PETROLEUM GEOLOGY
OF THE
YUKON FLATS NATIONAL WILDLIFE REFUGE

by

Arthur C. Banet
James Borkoski
and
Aden Seidlitz

EXECUTIVE SUMMARY

The Yukon Flats National Wildlife Refuge (YFNWR) is a fairly remote area in east-central Alaska, south of the Brooks Range, north of the Alaska Range, and east of the Dalton Highway ("Haul Road"). The geology of the area is complicated, and consists of several distinct litho-stratigraphic units; terranes, accreted, amalgamated, and emplaced along two major strike-slip fault systems; the Kaltag-Porcupine Fault Zone and the Tinitna Fault Zone. Of these terranes, the Yukon Flats Basin and Tatonduk terranes are considered important for oil and gas discovery Indirect geophysical data in the forms of aeromagnetic and Bouger Gravity surveys and inferred subsurface geology suggests that mostly moderate potential exists for oil and gas discovery within the Yukon Flats Basin. Also, similar geophysical evidence, oil well stratigraphic interpretations, and outcrop observations from areas nearby the refuge indicate that the Tatonduk terrane has moderate oil and gas discovery potential. All other adjoining terranes have low potential for oil and gas discovery.

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INTRODUCTION

The Yukon Flats National Wildlife Refuge (YFNWR) was created in November 1980 by Congressional legislation (Section d(2)) of the Alaska National Interest Conservation Act (ANILCA)) from lands earlier withdrawn from the Public Domain (through the Alaska Native Claims Settlement Act (ANCSA) of 1971). The refuge presently encompasses approximately 17,500 square miles of east-central Alaska. Its irregularly shaped boundaries follow township lines, river courses, and drainage divides. The area is approximately 225 miles east-west and from 60 miles to 120 miles north-south; it extends from approximately 142° west to 150° west latitude and 65°45' north to 67°30' north longitude (plate 1). The Arctic Circle essentially divides the area north and south. The U.S./Canada border is 35 miles east of the refuge's eastern boundary.

Fairbanks is the nearest large commercial center, approximately 150 air miles south-southwest of the area (figure 1). Fort Yukon and Circle (combined population less than 750) are the largest local settlements in the area, which is sparsely populated and largely unsettled.

With the small population in this area, access is minimal. At this time, there are no roads through the entire area. Vehicular traffic terminates at Circle, or is limited to the Dalton Highway, west of the area. Fort Yukon has the only regularly scheduled air service, and boat travel on the rivers is limited to the summer months. Winter travel is mostly by snow machine and dog sled, since weather frequently interferes with air travel.

PREVIOUS WORK

Gold discoveries at Dawson City, Yukon Territory, along Forty Mile Creek and Seventy Mile Creek ended this area's remoteness at the end of the

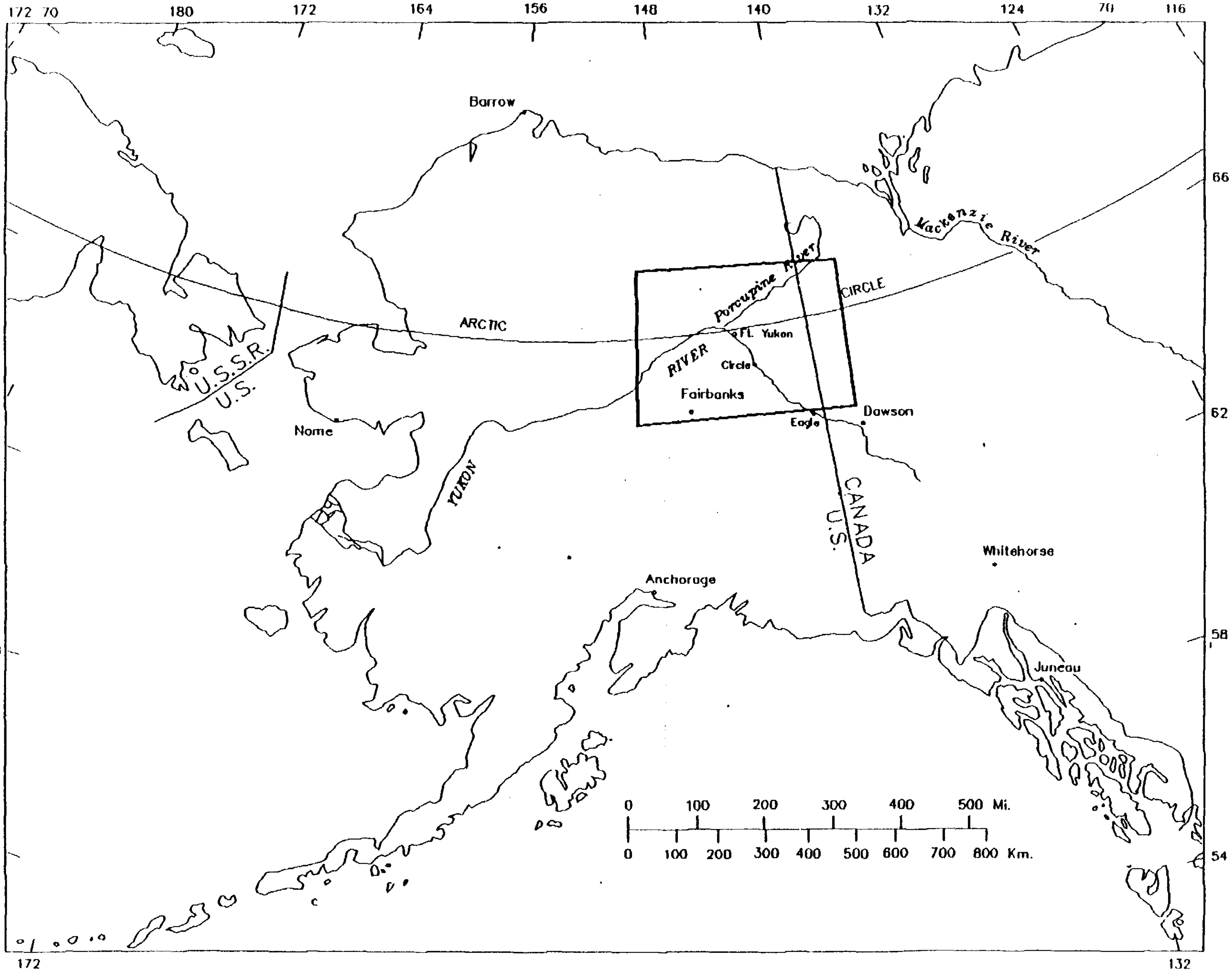


Figure 1. Index map showing East-Central Alaska.

nineteenth century. Dall (1870), Spurr (1898), and Raymond (1900) began scientific investigations along the Yukon River. Russell (1890), McConnel (1891), and Ogilvie (1898) explored north along the Porcupine River into Canada, and to the McKenzie River. Schrader (1900) and Mendenhall (1902) began exploration on the west portion of the area. Specific geologic investigations soon followed. Collier (1903) reported on coal deposits along the Yukon. Prindle (1906 and 1913) began descriptive work in the Circle area. Stone (1906), Brooks and Kindle (1908), Maddren (1913), and Eakin (1916) started regional reconnaissance studies. Cairnes (1914) described the geology along the nearby Canada/U.S. border. Mertie (1930, 1937, and 1942) published maps showing bedrock geology and the first stratigraphic interpretations of the areas to the south and southeast of the Yukon Flats.

Whereas gold spurred initial geological interest in this area, oil exploration activity spurred geologic activity during the 1950s and 1960s (Martin, 1973). Reconnaissance geologic field mapping and stratigraphic descriptions were expanded with the use of airphoto interpretations and improved access to areas between the major drainages. Brosge and Reiser (1964), Brabb and Churkin (1969), Brabb (1970), Chapman, Weber, and Taber (1971), Brosge, Reiser, and Yeend (1973), and Foster (1976) published geologic mapping and preliminary geologic interpretations at 1:250,000 of 2° quadrangles around much of the Yukon Flats area. Martin (1973) described the adjacent geology of Canada. At this time, Yukon Flats stratigraphy has been only partially described in detail (Churkin and Brabb, 1965; Laudon and others, 1966; Brabb, 1964; Nielsen, 1981; Payne and Allison, 1981). There are very few published measured sections (Blodget, 1978; Moore, 1979; and Clough, 1981) for the area. At present, there are no publicly available detailed petrographic descriptions or geochemical analyses of rocks in the area.

Geologic exploration of this area shows a complex assemblage of diverse rock types, stratigraphic sequences, fossil faunas, and structural styles. Rocks from all geologic time periods are recognized in this area, including one of the most complete, continuous, and fossiliferous sequences of Proterozoic to Lower Paleozoic carbonates in North America. Other rock types include mafic igneous rocks, nonmarine clastics, and oceanic, arc trench and continental margin sediments.

Even though well-defined sequences and stratigraphic successions are known in some areas, other areas have dissimilar coeval rocks, poorly known stratigraphic successions, or other relationships that cannot easily be explained by facies changes or faulting. At present, no correlations extend across the Yukon Flats. Many units do not correlate between adjacent quadrangles, and some time equivalent units do not correlate within mapped quadrangles. In addition, the entire Yukon Flats is covered by Holocene sediments, so the geology of almost half of the refuge can only be inferred.

PHYSIOGRAPHY

The Yukon Flats physiographic province covers approximately 9,000 square miles, or over 50 percent of the refuge. Its surface consists mostly of flat to undulating lowlands dotted with numerous shallow lakes, sloughs, and meandering and braided streams. Local relief, on flood plains, well-developed river terraces, and alluvial fans, generally does not exceed 150 feet (Williams, 1962). The Yukon River is the principal drainage, and it drops only about 200 feet in elevation in 180 miles, as it, literally, meanders across the Yukon Flats as a complexly braided stream. Plate 1 shows only one main channel of the many that actually exist. The Hodzana, Hadweenzic, Chandalar, Christian, Porcupine, Black, and Little Black rivers drain the area north of the Yukon River (plate 1). Creeks draining the area south of the Yukon River are lost in the marshland.

The Yukon Flats are surrounded by older river terraces, alluvial fans, and flood plain deposits that rest upon bedrock. These deposits are mostly flat lying and are separated from the Yukon Flats by a 100- to 500-foot-high marginal escarpment (Williams, 1962). These deposits are largely dissected by erosion on the north and west, but are somewhat preserved on the south and east sides and probably do not exceed 1,200 to 1,300 feet land surface elevations.

Bedrock exposures crop out in the Hodzana Highlands, the Southern Foothills of the Brooks Range, the Porcupine plateau, Crazy Mountains, White Mountains, and the Yukon-Tanana plateau which surround the Yukon Flats clockwise from the northwest. These hills are mostly low, rolling hills from 2,000 to 3,000 feet in elevation, with few areas that are steep or that exceed 4,000 feet in elevation.

LITHOLOGY AND STRATIGRAPHY

Mapping around the Yukon Flats basin has revealed many rock types. Many of these stratigraphic relationships are not well explained by faulting or facies changes. Both the styles of structural deformation in the area and the wide variations in stratigraphies are more accurately considered as belonging to separate entities called terranes rather than as vaguely related parts of a single geologic domain.

Terranes are lithostratigraphic or tectonostratigraphic units that are fault-bounded geologic entities of regional extent, each characterized by a geologic history that is different from the geologic histories of contiguous terranes (Jones and others, 1981). Terranes can be stratigraphic in nature, having coherent sequences and depositional histories. Stratigraphic terranes include continental fragments detached from basement rocks, fragments of oceanic basement with deepwater sediments overlying mafic, or ultramafic rocks, or they can be volcanic arcs with their associated plutons and sedimentary debris.

Disrupted terranes are entities of heterogeneous rocks surrounded by sheared and greatly deformed shale, flysch, or serpentinite. Regional metamorphism produces a third terrane type where unique rock fabrics develop or obscure a previous stratigraphy.

Terranes undergo amalgamation, the joining of two or more separate terranes to form a composite terrane, and accretion, which is the collision and welding of a terrane to a continental craton. Break-up rifting and dispersion along strike-slip or wrench faults also aid in juxtaposing various terrane types. Thus, terranes with widely differing structural deformational styles and stratigraphic histories can be emplaced into a region. By the same methods, terranes can be split apart and occupy non-contiguous parts of a region.

Churkin and others (1982) and Jones and others (1981) compared various fault bounded stratigraphic sequences in east-central Alaska, particularly in the Yukon Flats region. A mosaic of perhaps 17 allocthonous terranes emerges from the relationships between the severely deformed metamorphic rocks, mafic oceanic rocks, and continental margin sequences mapped in the area. Nine of these terranes or microterranes are identified in or contiguous to the Yukon Flats National Wildlife Refuge (plates 1 and 2). Two of these, the Yukon Basin and Tatonduk, are considered important to the oil and gas assessment. The White Mountains, Crazy Mountains, Takoma Bluffs, and Beaver terranes are predominantly sedimentary assemblages which could be favorable for oil and gas reserves, but have limited areal extent along the boundaries of the refuge. The Tozitna, Ruby, and Circle terranes are predominantly volcanic, mafic, oceanic, or metamorphic (plate 3) with low oil and gas potential.

Major Terranes

The Yukon Basin is a successor basin to the tectonic activity that amalgamated the terranes in this area. It is a downwarped area located at the approximate intersection of two major strike-slip/wrench fault systems (plate 4), the Tintina and the Kaltag-Porcupine. Unconsolidated Holocene sediments obscure direct observation of the basin limits and contacts with the other terranes, and there is no subsurface drill hole information describing pre-Pleistocene sediments in the basin. Mapping to the southeast of the refuge (Brabb and Churkin, 1964) and to the west (Williams, 1962, and Chapman, Weber, and Taber, 1971) shows Tertiary sediment angularly unconformable on older rocks of dissimilar terranes.

The Tertiary rocks are non-marine, consisting of mudstones, sandstones, conglomerates, siltstones, carbonaceous shales, and lignite, along the Yukon River. The sandstones are predominantly gray-green to black, poorly sorted, and comprised mostly of lithic fragments. The conglomerates are matrix-supported, varicolored chert, or white quartzite, mostly one to two inches in diameter, with a few five-inch-diameter cobbles, and rare boulders greater than two feet in diameter (Mertie, 1942). Locally, plant fossils are preserved on bedding planes, and, in some locations, heavy minerals are likewise concentrated. Brosge and others (1973) report that pollen found in siltstones exposed along Coal Creek, just beyond the western extent of the Yukon Basin terrane, are probable Miocene with additional indeterminate plant fossil assemblages. Barker (1981) reports a Late Eocene age from a water-laid tephra overlying that coal section from Coal Creek. Mapping northeast of the refuge (Brosge, 1973) identifies questionable Miocene clams, raising the possibility of Tertiary marine sediments being present in the Yukon Basin subsurface as initially suggested by Miller, Payne, and Gryc (1959)

Plate 5 shows aeromagnetic data covering the Yukon Flats Wildlife Refuge (Decker and Karl, 1977). The eastern two-thirds was compiled at high elevations (5,000 feet) and shows low frequency, deep anomalies. The western one-third was a lower elevation survey which shows high frequency and shallow anomalies. Brosge and Brabb (1971) interpreted the anomalies to be pre-Cenozoic shallow-depth volcanics. Alternatively, Barnes' (1971) Bouger gravity survey (plate 6) and Kirschner and others' (1985) gravity survey indicate the existence of over 16,000 feet of sediments in two troughs in the basin, which is comparable to some other Tertiary, mostly nonmarine basins in Alaska, as shown by Ehm (1983).

The basal contacts of the exposed Tertiary are angularly unconformable where mapped, and the upper contacts are obscured beneath Holocene sediments. In addition, the Tertiary sediments have been extensively folded and faulted so estimates on the maximum thickness vary from 3,000 feet (Brabb and Churkin, 1969) to 5,000+ feet (Collier, 1903), and up to 10,000 feet (Mertie, 1942). The uppermost Tertiary sediments may also grade into the unconsolidated Quaternary rocks and may be indistinguishable from them.

The Quaternary sediments consist of mappable alluvial fan deposits, multiple high and low terrace sequences, glacial drift, loess and eolian sand (Williams, 1962). Cuttings from water well No. 2 at Fort Yukon were logged as 148 feet, light tan silty sand, and gray sand interpreted to be Pleistocene alluvium. This section overlies 292 feet of blue and gray, poorly consolidated silt and silty sands interpreted to be possible late Tertiary (?) or early Quaternary lacustrine deposits (Williams, 1962). Ice lenses were reported to a depth of at least 393 feet.

The Tatonduk terrane occupies the east and northeast parts of the refuge (plate 2), where largely undifferentiated pre-Cambrian to Lower Paleozoic rocks are tentatively correlated to the Tindir Group, Funnel Creek Limestone, Adams Argillite, Hillard Limestone, Road River Formation, and McCann Hill Chert/Ogilvie Limestone (Canada) (plate 3). This represents one of the more continuous Proterozoic through Lower Paleozoic stratigraphic sequences in North America. It is similar to coeval rocks in both the Yukon Territory and the North American Cordillera, and may have an aggregate thickness of approximately 22,000 feet (Payne and Allison, 1981). Middle Paleozoic to Middle Mesozoic units include the Nation River Formation, Calico Bluff Formation, Tahkundit Limestone/Stepp Conglomerate, and the lower part of the Glenn Shale.

The Tindir Group (Upper pre-Cambrian to Cambrian) is the oldest sequence. The basal unit is thinly interbedded, grayish black dolostone, shale, and quartzitic sandstone, thick shale and phyllite, overlain by high magnesian dolostone with thin shale partings cut by diabase dikes. The middle units are dark greenish-gray amygdaloidal basalt, shale, hematitic dolostone, terrigenous volcanic and red basal conglomerate. The upper unit is a dolomitic arenite, unconformably overlain by conglomerate and dark, gray-black, laminated, platy limestone, dolostone, and shale. Louisiana Land and Exploration's Doyon Limited Well No. 3 penetrated at least two, probably fault repeated, sections with similar lithology just east of the refuge boundaries (plates 1 and 7).

In a complete succession, the Tindir Group in east-central Alaska is overlain by approximately 1,000 feet of light gray, non-fossiliferous, fine- to medium-grained oolitic, massive, silicious Funnel Creek (Lower Cambrian) limestone and dolostone. The olive-gray argillite and quartzite of the Adams argillite (Lower Cambrian - Lower Ordovician) records persistent tectonic activity in the area. The conformable basal Hillard Limestone is shaly, with edgewise beds of limestone conglomerate, boulders, and oolitic limestone. Upsection, it is a flaggy gray to massive crystalline limestone, with carbonaceous laminae and boudins at the top.

The Road River Formation (Lower Ordovician - Lower Devonian) disconformably overlies the Hillard Limestone. It is a widespread, deep-water unit up to 900 feet thick in east-central Alaska, thickening dramatically in Canada (Martin, 1973). It is predominantly dark gray graptolitic shale with minor amounts of dolomite, chert, arenite, and chert conglomerate.

Lower, Middle, and, possibly, Upper Devonian rocks disconformably overlie the Road River Formation. The lithology is mostly thin-bedded and laminated chert and siliceous shale and dark gray, bioclastic limestone, called the McCann Hill chert. Coeval rocks penetrated in LL&E Doyon No. 3 resemble more closely the platform equivalent facies, the Ogilvie Limestones, described further east in Canada. Consequently, this unit, if preserved in the subsurface, will probably be more similar to the Ogilvie Limestone, with increasing amounts of shale southward.

The Nation River Formation is a widespread rhythmically interbedded sandstone, shale, and conglomerate unit that overall fines upsection. The basal conglomerates are massive, with abrupt crosscutting channels. They are commonly clast supported with subrounded to subangular, unsorted gray, white, black, and green chert pebble clasts (chert arenite). Most pebbles are one to two inches in diameter, with rare cobbles to five inches in diameter; mud balls and carbonized plant fragments are not uncommon. The interbedded sandstones and matrix sandstones are medium- to coarse-grained and compositionally identical to the conglomerates. Load casts are common. The sandstones become thin bedded and more laterally extensive upsection, fining to mostly siltstone and shale at the top.

Nielsen and others (1980) estimate that the unit is 2,000 to 4,000 feet thick. LL&E Doyon No. 1 Well penetrated over 1,000 feet of this upper part of the Nation River Formation (9,962 - 11,044; TD).

The Ford Lake shale (Late Devonian - Early Mississippian) conformably overlies the Nation River Formation. At outcrop, it is mostly dark gray-black, hard, splintery or blocky, and mostly siliceous with minor amounts of phosphatic concretions. Fossils are common at the top of the section. Well lithologies (plate 7) are similar with minor hard, argillitic, dark gray siltstones and sandstones. Estimated thicknesses range from 2,000+ feet (Brabb and Churkin, 1969) to approximately 3,000 feet (Foster, 1976). The section may be fault repeated at LL&E Doyon No. 1 well (plate 7). It grades vertically into the overlying Calico Bluffs Formation along the Yukon River.

The Calico Bluff Formation (Upper Mississippian) is approximately 1,000 to 1,300 feet of black and brown shale, with rhythmatically interbedded debrisflow, bioclastic limestones. The development of the limestone lithology marks the base of this unit. The limestones are thin-to-massive bedded at the base and becomes thin-bedded upsection. Fossils are numerous and diverse (Mertie, 1932). Exposures along the Yukon River have a strong petroliferous smell, but active seeps are unknown.

A major angular unconformity separates the Permian rocks from the older succession with uplift and subsequent truncation, possibly related to uplift along the Kaltag-Tintina fault systems (Payne and Allison, 1981). The Step Conglomerate (Permian) is the basal clastic unit in this region. It consists of rounded, mostly gray, white, and black chert clasts ranging in size from very coarse sand to pea-gravel size (4 mm - 20 mm). The chert-pebble conglomerate typically grades into light- to dark-gray, very-fine-grained to fine-grained, quartzose sandstones. Also, Brabb (1969) reported at least two limestones in the lower part of the formation with fossils correlative to fauna in the coeval Tahkandit Limestone (Permian). However, drill hole data (plate 7) indicate that the limestone units are not persistent from mapped areas north of the wildlife refuge.

The Tahkandit Limestone (Permian) is coeval to the Step comglomerate. Rugged, cliff-forming, massive outcrops along the Yukon River are distinct and are very fossiliferous; brachiopods are partcularly abundant. This unit is approximately 350 ft thick (Brabb and Churkin, 1969). The sandstone units of the Tahkandit are approximately 100 feet of thin-to-thick bedded, mostly fine-grained sands, with stringers of pea-gravel-sized (4 mm - 20 mm), chert-pebble conglomerate, and thinner (less than 6 inches) stringers of non-oriented, broken shells. Limonite is the predominant cement, but glauconite is also very common, especially in the conglomerate layers. The sandstones are hard-to-friable, gray on fresh fracture, weathering to tan.

The Glenn Shale is approximately Middle Triassic to Early Cretaceous age, and it unconformably overlies the Step conglomerate and possibly older units north towards the refuge area. The unit consists of mostly grayish black, massive, highly fractured and faulted argillite, with lesser amounts of sandstone, black fissile shale, and carbonaceous shale, with pyritic concretions. The basal few hundred feet is locally interbedded, very fossiliferous (abundant Monotis, Halobia, and Diseophyllites) limestone, black fissile shale, and oil shale (Brabb and Churkin, 1969). This lithology and fauna is very similar to the Shublik Formation (Triassic), a source rock of North Slope oil. Oil seepages are also reported from outcrops along creeks draining into the Yukon River. The basal Glenn Shale is considered the top of northern derived sediments that comprise the Tatonduk Terrane (Churkin and others, 1982).

Minor Terranes

The Crazy Mountains are east-west-trending, fault-bounded uplifts along the south boundary of the refuge (plate 6). Mapped and described by Mertie (1937) as Devonian non-calcareous rocks (Dnc) and carboniferous limestones (Cml), they are now considered to be older. The basal unit is considered to be pre-Ordovician, slightly metamorphosed, and interbedded sandstone, gritstone, slate, and argillite. This is unconformably overlain by a middle unit of chert, slate, shale intruded by mafic dikes and limestones and dolomite with poorly preserved fossils. The top unit is very fossiliferous, Lower Devonian and upper Lower Devonian Limestone and chert-pebble conglomerate. The limestones have three kinds of corals, chrinoids, and stromatoperoids (Churkin and others, 1982).

A small slice of the White Mountains terrane occupies the south refuge boundary directly west of the Crazy Mountains (plate 2); and, like the Crazy Mountains, is also situated along the Tintina fault system. Mertie (1937) mapped at least 2,000 feet of Ordovician, interbedded, siliceous, marine sediments, basalt, tuffs, and breccia gradationally overlain by the Tolvana Limestone (Ordovician - Devonian). These are massive, light gray, mostly crystalline limestones, approximately 3,000 feet thick, overlain by Devonian age chert-pebble conglomerates. Both units are steeply dipping and tightly infolded, and trend east-northeast.

Plate 2 shows less than two townships along the southern boundary of the refuge comprised of Beaver-terrane rocks. These rocks are mostly quartzose sandstones and shales of probable Cambrian age, based on trace fossils (Hofman and Cecile, 1981). The rocks are mildly metamorphosed, but still commonly retain distinctive sedimentary structures and bedding features.

A sliver of Takoma Bluffs terrane cuts into the southeast part of the refuge (plate 2). Churkin and others (1982) describe Permian conglomerate, tentatively correlated to the Step Formation, overlying possible pre-Cambrian marine volcanics and interbedded dolostone. Along the Yukon, the pre-Cambrian facies consists of a thick sequence of thin-to-thick-bedded, dark gray siltstone, gritstone, and thin, fissile, gray shale overlain by black, crystalline limestone and dolostone with dolomite veins. At outcrop, the pre-Cambrian rocks are severely tectonized, commonly having steeply dipping, folded, and overturned sections.

The Ruby terrane occupies the northwest part of the refuge (plate 2). It is mostly Paleozoic schists and phyllite, Cretaceous-aged granitic plutons, and various-aged mafic rocks. Brosge and others (1973) show probable Devonian-age sandstones, and shales. West of the refuge, these are dark gray-brown argillitic and, mostly, highly fractured or splintered and tectonically disrupted.

Closely folded, faulted, and brecciated Rampart Group rocks of the Tozitna terrane crop out immediately east of Ruby terrane and in several isolated crops in the southwest part of the refuge. These are predominantly mafic intrusive and extrusive rocks, including pillow basalts, lava flows, tuffs, greenstone breccias, and diabase and sheeted dikes. There are minor amounts of interbedded and overlying black-brown shales, slates, sandstones, and isolated lenses of olistostromic limestones. Mertie (1937) estimated 5,000 to 10,000 feet of section.

Another unit of mafic igneous rocks similar to the Ruby terrane crop out in the southeast part of the refuge (plate 2). The Circle volcanics are different from the Tozitna rocks because they are intruded by diabase and gabbro, and have fewer, but more fossiliferous sediments (Mertie 1937). Radiolarians range in age from Upper Paleozoic to Triassic, and the Circle Terrane's proximity to the Tintina Fault system suggest that it may be a composite terrane (Churkin and others, 1982).

STRUCTURE AND TECTONICS

The Yukon Flats Refuge is located at the intersection of two major fault systems (plate 4). The Tintina system is an association of right-lateral strike-slip faults with symmetrical, en echelon second and third order thrust faults, folds, and normal faults which are visible along the Yukon River southeast of the refuge. This system is estimated to extend from the southwest part of the refuge (plate 4) some 600 miles south-southeast to the Rocky Mountain Cordillera with up to 260 miles of Lower Paleozoic to Upper Cretaceous episodic displacement (Templeman-Kluit, 1976). Displacement varies from terrane to terrane, depending on when and where each was initially emplaced and to what extent it has been sheared.

The Kaltag Porcupine fault system is another right-lateral system that cuts off the Tintina system (plate 4). McWhae (1986) postulates the Kaltag-Porcupine system to be a major plate boundary, extending from the western Bering Sea, through Alaska, into the Canadian Beaufort, and on to northern Greenland. Initial lateral movement began in the Early Cretaceous, much later than along the Tintina system. Major offsets during the Late Cretaceous and Late Tertiary caused the downwarp for the Yukon Flats Basin.

Stream offsets in the northern part of the refuge indicate at least some Quaternary activity. Estimates of offsets vary from 90 to 300 miles (Jones and others, 1981).

Outcrops surrounding the Yukon Flats Basin show the effects of the two major faults. Most bedrock exposures are sub-parallel to the main fault systems, but are typically cut off or additionally deformed by second and third order thrust faults, folds, and normal faults. The extent of deformation to the Tertiary rocks within the Yukon Flats Basin is mostly unknown, but inference and analogy to similar type basins suggests that the normal faults and sediments that created the basin are deformed similarly to surrounding highlands; consequently, symmetrical and enechelon structures should be expected in the Tertiary section in the basin.

In addition, the Tatonduk and other predominantly continental terranes were initially deformed by the subduction events that accompanied terrane emplacement and accretion. These older compressional events and their associated structures are mostly overprinted by the strike-slip associated deformation. Also, plate 7 shows several major unconformities in the Tatonduk section which indicates widespread regional uplifts in response to the various pre strike-slip tectonic events.

GEOPHYSICS

Publicly available geophysical data on this area consists of two partial aeromagnetic surveys (plate 5), a Bouger Gravity survey (plate 6), and a single CDP seismic line shot immediately east of the refuge's east boundary and west-southwest of the Doyon No. 2 well (Ehm, 1983). This line crosses the Takoma Bluff terrane and an alluvium-covered area which could possibly cover some Tertiary rocks. Reflector continuity is mostly poor on the line, but there is enough coherence to show some southward vergence, a possible indication of thrust faults emplacing older rocks over younger rocks. However, there is no clear indication of Tertiary rocks or distinct terrane juncture.

The two aeromagnetic surveys (Decker and Karl, 1977) show shallow-seated anomalies in the west, and deep anomalies in the east part of the refuge. The shallow, positive anomalies appear to be shallow, buried extensions of the Tozitna terrane (plate 2). This enlarges the area of low potential for petroleum discovery (plate 8) at the expense of the moderate potential area. Also, the deep-seated positive aeromagnetic anomalies of the east part of the area partly coincide with the Bouger Gravity minimums (plate 6) in the area north of Circle (plates 5 and 6). These possibly indicate thin veneers of sediment and possible basement uplift.

Overall, the Bouger Gravity map shows several minimums. The -50 mgal minimum, approximately 40 miles south-southwest of Fort Yukon is of similar setting, and magnitude to the -50 mgal minimum tested by the Doyon No. 1 well (plate 6). The No. 1 well encountered 11,044 feet of Lower Paleozoic to Cretaceous sediment, and the Fort Yukon -50 mgal low should indicate, also, a thick sedimentary sequence, but perhaps not as thick as the partially tested Lower Paleozoic sections since rock densities are not likely similar. However, the Bouger Gravity -50 to -70 mgal minimums in the northwest part of the area (plate 6) are associated with Cretaceous granite plutons, not sediments.

GEOCHEMISTRY

At present, there are no published quantitative geochemical analyses to demonstrate source rock potential of sediments in this area. However, Tatonduk terrane rocks, specifically the Upper Tindir Group, the Calico Bluff Formation, and Glenn Shale were found to have a strong petroliferous odor upon fresh fracture, where sampled along the Yukon River, southeast of the refuge.

Morgridge (personal communication) reports oil seepage at the Glenn Shale type section along the Trout Creek tributary southeast of the refuge. Mertie (1937) described oil shale lithologies near Nation that tested: 28 gal/ton, specific gravity 0.934, settling temp 0^{o}. Also, the lithology and fossil assemblages of the lower part of the Glenn Shale show that is is laterally equivalent to the Shublik Formation, a demonstrated North Slope petroleum source rock. Both these qualitative observations and some scant, unpublished proprietary surface outcrop geochemical data indicate that rocks with sufficient and potentially petroleum-generating kerogen types have been deposited and are at least partially preserved in the region east of the refuge.

These observations also show that at least the Glenn Shale and younger rocks are within the physical-chemical oil generating and preserving constraints (oil window) in this area. Blodgett (1978) notes that most of the interior Alaska Lower Paleozoic carbonates are at thermal maturities exceeding the base of the oil preservation window. He also indicates that these thermal maturities are less, closer to Canada, where oil and gas have been recovered from Upper Paleozoic rocks (Martin, 1973).

The Tertiary rocks of the Yukon Basin have less available geochemical data. Outcrops of coeval rocks are mostly nonmarine, and they are rich in coaly organic carbon (T.O.C.) and, thus, likely to generate gas upon reaching sufficient thermal maturity. Barker (1981) presents thermal maturity data, vitrinite reflectance (Ro) that range in value from Ro = 0.33% to Ro = 0.45% for isolated patches of Tertiary rocks north of the basin on the Ruby and Tozitna terranes. These crops are at least partly tectonically deformed and indicate that they have been buried deeply and sufficiently long enough to coalify the plant material to the lignite or subbituminous coal rank.

Figure 2 shows these outcrop vitrinite reflectance values to be in the early dry gas phase of hydrocarbon generation. If there is a tongue of

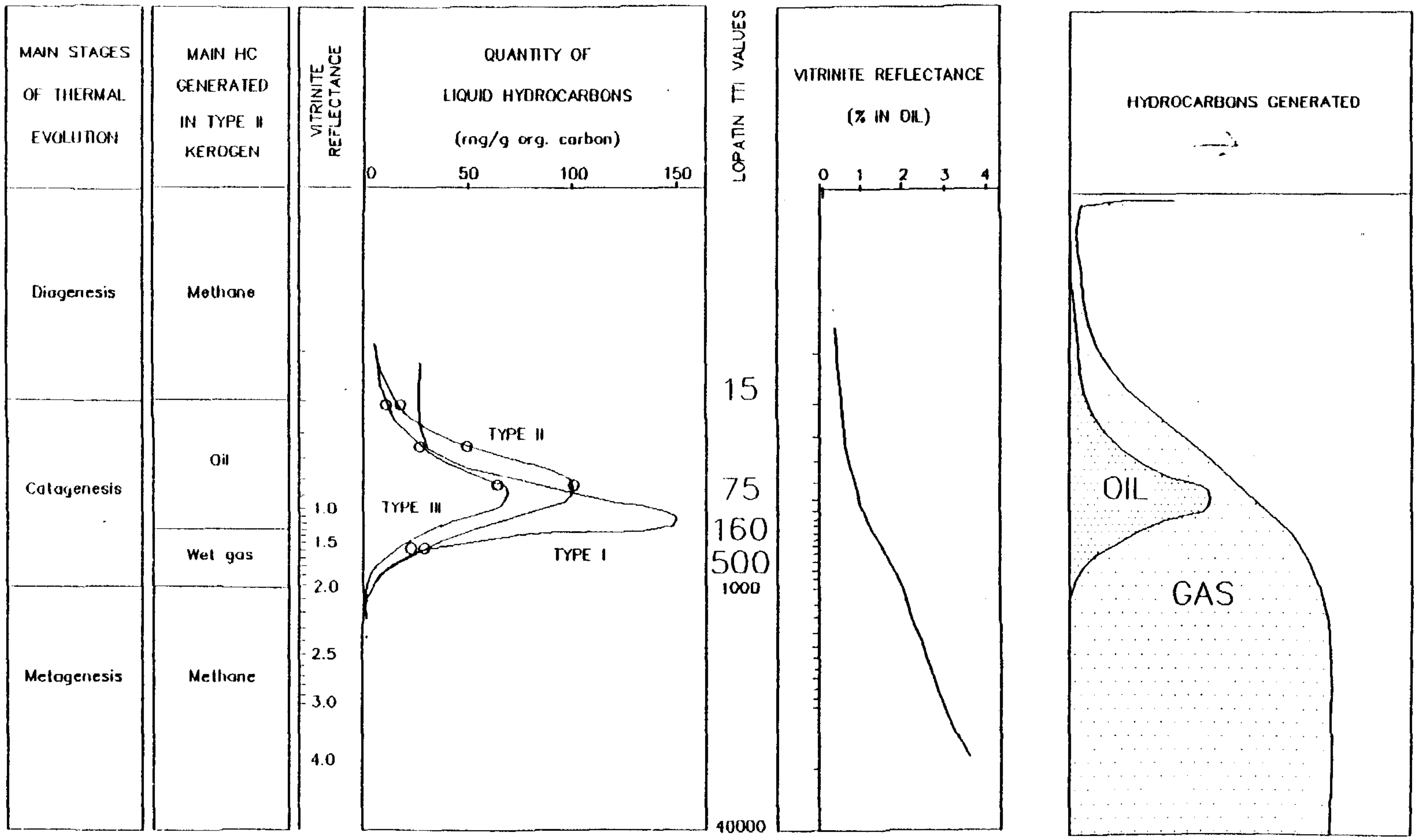


Figure 2. Major stages of thermal maturity , the major indicators of thermal maturity and hydrocarbons generated.

Miocene marine shale in the subsurface, as Miller and others (1959) suggest, the possibility of liquid hydrocarbons being generated upon thermal maturity increases.

Figure 3 shows the subsurface temperatures in the wells east of the refuge. Well Nos. 1 and 2 have geothermal gradients of approximately 14.0°F/1,000 feet for the thrust faulted Tatonduk terrane area. Well No. 3 shows an 8.5°F/1,000 feet gradient for the severely faulted and sheared Cretaceous Kandik section of arc-trench assemblage rocks (plate 3). Because the geologic histories of these rocks is very complicated, simple petroleum generation time-temperatures reconstructions cannot be made. However, the low temperatures indicate that oil and gas can be preserved to depths of at least 20,000 to 25,000 feet at the present temperature regime.

The only drilling within the Yukon Flats Basin has been a 400-foot-deep water well for Fort Yukon, which may have not reached the Tertiary section. However, some analogous Tertiary filled basins adjacent to large-scale strike-slip faults, such as the basins of the Great Valley in California and Los Angeles Basin, have geothermal gradients that range from 12°F/1,000 feet (low), to 20°/1,000 feet (average), to as high as 23°F/1,000 feet. Petroleum generation begins at depths of approximately 8,500 feet in the Los Angeles basin (Phillipi, 1965), or as deep as 13,000 feet in some Great Valley basins for Miocene age source rocks (Zieglar and Spotts, 1978). If marine Miocene age source rocks exist in the Yukon Flats Basin, as suggested by Miller and others (1959) and Brosge (1973), the geophysical surveys (plates 4, 5, and 6) indicate that the strata should be within the range of depths for petroleum generation to begin, and that the entire sedimentary section should be within the range of depths to preserve petroleum. However, until data on sediment types, rates of deposition, and geothermal gradients within the basin are available, time-temperature reconstructions of source rock burial history are speculative and based on analogies to other similar basins.

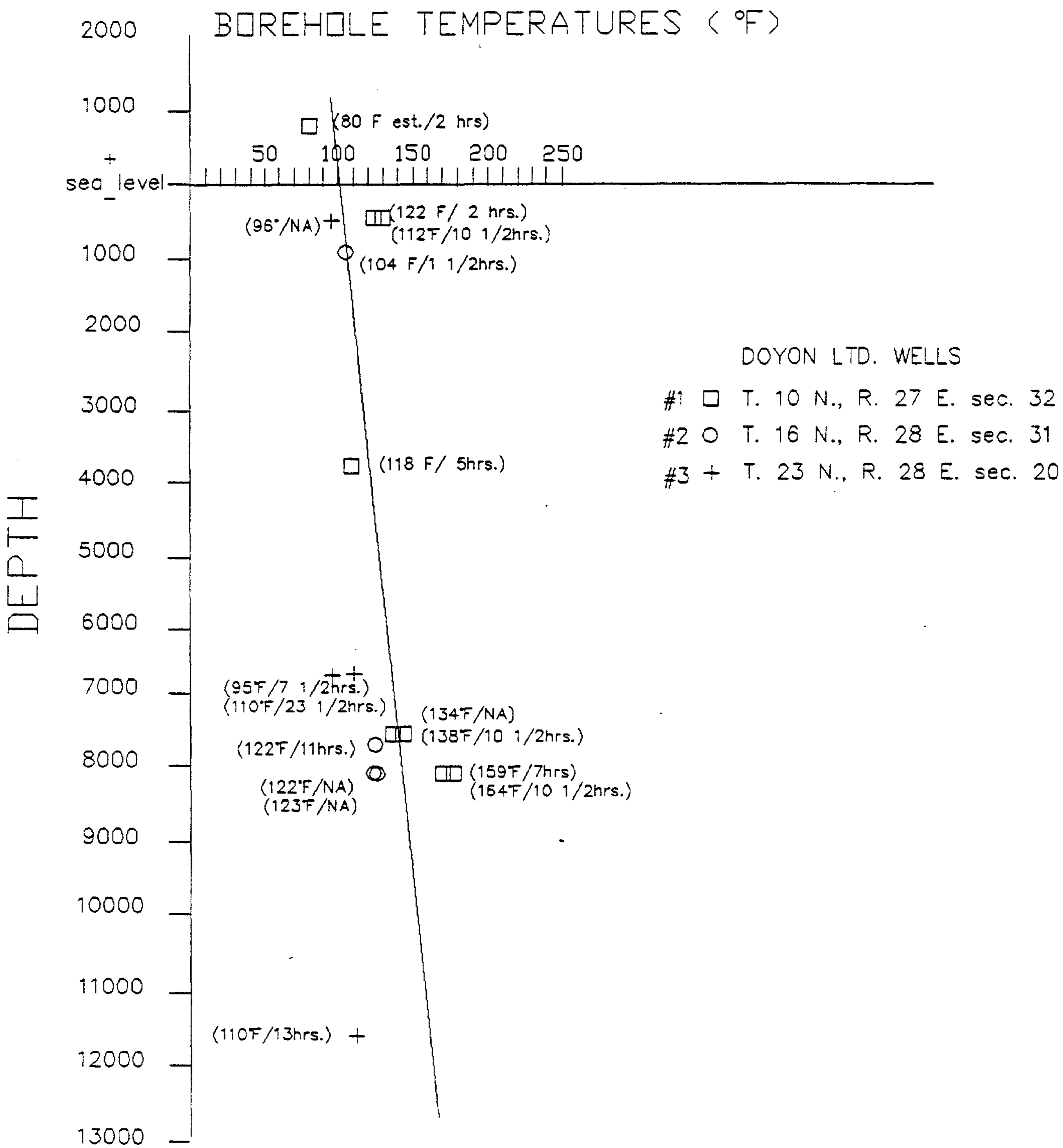


Figure 3. Borehole temperatures from logged intervals

HISTORICAL GEOLOGY

The thick succession of preserved Proterozoic and Paleozoic sediments records an exceptionally long, predominantly stable shelf sedimentation. Major unconformities are within the Tindir Group carbonate sequence, and at the top of the Calico Bluff Formation, with a limited disruption of deposition of the Hillard Limestone and Road River Formation. Late Paleozoic unconformities and conglomerates indicate considerable tectonic activity. A major change in depositional style and source occurred in the lower part of the Glenn Shale, as major carbonate deposition and stable shelf conditions ceased. Ensuing deposition of the Cretaceous section was mostly deep water, with abundant turbidites. Another change is noted in the dissimilar provenances of clasts in the lower Cretaceous Biederman Argillite and Kathul Graywacke. Following uplift, non-marine fluvial and lacustrine deposition began in the Late Cretaceous or Early Tertiary. These rocks are overlain, or interfingered, with the flood plain, river terrace, alluvial fan, and loess deposits that cover the Yukon Flats Basin today.

Churkin and others (1982) relate these stratigraphic interruptions to terrane accretions to the North American craton. Although the White Mountains, Circle, and other terranes may have accreted earlier, the greatest driving force appears to have been the shear movement along older strike-slip faults with the Late Cretaceous, early Tertiary emplacement of the Yukon terrane complexes.

DESCRIPTION OF OIL AND GAS RESOURCES

In summary, qualitative observations and proprietary information suggest that organic rich source rocks exist in the Tatonduk terrane rocks. Although the Lower Paleozoic and pre-Cambrian carbonates are mostly beyond the petroleum generating stage of thermal maturity, the Upper Paleozoic carbonates and clastic rocks have indications, ranging from strong petroliferous odors to oil seepages, that hydrocarbons have been generated and preserved. Geologic mapping shows that the Tatonduk terrane rocks have been deformed by at least two phases of deformation. Even though early structures formed by predominantly compressional tectonics may have been eroded or destroyed by later events, there are numerous mapped second and third order structures created during strike-slip deformation. Also, the lithology of nearby Tertiary rocks and geophysical surveys indicate that burial conditions exist that are favorable for the generation of gas and possibly for liquid hydrocarbons within the Yukon Flats Basin. In addition, the Late Tertiary through Quaternary deformation phases of the Kaltag-Porcupine fault zone have most likely created structures to trap hydrocarbons.

Plate 8 shows the petroleum potential for oil and gas discovery for the area, based on the Bureau of Land Management's Mineral Potential Classification System (Appendix A). These classifications, high, moderate, and low potential, are only relative to specific areas and for comparisons to similar classifcations of other areas owing to differences in the quality and quantity of data available. The area of moderate potential is based on the direct evidence of the outcrop of sedimentary rocks of Tatonduk and adjoining predominantly sedimentary terranes and the inferred extent of sedimentary rocks in the Yukon Flats Basin, based on the geophysical surveys and qualitative geochemical data. The low potential areas (plate 8) are based on direct evidence from the outcrops of metamorphic rocks, severely altered sediments, mafic rock, and igneous rocks exposed at the surface, or inferred indirectly to be buried beneath a relatively thin layer of sediments from the geophysical surveys. The extent of shearing and thrust faulting of low potential terranes over the sedimentary terranes is unknown and not likely to be determined unless the areas are drilled. It is incorporated with the low potential area until further data are available, as the physical conditions created during extensive shearing and thrust faulting are not favorable to the preservation of hydrocarbons.

The available data show that Yukon Flats Basin and surrounding area is similar to other interior Tertiary basins in Alaska. These basins are arealy large, remote, and mostly unexplored for oil and gas; having few drill holes and considerably large sized tracts of untested land. The closest discovery wells are in the Eagle Plain Basin across the border in the Yukon, Canada, where oil and gas have been tested, but as yet not economically produced from Tatonduk terrane rocks.

YUKON FLATS NATIONAL WILDLIFE REFUGE

Production Scenario

Since the Yukon Flats Wildlife Refuge (YFNWR) is divided by the Yukon River, two scenarios are presented. The south prospect will refer to development south of the Yukon River, and the north prospect will refer to development north of the river. The discussion below is applicable to both scenarios, except the north prospect would probably be developed without a main road to or from the field. This assumption is based on telephone conversations with the Yukon Flats Refuge personnel and professional judgment. It is possible, if the quantity of resources will justify it and a prospect south of the Yukon River has been discovered, that a river crossing and connecting road would be built; however, at this time it is felt that the chance of these factors all occurring is very slim. Other options considered were a road directly to the TAPS west of the prospect or a road east of the prospect to an established transportation infrastructure in Canada. Due to the distance between the refuge and TAPS and the native corporation witholdings between the refuge and TAPS, it presently appears unlikely. Political implications of transporting natural resources into a foreign country also makes a road directly east of the prospect a remote possibility. Therefore, a judgment was made to show a most likely scenario, although it should be noted that this type of development would also be very expensive. Equipment and facilities could be transported overland during the winter months. Initial road and pad construction, within the field, as well as the main pipeline construction would also be done during the winter season. Field personnel would be transported to and from the field by aircraft and the pipeline would be monitored by helicopter. Sizes of the shown prospects are based on previous drilling done by Louisiana Land and Exploration Company for the Doyon Native Corporation (plates 1, 5, 6, and 7) immediately east of the refuge.

In the event of an economic oil or gas discovery in YFWR, development and production activities would begin on a year-round basis. Proposed plans for the production and tranportation facilities are developed during the economic study of the discovery and submitted to local, State, and Federal agencies for approval. After completing the required review process, the plans are either approved or denied pending further information, studies, and/or modifications. Once approved, construction of permanent drilling/production pads, air support facilities, roads, and pipelines could begin. The first activity is to establish a temporary camp to support the construction workers who would begin constructing the permanent pads, connecting roads, airport facilities, and a main road between a staging area and the field. Potential staging areas for both prospects may be the city of Fairbanks, town of Circle, the TAPS haul road, or the nearest established field. Selection of the staging area is dependent upon the location of the field, economic and environmental factors, and lease stipulations issued by government officials. Once the main road is completed, the permanent camp and production facilities would be transported to the field and assembled onsite. These buildings will be designed to last the life of the field; depending upon the size of the field and the reservoir characteristics, one would expect the field to produce 15 to 30 years.

For illustrative purposes, figures 4 and 5 show the location of the facilities needed to produce the hypothetical prospects. Table 1 summarizes the acreage disturbed and gravel requirements for each facility, and tables 2 and 3 are a summary of total acres disturbed and gravel required for our hypothetical projects. Drilling/production pads used in these scenarios are each designed to produce approximately 5,000 acres. Depending upon actual reservoir characteristics found, more pads producing less acreage may be required to adequately deplete the resources. Once the hydrocarbons are depleted from the prospect, the wells would be plugged and abandoned, the facilities would be removed, and the disturbed surface would be reclaimed per Federal regulations.

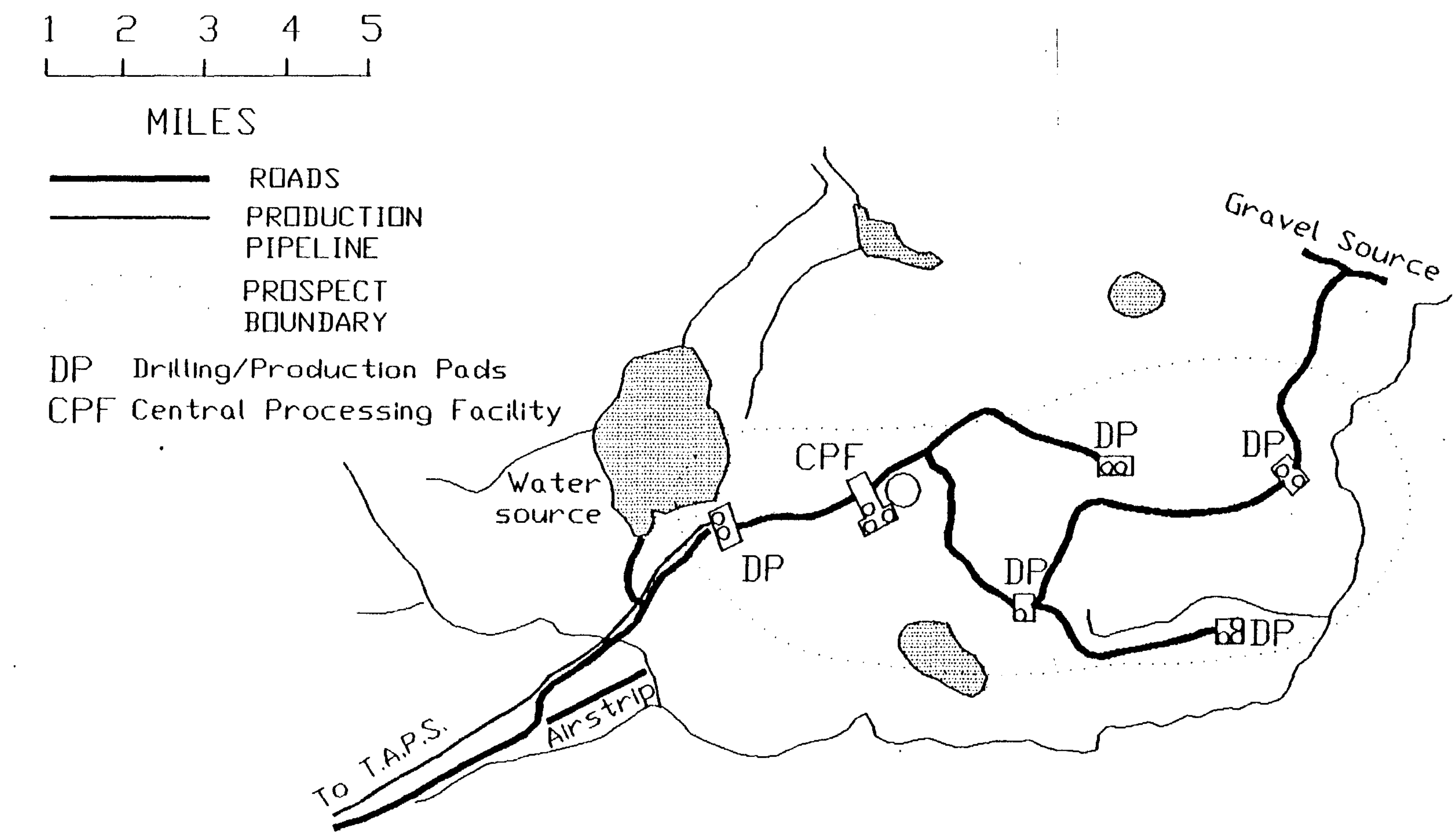


Figure 4. North Prospect Hypothetical Development Scenario

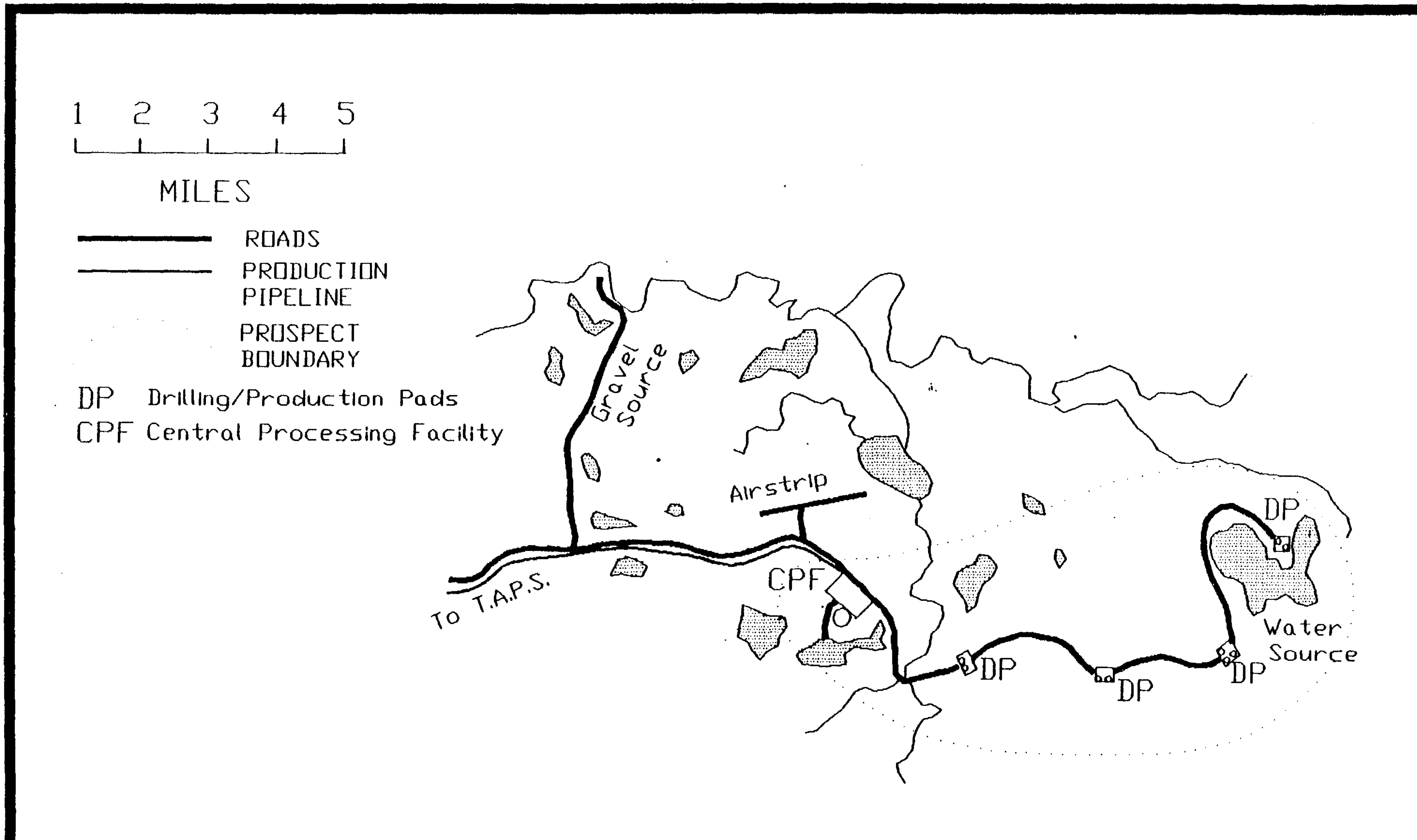


Figure 5. South Prospect Hypothetical Development Scenario

TABLE 1

PRODUCTION FACILITIES

YFWR

Facility	Acres Disturbed (each)	Cubic Yards of Gravel to Construct (each)
Central Production Facility Pad	90	725,000
Drilling/Production Pads	20-30	160,000-280,000
Airstrip and Facilities	30-35	275,000-325,000
Roads and Parallel Pipelines	5 acres/mile	40,000 yd^3/mile

TABLE 2

TOTAL ACRES DISTURBED AND TOTAL GRAVEL REQUIREMENTS FOR THE DEVELOPMENT OF THE SOUTHERN YFWR HYPOTHETICAL PROSPECT

Facility	Acres Disturbed	Cubic Yards of Gravel to Construct
Central Production Facility		
Facility Pad (1)	90	725,000
Drilling/Production Pads (5)	140	1,280,000
Airstrip and Facilities (1)	35	325,000
Roads and Parallel Pipelines (31.5 miles)	158	1,260,000
TOTALS	423	3,590,000

TABLE 3

TOTAL ACRES DISTURBED AND TOTAL
GRAVEL REQUIREMENTS FOR THE
DEVELOPMENT OF THE NORTHERN YFWR
HYPOTHETICAL PROSPECT

Facility		Acres Disturbed	Cubic Yards of Gravel to Construct
Central Production Facility			
Facility Pad (1)		90	725,000
Drilling/Production Pads (6)		160	1,440,000
Airstrip and Facilities (1)		35	325,000
Roads and Parallel Pipelines			
(35 miles)		175	1,400,000
	TOTALS	460	3,890,000

Production Facilities

Facilities needed for the production of oil and gas are the central production facilities (CPF), drilling production pads, airstrip, pipelines, and roads.

Central Production Facility

The CPF is the headquarters and primary operations center for the production activities of the field. It is anticipated that only one CPF would be needed as is shown in the example, but surface and subsurface conditions may require more than one CPF to adequately produce a field. Pads needed to support housing and production modules would be approximately five feet thick and cover approximately 90 surface acres. Each of these pads would require approximately 725,000 cubic yards of gravel. To protect the permafrost from thermal degradation, pads constructed on the North Slope are five feet thick, and it was assumed that the same amount would be required in the refuge. At the time of development, it may be found that more or less gravel would be required. Necessary modules would be built on pilings or shallow spread footings to ensure foundation integrity for the life of the project.

Gravel, needed for the construction of the production facilities, will probably be mined near the field. To minimize environmental impactss, two or three small deposits may be excavated rather than removing the gravel needed from one source.

Housing modules would include sleeping and eating quarters, food storage area, and recreational and sanitation facilities. The modules would be designed to accommodate 150-300 workers. Adjoining offices would house administration, engineering, communications, and other support services.

Production facilities would include the equipment necessary to process the crude oil into salable oil and usable gas. This process begins by separating the production fluid into oil, gas, and water. Oil would be dehydrated and piped to market. Produced gas would most likely be dehydrated and compressed for facility use or reinjected into the subsurface structure. Produced water would be pumped to injection wells for disposal.

Water for domestic use could be obtained from local lakes or water-filled pits (abandoned gravel source areas). Insulated tanks would store a sufficient amount of potable water for human consumption. Sewage treatment facilities and the incinerator would eliminate most of the human waste and trash. Items which could not be burned would be transported to an approved disposal site.

Fuel storage would hold diesel and other refined petroleum products necessary for operating the equipment of the CPF. The area would be diked to contain any spills which may occur. Electricity would be provided by a diesel or natural gas powered generation plant.

Drilling/Production Pads

Drilling rigs and support modules would be the initial equipment located on the drilling/production pads. As wells are completed, wellheads, pipelines, and the gathering facility would be put in place. The size of these pads are dependent upon the number of wells drilled and the distance between wellheads. In our south example, four pads are shown to cover 30 acres and one pad covers 20 acres. A 30-acre pad would support 88 wells, and a 20-acre pad would support 65 wells. The north example shows four 30-acre pads and two 20-acre pads. As previously mentioned, more smaller pads supporting fewer wells may be required to adequately deplete the resources. All pads would be five feet thick, and would require 160,000 to 280,000 cubic yards of gravel per pad.

Depending upon the proposed depth and subsurface conditions, production wells will take 10-60 days to drill and complete. Production from each well is piped to the gathering facility where it is metered and piped to the CPF.

Most production wells are directionally drilled from the pads to various bottom hole locations within the hydrocarbon reservoir. This procedure allows maximum depletion of the reservoir and minimizes the surface acreage disturbed. Unusable drilling mud and cuttings are temporarily stored in reserve pits located on the pad. As wells are completed, this material is transported to a disposal site and the reserve pit is filled in.

Airstrip, Pipelines, and Roads

The airstrip would be permanent and maintained year-round for the lifetime of the project. Minimum length of the airstrip would be 6,000 feet and minimum width would be 150 feet. Twenty acres of surface are covered by the airstrip itself and another 10-15 acres are required for the taxiway, apron, and support facilities. Approximately 300,000 cubic yards of gravel would be required to construct this facility.

Roads will connect all of the above facilities. They will be built with a crown width of 35 feet and will be five feet thick. Each mile of road will cover five acres of surface and require 40,000 cubic yards of gravel. Total road mileage varies between projects, depending on the size and surface features of each prospect.

Gathering lines will run from each production pad to the CPF. One line will transport the crude oil to the CPF and a parallel set of lines will transport the gas and water from the CPF to the production pads for fuel, injection, or disposal. These pipelines will be buried if possible, but most likely will be placed on steel vertical support members. Diameter of the pipe will range from three to twelve inches, and the pipelines will probably be laid parallel to the roads.

The main production pipeline leaving both fields would probably be 8 to 16 inches in diameter. The route of these pipelines to market will depend on circumstances at the time production begins. At the present time, it appears the most economical route, for the southern prospect, would be directly to TAPS, which is west of the Refuge. Other potential routes may be directly, or via Circle and the Steese Highway, to TAPS near Fairbanks. A main pipeline, for the northern prospect, would most likely be built from the prospect to the Yukon River and parallel to the river until it intersected with TAPS. As previously mentioned, it is doubtful that a road would be built parallel to the pipeline; therefore, extensive use of aircraft would be needed to protect and monitor the system. Another unlikely but potential scenario would be to build a pipeline from the prospect to a transportation system in Canada. If this was approved, a road probably would parallel the pipeline. In both scenarios, the pipelines would be buried or placed on steel vertical support members.

As more oil fields are developed under arctic conditions, engineers will discover improved and less expensive methods for pad construction, drilling procedures, refining processes, and transportation systems. This would not only reduce the described surface acreage disturbed, but it will also improve the economics of the arctic's smaller oil fields.

Economic Potential

Background

The Yukon Flats National Wildlife Refuge (YFNWF) was created in 1980 by an act of Congress and is located approximately 150 miles north of Fairbanks, Alaska (figure 6). The refuge encompasses 11.2 million acres (17,456 square miles) in the interior of Alaska. In the absence of roads, access is limited and in the winter months is quite difficult.

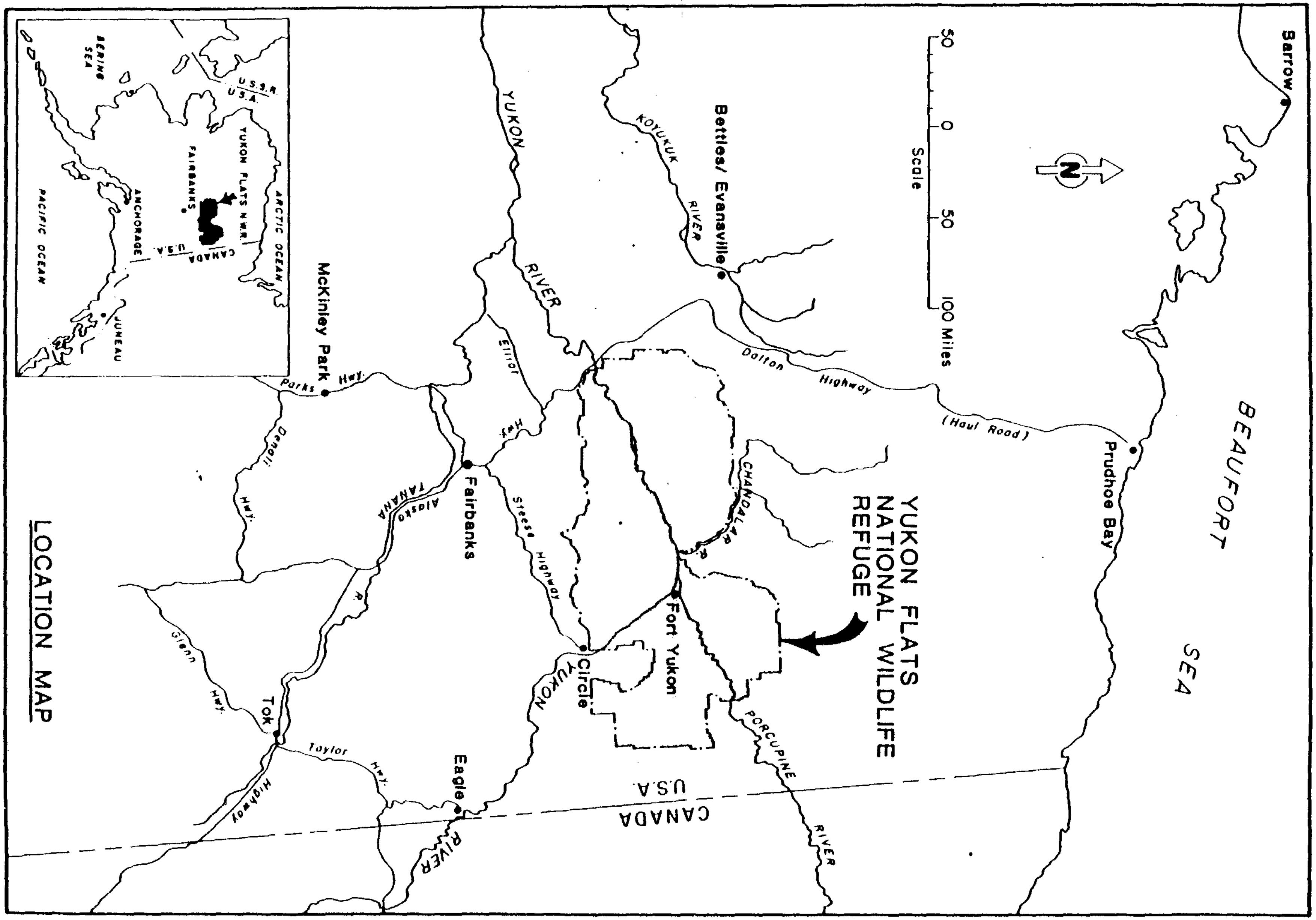


Figure 6. Location of the Yukon Flats National Wildlife Refuge.

Exploratory History

Presently, oil and gas leasing is prohibited on the refuge due to its status as a wildlife refuge. Subject to site-specific compatibility with refuge purposes, oil and gas exploration inclusive of seismic activities may be allowed.

About one-fourth of the refuge was under oil and gas lease applications in 1969 when further applications were rejected. Presently, there still remain about 600,000 acres of lease applications which have not been surrendered.

To date, drilling for oil and gas has not occurred within the boundaries of the YFNWR. In 1976 and 1977, three wildcat wells were drilled in close proximity to the eastern boundary of the refuge. These wells ranged from 9,123 feet to 13,583 feet in depth. No shows of oil and gas are recorded for these exploration activities.

Geologic Potential

The geological petroleum potential1/ of the YFNWR has been evaluated based on available geological and geophysical information. Using guidelines found in the BLM Manual, Section 3031 (see Appendix A), the entire

1/ Geologic petroleum potential refers only to the probability of the presence (occurrence) of a concentration of that mineral resource. It neither refers to or implies potential for extraction or that the concentration of the resource, if any, is economic or could be extracted profitably.

refuge was determined to have either a "moderate" or "low" potential for the accumulation of oil and gas resources (see plate 8). Based on these BLM guidelines as well as available information, it was further judged that no areas could be construed as having either "no" potential or "high" potential.

In classifying the mineral potential for lands within the YFNWR, the BLM Manual requires that a determination be made as to the reliability of the data used based on the type and quality of data available to make these judgmental calls. As can be seen in Appendix A, there are four categories for data quantification, known as "Levels of Certainty." These Levels of Certainty are, "A, B, C, and D," with "D" representing the highest level of certainty and data quantification, and "A" representing the lowest, or least reliable category based on the amount of data and type of evidence to make a decision.

The geological section of this report has not indicated the "Levels of Certainty" which best supports the indicated "Levels of Potential" determined for this refuge. It was noted with few exceptions, such as petroliferous odors and noted oil seepages, that the greatest amount of data available to support the possible existence oil and gas resources is indirect evidence. On this basis, the "Level of Certainty" determined to be the most apropos for areas determined to have either a "moderate" or "low" potential for the accumulation of oil and gas was "B." The definition for this lower level of certainty is: The available data provide indirect evidence to support or refute the possible existence of mineral resources.

Development Potential

The development or economic potential of an area considers not only the geologic environment concerning the existence of mineral resources, but also the nongeologic environment.

The nongeologic environment includes such considerations as market availability, the existing infrastructure in the subject area, price projections, costs of production and marketing, anticipated rate of return, and also alternative investment opportunities.

The YFNWR has been determined to be an area of "low" economic development potential for oil and gas resources (plate 9). As previously indicated, no drilling has occurred on the refuge and exploration wells in close proximity to the refuge have been unsuccessful. Tertiary sediment volume, depth, and continuity in the Yukon Flats cenozoic basin are considered questionable. The interpreted results of geophysical studies could not be considered very promising. In conjunction with these facts, the physical remoteness of the area, lack of infrastructure, inclusive of the nonexistence of roads, would result in high capital costs to industry to explore and develop this area. The closest existing production to this refuge is in the Prudhoe Bay field approximately 250 miles to the north. It is expected that industry, in ranking this area against other investment opportunities, would be strongly inclined to focus their interest on areas showing greater promise.

Current technology exists that would allow exploration and development of potential hydrocarbon resources from this refuge, should commercial quantities be discovered; so the interest in opening this area to exploration is dictated by the resource potential and economic viability of oil and gas development in the area.

Price Projections

Current petroleum price projections compiled from a variety of sources 2/ are significantly lower than previous forecasts completed earlier in the 1980s

2/ U.S. Department of Energy, 1985
Data Resources Incorporated, 1986
Chevron Corporation, 1986

(Appendix B, table 1). The range of oil prices projected in these current forecasts vary from $18 to $42 per barrel by the year 2000 (constant 1984/85 dollars). With such a wide spread in forecasts, it is difficult to assess future impacts of this variable on future exploration activities. It was of interest to note that both a private research firm and a major oil company forecast a crude oil price of $35/barrel, whereas the most optimistic level of $42/barrel was a forecast of the U.S. Department of Energy (DOE) and was dependent on high economic growth. Assuming that high economic growth is not achieved, the DOE mid-range forecast of $36.75 is less than $2/barrel higher than those of the private sector. This level ($36.75/barrel by the year 2000) is approximately $5/barrel, or 12 percent, less than the average annual refiners' cost of imported crude in 1981/82 (constant 1984 dollars). This scenario does reflect an optimistic picture as compared to the current pricing structure and would be expected to provide incentives for future exploration/production of the YFNWR.

Other forecasts from the same sources indicate an upward trend in petroleum demand, but conversely project a decline in domestic production which is indicative of a decrease in domestic exploration activities.

One last petroleum price projection that should be considered is the scenario presented by Arlon Tussing, a Seattle based energy economist. Mr. Tussing, in late 1980, against all conventional price projections, correctly forecast that international oil prices would soon collapse. In January 1984, prior to the concern of most energy forecasters, he stated that we were headed for a 10-year cycle of falling prices, and he projected that oil would soon drop within the range of $12 to $20 per barrel. To date, this forecast has been quite accurate.

Mr. Tussing's latest forecast is even more foreboding, as he expects oil prices in constant dollars to remain within a range of $10 to $20 a barrel through the rest of the century. Beyond this timeframe, he expects energy prices to decline even further.

The basis for this scenario is "fuel switching." Mr. Tussing states that "many" of the industrial users are now equipped to use alternate fuels such as oil, gas, or coal, depending on the prevailing price. He believes that the exceptional high prices during the six-year period between 1979 and 1985 were possible only because heavy industrial users were not at that time equipped to switch fuels and were heavily dependent on oil as a bulk fuel. This stemmed from the fact that exceptionally low oil prices prevailed in the 1950s and 1960s, and this trend was expected to continue ad-infinitum. He points out that for a century, between 1878 and 1978, crude oil prices never exceeded $15/barrel in 1986 dollars, and the average wellhead price during this 100-year period was between $8 and $9/barrel. Mr. Tussing believes that as long as technological progress is self-sustaining, the long-term price trend for oil can only be downward.

The wide divergence in oil price projections just presented are indicative of the future uncertainty which exists in the national petroleum industry. As we have seen, though, most mainline economists are forecasting an upward trend in long-term bulk oil prices. Although this is considered a promising sign for the industry as a whole, this is foreshadowed by forecasts of a long-term decline in U.S. production. This decline was brought on by a general cutback in drilling and production activities by U.S. petroleum companies triggered by an excess world supply and resultant low product prices. Future expansionary efforts by the petroleum industry would be anticipated to take place in areas where, hopefully, capital costs can be held down, or, in lieu of this, in areas of great promise.

Overview

In 1985, Alaska contributed nearly 20 percent of domestic petroleum production (United States Department of Energy, Energy Information Administration, 1986). In comparison, Alaska is a relatively minor producer of natural gas, with production of approximately 300 billion cubic feet per year in 1985 (United States Department of Energy, Energy Information Administration, 1986a). However, Alaska is an exporter of natural gas in the form of liquified natural gas (LNG), which is primarily shipped to Japan.

Fundamental changes in the petroleum industry since the early 1970s will certainly be a force in shaping the industry's future. This period brought two major crude oil price shocks, rapid expansion in petroleum demand and heavy reliance on foreign sources of supply to meet domestic needs. Similarly, the consumer experienced shortages in natural gas supply which resulted in a new era of gas price regulation (see Appendix B for a detailed discussion of these changes). The rapid growth of the energy sector in the late 1970s and early 1980s resulted in the highest petroleum prices ever experienced by the industry. This set the stage for a period of energy conservation efforts, followed by declining demand and excess world productive capacity with falling petroleum prices. By the middle of 1986, crude oil prices had dropped to levels at or below prices received in 1973, before the Arab oil embargo. Natural gas price increases stimulated drilling and production in the early 1980s, which has resulted in domestic surplus capacity (gas bubble) and depressed prices. The present unstable nature of the oil and gas industry has resulted in a great deal of restructuring within the industry and expectations for the future are very uncertain.

Most recent long-term price forecasts project an upward trend that will be realized in the 1990s and possibly beyond (see Appendix B for specific prices and trends). Domestic petroleum demand is expected to rise slightly above the 1985 level of 15.7 million barrels per day to a range from 15.9 to 18.1 million barrels per day by the year 2000. Natural gas demand could also increase from 17.4 trillion cubic feet per year in 1985 to a possible range from 17.1 to 20.4 trillion cubic feet per year in the year 2000. In contrast, domestic production of petroleum and natural gas is projected to decline below 1985 levels by the year 2000 (see Appendix B for a more detailed discussion of historic and future petroleum and natural gas demand and supply relationships). Therefore, the United States' dependency on foreign sources of hydrocarbon supplies is expected to increase above current levels. Based on these projections, there is a considerable gap between domestic consumption and production that can only be filled nationally be exploring new areas and developing any commercial discoveries that are made.

In summary, if the YFNWR were opened to oil and gas exploration and development, some benefits would accrue to the local economy through the expenditure of explorational dollars, with some small-scale benefits to the State. Economic benefits would of course be dependent on industry's interest in the area and investing the necessary capital for development. Presently, and at least through the turn of the century, it is not expected that industry would have significant interest in the area and would be more inclined to expend their exploration dollars in areas of greater promise. Any long-term benefits that would accrue, would of course be dependent on locating commercial quantities of oil and gas, that could be recovered from a favorable economic viewpoint.

Appendix A

Mineral Potential Classification System

APPENDIX A

3031 - ENERGY AND MINERAL RESOURCE ASSESSMENT

I. Level of Potential

O. The geologic environment, the inferred geologic process, and the lack of mineral occurrences do not indicate potential for accumulation of mineral resources.

L. The geologic environment and the inferred geologic processes indicate low potential for accumulation of mineral resources.

M. The geologic environment, the inferred geologic processes, and the reported mineral occurrences or valid geochemical/geophysical anomaly indicate moderate potential for accumulation of mineral resources.

H. The geologic environment, the inferred geologic processes, the reported mineral occurrences and/or valid geochemical/geophysical anomaly, and the known mines or deposits indicate high potential for accumulation of mineral resources. The "known mines and deposits" do not have to be within the area that is being classified, but have to be within the same type of geologic environment.

ND. Mineral(s) potential not determined due to lack of useful data. This notation does not require a level-of-certainty qualifier.

II. Level of Certainty

A. The available data are insufficient and/or cannot be considered as direct or indirect evidence to support or refute the possible existence of mineral resources within the respective area.

B. The available data provide indirect evidence to support or refute the possible existence of mineral resources.

C. The available data provide direct evidence, but are quantitatively minimal to support or refute the possible existence of mineral resources.

D. The available data provide abundant direct and indirect evidence to support or refute the possible existence of mineral resources.

For the determination of no potential, use O/D. This class shall be seldom used, and when used, it should be for a specific commodity only. For example, if the available data show that the surface and subsurface types of rock in the respective area is batholothic (igneous intrusive), one can conclude, with reasonable certainty, that the area does not have potential for coal.

* As used in this classification, potential refers to potential for the presence (occurrence) of a concentration of one or more energy and/or mineral resources. It does not refer to or imply potential for development and/or extraction of the mineral resource(s). It does not imply that the potential concentration is or may be economic, that is, could be extracted profitably.

3031 - ENERGY AND MINERAL RESOURCE ASSESSMENT

Consideration of the Potential for Development and the Economic Potential

Whenever known, the quality, quantity, current and projected development potential, or economic potential should be part of the mineral resource assessment. Although this is not necessary or required for most BLM actions, it is often useful to the decision-maker. Assessments of economic potential should not be attempted for actions requiring low levels of detail, or when data are scant.

Development potential means whether or not an occurrence or potential occurrence is likely to be explored or developed within a specified timespan, under specified geologic and nongeologic assumptions and conditions. Economic potential means whether or not an occurrence or a potential occurrence is exploitable under current or foreseeable economic conditions. The time period applicable to the economic or development potential assessment should be specified in the assessment report (e.g., the occurrence is likely to be exploited within the next 25 years). Conditions that could change the economic potential, such as access, world energy prices, or changing technology, shall be an important part of every economic potential assessment. Determining the economic or development potential of either an actual or an undiscovered mineral occurrence is a matter of professional judgement based on an analysis of geologic and nongeologic factors. The rationale for that judgment shall be part of the Mineral Assessment Report, when the economic potential is assessed. The rationale may include data on the current marketing conditions for the mineral commodity, technological factors affecting exploitability, distance from roads, anticipated capital costs, etc. In other words, if the economic or development potential is assessed, the rationale for the conclusions regarding that potential must be thoroughly documented.

Calculating the quality and quantity of an occurrence, where the quality and quantity are not known from existing data, is only done for actions requiring a high level of detail. These calculations involve methods appropriate to the type of action, and are described in the pertinent Bureau Manual (e.g., appraisal, validity, etc.).

Appendix B

Oil and Gas Demand and Supply Relationships

The importance of potential oil and gas resources from this refuge is dependent on the hydrocarbon potential of the area, national need for additional sources of oil and gas, and the economics of exploring and producing any hydrocarbons that might be discovered. This Appendix provides a detailed review of the factors that have contributed to the present domestic oil and gas situation and possible future demand for oil and gas, which is directly linked to the national need for oil and gas resources from the refuge.

Domestic Energy Trends

The domestic energy situation, as it relates to oil and gas consumption and production, has changed dramatically since the early 1970s. In 1970, petroleum and natural gas supplied 44 and 33 percent (United States Department of Energy, Energy Information Administration, 1984), respectively, of the total energy consumed in the United States (figure 1). By 1977, petroleum accounted for nearly 49 percent of domestic energy consumption, and natural gas consumption had declined to approximately 26 percent of total energy demands. The relative contribution of both petroleum and natural gas declined through 1985, when petroleum supplied nearly 42 percent, and natural gas contributed approximately 25 percent of total energy demand. Figure 1 shows the contribution of each major primary energy source to total national energy demand in 1970, 1980, and 1985. Coal, nuclear, and geothermal energy were the primary forms of energy to increase their market share of total energy consumption during this time period, at the expense of petroleum and natural gas resources.

Total domestic energy consumption peaked at 78.9 quadrillion (QUAD) British thermal units (BTU) in 1979 and subsequently declined to 73.8 QUADS in 1985 (United States Department of Energy, Energy Information Administration, 1986). Over the 15-year period from 1970 to 1985, total primary energy consumption increased 11 percent, from 66.4 QUADS to 73.8 QUADS; however, the rapid increase in energy consumption and escalation in the cost of energy (the

FIGURE I

PRIMARY ENERGY CONSUMPTION BY SOURCE

FIGURE 1A
1970
Total = 66.4 Quadrillion Btu

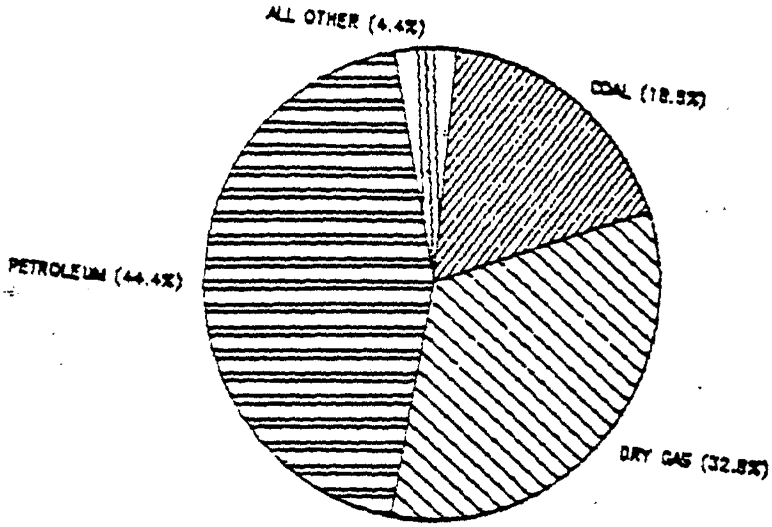


FIGURE 1B
1980
Total = 78.0 Quadrillion Btu

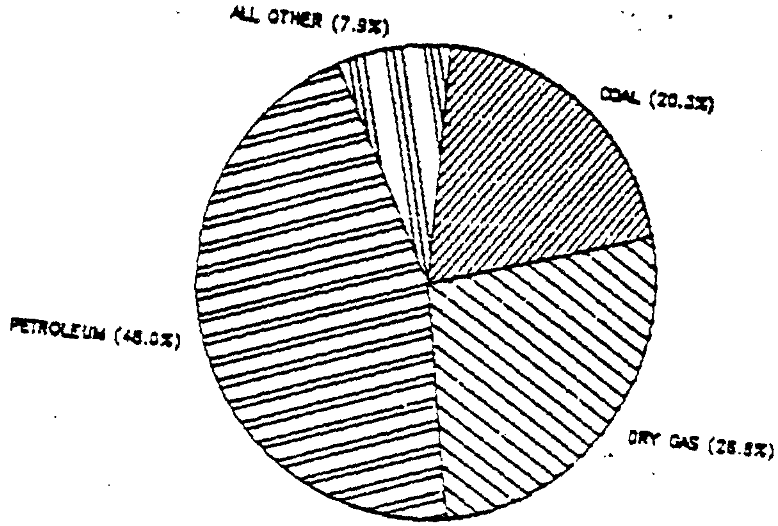
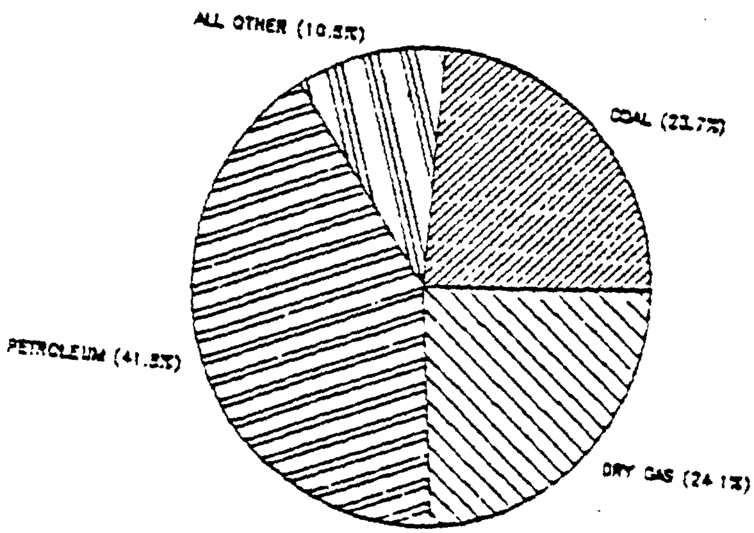


FIGURE 1C
1985
Total = 73.8 Quadrillion Btu



cost of energy more than doubled, from 1.35 constant 1972 dollar per million BTU in 1970 to 2.90 in 1981) during this time period resulted in a dramatic change in national energy consumption patterns. Total energy consumed per constant 1972 dollar of Gross National Product (GNP) ranged from 56,500 to 61,000 BTUs per 1972 dollar of GNP from 1960 through 1976 (United States Department of Energy, Energy Information Administration, 1985a). A decline in the intensity of energy utilization was realized in 1977, when total energy consumption dropped to 55,700 BTUs per dollar of GNP, and this downward trend continued through 1985, when energy consumption was reduced to 42,900 BTUs per 1972 dollar of GNP (United States Department of Energy, Energy Information Administration, 1986). The decline in energy consumption was led by the reduction in the intensity of petroleum and natural gas utilization. In 1985, only 68 percent as much petroleum and natural gas were consumed per dollar of GNP than in 1977, as compared to 77 percent for total energy consumption. The reduction in intensity of energy utilization was indicative of a national conservation effort which any be attributed to many factors, including: increased real energy prices, the increased service orientation of the economy, and changes in the mix of product production (United States Department of Energy, Energy Information Administration, 1985a).

Historical Oil and Gas Demand, Supply, and Price Relationships

The relationship between price and domestic petroleum supply and demand is shown in figures 2 and 3. Import prices utilized for petroleum in figure 3 are represented by the national average refiner's acquisition cost of imported crude oil, and wellhead prices are presented on the basis of the national average from all producing wells. Domestic crude oil prices were not completely decontrolled until January 1981 and, therefore, domestic wellhead prices do not follow import prices during the 1970s. Petroleum product demand rose throughout the early 1970s, until it peaked at 18.8 million barrels per day (MBPD) in 1978 (United States Department of Energy, Energy Information Administration, 1986a). Crude oil price increases began with the Arab oil

FIGURE 2
NATIONAL PETROLEUM DEMAND

AND SUPPLY 1970 – 1985

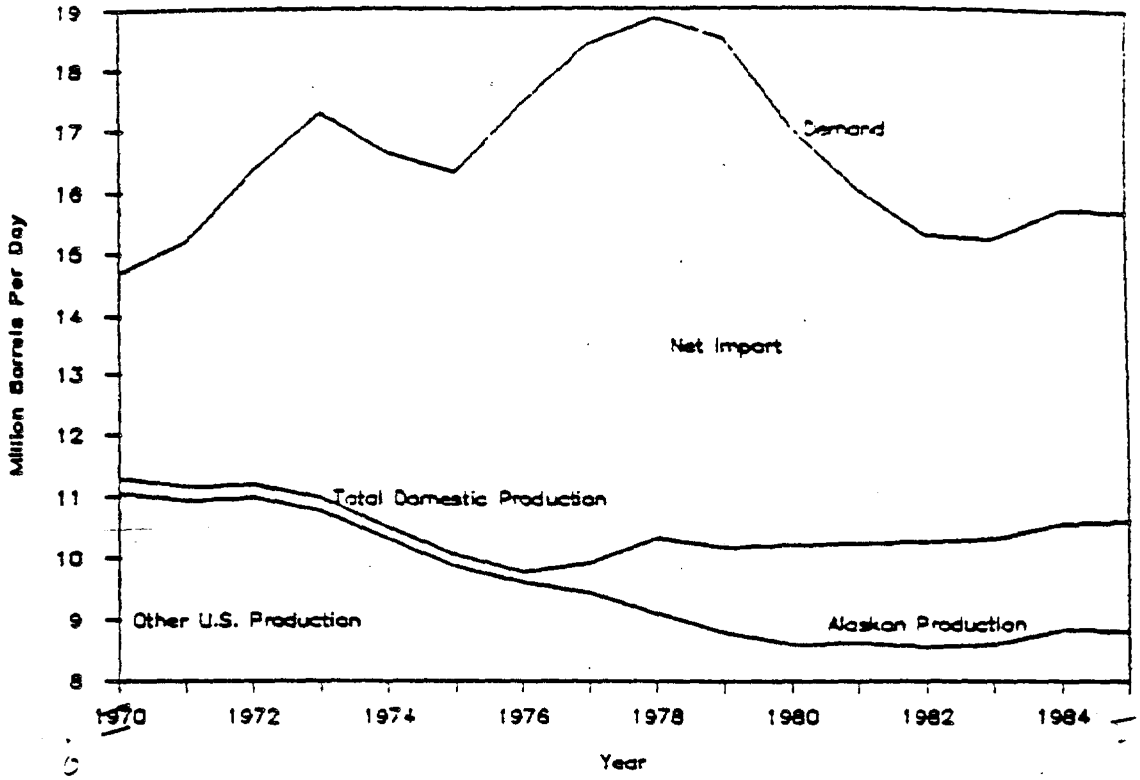
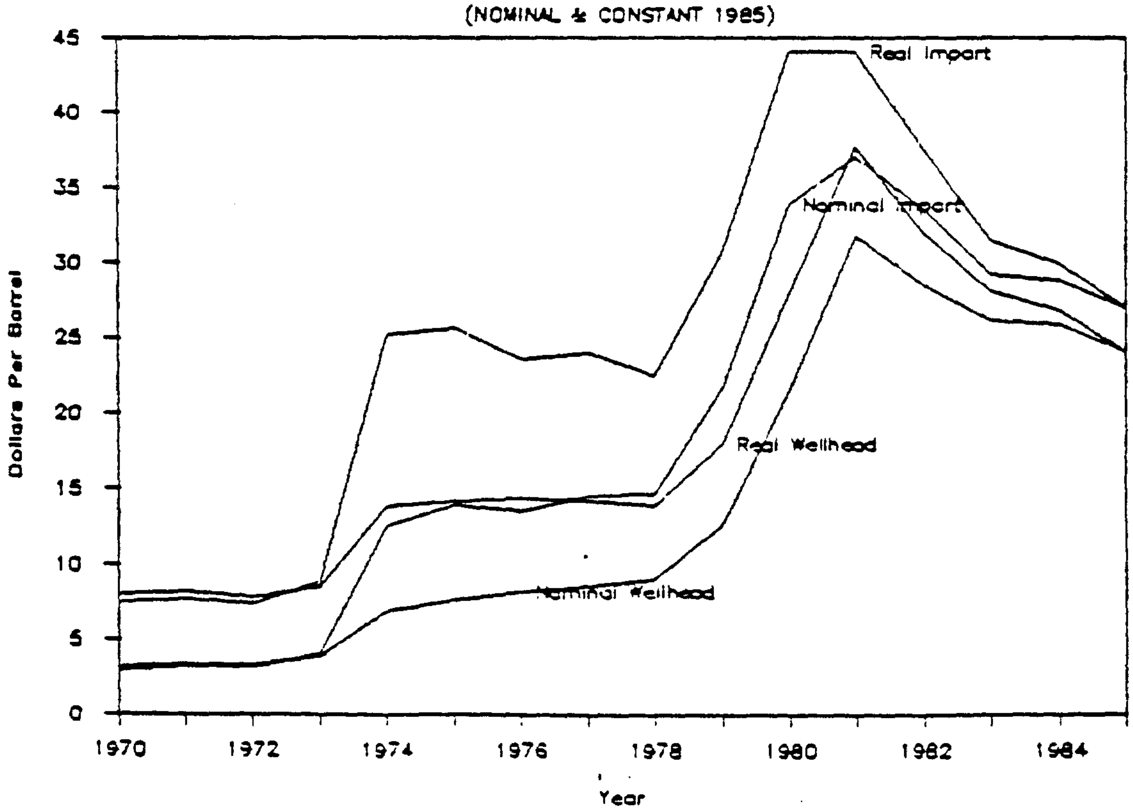


FIGURE 3
CRUDE OIL PRICES

(NOMINAL & CONSTANT 1985)



embargo in 1973, and a second major price run-up was triggered in 1978 by the Iranian revolution and subsequent oil stock building in anticipation of world oil shortages. Real import prices peaked at $44.00 per barrel (1985 dollars) in 1980.

Domestic petroleum product demand began a downward slide in 1979 which continued through 1983. The Organization of Petroleum Exporting Countries (OPEC) members sought to maintain the higher prices, that resulted from oil price shocks of the 1970s, by production restraints. However, oil prices have steadily declined since 1981 as a result of slow economic growth with subsequent declining petroleum demand and excess world productive capacity (United States Department of Energy, Energy Information Administration, 1986b). Domestic oil prices in the second quarter of 1986 had declined to the lower teens in nominal terms, which is comparable to 1974 prices in real dollars. Figures 2 and 3 show that petroleum demand is sensitive to price and is characterized by long lags and high elasticities.

Domestic petroleum production has been much more stable than petroleum product demand. Figure 2 shows that Alaskan production, primarily from the North Slope, contributes a significant portion of domestic supply. In 1985, Alaska accounted for more than 20 percent of the national crude oil production (United States Department of Energy, Energy Information Administration, 1986a). Price increases of the 1970s provided incentive for exploration and production from higher cost areas such as Alaska. Foreign imports have been required to fill the gap between domestic supply and demand. Crude oil and petroleum product imports peaked in 1977, when net imports accounted for more than 46 percent of domestic petroleum consumption. Net petroleum import levels declined to 27 percent of product demand in 1985, but the United States still remains highly dependent of foreign petroleum supply sources.

The history of natural gas production and consumption in the United States is quite different from petroleum, and it has a direct bearing on gas pricing policies, demand, and supply relationships in the 1970s and 1980s (figures 4 and 5). Natural gas went from a little used waste by-product of oil production in the 1930s to a source of energy that supplied nearly 33 percent of national consumption in 1970 (figure 1). By 1970, gas was being delivered to consumers at prices well below those of competing petroleum products (United States Department of Energy, Energy Information Administration, 1984). Prices paid to gas producers by interstate pipeline companies were held at low levels through regulation by the Federal Power Commission, which resulted in increased demand and reduced incentives for producers to explore and develop new gas reserves. Regulated prices allowed intrastate transmission companies and distributors to bid natural gas supplies away from interstate carriers (Tussing and Barlow, 1984). The 1970s has been noted for the gas supply shortages in the midwest and northern states. Imported gas prices increased in a pattern similar to oil prices, but domestic prices remained under regulation. The Natural Gas Policy Act was passed in 1978, which allowed wellhead prices to increase and it deregulated certain categories of gas. Price increases provided incentives to explore and develop new sources of gas. Natural gas consumption started a sharp decline after 1980 under the influence of higher gas prices, a weak economy, warm winters, and, since 1981, falling oil prices (United States Department of Energy, Energy Information Administration, 1984). This trend continued through 1985, with the exception of a small increase in gas demand realized in 1981, which may be attributed to the strong economic growth in the national economy in that year.

Net imports of natural gas are primarily received through pipelines from Canada and Mexico, although there are some liquified natural gas (LNG) imports from Algeria. Net imports generally ranged near five percent from 1970 to 1985. Alaska is a relatively small producer of natural gas, ranging from approximately 100 to 325 billion cubic feet per year from 1970 to 1985 (United States Department of Energy, Energy Information Administration, 1985b).. Alaska is, however, a net exporter of natural gas in the form of LNG, which is

FIGURE 4
NATIONAL NATURAL GAS DEMAND

AND SUPPLY 1970 – 1985

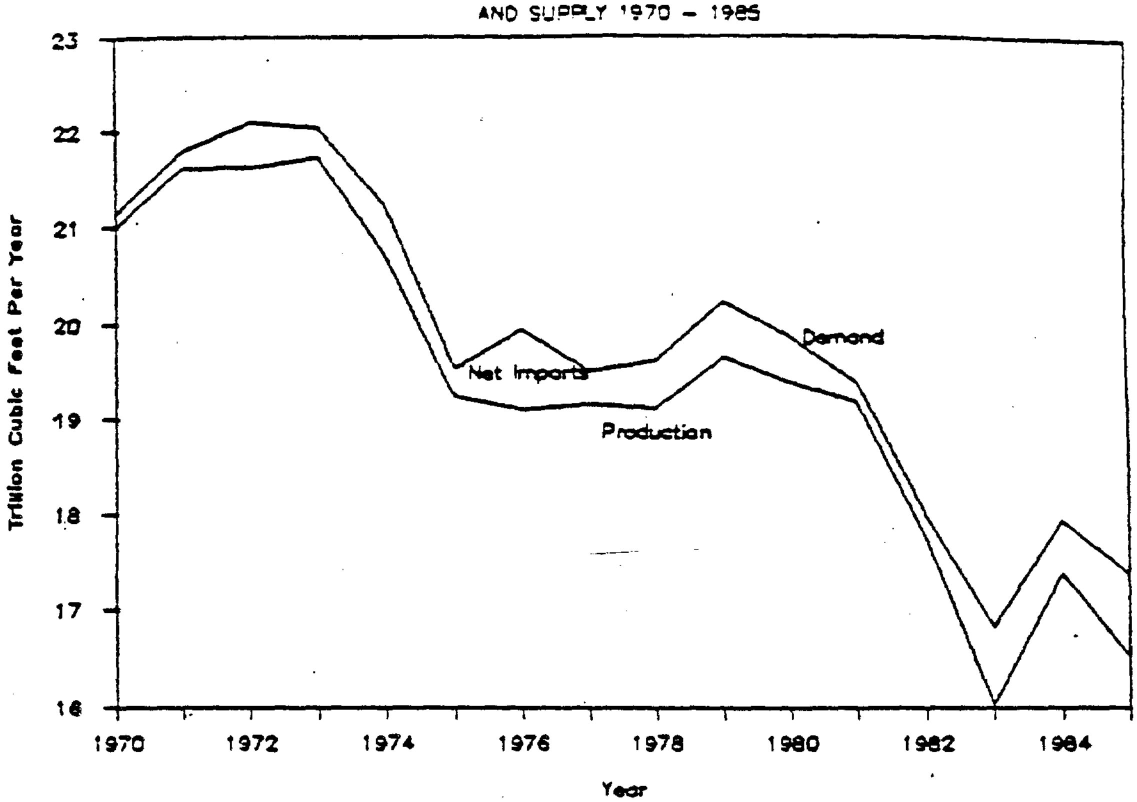
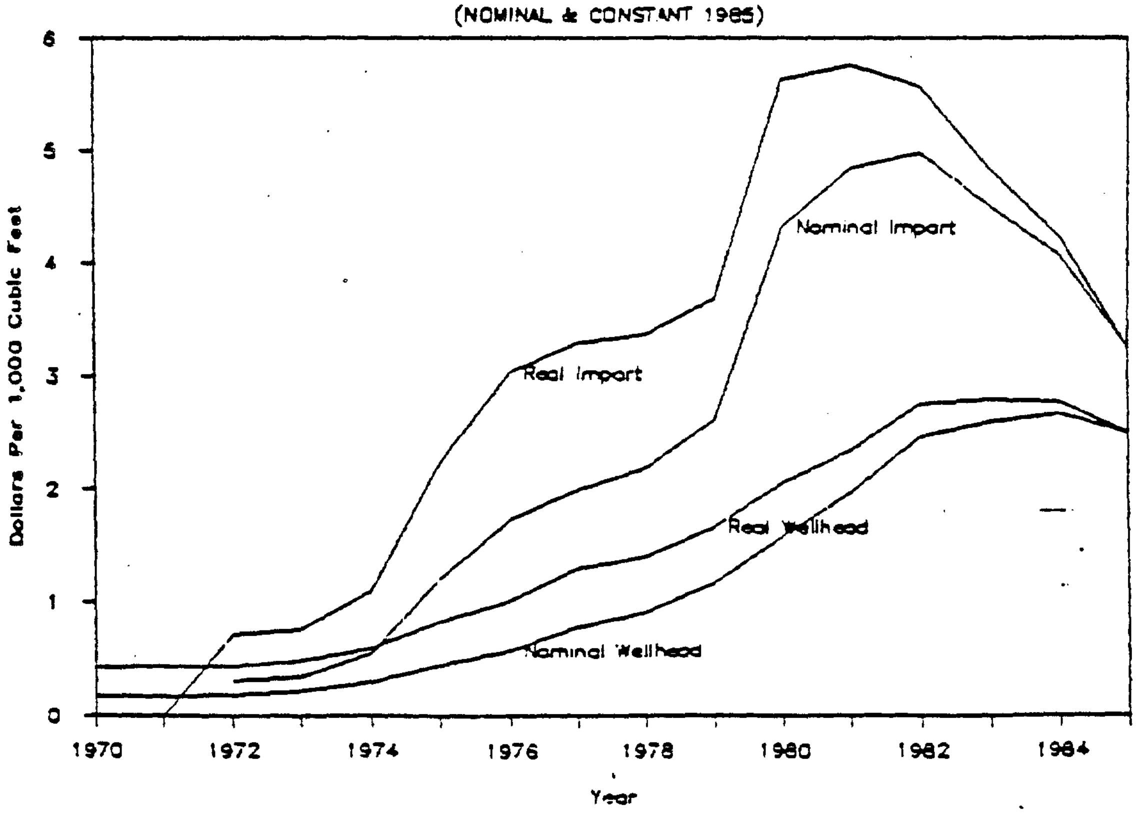


FIGURE 5
NATURAL GAS PRICES

(NOMINAL & CONSTANT 1985)



delivered to Japan. Huge gas reserves have been identified on the Alaskan North Slope, but this resource has not been commercially produced due to a lack of transportation infrastructure.

Future Oil and Gas Demand, Supply, and Price Relationships

From the review of historic petroleum and natural gas price, demand, and supply relationships, it is apparent that there have been fundamental changes, such as petroleum price deregulation and energy conservation efforts in the national energy market since the early 1970s that will likely affect future petroleum and natural gas production and consumption. At the present time, the national petroleum market is directly linked to the world petroleum market by price and supply. The situation is characterized by excess productive capacity in the world market, a strong desire by exporting nations to sell petroleum to meet financial obligations, a time of relatively slow economic growth, and declining petroleum prices. The domestic natural gas industry is currently working off surplus reserves added during the early 1980s, but depressed prices have resulted in a sharp reduction in drilling which could have serious implications for future domestic gas production.

Implications of the petroleum price slide during the first half of 1986 are not yet fully discernable. Middle eastern nations have been unable to reach accord in setting and adherence to self-imposed oil production quotas. In the past, Saudi Arabia has taken the position as swing producer for OPEC, and thereby reduced production to maintain quota levels. However, Saudi Arabia changed policies in 1986 to concentrate on achieving a "fair market share" of the international petroleum market with little concern for output quotas. The strategy behind this policy was not disclosed, but speculation as to the potential motivation and results of this action includes:

1. Saudi Arabia is making a show of strength to discipline OPEC members that have cheated on production quotas and prices with hopes of bringing member and possibly non-member nations together as a unified market group;

2. Saudi Arabia sought to increase revenue, but underestimated the effects additional production would have on price;

3. Saudi Arabia is flooding the world oil market in an effort to eliminate producers with higher costs of production and thereby reduce competition;

4. Saudi Arabia is acting to reduce prices and stimulate growth in petroleum demand to reverse conservation efforts initiated in the late 1970s and 1980s.

In any event, a tremendous amount of uncertainty exists in the national petroleum industry, which has resulted in major financial restructuring. The most evident signs of restructuring are major employment reductions and reduced capital expenditures for exploration and drilling.

The interest in mineral exploration and possible development in this refuge is driven by the future national demand for oil and gas, the cost and availability of domestic supplies, and the hydrocarbon potential of the area. The rate of future economic growth and hydrocarbon prices will be the major determinants of petroleum and natural gas demand. Future domestic production is dependent on resource availability and market prices. However, political forces are having an increasingly important effect on world oil prices, which will ultimately dictate future market conditions. The instability in the world oil market results in tremendous uncertainty in predicting future hydrocarbon prices and market conditions. Table 1 presents three recent crude oil and natural gas price forecasts by the United States Department of Energy, a private research firm, and a major oil company. The prices shown in these forecasts are significantly lower than previous forecasts completed earlier in the 1980s. The range of oil prices projected in these forecasts is $18.00 to $42.00 (constant 1984 and 1985 dollars) per barrel in the year 2000. The high price range is approximately equivalent to the average annual refiner's acquisition cost of imported crude received in 1981 and 1982 (constant 1984

TABLE 1

PETROLEUM AND NATURAL GAS PRICE FORECASTS[1]

Reference	Crude Oil ($/Barrel)			Natural Gas ($/MCF)		
	1990	2000	2010	1990	2000	2010
U.S. Department of Energy, 1985[2]						
Low Economic Growth	20.27	31.31	47.42	2.64	4.13	6.02
Reference Case	22.89	36.75	56.77	2.76	4.80	7.68
High Economic Growth	25.02	42.17	67.12	2.88	5.42	9.14
Data Resources Incorporated, 1986[2]	16.91	34.32	49.99	1.69	3.80	5.76
Chevron Corporation, 1986[3]						
Low Case	12.00	18.00	N/A	Rise to parity with fuel oil prices		
High Case	27.50	35.00	N/A			

1/ Some of the price estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

2/ Reported on the basis of constant 1984 dollars.

3/ Reported on the basis of constant 1985 dollars.

TABLE 2

FUTURE DOMESTIC PETROLEUM AND NATURAL GAS
DEMAND AND SUPPLY RELATIONSHIPS[1]/
(See Table 1 for Price Forecasts)

	Demand			Supply		
Reference	1990	2000	2010	1990	2000	2010
	Petroleum (Millions of Barrels Per Day)					
U.S. Department of Energy, 1985						
Low Economic Growth	16.1	15.9	15.5	9.8	9.0	7.8
Reference Case	16.7	16.6	16.5	10.0	9.4	8.3
High Economic Growth	16.8	17.0	17.3	10.0	9.7	8.9
Data Resources Incorporated, 1986	16.9	18.1	19.4	9.5	7.3	6.1
Chevron Corporation, 1986	16.0	16.8	N/A	9.2	7.0	N/A
	Natural Gas (Trillion Cubic Feet Per Year)					
Department of Energy, 1985						
Low Economic Growth	18.6	18.8	17.2	17.4	16.1	14.7
Reference Case	19.1	19.7	17.4	17.6	16.3	15.0
High Economic Growth	19.5	20.4	18.3	17.9	16.6	14.7
Data Resources Incorporated, 1986	18.9	18.1	16.7	16.7	15.3	13.9
Chevron Corporation, 1986	17.3	17.1	N/A	N/A	N/A	N/A

1/ Some of the numeric estimates presented in this table were interpreted from graphic displays and/or extrapolated from data series, so the reported prices may vary slightly from the actual values.

dollars). The range of prices projected for the year 2010 is $47.00 to $67.00 per barrel. These prices would be substantially above the peak levels paid in

Projections of future domestic petroleum and natural gas demand and supply conditions is presented in table 2. All three forecasts projected an upward trend in petroleum demand above current levels. Petroleum consumption is projected to range from 15.9 to 18.1 MBPD in the year 2000, and possibly increase to 19.4 MBPD by the year 2010. In comparison, domestic petroleum production is projected to decline to levels ranging from 6.1 to 8.9 MBPD by the year 2010. Domestic natural gas demand is projected to increase to a level ranging from 17.1 to 20.4 TCF per year by the year 2000 and then decline to a level of 16.7 to 18.3 per year by 2010. Domestic gas production is projected to follow a similar trend with domestic oil production and decline to levels ranging from 13.9 to 15.0 TCF by the year 2010.

Conclusion

National hydrocarbon markets have undergone substantial changes since the early 1970s. Energy conservation trends initiated by real price increases of the 1970s are expected to continue through the end of this decade and possibly beyond. However, future economic growth is expected to result in some increased demand for petroleum and natural gas, while domestic production of these finite resources is projected to decline. As a result, the United States will become increasingly dependent on foreign hydrocarbon sources to meet national requirements. New areas will need to be explored and any economically viable resources that are discovered will need to be brought into production in order to meet domestic needs. The potential contribution of this refuge to national oil and gas production is dependent on its resource potential and the potential cost at which any discovered hydrocarbon resources could be extracted and marketed within the constraints of future oil and gas prices.

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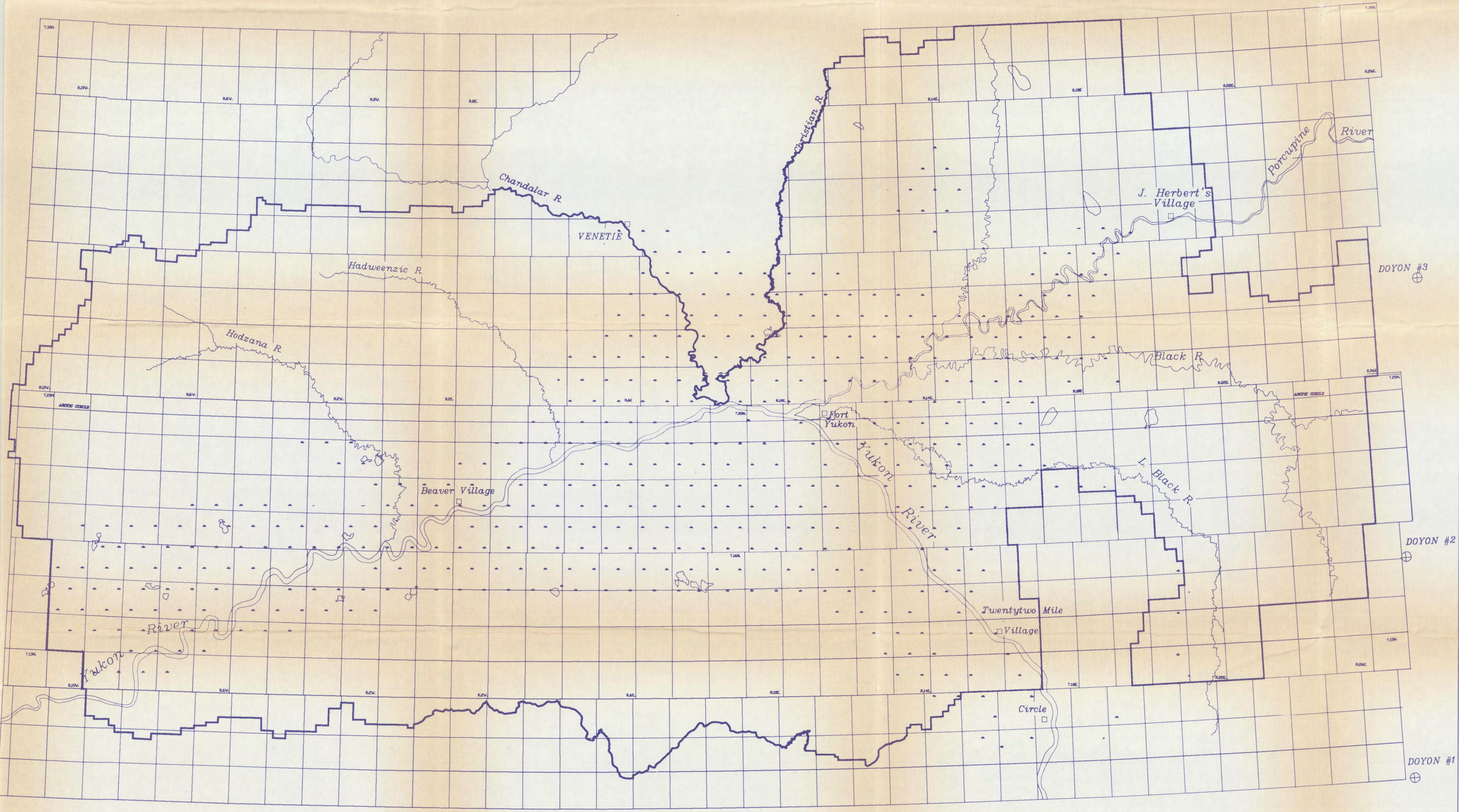
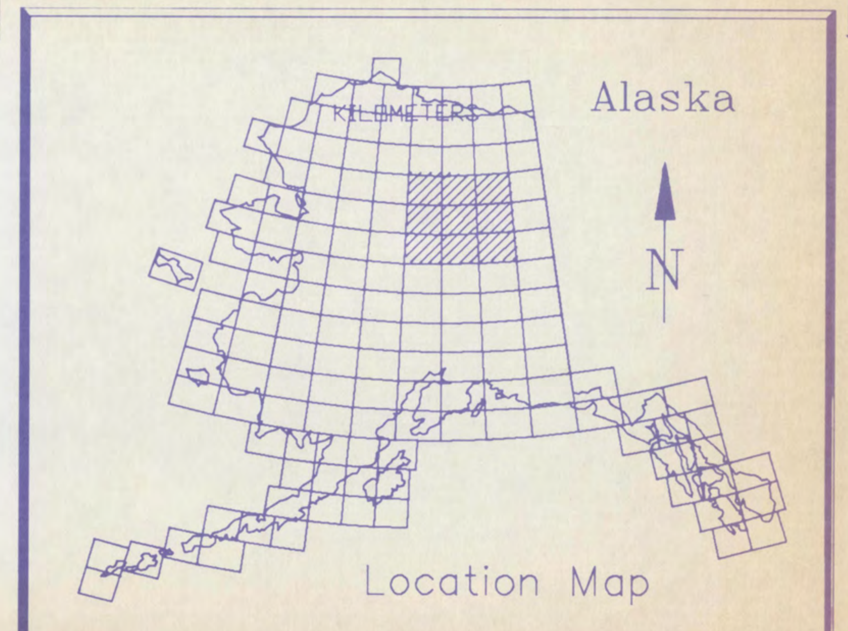
PLATE 1. YUKON FLATS WILDLIFE REFUGE



EXPLANATION

- town/village site
- Alaska Hiway system
- swamp
- DOYON #3 drillsite location
- Refgue Boundary

MILES 0 5 10 15 20 25 30
KILOMETERS 5 0 5 10 15 20 25



Department of the Interior
U.S. BUREAU OF LAND MANAGEMENT
Branch of Mineral Assessment
ALASKA STATE OFFICE

Mineral Assessment

Yukon Flats Wildlife Refuge

OIL AND GAS ASSESMENT

Scale = 1: 500,000

project manager: Mike Menge
lead geophysicist:
lead geologist: Arthur C. Banet
compiled by: Fred Conrath
date: 1987

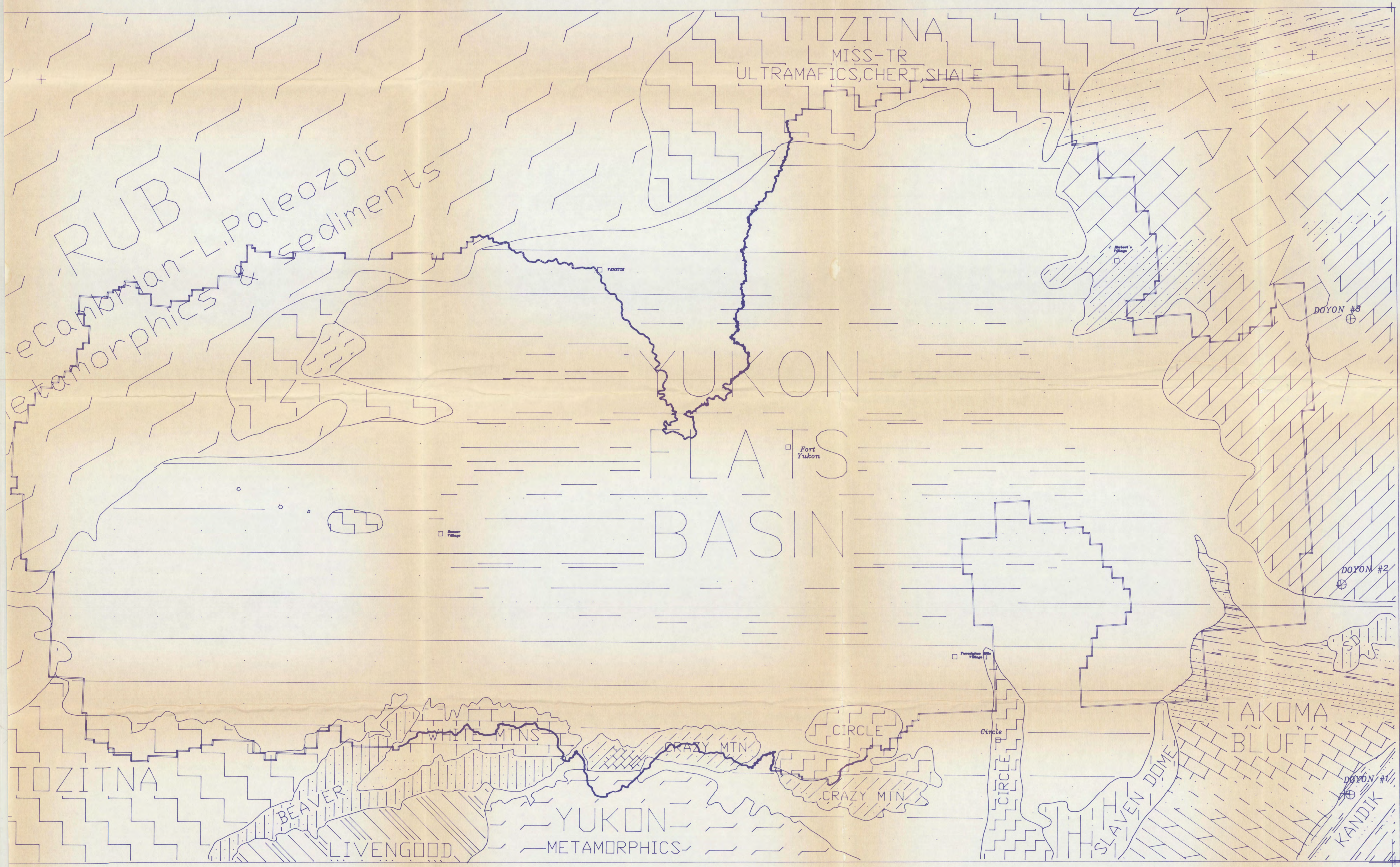


PLATE 2. YUKON FLATS WILDLIFE REFUGE

EXPLANATION

MAJOR GEOLOGIC TERRANES

MILES 0 5 10 15 20 25 30

5 0 5 10 15 20 25 KILOMETERS

PREDOMINANT LITHOLOGY

- DOLOSTONE
- MAFIC VOLCANICS GABBRO & DIABASE
- GRANITE INTRUSIONS PELITIC SCHISTS & CLASTIC SEDIMENTS
- INTERBEDDED SHALE AND SANDSTONE
- LIMESTONE
- SANDSTONE AND SILTSTONE
- SILICEOUS SHALE & CHERT

(modified from Churkin and others, 1982)

Plate 3, Stratigraphic sections of Yukon Flats terranes

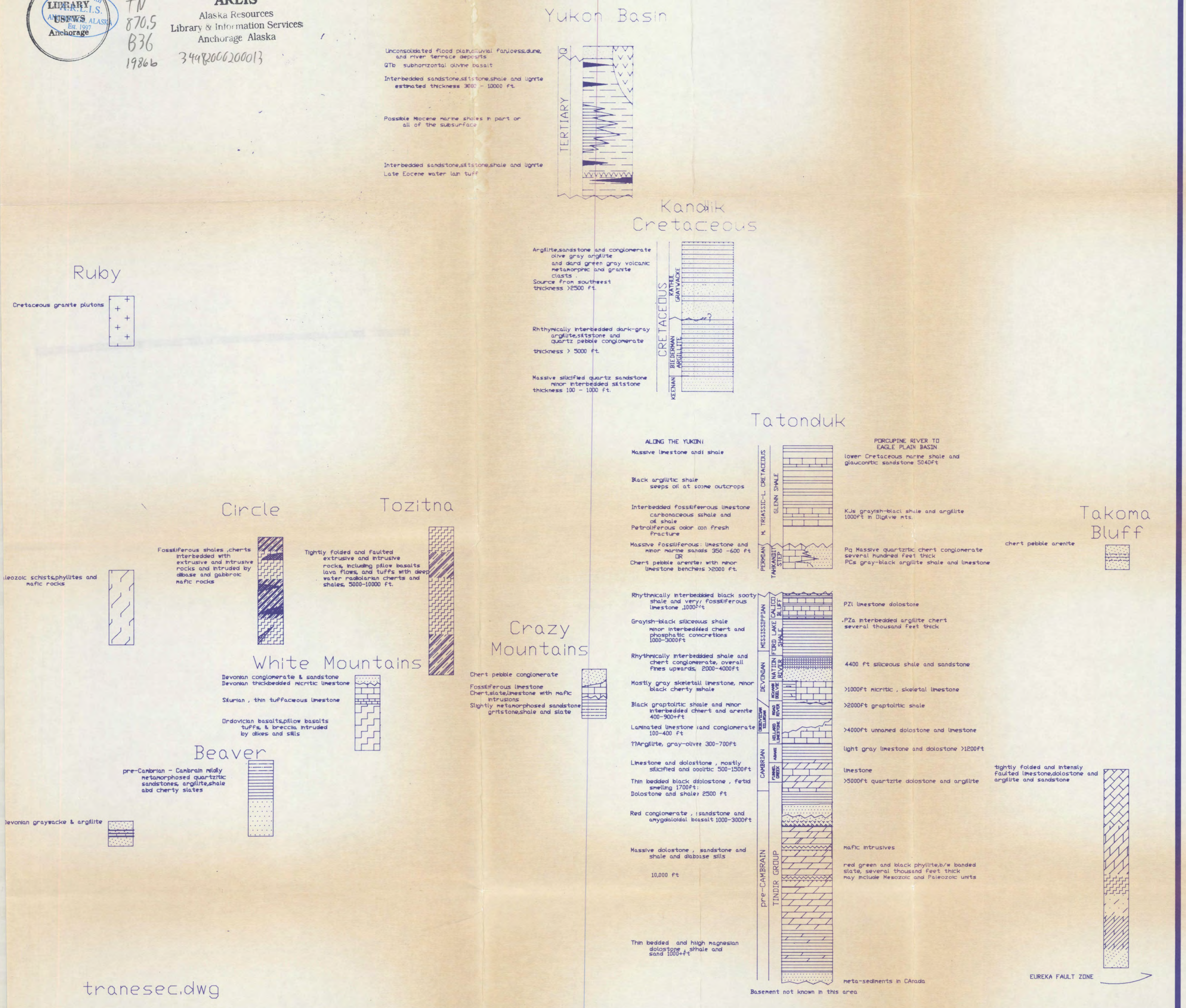


PLATE 6.

YUKON FLATS WILDLIFE REFUGE

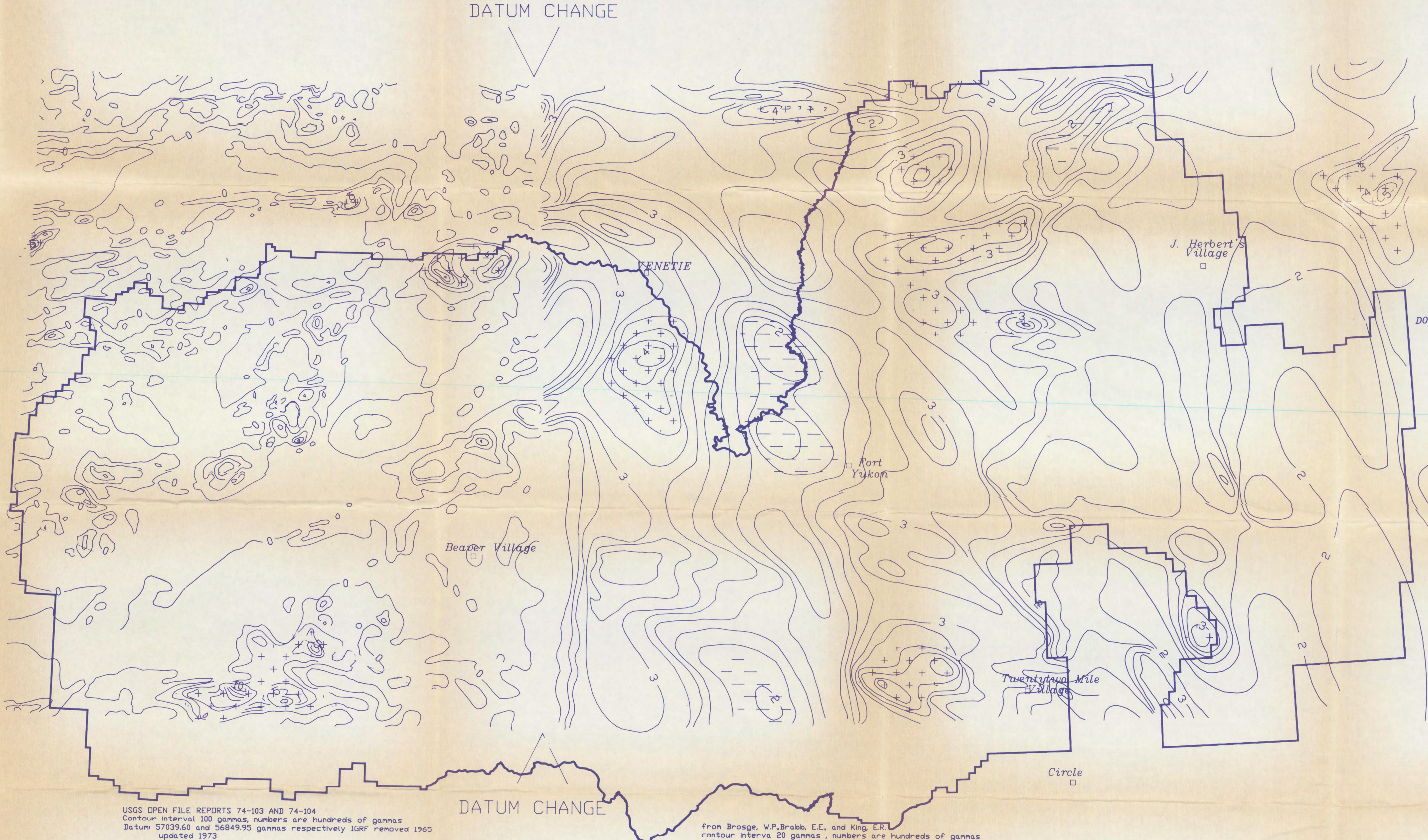
EXPLANATION

BOUGER GRAVITY MAP

contour interval: 10 mgals

(modified from Barnes , 1977)

PLATE 5. YUKON FLATS WILDLIFE REFUGE

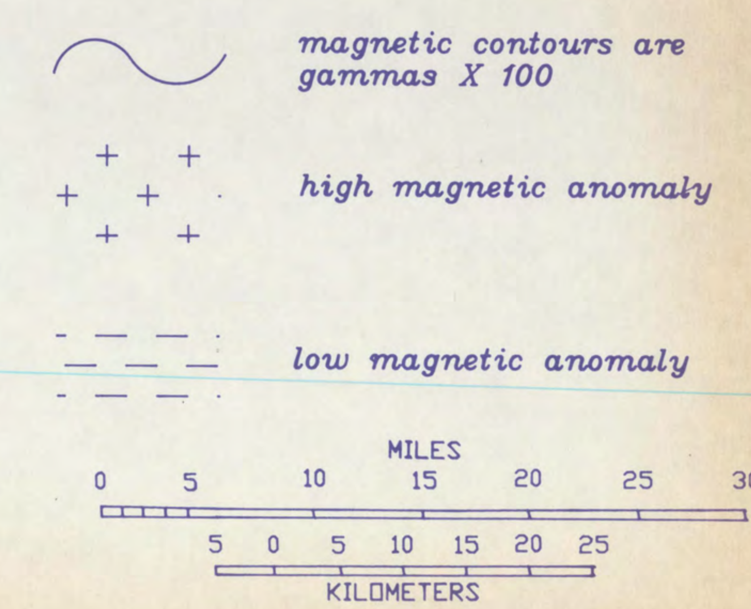


USGS OPEN FILE REPORTS 74-103 AND 74-104
Contour interval 100 gammas, numbers are hundreds of gammas
Datum: 57039.60 and 56849.95 gammas respectively IGRF removed 1965 updated 1973
Flight elevation 1000'
Year flown 1973

from Brosge, W.P., Brabb, E.E., and King, E.R.
contour interva 20 gammas , numbers are hundreds of gammas
datum : arbitrary , IGRF removed (1965)
Flight lines: North-South, 2 km. tie lines variable
Flight elevation 5000'+
Fluxgate magnetometer
Year flown 1965 and earlier

EXPLANATION

PRELIMINARY AEROMAGNETIC MAP

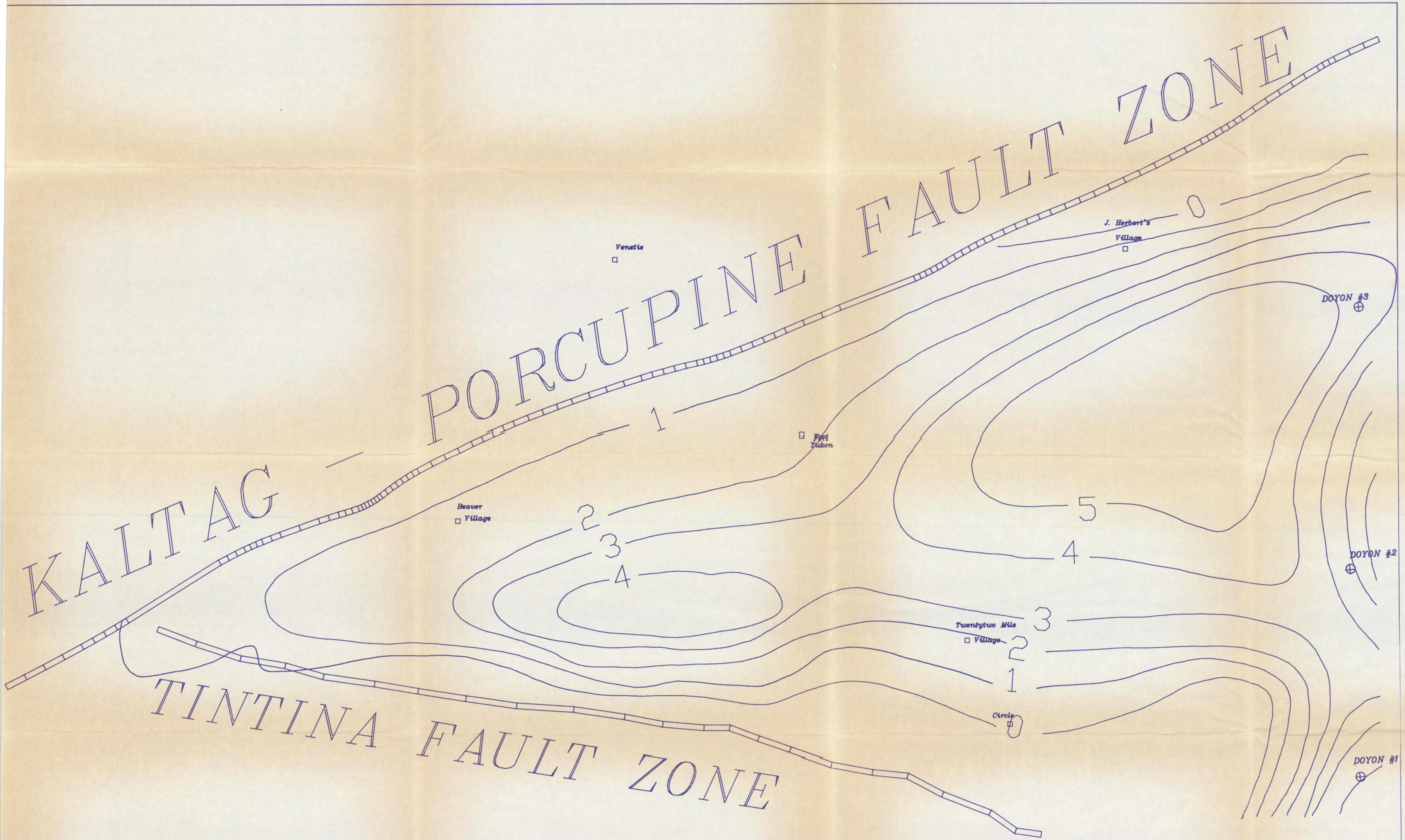


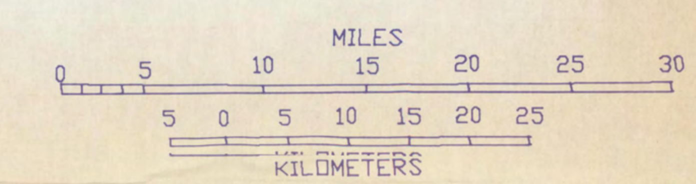
(modified frim Karl and Decker, 1977)

PLATE 4. YUKON FLATS WILDLIFE REFUGE

TECTONIC ELEMENTS

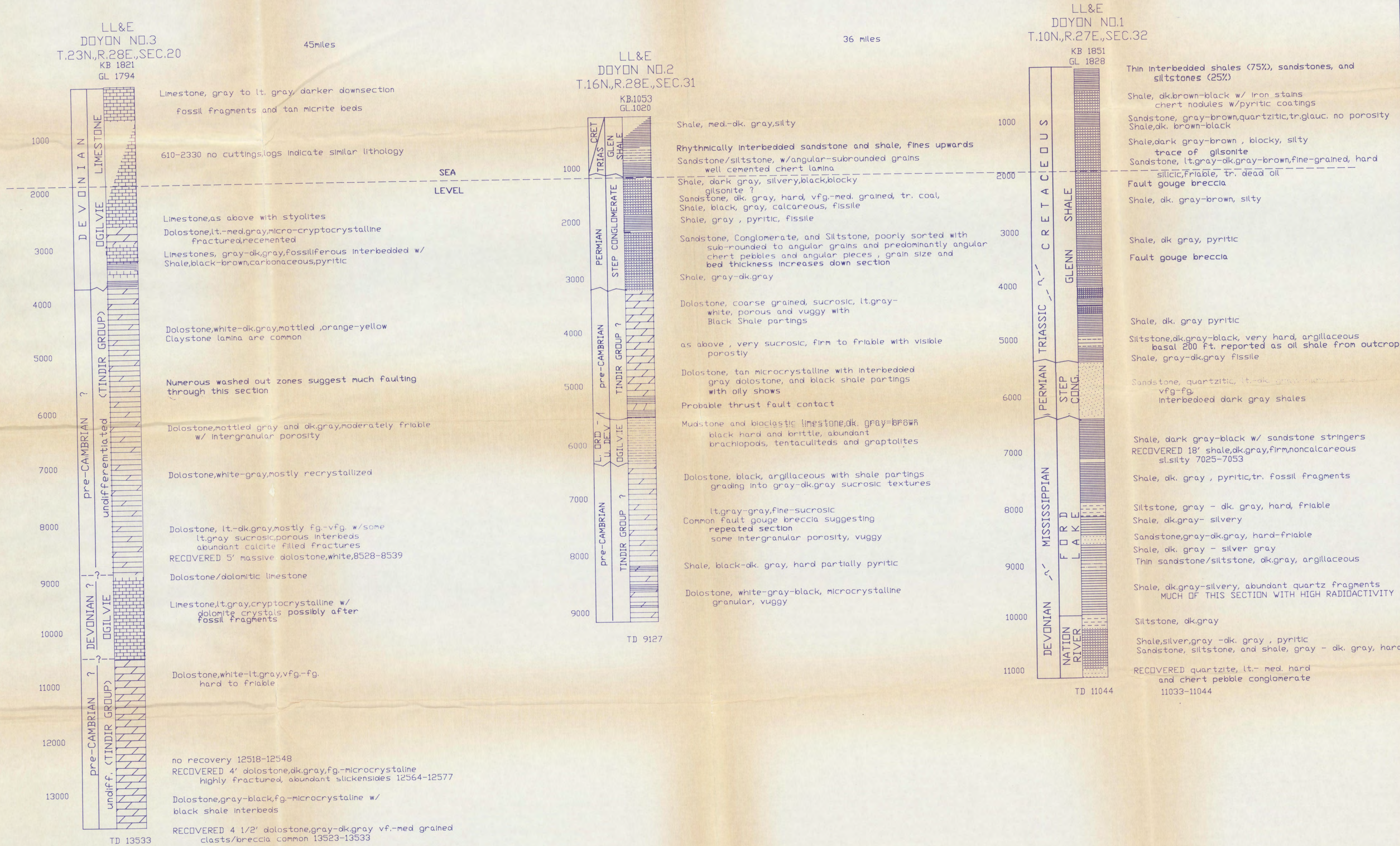
showing major fault zones and thickness of sediments





(modified from Ehm, 1983)

PLATE 7. North-South section through Doyon wells Nos. 1,2 and 3 showing the subsurface stratigraphy immediately east of Yukon Flats Wildlife Refuge



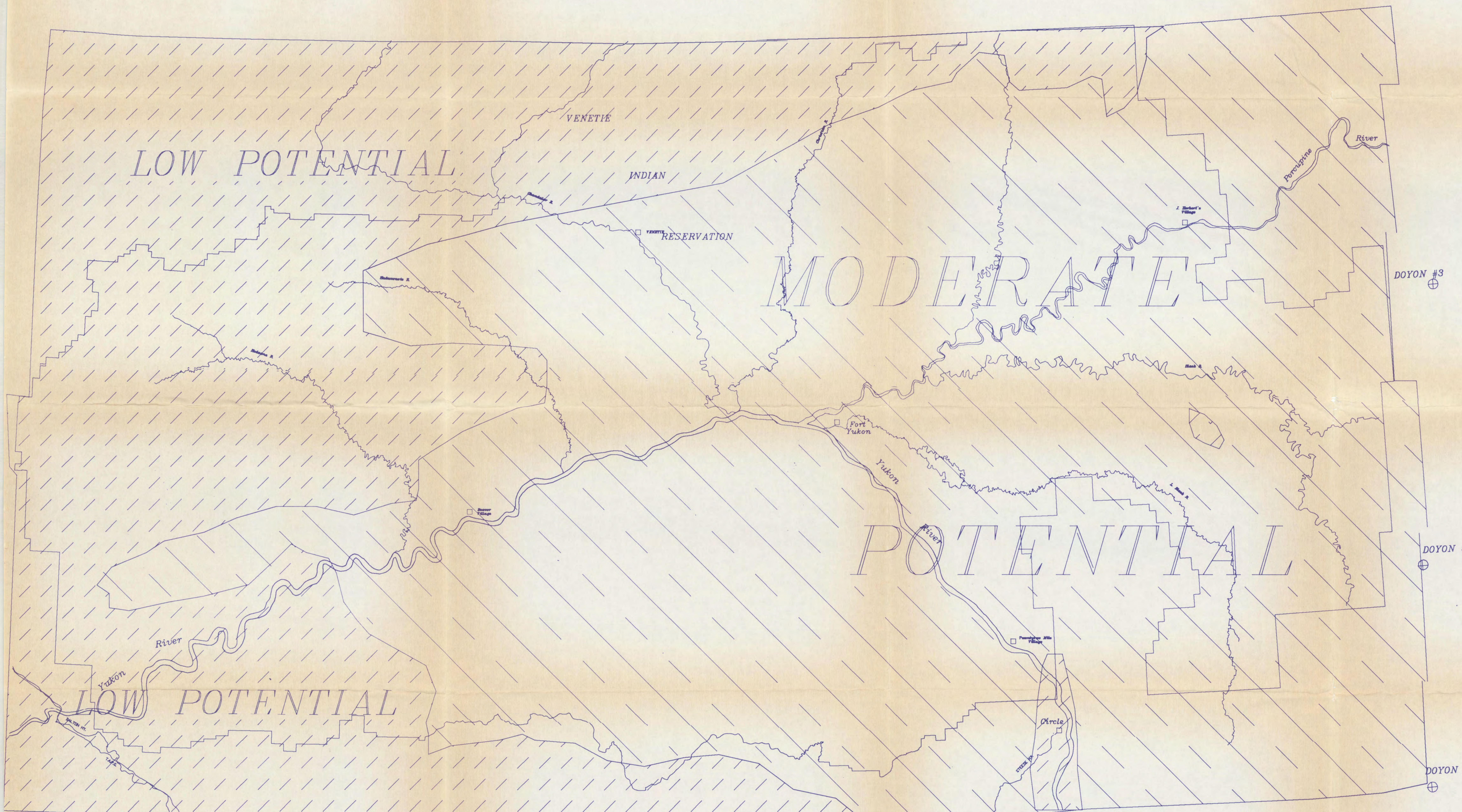


PLATE 8. YUKON FLATS WILDLIFE REFUGE

EXPLANATION

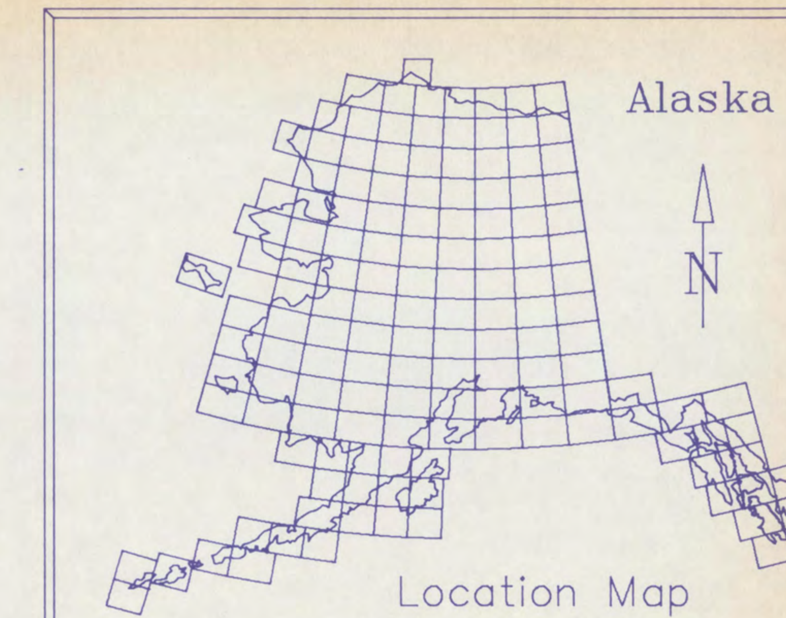
MODERATE POTENTIAL for oil ang gas discovery

LOW POTENTIAL for oil and gas discovery

REFUGE BOUNDARY

MILES 0 5 10 15 20 25 30

KILOMETERS 5 0 5 10 15 20 25



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ALASKA STATE OFFICE

Mineral Assessment

Yukon Flats Wildlife Refuge

OIL AND GAS ASSESMENT

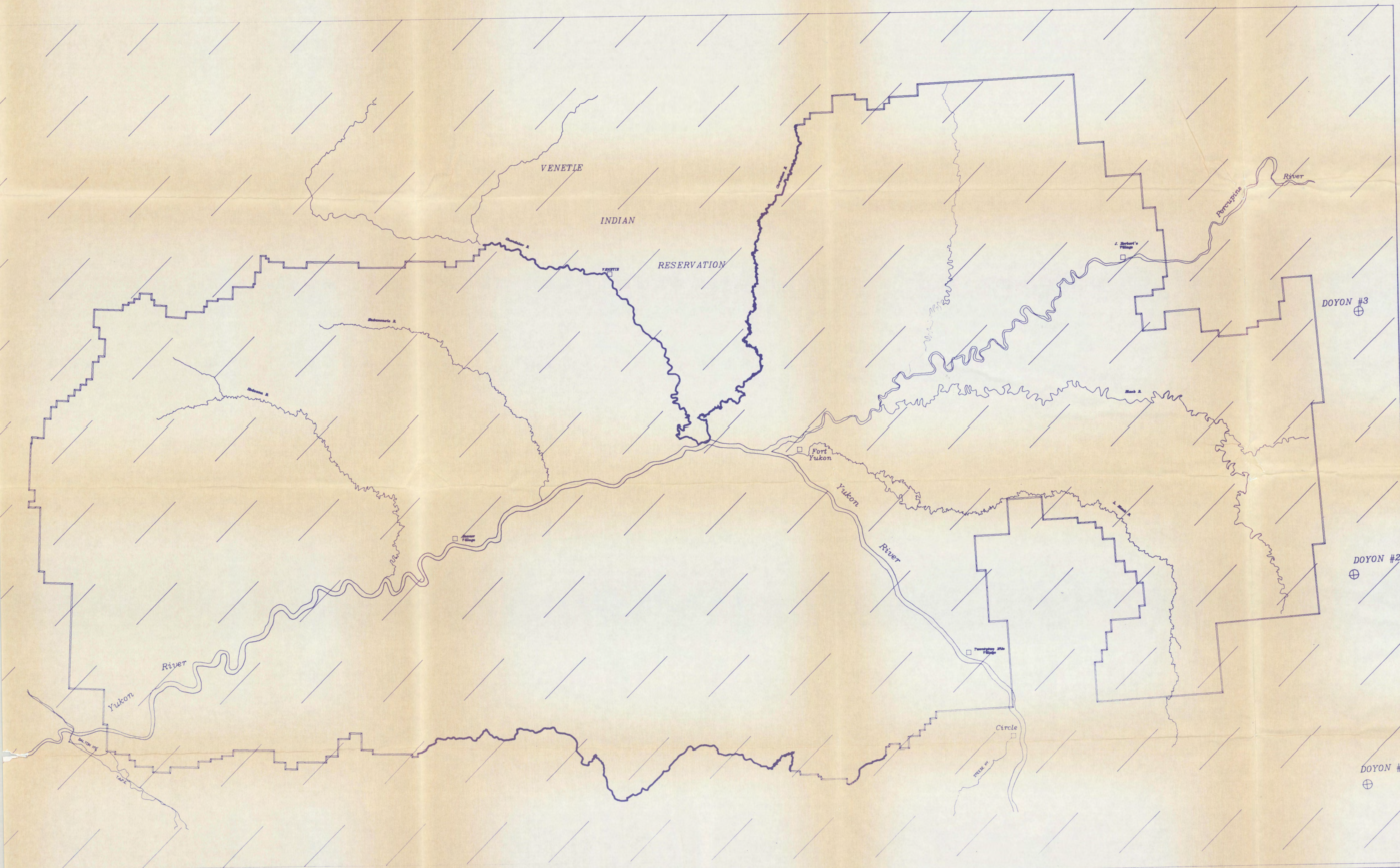
Land Status Map

Scale = 1:250,000

project manager: Mike Menge
lead geophysicist:
lead geologist: Arthur C. B
compiled by: Fred Conr
date: January,198

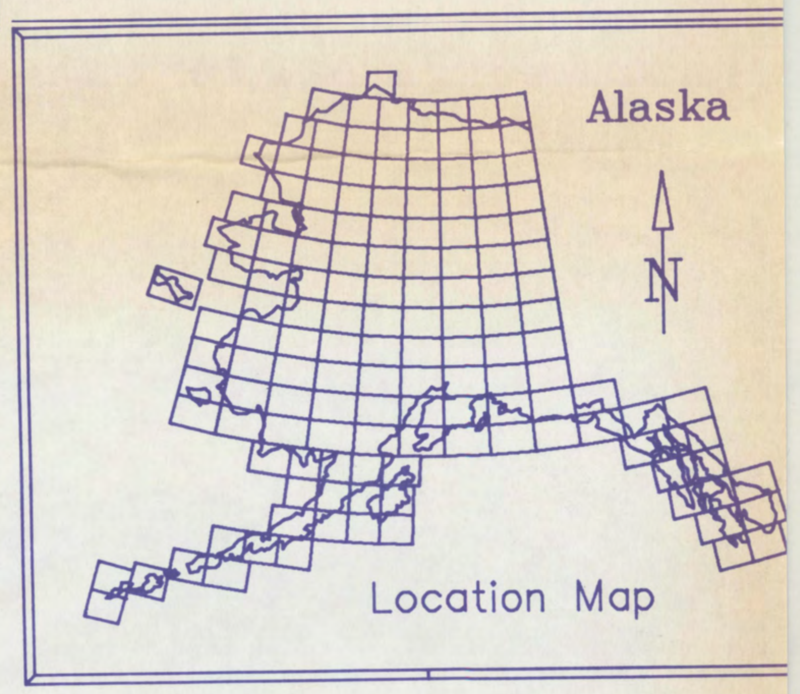
Plate 1

PLATE 9
YUKON FLATS WILDLIFE REFUGE



EXPLANATION

AREA OF LOW ECONOMIC DEVELPOMENT POTENTIAL



Department of the Interior
U.S. BUREAU OF LAND MANAGEMENT
Branch of Mineral Assessment
ALASKA STATE OFFICE

Mineral Assessm

Yukon Flats Wildlife Refuge

OIL AND GAS ASSESMENT

Land Status Map

Scale = 1:250,000

project manage
Mike Meng
lead geophysicis
lead geologist:
Arthur C. B
compiled by:
Fred Conr
date:
January,198