THE JURASSIC - CRETACEOUS BOUNDARY UNITS AND ASSOCIATED HYDROCARBON POOLS IN THE NITON FIELD, WEST - CENTRAL ALBERTA

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ABSTRACT

Palynology-supported study of the Jurassic-Lower Cretaceous boundary strata indicates that the main hydrocarbon-producing zone of the Niton field - here informally called the "Niton B" unit - is of Upper Jurassic age and shallow - marine in origin.

Formerly considered as a part of a continental to transitional Lower Cretaceous (Lower Mannville Ellerslie) succession, or as the uppermost part of the marine Middle Jurassic Rock Creek Member, this distinct lithostratigraphic unit is built up of sandstones, siltstones and rare shales containing Oxfordian-Kimmeridgian palynofloral assemblages, and unconformably overlies marine sediments of the Rock Creek Member which are characterized by Bajocian palynoflora.

Above the Niton B unit, impersistent shales corresponding to the "Upper Fernie" also contain Oxfordian-Kimmeridgian palynofloral relics, and are succeeded by the Lower Mannville Ellerslie strata. The latter lack diagnostic fossils and flora and fill erosional valleys carved into the Jurassic units (lower Ellerslie), or blanket larger areas (upper Ellerslie).

The areal limits of the Niton B unit reflect 1) lateral facies changes illustrated by silting and shaling-out of the reservoir-quality sandstones at the periphery of the unit, and 2) post-depositional erosion which removed the sandstones in pre-Ellerslie valleys cut into the unit, and also truncated the unit at the regional unconformity surface close to its updip depositional edge.

Hydrocarbon reservoirs in the Niton field are associated with sandstones of the Rock Creek Member, with sandstones of the Niton B unit and with sandstones present in the upper part of the Ellerslie. Oil and gas which are stratigraphically trapped in the Niton B unit are the most important source of hydrocarbons in the Niton field.

INTRODUCTION

The Niton field is located in west-central Alberta, some 160 km west of Edmonton (Fig. 1), and extends over an area of approximately 370 km^2. To date, 138 wells have been drilled in the field, with most of them bottoming in the Jurassic Nordegg Member. Since the late seventies oil and gas has been produced from several stratigraphic zones in this field, mainly from multiple-sandstone sequences at the Jurassic-Lower Mannville boundary, and also from the Cardium Formation.

Due to extreme lateral variation of lithologies in the hydrocarbon-bearing boundary clastic sequences the stratigraphic position of the individual sandstones at the Jurassic-Lower Mannville boundary has been a matter of much discussion. The use of local names such as Niton 'A', 'B', 'C' and 'D' sands (or simply Niton 'A', 'B', 'C' and 'D') has added to the confusion concerning their stratigraphic position and age. Although it is now generally agreed that the Niton 'A' corresponds to the Lower Mannville Ellerslie Member, and the Niton 'C' and 'D' are Jurassic, the stratigraphic position of the Niton 'B' - the most prolific producer in the Niton field - is still under discussion, with the Lower Mannville Ellerslie Member ("Basal Quartz") and the Jurassic Rock Creek Member proposed as possible equivalent units.

In recent years, an accurate stratigraphic identification of the strata at the Jurassic - Lower Mannville boundary has become necessary for legal purposes such as lease sales and continuation, especially when the deeper rights reversion was implemented in 1984. An effort has therefore been directed in this study towards a better understanding of the Jurassic-Lower Mannville stratigraphy of the Niton field and towards a more accurate stratigraphic dating of its productive zones.

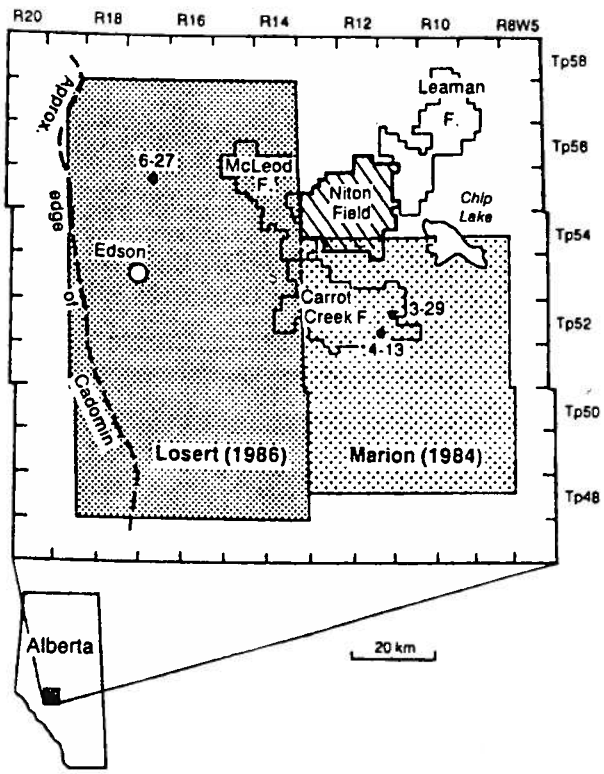

Fig. 1. Location map of the Niton field, and the study areas of Marion (1984) and Losert (1986). The numbers 6-27, 4-13, and 3-29 indicate the locations of the wells outside the Niton field that were used in this study.

PREVIOUS WORK

Except for a short abstract by Horne et al. (1982) no published work deals with the entire Niton field. Unfortunately, neither maps nor cross sections accompany the abstract and it is thus not clear whether ".. the reservoir sandstones .. of the Basal Quartz formation .. were deposited during Late Jurassic to Early Cretaceous transgression over an unconformable surface of Jurassic sediments " and " .. open marine sandstones deposited at the mouths of estuaries ... became the primary reservoir sandstones" refers to sandstones of the Rock Creek Member, or of the Niton B unit, or of the Lower Mannville Ellerslie Member.

Marion (1982, 1984) examined the Jurassic-Lower Mannville boundary sequence in the Carrot Creek - , West Pembina -, Pembina - and Cynthia-Pembina fields in his pioneering study of the Jurassic-Lower Cretaceous relationship in the subsurface of west-central Alberta. Stratigraphy, sedimentology and petrography of the Nordegg Member, the Poker Chip Shale, the Rock Creek Member, the "Upper Fernie" and the Ellerslie Member were discussed in this study, as were their depositional environments and intervening unconformities. Although only the southernmost part of the Niton field was included in the 3000 km^2 large study area (Fig. 1), many of the results are applicable to the whole Niton field. With new palynological data, however, alternative solutions to some of the problems addressed in the study can now be proposed.

Losert (1986) studied the subsurface geology of the Rock Creek Member and associated units in a 5500 km^2 area around Edson, immediately west of the Niton field (Fig. 1), with two cross-sections extending into the Niton field. Although a Jurassic age of the Niton B was established by palynofloral analysis, the unit at that time was not defined as a separate entity and was interpreted as the uppermost part of the Rock Creek Member (cross sections D-D' and E-E', Losert 1986).

METHODS OF STUDY

Using gamma-ray/sonic or gamma-ray/neutron + density - porosity logs, a set of eight northwest - southeast and twelve southwest - northeast working cross sections were constructed across the Niton field and adjoining areas to determine the geometry of and relationships between the stratigraphic units at the Jurassic - Lower Mannville boundary. From these were derived the four cross sections included in this study: section A-A' (Fig. 4), section B-B' (Fig. 5), section C-C' (Fig. 6) and section D-D' (Fig. 7). Their respective lines of section are shown in Fig. 2. In total, 220 well logs were studied and of these 85 per cent were included in the working cross sections. The examined interval encompassed all units between the Nordegg Member and the Glauconitic Sandstone (inclusive), with the latter used as a stratigraphic datum. However, prominent layers of calcareous rocks in the Ostracode Zone have also served as an additional datum where the top of the Glauconitic Sandstone was difficult to pick on logs. An isopach map of the Niton B gross sand (Fig. 9) was compiled to determine the areal geometry of the most important hydrocarbon-bearing zone of the Niton field, and to study the relationship between the sand geometry and extent of the associated Niton B pool.

Cores from 32 wells were studied and used for calibration of logs, and shale interlayers were sampled for palynological study and dating in 10 wells inside and three wells outside the Niton field.

Available technical data relevant to the hydrocarbon reservoirs (well logs, core analyses, DST - and flow-test results, completion data, production data and history) were evaluated and used to elucidate the nature and stratigraphic position of individual pools in the Niton field, especially those associated with the Niton B unit.

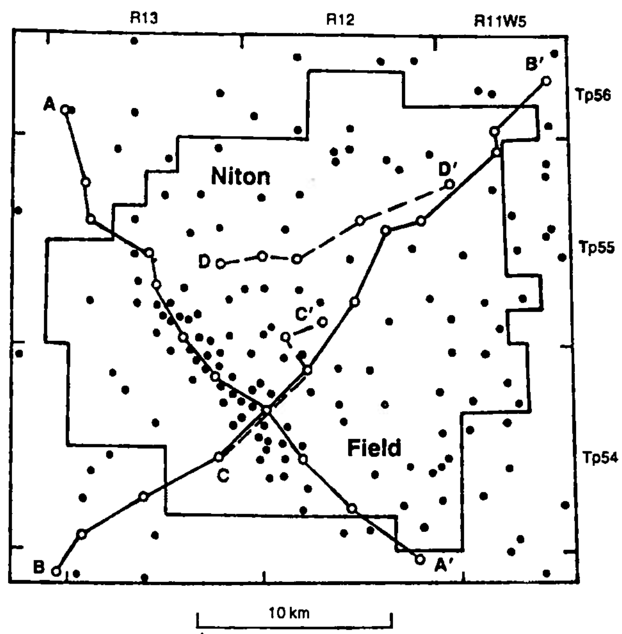

Fig. 2. Well control in the Niton field and adjacent area, and lines of the stratigraphic cross sections A-A', B-B', C-C' and D-D'.

OUTLINE OF LITHOSTRATIGRAPHY OF THE NITON FIELD

The lithostratigraphy of the Jurassic-Lower Cretaceous (Lower Mannville) boundary sequences in the Niton field is illustrated in the table of formations that also lists the typical diagnostic palynoflora and foraminifera (Fig. 3), and by four stratigraphic cross sections displayed in Figs. 4, 5, 6, and 7.

The Nordegg Member

The oldest Jurassic rocks in the Niton field are the sandstones and cherty and phosphatic carbonate rocks of the Lower Jurassic Nordegg Member. In the Niton field, this unit is unconformably underlain by the Mississippian Shunda Formation, and its thickness decreases from about 50 - 65 m in the southwestern part of the Niton field to about 20 - 40 m in its northeastern part.

The Poker Chip Shale

The Nordegg Member is overlain by the Poker Chip Shale, a Lower Jurassic (Toarcian) unit which is 10 - 25 m thick and consists of black shales with an upward increasing siltstone and sandstone content reflected by a generally upward-coarsening gamma-ray log pattern. One to three coarsening-upward pulses from 4 to 15 m thick can be recognized within the Poker Chip Shale. Where contacts between them are parallel to the Poker Chip - Rock Creek boundary, the pulses can be correlated over a 10 - 15 km distance (Fig. 4). Elsewhere, however, local channelling of the Rock Creek Member, such as that shown in the cross section B-B' (Fig. 5), may have partially or completely removed sediments of the upper pulse(s).

The Rock Creek Member

Above the Poker Chip Shale, the lithologically variable Rock Creek Member consists predominantly of marine, storm- and tidal-influenced shelf

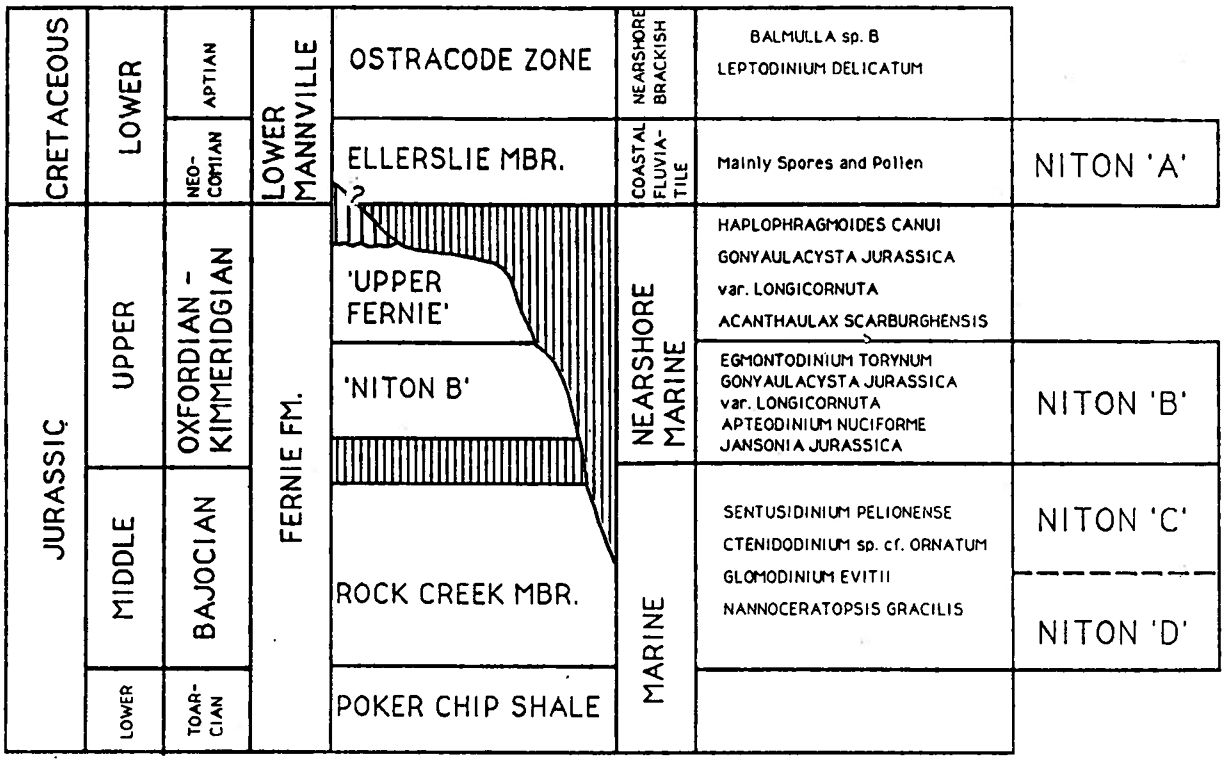

Fig. 3. Stratigraphy and diagnostic palynoflora and foraminifera of the Jurassic - Lower Mannville boundary sequences in the Niton field. Local stratigraphical terminology is at right.

deposits (Marion, 1982, 1984) represented by sandstones, siltstones and occasional coquinas and shaly interlayers which are often difficult to correlate from well to well. When partially eroded (Fig. 4) the unit is only 5 - 10 m thick, but elsewhere in the Niton field and in the adjacent areas its usual thickness is between 15 and 35 m. A regional thinning of the Rock Creek Member can be observed over a total distance of about 150 km, both to the southwest and northwest of the Niton field, approximately parallel to the cross section A-A'. The northeastward decrease in the thickness of the Rock Creek is, however, compensated by increased thickness of the Poker Chip Shale (Fig. 10).

Marion (l.c.) assumed that there was unconformity at the base of the Rock Creek Member based on the presence of shale clasts in the basal sandstone beds of the Rock Creek. However, it is possible that both the Poker Chip Shale and the Rock Creek Member form a single coarsening-upward sequence with no intervening unconformity. This alternative is discussed in following chapters.

In the local nomenclature (Figs. 3 and 12), the Rock Creek unit with its prominent sandstones corresponds to what has been termed Niton 'C' and Niton 'D' sandstones (or, simply, Niton 'C' and Niton 'D') in well-information cards, but the pronounced lateral variation of the lithology of the unit (cross sections Figs. 4, 5, 6 and 7) coupled with its partial erosion makes it impossible to apply the local nomenclature throughout the entire Niton field.

A juvenile ammonite Sonninia sp. found in a phosphatic nodule at the contact of the Rock Creek with the overlying "Upper Fernie" shale in the 4-13-52-12 W5 well (some 20 km south of the Niton field) indicates a Middle Jurassic (Bajocian) age of the Rock Creek Member (Marion l.c.). In the present study, this age has been confirmed by palynological analysis of shaly breaks in the Rock Creek sampled in several wells in and outside the Niton field (Figs. 6, 7 and 8) (see also Losert, 1986).

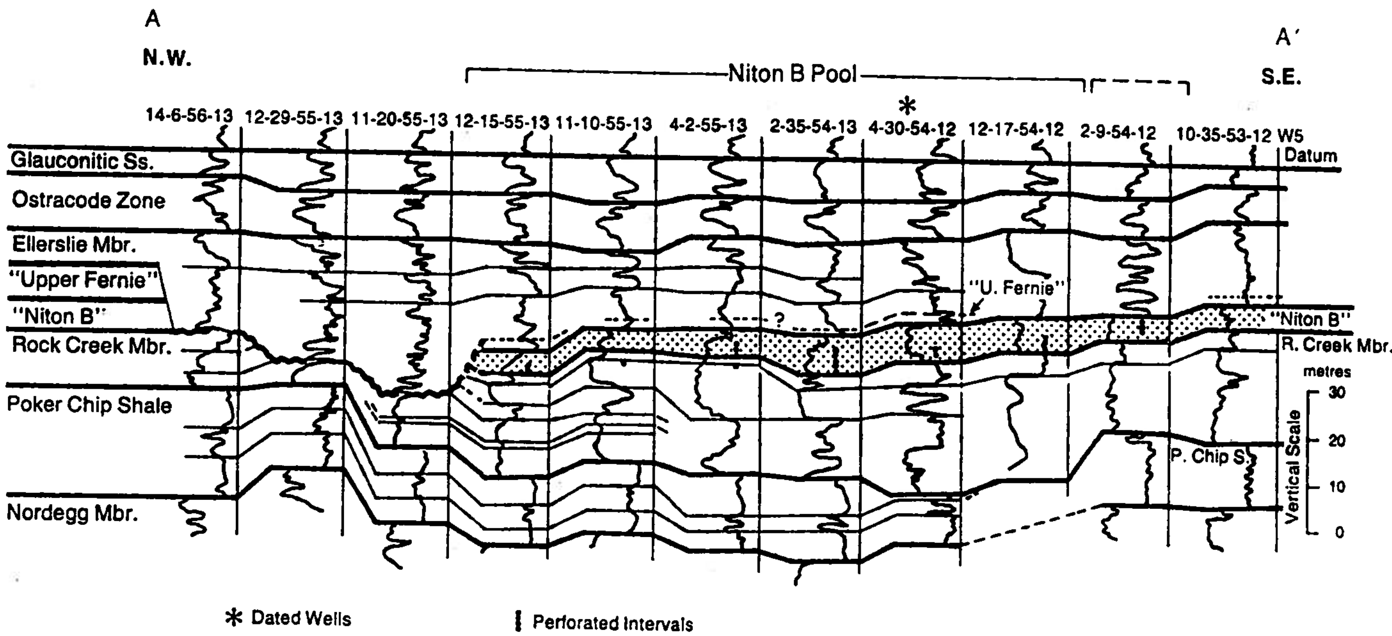

Fig. 4. Gamma-ray log stratigraphic cross section A-A'. Note the pronounced lithological variation in the Rock Creek Member, the erosional valley carved into the Niton B unit and into the upper part of the Rock Creek Member, and the blanket character of the upper Ellerslie, the Ostracode Zone and the Glauconitic Sandstone. Unconformity is shown only where angular relationships between units are obvious. Well spacing is not to scale. The total length of the cross section is approx. 30 km. See Fig. 2 for line of section.

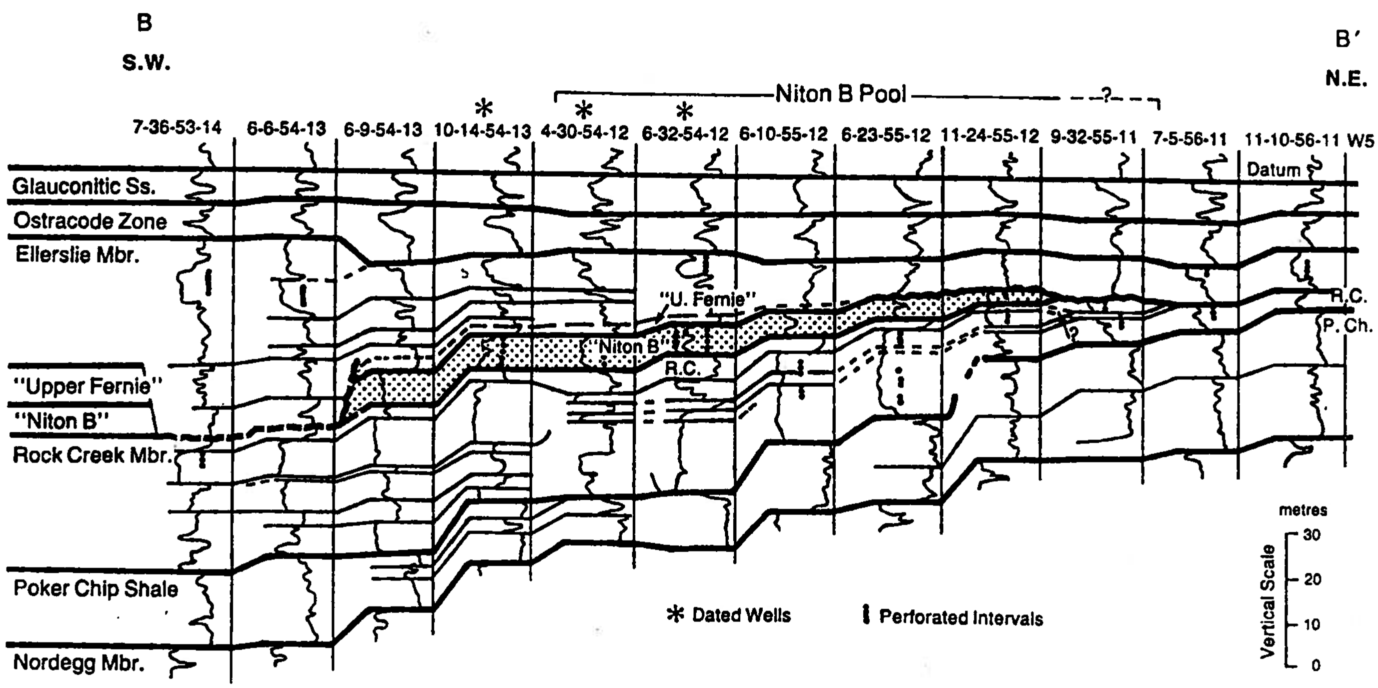

Fig. 5. Gamma-ray log stratigraphic cross section B-B'. Note the pronounced lithological variation in the Rock Creek Member, the northeastward thinning of the Niton B unit, and its truncation at both the southwestern and northeastern ends of the cross section. Unconformity is shown only where angular relationships between units are obvious. Well spacing is not to scale. The total length of the cross section is approx. 36 km. See Fig. 2 for line of section.

The Niton B unit

Overlying sandstones and shales of the uppermost part of the Rock Creek Member (Figs. 4, 5, 6 and 7) and extending beyond the Niton field limits is a distinct, up to 9 m thick sandstone-siltstone unit which is termed "Niton B" in this study. This has been traditionally referred to as the Niton 'B' (sandstone or sand), or the "Basal Quartz" (sandstone or sand) in older well cards (Fig. 3). Marion (1982, Part 2: Appendix - Well data listing, formation tops for two wells in section 18-54-12 W5) implies that the unit is the basal part of the Ellerslie sequence in the Niton field. However, diagnostic palynoflora identified in rare shales occurring in the sandstones and siltstones of this unit indicates that the Niton B unit is of Upper Jurassic (Oxfordian-Kimmeridgian) age and open marine in origin. (For location of samples, see Figs. 6, 7 and 8). Middle Jurassic (Bajocian) palynofloral assemblages encountered in the shales of the Rock Creek Member immediately below the Niton B unit sandstone point to the possible existence of an unconformity between the Niton B unit and the Rock Creek Member.

The "Upper Fernie"

A thin, discontinuous shale horizon usually less than 5 m thick can be seen on the cross sections (Figs. 4 and 5) above the Niton B sandstone and below the clastic sediments of the Ellerslie. This shale is equivalent to the marine "Upper Fernie" unit known from the areas south and west of the Niton field and dated (south of it) as Upper Jurassic to Lower Cretaceous based on palynological and micropaleontological data supplied by Shell Canada Resources (Marion, 1984, p. 324). In this study, however, only Upper Jurassic (Oxfordian-Kimmeridgian) palynoflora and Kimmeridgian foraminifera (such as <u>Haplophragmoides canui</u>) were detected in the "Upper Fernie" shale in several dated wells in the Niton field (Figs. 6 and 7), and in the two wells described by Marion (1984, Figs. 12 and 13 on p. 326 and 327) and shown here in fig. 8 (4-13-52-12W5, 3-29-52-11W5).

The contact between the "Upper Fernie" and the Ellerslie is difficult to determine due to lithological similarity of the units and the

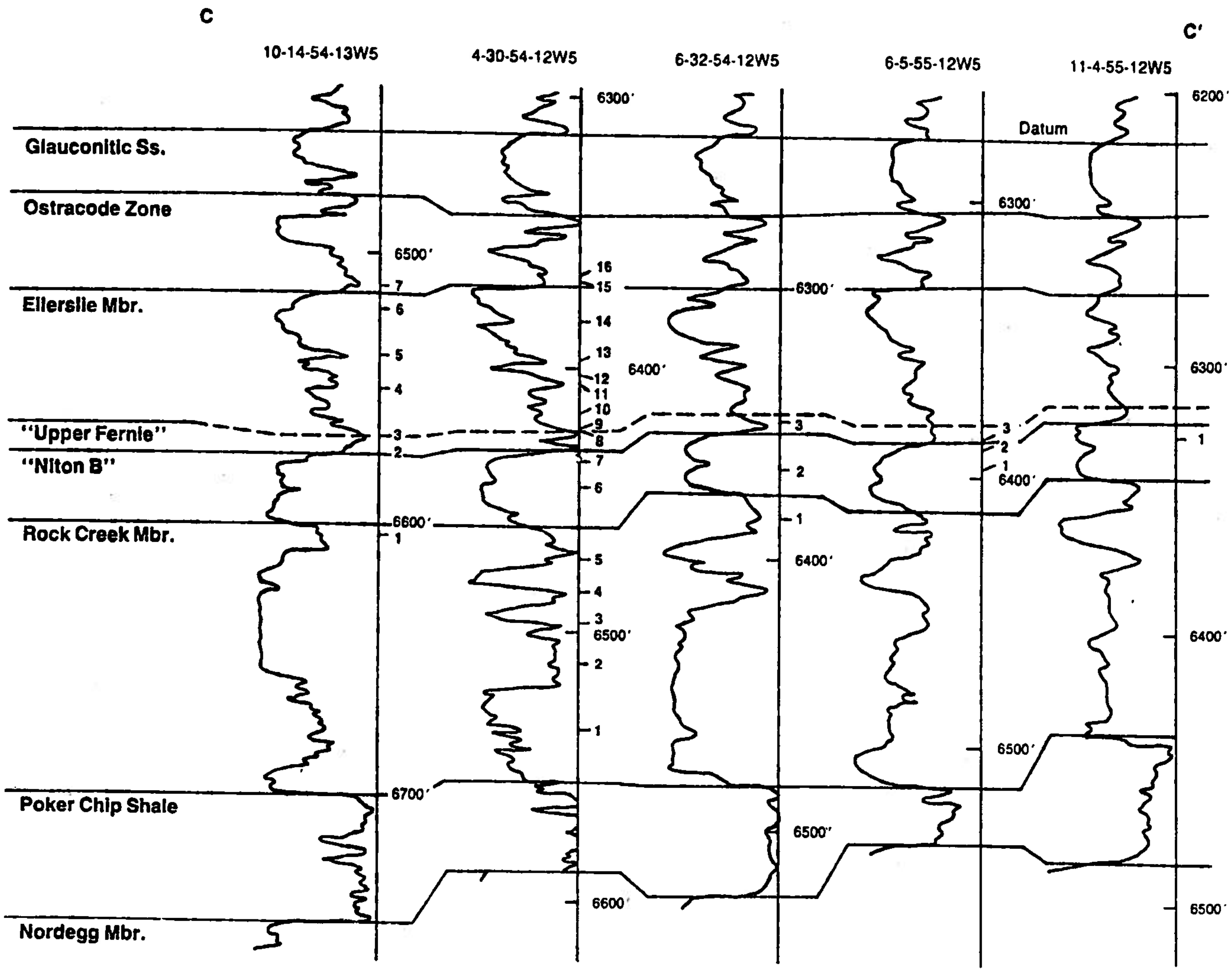

Fig. 6. Gamma-ray log stratigraphic cross section C-C' showing the location of samples analyzed for palynofloral content.

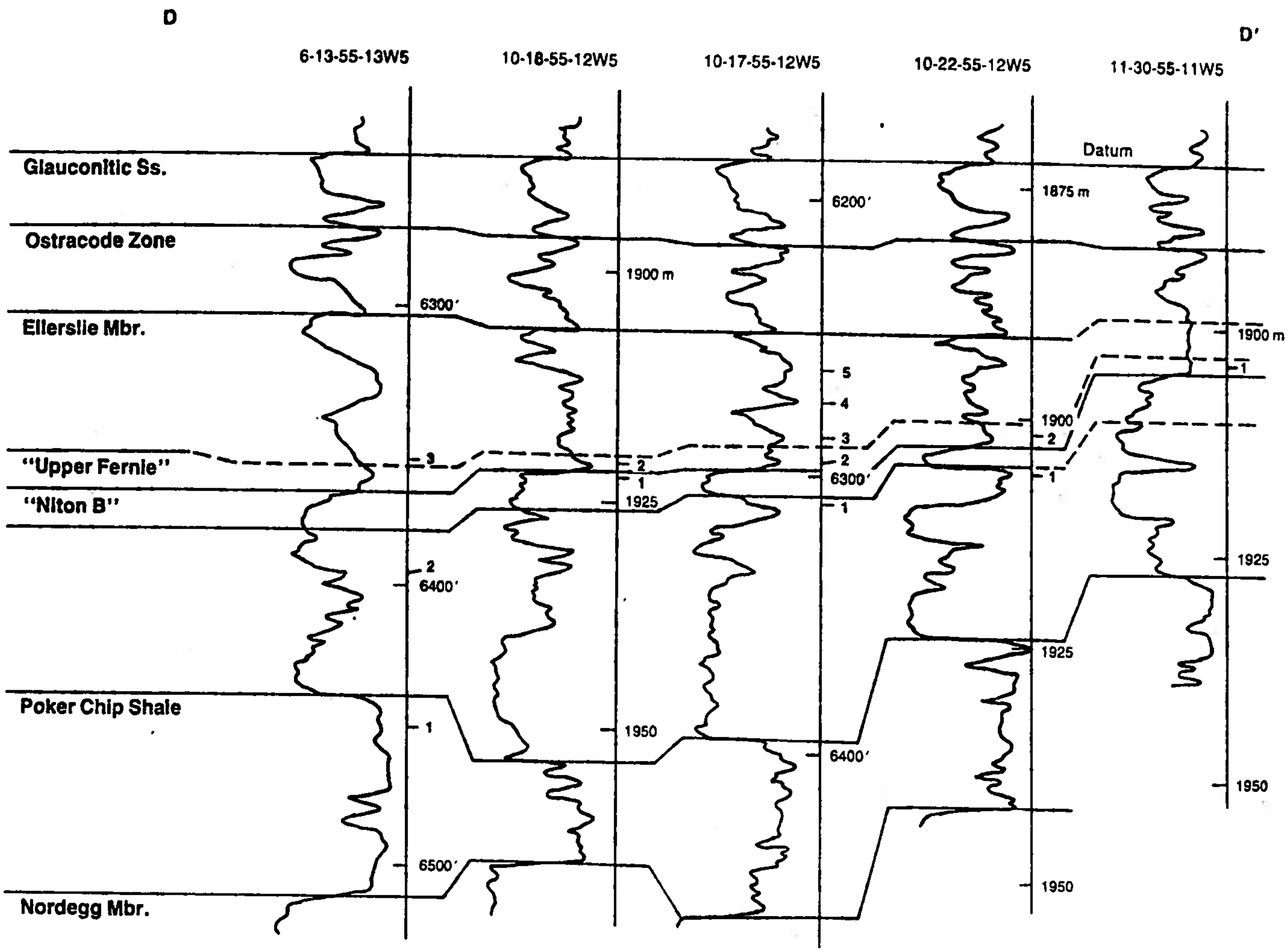

Fig. 7. Gamma-ray log stratigraphic cross section D-D' showing the location of samples analyzed for palynofloral content.

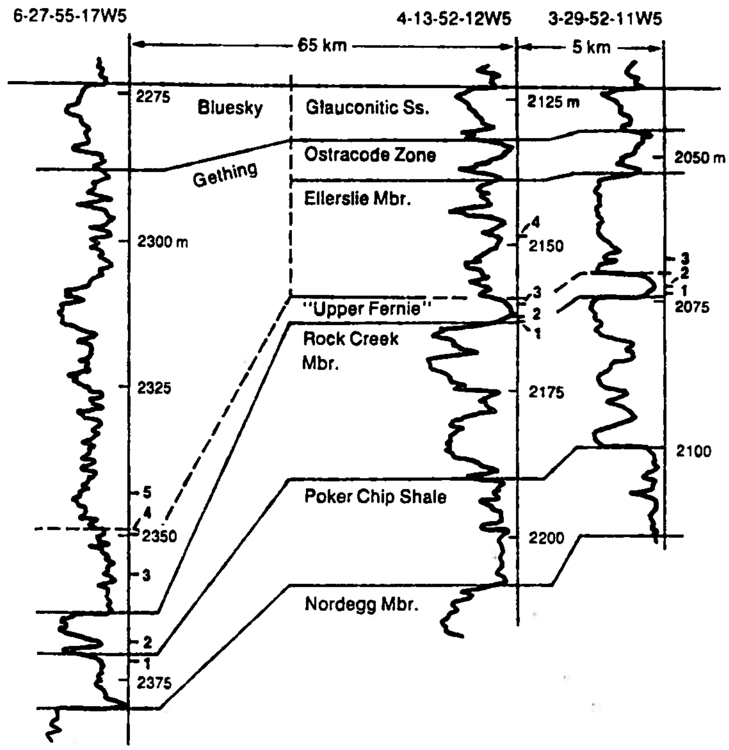

Fig. 8. Gamma-ray log cross section showing the location of samples analyzed for palynofloral content in the three wells situated outside the Niton field.

lack of diagnostic fossils and palynoflora,and remains insufficiently known except in the few dated wells shown in Figs. 6, 7 and 8. Consequently, in the cross sections accompanying this paper the contact has been extrapolated from those wells in which accurate dating was possible, or located using an arbitrary method employed by Marion (1984) and adopted by Losert (1986). To graphically reflect the uncertainty about the accurate position and character of the "Upper Fernie" - Ellerslie contact, a dashed line is used in the cross sections to mark the contact, and, hence, to indicate the approximate location of unconformity in places where no obvious angular discordance exists between the two units.

The Ellerslie Member

Over much of the Niton field the Ellerslie member above the Niton B unit (and above the residual "Upper Fernie" shale) shows a fairly regular south-westward thickening from about 8m to 24m (dip cross section B-B' in Fig. 5), but a sudden increase of thickness to 35 - 45m can be observed in buried erosional valleys immediately southwest and northwest of the Niton field (cross sections A-A' and B-B' in Figs. 4 and 5). One to three coarsening-upward sequences consisting of "ribbon" and "lenticular" shales and siltstones (with minor coals) and capped by sandstones can be distinguished in the upper part of the Ellerslie which, in addition to covering erosional valleys filled by lower Ellerslie sediments, also blankets larger areas (Figs. 4 and 5). Local hydrocarbon accumulations occur in small "Basal Quartz" pools associated with occasional thick sandstones (Niton 'A' sandstones, according to local nomenclature) which top some of the coarsening-upward sequences of upper Ellerslie.

Below the upper Ellerslie, in erosional valleys cut into the Niton B unit and locally also into the upper part of the Rock Creek Member (Fig. 4), sediments of lower Ellerslie are present as valley-fill characterized by an upward-fining sequence which is between 7 and 15m thick and consists of siltstones, shales, minor sandstones (and occasional coals) presumably of continental (fluvial) origin. No significant sandstone bodies or hydrocarbon accumulations were detected in the Ellerslie valley-fill in the study area.

In the southernmost part of the Niton field and to the south and south-east of it, deposits of the lower Ellerslie present in the valley-fill were interpreted as fluvial sediments grading upwards into marine sandstones and shales of upper Ellerslie which occur throughout the area investigated by Marion (1984, p. 328). However, no marine palynoflora was recovered during the recent study from samples of the Ellerslie shales taken between the "Upper Fernie" and the Ostracode Zone in the Niton field, and only spores and pollen were found.

The Ostracode Zone

The Ostracode Zone is built up of dark grey to black, highly fossiliferous calcareous shales to silty limestones with abundant shell fragments ("Calcareous Member"). Blanketing the entire Niton field and widespread beyond its limits, this unit has a fairly constant thickness between 7 and 13m and can be used as a stratigraphic marker where the top of the Glauconitic Sandstone is questionable on logs. Marine dinoflagellates identified from shale samples of the Ostracode Zone in the present study confirm the Aptian age and a near-shore, brackish origin of the Ostracode Zone sediments.

The Glauconitic Sandstone

Overlying the Ostracode Zone in the entire Niton field and extending over considerable larger areas are sandstones, siltstones and shales of the Glauconitic Sandstone unit. This unit, too, is fairly constant in thickness (from 5 to 11 m in the Niton field), but greater thickness, up to 25m, corresponding to marine sand bars, can be observed west of the study area where the Bluesky is the stratigraphic equivalent of the Glauconitic Sandstone (Losert, 1986).

CHARACTERISTICS OF THE NITON B UNIT

Among the units examined, the Niton B unit deserves special attention because of its economic hydrocarbon potential and because of its proximity to the Jurassic-Lower Cretaceous (Lower Mannville) boundary and to the pre-Cretaceous unconformity. Although the unit has been previously included either within the Lower Mannville Ellerslie Member or the Jurassic Rock Creek Member, results of the present study allow us to separate it as a distinct entity within the Niton field. This separation is made possible by the consistent character of the unit over larger areas (as opposed to the rapid lithological variation within the Rock Creek Member, even over short distances), by its specific log pattern that can be traced throughout most of the study area, and, in particular, by the palynological study pointing to its Upper Jurassic (Oxfordian-Kimmeridgian) age and marine origin.

The characteristic log signature seen on the gamma-ray response curve over the Niton B unit is a conspicuous two-prong pattern corresponding to a sandstone layer up to 9m thick and divided into two parts by a siltstone interlayer which is usually less than 2m in thickness. This pattern is evidently of depositional origin and can be traced - with only small modifications - for at least 15km along strike and 20km along dip (Figs. 4 and 5). However, as the unit thins and becomes siltier at the periphery of the sandstone body, the pattern is no longer reliably recognized. This lateral facies change, especially when coupled with the lack of core and poor development of shales immediately above and below the Niton B sandstone, makes the identification of the unit problematic and its distinction from sandstones and siltstones of the Rock Creek Member and the Ellerslie impossible. This is particularly evident in the extreme northeastern, southeastern and northern parts of the Niton field where, if present, the unit may be indistinguishable from the Ellerslie or the Rock Creek and can only be recognized by palentological study.

The Upper Jurassic Niton B is separated from the underlying sandstones of the Rock Creek Member by a shale - to siltstone break. This is up to 7m thick and contains traces of coal and Middle Jurassic (Bajocian) palynofloral remnants indicating that an unconformity exists at the base of the Niton B unit. The separation is also seen in the character of the gamma-ray response curve illustrating that the Niton B sandstones are generally less "clean" than the typical quartz-arenites of the Rock Creek Member, although core and log analysis suggests that their porosity and permeability may be actually better.

An isopach map of the Niton B gross sand (Fig. 9) and the two cross sections shown in Figs. 4 and 5 document the extent and geometry of the Niton B sandstone body and indicate that the Niton B unit extends beyond the limits of the Niton field, especially to the southwest. Two conspicuous thickness trends, the more prominent in the SW-NE direction and the other trending NW-SE, both of primary origin, can be seen in the map. However, the cross sections indicate that both depositional and post-depositional processes were involved in the shaping of the Niton B sandstone body. While depositional processes are responsible for the general northeastward (updip) thinning and probable pinch-out of the sandstone, and also for its disappearance due to facies change in the north, post-depositional erosion associated with the pre-Cretaceous unconformity reduced the primary thickness of the Niton B in erosional valleys delimiting the unit's extent in the northwest and southwest, and also truncated the unit in the northeast (Figs. 5 and 10).

Evidence for a depositional origin (as opposed to erosional origin) of the overall northeasterly thinning of the Niton B unit comes from the remarkable persistence, over much of the Niton field, of the characteristic two-prong log pattern discussed above. However, as documented in the dip cross section B-B' (Fig. 5), the general northeasterly vertical convergence of the entire, relatively steeper-dipping Jurassic sequence with milder-dipping sequences of the Lower Mannville and Glauconitic Sandstone suggests that a combination of updip depositional thinning and a successive northeastward elimination of the individual Jurassic units due to regional truncation can account for the disappearance of the Niton B unit in or close to the extreme northeastern part of the Niton field (Fig. 10).

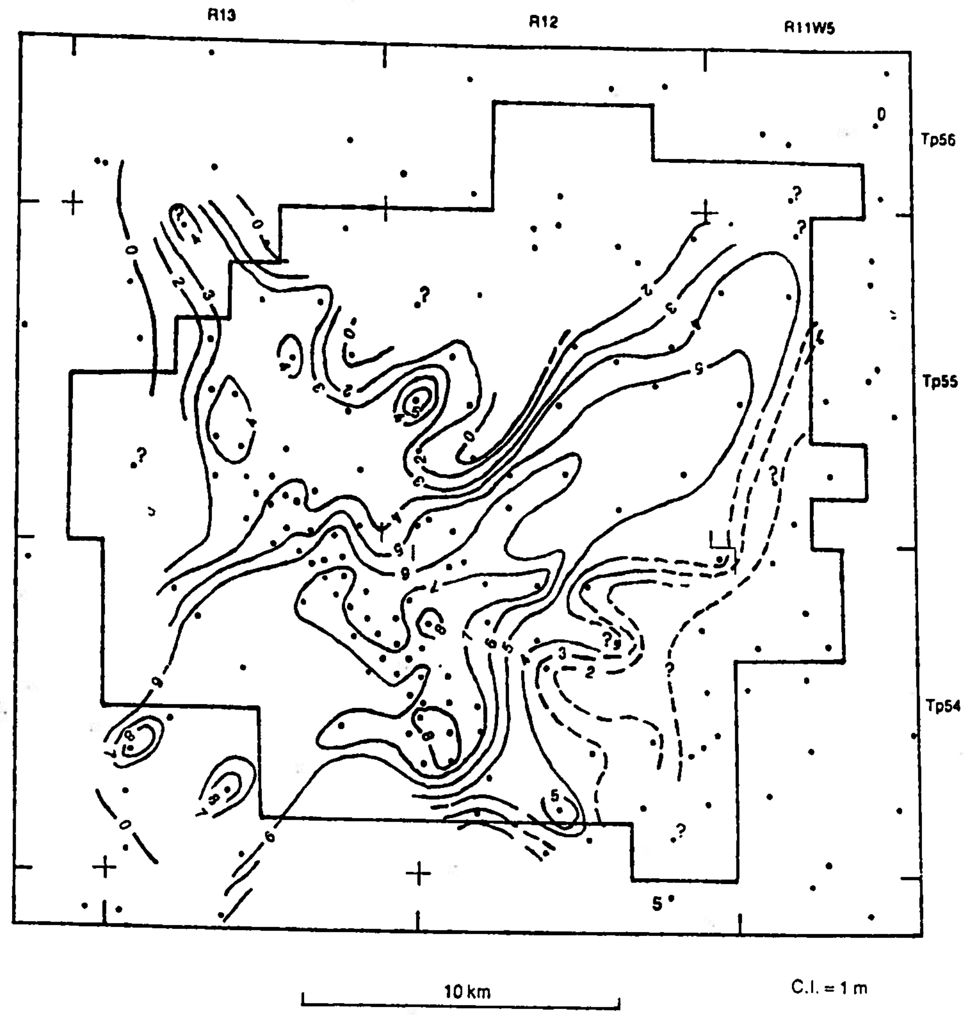

Fig. 9. Niton B gross sand isopach.

Core inspection reveals that the lithological variability of the Niton B unit is wider than the relatively simple "sandstone-siltstone" signature on gamma-ray logs would suggest. Rock types observed in cores of the Niton B include beige and grey sandstones which are massive to fine-grained, with or without bioturbation, and grade into siltstones of similar colors. "Salt-and-pepper" sandstones and glauconitic sandstones were occasionally observed, as were compact, whitish glauconite-free varieties. Although glauconite is present in variable amounts, accumulations of this mineral, locally associated with pyrite, can be sometimes encountered in dark green streaks, up to 20cm thick, at the top of the unit.

In addition to sandstones and siltstones, rare black shales were detected in the Niton B cores, and coquinoid sandstones which may likely be equivalent of the unit were found in some of the wells in the southeastern part of the Niton field. Although the shales are rare and unpredictably scattered throughout both sandstones and siltstones, usually as thin laminae or veneers only up to 1cm thick, their Upper Jurassic (Oxfordian-Kimmeridgian) palynofloral assemblage makes them invaluable for the dating of the entire Niton B unit. Also, the presence in these Niton B shales of Upper Jurassic assemblages - in contrast to Middle Jurassic assemblages detected in the shales of the underlying Rock Creek member - excludes the possibility of them being clasts derived from shales below the B unit.

Primary structures such as planar lamination, laminar cross-bedding and "flaser" - bedding are only infrequently found within the Niton B clastic sediments. The absence of structures is probably due to widespread bioturbation, sometimes with large megaburrows up to 2cm in diameter. However, despite the scarcity of diagnostic structures of primary origin, the shallow - marine origin and near-shore conditions of deposition of the Niton B unit are indicated by the geometry of the unit, the presence of glauconite, the existence of local coquinoid facies and the presence of marine dinoflagellates in the shales of the unit.

UNITS AND UNCONFORMITY RELATIONSHIPS

The relationship between the Jurassic and Lower Cretaceous lithostratigraphic units and the position and character of unconformities are the main geological problems encountered during the Niton field study. These problems have already been addressed in recent papers by Marion (1984) and Losert (1986), but the evidence provided in this paper which identifies the Niton B as being Jurassic rather than Lower Mannville (Ellerslie) makes it possible to propose an alternative interpretation of the Jurassic-Lower Cretaceous relationship in the Niton field.

There are two major angular unconformities characterized by regional truncation of older units within the sequence. They are the post-Mississippian unconformity and the Jurassic - pre-Aptian, or pre-Cretaceous, unconformity. Three other unconformities, with subtler erosional effects, have also been recognized in the southernmost part of the Niton field and to the southeast of it. According to Marion (1982, 1984), these are at the bases of the Poker Chip Shale, the Rock Creek Member and the "Upper Fernie", respectively.

The existence of an unconformity at the contact of the Nordegg and the Poker Chip Shale may be indicated by the occurrence of radioactive, possibly phosphatic rocks at or close to the Nordegg top (Losert, 1986, in the area west of the Niton field), and also by the presence in the Nordegg of chertified rocks indicating subaerial exposure (Bovell, 1979). However, the evidence for an unconformity at the contact between the Poker Chip and the Rock Creek is not as clear. The shale clasts in the basal sandstones of the Rock Creek Member which were described by Marion (1982, 1984) do not by themselves indicate an unconformity. Here, channelling of the Rock Creek sandstones in the partially lithified Poker Chip Shale (Marion, 1984, p.331) during the migration of shallow-marine sand banks, ridges and waves could be an alternative interpretation. An analogous, modern shallow-sea substrate erosion induced by tidal currents was reported by Allen (1970) from the southern North Sea.

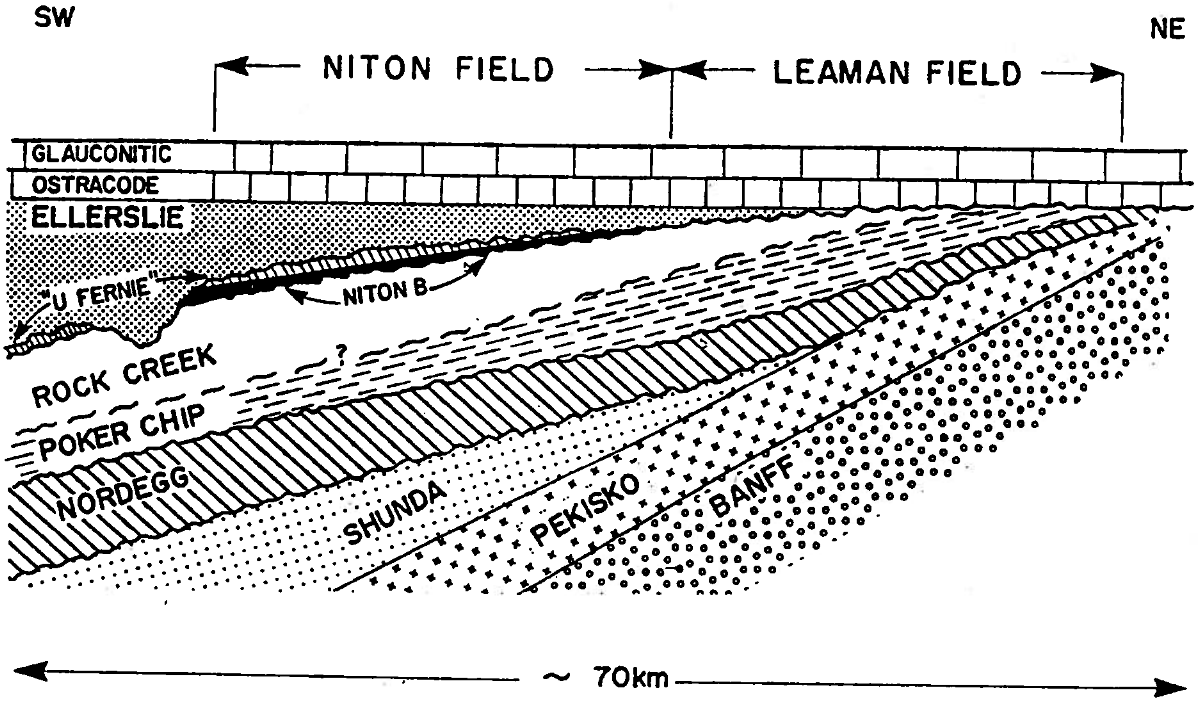

Fig. 10. Scheme of the unconformity relationships in the Niton field and Leaman field in west-central Alberta. The line of section runs approximately along the line of the cross section B-B' in Fig. 2.

The general coarsening-upward character of the Poker Chip Shale is visible from its siltstone and sandstone content increasing up-section, with basal sandstones of the Rock Creek representing a culmination of this depositional trend. The continuity of deposition across the boundary of the two units would suggest that both the Poker Chip Shale sediments and the basal Rock Creek sandstones are integral parts of a single, continuous, regressive sequence with no significant intervening unconformity. Although such situation would be analogous to gradational contacts and transitions between the Poker Chip Shale and the Rock Creek Member in Rocky Mountain sections described by Stronach (1981, 1984) and Hall (1984), further data are required to determine which of the two alternatives - unconformity or single sequence with local channelling - is true in the subsurface. One of such data should be the explanation of the fact that, so far, only Toarcian and no Aalenian fossils have been found in the Poker Chip Shale (Hall, l.c., Stronach, l.c.).

Palynofloral evidence suggests that a stratigraphic discontinuity possibly encompassing part or whole Bathonian and Callovian may exist between the Bajocian Rock Creek Member and the Oxfordian-Kimmeridgian Niton B unit in the study area (Figs. 3 and 10). The two units are generally almost parallel in cross sections, but the variable thickness to local absence of the intervening Middle Jurassic shales and siltstones of the uppermost part of the Rock Creek may be indicative of an unevenly advanced erosion associated with an intra-Jurassic (pre-Oxfordian) unconformity which was characterized by only a subtle uplift and limited erosion. A corresponding major gap in the Rocky Mountains would be that illustrated by Poulton (1984, Tab. 1 on p. 18 and 19) and described by Hall (1984, p. 242) as existing between the Early Bajocian Rock Creek Member and the Oxfordian Green Beds, e.g. in the Fiddle River section southwest of Hinton.

In such a broad correlation 1) the Niton B unit may be, at least in part, a subsurface stratigraphic equivalent of the Oxfordian-Kimmeridgian

(?) Green Beds known from sporadic outcrops in the Rocky Mountains (Hall, 1984). There, the Green Beds are likely to represent only a locally developed facies (Frebold et al., 1959), and occur as a basal unit marking a regional transgression during the Oxfordian time (Stott, 1984); 2) The "Upper Fernie" may be a stratigraphic equivalent of the Passage Beds outcropping in the Rocky Mountains and dated as (probably Late) Oxfordian and Kimmeridgian based on the presence of Buchia concentrica (Hall, 1984, p.241). The correlation of the "Upper Fernie" with the Passage Beds fits the remarkable westward (basinward) increase in thickness of this unit: while in the study area the "Upper Fernie" is less than 5m thick (in dated wells), its thickness increases to dozens of metres in the Edson area (Losert, 1986, comp. also Fig. 8 in this paper), and reaches several hundred metres in the Fernie area and in the northeastern British Columbia where it forms the bulk of thickness of the Fernie Formation. Although this pattern may have been modified by pre-Ellerslie and pre-Cadomin erosion, its depositional origin seems undoubtable.

The two youngest unconformities mentioned by Marion (l.c.) in his area are the one at the base of the "Upper Fernie" (between the Rock Creek and the "Upper Fernie"), and the Jurassic - pre-Aptian ("pre-Cretaceous") unconformity.

Log correlation (unsupported by paleontology and palynology) failed to prove with certainty the existence of the Niton B to the south and southeast of the Niton field. Consequently, only tentative conclusions can be made regarding the unconformity which Marion (l.c) placed between the Rock Creek and the "Upper Fernie". Three possible causes may account for the above failure: 1) the Niton B is absent due to non-deposition, 2) the Niton B was deposited but was removed by erosion, 3) the Niton B was deposited in a non-typical facies and is undistinguishable without a detailed, palynology-supported study. Notwithstanding this uncertainty, one interpretation fitting all three alternatives can be proposed. According to this, the unconformity between the Rock Creek Member and the "Upper Fernie" southeast of the Niton field corresponds to the unconformity between the Rock Creek Member and the Niton B unit in the Niton field.

Despite the new data, a full understanding of the role, effects and timing of the pre-Cretaceous unconformity in the study area is still difficult, as is the accurate portraying of its topographical surface in cross sections. In the Niton field, the main hindrance in this respect is the almost general absence of angular discordances between the individual units at the Jurassic-Lower Cretaceous boundary, the little known areal and also stratigraphical extent of the "Upper Fernie" and its relationships to associated units beyond the dated wells, and the lack of recovery of index fossils and palynoflora in the Ellerslie Member which is reflected in the uncertain age especially of its basal section.

Although relationships may appear less complex in Ellerslie-filled erosional valleys in which angular discordance does exist between the valley fill and older units exposed in the valley flanks, the possible presence of hitherto unidentified pre-Ellerslie units disguised in the base of the Ellerslie may actually render such relationships more complicated. Examples of such units which would normally be interpreted as part of the Ellerslie or the Basal Quartz are provided by the UJ2 and UJ3 sandstone units in the Medicine River area (Ter Berg, 1966). These have been called the J2 and J3 units by Hopkins (1981) who considered them as unconformity-bound units of Middle Jurassic to earliest Cretaceous age and as respective lithologic counterparts of the Roseray and Success Formation of southwestern Saskatchewan. That the presence of analogous units can be expected along the length of the eastern margin of the Alberta Trough (Hopkins, l.c., p. 27) is now documented by the recognition of a distinctive position of the Niton B unit, also formerly "hidden" in the Ellerslie. However, as the relationships of the Niton B indicate, such units are not necessarily restricted to the trough margin and to deeply-incised erosional channels, but may also occur farther west from the margin, and in a low-angle, disconformable, onlapping position.

Although it is not possible to accurately pin-point the topographic surface of the pre-Cretaceous unconformity, the configuration of the lithostratigraphic units at the Jurassic-Lower Mannville boundary indicates that this surface is likely to have a composite topography resulting from intermittent erosion and deposition. In the relatively deeply-incised fluvial valleys and channels a significant amount of repeated erosion was localized in limited areas and led to the formation of a pronounced relief. Here, the resulting unconformity surface is marked by an obvious truncation of older units. In contrast to valleys and channels, however, relationships between the boundary units elsewhere in the Niton field are characterized by southwesterly dipping, parallel to subparallel contacts between the Jurassic and Lower Mannville strata indicating that the unconformity surface, tentatively set at the top of the "Upper Fernie", has a gentle southwesterly slope that is more or less parallel to the dip of the strata involved. As a result, truncation of the Jurassic is imperceptible on the local scale within the Niton field. It is, however, visible from the regional-scale successive elimination of the Upper Jurassic units unconformably subcropping against the Ellerslie, and, farther to the northeast, in the northeastern part of the Leaman field, of the Middle Jurassic subcropping against the Ellerslie and the Ostracode Zone units (Fig. 10). This observation corroborates the conclusion that the same unconformity surface may change from one kind of structural relationship to another when traced laterally, and that an apparent parallel relationship in a small area may be shown to be regionally angular (Eicher, 1976).

It is thus far not clear whether the northeastward decreasing thickness of the Rock Creek, the "Upper Fernie" and the Ellerslie results from intermittent deposition, uplift and erosion occurring along the depositional edges of these units, and whether, under such circumstances, the deposition may have been locally continuous over the Jurassic-Lower Cretaceous time boundary. Also, it has yet to be proved whether this intermittent activity reflects tectonic events in the Cordilleran region, or eustatic sea level changes, or merely indicates readjustment of the sedimentary units to tectonic events during deposition (comp. Cant, 1986).

HYDROCARBON POOLS

In addition to hydrocarbon reservoirs in the Cardium Formation, several oil and gas pools, most of them of small size and limited economic value, have been defined by the Energy Resources Conservation Board (ERCB) in the Lower Mannville and Jurassic strata of the Niton field. These were classified as Niton Basal Quartz pools (A, B, C, E,G, H,I, J, K, L) and Niton Rock Creek pools (A, B, C, D) in the pertinent ERCB G-Orders. (The latter are issued by the ERCB to designate pools in geological formations, members or zones, in individual hydrocarbon fields recognized in Alberta, and use maps, reference wells and reference depth intervals to define the stratigraphic position and outline of the pools). A total of 2137 x $10^6 m^3$ of gas was produced to December 31, 1985, from the pools labeled as Basal Quartz and Rock Creek pools (ERCB Reserve Report Series 18: Alberta Reserves of Gas at 31 December 1985; Calgary, Alberta), and oil production from these pools was 962.6 x $10^3 m^3$ during the same period (ERCB Reserve Report Series 35: Alberta's Reservesof Crude Oil, Oil Sands, Gas, Natural Gas Liquids, and Sulphur at 31 December 1985; Calgary, Alberta).

In order to relate the individual ERCB - recognized pools to the stratigraphic units defined in this paper, the ERCB Basal Quartz and Rock Creek pools were identified using the available G-Order reference wells and intervals. Based on the present stratigraphic reinterpretation, the pools can now be subdivided into three groups, as follows:

1) Oil (condensate) and gas pools in the Middle Jurassic marine sandstones of the Rock Creek Member. These are the pools in the Niton 'C' according to the local nomenclature. (For correlation of nomenclatures, see Figs. 3 and 11).

2) Oil and gas pools in the Upper Jurassic marine sandstones of the Niton B unit. These pools are in the Niton 'B' according to local nomenclature.

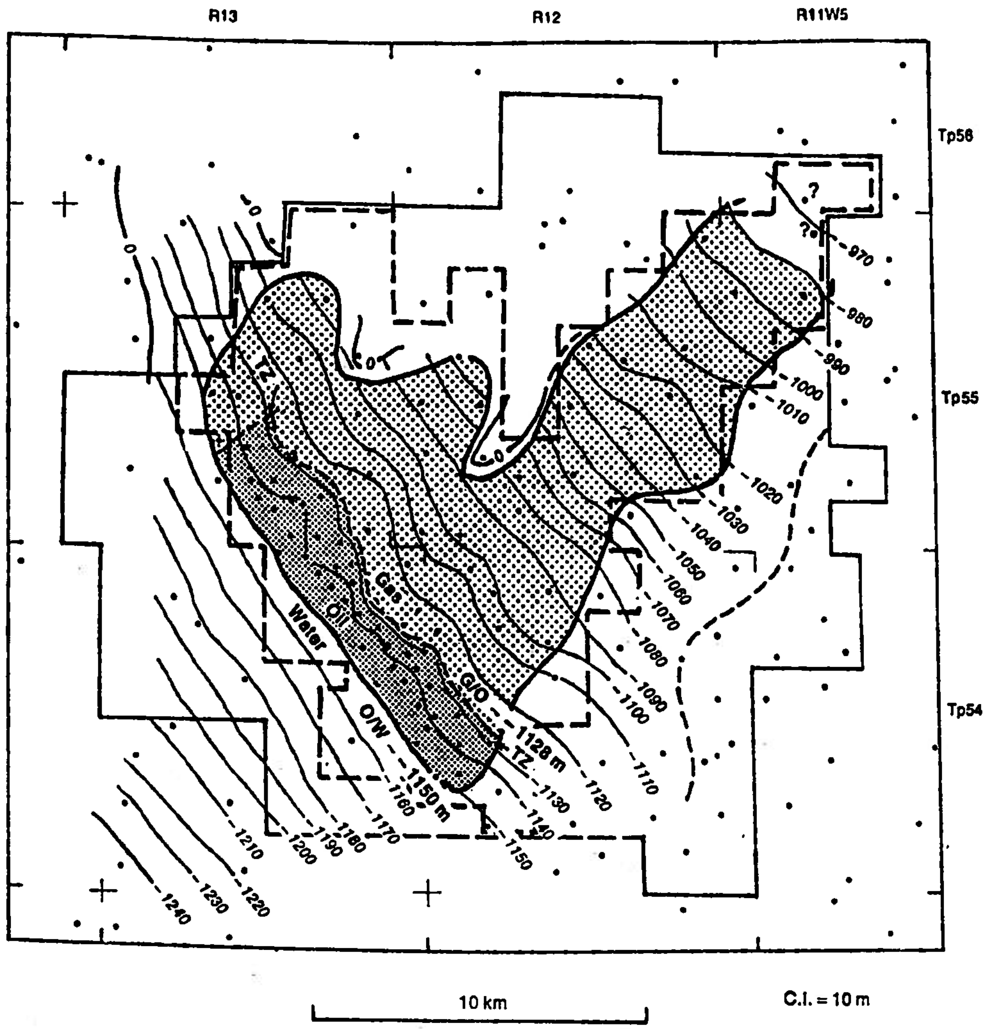

Fig. 11. Structure on top of the Niton B sand, and outline of the Niton B pool. The pool is differentiated into an oil leg, a gas cap and a transition zone (TZ). Dashed outline corresponds to the "Niton Basal Quartz B pool" of ERCB (according to the ERCB G-Order No. G4916 E, of August, 1986).

3) Oil and gas pools in the transitional to marine (?) sandstones of the upper part of the Ellerslie Member. These pools are in the Niton 'A' according to the local nomenclature.

The second group which contains the largest reservoir of the Niton field - the Basal Quartz B pool as defined by ERCB - is economically the most important. This pool produced 1613 x $10^6 m^3$ of gas and 950.8 x $10^3 m^3$ of oil to the end of 1985, or about 75 per cent of the field's total gas production, and some 97.6 per cent of its total oil production. However, as the ERCB reference depth interval for this pool (1980.0 - 1990.3m, in the well HB ZD Niton 11-35-54-13W5) now corresponds to the Upper Jurassic Niton B unit, and not to Lower Mannville Basal Quartz, use of an informal term "Niton B pool" is preferred in this study.

An analysis of geological and technical data including wire-line logs, drillstem tests as well as production tests and production history of some 132 wells in and adjacent to the Niton field led to the delineation of the Niton B pool as shown in Fig. 11. There is a good correlation between the Niton B sand thickness (Fig. 9) and reservoir development (Fig. 11). The reservoir is present throughout the area where the sand thickness is greater than 3 - 4m, except in the southwest. In the southwestern corner of the Niton field the sandstone is either tight or water-saturated, but it is possible that during the previous exploration the Niton B sandstone in this area was not recognized as such and it was either by-passed or insufficiently tested and evaluated.

In addition to partial to complete erosion of the Niton B sandstone, the thinning of isopach values along the periphery of the sandstone body and beyond the limit of the pool also reflects depositional features such as pinch-out and lateral facies change (silting-out) of the sandstone body. Both of these result in the loss of porosity and permeability and are thus responsible for poor and negative test results in several wells situated along the perimeter of, and in some cases also inside, the pool.

While the northern and northwestern limit of the pool reflects the absence of the Niton B unit caused by the pre-Ellerslie valley-cutting erosion and the loss of reservoir quality of the Niton B sandstone, the northeastern edge of the pool is due to a combination of depositional pinch-out and regional erosional edge of the B unit. Cross section B-B' (Fig. 5) and Fig. 10 reveal that both the gradual northeastward thinning of the unit (with possible tightening of its sandstones) and the truncation of these thin sandstones at the unconformity surface can explain the absence of the B unit and, hence, the limits of the Niton B pool in the extreme northeastern part and northeast of the Niton field.

All available data indicate that the hydrocarbon-trapping mechanism in the Niton B pool is of stratigraphic nature and independent of its structure. The latter, characterized by a homoclinal southwesterly dip (approx. 0.5 to 0.6°) of the sandstone body is, however, responsible for the pools' vertical differentiation into an oil leg (with an oil/water interface originally close to approx. -1150m s.s.), a transition zone (around approx. -1132m s.s.), and a northeast-southwest elongated gas cap with a gas column at least 150m high (Fig. 11). Since it was not possible to determine from available data whether the gas-testing intervals in the wells in and northeast of the extreme northeastern portion of the Niton field correspond to the Niton B or the Rock Creek Member, the accurate height of the gas column could not be established and the corresponding part of the pool outline is left open in Fig. 11.

Lithofacies changes within the Niton B from reservoir - quality sandstones to tight siltstones may have caused the formation of permeability barriers such as the one depicted in the western part of the pool in Fig. 11. Such barrier(s) can explain the "anomalous" gas - (or high gas/oil ratio -) production from some wells in that area where structural elevation of the Niton B sandstone is the same as in nearby oil-producing wells. Barriers of similar origin can also explain the existence of the two one-well reservoirs (gas well in 2-9-54-12W5 and oil well in 6-34-54-12W5) which, although confined to the same Niton B sandstone body, are separated from the main Niton B pool.

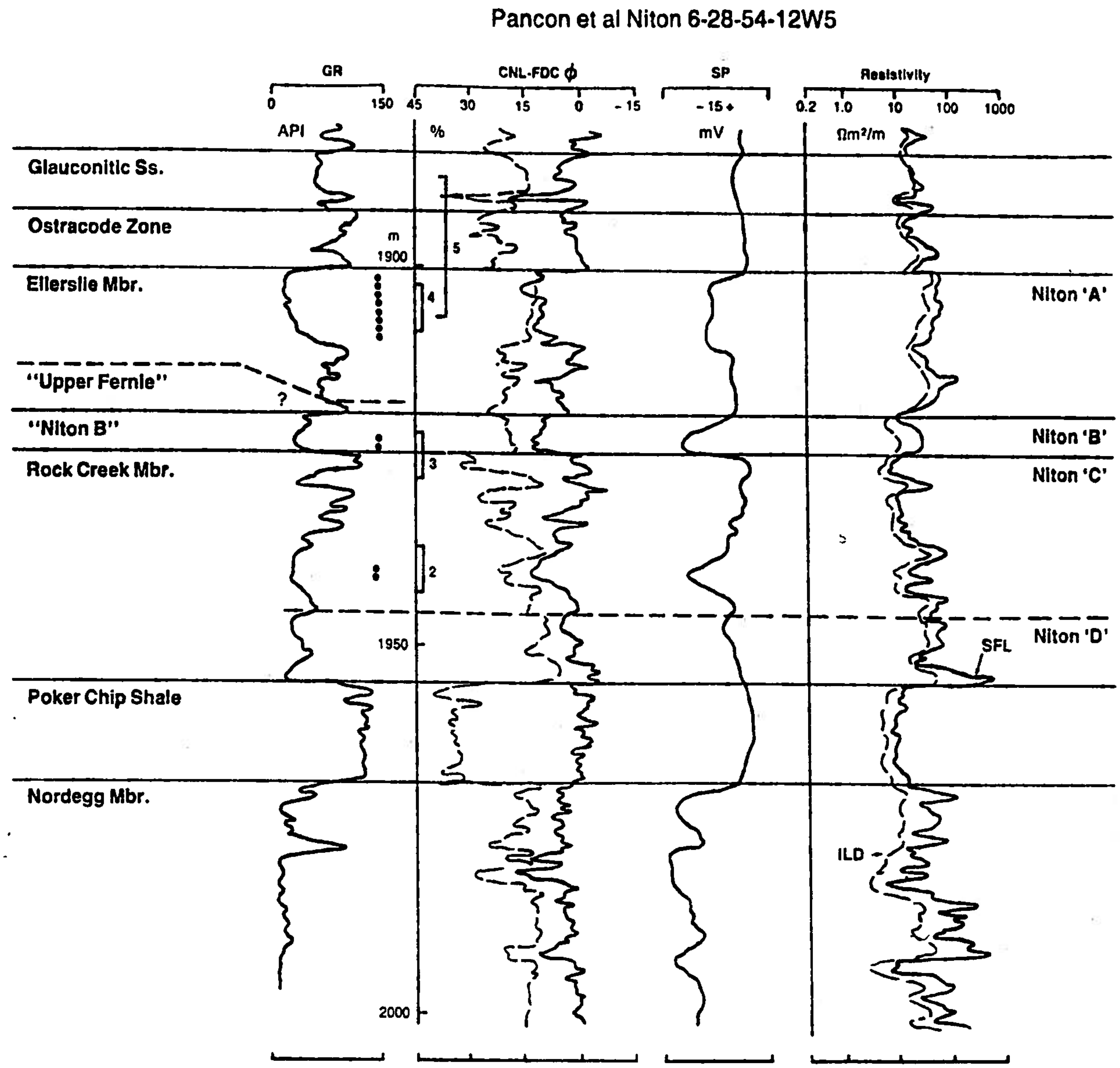

Fig. 12. Example of stacked hydrocarbon reservoirs in the Jurassic - Lower Mannville boundary sequence of the Niton field. Typically, no hydrocarbons were recovered on drillstem tests run across the three prospective zones, but each of the three zones flowed significant amounts of gas following completion; the Niton B flowed some light oil in addition to gas. Local names of the productive zones are shown at right. Heavy dots indicate perforated intervals.

Another possible explanation of "anomalies" in hydrocarbon production from the Niton B sandstone could be the presence of barriers formed by shale-filled channels which were incised into the Niton B unit and are similar to those found at the northwestern periphery of the Niton pool. However, well logs from the interior part of the pool do not provide evidence for the existence of such channels in the central part of the pool.

In some cases, however, no barriers at all need be invoked to explain the anomalous production from closely-spaced wells of structurally similar position. This is exemplified by the well 11-10-55-13W5 (cross section A-A' in Fig. 4) which, although classified as a Basal Quartz B gas well by the ERCB, was actually completed in and produced from the Rock Creek Member while pay in the Niton B was by-passed and not tested. Similar misleading conclusions were arrived at where commingled production from both the Rock Creek and the Niton B was regarded as coming from one single zone.

Good reservoir properties of the Niton B sandstone are reflected in core analyses showing porosities of up to 21 per cent (average 13-18 per cent) and permeabilities K_{max} attaining values up to 33md. Combined with the good continuity of the porous sandstone over the central part of the sandstone body, these properties make the Niton B unit an attractive reservoir horizon, in particular when compared with the hydrocarbon-bearing quartz-arenites in the underlying Rock Creek Member. In the sandstones of the Rock Creek strong reduction of porosity due to diagenetic quartz overgrowths (Marion, 1984) and due to reprecipitation of carbonate minerals restricts the good porosity and permeability to incoherent domains. This, together with the extreme lateral depositional variation of lithology, is responsible for the clean, reservoir-quality sandstones occurring only as irregular and discontinuous bodies separated by tight rocks. As a result: 1) test results often fail to reflect the true production capacity of the Rock Creek sandstones; 2) stimulation (hydraulic fracturing and/or acidizing) is often required to achieve economic flow rates from the Rock Creek sandstones; 3) the areal and vertical extent and the lateral and vertical continuation of, and communication between, hydrocarbon reservoirs within the Rock Creek unit are not readily predictable, and are probably less than commonly assumed. Also, in the absence of barriers formed by the Ellerslie valley-fill, the inconsistent, "patchy" distribution of good porosity and permeability in the Rock Creek may be a logical alternative of interpreting the anomalous oil versus gas production from wells with similar structural elevation of the Rock Creek.

With the present interpretation of the Niton B as an Upper Jurassic unit, earlier traditional ideas invoking communication between hydrocarbon reservoirs associated with the Rock Creek and those in the Lower Mannville Ellerslie ("Basal Quartz") should be reviewed. In the Niton field, no communication is now assumed to exist between the Niton B reservoir and the pools present in the Ellerslie, mainly because 1) the lower Ellerslie sequence, overlying the Niton B in erosional valleys, does not contain significant reservoir-quality sandstones, and 2) hydrocarbon pools associated with limited porous sandstone occurring in the upper Ellerslie (Niton 'A' in local nomenclature - Fig. 12) are isolated from the Niton B reservoir by impervious shales and siltstones present at the base of the upper Ellerslie. Discontinuous shales of the "Upper Fernie" may also act as local seal in this respect. On the other hand, local communication may exist between the Niton B pool and reservoirs present in the uppermost sandstones of the Rock Creek Member (Niton 'C' in local nomenclature) where the intervening Middle Jurassic shales and siltstones are absent.

CONCLUSIONS

A distinct, shallow-marine Upper Jurassic unit - here inrmally termed the "Niton B" unit - can be singled out in the clastic sequences which are developed at the Jurassic - Lower Cretaceous (Lower Mannville) boundary in the Niton field in west-central Alberta.

Consisting mainly of sandstones, subordinated siltstones, rare shales and rarely also of coquinas, the unit has previously been included either within the Lower Mannville Ellerslie Member (or "Basal Quartz"), or with the Jurassic Rock Creek Member. However, distinctive palynofloral assemblages found in the black shales enclosed in the sandstones date the Niton B unit as an Upper Jurassic (Oxfordian-Kimmeridgian) unit and separate it from the Rock Creek Member which is characterized by Middle Jurassic (Bajocian) palynoflora.

The Niton B unit is analogous to the Oxfordian-Kimmeridgian (?) Green Beds known from Rocky Mountain outcrops, and to the unconformity-bound, Middle Jurassic to earliest Cretaceous units underlying the Ellerslie in the Medicine River area in central Alberta.

A palynologically documented unconformity at the base of the Niton B unit separates the Niton B unit from the underlying shales and shallow-marine sandstones of the Middle Jurassic Rock Creek Member. However, channelling of the Rock Creek into the partially lithified Poker Chip Shale rather than an unconformity may be responsible for the local sudden change from shale- to sandstone lithology at the Rock Creek-Poker Chip contact, and also for the presence of shale clasts in the basal sandstones of the Rock Creek Member.

The discontinuous shale horizon conformably overlying the Niton B unit contains Upper Jurassic (Oxfordian-Kimmeridgian) palynoflora and represents an equivalent of the "Upper Fernie" known from the areas south and west of the Niton field, and is a counterpart of the Oxfordian-Kimmeridgian Passage Beds outcropping in the Rocky Mountains.

Above the "Upper Fernie", or locally directly above the Niton B unit, fluvial sediments of the lower Ellerslie infill buried erosional valleys and channels carved into the Niton B and into the upper part of the Rock Creek Member, mainly at the western and northern perimeter of the Niton field. In contrast to deeper-incised valleys to the southeast, the pre-Cretaceous erosion in the Niton field nowhere reached the Mississippian or Lower Jurassic units.

Sediments of the upper Ellerslie cover the lower Ellerslie valley-fill, but extend over larger areas. No diagnostic palynoflora of marine origin has been recovered from the shales between the Ostracode Zone and the "Upper Fernie", leaving the previously postulated marine character of younger Ellerslie strata unconfirmed in the Niton field.

Fresh-water to brackish sediments of the Ostracode Zone contain Aptian marine dinoflagellates and are succeeded by marine sediments of the Glauconitic Sandstone. Both units blanket extensive areas and can be used as datum horizons.

Deciphering of the effects and timing of the pre-Cretaceous unconformity in the Niton field is hindered by the little known areal and vertical extent of the "Upper Fernie", the lack of recovery of diagnostic fossils and palynoflora from the Ellerslie strata, and the lack of obvious structural discordances between the units, except where these are juxtaposed along the flanks of erosional valleys. However, the regional unconformity-associated truncation of Jurassic is visible on regional scale, and is documented by successive northeastward elimination of the Upper and Middle Jurassic units which subcrop against the Ellerslie and Ostracode Zones in the northeastern part of the Niton field, and in the adjacent Leaman field to the northeast.

In addition to hydrocarbon pools in the Cardium Formation, oil and gas reservoirs in the Niton field are associated with 1) marine sandstones in the upper part of the Rock Creek Member; 2) marine sandstones of the Niton B unit; 3) marine (?) to transitional sandstones in the upper part of the Ellerslie Member.

Hydrocarbons (oil, condensate, gas) associated with the Niton B unit are stratigraphically trapped in highly porous and permeable sandstones of this unit and form a well-defined reservoir - the Niton B pool - which is the most important hydrocarbon producer of the Niton field. The Niton B pool is differentiated into an oil leg, a transition zone and a gas cap with a high gas column. The updip limit of the reservoir is due to a combination of depositional pinchout and "tightening" of the Niton B unit, and to its truncation at the regional pre-Cretaceous unconformity surface. The lateral seal is provided by loss of porosity and permeability of the sandstones due to lateral facies change (silting-out), and also by impervious shaly and silty sediments of the lower Ellerslie which fill erosional valleys that had been incised into the Niton B and the underlying Rock Creek sediments.

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