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Ministry of Energy, Mines and
Petroleum Resources
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SEDIMENTOLOGY AND PETROLEUM GEOLOGY OF THE ARTEX MEMBER (CHARLIE LAKE FORMATION), NORTHEASTERN BRITISH COLUMBIA

By R. Higgs

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SEDIMENTOLOGY AND PETROLEUM GEOLOGY OF THE ARTEX MEMBER (CHARLIE LAKE FORMATION), NORTHEASTERN BRITISH COLUMBIA

by
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for

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CONTENTS

ABSTRACT

The Artex Member hosts several known oil and gas pools, including the recently discovered Brassey oilfield with estimated reserves of approximately 20 million barrels. A regional study of the Artex, based on cores and well logs, has been conducted to assist future exploration and development.

In the west half of the study area, the Artex shows abrupt lateral thickness changes (e.g., 5 m decreasing to 1 m in less than 2 km). Thick areas correspond to aeolian dunes, whereas laterally adjacent muddy sediment *between* the dunes was deposited *after* the dunes, in a lagoon formed by marine flooding of the (coastal) dune field due to breaching of a coastal sand barrier to the west. Flooding caused partial submergence of the Artex dunes. Prior to flooding, interdune areas accumulated halite, precipitated in a salina fed by sea water percolating laterally through the coastal barrier. Dissolution of the halite after burial accounts for the present-day thickness deficiency of interdune areas.

Hydrocarbons are stratigraphically trapped in individual dunes, sealed laterally and vertically by lagoonal mudstones. Subsurface mapping suggests that dunes occur as parallel strings oriented NNW-SSE; exploration potential therefore exists along these trends. Some dunes appear wet on wireline logs, but may contain hydrocarbons updip. Other dunes (e.g., Brassey field) are hydrocarbon-bearing throughout. Discovery and development of further Artex pools will be optimized by integrating subsurface mapping and sedimentology. In addition, refined seismic techniques may be able to locate Artex dunes directly.

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LIST OF CROSS-SECTIONS

Regional cross-sections: A, B and C (northwest-southeast)
D, E and F (southwest-northeast)

Detailed cross-sections: G (north-south)
H and I (west-east)
J and K (southwest-northeast)

LIST OF MAPS

Each map is on two sheets (north and south halves), at 1:125,000 scale.

LIST OF FIGURES

INTRODUCTION

The Artex Member attracted industry-wide attention with the discovery of Brassey oilfield by Canadian Hunter Exploration Limited in 1987 (Lyon, 1988; Klein and Woofter, 1989). One well had an initial productive capability of 2,500 barrels of light oil per day, and field reserves were estimated to be at least 20 million barrels (Lyon, 1988). The Artex is also hydrocarbon-bearing at Stoddart West (oil and gas), and at Buick Creek, Monias and Wilder (gas) (Fig. 1). Although the reservoir is thin (1 to 4 m), this is compensated by high productivity (Lyon, 1988; Klein and Woofter, 1989), and by relatively shallow depth over much of the study area.

This report is based on a 3-month regional study of Artex sedimentology and petroleum geology, aimed at determining depositional environments and paleogeography, in order to elucidate reservoir distribution and geometry, and to assist the explorationist in finding and developing additional Artex pools.

The study area is mainly within the Peace River Block of northeastern British Columbia (Twp. 77-88, Rge. 13-26W6; Fig. 1) and parts of the contiguous regions to the south, west and north, namely NTS areas 93-P-5 through 93-P-13, 94-A-4 and 5, and 94-A-9 through 16. The north and south limits of the study area were chosen to embrace all known hydrocarbon accumulations in the Artex Member, from Buick Creek in the north to Brassey in the south (Fig. 1).

Geological setting

The Artex Member belongs to the lower part of the Charlie Lake Formation, of late Triassic age (Fig. 2). The Charlie Lake in the report area consists of up to 400 m of fine siliciclastics, carbonates and evaporites, interpreted as partly or largely supratidal deposits of an arid salt flat, or sabkha (Roy, 1972; Campbell and Horne, 1986; Cant, 1986; Podruski *et al.*, 1988; Gibson and Barclay, 1990; Gibson, in press). The plate-tectonic setting was a low-relief, west-facing passive continental margin (Podruski *et al.*, 1988). Subrounded, frosted sand grains are common in the Charlie Lake (Barss *et al.*, 1964; Roy, 1972), suggesting some aeolian deposition (Barss *et al.*, 1964). The various lithologies of the Charlie Lake are interbedded on a decimetre-to-metre scale; they possibly comprise transgressive-regressive (shallowing-upward) cycles, similar to other modern and ancient sabkha deposits (see Kendall, 1984; Schreiber, 1986 and references therein). Indeed, shallowing-upward cycles have been recognized in part of the Charlie Lake (Roy, 1972).

Underlying the Charlie Lake is the Halfway Formation, a regressive blanket sandstone deposited as part of a west-prograding beach face (Campbell and Horne, 1986; Cant, 1986). The contact between the Charlie Lake and Halfway Formations is generally thought to be conformable (Hunt and Ratcliffe, 1959, and many subsequent authors). However, an unconformity has recently been inferred between the two formations by Campbell *et al.*, (1989), and its presence is supported in the present study by evidence for onlap of Charlie Lake marker beds onto the Halfway Formation, implying subtle erosional relief at the top of the Halfway (Fig. 3; see also "onlap" annotations on Cross-Sections H and I).

Conformably overlying the Charlie Lake is the Baldonnel Formation, which consists in the report area of shallowing-upward, subtidal to supratidal carbonate cycles (Bever and McIlreath, 1984; see also Barss and Montandon, 1981).

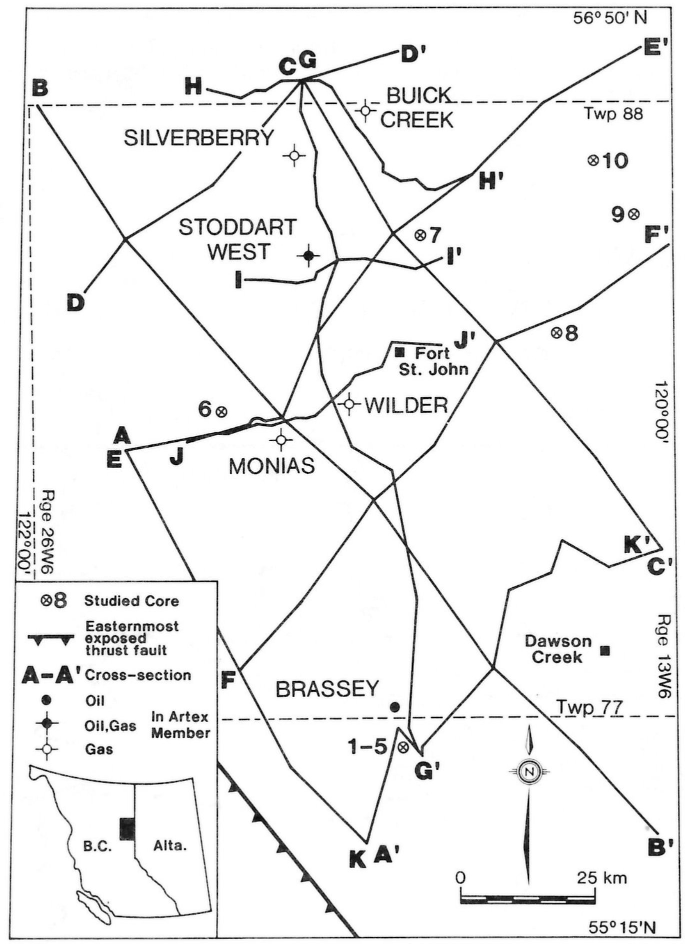


Figure 1. Map of the study area, showing location of cross-sections, studied cores, and Artex hydrocarbon occurrences. Area within the dashed lines is the "Peace River block". Easternmost Cordilleran thrust fault is shown (from Law, 1981).

The Charlie Lake Formation shows lateral facies changes, first recognized by Armitage (1962, his Fig. 8). For example, in the central part of the study area, the basal 20 m of the Charlie Lake consists of interbedded mudstones, evaporites and sandstones, capped by the Artex Member. Traced westward, this 20 m package grades into a continuous sandstone sequence (Fig. 4). The sandstone sequence is contiguous with the underlying Halfway Formation, and the (unconformable) contact is unrecognizable on wireline logs. Consequently, the sandstone is commonly assigned to the Halfway Formation. To add to this confusion, in Monias field, east of the continuous sandstone sequence, the interval concerned contains three sand units generally known as the Halfway "A", "B" and "C" sands (Fig. 4). The uppermost ("A") sand is correlative with the Artex Member (Fig. 4). Due to the lateral (westward) mergence into continuous sandstone, the Artex is indistinguishable in the west, as noted on enclosed Maps 1 to 4.

Lateral facies changes in the Charlie Lake Formation also occur at a larger scale. West of the study area, deeper water correlatives of the Charlie Lake crop out in the westernmost foothills of the Rocky Mountains. There, carbonates, siliciclastics and coquinas characterize the Ludington Formation, of marine-shelf origin (Thompson, 1989; Gibson, in press). It should be noted that the

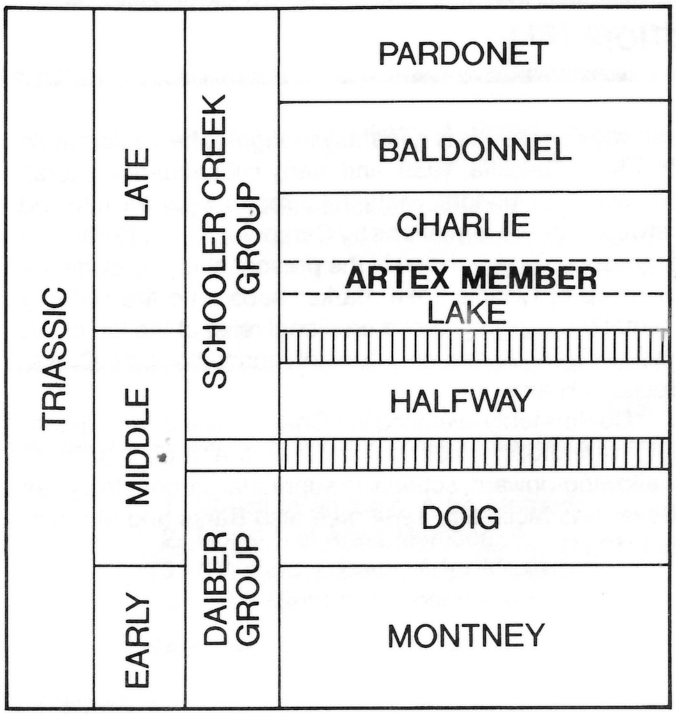


Figure 2. Table of Triassic formations, Peace River area subsurface, northeast British Columbia (after Stewart, 1984 and AGAT, 1988).

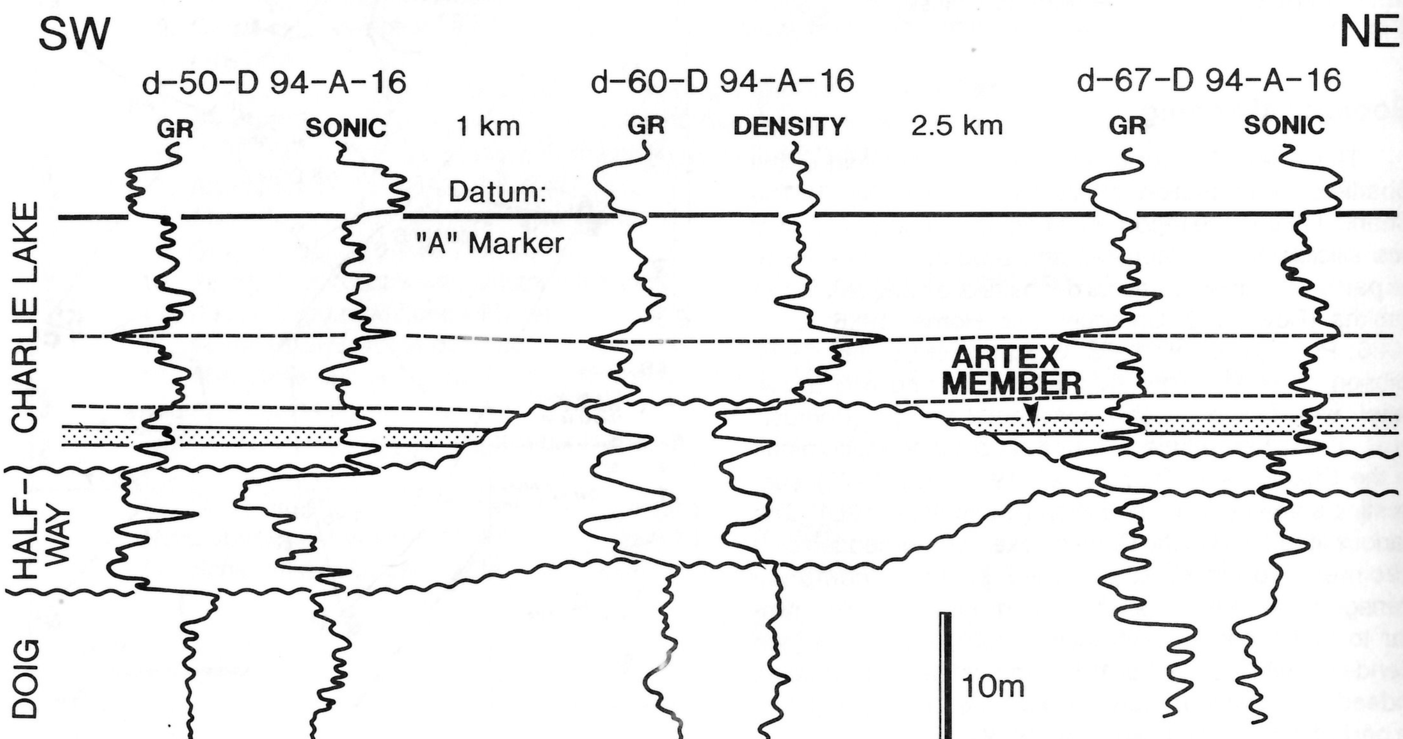


Figure 3. Mechanical-log cross-section in the Peejay area (northeasternmost part of study area), illustrating onlap of Charlie Lake Formation markers (including the Artex Member) onto the Halfway Formation. This onlapping relationship implies that the top of the Halfway is an erosional unconformity. See also Cross-Sections H and I.

Ludington Formation restores palinspastically to an original location farther west, relative to the study area, after accounting for tectonic shortening on folds and thrusts in the foothills (see thrust fault in Fig. 1).

In terms of regional paleogeography, the east-to-west facies change described above, from anhydritic deposits, through a continuous sandstone sequence (Fig. 4), to the Ludington Formation suggests a lateral transition from an evaporitic plain (sabkha or salina), through a coastal (barrier?) sand belt, to a marine shelf. Within this overall paleogeographic framework, facies belts may have oscillated slightly with time, possibly reflecting cyclic transgressions and regressions due to fluctuations of eustatic sea level (cf. Goodwin and Anderson, 1985).

Formal definition of the Artex Member

The name "Artex Member" was first published by Stewart (1984), but has never been formally proposed. Formal definition is now desirable, in view of the importance of the Artex as a hydrocarbon reservoir, as exemplified by the recently discovered Brassey oilfield. Following McAdam and Rowling (1990), the Artex Member is here defined as a distinct sandstone (passing laterally into mudstone) unit in the lower Charlie Lake Formation.

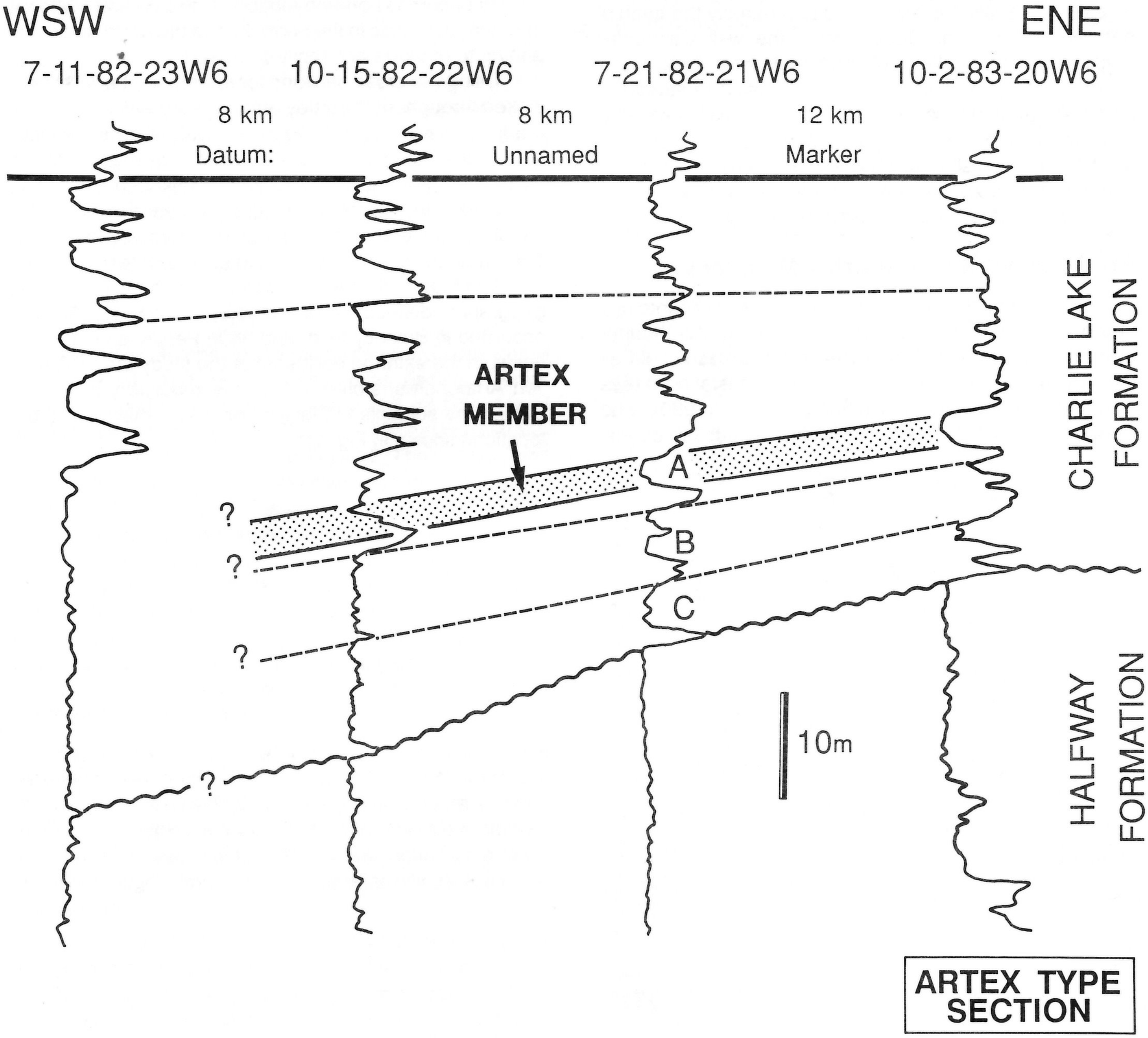


Figure 4. Gamma-log cross-section in the Monias area (Fig. 1), illustrating lateral facies change in the Charlie Lake Formation. Below the Artex Member, interbedded sandstones, mudstones and evaporites in the east pass westward into a continuous sandstone sequence. See also Cross-Section J. The well 10-2-83-20W6 (right-hand side) is the type section of the Artex Member. The letters A, B and C denote the so-called Halfway A, B and C sands.

The name is an anagram of "extra", devised by R. Stewart, formerly of the British Columbia Ministry of Energy, Mines and Petroleum Resources. Although this name is non-geographic, contravening standard stratigraphic practice, it is retained here in view of widespread industry usage. The type section is the well Baay *et al.*, Wilder 10-2-83-20W6 (Baay *et al.*, 1979), between 1478 and 1481 m, corresponding to a prominent, clean (i.e., low gamma), high-porosity interval on well logs (Cross-Section J, Well 39; McAdam and Rowling, 1990). The lithology of the type section is fine grained sandstone, as interpreted from ditch cuttings described by Baay *et al.*, (1979) and archived at the B.C. government core-storage facility in Charlie Lake. A reference section is also proposed, namely the interval between 3036.0 and 3039.5 m in the well Canhunter Brassey d-93-C/93-P-10 (Canadian Hunter Exploration Limited, 1988), consisting of cross-stratified to structureless fine sandstone in core (stored in Charlie Lake) The Artex Member occurs throughout the Peace River Block of northeastern British Columbia. Traced laterally by correlation of well logs, the Artex Member varies in thickness (up to 6 m) and in lithology (sandstone to mudstone).

Previous work on the Artex Member

The only published information on the sedimentology of the Artex are two abstracts, one by Klein and Woofter (1989), who interpreted the Artex in the Brassey field as aeolian sandstone deposited on an arid coastal plain (see also Lyon, 1988), and the other by Higgs (1990), who likewise interpreted Artex sand bodies as aeolian dunes.

Scope and methods of the present study

Two suites of cross-sections were constructed, one with large well-spacings (Cross-Sections A-F) and the other closely spaced to enable detailed study of lateral facies changes (Cross-Sections G-K). All cross-sections are stratigraphic, hung on the Charlie Lake "A" marker (McAdam, 1979). The Artex was then correlated throughout the grid of cross-sections. This exercise required caution to avoid misidentification of the Artex Member due to mis-correlation of log markers; for example, two anhydrite markers occur below the Artex in 2-12-82-20W6 (Cross-Section G, Well 40), but the upper marker becomes non-anhydritic in the south and the lower one non-anhydritic in the north; hence the north and south anhydrite markers are easily confused.

Using the cross-sections for reference, the Artex was picked throughout the study area in every well of sufficient depth, a total of some 1700 wells. (Data sheets are available for reference at the Petroleum Geology Branch, Ministry of Energy, Mines and Petroleum Resources, Victoria.) Picks were then used to generate maps showing Artex structure, isopach, net sand, and net porous sand (Maps 1-4). In addition, Artex cores and drill-stem tests are indicated on Map 4. A total of 99 wells cored the Artex, but the geographic distribution of the cores is uneven, 25 cores occurring in Brassey field, and 38 in Peejay and adjacent fields, in the extreme northeast of the study area (Map 4). Ten Artex cores, stored at the core repository in Charlie Lake, were subjected to facies analysis in this study (core locations shown in Fig. 1).

Introduction

The Artex Member thins regionally from about 3-5 m in the SW to about 1 m in the NE (Map 2). In detail, however, thickness values show considerable scatter; rapid lateral thickness changes are typical (Fig. 5). The Artex is missing in part of Block L 94-A-9 and Block D 94-A-16, in the extreme northeast of the study area (Map 2), where the Artex apparently laps onto a high on the Halfway Formation erosional surface (Fig. 3).

Facies

In a gross sense, the Artex grades laterally from sandstone in the west to mudstone in the east (Figs. 6 and 7; Cross-Sections A to K). Two facies belts are recognized, based on well logs and cores: a western belt of sandstone bodies with intervening areas of sandy mudstone; and an eastern belt of mudstone (Fig. 7). The facies belts are described and interpreted below.

Western sand belt

The Artex Member in this region consists of patches of thick (2-5 m) sandstone designated as Facies 1, interspersed laterally with areas of thin (ca. 1 m) bioturbated sandy mudstone assigned to Facies 2. The patchy distribution of sandstone is reflected in Figure 7. The western limit of the sandstone belt is uncertain because the Artex becomes indistinguishable westward, as described earlier.

The sandstone is commonly stained black by dead oil; staining can be speckled or pervasive (Fig. 8). Thin sections suggest that speckled staining reflects spotty development of secondary, granomoldic porosity in an otherwise tightly cemented sandstone. The sandstone is quartz-rich and consequently has a low gamma-ray signal. Two sandstone subfacies are recognized: cross-stratified sandstone and massive sandstone.

Facies 1A: Cross-stratified sandstone. This facies consists of well sorted, fine grained, quartzose sandstone forming units up to at least 2 m thick (Fig. 8; Core 1 in Fig. 9). Foreset laminae are 1-15 mm thick, inversely graded, and dip at angles up to 30°. No set boundaries were observed, suggesting that sets are relatively thick (i.e., at least 2 m in Core 1).

Facies 1B: Massive sandstone. This facies consists of fine grained sandstone in units up to at least 3 m thick (e.g., Fig. 8; Core 3 in Fig.9). The sandstone is generally massive (i.e., structureless), except for intervals of vertically-climbing symmetrical-ripple lamination (Figs. 8A, C). Ripple-laminated intervals are up to 5 cm thick, and are separated by massive intervals up to 50 cm thick. Ripple lamination is conspicuous because the ripple-form laminae are tightly cemented and therefore non-stained. In some cases the ripple lamination is slightly deformed.

Facies 2: Bioturbated sandy mudstone. Facies 2 occurs between Facies 1 sand patches. Facies 2 is characterized by intermediate gamma-log values (Cross-Sections A-K) and consists of grey sandy mudstone to muddy sandstone (Cores 2, 5 and 7, Fig. 9). The rock consists of mudstone with laminae, 1 to 20 mm thick, of silt and very fine sand. The laminae comprise 30-90% of the rock volume. Bioturbation is moderate to intense, produc-

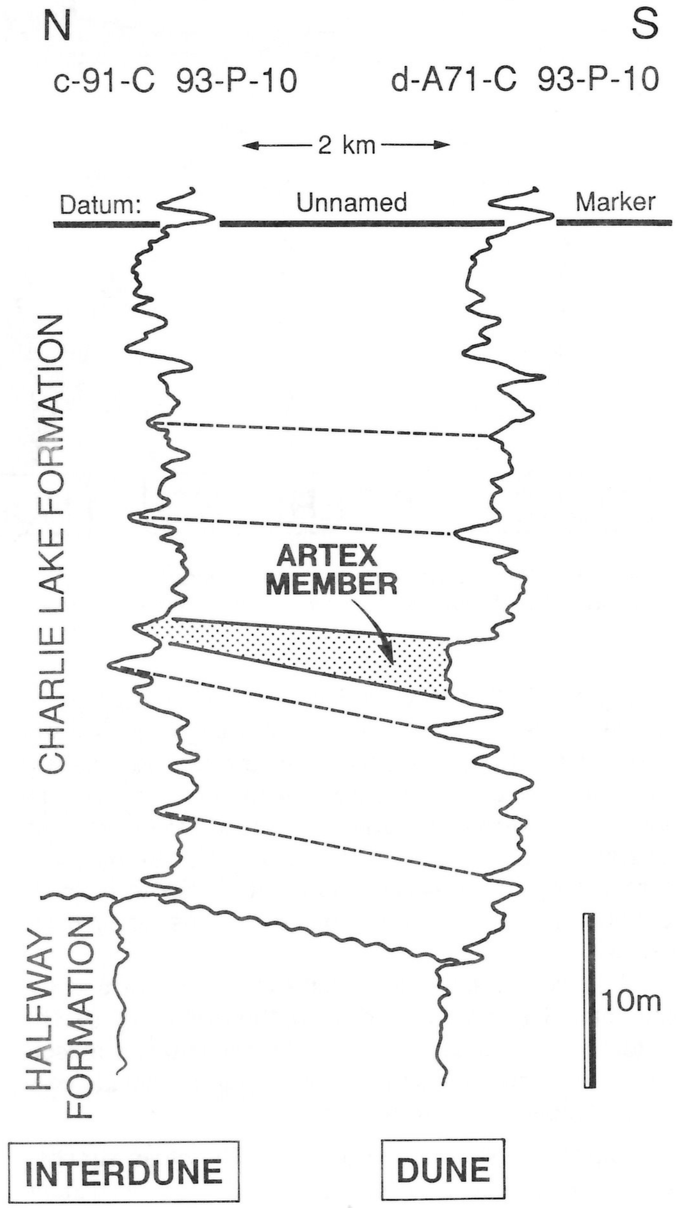


Figure 5. Gamma-log cross-section showing abrupt lateral thinning of the Artex Member in the Brassey field. In contrast, no thinning is evident in strata above and below the Artex, as shown by the dashed markers.

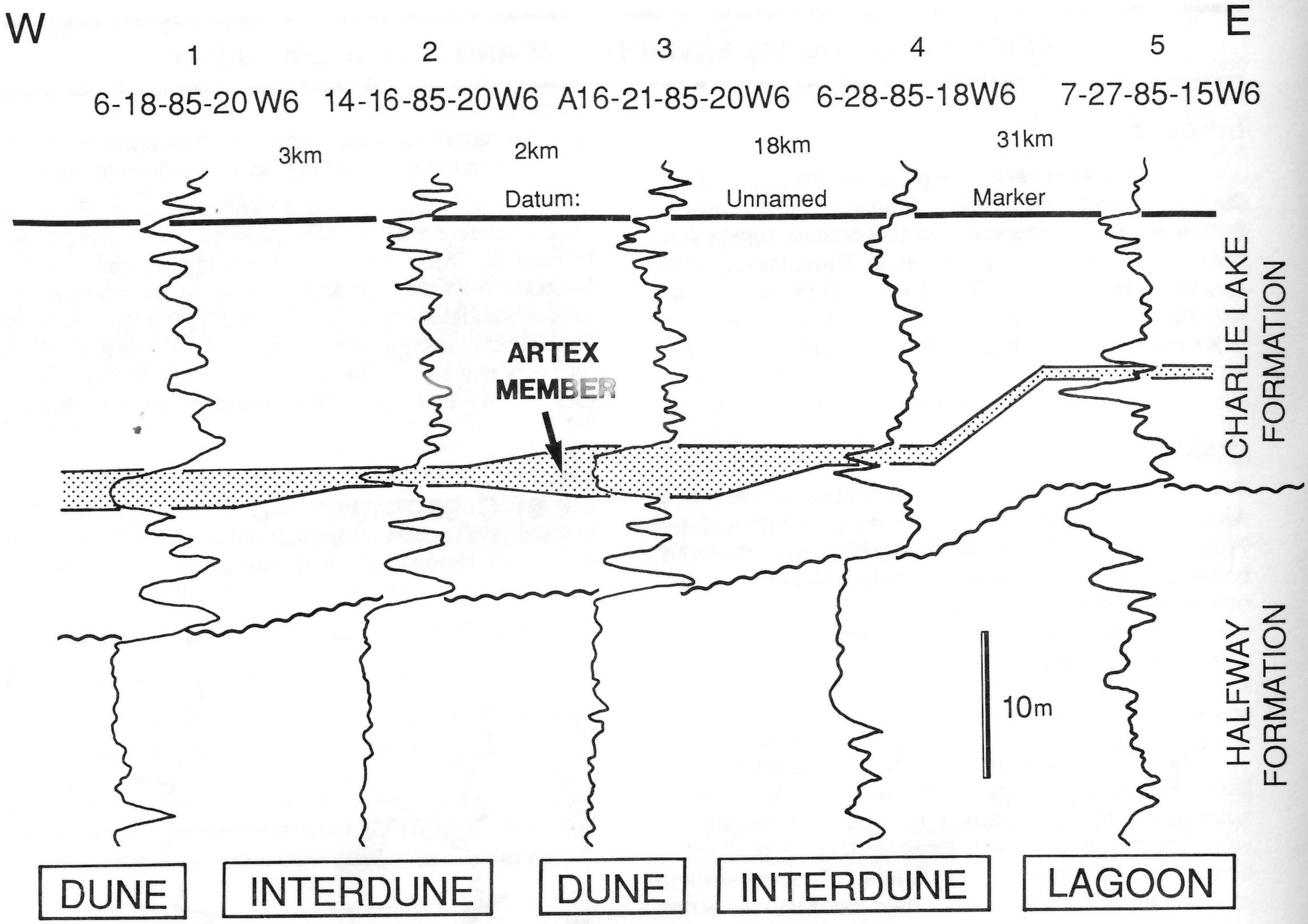


Figure 6. Gamma-log cross-section to illustrate lateral facies changes in the Artex Member. Thick dune sand occurs in Wells 1 and 3, separated by lagoonal-interdune deposits (Wells 2 and 4). The dune field passes eastward into lagoonal silty mud (Well 5).

ing burrow-mottled silty mudstone, sandy mudstone or muddy sandstone (Figs. 10, 13). Although laminae are largely obscured by burrowing, some are seen to consist of connected ripples, in some cases with bidirectional cross-lamination. Burrows include an unlined, *Planolites*-like, horizontal ichnospecies 1-5 mm across, with an ellipsoidal (compacted) cross-section and a silt fill. Some intervals contain irregular to elliptical pyrite nodules up to 5 cm across.

A lithology identical to Facies 2 dominates the succession immediately *above* and *below* the Artex (Fig. 9). The fluctuating gamma-log response in these intervals reflects vertical fluctuations in sand content. Colours include grey, red, and mottled grey-red-green.

Interpretation of Facies 1 and 2. The cross-stratified sandstone of Facies 1A is interpreted as aeolian dune sand, based on the following combination of features: large-scale cross-stratification; lack of burrows and fossils; good sorting; and close lateral and vertical association with evaporites and red beds (see below). An aeolian origin was likewise proposed by Klein and Woofter (1989). The inversely graded laminae may be due to migration of wind ripples along dune slip-faces (Langford and Chan, 1989). The inferred dunes probably belonged to a coastal dune field rather than an inland desert, given the proximity of coeval (Ludington Formation) marine strata west of the study area.

In the massive sandstone of Facies 1B, the lack of sedimentary structures may be secondary in some cases, due to the development of pervasive secondary porosity. In other cases, the lack of structure could be primary, resulting from rapid deposition; there are two possible mechanisms, both involving deposition in a standing body of water: 1) slumping of dune flanks as a result of undercutting by an interdune water body. Similar slumping of modern dunes has been described by Ahlbrandt and Fryberger (1981, Fig. 2D) and by Langford (1989); and 2) grain-by-grain settling through the water column of sand blown from adjacent dunes during wind-storms. Both models imply that the dunes were initially higher than the present thick-

ARTEX NET SAND

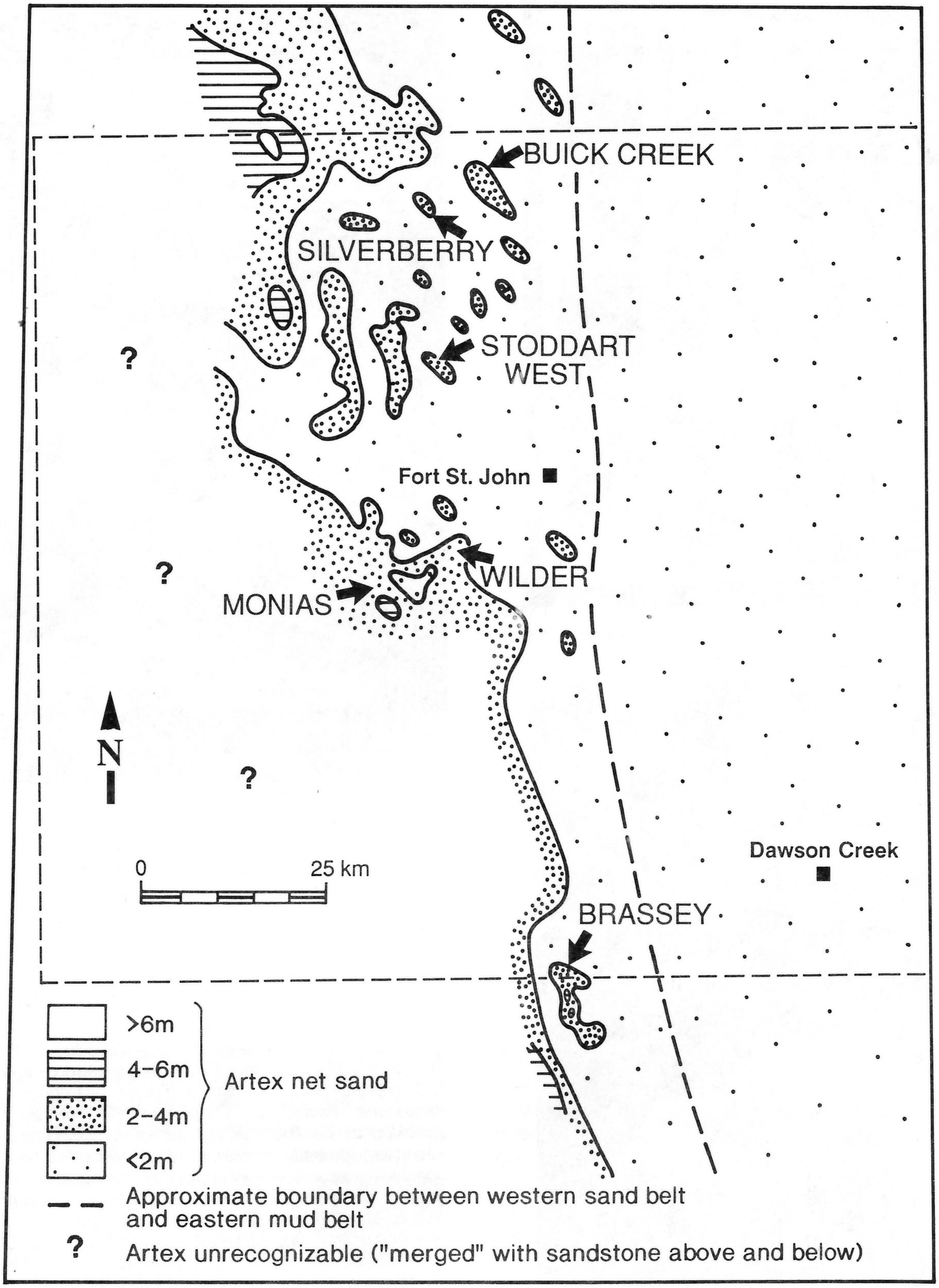


Figure 7. Artex Member net-sand isopach, showing known Artex pools (contours from Map 3). The map shows numerous closed contours, interpreted as discrete aeolian dunes (see text). The map also reflects the overall eastward decrease in sand/shale ratio in the Artex. "Net sand" is defined as all strata with a gamma-log response of less than 60 API units.

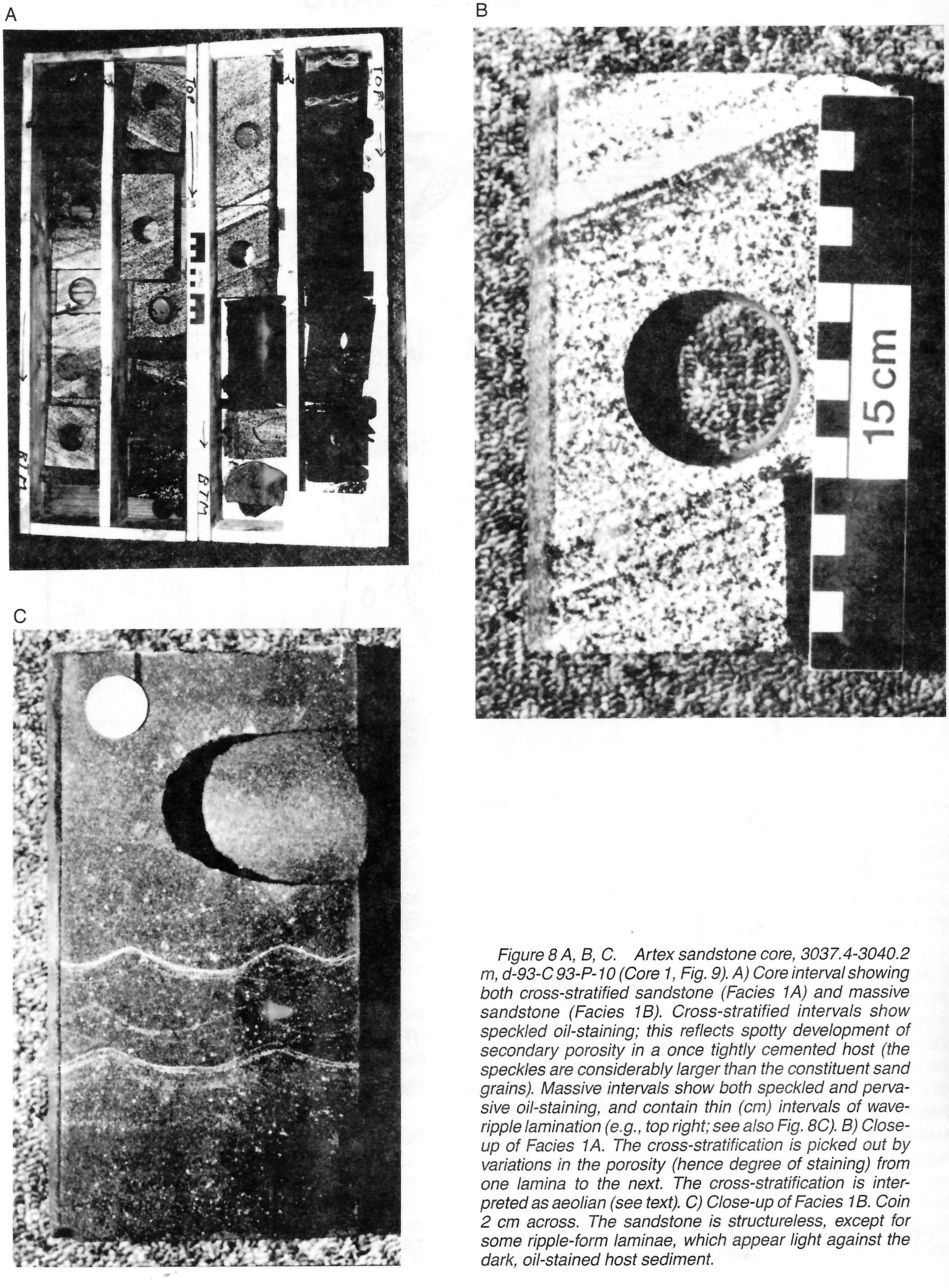


Figure 8 A, B, C. Artex sandstone core, 3037.4-3040.2 m, d-93-C 93-P-10 (Core 1, Fig. 9). A) Core interval showing both cross-stratified sandstone (Facies 1A) and massive sandstone (Facies 1B). Cross-stratified intervals show speckled oil-staining; this reflects spotty development of secondary porosity in a once tightly cemented host (the speckles are considerably larger than the constituent sand grains). Massive intervals show both speckled and pervasive oil-staining, and contain thin (cm) intervals of wave-ripple lamination (e.g., top right; see also Fig. 8C). B) Close-up of Facies 1A. The cross-stratification is picked out by variations in the porosity (hence degree of staining) from one lamina to the next. The cross-stratification is interpreted as aeolian (see text). C) Close-up of Facies 1B. Coin 2 cm across. The sandstone is structureless, except for some ripple-form laminae, which appear light against the dark, oil-stained host sediment.

ness of the Artex, because Facies 1B occurs at the *top* of the Artex in some wells (e.g., Cores 1, 3 and 4, Fig. 9). However, the dunes were subsequently bevelled, as described below.

The symmetrical ripples in Facies 1B were formed in water by wave action. The vertical climb-angle of the ripple-lamination indicates a relatively high rate of sand fallout (Harms *et al.*, 1982, p. 3-28 and Fig. 3-13), possibly reflecting wind-fallout (cf. model "2" above). Hence, both ripple-laminated intervals and massive intervals possibly reflect wind-storms. The wind would account not only for transportation of sand but also for generation of waves. Speculating further, Facies 1B possibly consists of amalgamated "wind-storm beds", each bed comprising: 1) a basal massive division deposited when sediment fallout was too high for any wave-induced sediment traction to occur; and 2) an upper ripple-laminated division. Deformation of the ripples was possibly caused by loading due to rapid deposition of overlying sand.

Regardless of the exact depositional process, the inferred depositional environment of Facies 1B was a water body beside a dune. Hence, the presence of Facies 1B in any borehole suggests a dune-flank position, and is therefore a potentially useful guide to further exploration (or development). The water body was probably a lagoon, formed by catastrophic marine inundation of the dune field in response to breaching of a coastal sand barrier (see below).

Finally, the bioturbated sandy mudstone of Facies 2 is interpreted as a subaqueous deposit, based on the pervasive burrowing and the lack of evidence for emergence such as desiccation cracks. The presence of pyrite suggests a saline water body, rather than a fresh-water lake (Berner, 1984). In view of the proximity of marine strata (Ludington Formation), the most likely environment is a lagoon (i.e., coastal) rather than a saline lake. The bidirectional cross-lamination, reflecting wave action, is consistent with a lagoon (e.g., Reineck and Singh, 1980, pp. 424-429). The lagoon interpretation requires the existence of a barrier island to the west, separating the lagoon from the Ludington Formation shelf. The barrier may have lain in the extreme west of the study area, within the continuous sandstone sequence discussed earlier, which could represent the deposits of a long-lived (pre- to post-Artex) barrier. The lagoon occupied the areas between the Artex dunes, and also covered the eastern facies belt (see below); the eastern shoreline probably lay in Alberta. The Artex dunes may have been "relict" features, formed on a formerly dry lagoon floor and then partially drowned by sudden flooding of the lagoon, as discussed below. The lagoon was probably hypersaline, judging by the lack of shelly fossils and by the evidence for semi-aridity in associated Charlie Lake strata (caliche, red beds and evaporites; see below). Sediment was probably supplied to the lagoon through inlets by tides and storms, by storm washover, and by wind.

Eastern mud belt, Facies 3

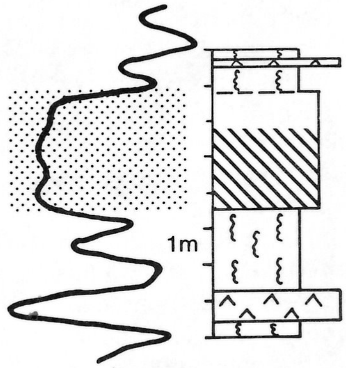
The Artex Member in the eastern belt is assigned to Facies 3, and is characterized by relatively high gamma-log values (Cross-Sections A to K). Facies 3 consists of burrowed-mottled silty mudstone, distinguishable from Facies 2 by: 1) its red rather than grey colour; 2) finer grain size overall; and 3) the presence of calcareous nodules (Cores 8, 9 and 10, Fig. 9; Fig. 11). Nodules are up to 5 cm across, with angular to rounded, irregular outlines and with sharp borders (Fig. 11). The nodules are paler than the surrounding matrix and consist of microcrystalline calcite. The proportion of nodules in any 5 cm interval ranges from 0 to 50%. Nodules commonly show a fitted arrangement, separated by mud seams, comparable to "chicken-wire texture" (e.g., Collinson and Thompson, 1982). The red colour is interrupted by centimetre-size pale green patches which are cumulus-shaped, with diffuse margins, and which cross-cut calcareous nodules (Fig. 11).

Interpreting Facies 3, the resemblance of the silty mudstone (between concretions) to Facies 2 suggests deposition in a lagoon. Hence, a single large lagoon is envisaged, encompassing both the eastern belt and the interdune areas of the western belt. Lagoon sediments are finer in the eastern belt (Facies 3) than in the western belt (Facies 2) because they were deposited farther from inlets and washovers supplying sand. Unlike Facies 2, deposition of Facies 3 was followed by subaerial exposure and lowering of the water table, as shown by the red colour and by the calcareous nodules. Red beds and calcareous nodules are typical of modern and ancient caliche soils developed in a semi-arid climate (Collinson, 1986a); the fitted fabric of the nodules is evidence for in-situ growth (Collinson and Thompson, 1982).

"Missing" Artex facies

The Artex is characterized by abrupt lateral thickness changes, as mentioned above. For example, in less than 2 km, the Artex passes from (dune) sandstone 3-5 m thick into muddy lagoonal-interdune deposits only 1 m thick (Fig. 5; Cross-Sections H-K). These rapid changes cannot be attributed to dune-field topography, because the beds immediately overlying the Artex are of laterally uniform thickness (Fig. 5), indicating that the Artex upper surface was planar upon burial. Instead, the thickness deficiency of interdune areas is attributed to post-burial dissolution of an interdune halite layer (Fig. 12). Support for this model comes from an interdune core, which shows a possible "dissolution surface" in the form of a sharp, irregular contact at the base of the Artex (see "Artex suture" in Core 2, Fig. 9; Fig. 13). A similar sharp, irregular contact attributed to subsurface dissolution of the Black Creek halite (Muskeg Formation, Devonian) of northwest Alberta was illustrated by McCamis and Griffith (1967, Plate 3). In the Artex example (Fig. 13), the contact is lined with a carbonaceous film, possibly representing the insoluble residue of dissolved evaporites. Further support for the "missing halite"

1 Canhunter Brassey
d-93-C 93-P-10
3036.0-3045.0, rec. 8.0m



2 Canhunter et al Brassey
c-91-C 93-P-10
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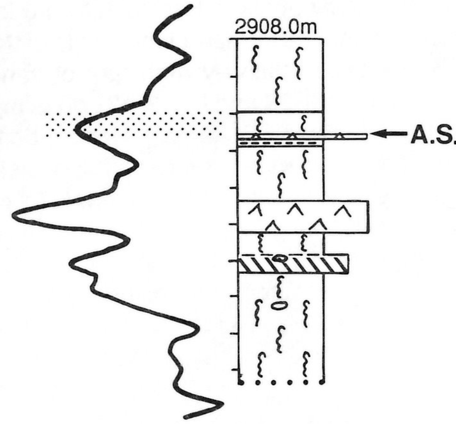

3 Canhunter Brassey
d-13-F 93-P-10
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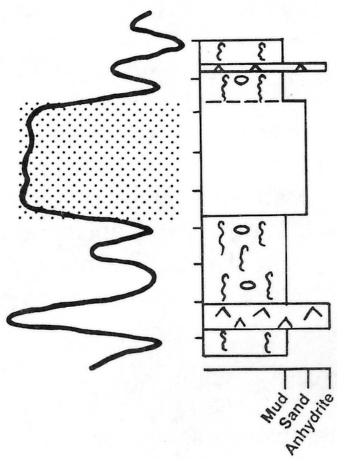
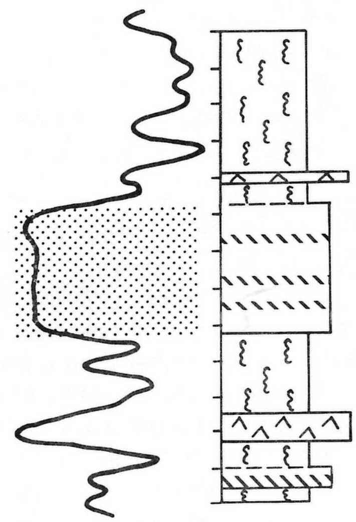
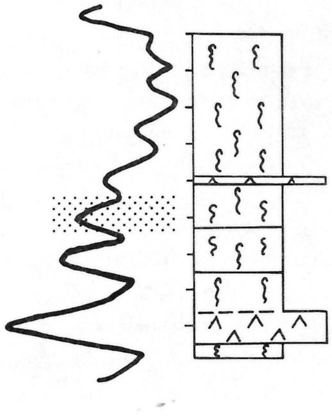


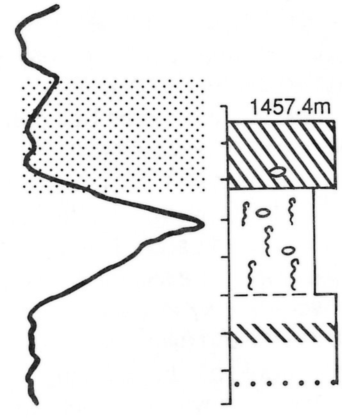
4 Canhunter Brassey
c-23-F 93-P-10
3012.0-3025.0, rec. 12.9m



5 Canhunter Brassey
14-2-77-19W6
2827.0-2842.0, rec. 8.9m



6 Canterra Moberly
7-33-82-22W6
1457.4 - 1475.4, rec 18.0 m



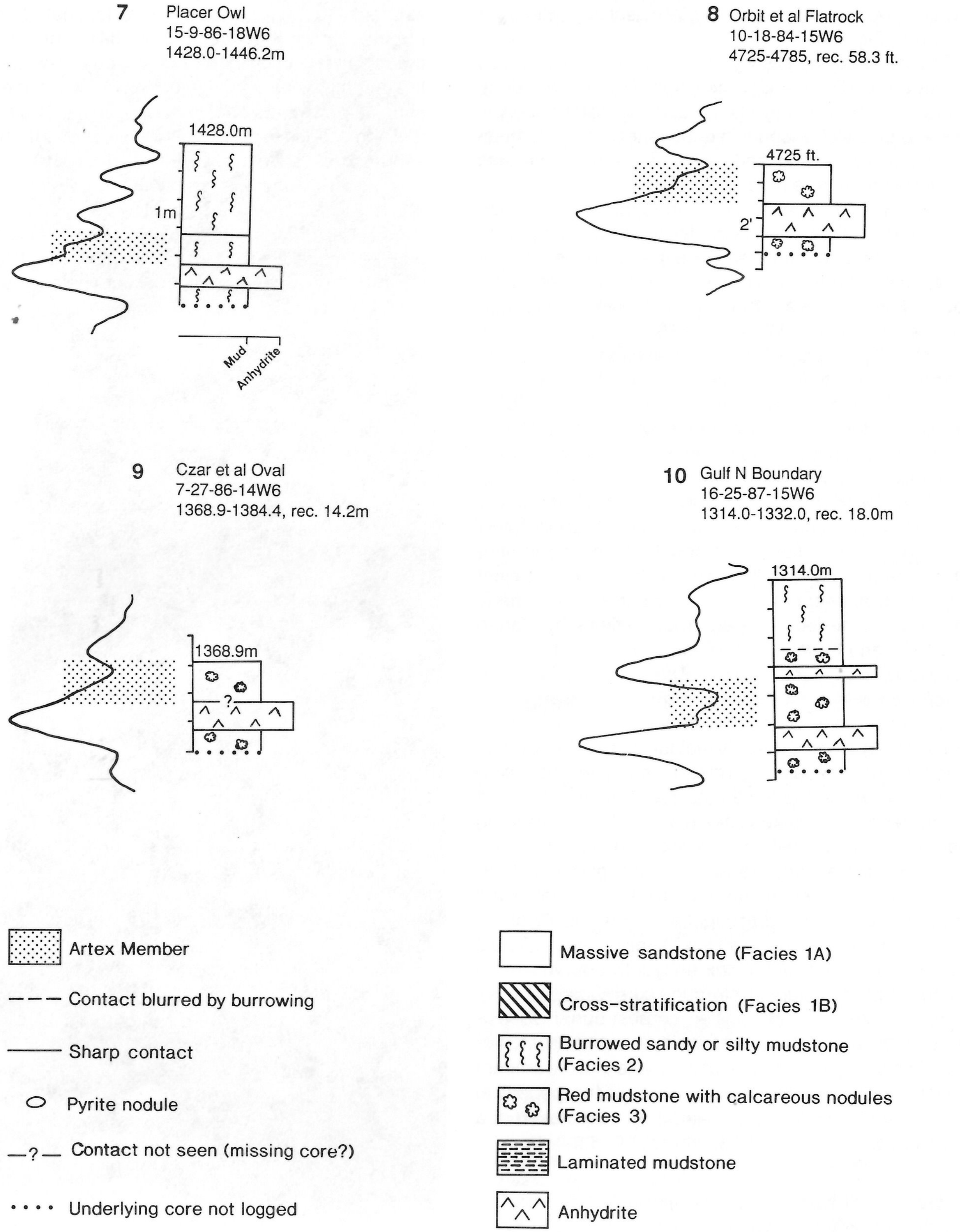


Figure 9. Graphic logs of the studied cores. Note that the lithology of the strata immediately beneath the Artex Member is variable from one well to another; these lateral facies changes are also evident on Cross-Sections A to K. Core locations are plotted on Fig. 1. A.S. = Artex suture (see text).

model comes from the presence of a halite layer higher in the Charlie Lake Formation (Torrie, 1973), which can be shown to have undergone post-burial dissolution within the study area (Fig. 14).

The thickness deficiency of interdune areas may also be partly due to differential compaction of muddy interdune sediment (Facies 2; Fig. 14). However, compaction is unlikely to be *solely* responsible, because Facies 2 muds contain abundant sand and silt, and are therefore less compactible than pure mud.

The missing Artex halite is thought to have been deposited in a salina which occupied interdune areas prior to flooding of the lagoon (see below). A salina is a saline lake "adjacent to the ocean in which the salina water level is below that of the ocean and is replenished by seawater seepage" (Kendall, 1984, p. 275). Modern salinas replenished by seepage through a coastal sand barrier are well known in Australia and Sinai (Kushnir, 1981; Warren, 1982; Kendall and Warren, 1988). However, these modern examples are less than 10 km across, whereas the inferred Artex salina, encompassing the entire western dune belt, was at least 50 km wide and 150 km long (Fig. 7). The Artex salina was replenished by sea water seeping through the adjacent barrier island. Salinity was high enough for halite precipitation. The halite was probably deposited in very shallow water (Fig. 15), like most modern and ancient halite, which appears to form in very shallow ephemeral lakes and marine-fed salt pans (see reviews by Hardie *et al.,* 1978 and Kendall, 1984). Precipitation of the Artex halite was accompanied by minimal clastic input, due to the lack of tidal inlets, washovers or inflowing rivers, and perhaps also due to the rapidity of halite deposition (e.g., Kendall, 1988). Hence, the only residue after halite dissolution is a carbonaceous film, possibly representing microscopic algae which lived in the salina. The missing halite might have been precipitated alone, without accompanying gypsum, given a suitable balance between the rate of seawater replenishment and the lateral salinity gradient. Alternatively, gypsum interlaminae may have been deposited with the halite; this could account for some (or all) of the anhydrite immediately beneath the "Artex suture" in Core 2 (Figs. 9, 13). In contrast, Artex anhydrite appears to be missing in the other studied interdune core (Core 5, Fig. 9), suggesting either non-deposition or post-burial dissolution; alternatively, a thin anhydrite layer could have been overlooked during core examination. (Note that the amount of any "missing" anhydrite is small, because the theoretical ratio of halite to gypsum precipitated by evaporation of a volume of sea water is 22:1 (Schreiber, 1986).)

Depositional history of the basal Charlie Lake Formation

In all of the studied cores, the strata above and below the Artex comprise an alternation of: 1) burrowed sandy or silty mudstone similar to Facies 2 and 3; and 2) anhydrite units showing millimetre-scale parallel lamination (Fig.9). The burrowed mudstone is interpreted as lagoonal, like that of the Artex. The anhydrite is subaqueous rather than subaerial (sabkha), based on its laminated rather than nodular character (Kendall, 1984). The anhydrite is thought to reflect episodes of reduced sea-water access to the lagoon, whereupon evaporation caused the lagoon to shrink (i.e., regression), forming a salina. The transformation from lagoon to salina may have resulted from a eustatic sea-level fall, so that sea water was no longer admitted to the lagoon via inlets and washovers. The laminated anhydrite was possibly deposited as gypsum-algal laminites, like the laminites forming today in Ras Mohamad pool, a modern salina in Sinai (Kushnir, 1981). While gypsum (anhydrite precursor) accumulated in some parts

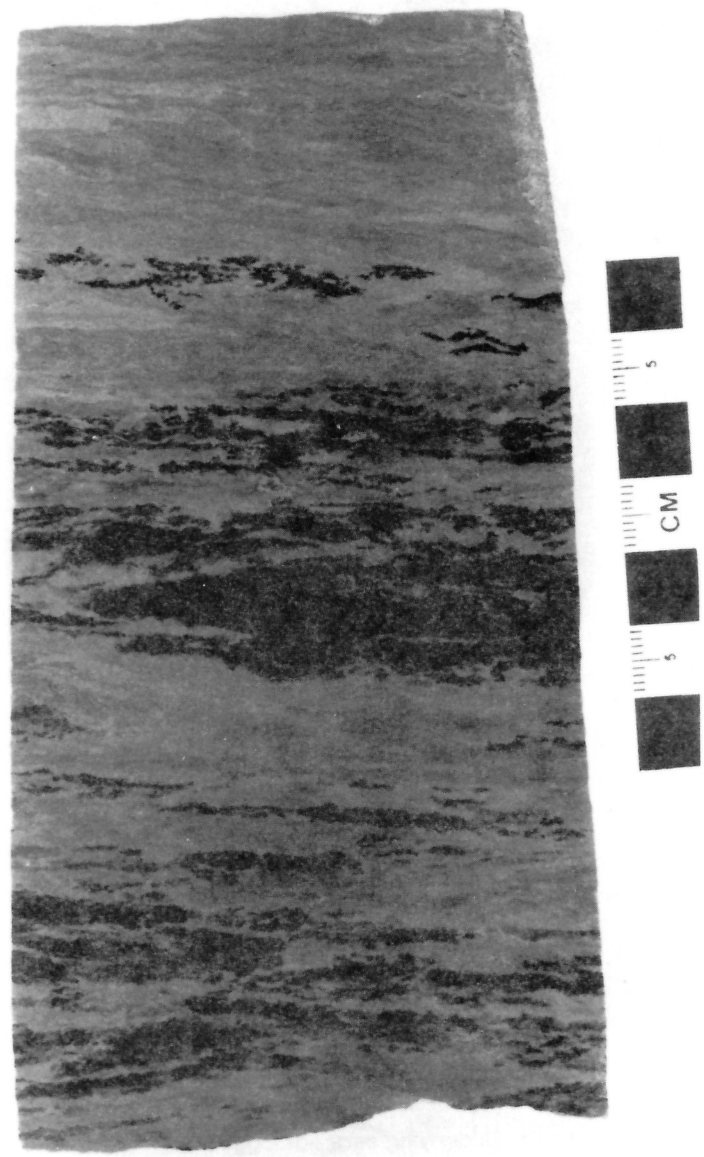


Figure 10. Facies 2 mudstone with (dark) siltstone streaks, partially homogenized by bioturbation. A nodule of pyritized siltstone about 1.5 cm across (centre) has retained its primary lamination, indicating that the nodule formed early (i.e., pre-burrowing). Sample from 15-9-86-18W6, 1428.6 m (Core 7, Fig.9).

west Texas and New Mexico (Lowenstein, 1982). The Salado cycles are capped by halite, whose absence in the Charlie Lake cycles may reflect either non-deposition or post-burial dissolution.

The cyclic deposits of the "Charlie Lake lagoon" pass westward into amalgamated sandstones, as mentioned earlier. These sandstones are thought to be deposits of a barrier island which persisted throughout the basal Charlie Lake time interval.

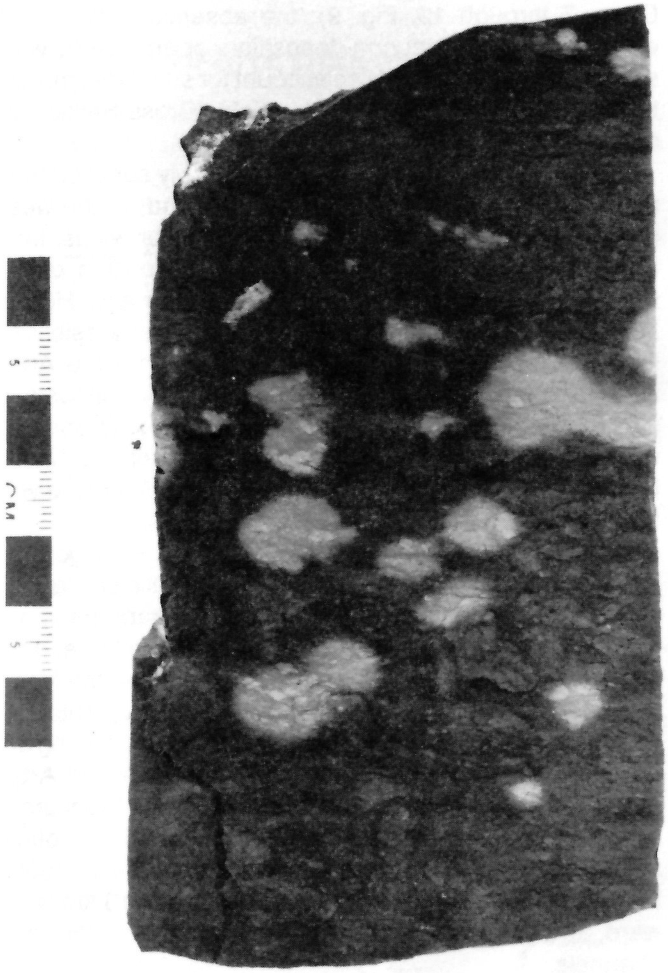


Figure 11. Facies 3 red mudstone. The cm-size light patches are pale green. The mudstone contains pale calcareous nodules of inferred pedogenic (caliche) origin. Note the sub-vertical fracture on the left-hand side, filled with anhydrite. Sample from 7-27-86-14W6, 1370.0 m (Core 9, Fig. 9).

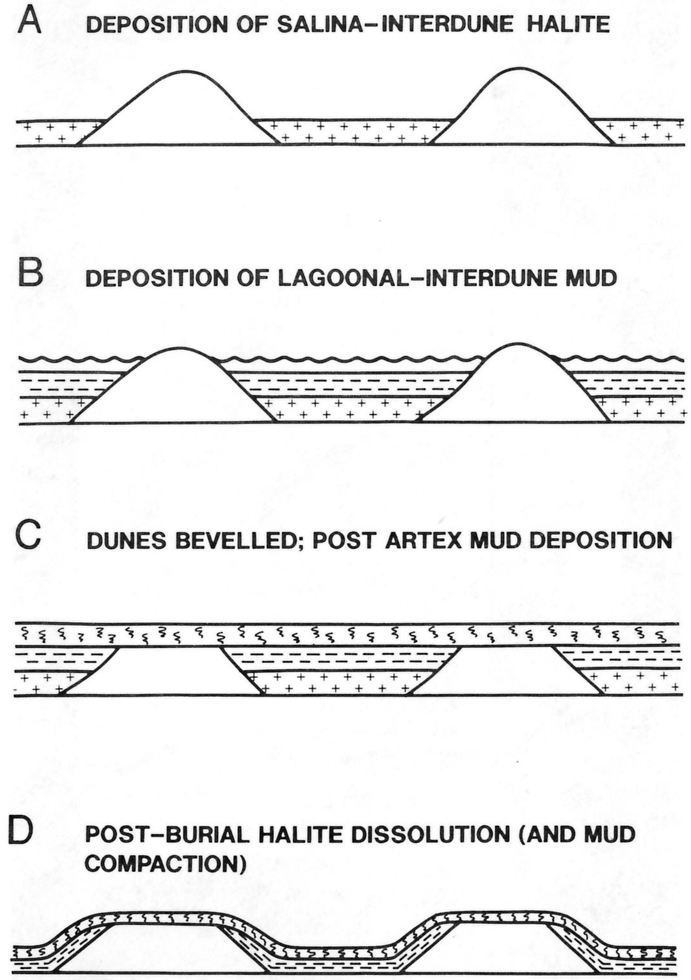


Figure 12. Model to explain the difference in thickness between Artex dunes and interdune areas. Note gross vertical exaggeration. (A) Artex dunes pass laterally into halite precipitated in a salina which occupied interdune areas. (B) Deposition of lagoonal muddy sediment (Facies 2) fills in some of the remaining dune topography. (C) Dune crests are bevelled, probably by wave undercutting and/or wind deflation, and post-Artex sediments are deposited. The Artex is thus buried as a tabular layer. (D) The halite is dissolved after burial. Overlying sediments collapse and "wrap around" the dunes. Note that boreholes drilled on dune flanks would encounter both dune sand and interdune mud.

of the salina, clastic deposition occurred concurrently elsewhere, as shown by the fact that some anhydrite units pass laterally into muddy deposits (e.g., observe the lateral disappearance of the two anhydrite "spikes" underlying the Artex in 2-12-82-20W6 (Well 40, Cross-Section K)). Each episode of gypsum deposition was abruptly terminated by re-establishment of the lagoon (i.e., transgression), probably due to rising eustatic sea level.

Hence, the basal Charlie Lake Formation can be interpreted as a series of transgressive-regressive lagoonal cycles, corresponding to repeated flooding and shrinking of a lagoon in response to eustatic sea-level fluctuations. This interpretation is consistent with Goodwin and Anderson's (1985) proposal that much of the stratigraphic record consists of transgressive-regressive cycles of eustatic origin. Similar clastic-and-evaporite cycles of lagoonal origin occur in the Salado Formation (Permian) of

Depositional history of the Artex Member

The history of Artex deposition is summarized as a series of four stages in Figure 15. In Stage I, the Artex dune field developed on the floor of a dried-out lagoon during a eustatic lowstand (Fig. 16). Evidence for subaerial exposure of the lagoon floor is the invariably sharp base of the Artex (Fig. 9), consistent with a break in deposition. Before completely drying out, the lagoon is likely to have become highly saline, with precipitation of evaporites; this is consistent with the presence of anhydrite immediately below the Artex in much of the study area (e.g., Core 2 and Cores 7 through 10, Fig. 9); the absence of anhydrite elsewhere may reflect non-deposition, or erosion by wind scour. Wind scour could also account for sub-Artex truncation of log markers in Brassey field (Cross-Section K, compare Wells 87, 44 and 88).

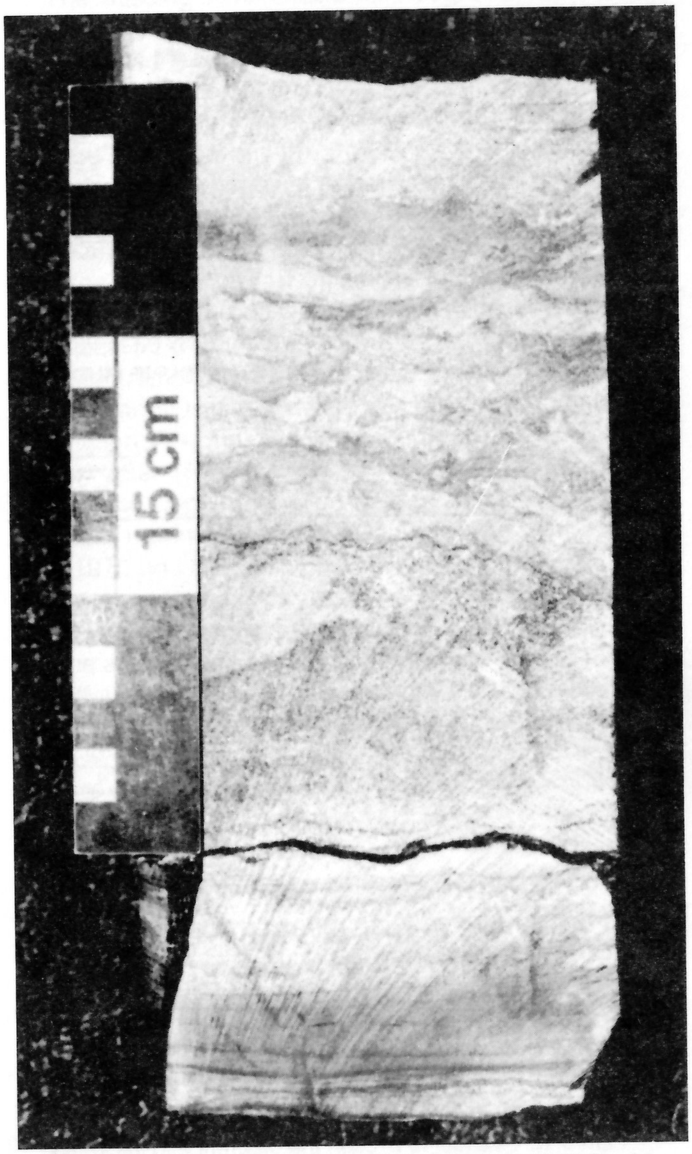


Figure 13. The "Artex suture" (see text), at 2910.6 m in c-91-C 93-P-10 (Core 2, Fig. 9). The suture is an irregular, dark (carbonaceous) seam, about mid-way up the core, adjacent to "1" on the scale. The suture has a vertical relief of 6 cm in the core (only 2 cm relief visible here on the slabbed surface). The suture separates Artex bioturbated muddy sandstone (above; Facies 2) from anhydrite below. Note that the top half of the anhydrite is massive, while the remainder is laminated. The suture is thought to represent a "dissolution surface", corresponding to a "missing" halite layer (see text). The carbonaceous seam may represent the insoluble residue of the dissolved halite layer.

Sand for the Artex dunes was probably supplied from a coastal sand barrier (former barrier island) to the west, implying that the wind blew onshore. Similar winds, from the west or southwest, accompanied deposition of the underlying Halfway Formation (Campbell and Horne, 1986). As mentioned earlier, the coastal barrier possibly lay in the extreme west of the study area, where the Artex becomes indistinguishable within a continuous sandstone succession (Fig. 17). The barrier was probably oriented north-south, parallel to the eastern edge of the "indistinguishable" belt (cf. Map 1). A north-south shoreline was also postulated by Klein and Woofter (1989).

No modern analogue for the inferred dry lagoon is known to the author, possibly because eustatic sea level is presently high following the Holocene transgression. However, a future fall in sea level might cause large, arid-climate lagoons such as the Bardawil lagoon on the Mediterranean coast of Sinai (West *et al.,* 1979; Levy, 1980), or Laguna Madre on the Gulf of Mexico, to dry out, forming dry lagoons similar in size and nature to the inferred Artex lagoon. A *partial* analogue for the Artex dune field occurs at Laguna Guerrero Negro in Mexico, an arid mesotidal lagoon behind a 45 km long barrier (Fryberger *et al.,* 1990). Here, a barrier-connected dune field extends 13 km landward, advancing over back-barrier marshes, tidal flats and channels.

Inferences can be drawn regarding the *shape* of the Artex dunes. The gross arrangement of Artex sand bodies, as parallel strings oriented NNW-SSE (Fig. 7; Map 3), is suggestive of either star dunes or seif dunes. For example, modern star dunes in the Gran Desierto in Mexico "lie in 20-30 km long chains with WNW-ESE trends and a spacing of 2-3 km" (Lancaster, 1989, p. 274). Similarly, seif dunes occur as groups of parallel dunes, both in the modern and the ancient (Collinson, 1986). The irregular outline of the dune(s) at Brassey (Fig. 7; Map 3) is suggestive of star dunes rather than seif dunes. Between the Artex dunes, interdune areas were probably deflationary due to wind scour.

In Stage II, rising eustatic sea level allowed sea water to percolate laterally through the coastal barrier into the dune field, forming a salina between the dunes throughout the dune field. Halite was precipitated in the interdune-salina, perhaps analogous to modern interdune halite in Saudi Arabia (Ahlbrandt and Fryberger, 1981; Fryberger *et al.,* 1983). Halite precipitation kept pace with rising sea level (see arrow in Fig. 15).

Ultimately, sea level rose high enough to breach the coastal barrier, allowing sea water to flood catastrophically into the lagoon through one or more inlets (perhaps during a storm) (Stage III). This caused drowning of the dune field,

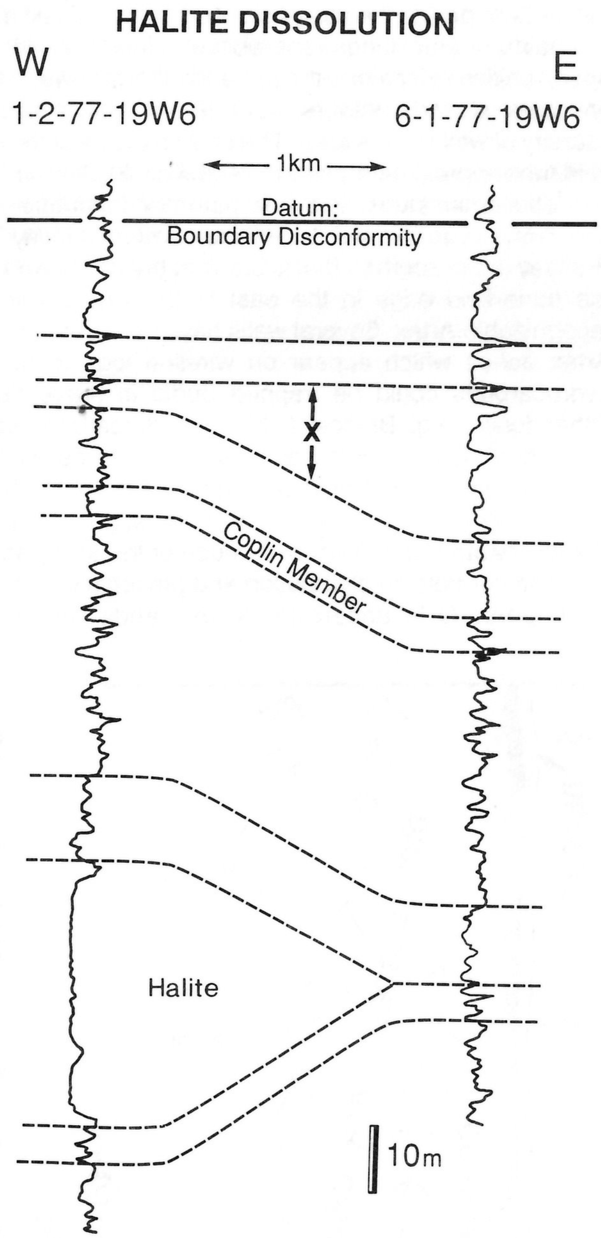


Figure 14. Gamma-log cross-section in northern Brassey field, above the Artex Member, showing lateral disappearance of a thick (ca. 40 m) halite interval in the Charlie Lake Formation. Log markers enveloping the halite show no lateral truncations or thickness changes, indicating that the halite interval was continuous and tabular upon burial. Hence, the halite must have been removed by dissolution. The dissolution can possibly be dated: the interval marked "X", between the Coplin Member and the Boundary disconformity, is much thicker in the right-hand well, partially compensating for the missing halite; the extra thickness may reflect differential subsidence due to localized dissolution of the halite interval below. The "compensating interval" is thinner than the missing halite, possibly due to compaction. If deposition of "X" was indeed synchronous with halite dissolution, the implication is that dissolution took place relatively early, beneath less than 100 m of overburden.

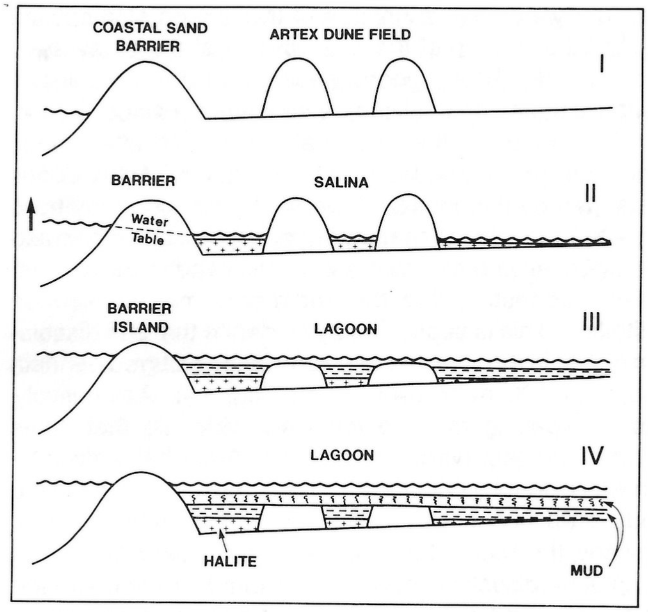


Figure 15. Depositional history of the Artex Member. In Stage I, Artex dunes developed on a dry lagoon floor, behind a coastal sand barrier, during a lowstand of eustatic sea level. In Stage II, rising sea level (arrow) allowed sea water to seep laterally through the barrier into interdune areas, forming a salina in which halite was precipitated. In Stage III, sea level was high enough to breach the barrier, causing the lagoon to flood, thereby inundating the dunes. Following establishment of the lagoon, the dunes were gradually bevelled, probably by wave undercutting and wind deflation, while muddy lagoonal sediments were deposited between them. Finally, in Stage IV, the Artex dunes and interdune areas were buried due to continued deposition of lagoonal mud, accomodated by subsidence. No vertical scale implied.

similar to that envisaged by Glennie and Buller (1983) for Permian dunes in England, preserved by extremely rapid marine inundation. Artex dune summits remained emergent, as shown by evidence for undercutting and slumping of dunes (i.e., Facies 1B). In the newly formed lagoon, marine-derived clastics (Facies 2 and 3) were deposited, including the flooded interdune areas. Emergent dune summits initially supplied sand to interdune areas by slumping or wind transport (Facies 1B). Eventually, however, the dunes were bevelled, probably by wave undercutting and wind deflation.

Continued subsidence and lagoonal deposition caused burial of the bevelled Artex dunes and their interdune equivalents (Stage IV). Thus, Artex dunes are overlain by post-Artex lagoonal sediment; bioturbation in the latter extends down into the Artex dune-sand (Cores 1, 3 and 4, Fig. 9), giving rise to a diffuse contact, and demonstrating that the dune sand was soft when buried.

The post-Artex lagoon was subsequently cut off from the sea, probably by a drop in eustatic sea level. The isolated lagoon shrank by evaporation to form a salina, with precipitation of a gypsum layer (now an anhydrite layer, about 1 m above the Artex Member in Cores 1, 3, 4 and 5, Fig. 9). Evaporative shrinkage of the lagoon also caused subaerial exposure of the eastern belt of the study area; consequently, Artex lagoonal sediments in this area underwent reddening and caliche development (Facies 3).

Dissolution of the Artex halite occurred after burial, producing the present-day configuration of Artex dunes separated by thin interdune areas. Dissolution may have occurred at relatively shallow burial depths, since no fracturing of overlying sediments was observed in the studied cores, suggesting that the sediments may have been unlithified. This is supported by evidence that salt dissolution higher in the Charlie Lake Formation occurred beneath less than 100 m of overburden (Fig. 14). Alternatively, fracture spacing may be relatively wide, so that cores seldom intersect (vertical) fractures. Artex halite dissolution was evidently pervasive, since no well anywhere in the study area has encountered any Artex halite remnant. Similarly, the Black Creek halite of northwest Alberta was completely dissolved over large areas in Devonian time (McCamis and Griffith, 1967). The Artex halite was possibly dissolved by migrating (undersaturated) pore water expelled from enveloping muds during compaction.

Implications for petroleum exploration

Most of the known Artex pools appear to be stratigraphic traps corresponding to discrete sand dunes. The lateral seal is provided by Artex lagoonal-interdune muddy strata, and the top-seal by similar lagoonal deposits of post-Artex age. Structure may play a role in the Artex trap at Monias, which is a pronounced anticline (Map 1).

Artex dunes are confined to the western belt of the study area. The net-sand map shows important aspects of dune distribution (Fig. 7; Map 3). Using the 2 m net-sand contour as an approximate indicator of dune outlines (Fig. 7), numerous closures oriented NNW-SSE occur in the eastern part of the dune field, suggestive of seif dunes or chains of star dunes (see above). Hence, exploration opportunities exist along these trends. Farther west, there are fewer closed contours, but this may only reflect the scarcity of wells in this area. The eastern edge of the dune field runs approximately N-S through Fort St. John (Fig. 7).

The entire dune field has potential for future Artex discoveries, defining a broad exploration fairway from Brassey in the south to Buick Creek in the north, and from the dune-field edge in the east to the western limit of recognizable Artex. Several wells have penetrated porous Artex dunes which appear on wireline logs to be wet; hydrocarbons could be trapped updip in these dunes. Other dunes (e.g., Brassey field) are hydrocarbon-bearing throughout. Undiscovered pools are likely to be relatively small and less than 4 m thick, but this is mitigated by the potential for excellent reservoir properties, good seal, and shallow depth (1.5-2.0 km over much of the study area).

The controls on distribution and preservation of Artex dune *porosity* is uncertain. Artex sands range from

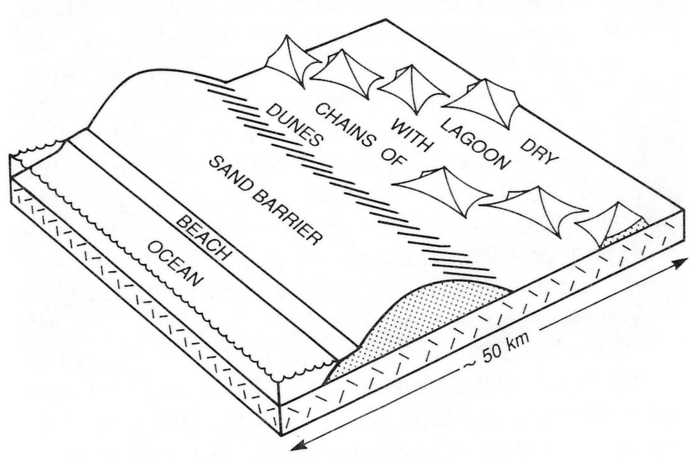


Figure 16. Depositional-environment model of the Artex back-barrier dune field. The dune field developed on a dry lagoon floor, with wind-blown sand supplied from a coastal barrier to the west. The dunes are depicted as chains of star dunes, but may instead have been seif dunes (see text). The existence of the barrier is based on indirect evidence; further core studies are required to confirm its presence.

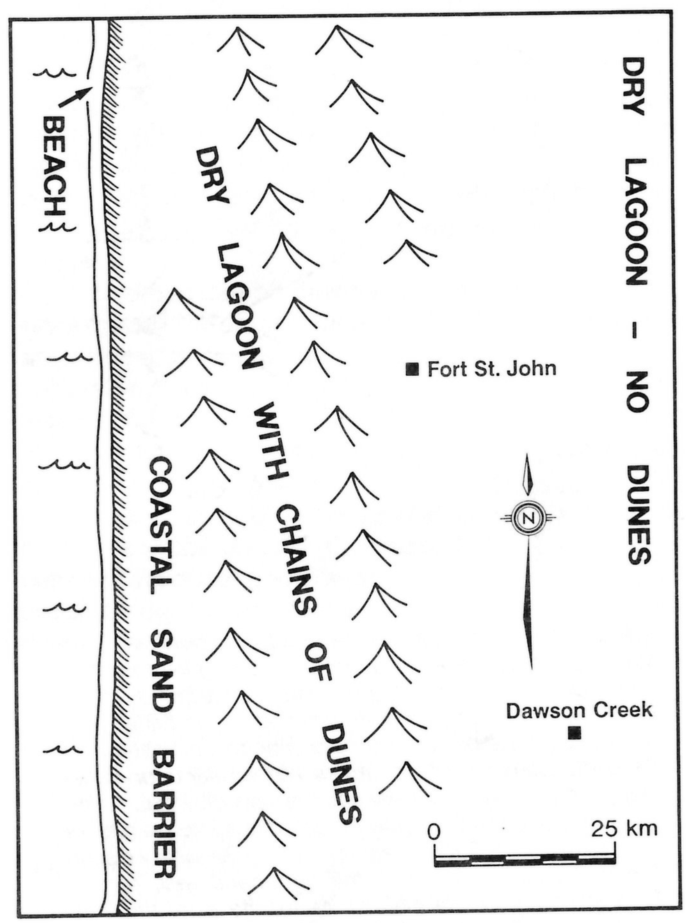


Figure 17. Schematic paleogeographic map of the study area during deposition of the Artex aeolian dunes. The dunes are depicted as chains of star dunes, but may instead have been seif dunes (see text).

extremely porous in some wells to tight in others, even within individual pools (e.g., Brassey). This lateral variability, which constitutes a significant risk in exploration and development, is probably a diagenetic rather than depositional effect, but the precise control is unclear. Examination of thin sections suggests that the porosity at Brassey is mainly secondary.

The lagoonal deposits which seal the Artex dunes may also function as source rocks, since the hypersalinity which characterizes arid-climate lagoons is conducive to high phytoplankton productivity (Fryberger *et al.,* 1990).

Discovery and development of further Artex pools will be optimized by an integration of subsurface mapping and sedimentology. In addition, refined seismic techniques may be able to locate Artex dunes directly, and perhaps differentiate hydrocarbon-bearing and barren dune sands.

Finally, the model presented here, of aeolian dunes forming on a dried-out lagoon floor, is perhaps applicable in the exploration and development of other "stray" sand members of the Charlie Lake Formation (e.g., McAdam, 1979).

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Province of British Columbia
Ministry of Energy, Mines and
Petroleum Resources
Hon. Jack Davis, Minister

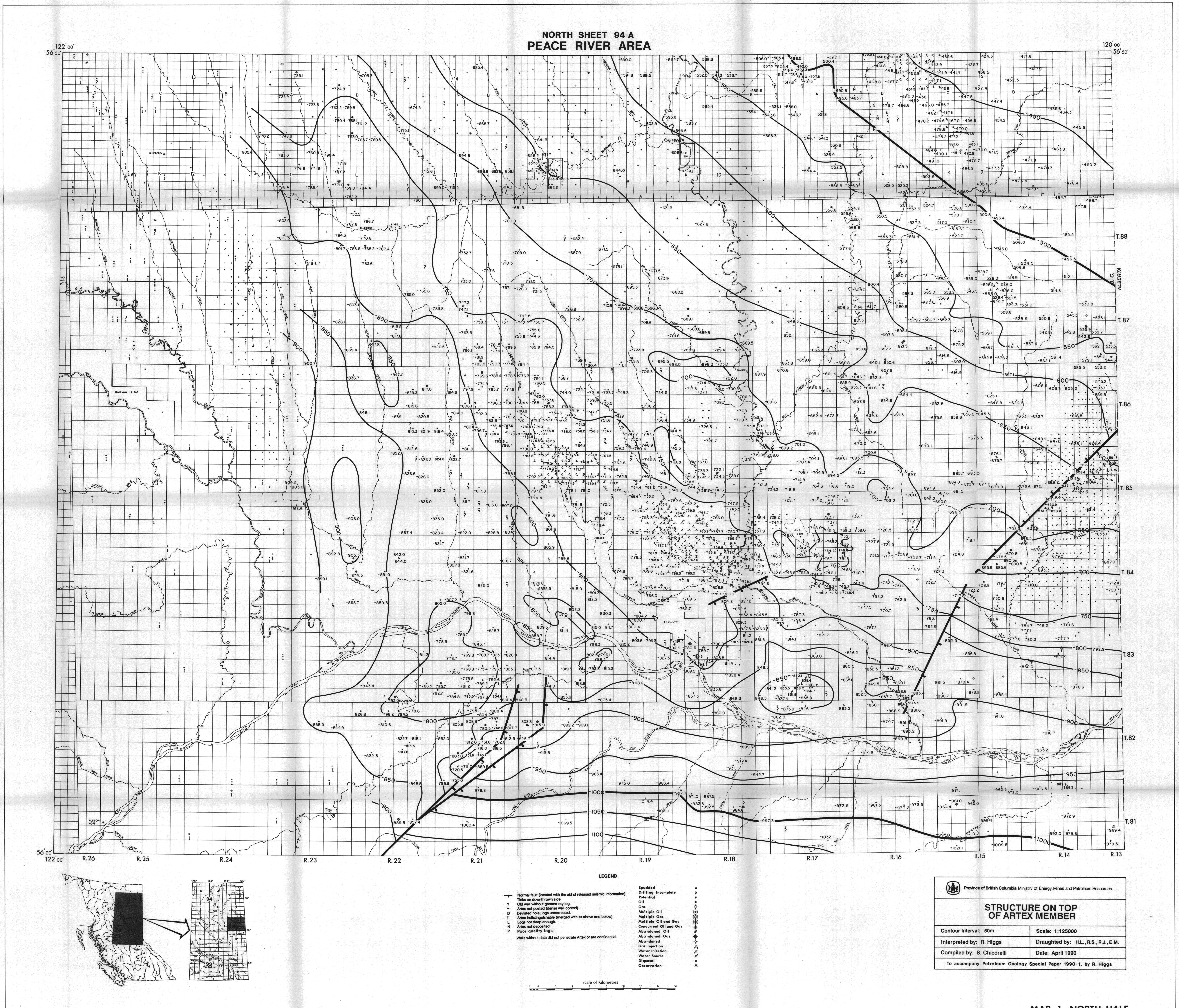
PETROLEUM
GEOLOGY
BRANCH

SEDIMENTOLOGY AND PETROLEUM GEOLOGY OF THE ARTEX MEMBER (CHARLIE LAKE FORMATION), NORTHEASTERN BRITISH COLUMBIA

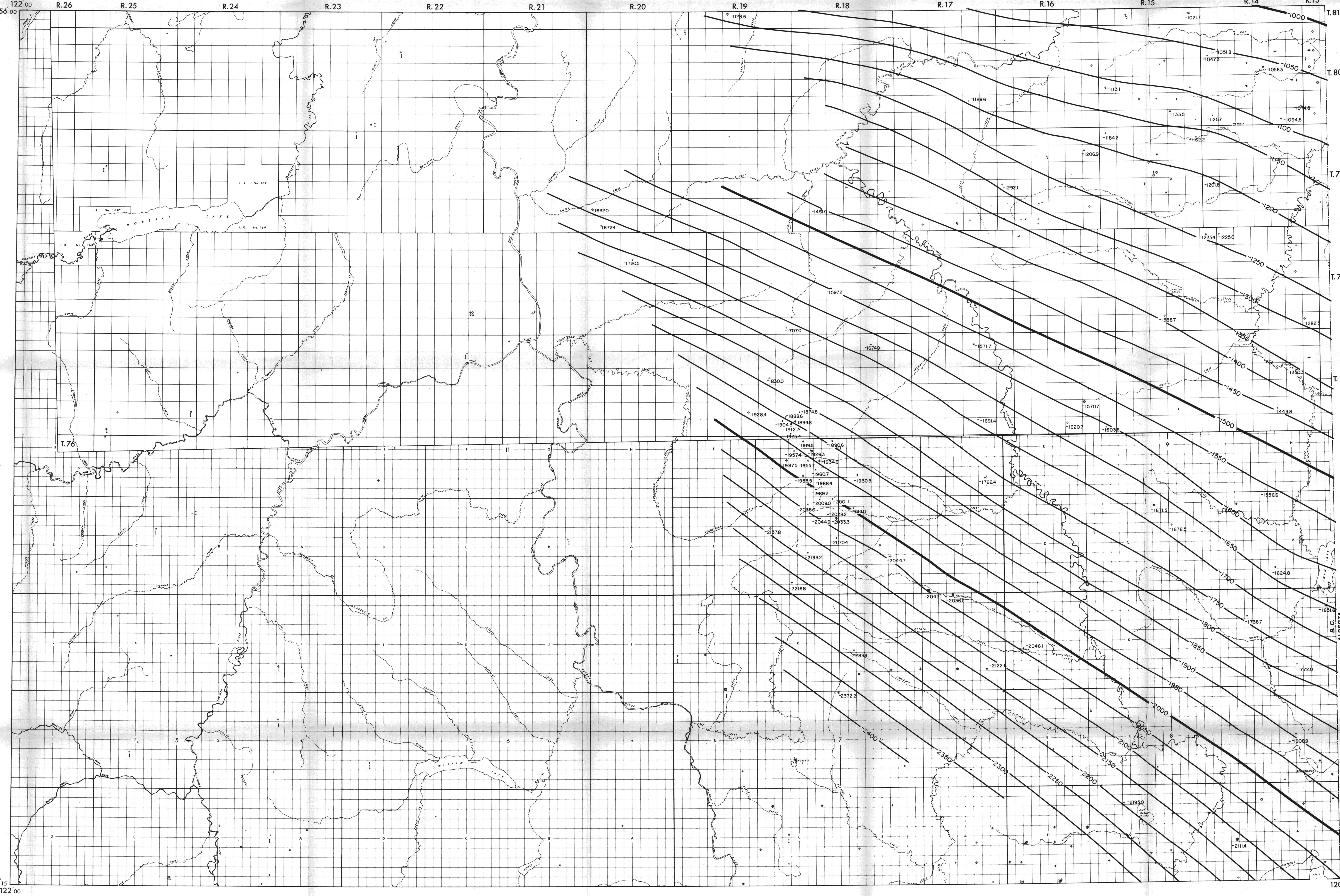
By R. Higgs

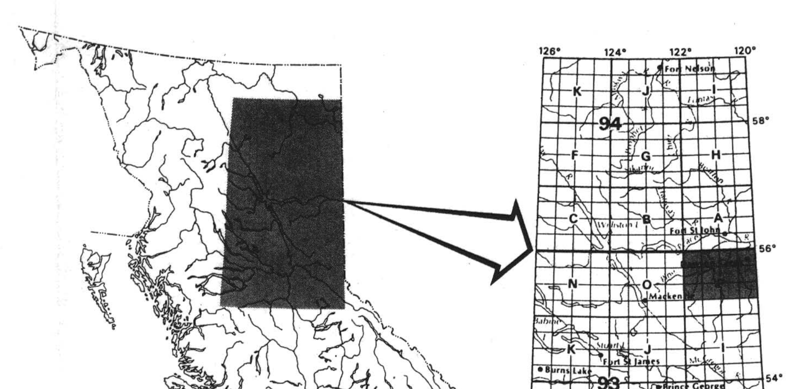
PETROLEUM GEOLOGY
SPECIAL PAPER 1990-1

1040
(S.P. 1990-1)
94-A



SOUTH SHEET 93-P
PEACE RIVER AREA





LEGEND

? Old well without gamma-ray log.
I Artex indistinguishable (merged with ss above and below).
D Deviated hole; log uncorrected.

Wells without data did not penetrate Artex or are confidential.

Spudded
Drilling Incomplete
Potential
Oil
Gas
Multiple Oil
Multiple Gas
Multiple Oil and Gas
Concurrent Oil and Gas
Abandoned Oil
Abandoned Gas
Abandoned
Gas Injection
Water Injection
Water Source
Disposal
Observation

Scale of Kilometres

1 0 2 4 6 8 10 12 14 16

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

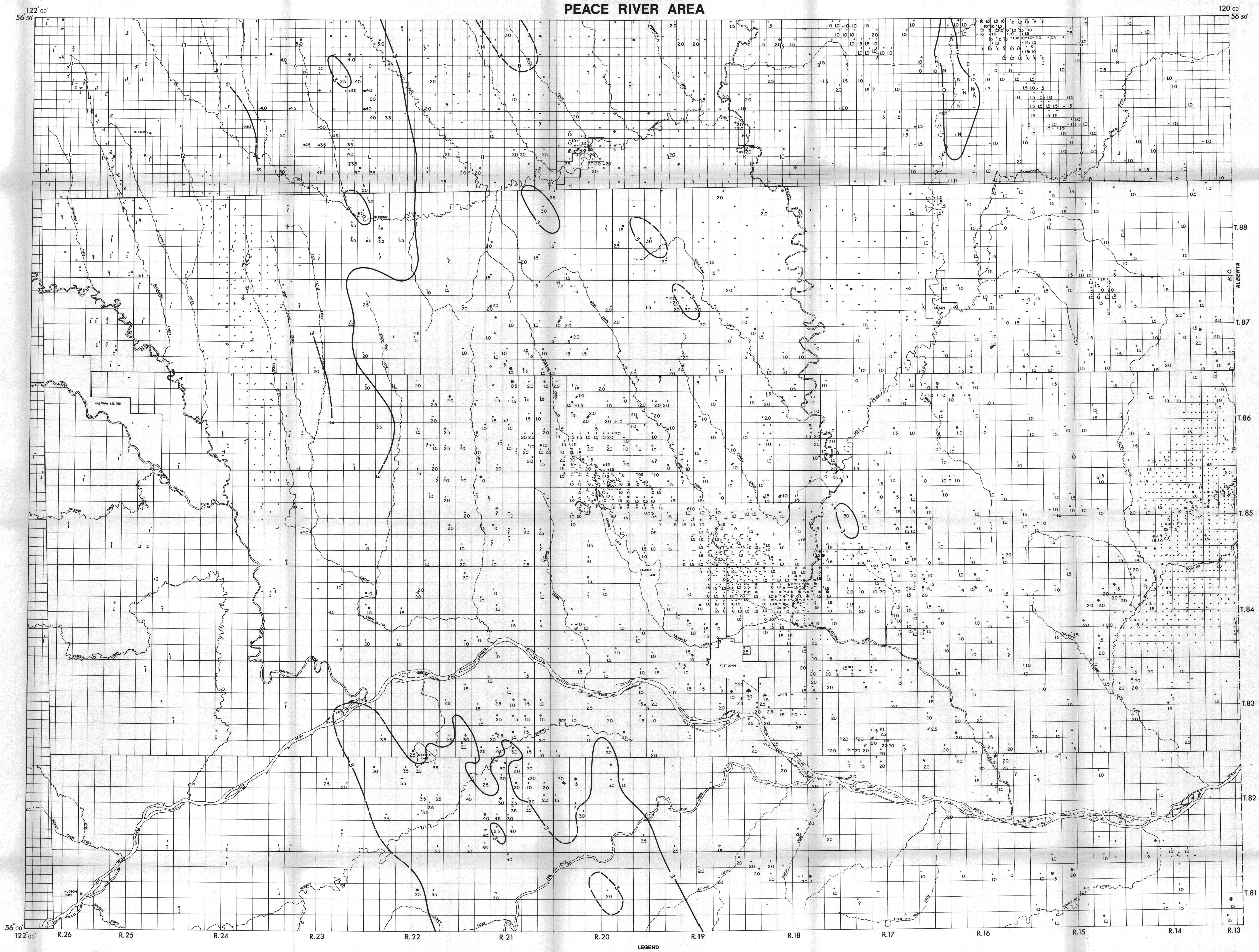
STRUCTURE ON TOP OF ARTEX MEMBER

Contour Interval: 50m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: E. Mullins
Compiled by: S. Chicorelli	Date: April 1990

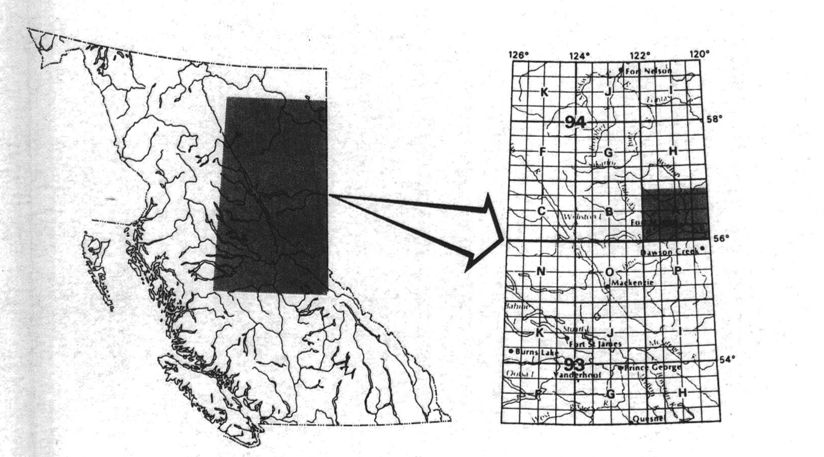
To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

MAP 1 SOUTH HALF

NORTH SHEET 94-A
PEACE RIVER AREA



LEGEND



- Artex isopach.
- Artex isopach (approximate).
- ~ Artex not posted (dense well control)
- I Artex indistinguishable (merged with ss above and below).
- L Logs not deep enough.
- N Artex not deposited.
- P Poor quality logs

Well picks are to nearest 0.5m
Wells without data did not reach Artex or are confidential.

Spudded
Drilling Incomplete
Potential
Oil
Gas
Multiple Oil
Multiple Gas
Multiple Oil and Gas
Concurrent Oil and Gas
Abandoned Oil
Abandoned Gas
Abandoned
Gas Injection
Water Injection
Water Source
Disposal
Observation

Scale of Kilometres
1 0 2 4 6 8 10 12 14 16

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

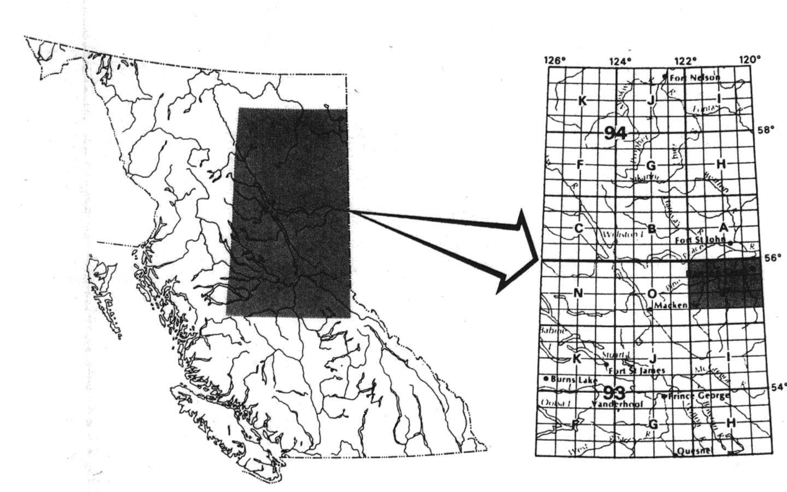
ISOPACH OF ARTEX MEMBER

Contour Interval: 3m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: E. Mullins
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

MAP 2 NORTH HALF

SOUTH SHEET 93-P
PEACE RIVER AREA



LEGEND

—	Artex isopach.
– –	Artex isopach (approximate).
?	Old well without gamma-ray log.
I	Artex indistinguishable (merged with ss above and below).

Well picks are to nearest 0.5m.
Wells without data did not reach Artex or are confidential.

Spudded
Drilling Incomplete
Potential
Oil
Gas
Multiple Oil
Multiple Gas
Multiple Oil and Gas
Concurrent Oil and Gas
Abandoned Oil
Abandoned Gas
Abandoned
Gas Injection
Water Injection
Water Source
Disposal
Observation

Scale of Kilometres
1 0 2 4 6 8 10 12 14 16

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

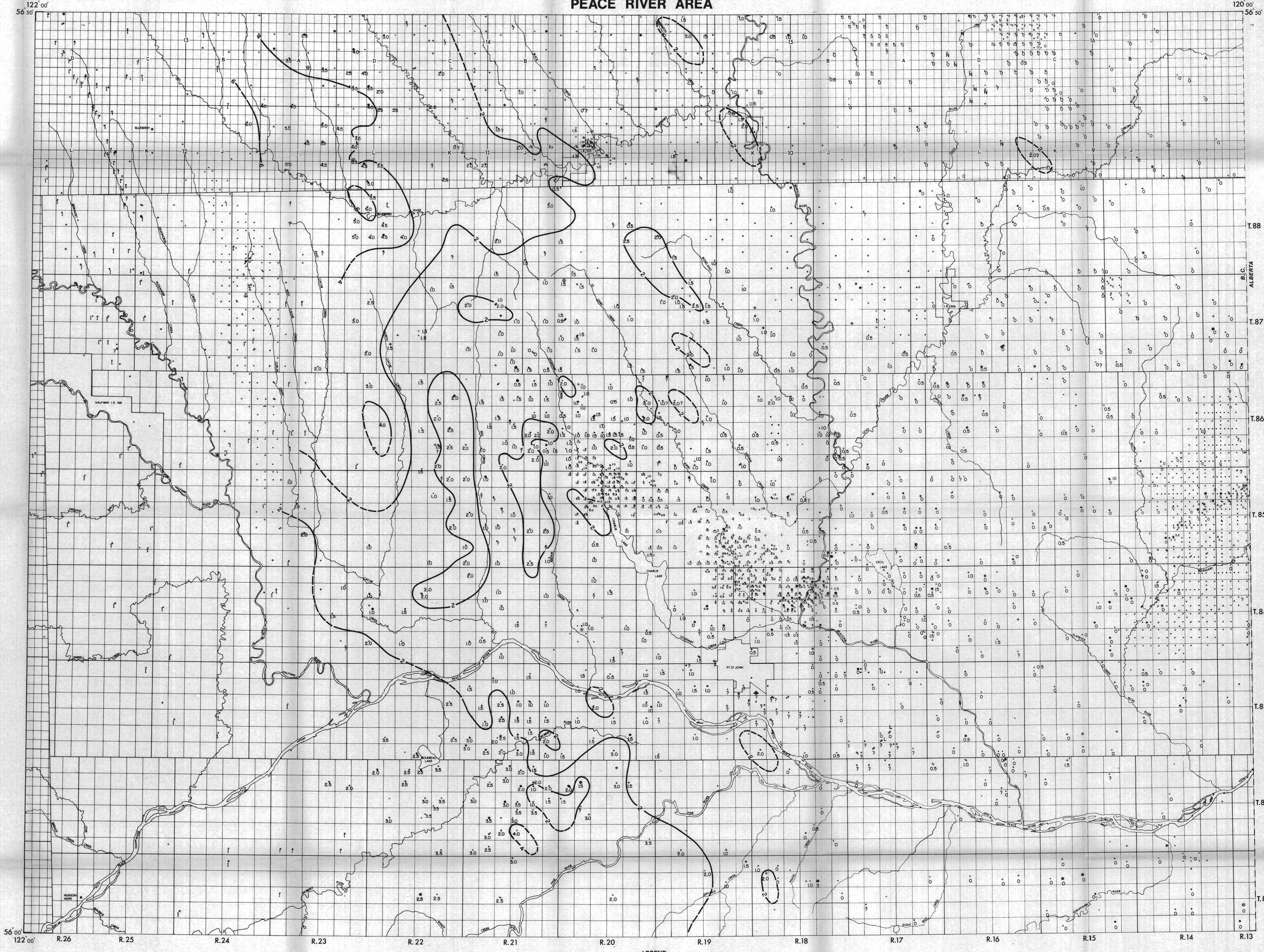
ISOPACH OF ARTEX MEMBER

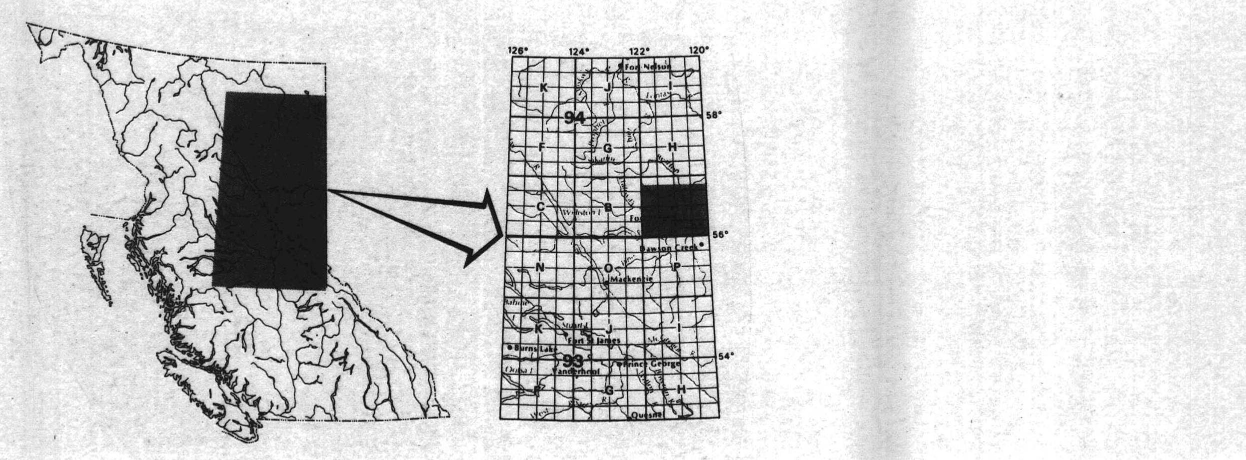
Contour Interval: 3m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: R.G. Jolley
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

MAP 2 SOUTH HALF

NORTH SHEET 94-A
PEACE RIVER AREA





LEGEND

Artex net sand isopach
Artex net sand isopach (approximate)
? Old well without gamma-ray log
2.0 ? Posted net-sand value uncertain (gamma-ray scale questionable)
I Artex indistinguishable (merged with ss above and below)
L Logs not deep enough
N Artex not deposited
Well picks are to nearest 0.5m
No "O" contour given, to avoid congesting maps
Wells without data did not reach Artex or are confidential

Spudded
Drilling Incomplete
Potential
Oil
Gas
Multiple Oil
Multiple Gas
Multiple Oil and Gas
Concurrent Oil and Gas
Abandoned Oil
Abandoned Gas
Abandoned
Gas Injection
Water Injection
Water Source
Disposal
Observation

Scale of Kilometres
1 0 2 4 6 8 10 12 14 16

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

NET SAND ISOPACH, ARTEX MEMBER
(GAMMA-RAY CUTOFF = 60 API UNIT)

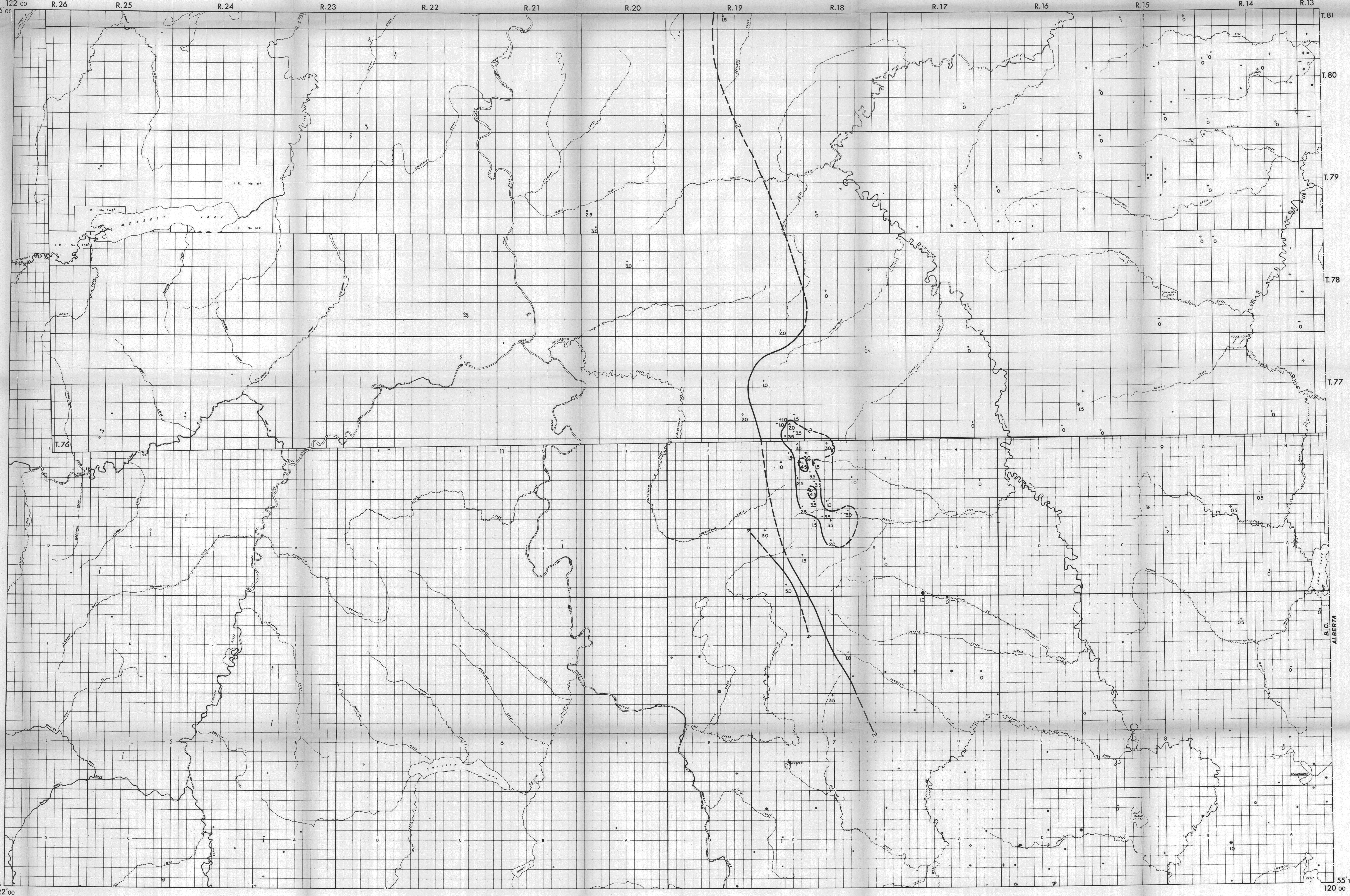
Contours: 2, 4, and 6m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: R.G. Jolley
Compiled by: S. Chicorelli	Date: April 1990

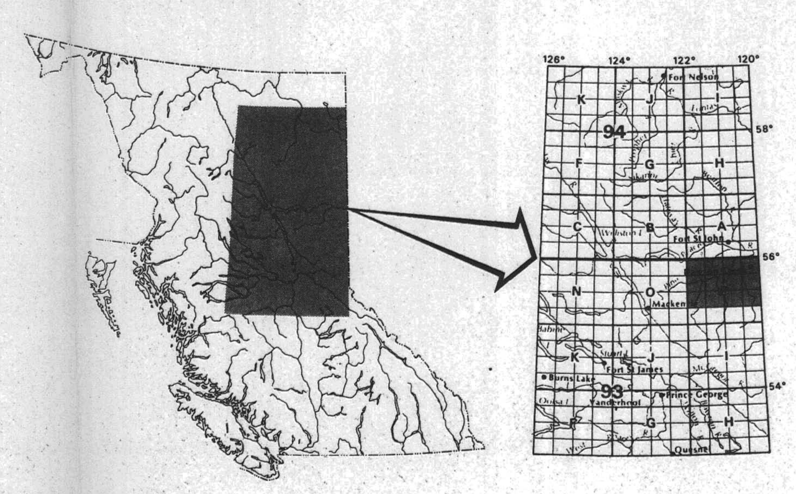
To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

MAP 3 NORTH HALF

1040
(S.P 1990-1)
93-P

SOUTH SHEET 93-P
PEACE RIVER AREA





- Artex net sand isopach
- Artex net sand isopach (approximate)
- ? Old well without gamma-ray log
- 2.0 ? Posted net-sand value uncertain (gamma-ray scale questionable)
- I Artex indistinguishable (merged with ss above and below)
- L Logs not deep enough
- N Artex not deposited
- Well picks are to nearest 0.5m
- No "O" contour given, to avoid congesting map
- Wells without data did not reach Artex or are confidential

- Spudded
- Drilling Incomplete
- Potential
- Oil
- Gas
- Multiple Oil
- Multiple Gas
- Multiple Oil and Gas
- Concurrent Oil and Gas
- Abandoned Oil
- Abandoned Gas
- Abandoned
- Gas Injection
- Water Injection
- Water Source
- Disposal
- Observation

Scale of Kilometres

1 0 2 4 6 8 10 12 14 16

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

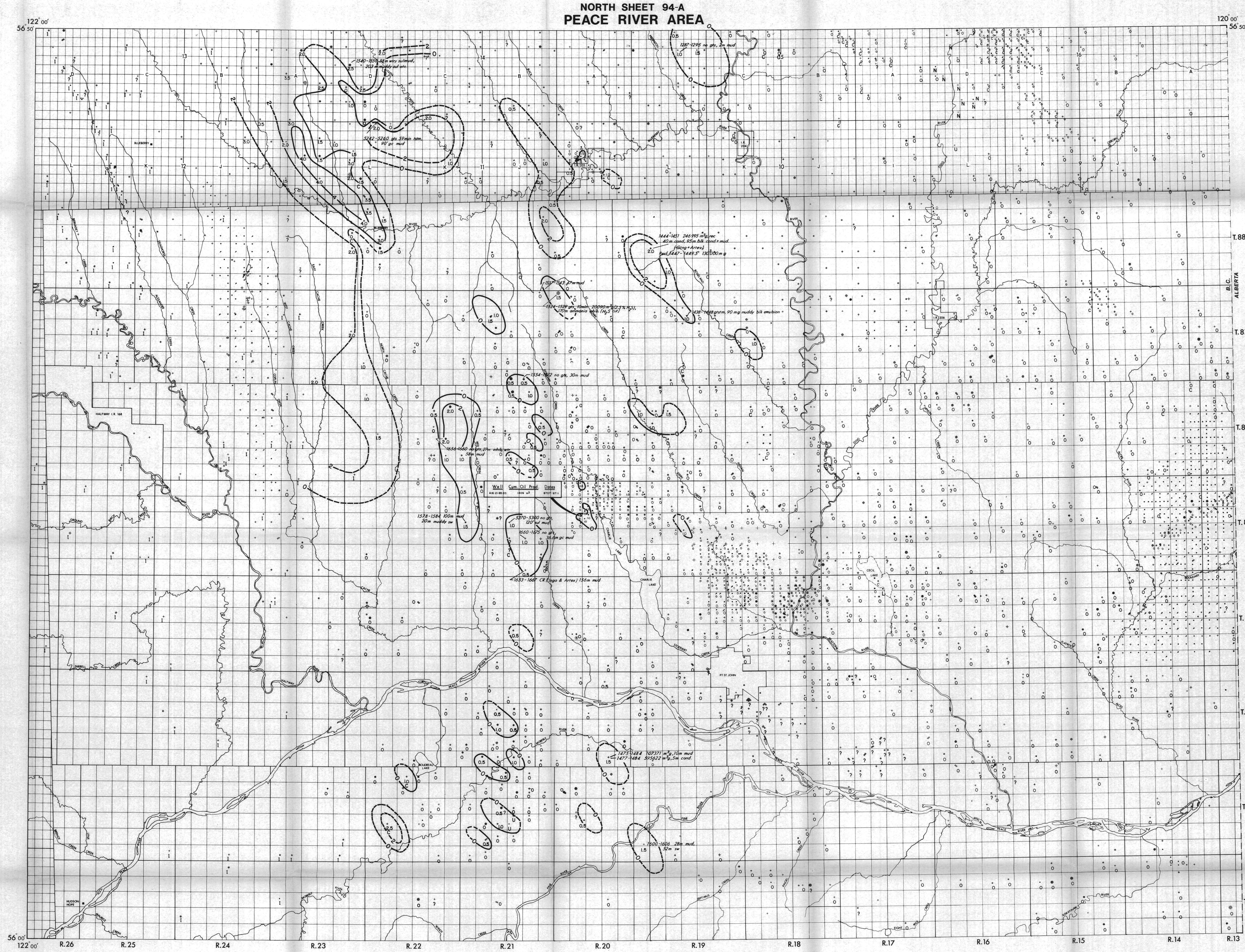
NET SAND ISOPACH, ARTEX MEMBER
(GAMMA-RAY CUTOFF = 60 API UNIT)

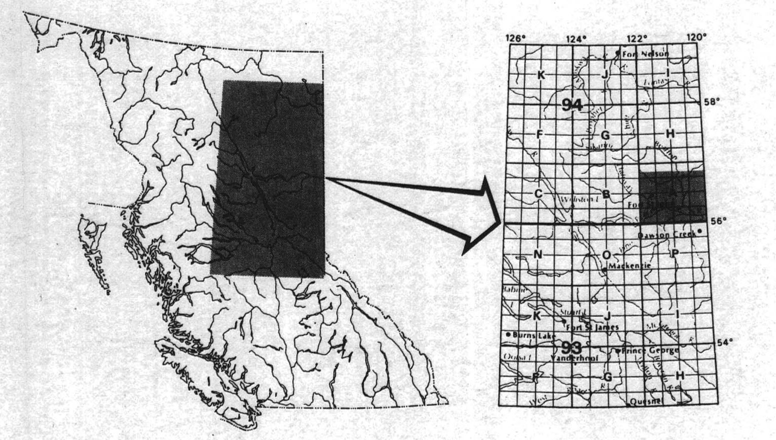
Contours: 2 and 4m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: E. Mullins
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

MAP 3 SOUTH HALF

NORTH SHEET 94-A
PEACE RIVER AREA





LEGEND

- Artex net porous sand isopach.
- Artex net porous sand isopach (approximate).
- ? Old well without gamma-ray or porosity logs.
- 0.5? Net-sand value uncertain (e.g. old GRN Log).
- C Artex cored.
- CR Combined recovery.
- I Artex indistinguishable (merged with ss above and below).
- U Unable to calculate net pay (e.g. poor logs; cycle skipping; logged through casing).
- L Logs not deep enough.
- N Artex not deposited.

Well picks are to nearest 0.5m
Wells without data did not reach Artex or are confidential.
Drill-stem tests listed are for discrete Artex tests only (excludes tests which overlap other porous units, e.g. Halfway Formation)

Spudded
Drilling Incomplete
Potential
Oil
Gas
Multiple Oil
Multiple Gas
Multiple Oil and Gas
Concurrent Oil and Gas
Abandoned Oil
Abandoned Gas
Abandoned
Gas Injection
Water Injection
Water Source
Disposal
Observation

Scale of Kilometres
1 0 2 4 6 8 10 12 14 16

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

ARTEX MEMBER, NET POROUS SAND ISOPACH, DRILL - STEM TESTS, PRODUCTION DATA, AND CORES (LOG - POROSITY CUTOFF = 5%)

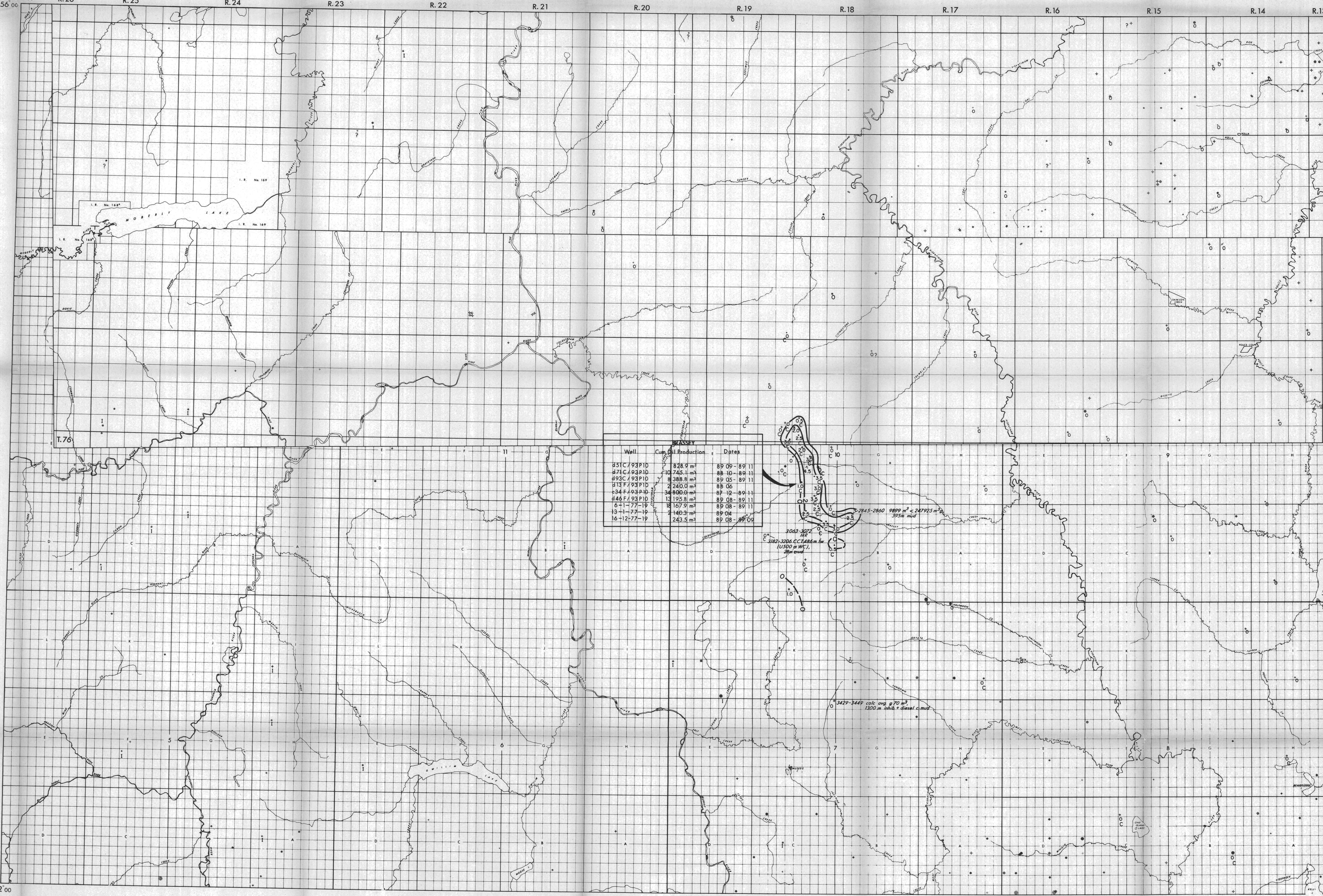
Contour Interval: 2m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: R.G. Jolley
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

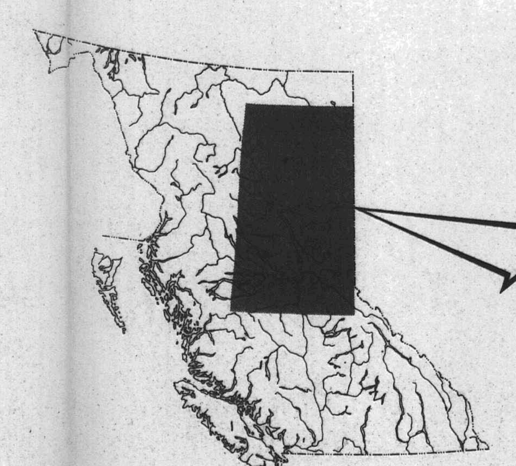
MAP 4 NORTH HALF

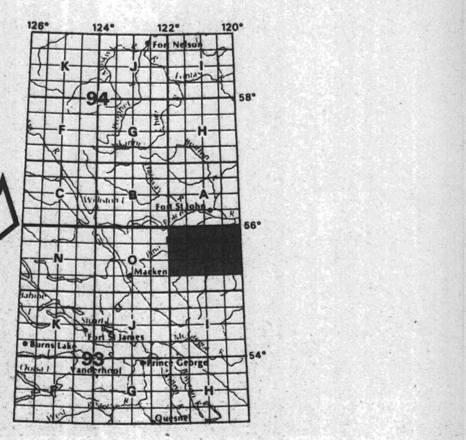
1040
(S.P. 1990-1)
93-P

SOUTH SHEET 93-P
PEACE RIVER AREA



Well	Cum Oil Production	Dates
d51C/93P10	828.9 m³	89 09 - 89 11
d71C/93P10	10 745.1 m³	88 10 - 89 11
d93C/93P10	8 388.8 m³	89 05 - 89 11
d13F/93P10	2 240.0 m³	88 06
c34F/93P10	34 800.0 m³	87 12 - 89 11
d46F/93P10	13 195.8 m³	89 08 - 89 11
6-1-77-19	18 167.9 m³	89 08 - 89 11
13-1-77-19	2 140.3 m³	89 04
16-12-77-19	243.5 m³	89 08 - 89 09





LEGEND

- Artex net porous sand isopach
- Artex net porous sand isopach (approximate)
- ? Old well without gamma-ray or porosity logs
- C Artex Cored
- I Artex indistinguishable (merged with ss above and below)

Well picks are to nearest 0.5m
Wells without data did not reach Artex or are confidential.
Drill-stem tests listed are for discrete Artex tests only (excludes tests which overlap other porous units, e.g. Halfway Formation)

Spudded
Drilling Incomplete
Potential
Oil
Gas
Multiple Oil
Multiple Gas
Multiple Oil and Gas
Concurrent Oil and Gas
Abandoned Oil
Abandoned Gas
Abandoned
Gas Injection
Water Injection
Water Source
Disposal
Observation

Scale of Kilometres
1 0 2 4 6 8 10 12 14 16

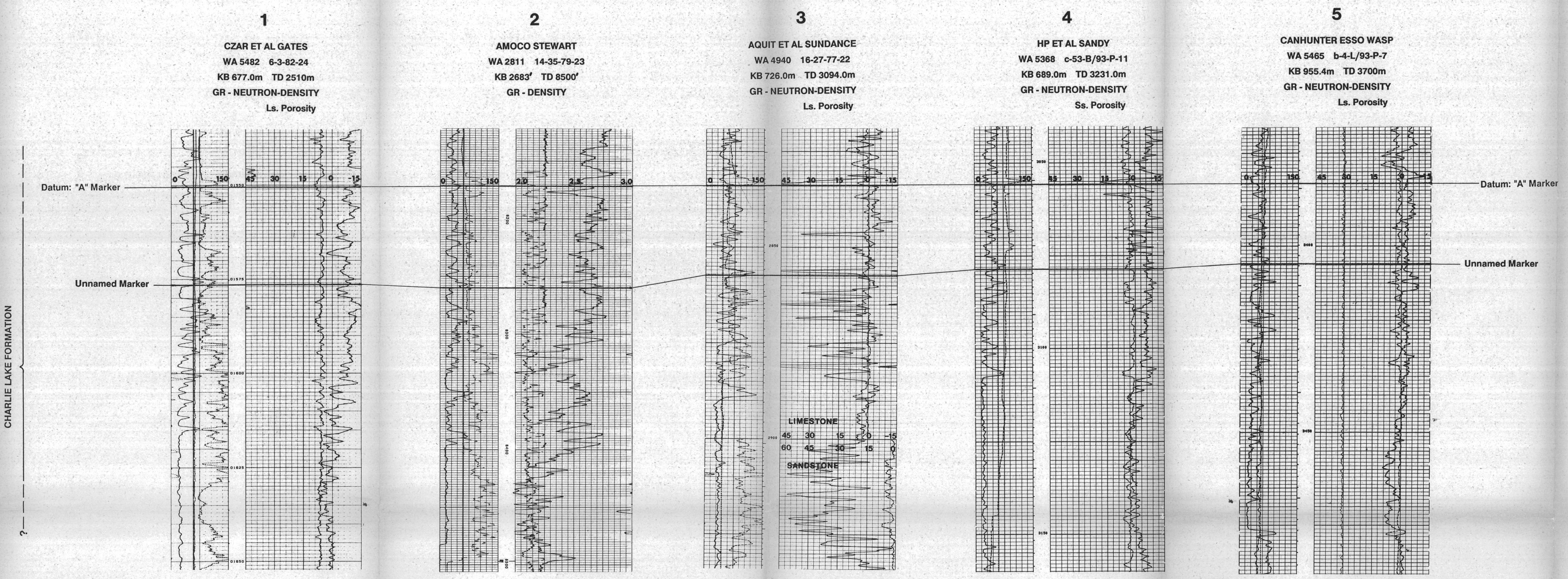
Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

ARTEX MEMBER, NET POROUS SAND ISOPACH, DRILL-STEM TESTS, PRODUCTION DATA, AND CORES (LOG - POROSITY CUTOFF = 5%)

Contour interval: 2m	Scale: 1:125000
Interpreted by: R. Higgs	Draughted by: S.H. Lowe
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

MAP 4 SOUTH HALF



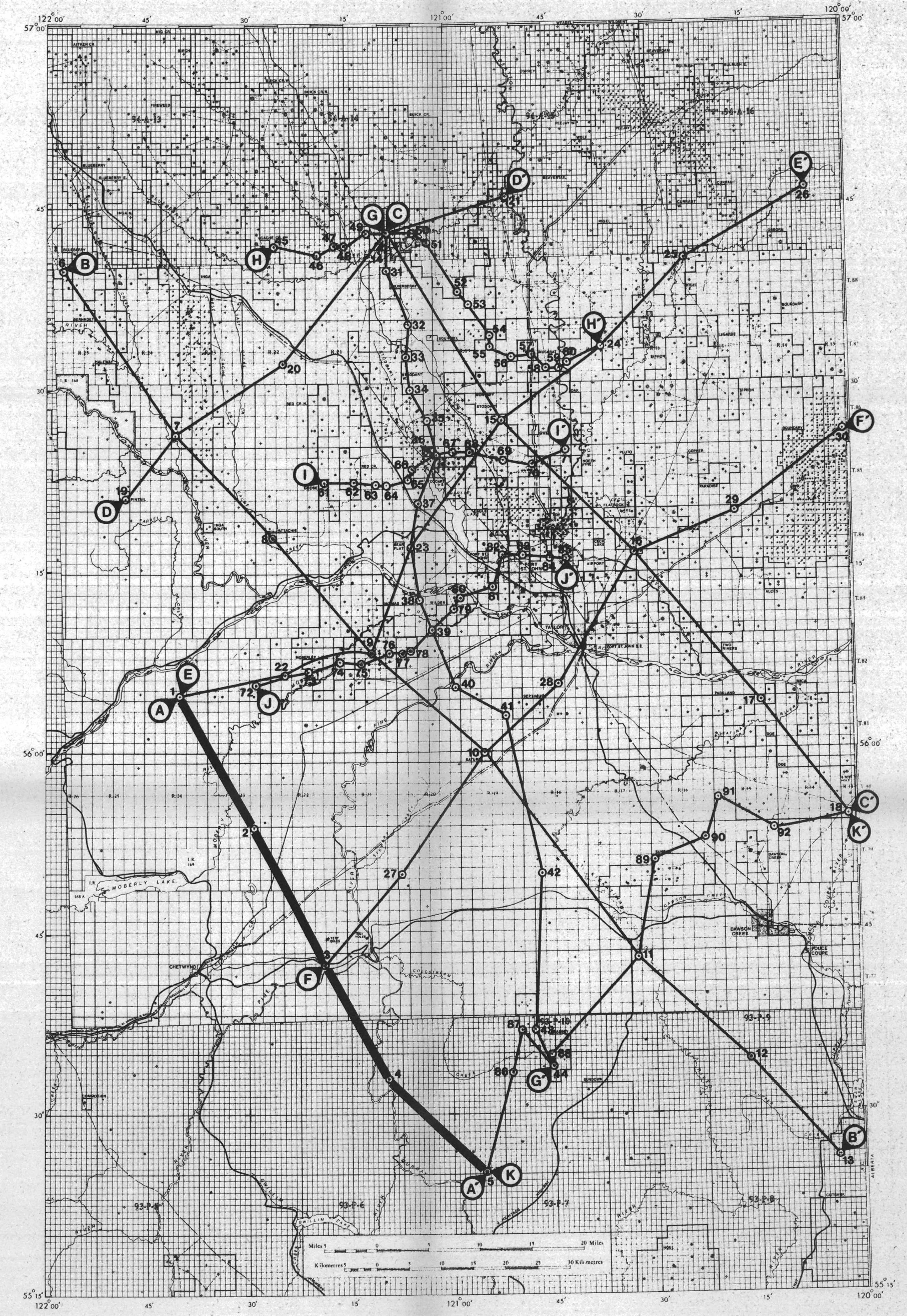
Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

Peace River Area, British Columbia

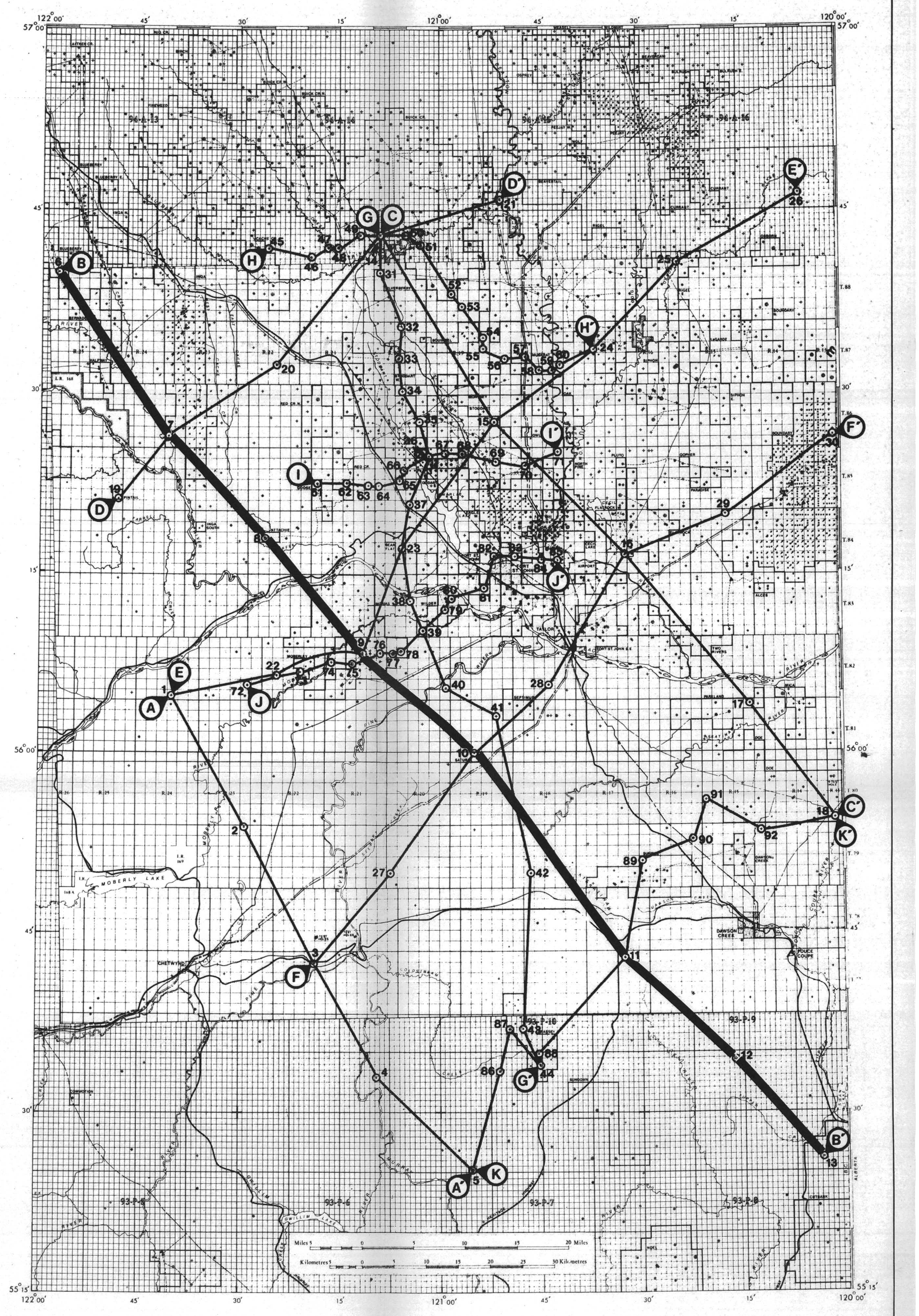
Artex Member Subsurface Correlation Stratigraphic Cross-Section A - A′

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs



X-SEC A-A′ 1990-1



LEGEND

Core

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

Peace River Area, British Columbia

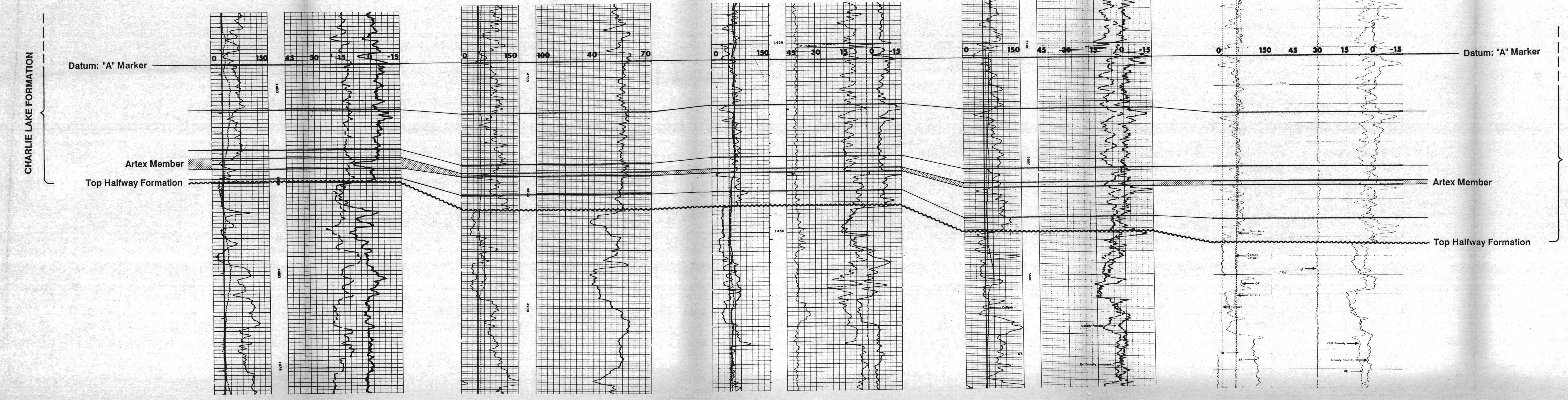
Artex Member Subsurface Correlation Stratigraphic Cross-Section B – B′

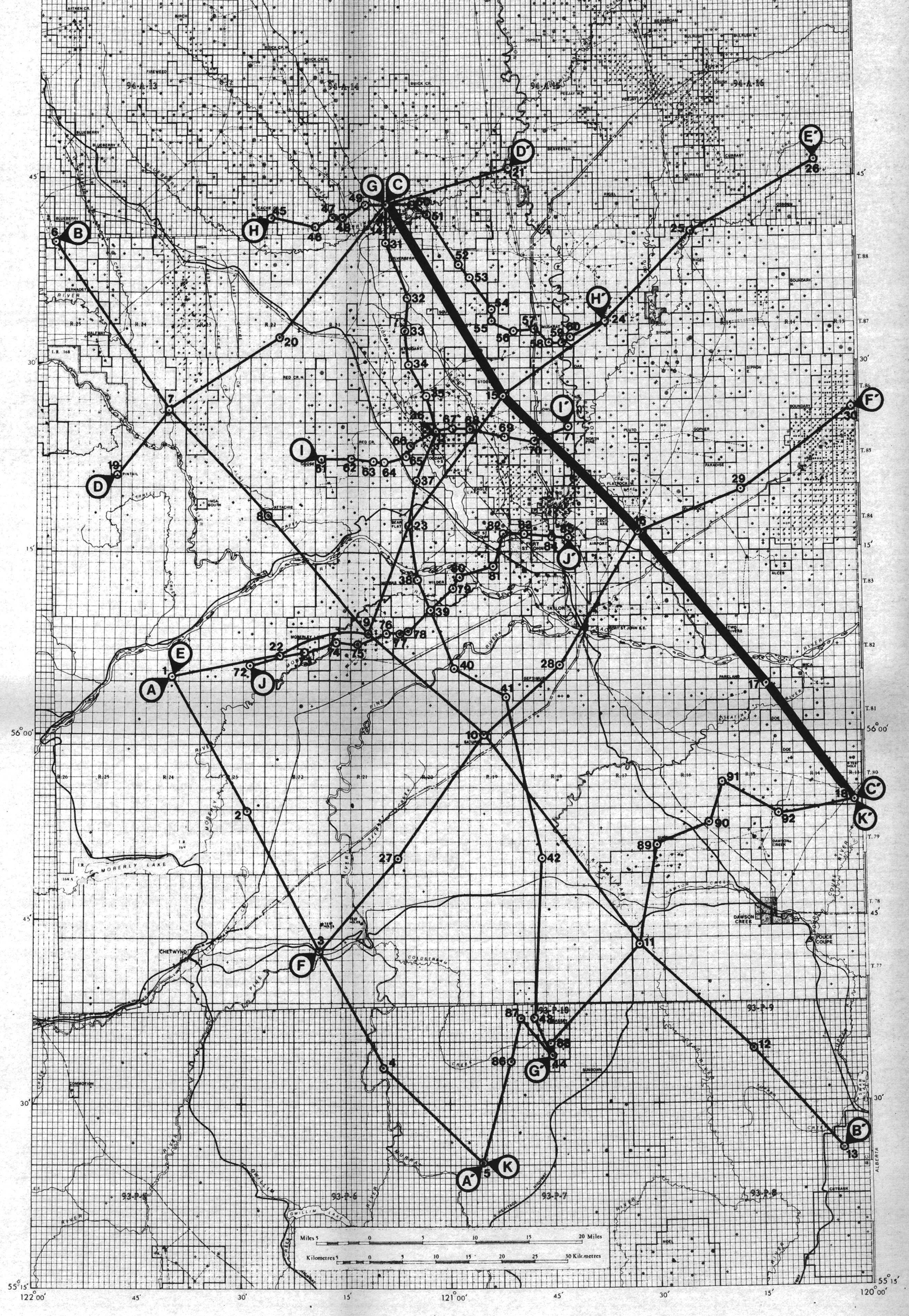
No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC B-B′ 1990-1

14	15	16	17	18
DOME BUICK	WOODS WAINOCO STODDART	SCURRY CEGO FLATROCK	GULF ET AL PARKLAND	DOME PCP ET AL DOE
WA 5665 d-52-J/94-A-11	WA 3812 6-13-86-19	WA 6245 A16-12-84-17	WA 4053 10-35-81-15	WA 6123 1-12-80-14
KB 759.4m TD 1550m	KB 2366′ TD 6060′	KB 658.0m TD 1980m	KB 2363′ TD 12420′	KB 650.2m TD 1783.8m
GR - NEUTRON - DENSITY	GR - SONIC	GR - NEUTRON-DENSITY	GR - NEUTRON - DENSITY	GR - NEUTRON-DENSITY
Ss. Porosity		Ss. Porosity	Ls. Porosity	Ls. Porosity





Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

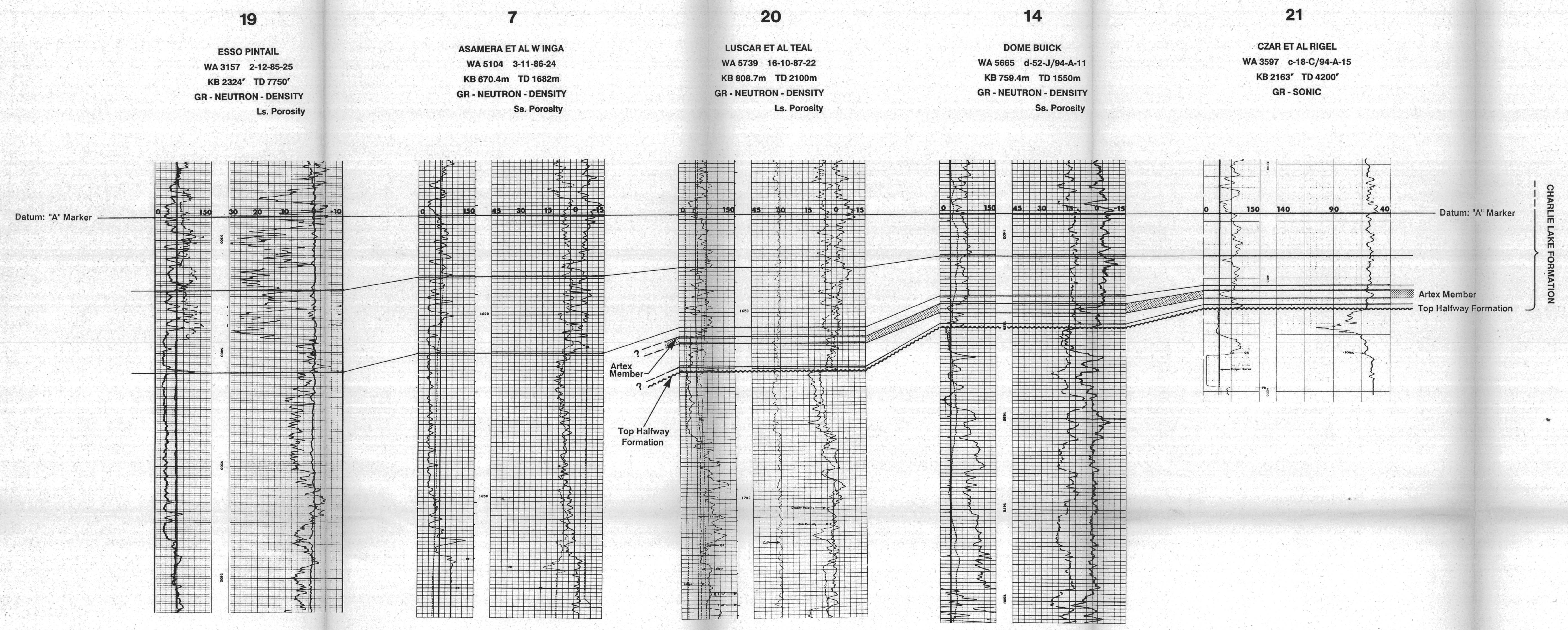
Peace River Area, British Columbia

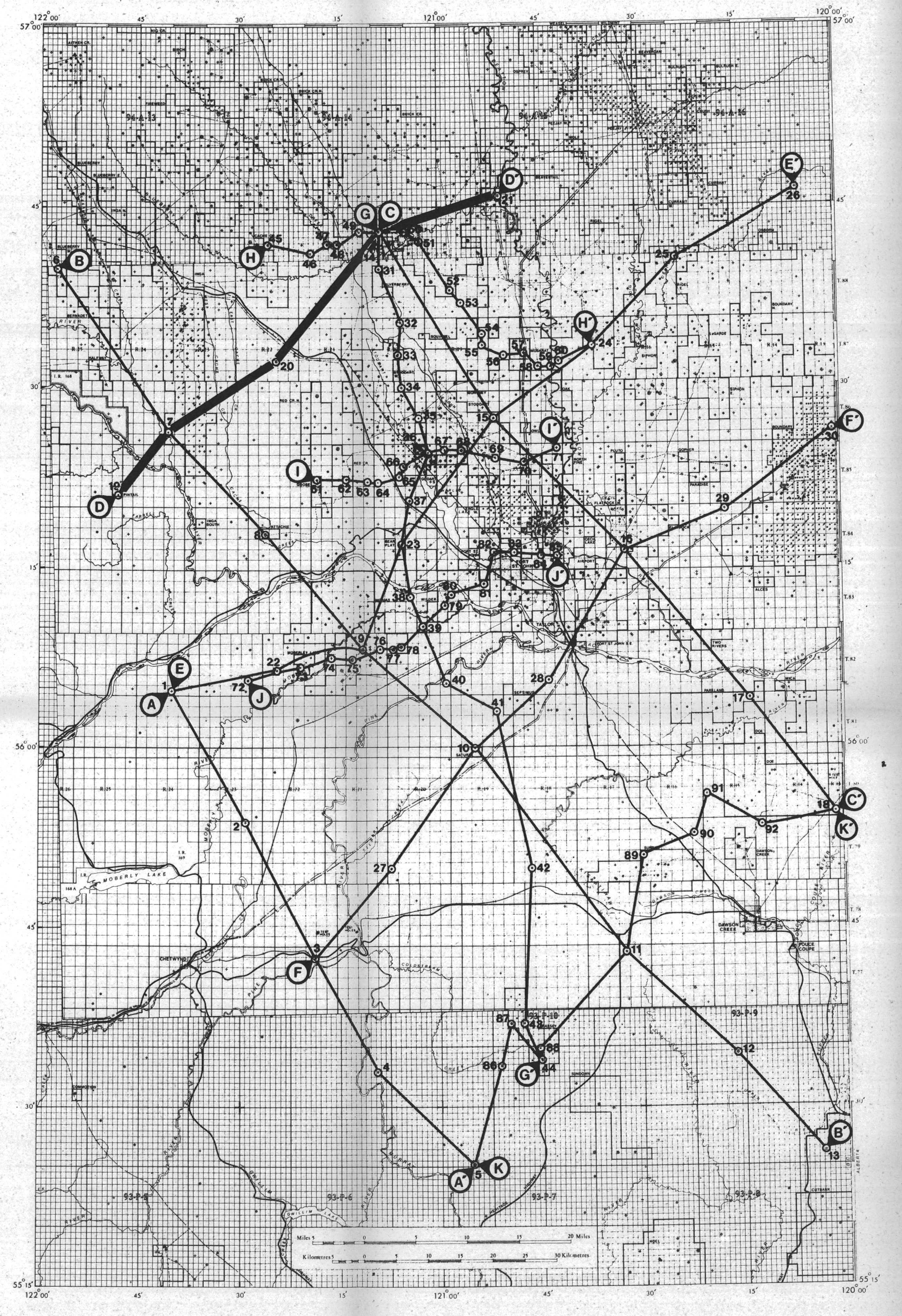
Artex Member Subsurface Correlation
Stratigraphic Cross-Section C - C′

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC C-C′ 1990-1





Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

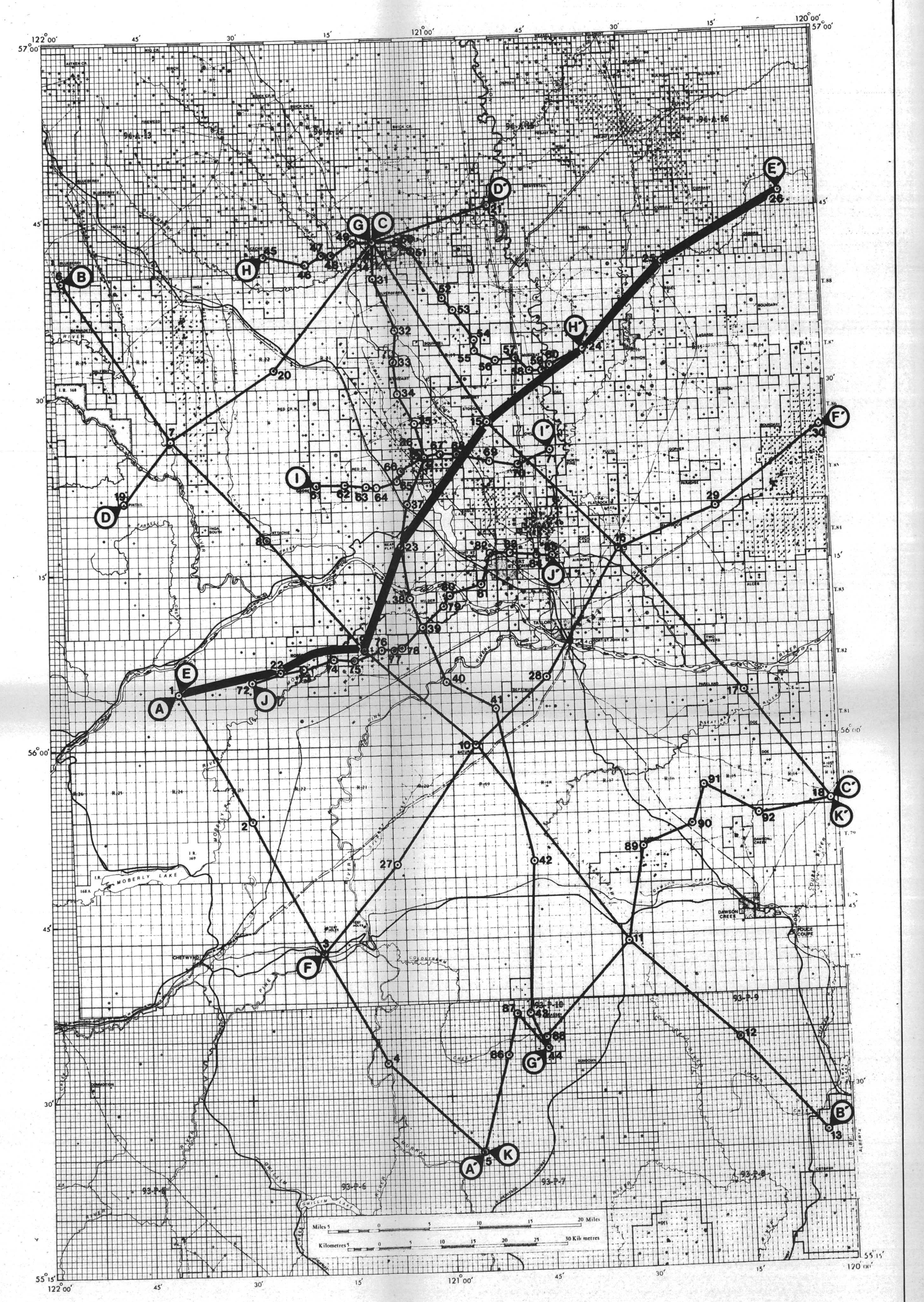
Peace River Area, British Columbia

Artex Member Subsurface Correlation
Stratigraphic Cross-Section D - D'

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC D-D' 1990-1



LEGEND

Core

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

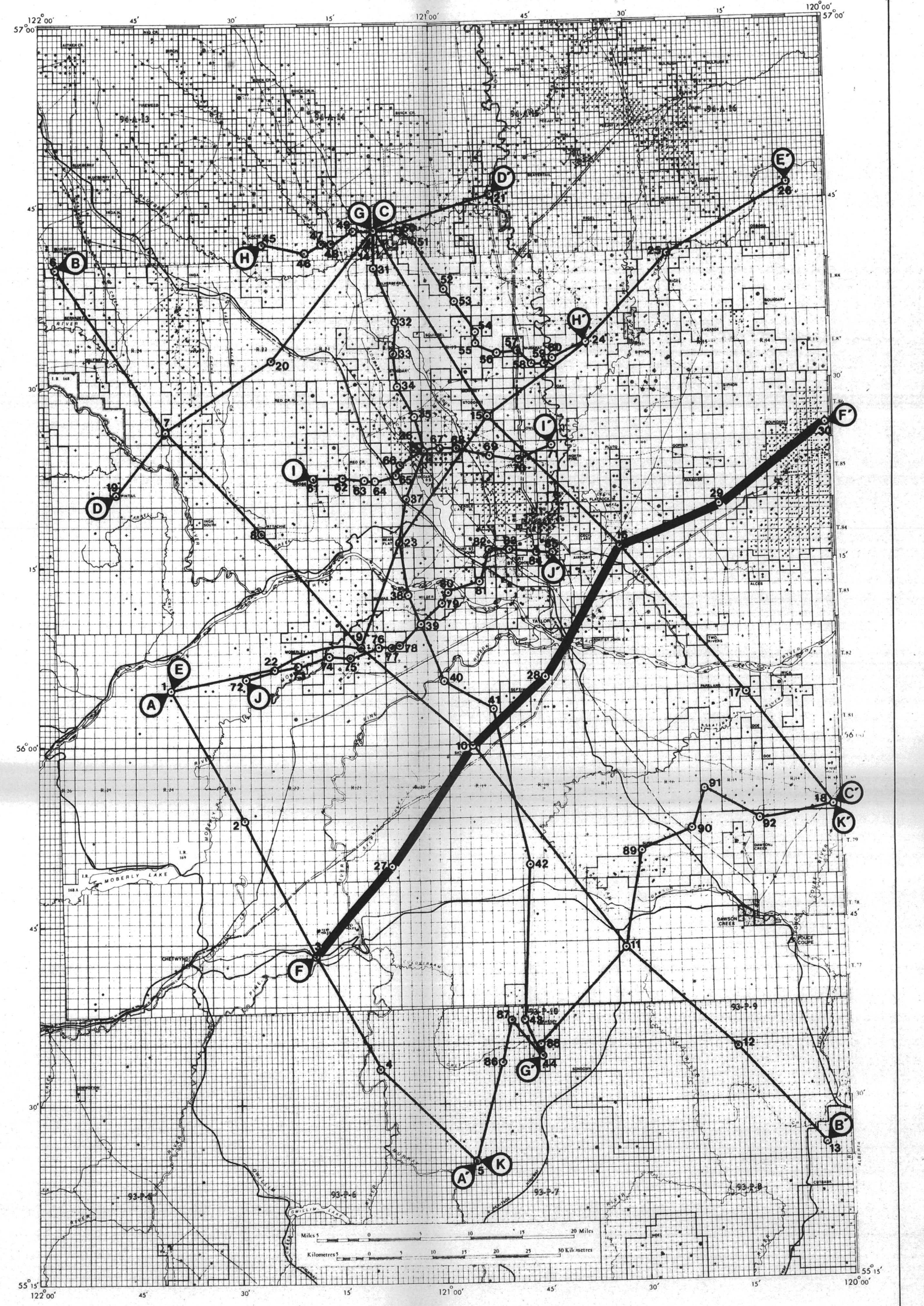
Peace River Area, British Columbia

Artex Member Subsurface Correlation
Stratigraphic Cross-Section E-E'

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC E-E' 1990-1



Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

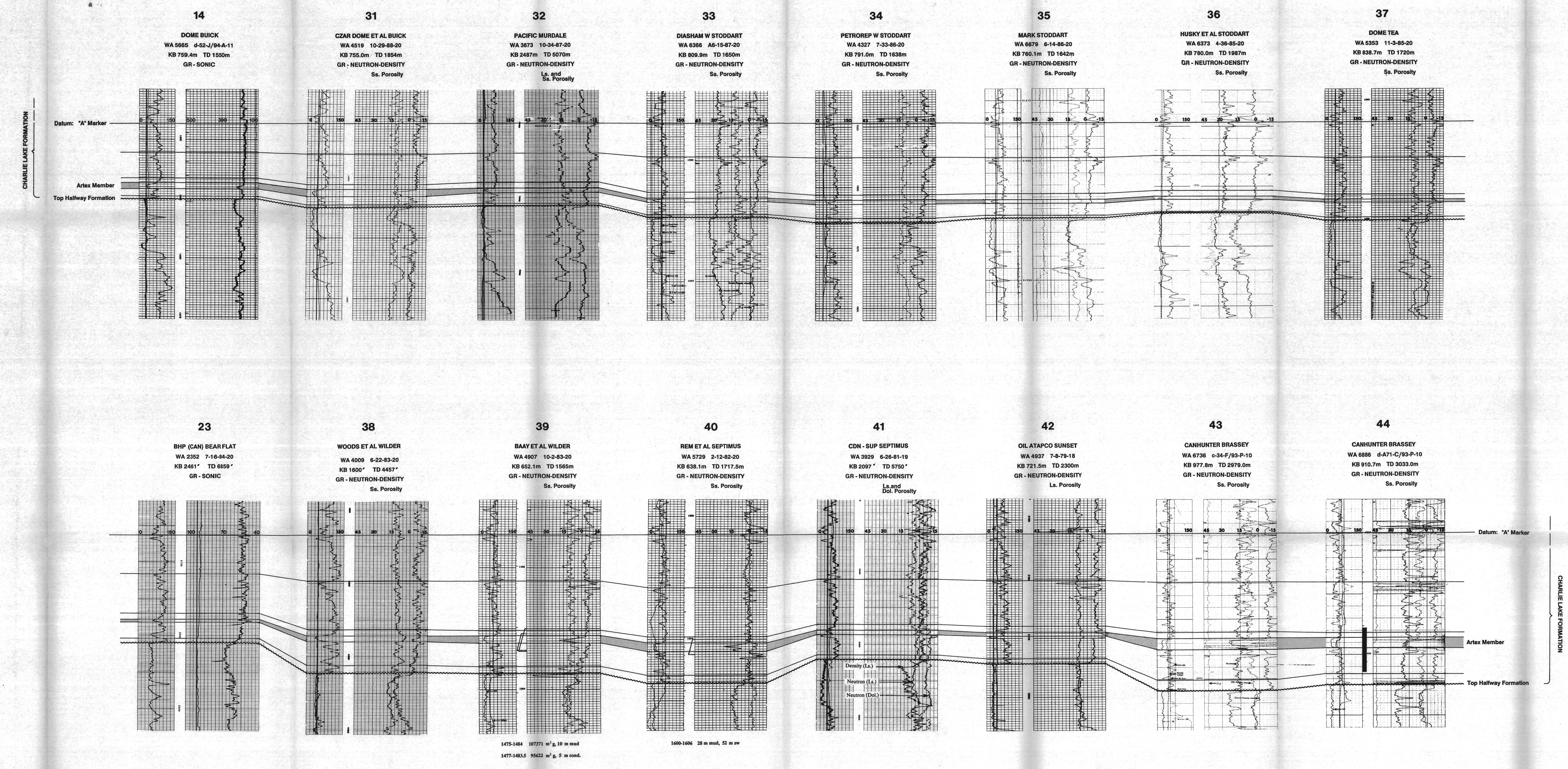
Peace River Area, British Columbia

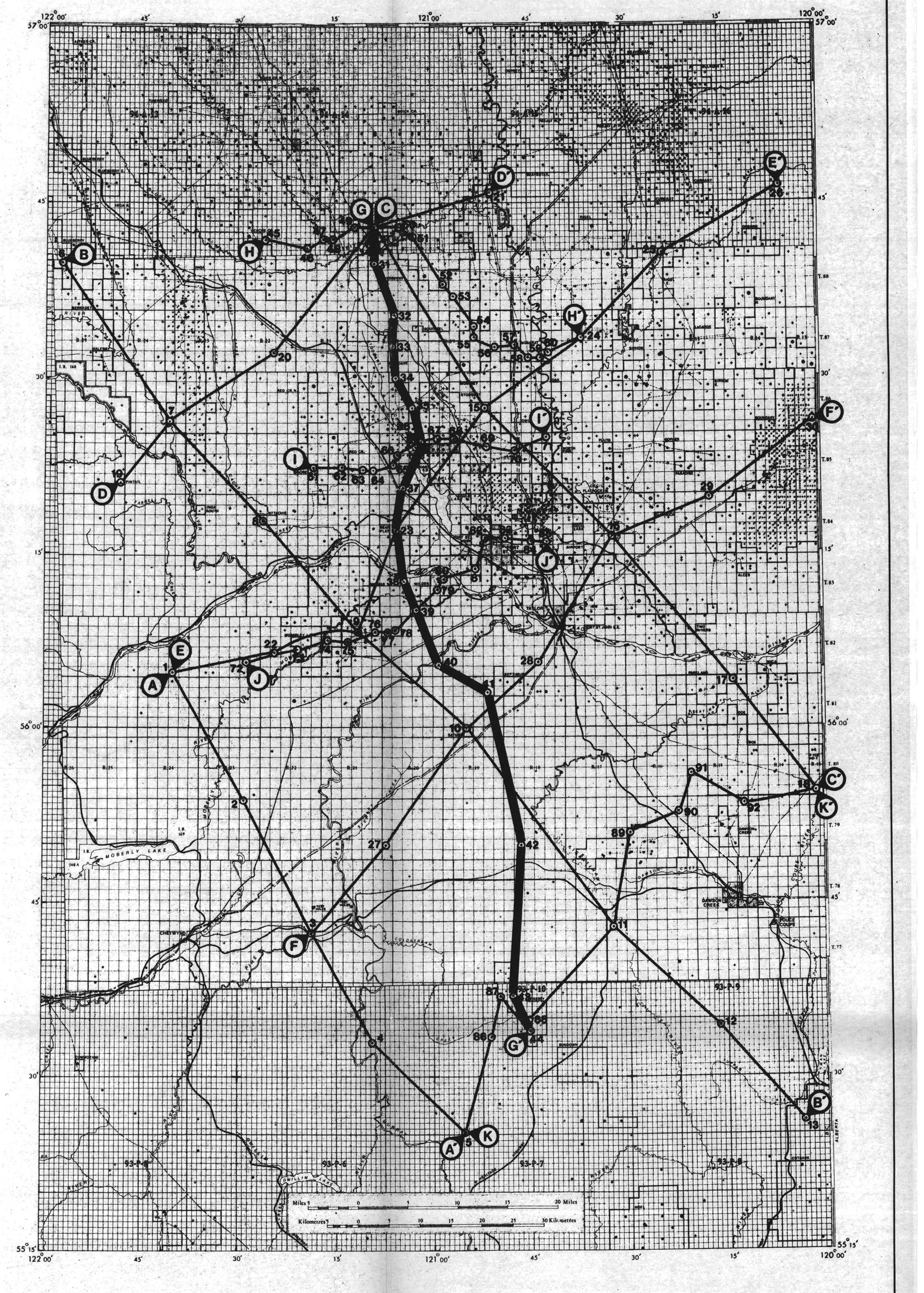
Artex Member Subsurface Correlation
Stratigraphic Cross-Section F-F'

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC F-F' 1990-1





LEGEND

Core

Drill Stem Test

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

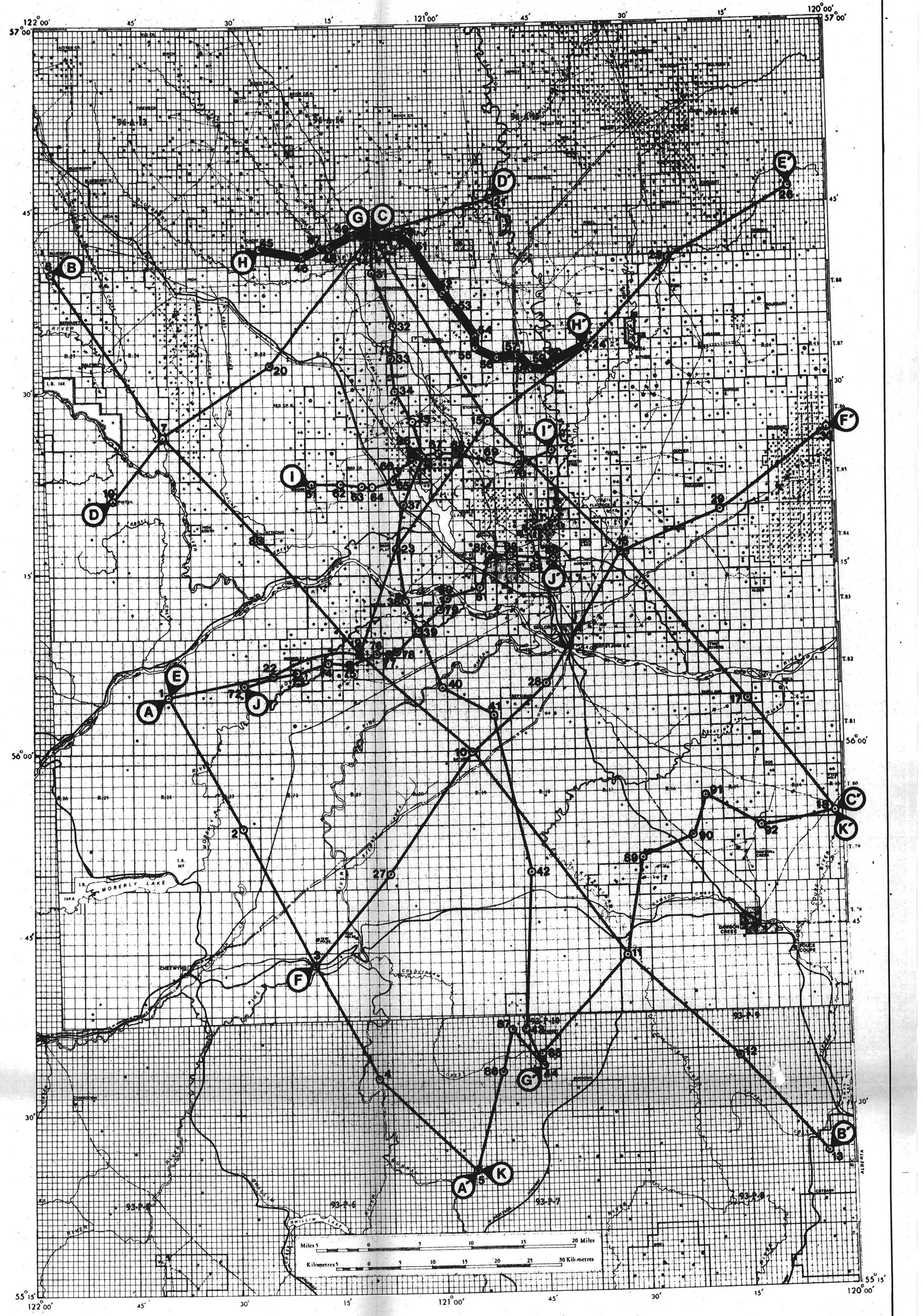
Peace River Area, British Columbia

Artex Member Subsurface Correlation Stratigraphic Cross-Section G-G′

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC G-G′ 1990-1



LEGEND

Drill Stem Test

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

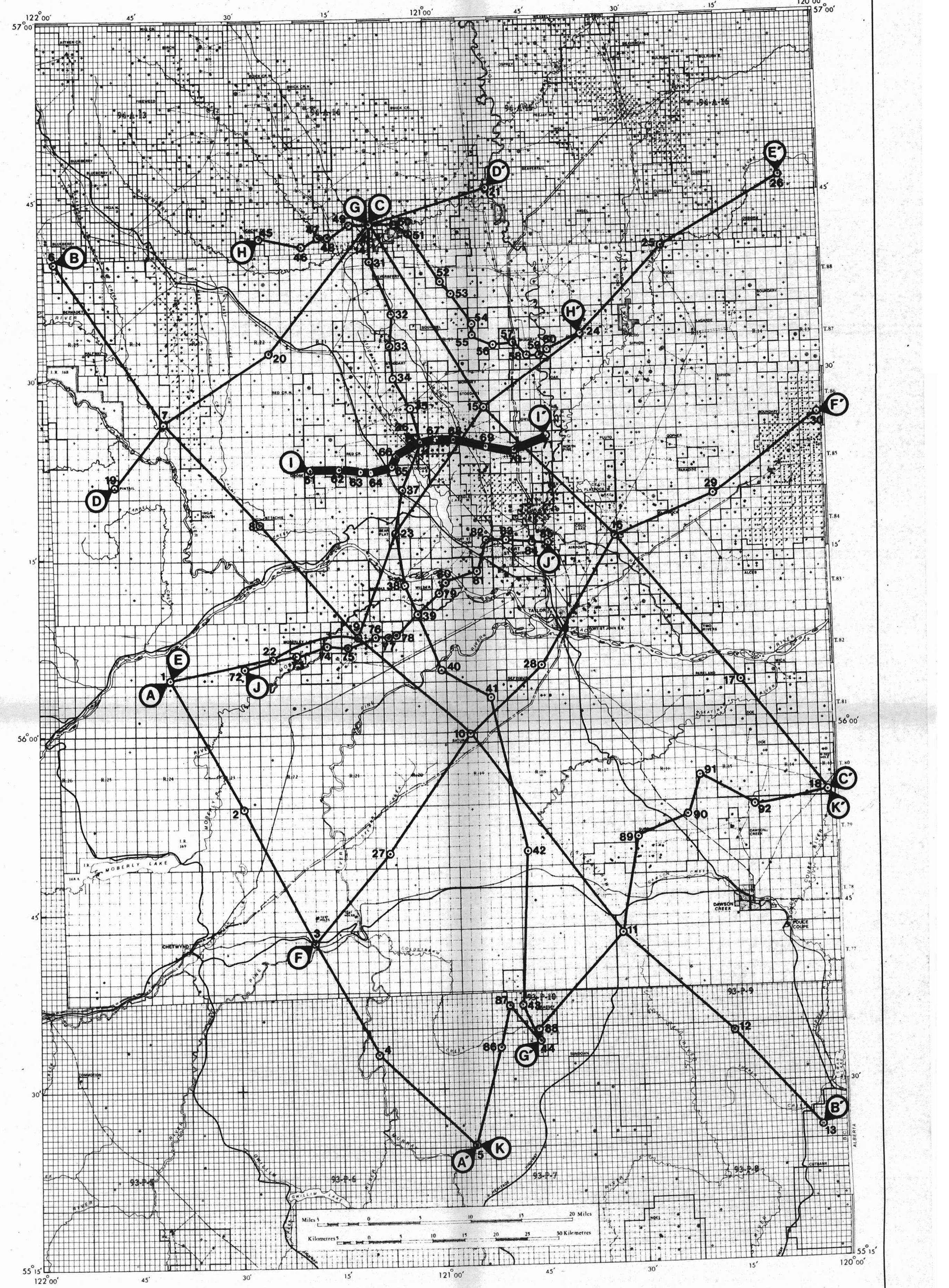
Peace River Area, British Columbia

Artex Member Subsurface Correlation Stratigraphic Cross-Section H-H′

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC H-H′ 1990-1



Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

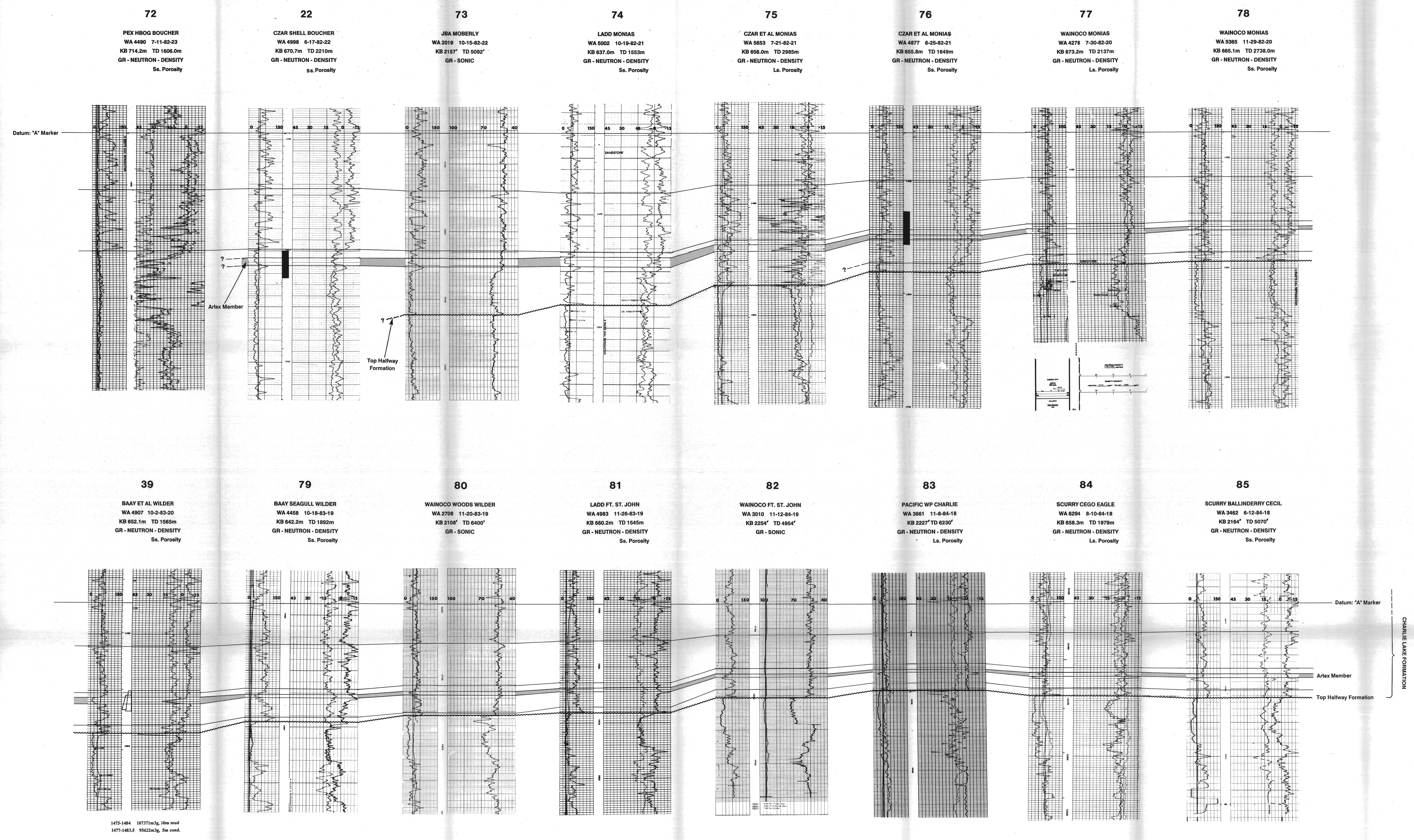
Peace River Area, British Columbia

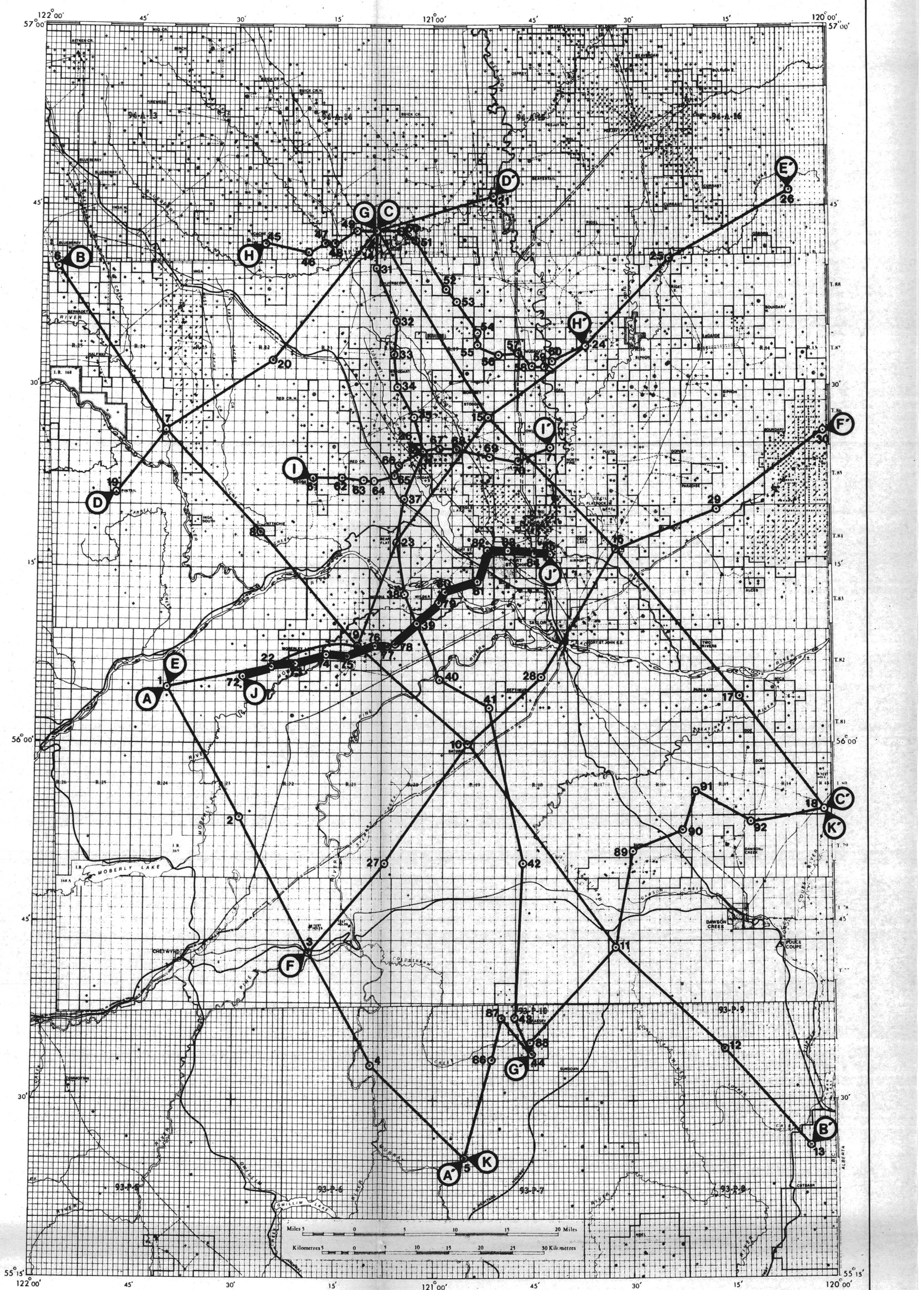
Artex Member Subsurface Correlation Stratigraphic Cross-Section I - I′

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC I-I′ 1990-1





LEGEND

Core

Drill Stem Test

Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

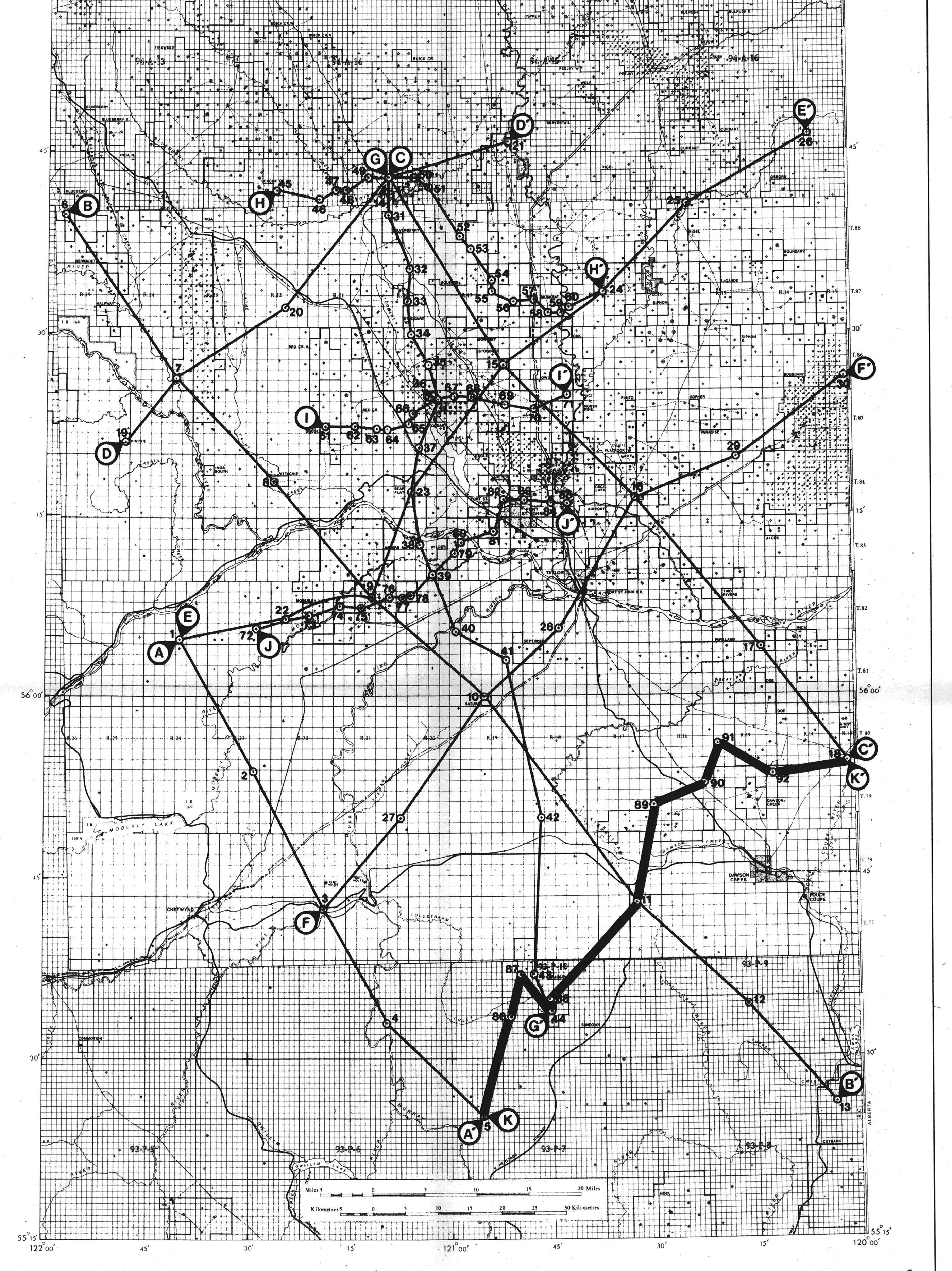
Peace River Area, British Columbia

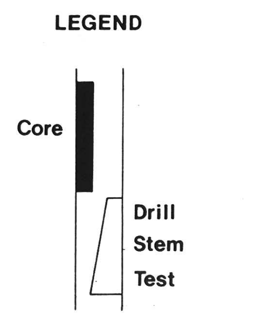
Artex Member Subsurface Correlation Stratigraphic Cross-Section J–J′

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC J-J′ 1990-1





Province of British Columbia Ministry of Energy, Mines and Petroleum Resources

Peace River Area, British Columbia

Artex Member Subsurface Correlation Stratigraphic Cross-Section K-K'

No Horizontal Scale	Datum: 'A' Marker
Interpreted by: R. Higgs	Draughted by: H.L., R.S., R.J., E.M.
Compiled by: S. Chicorelli	Date: April 1990

To accompany Petroleum Geology Special Paper 1990-1, by R. Higgs

X-SEC K-K' 1990-1