Reserve No. 4
Alaska

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PROGRESS REPORT ON THE KILIGWA ANTICLINORIUM

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By

Irvin L. Tailleur and Bion H. Kent

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SUMMARY

This report was prepared to assist in the planning of seismic profiles to be run across the anticlinorium in the vicinity of the Kiligwa River. The stratigraphy and structure of the mapped area south of the anticlinorium are reviewed. Two facies of the Lisburne formation, a calcarenite-hydroclastic limestone facies and a black shale, black chert and dark limestone facies, have been distinguished. In the southern foothills, the black shale facies appears to have been thrust from the south over the limestone facies. The available evidence indicates that the Lisburne formation, as limestone or a more proximal facies was deposited over the area of the anticlinorium. Following a redefinition of the Torok formation in the type area, strata formerly mapped as Torok have here been designated Castle Mountain formation. The depositional history of the Castle Mountain formation reflects active orogeny. Lenses of coarse clastics appear to have been dumped in local basins; equivalent beds to the north are much finer. A basal zone of sandstone may be more extensive and may correlate with the sandstones noted along and north of the anticlinorium.

The flat thrusts dominate the foothills structure and the displacements on them may be in the order of several miles. Unconformities are locally present under most of the post-Lisburne units. The major deformation began in the Jurassic and continued spasmodically into Albian time. At the Liberator Ridges, the Castle Mountain formation overlies Shublik (Triassic formation); at Ekakevik Mountain, several thousand feet of folded Castle Mountain formation are missing under the uppermost Castle Mountain strata.

Okpikruak fossils have been identified from the axis of the Brady anticline on the Kiligwa River. The structure and lithology there indicate an anticline a few hundred feet wide. There is evidence of faulting on the north limb. Information from the Kiligwa and Ipnavik Rivers indicate that lower strata of the Castle Mountain formation are present along the axis of the anticlinorium, supporting the supposition that a structural high is present between the north dipping beds at Lookout Ridge and south dipping beds along the north margin of the foothills complex. Traces and other evidence of lineation on photographs show an apparent convergence away from the change in strike of the anticlinorium in the area of the Kiligwa-Nuka Rivers which may indicate plunge away from the area of bowing.

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Of the many possible structural situations that would fit the scanty data available, the following are believed to be the most likely to occur: 1) the Brady anticline is on the crestal area of a broad arch in the basement (Lisburne formation); 2) the Brady anticline is the surface expression of a thrust fault in the basement, analagous to Albertan foothills structures; 3) the relatively incompetent post-Lisburne beds have been crumpled by decollement folding on a comparatively flat, competent basement. Surface evidence is not definitive and the sub-surface structure will have to be determined by other methods such as seismic studies or by drilling.

An estimated 3,600-5,000 feet of section would normally overlie the Lisburne formation at the Brady anticline, and would consist of 1,500-2,000 feet of Okpikruak shale and siltstone, 1,500-2,000 feet of Jurassic shale, 300 feet of Triassic shale and limestone, and 300-600 feet of Carboniferous-Permian shale and chert. It should be noted that these figures are reasonable estimates based on the information available.

Proposed seismic profiles are shown on the geologic map. They are designed to test the subsurface locally at the Brady anticline and also the subsurface over the broader area of the bowing of the anticlinorium. The apical area of the bowing, in the vicinity of the Nuka River, appears more promising from a regional viewpoint than the Brady anticline and should be prospected for an adequate evaluation of the anticlinorium trend and regional high. However pre-Castle Mountain beds, the oldest beds along the trend, are exposed at the Brady anticline and therefore this structure has been selected for the initial test.

INTRODUCTION

Scheduled seismic and drilling activity within the Kiligwa-Nuka Rivers area makes a progress report on the evaluation of field data pertinent. The information presented in Preliminary Report 37 (Kiligwa River area, 1951) has been revised and reinterpreted.

The authors have spent much of the past year's part-time employment with the U. S. Geological Survey synthesizing a logical stratigraphic and structural picture of the Castle Mountain-Torok formations. Field data were analyzed and photographs were studied to complement and to add to field information. These investigations, however, have not yielded any conclusive results because the original mapping scale was too small to permit the desired large-scale, detailed interpretations. The following observations and conclusions are therefore speculative. They are the result of converging lines of evidence or the most logical explanation, in the light of our experience, of observed facts. In order that the reader may independently evaluate the conclusions, objective data will be distinguished from subjective evidence and personal impressions or opinions.

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GENERAL GEOLOGY

The objective of the recent studies has been to locate a drilling site that would test the Lisburne formation in the Etivluk-Nuka Rivers area. The controlling factors are: (1) that the location be close enough to outcrops of Lisburne formation to warrant the assumption that it will be present in the subsurface; (2) that the location have reasonable (estimated) depth to the Lisburne; (3) that the location be far enough north to be out of the area of extreme structural complexity; (4) that the location have favorable subsurface structure. No locality is ideally situated with respect to these factors. The best site in the area studied is on the Brady anticline where it is cut by the Kiligwa River.

The Brady anticline is 17 miles north of outcrops of Lisburne formation. It lies near the axis of an anticlinorium or broad dip reversal which is indicated by south-dipping beds to the south and younger, north-dipping beds to the north. In this report this major structure is referred to as the "Kiligwa anticlinorium". Aucella sublaevis Keyserling, restricted to the Okpikruak formation as far as known, has been identified from beds on the Brady anticlinal axis, indicating that if the underlying strata is in normal sequence only a few thousand feet of section overlies the Lisburne formation. The local structural complexity cannot be determined. The only permissible observation is that the Brady anticline is 8 to 9 miles north of intensely deformed competent beds and 17 miles north of recognizable flat thrusts.

STRATIGRAPHY

Pre-Lisburne rocks.--A limestone containing Upper Devonian fossils is associated with the thrust plates that comprise the eastern end of the DeLong Mountains. It crops out directly below a limestone unit lithologically similar to the Lisburne formation and appears to form the sole of the thrust sheets. This Devonian limestone has biostromal aspects in one exposure on the south side of the DeLong Mountains, opposite the headwaters of the East and West Forks of the Kiligwa River. No prediction of its presence in the Brady area can be made.

The Kanayut-Kayak (Devonian-Mississippian) strata forming the front ridges of the Brooks Range at the headwaters of the Kuna River plunge out to the west and are not present in the DeLong Mountains. Outcrops on the north side of the DeLong Mountains, at the head of the East Fork of the Kiligwa River, may be equivalent to the Kayak formation but contained fossils have yet to be identified. No speculation on the northerly projection of the Kanayut-Kayak formations is warranted.

Lisburne formation.--Several lithologic units of the Lisburne formation (Mississippian) have been distinguished: (1) a calcarenite-hydroclastic limestone unit; (2) an interbedded dark chert and limestone unit; (3) a black shale, black chert and dark limestone unit.

Table 1. Estimated normal stratigraphic section on the Brady anticline

Stratigraphic unit	Thickness (feet)	Composition Lithology	Depth to top (feet)
Okpikruak formation	1,500-2,000	Shale (siltstone)	0
Jurassic (Tiglukpuk formation)*	1,500-2,000	Shale	1,500-2,000
Triassic (Shublik formation)	300	Limestone and shale	3,000-4,000
Carboniferous-Permian (Siksikpuk formation)	300-600	Shale, minor chert	3,300-4,300
Lisburne formation	?	Limestone, possibly sandstone	3,600-4,900

* Tiglukpuk formation includes all Jurassic age strata in central Brooks Range region.

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(1) The lithologic characteristics of the Lisburne formation at the Lisburne Ridges and at Mt. Bupto described in Report 43 1/ are similar to sections of hydroclastic limestone exposed in the Brooks Range farther east. Thin diabase sills have intruded the Lisburne formation at the Lisburne Ridges but are not present at Mt. Bupto. Two zones of black shale and black chert similar to the strata of the Kiruktagiak member occur in the Mt. Bupto section; similar strata cap the limestone on the Ridges.

(2) Lisburne strata on the Ipnavik thrust sheet are composed of irregularly interbedded limestone and chert. Similarly interbedded chert and limestone occur in the DeLong Mountains thrust sheets. Both sections have been intruded by mafic sills and now crop out in broad synclinal structures, resulting in reverse topography. In contrast, Mt. Bupto appears to have been pushed up through the Ipnavik thrust sheet as an overturned anticline.

(3) About 200 feet of thick-bedded black chert overlying several hundred feet of black shale crops out in the foothills bordering the DeLong Mountains on the north. Intrusives are absent and the structure appears to be a series of curving inbricate thrusts.

Minor lithologic types

On the headwaters of the East Fork of the Kuna River, strata lithologically similar to the Kiruktagiak member are in gradational contact with the Kayak formation. At least 100 feet of crinoidal limestone crops out both north and south of the DeLong Mountains. On the westernmost headwater drainage of the East Fork of the Kiligwa River a calcarenite or limestone conglomerate containing pelitic fragments is faulted against the black chert-shale (section 3 above) unit.

The correlations of the above major units have not been established. Undoubtedly they are, in part, local variations. But Tailleur believes that, at Mt. Bupto, units 1, 2, and 3 (above) are largely lateral equivalents juxtaposed by thrusting. The facies distribution is interpreted to be limestone to the north and black chert and shale to the south.

Post Lisburne, pre-Torok units.--An arkosic quartzose facies crops out sporadically across the central part of the foothills complex. A similar facies has been found in the Nuka River area. Formerly it was thought that these rocks represented the topmost strata of the Lisburne formation (Mississippian) 2/; however, more recent paleontological study made by J. T. Dutro, indicates that they are more correctly re-

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1/ Tailleur, I. L., Kent, B. H., Stratigraphy and structure of the Southern Foothills section between the Etivluk and Kiligwa Rivers, U. S. Geological Survey Navy Oil Unit Prelim. Rept. 43, 1951.

2/ Tailleur, I. L., Kent, B. H., Reiser, H. N., Stratigraphy and structure of the Kiligwa River area, Alaska: U. S. Geol. Survey Navy Oil Unit Prelim. Rept. 37, 1951.

ferred to the Permian. Dutro proposes that the name Nuka formation be applied to them. A northern source area for these sediments is indicated by an increasingly coarser facies in that direction. The Nuka formation was referred to the Permian after the map was drafted and is therefore not differentiated on the map from the Lisburne.

Little pertinent information has been added to the descriptions of the Siksikpuk (Permian), Shublik (Triassic), or Tiglukpuk (Jurassic) formations included in previous Navy Oil Unit reports. Evidence of unconformities developed locally below each of these units has been strengthened. The estimated maximum aggregate thickness in the foothills complex is still 2,000 feet. The Siksikpuk and Shublik formations should not thicken northward, but the effect of the Jurassic on the total thickness is not known. Because Jurassic (Tiglukpuk) sections in the foothills are incomplete and varied, projected thickness estimates of the Jurassic are highly speculative. Intra-Jurassic unconformities, suggested in the foothills, may not be present to the north, with consequent thickening of the subsurface. However, the axis of deposition may have been along or south of the foothills, and northward thinning would be expected. A range of 1,500-2,000 feet of Jurassic beds, greater than the thickness of controlled sections to the south, is considered a reasonable estimate.

Okpikruak formation (Lower Cretaceous).—The interbedded sandstone and shale of the Okpikruak formation are persistent over the foothills and correlative units on the DeLong thrusts are similar. But the varicolor-weathering clay shale on the axis of the Brady anticline is distinctly different. Not enough section is present there to permit generalization, although the rapid change to shale may be significant. If the observation that many of the thick sections of Okpikruak are related to thrust faults is valid, the facies gradient may have been steepened by foreshortening. Within the foothills a marked unconformity places basal beds of the Okpikruak formation in contact with various older units. Some deformation preceded deposition of the Okpikruak formation, although its effect to the north cannot be determined. Because a northward thickening of the Okpikruak is not expected, 2,000 feet is considered its maximum normal thickness on the Brady anticline.

Castle Mountain-Torok formations (Lower Cretaceous).—Patton 3/ has separated the Torok formation at the type sections into the Castle Mountain formation, an essentially coarse clastic southern unit, and the Torok formation, a northern shale unit of wide distribution. He believes that the two units probably are time equivalents but that this correlation is not conclusively established.

The strata formerly designated Torok formation in the Etivluk-Nuka Rivers area are now called Castle Mountain formation. No significant thicknesses of beds comparable to the Torok formation have been recognized south of the Colville River. The shale underlying the Namishuk escarpment north of the Colville is probably correlative with the Torok formation.

3/ Patton, William W., Jr., personal communication.

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The Castle Mountain formation can be vertically subdivided into two units. The lower unit consists of conglomeratic graywacke, quite severely crumpled, that crops out on Liberator Ridge, Monument Ridge, and Smith Mountain, marginal to the Colville River plain to the north. The upper part of this unit apparently grades northward to interbedded rippled sandstone and silty shale. The upper unit of heavy conglomerate forms Ekakevik and Swayback Mountains. No northerly equivalent has been recognized, but the conglomerate is assumed to shale northward. Capping beds on Ekakevik Mountain are fine-grained sandstone that resembles the basal sandstone of the Nanushuk group.

The base of the lower unit at Liberator Ridge overlies Shublik and Tiglukpuk strata. Outcrops of the Shublik formation on either side of Monument Ridge and its eastward extension suggest that the Okpikruak and Tiglukpuk formations are absent there also. Conglomerates of sharp angular fragments that appear to be reworked rubble are locally characteristic of the basal beds.

North of the Liberator Ridges beds believed to be part of the basal unit are sandier than the overlying sequences. Actually, the only workable stratigraphic index in that area is this zone of fine-grained, dark-gray, ripple-bedded, yellow-red weathering sandstone in 6-inch to 8-foot beds separated by nearly equal thicknesses of dark fissile clay shale or claystone. On the Ipnavik River, and to a lesser extent on the Kiligwa River, scattered ammonites and pelecypods occur in these strata. Although this zone could well be a lithofacies that transects time lines with migrating depositional environment, available evidence places it in a basal position in the Castle Mountain stratigraphic sequence. Because no horizon within the Okpikruak formation on the Brady anticline is positively identified by lithology or fossils, the character of the contact between the Castle Mountain and Okpikruak formations is indeterminate.

The coarse clastics of the folded, marginal ridges (Liberator, etc.) are broadly lenticular; individual beds persist only over short distances. The geographic distribution suggests deposition in restricted basins.

A more restricted aspect is evident in the upper conglomerates of the Ekakevik Mountain and Swayback Mountain sequences. Both are underlain by unconformities representing 1,000-2,000 feet of missing lower unit. At Ekakevik Mountain, an initial sequence of shale grading upward to conglomerate was depressed and then truncated by a subsequent sequence of thick beds of conglomerate. On the eastern end of Ekakevik Mountain the thick conglomerates overlie pebble conglomerates of the lower unit, whereas on the western end, they overlie horizons within the Okpikruak formation. Approximately 1,500 feet of this thick conglomerate was measured on the north front of Ekakevik Mountain, but none is present on the south side. Apparently the sequence of conglomerate was uplifted on the south side, truncated, and buried by more conglomeratic beds which make up the main mass of the present mountain. This local detail is cited as an example of the variable conditions under which the Castle Mountain formation accumulated.

The thick conglomerates are composed of subrounded chert and mafic pebbles and cobbles with occasional fragments of limestone. Quartzite becomes more abundant toward the top of the conglomerate. The source could have been an active thrust sheet of Lisburne limestone and igneous sills to the south.

The lack of intense folding of the upper unit can be explained by competency alone. More likely, however, a partial explanation is that deforming stresses had waned by the time the upper unit was deposited or that the upper unit, being younger, suffered fewer pulses of the deformation.

Nanushuk group (Lower and Upper Cretaceous).--No rocks of the Nanushuk group are present south of the Colville River. But they extend south of the latitude of the Kiligwa-Nuka Rivers bowing (a previously recognized change in regional strike) to the east and to the west. They were probably deposited over the area and since eroded. Some clastic zones within the Torok formation appear to lie closer to the Nanushuk group contact than would be normal if a basal position for the clastic zone is assumed. Either strong faulting or thinning of the Torok by nondeposition or erosion is suggested. In spite of the observed gradational contact between the Nanushuk group and Torok formation on the flanks of structures, a reflection of the folding to the south may have caused erosion or nondeposition over growing folds.

STRUCTURE

The most striking structural features of the foothills complex are the probable flat thrust sheets composed of gently folded Lisburne formation and mafic sills. The Ipnavik sheet was described in Report 43 4/ and the DeLong sheets were mentioned in Preliminary Report 37 5/. Although not all evidence supports the hypothesis of large-scale thrust faulting, it is assumed that flat thrust faults were a primary element in the deformation of the foothills.

The Ipnavik sheet passes northward into a complexly faulted series of ridges. Similar fault ridges of Lisburne formation and diabase trend N. 60° to 75° W. across much of the foothills area. They are not associated with flat thrusts to the south but are in high-angle fault contact with the surrounding strata. Whether these ridges are related to flat thrusts, either as down-faulted blocks of formerly more extensive sheets, or as up-faulted blocks of subsurface thrusts, or whether they are related to other types of major structure cannot be determined. Because they are dominant structural features, however, their presence along the southern margin of the Castle Mountain formation exposures is significant evidence of strong stresses active as far north as the folded ridges.

The crumpling of the beds of the lower unit, Castle Mountain formation, in the folded ridges indicates considerable north-south compression but surface expression of large-scale faults has not been recognized.

4/ Tailleur, I. L., and Kent, B. H., op cit.
5/ Tailleur, I. L., Kent, B. H., and Reiser, H. N., op cit.

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The doubly plunging synclines in which the upper unit of the Castle Mountain formation occurs are folds of the same order as the broad Nanushuk structures to the north. Similar open folds were imposed on the thrust sheets and probably were superimposed on the complex within the foothills. The conclusion that strong compressional stresses were not active after deposition of the upper unit of the Castle Mountain formation is not justified, although evidence of intense compression of strata younger than the lower unit of the Castle Mountain formation is lacking.

Structures underlying the plain north of the folded ridges are exposed by the Ipnavik and Kiligwa Rivers. Cross sections (pl. 1) of outcrops along the two rivers have been prepared to show the amount of information available and the degree of structural complexity developed. No attempt to show the stratigraphic order was made on the Ipnavik River cross section; the interpreted stratigraphic sequence is indicated by inferred structural traces on the Kiligwa cross section. Several orders of folds may be distinguished on the cross sections, ranging from the broad arch of the presumed anticlinorium through Nanushuk-type open folds to minor complexities of drag folds. Analysis of the sketchy data on the two rivers gives the impression that not much of the Castle Mountain section observed in the foothills is present under the plain.

All available indications of underlying conditions were utilized in plotting the strike traces shown on the map. The Colville River plain is an erosional surface developed in fairly recent time. Drainage consequent to a lowered local base level, (rejuvenation of the Colville River), is now becoming subsequent as dissection of the higher surface proceeds. Linear divides and incipient trellis patterns are assumed to reflect differential competency of the underlying strata. The plotted traces are, then, highly subjective and any derived conclusions are only as valid as the traces.

Several observations, though, may be made with some certainty. Sufficient parallelism is exhibited by the traces to demonstrate a regional bowing in the structural grain producing a northward bulge across the Kiligwa-Nuka Rivers area. Broad undulations in the traces, secondary to the major bowing, are also apparent. These would be very interesting if they are a reflection of underlying structure.

Convergence of the trends east of the Kiligwa River and east of the Kuna River suggest an east plunge off the bowing. The density of the traces diminishes to the east. If the heavier traces actually represent the lower part of the Castle Mountain formation, an easterly plunge would cause less competent (younger) strata to be preserved on the surface of the plain. West plunge of the Brady anticline is shown by measured attitudes on Mitten Creek. The traces to the west are not carried far enough for a fair evaluation of regional west plunge. Photogeologic maps show synclines in the Nanushuk group plunging west from the bowing and Sable [6] reports more shale on the western site of the arch than is present on the Kiligwa River. Therefore, indications of a gentle regional plunge east and west off the bowing are fairly strong. The

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6/ Sable, Edward G., Dutro, J. T., and Morris, R. H., Stratigraphy and structure of the Driftwood-Noluk area, Alaska: U. S. Geol. Survey Prelim. Rept. 39, 1951.

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traces extending east from the Brady anticline project into the independently determined structural high on the Ipnavik (along the east-flowing part of the river) 7/. Again, nothing definite may be concluded. The Brady trend seems to be reflected in the heavy, arcuate traces just west of the Nuka River and south of the Colville River. These traces converge at either end to indicate, if they are reflections of a structure, double plunge. The Nuka River may not transect, therefore, the structure represented by the traces. However, the structure is sufficiently interesting to warrant further study.

The Ayiyak anticlinorium, as projected to Kucher Creek and the Etivluk River, was traced on available photos. It appears to project into the Carbon Creek anticline. The Kiligwa anticlinorium (Brady) would then be related en echelon to the Ayiyak high. The eastward projection of Driftwood anticline cuts the Kiligwa River several miles south of the Brady anticline (photogeologic map K-17). This en echelon pattern is duplicated by linear trends in the foothills complex, e. g., the fault ridges of the Lisburne formation and mafic sills.

A subject for further investigation is the measurement of the wave lengths (the distance between anticlinal crests) of Nanushuk group folds, the determination of the rate of change, and the southward extrapolation of this change to attempt restoration of Nanushuk folds over the anticlinorium. Restored Nanushuk folds might coincide with observed surface structures and would be an aid in evaluating surface features.

Of the many possible structural situations that the surface information will fit, we believe the three given below are the major alternatives to consider:

(1) The anticlinorium represents a broad arch of Lisburne formation on which secondary and tertiary folds have been superimposed. This would be a typical anticlinorium and surface structures would reflect those at depths.

(2) The anticlinorium represents a broad arch in the Lisburne formation on which the less competent overlying beds have been crumpled in a decollement-type of folding. Surface structures would be independent of the basement. The apical area of the arch could be determined only indirectly from surface information. Similar crumpling of Mesozoic strata over undisturbed Madison limestone on the west flank of the Sweetgrass arch in Montana has been described 8/.

(3) The anticlinorium is a superficial or nonexistent structure that has resulted from subsurface thrusting against or over a regional north dip. Surface structures might reflect structure on the thrust plate but would be quite independent of the structure below the thrust.

7/ Tailleur, I. L., Kent, B. H., and Reiser, H. N., op cit.
8/ Weimer, R. J., personal communication.

The first possibility would be hoped for but the least likely to occur. The gross similarities of the Southern Foothills section to the disturbed foothills belt of the Alberta Rocky Mountains justify the interpretation that structures on the anticlinorium are reflections of thrusts at depths (see (3) above), analagous to penetrated structures in Alberta. Considerable doubt of the validity of this interpretation was caused by the flat basement indicated at Castle Mountain by seismic work. No preferred interpretation can be justified at present. Additional field work probably will not resolve the problem; subsurface conditions will have to be determined by geophysical means or by drilling.

The Brady anticline

Many references to the Kiligwa River cross section (pl. 1) will be made in the following discussion and specific references will be made to various field stations that are noted on the section directly below the surface data.

In the southern part of the cross section (K10L to R27) there is an over-all predominance of south dips. The cross bedding and the prevalence of strand markings of various types in the interbedded sandstone in this area are believed to be valid criteria to determine the top and bottom of the beds. Thus it was concluded that the strata shown in this part of the cross section are, in general, not overturned and that station R27 is stratigraphically lower than station K10L.

The microfossil samples of this part were barren and no macrofossil localities were found. No conclusive data are available to indicate the age of the K10L-R27 sequence relative to the stratigraphy of the Castle Mountain formation. However, an interesting coincidence was noted: The strata at stations K16, R25, K17, and R26 contain significant amounts of pyrite, whereas rocks from stations south of K16 do not contain noticeable amounts of pyrite. In his report on microfossils collected in the Okpikruak-Kiruktagiak Rivers area, 1949, H. R. Bergquist 9/ mentioned that pyritized forms are characteristic of the lower part of the Castle Mountain formation (Torok). Although correlation of strata on the basis of contained pyrite is not justifiable, the pyritiferous nature of both the lithologic unit noted on the Kiligwa River and the lower part of the Castle Mountain formation in the Okpikruak-Kiruktagiak Rivers area may be contributory evidence of their correlative age.

Station K17 was originally believed to mark a structural high because of an observed major south-dipping reverse fault. The composition of beds at K17 is similar to that of the shale locally underlying conglomeratic strata of the lower unit of the Castle Mountain formation in other areas. The hackly bedded shale with lime-silt layers and pyrite nodules is a distinct lithologic assemblage.

9/ Bergquist, H. R., personal communication.

At station K27, evidence of faulting and lithology dominated by fissile shale with thin interbeds of red-weathering, fine-grained graywacke sandstone were observed. These distinctive beds may be correlated with similar beds on the flanks of the K22 (Brady) anticline.

Ammonites were found at station K20, in the northern part of the cross section (i.e., north of 68°55'N.). No positive identification of these fossils has been made. Ammonite zones described elsewhere have been limited to lower horizons of the Castle Mountain formation. The rocks at station K20 do not have the shallow-water aspect common to those to the south.

A fault marks the northern limit of K28 where steep dips and overturned beds are characteristic. Station K21 shows a markedly different structure: small, undulating, symmetrical folds with 30° flank dips. The rocks at K21 are much coarser, strand markings are common, and yellow-weathering sandstone beds are prominent.

Rocks at station K29 have a distinctive composition. The sandstone beds are massive, well-indurated, and cross-bedded. The color on fresh surfaces is dark gray but weathering produces a brownish red. Carbonaceous material and silt inclusions are abundant. Fissile black shale (comprising 50 percent of the section) is interbedded with the sandstone. The structure is one of very gentle (5° to 10°) south dips, gradually increasing northward to 50° S. at station K22.

Strata on the south flank of K22 are fissile black shale (80-90 percent) with interbeds of evenly bedded, red-weathering, dark-gray sandstone. The north flank of the structure at station K22 repeats this sequence and dips 30° north, but chevron folds are present.

The anticline thus outlined at station K22 is the focal point of interest. Within a dominant lithology of black fissile clay shale (green, black, yellow, and red weathering) on the crestal part of the anticline, a 20-foot zone of shell beds occurs. The shell beds are yellow brown and contain pelecypods in an excellent state of preservation.

The fossils were identified as Aucella sublaevis Keyserling 10/ (of Valanginian age), a form that elsewhere is characteristic of the Okpikruak formation. Microfossil samples from the associated shales were barren.

The following broad structural interpretation is believed to be substantially correct to this point: the fossil determination and the analysis of the exposure to the south indicate a structural high at station K22. From station K27 to K23, strata believed to be the lower unit of the Castle Mountain formation indicate that not a great stratigraphic thickness is involved.

The relative subsurface position of the Okpikruak formation in the area is of course speculative and the positions of older formations are even more so. If the sequence is normal, the Lisburne formation should be present about 4,000 feet below the structural high at station K22.

10/ Imlay, Ralph W., personal communication.

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Strata on the north flank of the structural high (K22) do not correlate very well with those on the south flank. The strata at station K24, K25, and R30 cannot be assigned with assurance to any stratigraphic position within the Castle Mountain formation. None of the criteria of the lower unit apply, and contradictory interpretations are possible from what little factual data is at hand.

The only fossil found is an unidentified pelecypod fragment in the matrix of a zone of coarse-grained rocks at station R30. Microfossil samples were barren.

At station K24 steeply dipping overturned shale and sandstone are in fault contact to the north with a gently dipping (15° N.) section of massive sandstone. A short distance to the north this section also becomes crenulated and overturned (70° S. dips in the overturned beds). The sandstone is light gray green on fresh surfaces and contains carbonaceous material and silt inclusions. They are much "cleaner" in appearance than the sandstones south of the K22 high.

The rocks at station K25 consist of light neutral green sandstones interbedded with darker gray shales. The sandstones are ripple-marked and cross-bedded; there is some tendency to lamination. A northeast strike here contrasts to the approximate N. 80° W. strike that is prevalent to the south. Folds are gentle to intense.

The beds at station R30 strike east and dip 65° N. A 20-foot zone of conglomeratic beds is present. The pebbles include black, gray, and green chert, and white quartz. Pebble size averages a quarter of an inch in diameter. Silt inclusions are larger (1 to 6 inches in diameter). Similar pebble suites are common in conglomeratic beds locally throughout the Castle Mountain formation.

At station K24 a fault separates beds of markedly different composition. The rocks at station K23 resemble those on the flanks of the structure at station K22. Also from K23 to K24 more intensively deformed beds were noted. The rocks at K24 (north of the fault) and K25 are lithologically similar to strata elsewhere considered to be stratigraphically higher in the formation. For this reason and in consideration of the over-all structural information available, a hypothetical fault was drawn between K23 and K24. The line of reasoning and interpretation would then follow patterns established for the foothills of Alberta.

However valid such an interpretation may be, the following interpretation appears to be equally valid:

(1) Facies changes are pronounced in the Castle Mountain formation. The formation shales to the north.

(2) A basal clastic tongue of Castle Mountain strata extends northward.

(3) Regardless of the appearance of the strata at stations K24, K25, and R30 they represent sections of fairly coarse clastics in terms of grain size and percent of shale.

(4) Facies changes in characteristics other than grain size cannot be predicted across the crest of the structural high.

(5) The northern sections may be correlative (with minor faults) with sections at stations K18, K20, R28, or K21, completing the limb of the indicated structural high. The strata of the north limb contain no appreciable amount of pyrite, but that may be the significant difference. However, pyrite neither proves nor disproves such a correlation.

In an over-all evaluation of possible drill sites the location 2,000 feet or so south of K22 was proposed for the following reasons:

(1) If the indicated structure is simple, such a drill site should reach the Mississippian at moderate depth and should not be too far down the flank. The site would be near the oldest strata known at the surface.

(2) If the structure is complex, the proposed well should intersect a significant fault and valuable stratigraphic information may be obtained from both sides of the fault plane. From more precise mathematical calculations it was concluded that Mississippian strata would be reached before such a fault plane would be cut, but the fault plane would lie at drillable depth. These calculations were based on an analysis of producing wells in the Alberta foothills fields. Average ratios were obtained between the horizontal distance south of a surface (axis) and the vertical depth to a pay zone. The estimated depth of the Lisburne formation and the curvature of the hypothetical fault with the surface location determined by the average ratio resulted in this conclusion.

The indicated structural high at station K20 should be mentioned. It is based on the occurrence of ammonites which are not specifically identified; the attitude of the beds is nearly vertical but anticlinal flanks are indicated at some distance both north and south of K20. Thus general stratigraphic and structural control is inadequate, but such indications as are present merit more detailed inspection as a possible future drill site. At the present time the drill site at station K22 is favored because such a site would more adequately test the subsurface characteristics of the area; more pertinent stratigraphic information would be gained, and the "economic potential" is about equal at both sites or slightly in favor of the drill site at (or near) K22.

OIL POTENTIALITIES

Favorable petroleum indications were noted: (1) asphaltic residue in porous dolomite on the ridges of Lisburne formation; (2) generally bituminous character of the shale and limestone; (3) asphalt veins in deformed beds; (4) positive oil cuts from some specimens of the Nuka (quartzose) formation; and (5) strong oil cuts from Jurassic sandstone cut by a fault zone that apparently intersects the Lisburne formation at shallow depths.

The Lisburne limestone in the southern foothills probably accumulated under geosynclinal conditions. An expected northward change to shelf environment might occur very rapidly, comparable to the rapid eastward thinning of the Mississippian in Alberta. However, we infer that the Lisburne in a favorable facies would normally be present under the Brady anticline.

RECOMMENDATIONS

Seismic profiles believed necessary to adequately prospect the Kiligwa-Nuka Rivers bowing are shown on the map. Also shown are the lines proposed by C. L. Mohr. Our profile across the Brady structure (profile 1) practically coincides with Mohr's. Assuming that this long line yields no positive results, Mohr's line along the Kiligwa would seem to have less promise than our lines to the west (profiles 2 and 3). As pointed out above, the apex of the bowing is west of the Kiligwa River. At least one of the western profiles should be run to conduct a diagnostic test of the area. Without it, we believe the preliminary evaluation of the bowing would be inadequate. If a reversal at depth across the Brady anticline is found, the eastern profile should be run to test east plunge. Profile 3 would test west plunge. In any case, the long line (1) from Lookout Ridge to the vicinity of Liberator Lake is essential for the broader outlines of the anticlinorium. North of the Colville River it will cross a possible structure that may prove interesting. If any conclusions are gained, a similar line might be extended north from profile 2.

Of course, if the Brady location is to be drilled as a stratigraphic test regardless of seismic results, the lines have to be considered from the viewpoint that the most possible local sources of information should be tested. The coverage shown by Mohr's shorter lines and our profiles would then be required. However, any reevaluation of the subsurface subsequent to completion of a well would require at least one line to the west.

It is suggested that the Triassic (limestone)-Jurassic (shale) contact might be an additional reflecting horizon. It should occur within 600-1,000 feet above the top of the Lisburne.

We also recommend that 5- to 10-pound bottom-hole samples be collected along the profiles. In the case of sandstone samples, the lithology may be correlated with lithologies on the river; in the case of shale samples, a large, relatively unweathered sample may yield microfossils. Although microfossils are rare in outcrop, careful processing of large samples may be more profitable.

It seems advisable that either Tailleur or Kent be available to assist in the interpretation and evaluation of the seismic returns. Tailleur can be in Fairbanks about March 1 for that purpose.

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A field party has been proposed to map in detail the exposures in the area of the bowing. Seismic results may be definitive and thereby obviate surface investigation. In the event that the geophysical work is inconclusive and a well location must still be made, a detailed surface survey will be necessary. We are not optimistic about the probable results of more field mapping. Close mapping of the cutbanks and inter-stream traces should afford the basis for a statistical analysis of the structures. Detailed logging of surface sections should give a better understanding of the stratigraphic sequence and interpretations based on stratigraphy would be sounder. A study of the exposures and traces north of the Colville River to Lookout Ridge offers some promise of pertinent information.

PHOTOGEOLOGIC OBSERVATIONS ON THE BRADY ANTICLINE

By William A. Fischer

A study of the aerial photographs of the Brady anticline in the vicinity of the Kiligwa River yields little information not thoroughly covered in Special Report 40. Some of the observations strengthen the structural interpretations it presents.

Stratigraphy

The aerial photographs yield little stratigraphic information; however, it is evident that the area is one largely covered by rocks which poorly resist the effects of weathering, (probably largely shale). The surface appears slightly more "mottled" along the trend of the Brady "anticline", this may represent a slight change in lithology or may be due to a local structural condition, such as tight folding and minor faulting.

Structure

Three possible structural interpretations can be made from the data visible on the aerial photographs. The first, that of a normal anticline or anticlinorium, is supported by the apparent convergence of "traces" immediately east of the Kiligwa River. The greater convergence is on the north limb. This could be due to faulting. The photogeologic studies indicate a slightly greater convergence than that indicated on Plate 1, Special Report 40.

The second interpretation, that of a strike fault (possibly an overthrust) is strongly supported by an almost startling alignment of drainage features along the supposed trend of the anticlinorium. Similar alignments occur south of the "axis" and a comparison of the position of these features to the position of faults shown on the cross section, Special Report 40, Plate 1, shows a near perfect correlation. It is interesting to note that the course of the Colville River approximately 1½ miles north of the "axis" of the Brady anticline is parallel to the alignment of the drainage features and faults south of the axis.

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The third structural interpretation is based on regional and local considerations and data. This interpretation is favored by the author. The four main parts of this interpretation are:

1. That the Brady "anticline" is at depth a high angle strike fault; upthrown on the south.

2. That the south limb or upthrown block is cut by several thrust faults of minor displacement. Southward from the "axis" each successive fault has a shallower angle of thrust.

3. That displacement on the high angle fault increased during deposition of the Torok formation resulting in the deposition of a much thicker section of Torok north of the fault.

4. That the main fault trend continues to the east and west of the Kiligwa River for many miles, probably in an en echelon arrangement.

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