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GAS RESOURCES OF N.E. BRITISH COLUMBIA

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INTRODUCTION

This report contains estimates of the gas resources of northeast British Columbia with major emphasis on the undiscovered component of the resource commonly referred to as gas potential. For convenience, estimates of the discovered component, or established reserves, prepared by the British Columbia Department of Energy, Mines and Petroleum Resources are included. The study of gas resources was based on the examination of 20 exploratory plays identified within the region. During the study, the geology related to each of the plays was examined and extensive use was made of statistics related to reservoir variables, as described in Pool File computer tapes prepared by the British Columbia department.

The methodology used in the preparation of the estimates is commonly known as the probability approach. In this method, equations are established to describe the total range of possible values of the potential of any given play, considering the uncertainties that are attached to various reservoir and geological parameters that control the occurrence of oil and gas. Steps in the process include the identification of the pool size distribution and a distribution of the number of possible pools (or a distribution of the number of prospects and the risk associated with exploration). The pool size distributi describes the range of pool sizes that can be expected in a given play, dependent on the reservoir geometry, depth, pressure, temperature, porosity, hydrocarbon saturation, etc. and the relative frequency in which various pool sizes may be anticipated. Much of the information required for this component of the estimation process is contained in existing statistics of discovered pools.

The second component, the distribution of the number of possible pools is much more dependent on an analysis of the geological opportunity either shown to exist by mapping or inferred by geological judgment. A combination of the two distributions using a Monte Carlo process generated a distribution of estimates of total potential for each play, properly reflecting the combined opinion from the two estimates and their various components. Details of the probability approach are available in Report EP77-1 (1977).[1]

The present report contains a discussion of the potential gas resources, followed by a discussion of the discovered reserves plus a brief description of the geology related to each of the exploratory plays. Selected values of potential as well as established reserves for individual plays are tabulated in Appendix I and II.

[1] Oil and Natural Gas Resources of Canada, 1976; Canada, Energy, Mines and Resources Report EP77-1, pp. 61-73.

POTENTIAL GAS RESOURCES

Undiscovered gas resources of northeast British Columbia are estimated at an average expectation to be 32.1 trillion cubic feet (approximately 901 billion cubic metres). A more speculative view of the estimates suggest as much as 47 trillion cubic feet (approximately 1,325 x $10^9 m^3$) may exist at a probability level of 5%. The total range of estimates is indicated in the frequency distribution described in Figure 1. These estimates represent a significantly increased opinion from those contained in Open File Report 672 (January, 1980)*. Reasons for the improvement of the current estimates over

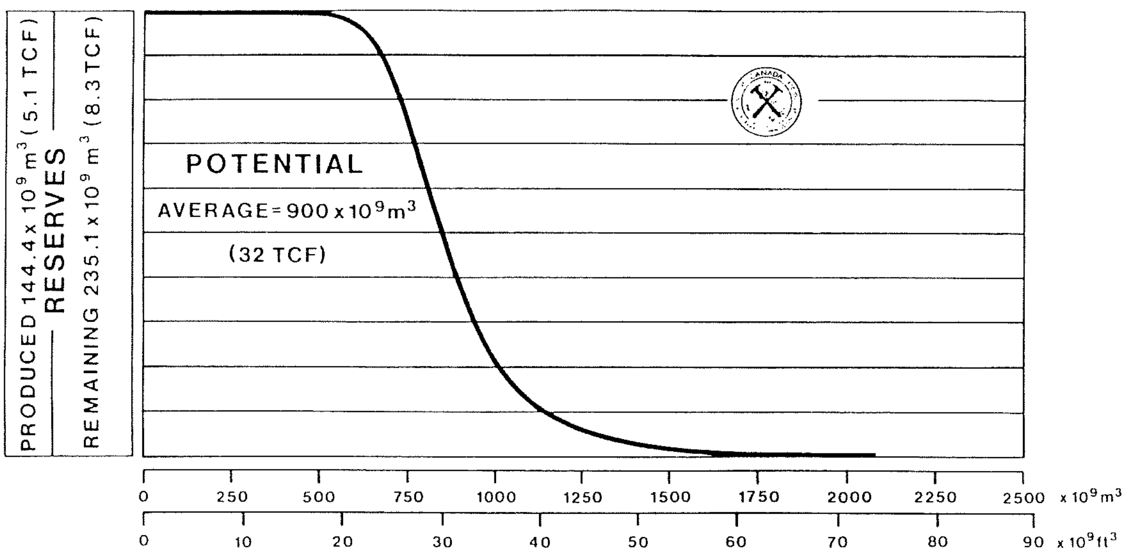

Figure 1, showing both marketable gas reserves and estimated marketable gas potential. The horizontal lines represent 10% increments in the cumulative frequency curve for the estimate of potential.

* Gas Resources of Western Canada, Procter, R.M. and McCrossan, R.G., Geological Survey of Canada, Open File Report 672, January, 1980.

previous ones include the addition of significant geological information, a greater opportunity to analyze the available data, and improvements in the methods of analysis incorporating better consideration of correlation among variables. An examination of northeastern British Columbia drilling activity to date indicates that much of the deeper part of the section is not yet evaluated and indeed plays in some parts of the region are not tested at all. Many geological concepts appear to be either unrecognized or the significance of some of the available geological evidence not fully understood.

The estimate presented in Figure 1 is based on the consideration of some 20 exploratory play concepts. As indicated in Appendix I and II, the estimates are dominated by two or three plays. The largest of these, the Foothills Belt, is thought to contain approximately one-third of the estimate. This play is still considered to be in a very immature stage of exploration with many structural anomalies untested, deeper horizons not investigated, and is an area in which the structural-stratigraphic complexities are difficult to resolve without extensive geophysics and exploratory drilling. The second most important group of plays include carbonate targets of the Middle Devonian. One of these plays, containing the Clarke Lake Field, has been the source of most of the reserves in northeast British Columbia to date. In the committee's opinion, there is still room for important additional discovery at both ends of the play, as well as significant potential in associated targets behind the barrier on the carbonate shelf to the southeast. Almost all of the existing plays in British Columbia have significant remaining potential requiring deeper drilling and exhaustive geological analysis. The success ratio is considered to be average to slightly better than average in a western Canada context.

In addition to the twenty named exploratory plays, several purely conceptual or confidential plays were considered. Although not specifically evaluated, their probable existence has contributed to the rather robust estimates listed in Appendix I and II and leads to some of the increase in the potential identified in the current estimate.

British Columbia gas resources generally tend to be sour, containing modest quantities of H_2S over most of the region, and high content in the foothills pools. Shallow plays such as the Jean Marie, Bluesky-Gething, and Bullhead plays tend to be low pressure, poor quality reservoirs with attendant low deliverability characteristics. The Foothills plays in the northern and southern ends of the belt are characterized by severe fracturing in strongly folded structures.

During the estimation procedure, consideration of pool size was a major component of the activity. Although numerous pools in the 1 TCF range were determined to be probable, the estimate implies the existence of several hundred intermediate and small size pools. This will require thousands of exploratory wells to be drilled, many in logistically difficult and expensive areas. The current level of drilling of approximately 200 exploratory wells per year, or even the historically recent 400 wells per year rate, indicates that effective exploration could continue for several decades.

GAS RESERVES

Discovered reserves of marketable gas are reported by British Columbia Department of Energy, Mines and Petroleum Resources as 13 trillion cubic feet (approximately 379.5 billion cubic metres). The remaining reserves are listed as 8.3 TCF or approximately 235.1 billion cubic metres. Produced and remaining reserves are shown graphically in Figure 1, and reserves associated with the individual plays are tabulated in Appendix I and II. In coding individual pools to plays some difficulty was encountered with the definition of the Northern Foothills play, and different analysts might arrive at somewhat different values. The general distribution of reserves, however, clearly indicates the most important play to be the Middle Devonian followed by Baldonnel and Halfway plays, with Foothills as a fourth largest category. During the assessment of undiscovered potential, it was noted that many of the pools identified in the British Columbia reserve tape have arbitrary pool area assignments, indicating in most cases single well pools. It is expected that most of these pools will, when fully delineated, contain greater reserves than those shown on the tape. This addition, by appreciation of existing reserves, has been included in the estimates of potential.

Comparison with Other Estimates

The combination of reserves and potential identified in this report can be compared to other estimates using Figure 2, which is a reproduction of Table 11-3 of the recent National Energy Board Report[1]. Using marketable gas estimates of 13.4 TCF and an average expectation of potential of 32 TCF, conversion to exajoules gives a value of approximately 43 and a speculative

[1] Canadian Energy Supply and Demand, 1980-2000, National Energy Board, June, 1981.

Table 11-3

ULTIMATE POTENTIAL ESTIMATES OF MARKETABLE NATURAL GAS CONVENTIONAL AREAS (Exajoules)

	B.C.	Alta.	Sask.	Southern Territories	Eastern Canada	Total
AERCB[1]	—	137-148	—	—	—	—
Saskatchewan	—	—	3	—	—	—
B.C.	27	—	—	—	—	—
CPA	41	165	4	2	1	213
IPAC	—	—	—	—	—	190+[2]
Consolidated	—	—	—	—	—	170
Consolidated (high)	—	—	—	—	—	200
Dome	34	168	7	4	1	214
Gulf	31	169	3	—	2	205
Imperial	26	152	3	2	1	184
NOVA	25	181	12	—	—	218
Petro-Canada	33	170	3	2	1	209
Shell	40	157	3	—	—	200
TCPL	34	141-187	3	2	1	181-227
Westcoast	26	—	—	—	—	—
NEB (base)	21	145	3	(3)	1	170
NEB (low)	19	135	3	(3)	1	158
NEB (high)	26	165	3	(3)	1	195

Gross heating values used in conversion, as required, to energy units:

British Columbia	38.5 MJ/m^3
Alberta	38.5 "
Saskatchewan	36.5 "
Southern Territories	36.5 "

(1) From AERCB Report 80-18. AERCB estimated that with higher gas prices than currently anticipated and substantial technological breakthrough, the ultimate potential of Alberta could exceed 211 EJ.
(2) IPAC's estimate of ultimate potential was stated to be in excess of 190 EJ.
(3) Southern Territories included in British Columbia total

Figure 2. Table 11-3 of National Energy Board (1981) showing estimates of ultimate potential (reserves plus undiscovered potential).

value of almost 60 exajoules. Both values would be higher than any indicated in the Figure 2 for British Columbia. This may reflect not only the fact that the present estimates are higher than most industry estimates, but that no economic discounting has been imposed in the current estimates.

GEOLOGY

The geology of northeastern British Columbia was examined, for the purpose of this report, in terms of twenty exploration plays. The basic play concepts are described below along with play numbers used in Appendix I and II.

The Middle Devonian Elk Point Group is a sequence of evaporites, carbonates and clastics over 450 metres thick in northeastern British Columbia. The Keg River Formation, the basal carbonate of the Elk Point Group, conformably overlies the Lower Devonian Chinchaga evaporites and clastics. The Pine Point-Sulphur Point reef complex developed on the Keg River carbonate bank. Muskeg evaporites were deposited in the restricted marine basin behind the main barrier; Klua shales were deposited in front of the barrier and in embayments along the reef front. Deposition of the Watt Mountain Formation (shales and clastics) terminated Pine Point-Sulphur Point reef growth. The Slave Point reef developed on top of, or in some areas overstepped, the previous reef front. The Upper Devonian Beaverhill Lake carbonates represent the last stage of carbonate deposition before a major marine transgression that deposited the Muskwa and Fort Simpson shales. Large stratigraphic traps occur along the reef margin and within the pinnacle reefs in front of the barrier reef (Play 4). The potential for stratigraphic traps exist in large patch reefs formed behind the main barrier (Play 63).

The Jean Marie Formation (Play 17) is an Upper Devonian shelf carbonate. It underlies northern Alberta and extends across northeastern British Columbia to the shelf edge, passing into deep water lime muds of the Fort Simpson Formation. The facies front of the Jean Marie Formation follows along a north-south line roughly parallel to longitude 122° W. Over much of the shelf

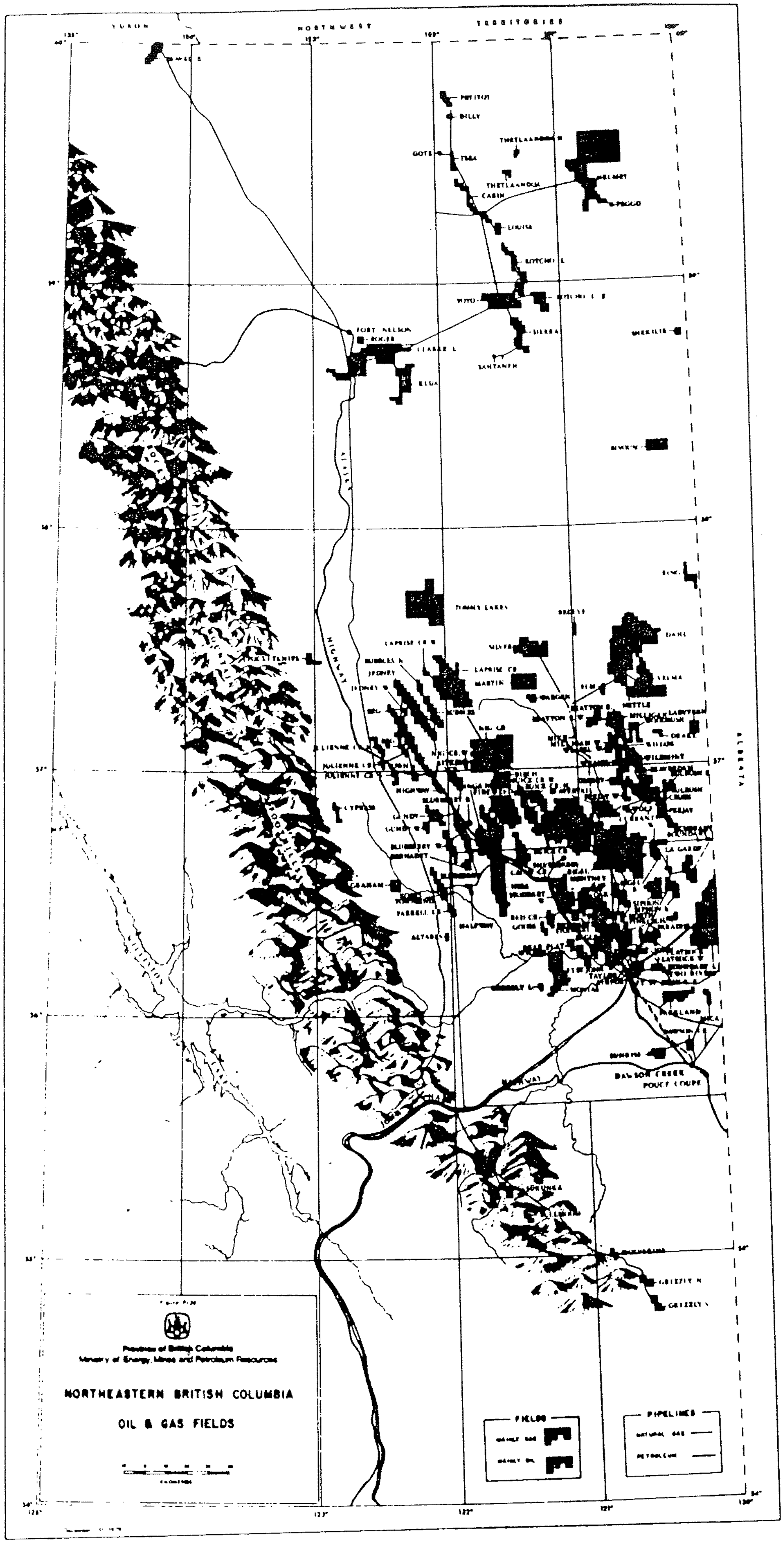

Figure 3. Index map of oil and gas pools.

the carbonate is 9 - 18 metres thick. Closer to the shelf edge, however, the formation thickens, in places to over 123 metres, and develops occasional reef-like masses composed of stromatoporoids and corals. The average porosity is low as secondary cement reduces the porosity even in some of the thickest buildups. Stratigraphic trapping is controlled by porosity distribution.

The Wabamun Group (Play 20) is the uppermost Devonian unit in the southern part of northeastern British Columbia. The Wabamun carbonates were deposited on a shallow platform bordering the Peace River Arch. The formation is predominantly carbonate in Western Alberta but becomes thicker and intertongues with the limestones and shales of the Tetcho and Kotcho formations of northern northeastern British Columbia. Stratigraphic traps are developed in porous (intercrystalline and vuggy) dolomites.

The lower Mississippian Banff Formation (Play 21) was deposited on a broad stable shelf in the northeastern plains area of British Columbia. It is a relatively thick accumulation (305 metres) of calcareous shale with very-fine to fine-grained, discontinuous, calcareous sand lenses, up to 0.6 metres thick, developed in the basal portion.

The strata overlying the Banff shale are more calcareous, being inter-bedded shales and carbonates assigned to Shunda and Pekisko Formations (Play 23). In northern Alberta and British Columbia, both formations are predominantly shale and, therefore, the separation is not always possible. Faults formed during the downwarping of the Peace River Arch in the Late Mississippian provided migration paths for fluids to locally developed porous zones. The overlying shales acted as a barrier to further fluid migration.

The Upper Debolt Formation (Play 26) is a microcrystalline to finely crystalline dolomite with minor anhydrite, micritic limestone and shale. The Debolt sediments grade westward from shelf carbonates into the Besa River Formation shales; the facies front approximately parallels longitude 123°40' W. Extensive erosion prior to deposition of the Belloy Formation truncated the westerly dipping Upper Debolt Formation throughout most of northeastern British Columbia and resulted in the peneplation of the Mississippian-Pennsylvanian sediments. Downwarping of the Peace River Arch, initiated in Late Mississippian, was accomplished by displacement along northeast and northwest trending faults resulting in horst and graben structures. These structures acted as basins of preservation for Upper Debolt strata. In addition to primary stratigraphic traps (lateral facies changes from permeable to impermeable strata), and secondary stratigraphic traps (the porous and permeable subcrop edge of the Upper Debolt pinches out against impermeable Triassic or Lower Cretaceous strata), there exists the possibility for significant reserves from structural plays (folds and fractures formed during the Laramide orogeny may have enhanced the original vuggy porosity and allowed fluid migration along faults or fractures).

The Late Mississippian-Pennsylvanian Stoddart Group conformably overlies the Debolt carbonates and consists of three formations: Golata (basal shale), Kiskatinaw (sandstone and shale), and Taylor Flat (argillaceous limestone and sandy dolomite). The Kiskatinaw Formation (Play 28) changes eastward from a basinal facies of shale, siltstone, sandstone and carbonate to a more arenaceous facies. Fragmentation of the Peace River Arch, partly contemporaneous with Stoddart deposition, was followed by extensive pre-Belloy erosion removing much of the section. Thick intervals of Kiskatinaw sandstones were preserved in grabens during the downwarping. Rocks of equivalent age are preserved in northern British Columbia called Mattson Formation (Play 29). The Mattson Formation is a deltaic complex that prograded into the Liard Basin from the northeast. Potential reservoirs are developed within the middle Mattson. Both structural traps and stratigraphic traps are conceived in this play.

The Permian Belloy Formation (Play 30) unconformably overlies the Stoddart Group and the Debolt Formation. In northeastern British Columbia the Belloy Formation is generally subdivided into three members: a basal carbonate, a middle sand, and an upper carbonate. It thickens from an erosional edge in Alberta to over 180 m. west of Fort St. John, B.C. The preserved westward thickening mimics the original depositional pattern with minor post-Belloy erosion: as the formation thickens it becomes more argillaceous. Preservation of Belloy rocks within rejuvenated grabens record up to 90 metres of differential displacement.

In early Triassic, the western sea transgressed over the stable shelf depositing silty, argillaceous sediments of the Montney Formation (Play 31). Porous coquina banks trending in a northeasterly direction occur within the upper part of the Montney Formation. The banks, up to 36 metres thick, are composed of dolomitized and fragmented brachiopod-pelecypod shells. Average thickness of the banks is 3 metres with the thicker sections occurring in the south. Although the coquina banks are stratigraphic traps, their location was controlled along paleostructural highs. The Middle Triassic Doig Formation (also included in Play 31) overlies the Montney Formation and consists of argillaceous to arenaceous siltstones and calcareous shales with thin beds of very fine-grained sandstones.

The Middle Triassic Halfway Formation (Play 33) was deposited on the undulating erosional surface of the Doig Formation. The Halfway Formation consists of medium to fine-grained sandstone with coquina beds. The coquina banks are composed of dolimitized pelecypod shells and are associated with discontinuous northwest trending sand bars up to 12 metres thick, formed parallel with the eastern shoreline. In the western part of the area, an increase in interstitial clay content and diagenetic cementation limits porous lenses within the Halfway Formation. In addition to stratigraphic traps, structural traps (long, narrow en echelon Laramide folds or traps associated with the rejuvenation of faults related to the collapse of the Peace River Arch) are present.

The Upper Triassic Boundary Lake Member (Play 34), of the Charlie Lake Formation, is a stromatolitic limestone and dolomite contained within the eastern evaporitic facies. The distribution of this member is controlled by erosion to the east, and facies change to calcareous or dolomitic siltstone to the west. Intergranular and vuggy porosity is associated with the coarsely crystalline skeletal material. The trapping mechanism in the Boundary Lake Field is a combination of differential erosion and structure.

The Triassic Charlie Lake Formation (Play 35) conformably overlies the Halfway Formation. Thickness varies from an erosional edge in Alberta to over 425 metres in British Columbia. The lithology of the formation is complex. Deposition over the entire area was relatively continuous during early Charlie Lake time. Significant depositional irregularities caused local restrictions resulting in the deposition of evaporites. Sea level fluctuations throughout Charlie Lake time are reflected by numerous diastems recorded by numerous thin sandstone beds (Play 35) within the formation. Erosion during a widespread regression in mid-Charlie Lake time (the Coplin unconformity) removed much of the previously deposited strata. Shallow, restricted marine conditions returned in upper Charlie Lake time resulting in the deposition of interbedded dolomite, anhydrite and siltstone. The anhydrites enclosing the Boundary Lake member were deposited during this period. Lateral variation in facies from permeable to impermeable strata, or the pinchout of Lower Charlie Lake sands against the Coplin unconformity form the stratigraphic traps. Structural traps are associated with the Laramide episode of folding.

The Upper Triassic Baldonnel Formation (Play 36) conformably overlies the Charlie Lake Formation and is composed of alternating bioclastic and micritic carbonates. It thickens from an eastern erosional edge to over 90 metres in the west. In the disturbed belt of northeastern British Columbia, the Baldonnel Formation changes to a basinal facies of siltstone, shale and limestone where the play includes overlying Pardonet Formation. Porosity is developed by dolomitization of the bioclastic material and leaching of the skeletal components within the microcrystalline matrix.

Jurassic time saw the initiation of major tectonic changes resulting from the collage of exotic allochthonous terrane with the North American miogeocline. Debris shed from the rising Rocky Mountains created the Jura-Cretaceous clastic wedges of northeastern B.C. The sediments of the Cadomin, Gething and Bluesky Formations (Play 43) were derived from this western source area which was uplifted by a pulse of the Columbia orogeny. The coarseness, thickness and distribution of the Cadomin and Gething Formations indicate that a deltaic-alluvial plain complex was developed along the western edge of a mid-continent basin. The Bluesky Formation was deposited during a southward transgression of the boreal sea. The clean porous sands of the Bluesky Formation are partly the result of this advance and consequent winnowing of original deltaic sediments. Traps are stratigraphic or combined structural-stratigraphic in clean, porous sandstones in part due to reworking of sands over positive features on the pre-Cadomin erosional surface. Play 44 refers to more proximal facies of the Bullhead plus the underlying Minnes Group.

The Elmworth-Falher (Play 45) is an extension of the Albertan Elmworth-Deep Basin play into northeastern British Columbia. Although several potential gas-bearing horizons exist in this play, attention is focussed on the deltaic sandstones and conglomerates of the Falher formation.

The Lower Cretaceous Peace River Formation is subdivided into three members: the Harmon shale overlain by sandstones of the Cadotte and Paddy members (Play 47) The Cadotte Member, considered to be the equivalent of the Viking Formation in central Alberta, is a fine-grained, marine sandstone with minor sandstone with minor shale and thin coal beds. The Peace River Formation represents one of the large fluvial-deltaic complexes which prograded into the late Cretaceous boreal sea. Both the marine Cadotte and the non-marine Paddy members are gas reservoirs. Structural traps within the Peace River Formation are the result of differential compaction and the reactivation of the pre-existing fault system.

The British Columbia foothills (Play 55) are essentially a 740 km north-westerly extension of the Alberta foothills and can be loosely defined as that part of the eastern slope of the Rockies underlain by Mesozoic or Tertiary sediments. Although complicated by an overlapping of structural configurations associated with the Peace River Arch in the central section and the Mackenzie Mountains in the north, the eastern margin of the foothills in British Columbia is considered to be the most easterly zone of folded and faulted Triassic strata. The foothills play is dominated by tectonically induced closed structures. The southern segment of the British Columbia foothills from the British Columbia-Alberta border to the Peace River is structurally and stratigraphically similar to the northern Alberta foothills (i.e. a tectonic style dominated by horizontal foreshortening by thrust faults). The tectonic style changes in the central segment (from the Peace River to latitude 57°30' N.)

to an apparently more vertical and anticlinal type of deformation dominated by folding and blind thrusting. The northern segment (from latitude 57°30' N. to the British Columbia-Yukon border) is similar to the central segment (i.e. folds predominate over thrusts or vertical displacement predominates over horizontal), however, the symmetry of the structures is reversed.

APPENDIX I

BRITISH COLUMBIA GAS RESOURCES

(Units of: Billion Cubic Metres)

PLAY NO.	PLAY NAME	RESERVES*		POTENTIAL** (APPRECIATION ADDED)	
		ULTIMATE	REMAINING	MEAN	5 %
4	Middle Devonian (Barrier & Pinnacle)	128.8	63.6	91.8	161.2
17	Jean Marie	2.2	2.1	36.6	57.4
20	Wabamun	5.0	2.6	4.0	10.2
21	Banff Sand & Clarks Mbr.	.1	.1	0.6	1.3
23	Pekisko/Shunda	.5	.5	1.0	6.5
26	Upper Debolt	12.0	10.1	39.0	65.0
28	Stoddart	2.5	2.4	29.7	49.0
29	Mattson	.7	.7	32.7	95.1
30	Belloy	15.2	6.4	36.1	61.8
31	Montney-Coquina & Doig	1.8	1.7	33.3	48.4
33	Halfway	74.1	55.5	66.7	98.3
34	Boundary Lake	4.5	1.2	4.5	10.7
35	Charlie Lake Stray Sand	10.6	6.0	14.1	22.4
36	Baldonnel	97.0	62.7	15.8	35.7
43	Bluesky-Gething	25.6	21.0	31.2	45.9
44	Bullhead Group	42.1	21.1	52.3	73.6
45	Elmworth-Falher	Nil	Nil	9.4	25.7
47	Paddy-Cadotte	1.4	1.2	5.7	8.9
55	Northern Foothills	38.6	29.5	324.0	741.4
63	Middle Devonian (Patch Reef)	Nil	Nil	72.2	136.0
	TOTALS - Raw	462.6	288.3		
	- Marketable	378.7	234.9	900.6	1325.0***

* NOTE: Raw gas reserves data from B.C. Energy, Mines & Petroleum Resources Reserves File (December 31, 1980).

** NOTE: Marketable gas potential.

*** NOTE: Sum of potentials at 5% probabilistic (not algebraic).

APPENDIX II

BRITISH COLUMBIA GAS RESOURCES

(T.C.F.)

PLAY NO.	PLAY NAME	ESTABLISHED RESERVES* INITIAL	ESTABLISHED RESERVES* REMAINING	POTENTIAL** (& APPRECIATION) MEAN	POTENTIAL** (& APPRECIATION) 5%
4	Middle Devonian	4.517	2.206	3.277	5.757
17	Jean Marie	0.077	0.075	1.308	2.053
20	Wabamun	0.178	0.091	0.142	0.362
21	Banff Sand & Clarks Mbr.	0.004	0.003	0.019	0.046
23	Pekisko/Shunda	0.017	0.017	0.036	0.231
26	Upper Debolt	0.424	0.358	1.391	2.323
28	Stoddart	0.087	0.085	1.060	1.749
29	Mattson	0.026	0.024	1.159	3.375
30	Belloy	0.540	0.227	1.290	2.207
31	Montney-Coquina & Doig	0.062	0.061	1.189	1.728
33	Halfway	2.631	1.970	2.382	3.510
34	Boundary Lake	0.241	0.094	0.159	0.381
35	Charlie Lake Stray Sand	0.377	0.213	0.505	0.800
36	Baldonnel	3.443	2.226	0.562	1.267
43	Bluesky-Gething	0.908	0.747	1.113	1.637
44	Bullhead	1.495	0.749	1.869	2.627
45	Elmworth-Falher	Nil	Nil	0.334	0.913
47	Paddy-Cadotte	0.050	0.042	0.202	0.314
55	Northern Foothills	1.369	1.046	11.570	26.480
63	Middle Devonian (Patch Reef)	Nil	Nil	2.579	4.857
	TOTALS - Raw	16.419	10.234		
	- Marketable	13.442	8.336	32.131	47.030***

* NOTE: Raw gas reserves data from B.C. Energy, Mines & Petroleum Resources Reserves File (December 31, 1980).

** NOTE: Marketable gas potential.

*** NOTE: Sum of potentials at 5% is probabilistic (not algebraic).