

Eastern Cordilleran Foldbelt of Northern Canada: Its Structural Geometry and Hydrocarbon Potential¹

D. K. NORRIS²

ABSTRACT

The eastern Cordilleran foldbelt of northern Canada embraces that part of the foreland thrust and foldbelt north of lat. 60°N, including the continental shelf of southern Beaufort Sea. The sedimentary succession there lies with pronounced unconformity on continental crust, presumably crystalline rocks of the Hudsonian (1,750 Ma) basement, and ranges in thickness from an estimated 4 mi (7 km) along the eastern margin of the foldbelt to more than 12 mi (20 km) in the interior. Regional and interregional unconformities divide the succession into five discrete tectono-stratigraphic sequences, ranging in age from Proterozoic (Helikian) to Holocene. These sequences are termed, from oldest to youngest, Inuvikian, Rapitanian, Franklinian, Ellesmerian, and Brookian.

The region is characterized by bundles of en echelon folds cut by two major fault systems, the Richardson fault array bordering the foreland and the Kaltag fault zone transecting the foldbelt. Late Cretaceous and Tertiary horizontal contraction with concomitant vertical thickening of the supracrustal wedge is roughly one-fourth that of the eastern Cordillera of southern Canada.

Potential hydrocarbon traps in Paleozoic and Mesozoic rocks of the northern Cordillera commonly occur within these en echelon fold bundles. Thus, their locations are predictable because they are arranged systematically right- and left-hand en echelon. In the Cenozoic succession of the Arctic coastal plain and continental shelf, however, closures are arranged only crudely en echelon. Current estimates of the combined oil and gas resources of the eastern Cordilleran foldbelt of northern Canada and the adjacent interior platform are about 10 billion bbl of oil and 123 tcf of natural gas, with the preponderance of resources being confined to the Upper Cretaceous and Tertiary (Brookian) sequence.

INTRODUCTION

The eastern Cordilleran foldbelt of northern Canada embraces that part of the Cordilleran orogene between the autochthon of the northern interior platform on the east, the Tintina fault on the southwest, the Alaska border on the west, and the southern rim of the Canada basin on the north (Figure 1). It comprises an area of approximately 190,000 mi² (500,000 km²) and is divisible into a number of regions, each with distinctive characteristics of structural style and physiography (Figure 2). The area is in an equivalent structural position to the southern Canadian Rocky Mountains and foothills. It is, however, markedly different in structural geometry and mobility, so models proposed for the tectonic evolution of the eastern Cordillera of southern Canada have limited application here. In order that the integrity of the Cordillera may be maintained in space and during time, the only models of lasting value will be those that can explain the evolution of the orogene throughout its length.

The identification of the northern Cordillera as an area of contrasting tectonic style, and the recognition of the reasons for these contrasts, have revolutionized our understanding of the tectonic evolution of this part of the foreland thrust and foldbelt. The physical history of both hydrocarbon source and reservoir rocks as well as concepts for hydrocarbon exploration are necessarily different from those of other parts of the orogene.

The purpose of this paper is to review the known major oil and gas occurrences in this segment of the foreland thrust and foldbelt in the context of the new understanding, to identify regions promising to hydrocarbon exploration because of their structural geometry and tectonic history, and to formulate basic principles that will encourage industry to further its exploration programs in the Cordilleran orogene. Many oil companies have pioneered the geologic assessment of the hydrocarbon potential of this remote area. They have shared generously their knowledge of the geology there, and they have spared the writer some of the frustrations that go with carrying out field programs in such a climatically hostile environment.

SUPRACRUSTAL WEDGE

The stratigraphic succession comprising the northern Cordillera of Canada and the adjacent interior platform has the form of an eastward-tapering and northward-truncated wedge. It ranges in thickness from zero at the edge of the Canadian shield to approximately 4 mi (7 km) along the interface between the interior platform and the Cordilleran orogene, to more than 12 mi (20 km) well

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and it lies with pronounced unconformity on basement rocks, presumed to be the westward continuation of the Canadian shield. Should the basement include those rocks remobilized and recrystallized by the Hudsonian orogeny, their age would be of the order of 1,750 Ma (Douglas, 1980).

The overlying suprawedge consists of the Lower Cretaceous to Paleogene exogeoclinal assemblage spanning approximately 100 m.y. (25 Ma to 125 Ma). It is the synorogenic and postorogenic suite of clastic rocks derived primarily from regions deformed and uplifted in the Columbian and Laramide orogenies. Collectively, the two assemblages form the stratigraphic link between the northern Rocky Mountains of British Columbia and the Alaskan orogene northeast of the Tintina and Kobuk faults.

Of the many unconformities punctuating the stratigraphic succession of the supracrustal wedge, a few are regional as well as interregional. They play an important role in the division of the wedge into five, discrete tectono-stratigraphic sequences that are continuous through large areas of the northern mainland as well as the southwestern Arctic Archipelago (Norris and Yorath, 1981). The sequences are termed, from oldest to youngest, the Inuvikian, Rapitanian, Franklinian, Ellesmerian, and Brookian (Figure 3) (Norris, 1983a). The first four make up the infrawedge, and the last is the sole member of the suprawedge. They are assemblages of formations and groups, separated either by unconformities or by depositional contacts, that identify suites of rocks of fundamentally different origins and commonly of different compositions.

The Inuvikian embraces the lowest, relatively unaltered, interregional sedimentary sequence of the infrawedge. It includes the slaty argillites, quartzites, and dolomites of the Wernecke Supergroup as well as the shelf carbonates and clastics of the Mackenzie Mountain and Pinguicula Supergroups (Young et al, 1979). In due course, the Wernecke Supergroup may be split from the Inuvikian because it can be separated from overlying rocks by a major, angular unconformity (Nadaleen orogeny) (Yeo et al, 1978; Norris, 1983a). Moreover, its lithofacies suggests, for the most part, a much deeper water environment of deposition. Radiometric ages from the breccias in the Wernecke Supergroup indicate that the lower part of the Inuvikian may be as old as Aphebian (Archer et al, 1977).

The Rapitanian embraces the stratigraphic interval lying unconformably (Racklan orogeny) on the Inuvikian and overlain both unconformably and gradationally by the Franklinian. It includes the glaciogenic Rapitan Formation of northwestern Mackenzie Mountains and the coeval Tindir Group of western Ogilvie Mountains, as well as the very thick (> 20,000 ft or 6 km) succession of interbedded clastics, carbonates, and volcanics of the Neruokpuk Formation of the British Mountains. The Rapitanian is in a stratigraphic position equivalent to the Windermere Supergroup of the southern Canadian Cordillera and may well be coeval with it (Gabrielse, 1972).

The Franklinian sequence embraces the interregional succession from the base of the Cambrian System to the top of the Devonian (Norris and Yorath, 1981). It includes a basal, shallow-water clastic unit overlain by a wide-

SEQUENCE	AGE	FACIES	SYMBOL
BROOKIAN	NEOGENE	Ss, Sh	B
	E. CRET. -	Sh, Ss	
	PALEOGENE		
ELLESMERIAN	E. CARB. - E. CRET.	Ls, Dol, Sh, Ss	E
FRANKLINIAN	E. CAMB. - L. DEV.	Ls, Dol, Ss	F
RAPITANIAN	HADRYNIAN	Sh, Ss, Dol, Cgl	R
INUVIKIAN	HELIKIAN	Ls, Dol, Ss	I

Figure 3—Tectono-stratigraphic assemblages comprising upper part of supracrustal wedge in northern Canadian Cordillera.

spread blanket of stable, shallow-water, reefoid platform carbonates and clastics of considerable economic importance because of its contained hydrocarbons adjacent to the interior platform in the Norman Wells area.

The carbonate platform of the Franklinian sequence is interrupted in the position of the Richardson anticlinorium by a narrow, north-trending, structurally controlled site of graptolitic shale and limestone deposition known as the Richardson trough (Figure 4). Within the trough these rocks range at least from Upper Cambrian to Lower Devonian. They are coeval with the graptolitic shale succession of the Selwyn basin to the south. Northward, the trough widens markedly so that the edge of the carbonate shelf west of the trough is approximately in the position of the Aklavik arch complex (Figure 2). The carbonate shelf edge along the eastern margin of the trough, on the other hand, follows a northeast-trending curvilinear trace onto the Holocene continental shelf to link with the Hazen trough of the Arctic Archipelago (Miall, 1976). Graptolitic shales and limestones equivalent to the lower and middle Paleozoic carbonate banks beneath the northern interior platform and Eagle foldbelt, therefore, are widespread on the northern mainland west of the Mackenzie Delta. They should occur on the continental shelf beneath southern Beaufort Sea (Norris and Yorath, 1981), although they are doubtless out of reach of the drill. Franklinian carbonate rocks host major reserves of both oil and gas in the eastern Cordillera of northern Canada.

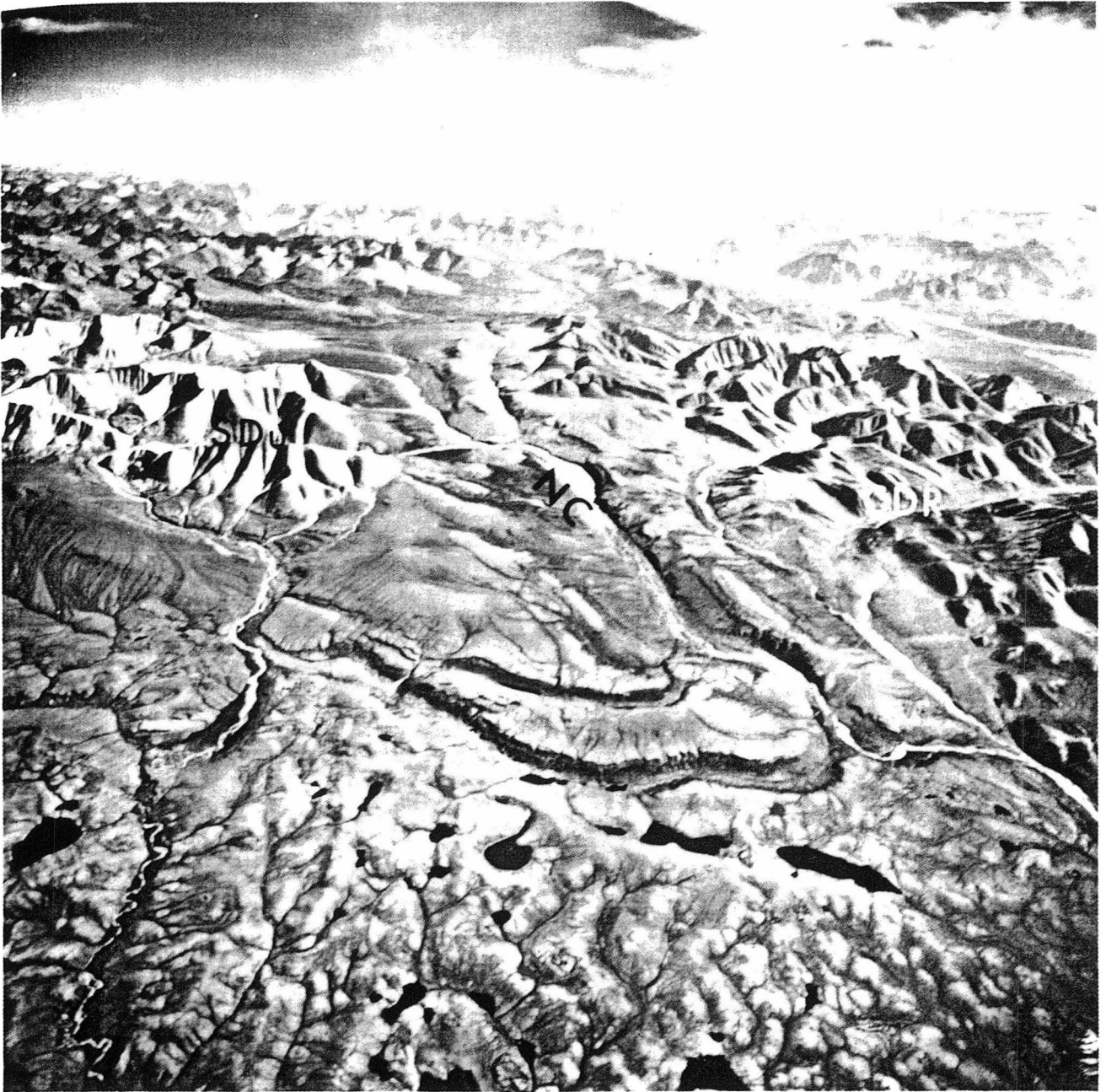


Figure 4—Eastern margin of Richardson trough between Knorr Range and Mackenzie Mountains at headwaters of Noisy Creek (NC). Undifferentiated light-gray weathering dolomite (SDU) of Mt. Kindle Formation and equivalents of Delorme Formation face dark-gray shale of Road River Formation (CDR) across creek. NAPL oblique photo T4-100R looking south.

The Ellesmerian sequence includes the rock succession from the Lower Carboniferous (Viséan) to the mid-Lower Cretaceous (Hauterivian). It is bounded below by the interregional unconformity representing the latest Devonian and earliest Carboniferous Ellesmerian orogeny. Shelf carbonates with associated clastics predominate in the lower part of the sequence (Carboniferous, Permian, and Triassic) and texturally and mineralogically mature, easterly derived, epicontinental clastic rocks (Jurassic and Lower Cretaceous) predominate in the upper part. Both the Lower Carboniferous and the Lower Cretaceous are known to contain economically significant reserves of

hydrocarbons in the eastern Cordillera of northern Canada.

The Brookian embraces the stratigraphic succession from the upper part of the Hauterivian to the Holocene. It includes, therefore, the entire sedimentary record of the fundamental redistribution of source areas and depositional basins concurrent with the onset of the Columbian orogeny during the Hauterivian and climaxing with the Laramide orogeny during the early to mid-Tertiary. Remnants of the Columbian foredeeps in which these clastic rocks were trapped are preserved on the north flank of the Mackenzie Mountains (Figure 5) and in the Eagle plain on



Figure 5—Sandstone mesas of mid-Cretaceous Trevor Formation (KTR) comprising erosional remnants of Columbia foredeep on north flank of Mackenzie Mountains (MM) in northern Yukon Territory just west of boundary with Northwest Territories. NAPL oblique photo T5-185R looking south-southeast.

the north flank of the Ogilvie Mountains. Remnants of the Laramide foredeeps, on the other hand, are largely on the continental shelf beneath southern Beaufort Sea. Their southern feather edges are preserved and exposed on the Yukon coastal plain in the vicinity of the mouths of Big Fish (Figure 6) and Babbage Rivers, and in the Caribou Hills east of the Mackenzie Delta. The Brookian can be subdivided (Figure 3) into a supra-Neocomian (Creta-

ceous) to lower Tertiary flyschoid and molassoid succession and an upper Miocene(?) and higher unstructured, alluvial-deltaic clastic interval (Dixon et al, 1984).

STRUCTURAL STYLE

The foreland thrust and foldbelt of the northern Canadian Cordillera is divisible into several discrete tectonic elements characterized by their structural and stratigraphic styles. They range from the homocline of the northern interior platform to the en echelon fold bundles of the Mackenzie and Taiga-Nahoni foldbelts,³ to the strike-slip regimes of the Richardson anticlinorium and

³The term "foldbelt" is used here to identify structural domains dominated by an echelon fold bundles within the foreland thrust and foldbelt. They are, therefore, integral components of the Cordilleran foldbelt as defined by King (1969).

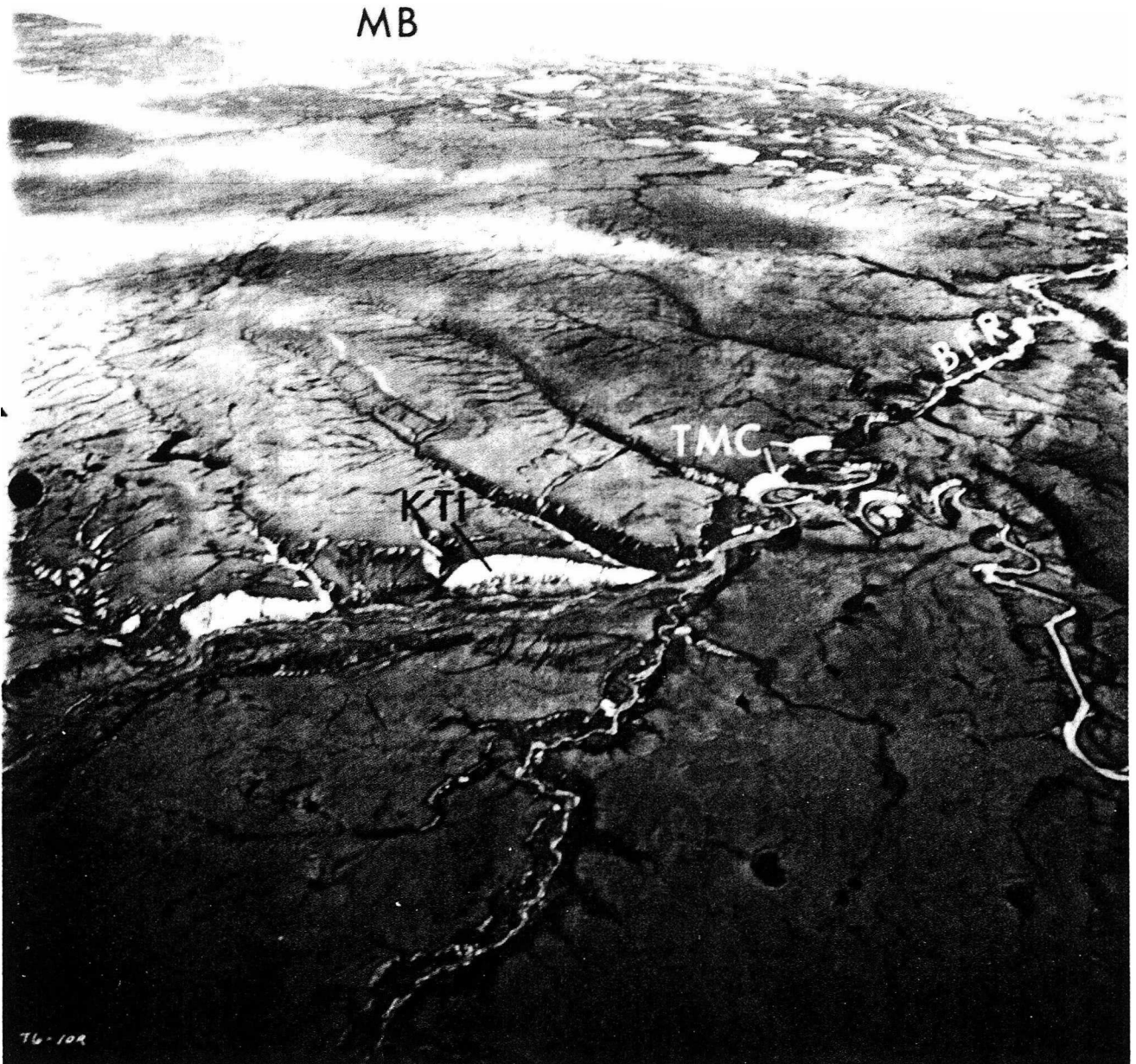


Figure 6—Mudstone and sandstone of Upper Cretaceous Tent Island (KTI) and lower Tertiary Moose Channel (TMC) Formations including part of Laramide foredeep on northwest flank of Cache Creek uplift in vicinity of Big Fish River (BFR). Northwesternmost Mackenzie Delta and Mackenzie Bay (MB) in background. NAPL oblique photo T6-10R looking north.

Rapid depression (Figure 2). Collectively these elements make up a complex part of the foreland thrust and foldbelt whose structural development and consequent tectonic style contrast markedly with those parts of the Cordilleran orogene in an equivalent structural position east of the southern Rocky Mountain trench. Of prime importance to hydrocarbon exploration in this part of the Cordilleran orogene are the Mackenzie, Taiga-Nahoni, and Eagle foldbelts, the Aklavik arch complex, the Rapid depression, and the Richardson anticlinorium. For a systematic description of neighboring elements, refer to Norris (1974a) and Norris and Yorath (1981).

Mackenzie Foldbelt

The Mackenzie foldbelt embraces that part of the Cordilleran orogenic system between the Selwyn foldbelt and the western margin of the northern interior platform (Figure 2). The arcuate length of the belt is 600 mi (950 km), or slightly more than twice that of the Jura. Fold bundles with associated strike-slip faults dominate the structural style. They swing in a great curve to outline the structural grain of the Mackenzie deflection as it changes trend from a northerly strike in the vicinity of the 60th parallel to a westerly strike in the headwaters of the Ramparts and Arc-

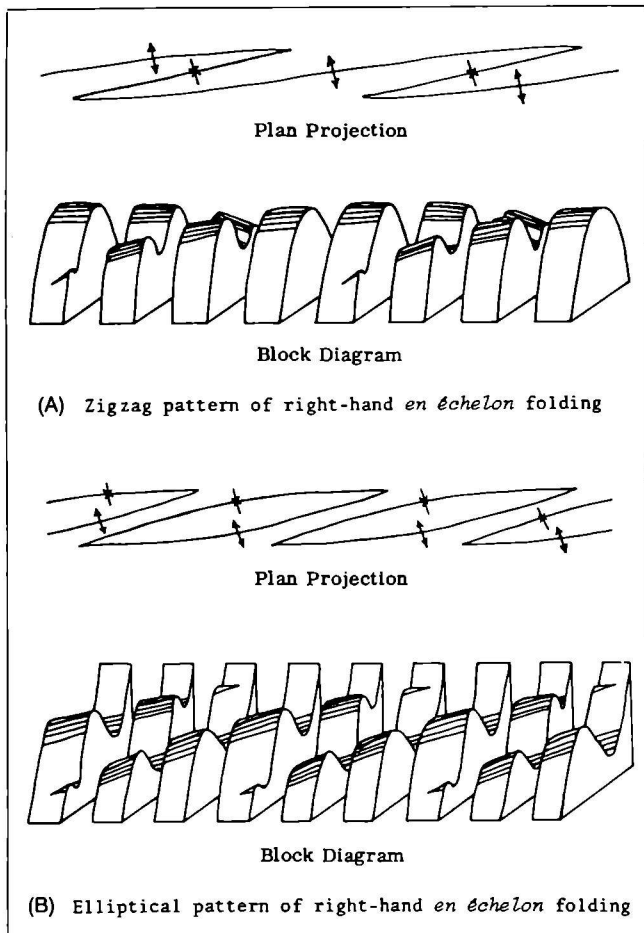


Figure 7—Basic patterns of *en echelon* folding (Norris, 1972, after Campbell, 1958).

tic Red Rivers. Although the folds have not been examined in detail, they appear to be flexural slip and cylindrical, similar to those in the Cordilleran foreland thrust and foldbelt of southern Canada. They would be expected, therefore, to be parallel or concentric in style only at low amplitudes (Norris, 1971). Moreover, they commonly have curvilinear axial surfaces dipping either steeply toward or away from the interior platform. Some are symmetrical, however, and others reverse their direction of vergence along strike.

Characteristic of these fold bundles is the arrangement of individual folds or fold pairs in *en echelon* arrays (Norris, 1972) that systematically lie to the right and left, depending on their position on the Mackenzie deflection. The basic patterns in these arrays are the characteristic zigzag and elliptical forms (Campbell, 1958). In the zigzag pattern (Figure 7A) the folds are observed to overlap along strike and to alternate between anticlines and synclines. As one faces in the direction of termination of a given anticline, its closest neighbor is a syncline that is connected to it. In a right-hand array, the neighbor lies to the right, and in a left hand array, it lies to the left. Where the folds overlap, any two anticlines (or synclines) dive past each other with opposing plunges like trained porpoises at Sealand. In the elliptical pattern (Figure 7B), anticlines and syn-

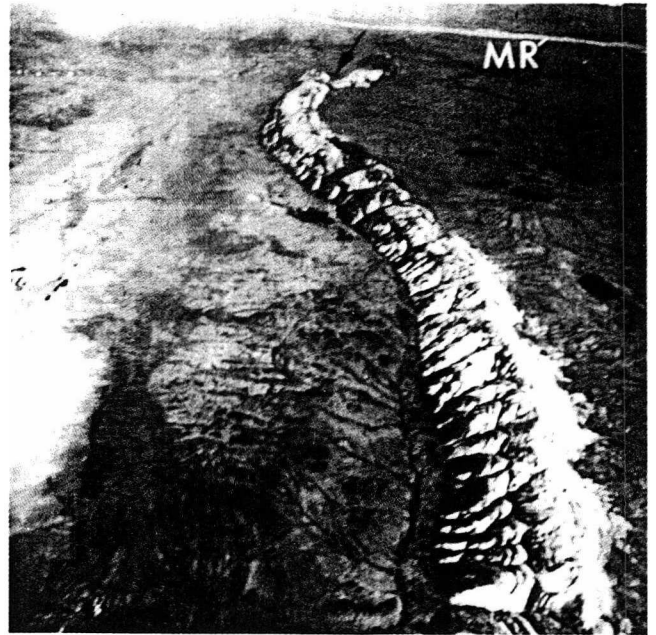


Figure 8—Right-hand overlap (black arrow) and longitudinal buckling of mid-Paleozoic dolomite and limestone of Camsell Range near Wrigley, western District of Mackenzie. Mackenzie River (MR) in upper right background. NAPL oblique photo T12-15R looking northeast.

clines are paired, and the pairs may lie right- or left-hand *en echelon*, depending on structural position on the deflection. A third and less common association of folds, seen notably in the Anderson plain (see Cook and Aitken, 1975a, Map 1410A), is that in which parallel or subparallel fold axes are arranged right- or left-hand *en echelon* with no obvious linkages. Individual folds appear to die out along strike.

Ideally, the traces of axial surfaces of folds are curvilinear to rectilinear, whereas in practice they are highly sinuous, suggesting refolding of the bundles. Moreover, individual bundles are not exclusively right- and left-hand *en echelon*, although a dominant configuration commonly appears in a given bundle.

On the north-trending domain of the Mackenzie deflection, the fold bundles are preferentially arranged right-hand *en echelon*. They are commonly associated with contraction-faulted mountain ranges whose trends can be strongly curvilinear, as in the northern Camsell Range (Figure 8), or disrupted by transverse faults, as in the southern Camsell Range (Douglas and Norris, 1976a). In both instances a case can be made either for longitudinal buckling of the ranges after contraction and uplift, or for oblique slip displacement concurrently with longitudinal buckling and development of *en echelon* fold bundles of diverging structural trends. In either instance, the major principal axis of compression is oblique to the mean trend of the range.

On the outermost part of the Mackenzie deflection, in the Norman Wells area (Figure 2), both right- and left-hand configurations of fold axes are equally common. On the west-trending domain of the deflection, however, a

preferred configuration is again observed. There, the fold axes are more commonly arranged left-hand en echelon, and the sense of the configurations is the reverse of that in the north-trending domain.

The preferred disposition of anticlines (and synclines) relative to one another, as well as the structural position of their culminations in the Mackenzie deflection, is of great economic importance. Some closures are known to have trapped economically significant amounts of hydrocarbons, as for example, in the Pointed Mountain, Kotaneelee, and Beaver River gas fields.

Potential lower and middle Paleozoic source and reservoir rocks can be inferred to underlie a large area beneath the Plateau thrust plate in the north-central Mackenzie Mountains (Cecile et al, 1982). In addition, broad, high-relief structures involving Lower Cambrian rocks in the northern Franklin Mountains and the Colville Hills (Cook and Aitken, 1976) may provide substantial structural traps in the parautochthon between the interior platform and the orogene. None of these kinds of structural traps has thus far been tested with the drill, either in Mackenzie and Franklin Mountains or Colville Hills.

Taiga-Nahoni Foldbelt

The Taiga-Nahoni foldbelt comprises the west-trending fold bundles of the Taiga Ranges and the north-trending bundles of the Nahoni Ranges. The bundles meet in a deep reentrant in the Ogilvie Mountains at the headwaters of the Ogilvie River (Norris, 1982a). Folds are again the dominant structural feature of the belt. From east to west in the Taiga Ranges, the anticlines and synclines are preferentially arranged left-hand en echelon, similar to those along the west-trending domain of the northern Mackenzie Mountains. At the headwaters of the Ogilvie River, in a plunge depression, the foldbelt turns abruptly more than 90° and continues in the Nahoni ranges, first northeastward, then northward, and finally northwestward. Right-hand en echelon folds predominate, as they do in the north-trending domain of the Mackenzie foldbelt. Therefore, a mirror image of the reversal in configuration of fold axes is observed around the Mackenzie deflection (Norris, 1974a).

In contrast to the somewhat irregular and locally ill-defined eastern margin of the Mackenzie foldbelt and the broadly curvilinear northern margin, the flanks of the Taiga-Nahoni foldbelt are well defined and strongly curvilinear. The mountain front steps systematically southward on the north flank of the Taiga Ranges and eastward on the east flank of the Nahoni Ranges in conformity with the en echelon arrangement of the weather-resistant limestone and dolomite cores of the folds.

Eagle Foldbelt

The Eagle foldbelt lies within the deep reentrant of the Taiga-Nahoni foldbelt. It is flanked on the east by the Richardson anticlinorium and is truncated on the north by the Aklavik arch complex. Lowermost Upper Cretaceous clastic rocks of the Eagle Plain Formation are widespread at the surface and their zebra-striped pattern of light and medium gray units outlines the folded nature of the ter-

rain. The folds trend slightly west of north, and some have axial surface traces up to 75 mi (120 km) long. They are commonly arranged right-hand en echelon in conformity with the north-trending domain of the Taiga-Nahoni foldbelt. The few that are asymmetrical verge westward. Of particular importance is the sub-Upper Cretaceous unconformity that truncates systematically Upper Devonian through Lower Cretaceous formations from north to south across the foldbelt. Updip truncation of porous Carboniferous sandstones at the unconformity is known to produce traps favorable to the retention of hydrocarbons in the southern Eagle foldbelt.

Aklavik Arch Complex

The Aklavik arch complex is a composite, northeast-trending element extending in Canada from the Keele Range adjacent to the Alaska border to the continental shelf beyond the Tuktoyaktuk Peninsula east of the Mackenzie Delta (Figure 2). From southwest to northeast, it embraces a series of uplifted and depressed blocks whose long axes trend approximately 25° counterclockwise from the long axis of the complex. The blocks, therefore, are arranged right-hand en echelon and collectively form an abrupt northern termination to the Eagle foldbelt and to part of the northern interior platform.

Many unconformities, some spectacularly angular, are present in the complex and attest to intermittent and prolonged tectonic activity at least as early as Cambrian time (Norris and Yorath, 1981). At the northeast extremity of the complex in the Campbell uplift, for example, transgressive shoreline sandstones and shales have been penetrated by the drill (Amoco Ulster Scurry Inuvik D-54 well) at the base of gently dipping to flat-lying lower and middle Paleozoic carbonate rocks. They lie unconformably on steeply dipping Proterozoic clastics and carbonates. Although the contact has not been seen, it is assumed to be an angular unconformity.

Immediately west of the Mackenzie Delta, moreover, Lower and Middle Permian carbonates and clastics are observed to lie with angular unconformity on Lower Devonian or lower cherty shales of the Road River Formation in Aklavik Range (Nassichuk et al, 1978), and on Upper Devonian flyschoid clastic rocks in Rat Pass, 40 mi (64 km) to the southwest. Both of these unconformities appear to be manifestations of the Ellesmerian orogeny in the northern mainland.

Disconformities or very acutely angular unconformities at the base of the Jurassic System, within the Lower Cretaceous Series and beneath the upper Miocene Stage, also attest to intermittent uplift and depression. The fact that angular discordances characterize those contacts in and immediately adjacent to the Aklavik arch complex, whereas paraconformities predominate away from it, is a direct measure of the mobility of the complex and of the localization of updip truncation of potential source and reservoir rocks within it.

Rapid Depression

Rapid depression on the northern mainland is a structurally controlled low between Old Crow-Babbage depres-



Figure 9—Rapid fault array in Rapid depression at headwaters of Blow River. Conglomerates and sandstones of Lower Carboniferous Kekiktuk Formation (CK) lie with angular unconformity on slaty argillites (OSH) coeval with lower and middle Paleozoic Road River Formation. Downthrown walls identified by black dashes. KF is Kaltag fault and BL is Bonnet Lake. NAPL oblique photo T13R-114 looking south.

sion and Romanzof and Barn uplifts on the west and the Aklavik arch complex (including Cache Creek uplift) on the east (Figure 2). Seaward on the Beaufort Shelf, it is overlain by a thick, gravitationally uncompensated wedge of Mesozoic and Tertiary clastic rocks. The depression terminates up the plunge in Blow Pass at long. 137°W, lat. 68°N. The flyschoid rocks filling the depression signal the fundamental and widespread restructuring of landmasses and depositional sites beginning during the mid-Early Cretaceous (late Hauterivian) and the resulting deposition of more than 2.5 mi (4 km) of flyschoid strata in the axial region of the depression by the mid-Tertiary. The texturally and mineralogically immature chert, lithic sandstones, and conglomerates shed from deforming and uplifting regions to the south and west contrast markedly with the mature, epicontinental Jurassic and lowest Creta-

ceous clastics shed from cratonic areas to the east prior to the initiation of the depression.

The presence of transgressive and regressive formations lying on various stratigraphic units in the axial regions of the trough and on progressively older units away from the axis indicates not only that Rapid depression was structurally controlled but also that it had a long antecedent history (Norris and Yorath, 1981). This is evident, for example, from the spectacular angular unconformity separating the Franklinian and Ellesmerian sequences in Blow Pass (Figure 9). It identifies the Ellesmerian orogenic event on the northern mainland 60 mi (100 km) to the northwest of those localities mentioned earlier in the Aklavik Range and Rat Pass.

Rapid depression is especially important for three reasons. First, it would appear to have formed in response to

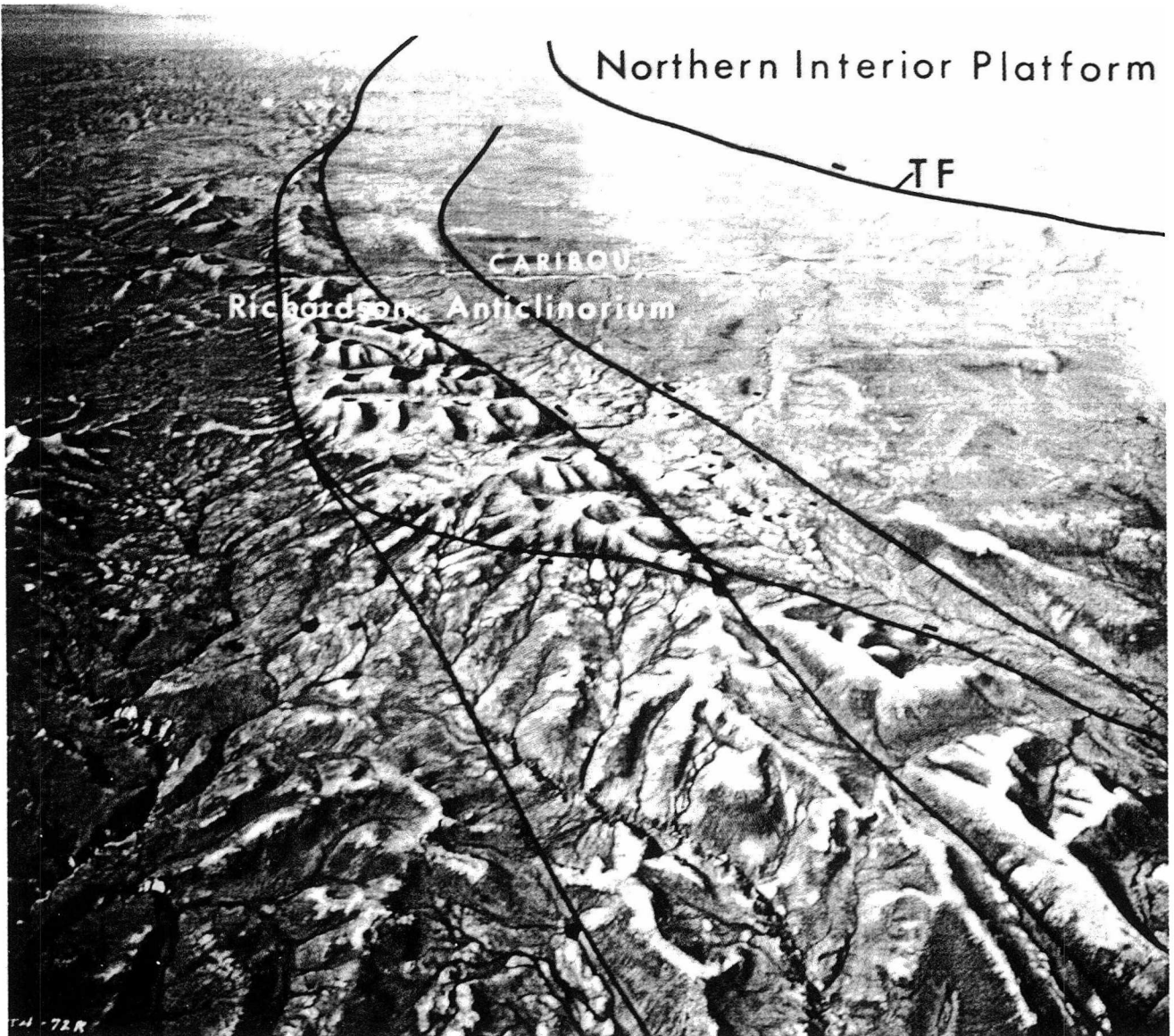


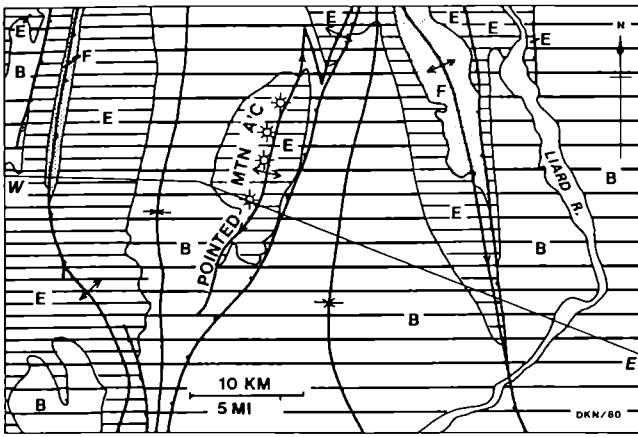
Figure 10—Richardson anticlinorium and some strands of Richardson fault array in southern Richardson Mountains in vicinity of Caribou River. Trevor fault (TF) defines interface between the Cordilleran foldbelt and the northern interior platform. Downthrown walls shown by black dashes. NAPL oblique photo T4-72R looking north.

rotation of northernmost Yukon Territory and contiguous parts of Alaska and Siberia away from a medial position in ancestral Canada basin opposite the Arctic Archipelago (Norris, 1983b). Second, the ancestral Rapid fault array preordained and localized the position and orientation of the Kaltag fault as it threaded its way through the depression during the early Tertiary. Third, it localized depositional thickening in both the Columbian and Laramide foredeeps of the northernmost mainland and contiguous continental shelf. As a structurally controlled trough, Rapid depression is the Mesozoic and Tertiary analog of the early and middle Paleozoic Richardson trough (Norris and Yorath, 1981) in the northern Canadian Cordillera.

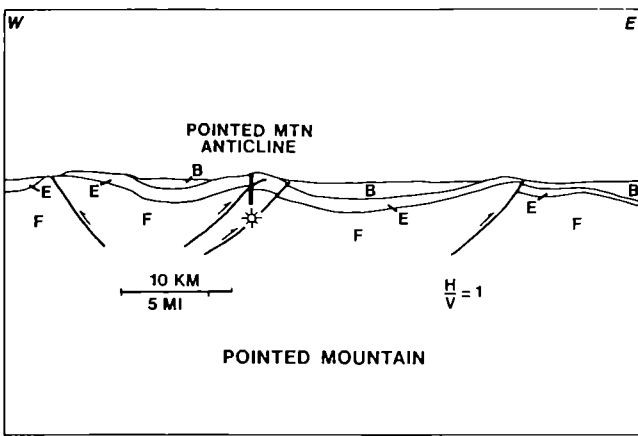
Richardson Anticlinorium

Richardson anticlinorium is the broad, north-trending anticlinal structure between the autochthon of the north-

ern interior platform on the east and Eagle foldbelt on the west (Figure 2). It is bounded on the east through much of its length by the Trevor fault (Norris, 1982b) and on the west by the Deception fault (Norris, 1982c). The anticlinorium coincides in position with the early and middle Paleozoic Richardson trough. Deep-water, graptolitic shale with resistant limestone breccia interbeds, composed of material shed from the coeval carbonate shelves of the adjacent interior platform and Eagle foldbelt, comprise the dominant lithology on the flanks of the anticlinorium. In the core, moreover, Lower Cambrian limestone overlies with angular unconformity phyllitic argillites of the Wernecke Supergroup, which contains the lowest and oldest rocks in the region. The removal of more than 6 mi (10 km) of younger Proterozoic rocks at this unconformity is clear evidence of major differential vertical uplift and of potential involvement of the Hudsonian(?) basement in the



(A)



(B)

Figure 11—Simplified geologic map (A) and structure section (B) across Pointed Mountain gas field, southwestern District of Mackenzie (after Douglas, 1976b; Douglas and Norris, 1976b).

faulting prior to the Early Cambrian (Figure 10).

The anticlinorium is laced with north-trending, curvilinear, near-vertical faults (Richardson fault array) involving rocks as young as early Tertiary. Various strands have right-lateral separations of up to 25 mi (40 km) (Norris and Hopkins, 1977) and illustrate the cumulative effects of dextral shear—the older the rocks that are displaced, the larger is the horizontal separation. Insofar as Carboniferous and younger formations lack horizontal separations across faults of the array, it would appear that strike-slip displacement largely, if not completely, ceased by the close of the Devonian. The building of the anticlinorium from the Richardson trough came about through reactivation of the ancestral Richardson fault array by differential vertical motion during the early to mid-Tertiary by the Laramide orogeny.

The absence of a foredeep at the interface between the northern interior platform and the anticlinorium may well be due to the contrasting style of the Laramide deformation. In contrast with the 50% shortening of the supracrustal wedge in the Cordilleran foreland thrust and foldbelt of southern Canada, shortening between the Tintina fault and the interior platform at the latitude of the Mackenzie Mountains is 14% (Gordey, 1981). There were

markedly less contraction and thickening of the supracrustal wedge and correspondingly less accumulation and migration of tectonic load to depress the crust.

OIL AND GAS OCCURRENCES IN THE OROGENE

Several important discoveries of hydrocarbons have been made in the foreland thrust and foldbelt of northern Canada, and doubtless many more will be made with increased sophistication of exploration methods and tools. A review follows of the major discoveries in terms of their structural setting in order that predictive principles of hydrocarbon entrapment may be formulated. Treatment of fields is from south to north and not according to any preconceived stratigraphic or structural order.

Pointed Mountain–Kotanelee–Beaver River Gas Fields

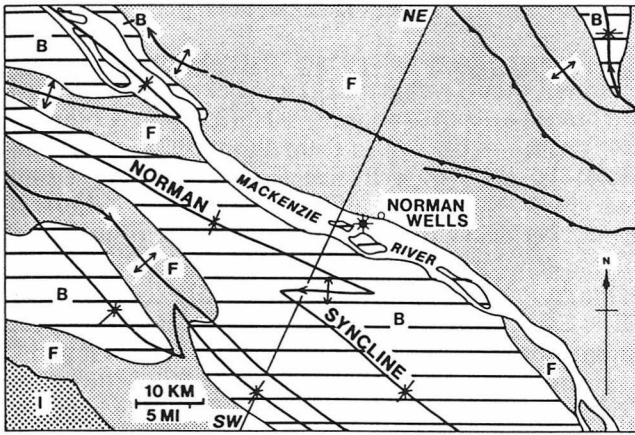
The Pointed Mountain, Kotanelee, and Beaver River gas fields occur close to the eastern margin of the foreland thrust and foldbelt. Pointed Mountain is about 30 mi (45 km) north of the 60th parallel (Figure 1), Beaver River is astride the 60th parallel, and Kotanelee is midway between. Pan American Petroleum Corporation spudded the first well on the Beaver River anticline, one of the major closures in the field (deWit et al, 1973). Gas was discovered there during 1959. It was 1966, however, before gas was discovered in the Pointed Mountain anticline under almost identical structural and stratigraphic conditions. The first producing well in the Kotanelee field was drilled during 1977. All of the reservoirs are in the upper part of a monotonous succession of Ordovician to Middle Devonian (Franklinian) shallow-water carbonates and evaporites (Snowdon, 1977). Fracture porosity in the hinges of the folds is responsible for the high deliverability.

The structural style in the fields is one of generally north-trending broad folds with some thrust and high-angle reverse faults (Figure 11). In contrast with the strong asymmetry in the deformation observed in the Cordilleran foreland thrust and foldbelt of southern Canada, the deformation observed here is approximately symmetrical. As many major folds and reverse faults verge toward the foreland as away from it.

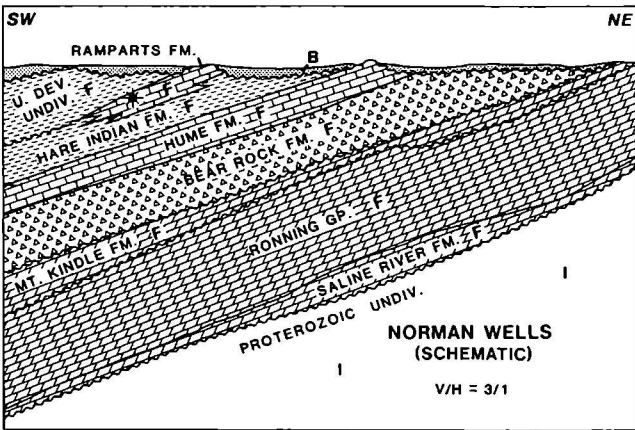
The folds and their associated contraction faults characteristically have curvilinear traces (see Douglas, 1976; Douglas and Norris, 1976b), possibly because of refolding. Moreover, the fold hinges commonly step to the left or right through an echelon linkage, and the structural level of a given stratigraphic zone rises and falls along the strike to produce recurring culminations favorable for hydrocarbon entrapment.

Norman Wells Oil Field

The Norman Wells oil field lies near the eastern boundary of the foreland thrust and foldbelt and close to the northeasternmost limit of the Mackenzie deflection. Like the region of the Beaver River, Kotanelee, and Pointed Mountain gas fields, folds and thrust or high-angle reverse faults are equally important in controlling the structural style of this part of the orogene.



(A)

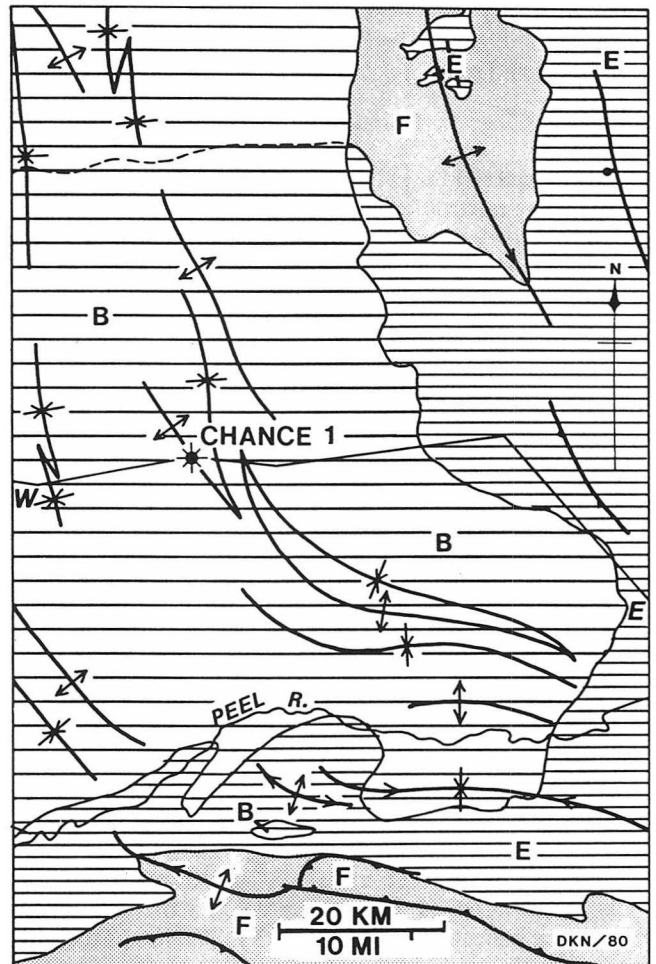


(B)

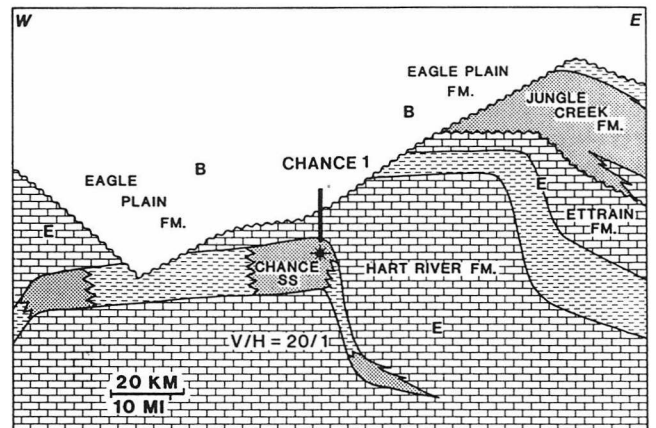
Figure 12—Simplified geologic map (A) and structure section (B) across Norman Wells oil field, western District of Mackenzie (after Cook and Aitken, 1973, 1975b). Interregional unconformities separate Inuvikian (I), Franklinian (F), and Brookian (B) sequences.

Oil was discovered at Norman Wells during 1920 at a location chosen by T. A. Link in the vicinity of seepages at the confluence of Bosworth Creek and the Mackenzie River. The discovery well encountered oil at a depth of 783 ft (239 m) near the updip limit of a gently west-dipping homocline in Middle Devonian (Franklinian) reefoid rocks (Figure 12). The lower Upper Devonian Canol Formation is important here both as source and seal, because of its high organic content, its bituminous nature, its position with respect to the reefs, and its impermeability (Bassett and Stout, 1967). Much of the field is beneath the Mackenzie River, so production has been largely from directionally drilled holes on the north shore of the river and from Goose and Bear Islands. A major development program for the field (Kempthorne and Irish, 1981) includes the use of artificial islands in the river to increase production.

The position of the field on the northwest flank of the Norman syncline (Figure 12A) would suggest that, under comparable stratigraphic conditions, other folds in the region may have hydrocarbon potential both in their crests as well as down their flanks. This is especially true where a



(A)



(B)

Figure 13—Simplified geologic map (A) and structure section (B) across Chance field, southern Eagle foldbelt (after Graham, 1973; Norris, 1982c). Interregional unconformity separates Ellesmerian (E) and Brookian (B) sequences.

cover of Brookian rocks is present to serve as an additional seal. The hinge of the Norman syncline steps to the right directly southwest of the field. Reversals in dip associated with the adjacent anticlines both to the northeast and southwest warrant closer examination with the drill, not