Allostratigraphic subdivision of the Upper Cretaceous Dunvegan, Shaftesbury, and Kaskapau formations in the northwestern Alberta subsurface

JANOK BHATTACHARYA[1] AND ROGER G. WALKER
Department of Geology
McMaster University
Hamilton, Ontario
L8S 4M1

ABSTRACT

The mid-Cenomanian Dunvegan Formation is a lithostratigraphically defined clastic wedge comprising sandstones, siltstones, and mudstones. Over the 30,000 km^2 study area, the Dunvegan Formation has been subdivided into 7 allomembers (from youngest to oldest, A to G). The bounding discontinuities that are used to define the successive allomembers are represented by major marine flooding surfaces (MjF surfaces). The allomembers cut across the conventional lithostratigraphic boundaries and extend into the underlying Shaftesbury and overlying Kaskapau formations.

Each allomember is heterolithic and comprises sets of offlapping (regressive) units, here termed shingles, punctuated by a thin transgressive unit. Downdip, the facies successions within the shingles usually coarsen upward. Updip they may be be represented by fining-upward channel fills. Each allomember is interpreted as representing a genetically related package of sediment characterized by progradation but including the thin transgressive unit above.

A radioactive shale horizon (FSU marker) occurs throughout the study area. It lies between 10 and 40 m above the Fish Scale Marker Horizon within the underlying upper Shaftesbury. The allostratigraphic relationships show that the lower allomembers pass into the upper Shaftesbury Formation and downlap onto this marker, which is interpreted as a major condensed section.

The Shaftesbury shales above the FSU marker are interpreted as being genetically related to the progradational phase of the Dunvegan Formation. This progradational phase is erosionally truncated by a widespread transgressive surface of erosion (TSE) in allomember C. The overlying allomembers B and A pass laterally into shales of the Kaskapau Formation and are interpreted as being genetically related to the ensuing Kaskapau transgression.

Progradation of the Dunvegan Formation is thought to be driven, in part, by a third-order eustatic lowstand of sea level. The allomember bounding MjF surfaces are interpreted as being a result of superimposed, 4th-order, relative rises of sea level, probably caused by tectonically induced subsidence. The shingles are interpreted as representing the deposits of individual deltaic and shallow marine depositional systems and are largely autocyclic in nature.

RÉSUMÉ

La formation Dunvegan du Cénomanien moyen est un dépôt clastique en biseau défini lithostratigraphiquement et composé de grès, de microgrès et de schistes argileux. Sur l'étendue de la surface de 30 000 km^2 que constitue la région sous étude, la formation Dunvegan a été divisée en 7 allomembres (du plus récent au plus ancien, de A à G). Les discontinuités limites qui servent à définer les allomembres successifs sont réprésentées par des surfaces d'inondation marines importantes (les surfaces IMI). Les allomembres recoupent les limites lithostratigraphiques conventionnelles et s'étendent jusque dans le formation Shaftesbury sous-jacente et la formation Kaskapau sur-jacente.

Chaque allomembre est hétérolithique et comprend des ensembles d'unités régressives, ici nommées structures imbriquées ("shingles"), ponctuées par une mince unité transgressive. En aval-pendage, les successions de faciès à l'intérieur des structures imbriquées ont habituellement une granulométrie qui augmente vers le haut. En amont-pendage, elles peuvent être représentées par des remblais de chenal dont la granulométrie diminue vers la haut. En amontpendage, elles peuvent être représentées par des remblais de chenal dont la granulométrie diminue vers la haut. Chaque allomembre est interprété comme représentant un ensemble de sédiments génétiquement reliés, caractérisés par la progression vers la mer mais incluant les minces unités transgressives situées au haut.

Un horizon de schiste argileux radioactif (niveau repère FSU) se retrouve à la grandeur de la région étudiée. Il se retrouve entre 10 et 40 m au-dessus du niveau repère Fish Scale, au sein de la formation Shaftesbury supérieure sous-jacente. Les rapports allostratigraphiques démontrent que les allomembres inférieurs deviennent la formation

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[1] Present address: Alberta Geological Survey, P.O. Box 8330, Stn. F, Edmonton, Alberta T6H 5X2

Shaftesbury supérieure et recouvrent en échelon ("downlap") ce niveau repère, que l'on interpète comme étant une importante coupe complète d'épaisseur réduite.

Les schistes argileux Shaftesbury au-dessus du niveau repère FSU sont interprétés comme étant reliés génétiquement à l'étape de progression vers la mer de la formation Dunvegan. Cette étape de progression vers la mer est tronquée par une surface d'érosion transgressive (SÉT) à grande étendue dans l'allomembre C. Les allomembres surjacents B et A deviennent latéralement les schistes argileux de la formation Kaskapau et sont interprétés comme étant reliés génétiquement à la transgression Kaskapau qui s'ensuit.

L'on croit que la progression vers la mer de la formation Dunvegan est gouvernée en partie par un niveau marin eustatique abaissé de troisième ordre. Les surfaces IMI qui bornent las allomembres sont interprétées comme étant un résultat de hausses superposées, de quatrième ordre, du niveau marin relatif, causées probablement par une subsidence provoquée par des forces tectoniques. Les structures imbriquées sont interprétées comme représentant les dépôts de systèmes deltaïques et marins d'eau peu profonde individuels, et sont surtout de nature autocyclique.

Traduit par Marc Charest.

INTRODUCTION

The purpose of this paper is to document and describe newly defined allostratigraphic subdivisions in Cenomanian rocks of the Dunvegan, upper Shaftesbury, and lower Kaskapau formations of northwestern Alberta. The concepts of allostratigraphy are given in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). A companion paper (Bhattacharya and Walker, *this volume*) describes the facies and facies successions in the Dunvegan Formation. Together, the two papers set up the factual and descriptive basis for detailed work on the various deltaic and coastal depositional environments in the different allomembers (Bhattacharya, 1989a,b, and *in press*), along with their evolution in terms of tectonics and fluctuations of relative sea level. This paper represents a revised and much expanded version of work presented earlier (Bhattacharya, 1988).

DUNVEGAN FORMATION - BACKGROUND

The clastic wedge of the Dunvegan Formation comprises up to 350 m of mudstones, siltstones, sandstones and conglomerates. These were deposited into the actively subsiding foreland basin of Alberta during the waning stages of the Columbian Orogeny over a total area of about 300,000 km² (Stott, 1984). Conglomeratic facies are confined to outcrops in the far northwest, including the Northwest Territories, and are interpreted as having being deposited in alluvial fans (Stott, 1982). This basin is part of the Cretaceous Western Interior Seaway, and received sediment from the rising cordillera to the west.

The study area covers about 30,000 km², between Townships 51 and 67 and Ranges 15W5 to 10W6 (Fig. 1) and represents the distal portion of the Dunvegan clastic wedge. Within this area, no extraformational conglomerates occur and the Dunvegan Formation reaches a maximum thickness of about 100 m. Cross-sections used to establish the allostratigraphy are based on about 500 well logs and 130 measured cores, selected from the total available database (Fig. 1). This area includes most of the important pools that produce from the Dunvegan Formation including Lator, Jayar, Simonette,

Waskahigan, Bigstone and Ante Creek (Fig. 1). The area also spans that part of the Dunvegan Formation where major facies changes take place. To the northwest, the rocks are dominantly nonmarine, and to the southeast, the Dunvegan passes seaward into marine mudstones of the Shaftesbury and Kaskapau formations. The only previously existing isopach and isolith maps (Burk, 1963) are based on the undifferentiated entire formation ("Dunvegan Delta", Fig. 1) and the maps were not interpreted in terms of individual depositional systems within the Dunvegan.

LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

Before developing an allostratigraphy, it is necessary to discuss the existing litho- and biostratigraphy. Lithostratigraphically, the Dunvegan Formation is conformably overlain by shales of the Kaskapau Formation, and conformably underlain by shales of the Shaftesbury Formation. Both contacts have been described as gradational and diachronous (Alberta Society of Petroleum Geologists (ASPG), 1960 p.105; Stelck and Wall,1955; Stelck *et al.*, 1958). The Shaftesbury Formation has been subdivided into upper and lower units separated by the Base of Fish Scales Marker horizon (BFS).

Markers

Highly radioactive horizons within these bounding shaly formations are interpreted as indicating major condensed sections related to times of peak transgression, similar to those described by Leckie *et al.* (1990). The informally named Doe Creek Marker (D.Ck.), in the overlying Kaskapau Formation, lies above the Doe Creek sandstones, although farther north it overlies the Pouce Coupe interval. The Base of Fish Scales marker and an upper horizon above BFS, here termed the FSU marker (Fish Scale Upper), lie within the Shaftesbury Formation. The FSU marker lies between 10 and 40 m above the BFS marker throughout the study area. These interpreted condensed sections form important well log markers and are illustrated in Figure 2. They are marked by an increase on both gamma-ray and resistivity logs. They are easy to recognize and formed the basis for constraining initial correlations of the strata between these markers. In addition, we have used a silty bioturbated horizon (informally designated K-1 in

Figure 2) as another marker and as a datum on which to hang the cross-sections. An isopach map of the K-1 to FSU interval (Fig. 3) shows that these strata thin southeastward, establishing the overall depositional dip and strike of the units studied. Structural dip is to the southwest.

Biostratigraphy and Chronostratigraphy

Previous work indicates that the Dunvegan Formation probably belongs to the middle Cenomanian substage where it is assigned to the *Verneuilinoides perplexus* foraminiferal zone (Stelck *et al.*, 1958; Caldwell *et al.*, 1978; Stott, 1982; Singh, 1983). Workers in the Peace River area of Alberta and British Columbia indicate that the Dunvegan Formation belongs to the *Acanthoceras athabascense* ammonite zone, which has been subdivided on the basis of inoceramids into the *Inoceramus rutherfordi* and *Inoceramus dunveganensis* subzones respectively (Jeletzky, 1968). The beds of the Kaskapau Formation, immediately overlying the Dunvegan

Formation, belong to the upper Cenomanian *Dunveganoceras* Zone. The strata above the BFS marker (below the Dunvegan) in part belong to the *Beattonoceras beattonense* Zone, although ammonites have not been recovered from the uppermost part of the Shaftesbury Formation in outcrop (Stelck, pers. comm.). Foraminifers collected in the Dunvegan and lower Kaskapau formations from wells in the study area (Wall, pers. comm.) also correlate with the *Verneuilinoides perplexus* Zone. Far to the northwest, in the Peace River and Fort St. John areas, the upper Shaftesbury and the lower part of the Dunvegan Formation are assigned to the early Cenomanian *Textularia alcesensis* Zone (which includes the *Beattonoceras beattonense* ammonite zone), but to the southeast, and in the Plains, this zone is not recognized and the upper Shaftesbury is assigned entirely to the *V. perplexus* Zone. (Caldwell *et al.*, 1978). The contact between the upper Shaftesbury and the Base of Fish Scales marker has been described as a regional paraconformity over much of the
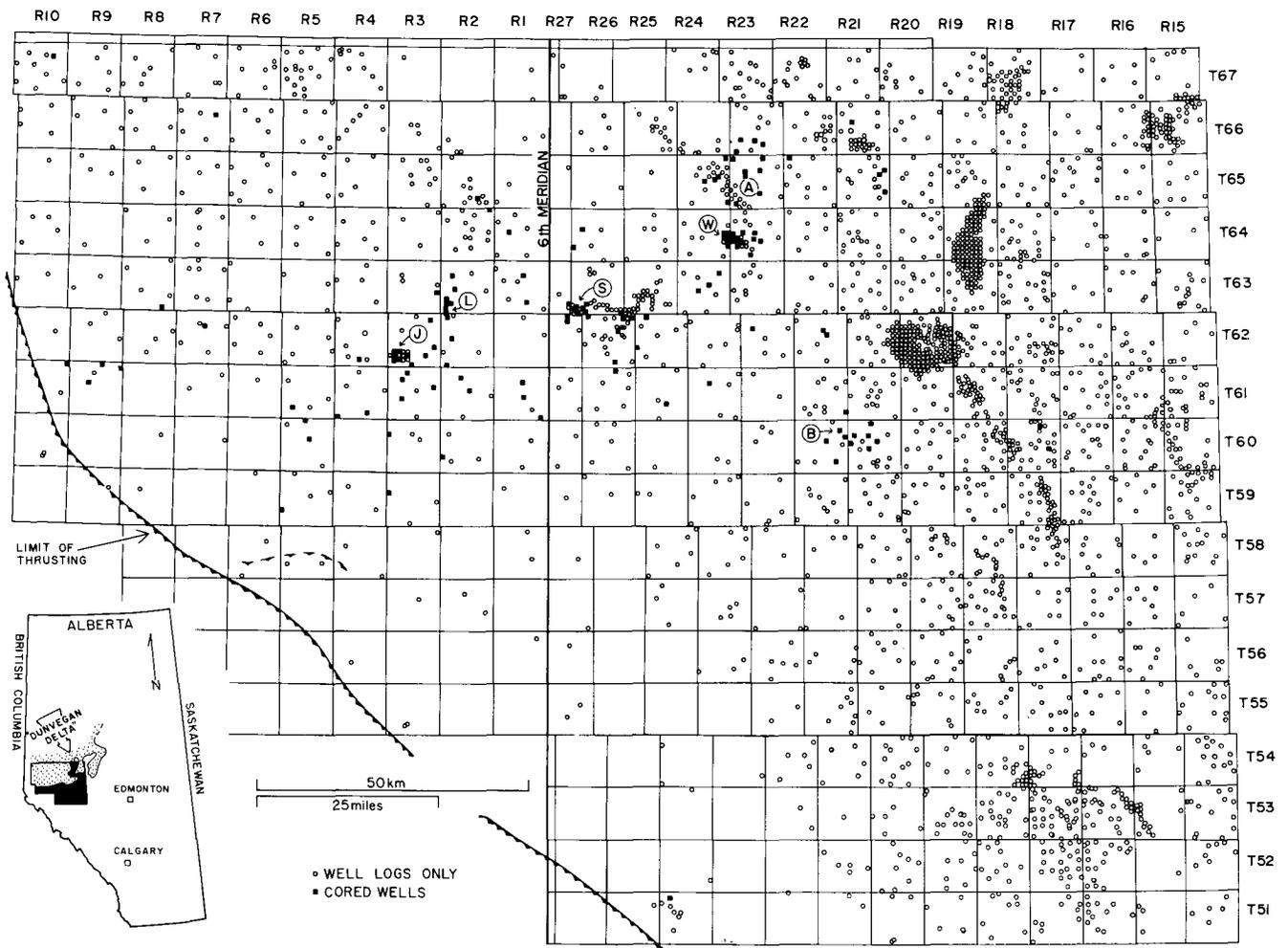
Fig. 1. Base map showing well logs, core control, and Townships (T) and Ranges (R). Each Township measures 6 miles by 6 miles (about 50 km²). The inset map shows the approximate limit of sand deposition in the so-called "Dunvegan Delta" (based on Burk, 1963). Oil pools are indicated with letters: B, Bigstone; S, Simonette; A, Ante Creek; W, Waskahigan; L, Lator; J, Jayar.

southern Interior Plains where the *T. alcesensis* Zone has been shown to be missing (Caldwell *et al.*,1978). In absolute time, the middle Cenomanian probably represents about 1.5 m.y. (Obradovich and Cobban, 1975; Odin, 1982; Weimer, 1984; Haq *et al.*, 1988).

ALLOSTRATIGRAPHIC UNITS

CONCEPTS

A stratigraphic scheme should be practical and easy to apply and ideally should form the basis for understanding the genetic relationships of geological events within the stratal units under study. Sequence stratigraphy emphasizes a set of vertically- and laterally-heterogeneous units separated from each other by unconformities and their correlative conformities. It provides a conceptual framework for time-stratigraphic analysis (Van Wagoner *et al.*, 1990, 1988; Posamentier and Vail, 1988; Posamentier *et al.*, 1988). A similar scheme has been formalized in the North American Stratigraphic Code as **allostratigraphy**, in which a unit is a "mappable stratiform body of sedimentary rock that is defined and identified on the basis of its bounding discontinuities" (NACSN, 1983, p. 865). **Bounding discontinuities** are physically continuous surfaces that represent a hiatus or break in deposition, with or without
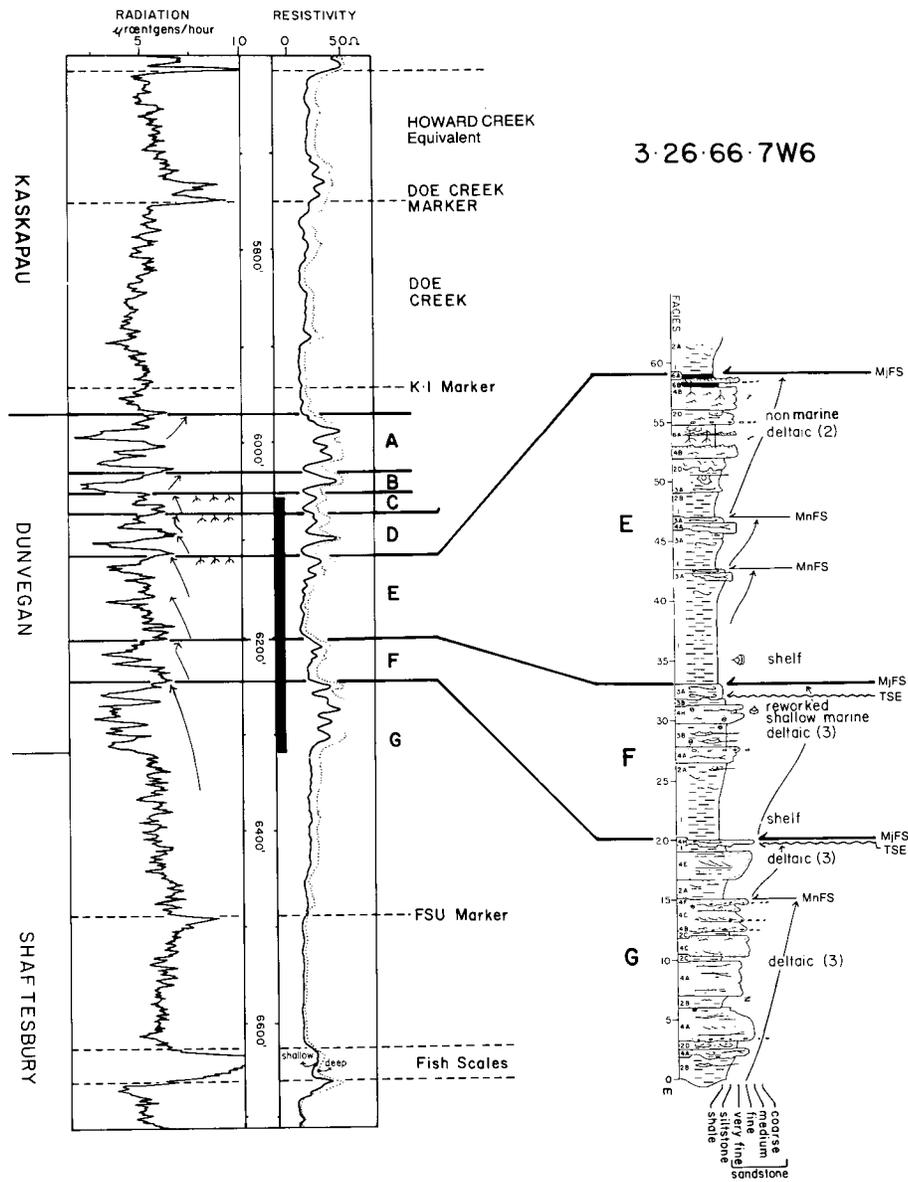
Fig. 2. Reference well log and core through the Dunvegan Formation, well 3-26-66-7W6. Upper portion of the core is not illustrated. Arrows indicate coarsening-upward cycles. Facies designations in the left portion of the core section are given in Table 1, numbers in brackets indicate the facies succession given in Table 2. MjFS, major marine flooding surfaces; MnFS, minor marine flooding sufaces; TSE, transgressive surface of erosion. Facies legend in Bhattacharya and Walker (*this volume*).

accompanying erosion. Bounding discontinuities may include unconformities, disconformities, omission surfaces and discontinuity surfaces. **Discontinuity surfaces** are defined as surfaces of nondeposition of lower rank than a disconformity (Bates and Jackson, 1987). Thus bounding discontinuities include the marine flooding surfaces of Van Wagoner et al. (1990, 1988). The allostratigraphic subdivision of the Dunvegan Formation and related units is presented in Figures 4 and 5, and is based on these newer stratigraphic concepts.

SETTING UP THE DUNVEGAN ALLOSTRATIGRAPHY: RECOGNIZING FLOODING SURFACES AND EROSION SURFACES

The definition of allomembers in the Dunvegan Formation required the description of facies and facies successions, and regional correlation of the bounding discontinuities that terminate the successions. Tables 1 and 2 summarize the facies schemes used in this study and presented in greater detail in Bhattacharya and Walker (this volume). The most prominent facies successions are those that begin with marine mudstones, and then coarsen and become sandier upward (Facies Successions 1, 2 and 3, Table 2). These successions are the equivalents of the progradational parasequences of Van Wagoner et al. (1988, 1990) and commonly culminate in nonmarine facies. Several of these are indicated with arrows in Figure 2. They may be overlain by a thin, pervasively bioturbated sandy mudstone or muddy sandstone (Facies 3A or Facies 4A) averaging a few centimetres in thickness (Figs. 6, 7). This contact may be sharp or the degree of bioturbation may decrease gradually downward. These pervasively biotur-

bated facies are commonly sharply overlain by several metres of bioturbated to stratified marine shales and mudstones belonging to the next succession (Figs. 6, 7). The bioturbated marine sandstone in Figure 6 is interpreted as representing reworking of the underlying rooted facies succession during transgression. We interpret the sharp contact between the bioturbated sandy facies and the overlying marine mudstones as a **marine flooding surface** (Van Wagoner et al., 1988). These surfaces are descriptively identical to the parasequence boundaries illustrated by Van Wagoner et al. (1990, Fig. 6, p. 15). The overlying thick marine mudstones are easy to recognize in both cores and well logs, and preliminary correlations showed that seven of them could be correlated across most of the study area. At first, seven sandy units were tentatively erected, separated from each other by the extensive marine shales. As the work proceeded, it became apparent that each sandy unit was built up of several offlapping or "shingling" sand bodies, and that each sandy shingle graded southeastward into the underlying marine mudstones (Fig. 4). Thus the "underlying" mudstones were actually time equivalent facies variants of the shingled sandstones to the northwest. No physically continuous surface separates the "overlying" shingled sandstones from the "underlying" marine mudstones. Thus the shingled sandstones and marine mudstones can be grouped together into a heterogeneous unit, which we have termed an allomember (Fig. 4). Each allomember comprises a set of offlapping shingles separated from other sets by a thin transgressive unit, and overlain by thicker mudstones of the next regressive phase of deposition. The allomembers are equivalent to an **offlapping parasequence set** in sequence
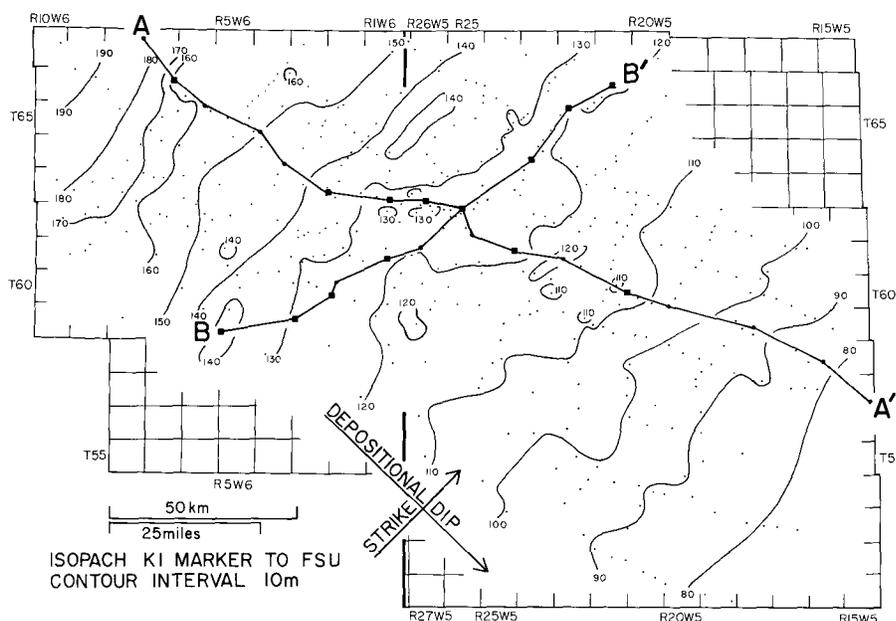
Fig. 3. Isopach of K-1 to FSU marker horizons showing locations of major cross-sections illustrated in this paper. The contours indicate thinning to the southeast. Dots indicate well control. Large filled circles on cross-sections indicate well logs only; filled squares indicate cored wells.

stratigraphic terms (Van Wagoner *et al.*, 1990). They are also analogous to the **formats** of Forgotson (1957). The marine flooding surfaces that cap the transgressive units are interpreted as the bounding discontinuities that define each allomember. Because of their regional lateral extent we designate them as **major marine flooding surfaces** (MjF). These are distinct from the **minor marine flooding surfaces** (MnFS) that cap many of the shingles. Each allomember can be interpreted as having formed during one regressive, or progradational episode capped in places by a thinner transgressive unit (the pervasively bioturbated facies). In places, (*e.g.*, top of allomember E, Fig. 2) this normally thin transgressive unit is entirely missing. Most of the thick mudstones comprising the lower portions of the sandier upward successions are thus interpreted as being genetically related to the progradational phase of sand deposition; the mudstones were deposited on top of the underlying flooding surface, which was therefore also a surface of downlap (Fig. 4). We interpret transgressive mudstones facies to be vanishingly thin. At the scale of the cross-section (Fig. 4) the shingles appear to downlap onto the tops of the underlying allomembers, although in

cores they might be separated by a thin bioturbated mudstone (Figs. 7, 8), and in fact they downlap onto the **maximum flooding surface** (MXES). Thick onlapping mudstones were not documented at any of the allomember boundaries.

We reiterate that allomembers are distinguished by their bounding discontinuities (NACSN, 1983). Broadly speaking, in each allomember, the much thicker progradational phase (offlapping shingles) is truncated by a much thinner transgressive unit. In detail, there are at least three possible horizons related to the transgressive unit that could be used to define the allomember boundary. Examples of these are illustrated in Figures 6, 7, 8, 9 and 10. The first is the surface of initial transgression (IT, Walker, 1990), which in many cases is erosive, and is therefore a **transgressive surface of erosion** (TSE). In the Dunvegan, these lie at the top of the succession-capping sandstone or nonmarine facies (*i.e.* Facies 6A or B). In some cases (*e.g.* allomember C, Figs. 9, 10) the successions are erosively truncated by up to 2 m of bioturbated sandstone (Facies 4H) or by a distinct intraformational lag (Facies 5). Where present, these erosionally based sandstones are also interpreted as a preserved transgressive "lag" overlying the
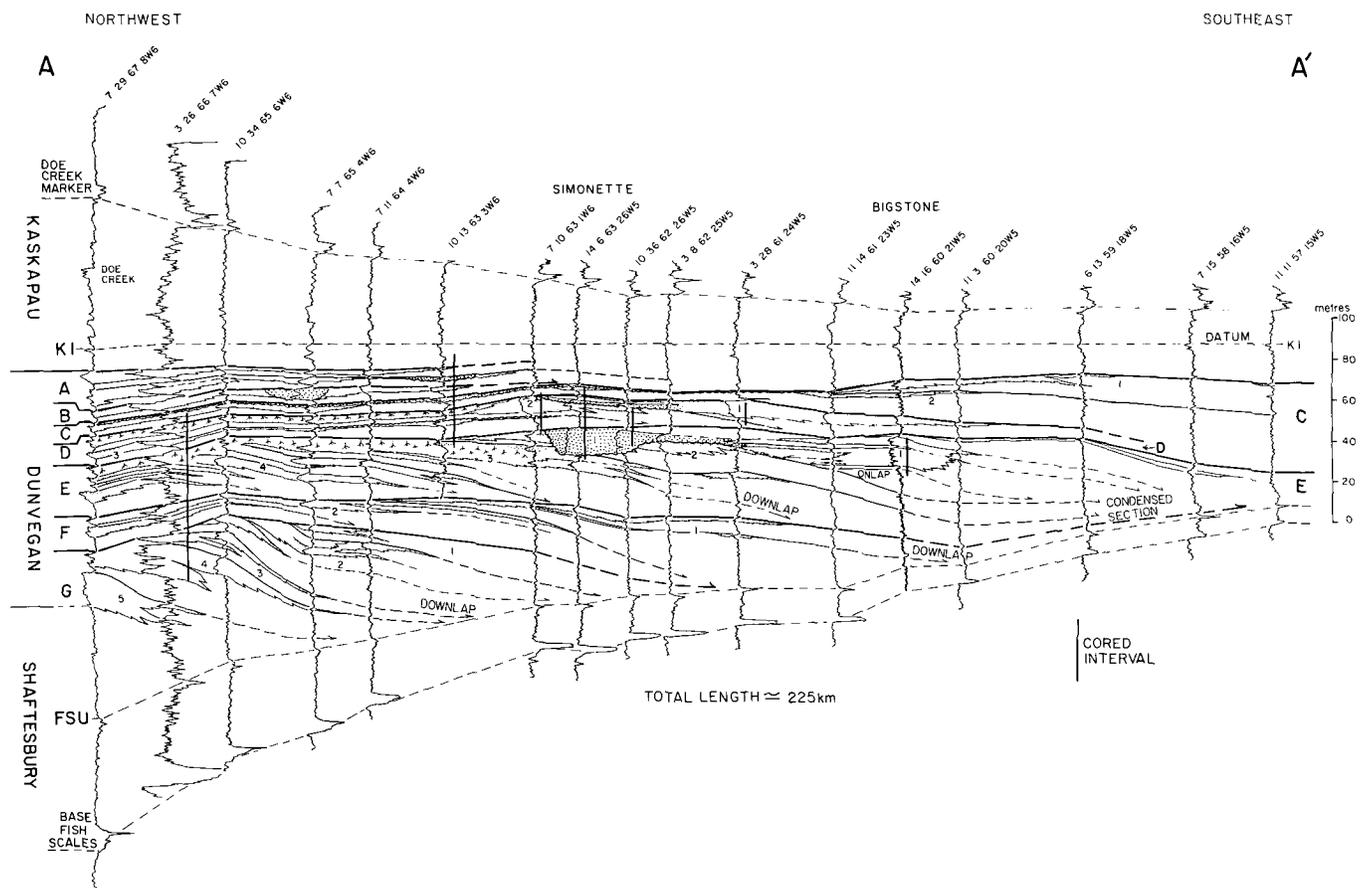
Fig. 4. A-A', dip-oriented well log cross-section emphasizing correlation of flooding surfaces. Major flooding surfaces (thick correlation lines) separate sets of offlapping shingled units (allomembers A to G). The cross-section emphasizes the downlapping nature of the Dunvegan to the southeast. Numbers within the allomembers refer to the offlapping shingles. The coarse stipple represents channelized sand bodies whereas the light stipple represents marine sandstone. Root symbols indicate largely nonmarine facies. This cross-section represents a distillation of more detailed correlations using a much greater number of well logs. All well traces represent long-scale gamma-ray logs. Location of cross section in Figure 3.

TSE (Fig. 10). Unfortunately, in places where core control is limited, and especially where there is a sand-on-sand contact, these TSE surfaces may be impossible to distinguish and are hence less useful as regional correlation markers. Nummedal and Swift (1987) point out that TSE's (also called ravinement surfaces) are commonly time-transgressive and are inappropriate sequence boundaries. Despite their geological significance, they were not used to designate the allomembers defined in this study.

The second horizon that might be taken as the allomember boundary is the **maximum flooding surface** (MxFS) or downlap surface. This may not be easy to identify in core without extensive chemical or micropaleontological analysis. We assume that in most cases it is within the immediately overlying mudstones, and probably very close to their bases. It should separate transgressive facies from regressive facies and, as in Figure 8, may be marked by a transition from bioturbated silty mudstones (Facies 3A) into marine shales (Facies 1), or into stratified silty mudstones (Facies 2A) (Figs.

6, 8), although the log signature of this transition is not usually distinct. This transition, at 16 m from the base of the core shown in Figure 8, is marked by a narrow shoulder on the accompanying gamma-ray log. Based on our inability to confidently correlate and recognize these surfaces around the study area, we have not used them as the bounding discontinuities either.

Much of the data used to define allomembers comes from well logs, where the contact of sandstone with overlying mudstone forms the most obvious "log pick" (Figs. 2, 8, 9). This third surface represents a marine flooding surface intermediate between the TSE and MxFS. From a practical point of view, the allomember bounding discontinuity is taken at this log pick (Figs. 2, 8, 9). We emphasize that at the scale of well log correlations shown in this paper, in most cases the difference between the TSE, MjFS and MxFS is probably no more than the thickness of the correlation line used to depict allomember boundaries, and in many cases they are coincident. The correlation of MjF surfaces is shown in the two cross-sections
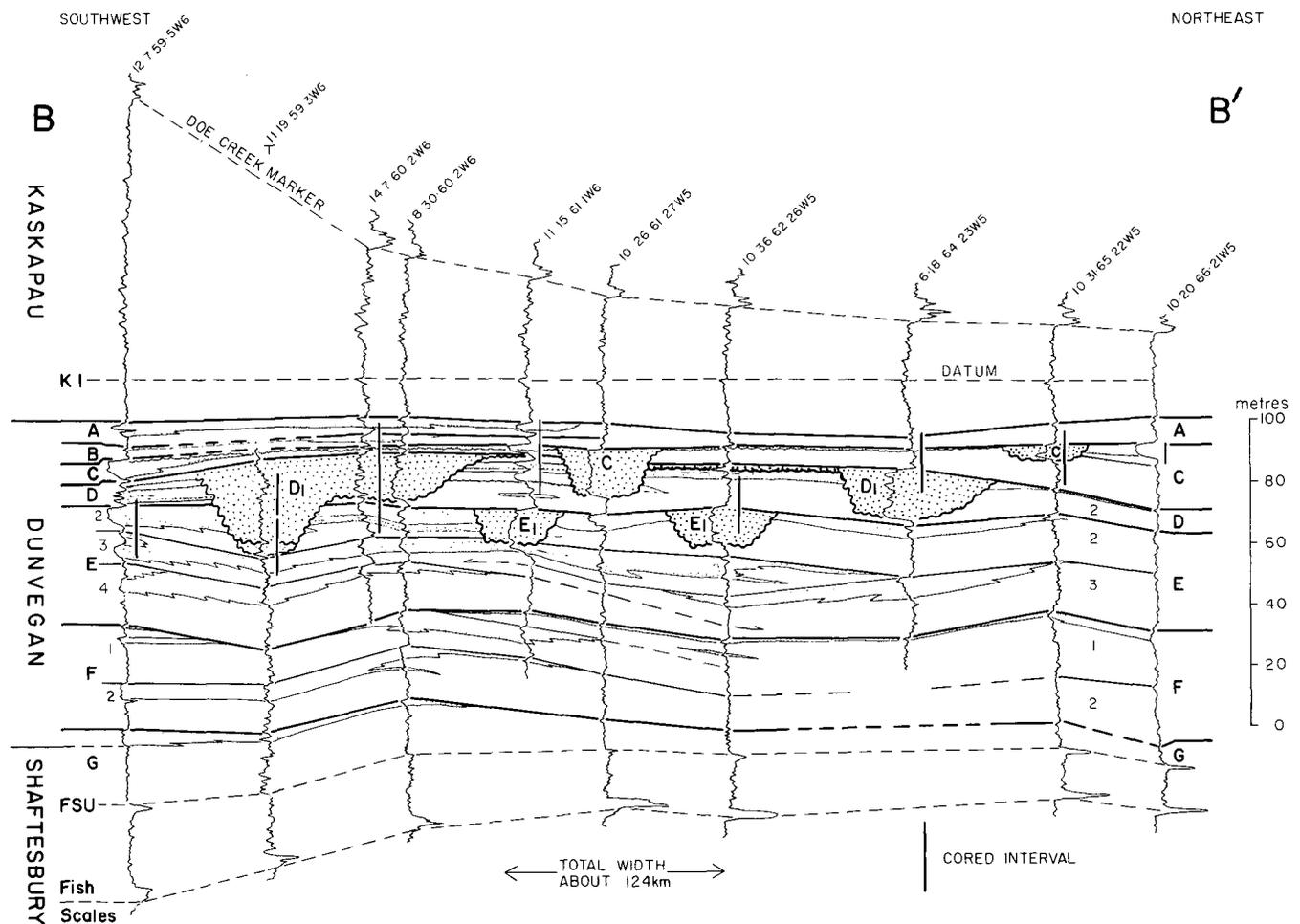
Fig. 5. B-B', strike-oriented well log cross-section, emphasizing erosional channels and lateral geometries of allomembers. Successive channels are offset from each other. Shingles E1 and D1 are represented only by channels along the line of this section. The corresponding lowstand deltaic systems fed by these channels lie to the southeast and are evident on cross-section A-A' (Fig. 4). Letters indicate allomembers and numbers indicate shingles.

(Figs. 4, 5). Where there is a significant departure of the MjFS from the TSE we have distinguished them on the cross-sections and in the cored units.

We believe that the MjF surface best satisfies the criteria of "mappability" as embodied in our ability to correlate them regionally. We recognize that it is not ideal in that it may lie within a transgressive unit, albeit thin. As we will show below, however, this has not severely limited our ability to recognize and map significantly thicker sandy transgressive facies within the Dunvegan Formation in places where core is available.

Dixon and Dietrich (1988) point out the same problem in distinguishing sequence-bounding erosional unconformities in their study of Cretaceous-Tertiary strata of the Beaufort-MacKenzie Basin, since they represent a sand-on-sand contact. They suggest that in well logs, the hiatal surface (maximum flooding surface) is a more mappable boundary since it

is usually represented by a shale-on-sand contact. Thin transgressive deposits are included within their sequences.

As well as the allomember-bounding marine flooding surfaces, we have also identified **regressive surfaces of erosion** (RSE). We define these as erosional sufaces across which there is evidence for a regression of the shoreline. They may be cut during a relative lowering of sea level causing fluvial downcutting and channelization. Interfluve areas are characterized by **subaerial exposure surfaces** (SES) and the development of pedogenic features, including root traces, soils, and coals (Facies 6A). In core they are marked by intraformational lags up to 20 cm thick (Facies 5), and they commonly define the bases of fining-upward facies successions (Facies Successions 4 and 5, Table 2). These erosion surfaces may become conformable where they can be traced seaward, or they may develop into marine erosion surfaces. Several of these erosional surfaces are recognized in cross-section B-B'

Table 1. Facies

FACIES DESCRIPTION	INTERPRETATION
1. Unstratified shaly mudstone	deep marine, below storm wave-base
2A. Stratified silty mudstone	below fairweather wave-base
2B. Rippled sideritic silty mudstone	shallow agitated water, transitional marine to nonmarine
2C. Rippled sandy mudstone	shallow subtidal, lagoonal
2D. Massive deformed sandstone and mudstone	prodelta, bay
3A. Pervasively bioturbated silty to sandy mudstone	marine shelf, commonly transgressive marine
3B. Burrowed, poorly stratified mudstone and sandstone	restricted to brackish marine (e.g. estuary, lagoon)
4A. Hummocky to swaley cross-stratified sandstone	lower shoreface, shallow shelf, above storm wave-base
4B. Parallel-laminated to current rippled sandstone	various, unidirectional currents
4C. Crossbedded sandstone	various (shallow water, high energy, fluvial to marine
4D. Crossbedded to rippled sandstone with mud couplets	tidal crossbedding
4E. Flat laminated sandstone	beach/foreshore
4F. Structureless sandstone	various
4G. Deformed sandstone	delta front
4H. Pervasively bioturbated muddy sandstone	marine (commonly transgressive)
5. Intraformational lag	erosional
6A. Coal and coaly mudstone	nonmarine, subaqueous
6B. Paleosol	nonmarine, exposed

Table 2. Facies Successions

FACIES SUCCESSION	THICKNESS	FACIES	INTERPRETATION
1. coarsening-upward (smooth)	10 - 20m	1 - 3A - 4A - 4C - 4E - 6	prograding wave-and storm-dominated strand plain (shoreface)
2. coarsening-upward (irregular)	10 - 30m	1 - 2A - 2D - 4B/ 4G - 4C - 6	prograding river-dominated delta front
3. coarsening-upward (smooth)	10 - 30m	1 - 2A - 4A - 4C - 4E - 6	prograding wave-influenced delta front
4. fining-upward (nonmarine fill)	5 - 35m	5 - 4C/4F 4B/4G - 2B/2D - 6	fluvial channel
5. fining-upward (marine fill)	5 - 20 m	5 - 4D - 2C/3B - 4A	estuary fill
6. fining-upward (marine fill)	5 - 10m	4D/4C - 4B	tidal inlet
7. irregular but muddy, commonly shallowing upward	5 - 30m	1-2A/2B/2C- 3B - 4B - 6	bay fill/lagoon/coastal plain

(Fig. 5) and are used to help define shingles within allomembers as explained below.

SHINGLES

Shingles are defined as regionally discontinuous, lens-shaped, heterolithic sedimentary units arranged in an en echelon or offlapping pattern within a given allomember (Fig. 4). Lateral overlap may also occur along strike (Fig. 5). Typically, a shingle comprises a single sandier-upward facies succession (Facies Succession 1, 2, or 3, Table 2) usually culminating in a sandstone interpreted to have been deposited in a shallow marine or nonmarine environment. Shingles are descriptively similar to parasequences (Van Wagoner *et al.*, 1988, 1990) and

Fig. 6. Major marine flooding surface (MjFS) marking top of allomember E, from well 12-31-62-2W6 (2300 m). Top of the underlying rooted sandstone is pervasively bioturbated (Facies 4H) and is sharply overlain by bioturbated silty mudstone (Facies 3A). This contact represents a surface of major marine flooding. Scale is 3 cm.

depositional events (Frazier, 1974; Galloway, 1989). The shingle-bounding surfaces cannot be correlated laterally as far as can the allomember-bounding discontinuities, especially updip (Fig. 4). Commonly, shingle-bounding surfaces are represented by RSE's in the northwestern part of the area, which commonly change in character to marine erosion surfaces or their correlative conformities southeastward. In some cases, it was not possible to determine whether multi-storey sandstones defined one or two different shingles; the shingles are therefore largely defined on the basis of the ease with which they can be recognized and correlated within allomembers. In general, they have not been as rigorously delimited over the study area as have the allomembers.

DESCRIPTION OF THE ALLOMEMBERS

The following allomember descriptions emphasize their overall geometry and distribution and give examples of the bounding discontinuities. The shingle geometry is also described, along with brief characterizations of the facies successions. The allomember geometry is either wedge- or pod-like: wedges (*e.g.*, allomember G, Fig. 4) thin progressively basinward, whereas pods (*e.g.*, allomember E, Fig. 4) thicken and then thin again basinward. A "reference core", equivalent to a type section, is designated for each allomember.

The degree of offlap or progradation is estimated by the downdip distance between the distal toes of successive shingles.

ALLOMEMBER G

Allomember G is confined to the northwestern part of the map area and is distinctly wedge shaped. It thins from about 90 m in the far northwest to a zero edge in the southeast (Fig. 11). It contains at least five sandier-upward shingles, separated in places by several metres of mudstone (Fig. 4). In some cross-sections, these shingles erode into each other, making correlation difficult because of the complex intertonguing relationships (Bhattacharya, 1989a). In general, these shingles dip southeastward and downlap onto the FSU marker horizon (Fig. 4). The downlapping is crucial in clarifying the relationship between the Dunvegan and upper Shaftesbury formations, as discussed below. Although the successive shingles offlap to the southeast, the degree of offlap, or progradation, is less than in most of the other overlying allomembers. The upper surfaces of these shingles terminate updip (northwest) against the upper TSE where they are truncated by a thin, bioturbated, sandy mudstone (Facies 3A) blanketed by marine shale (Facies 1).

The reference core for allomember G is in well 3-26-66-7W6 (Fig. 2, left hand side), 6248 to 6312 ft. (1904-1924 m). Only the upper 20 m are penetrated in this well, and no core was recovered within the study area that included the lower contact. The 3-26 core shows two, stacked, coarsening-upward units similar to Facies Succession 3 (Table 2), which correlate with shingles G3 (upper arrow in Fig. 2) and G4 (lower arrow). Allomember G is truncated by a thin, pervasively bioturbated sandstone (Facies 4H) which is in turn
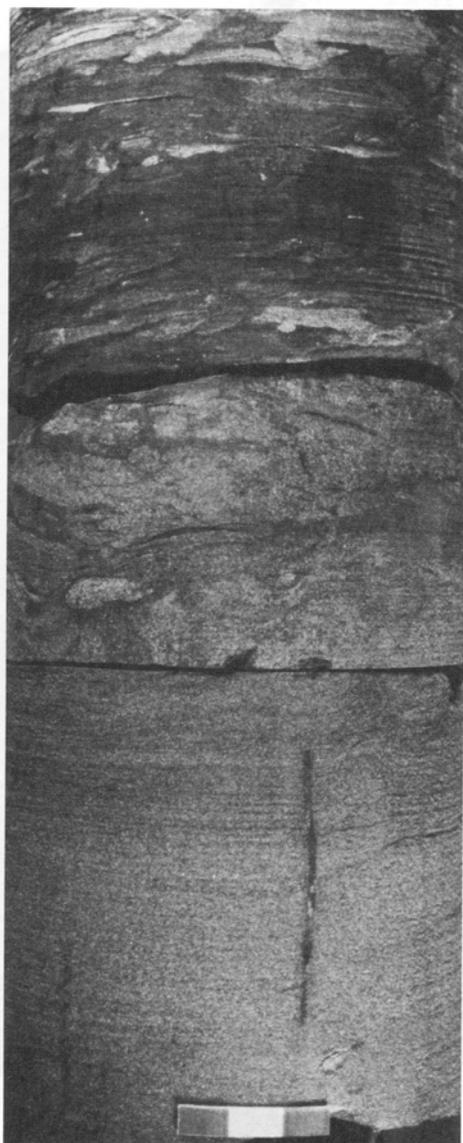
overlain by marine shale (Facies 1) of allomember F. The sharp base of the sandstone is interpreted as TSE, while the contact with overlying shales is interpreted as representing the allomember-bounding MjFS.

In general, allomember G is characterized by wave-influenced deltaic depositional systems (Facies Succession 3, Table 2). Major fluvial erosion was not noted within the study area.

Gas is produced from delta front and distributary channel sandstones of allomember G in the Kakwa area (T61, R9W6).

ALLOMEMBER F

Allomember F is roughly pod-shaped with a maximum thickness of about 40 m (Fig. 12). It thins to about 15 m northwestward and dies out completely southeastward. It contains two shingles (Figs. 4, 5), each containing composite sand bodies that dip southeastward and downlap onto the top of allomember G (Fig. 4). The degree of offlap (or progradation) is greater than in allomember G. Sandstones in the upper shingle are truncated northwestward (indicating a probable TSE)
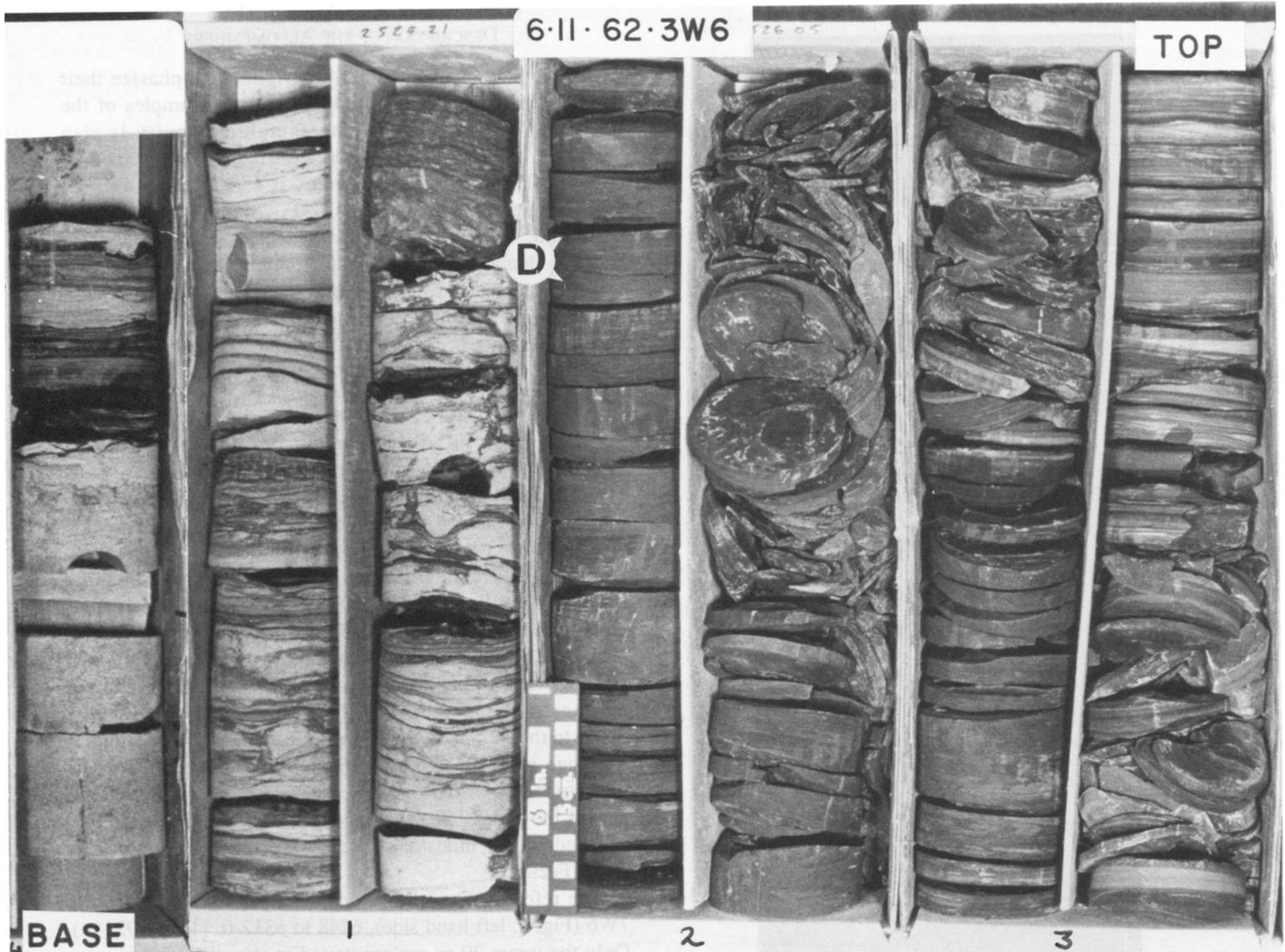
Fig. 7. Major marine flooding surface (MjFS) marking the top of allomember D (from well 6-11-62-3W6, 2524.9-2529 m). Massive rooted sandstone (Facies 4G) at the base of the core is overlain by about 1.5 m of rippled sandy mudstone (Facies 2C) interpreted as lagoonal in origin (note the syneresis cracks and scattered burrows). These sandy mudstones are sharply overlain by about 5 cm of bioturbated silty mudstone (Facies 3A). The contact, shown by the D arrow, represents the MjFS. The bioturbated silty mudstones pass up into black, featureless, shaly mudstones (Facies 1) deposited during peak transgression. The maximum flooding surface is interpreted to be at about the base of the black mudstones. See Figure 8 for illustration of well log and core.
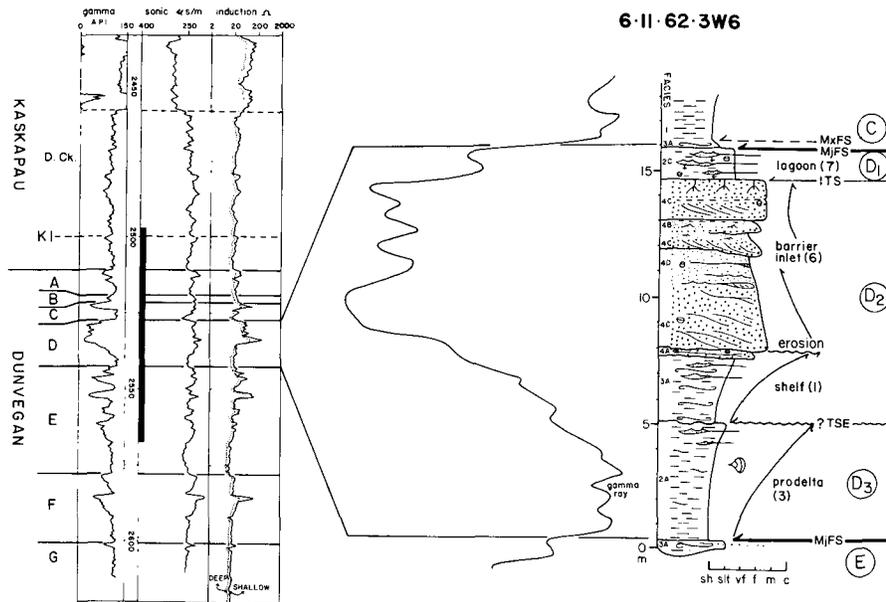
Fig. 8. Allomember D reference well, 6-11-62-3W6. Stratigraphic context of allomember D within the Dunvegan is shown in well log to the left. Transgressive unit from 14.7 to 16.2 m shows the different surfaces that can be recognized in core as shown in Figure 7. The major marine flooding surface (MjFS) is used to define the allomember boundary. Other surfaces associated with the transgressive units include the surface of initial transgression (ITS) and the maximum marine flooding surface (MxFS). Numbered facies are explained in Table 1, numbers in brackets indicate facies successions outlined in Table 2.
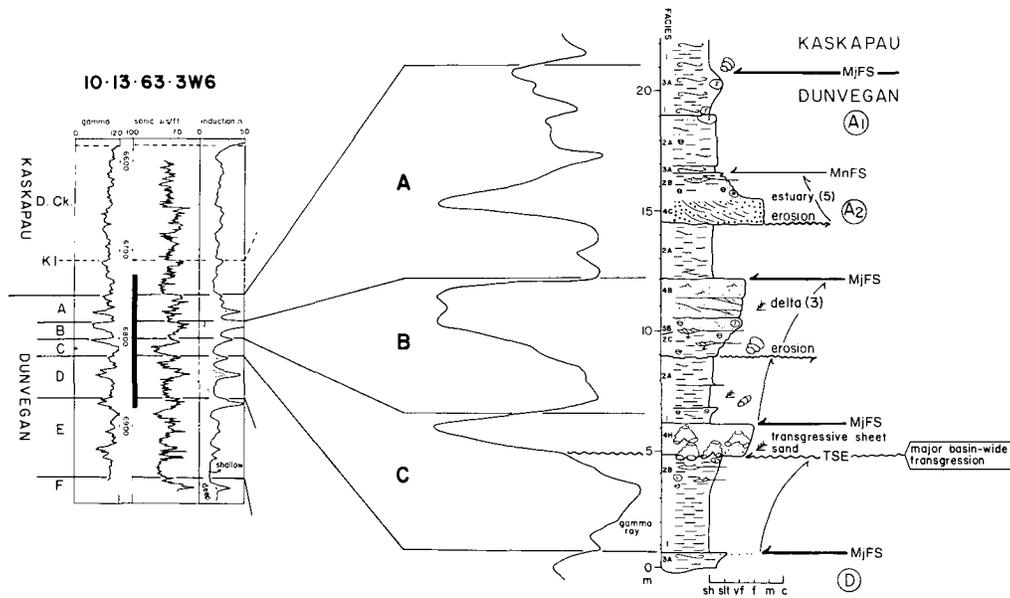
Fig. 9. Well 10-13-63-3W6. The cored interval represents the reference well for allomembers A, B, and C showing the bounding discontinuities. Allomember C is erosionally truncated by a major transgressive sheet sand. Well log is shown in stratigraphic context in Figure 4. Numbered facies are explained in Table 1, numbers in brackets indicate facies succession outlined in Table 2. See text for discussion.

and are overlain by relatively thick shales making up the base of allomember E. The strike-oriented regional cross-section (Fig. 5) shows that allomember F is truncated by allomember E in well 11-19-59-3W6. The isopach map of allomember F also indicates erosional thinning in this area (Fig. 12).

The lack of major channels in allomember F and the marine nature of the truncating facies is interpreted as indicating marine rather than fluvial erosion.

There are very few cores through allomember F. The reference core is in well 3-26-66-7W6, 6200 to 6248 ft. (1890-1904 m) shown in Figure 2. In the type well, allomember F coarsens upward, resembling Facies Succession 3 (Table 2), although the upper sandy facies are bioturbated. The top of the sandstone, at about 31 m from the base of the core (Fig. 2), contains a shelly lag rich in gastropods and pelecypods, including *Melania sp.* and *Corbula sp.* These fauna suggest a brackish to nonmarine environment (Plint, and Walker, 1987; Kauffman, 1969). A TSE terminates the progradational phase of allomember F and is followed by about 1 m of pervasively bioturbated sandy mudstone (Facies 3A). This mudstone is in turn capped by an MjF surface, which passes into the overlying marine shales (Facies 1) of allomember E.

No hydrocarbon production is known from allomember F.
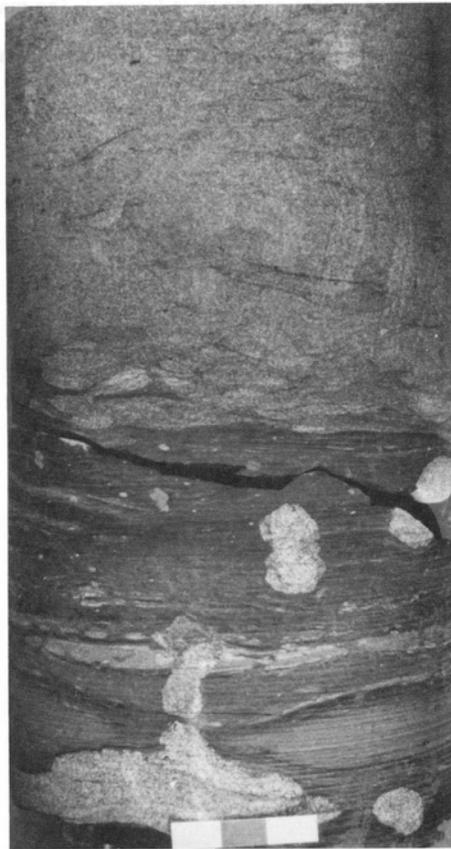
Fig. 10.   Transgressive surface of erosion (TSE), allomember C, from well 6-11-62-3W6 at about 2520 m. *Thallasinoides* burrows indicate a firm ground characteristic of the *Glossifungites* ichnofacies (MacEachern, *et al.,* 1990).

ALLOMEMBER E

Allomember E is roughly pod-shaped. It extends over the entire map area and ranges in thickness from about 20 m in the far southeast to a maximum of about 65 m in the east-central part of the study area (Fig. 13). The reference well is 3-26-66-7W6, 6114 to 6200 ft. (1863-1890 m) in which the upper and lower MF surfaces are cored (Fig. 2). In the cross-sections (Figs. 4, 5) there are four shingles that offlap to the southeast. At the scale of the cross-section, the lower three also appear to downlap onto the top of allomember F, although the relationship is probably more asymptotic as the shingles merge into the thin transgressive facies (*i.e* condensed section) which terminate allomember F. The upper surfaces of the shingles appear to toplap to the northwest. The degree of offlap (or progradation) is higher in allomember E than in allomembers F or G.

A major regressive surface of erosion underlying shingle E1 in the northwest, is represented by prominent channels in wells 11-15-61-1W6 and 10-36-62-26W5 (E1, Fig. 5). This RSE is also seen in well 14-6-63-26W5 and 10-36-62-36W5 (Fig. 4) where it is seen to truncate portions of shingles E2 and E3. The RSE underlies shingle E1 but passes basinward into a correlative conformity rather than an erosion surface (Fig. 4). In the Bigstone area, sandstones of shingle E1 are interpreted as onlapping this erosion surface to the northwest (*i.e.,* landward, Fig. 4). The onlapping facies, immediately seaward of the thick sandy channel deposits in the Simonette area, are shown in Bhattacharya (well 16-10-61-25W5, Fig. 12, *in press*) and comprise a transgressive fining-upward facies succession beginning with nonmarine current rippled sandstones (Facies 4B) penetrated by *in situ* roots, overlain by carbonaceous mudstones (Facies 6A) interpreted as nonmarine in origin, and passing up into shallow marine mudstones and sandstones. The underlying erosion surface has been interpreted as a possible sequence boundary resulting from a relative fall of sea level (Bhattacharya,1988). Based on comparison with Haq *et al.* (1987), it has been tentatively correlated with a third order global sea level drop dated at 94 Ma, in the mid-Cenomanian (Bhattacharya, 1988), although Bhattacharya (*in press*) suggested that it could also be autocyclic in origin. Although not shown on these cross-sections, other major channelized sand bodies also occur lower down in allomember E in shingle E3 (Bhattacharya, 1989a, and *in press*).

Allomember E is abruptly overlain by widespread marine shales (Facies 1) or stratified silty mudstones (Facies 2A), which make up the base of the overlying allomember D (Fig. 5). This contact may be marked by a thin, sharply based, bioturbated, sandy mudstone (Facies 3A), which in places reaches a few metres in thickness. Elsewhere there is a sharp contact between the underlying shallow marine facies and the overlying marine mudstone with no intervening bioturbated unit. Such an example occurs at 58 m above the base of the core in 3-26-66-7W6 (Fig. 2). Here the MjFS is marked by a sharp contact between a coaly mudstone (Facies 6A) and the overlying shaly marine mudstones (Facies 1) of allomember D.
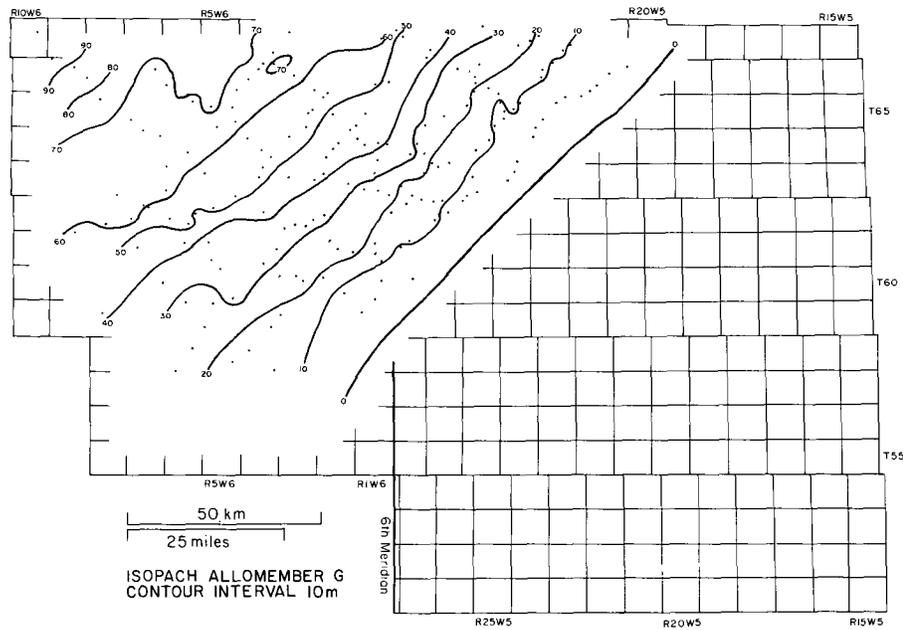
Fig. 11.   Isopach of allomember G displaying a strongly wedge-shaped geometry thinning to the southeast. Dots indicate data points.
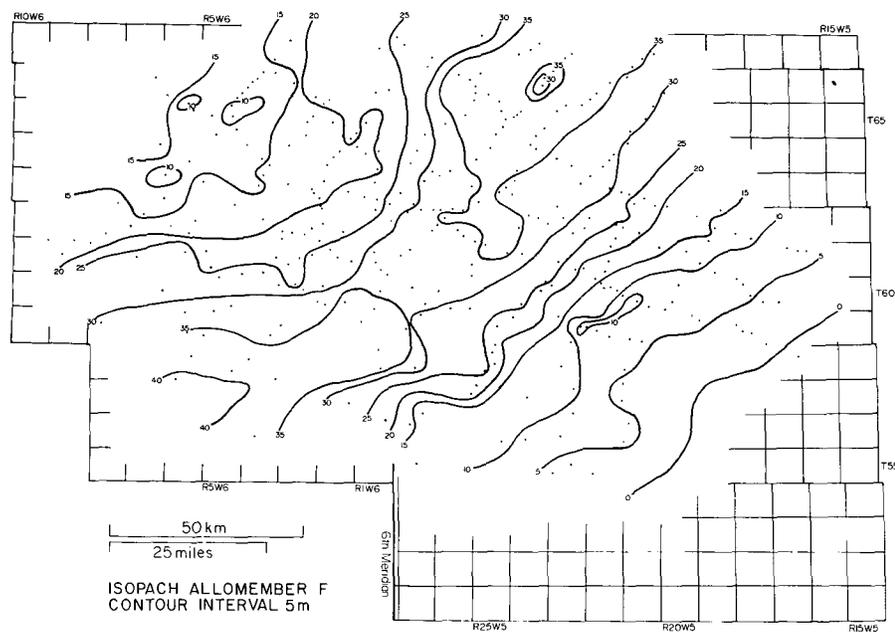
Fig. 12.   Isopach of allomember F showing a pod-shaped geometry. The thinner area in the middle of the map (centred on T60, R27W5) may result from marine erosion. Dots indicate data points.

Within allomember E, the facies coarsen upward into deltaic to nonmarine deposits typical of Facies Succession 2 (Table 2). A paleosol horizon (Facies 6B) lies about 1 m below the allomember-bounding MjF surface and may represent a subaerial exposure surface related to the possible E1 sequence boundary (*i.e.*, RSE) referred to above.

Allomember E consists mainly of the deposits of river-dominated deltas and associated environments (Facies Successions 2, 4 and 7, Table 2, and Bhattacharya, *in press*). In general, nonmarine facies increase toward the northwest (Fig. 4).

Important producing sandstones in allomember E include channelized sandstones in the Simonette area (shingle E1) and associated delta front sandstones in the Bigstone area (shingle E1) (Figs. 1, 4).

Allomember D

Allomember D extends throughout the map area. The reference well is 6-11-62-3W6 (2527-2543 m, Fig. 8) and illustrates the upper and lower allomember-bounding MjF surfaces as well as the intervening facies successions. In map view, allomember D is irregular to pod shaped, and ranges from about 8 to 35 m in thickness (Fig. 14). In the cross-sections it is seen to contain three shingles that offlap to the southeast and downlap onto allomember E (Fig. 4). In the northwest, shingle D1 lies erosionally on D2, which in turn lies erosionally on D3; southeastward, they become conformable toward the basin. Major channels characterize allomember D along strike (Fig. 5). Erosion at the base of shingle D1 is associated with major channels and development of an RSE, but erosion

at the base of D2 is apparently marine, possibly representing a TSE (Fig. 8).

The reference well (Fig. 8) shows the allomember-bounding MjF surfaces (at 0.5 and 16 m in the core section). The lower MjF surface represents a sharp transition from underlying sandy bioturbated mudstones (Facies 3A) into the overlying stratified silty mudstones (Facies 2A). The upper MF surface is marked by a sharp transition between the lagoonal sandy mudstones (Facies 2C) and the overlying bioturbated sandy mudstones (Facies 3A) of allomember C (Figs. 7, 8). The transition immediately above this into marine shales (Facies 1) is interpreted as marking the maximum marine flooding surface (MxF surface, Fig. 8), although the gamma-ray log may indicate that it is a little higher at 17 m.

Allomember D has been abundantly logged and cored and consists mostly of the deposits of wave-dominated depositional systems including wave-dominated deltas (Facies Successions 1 and 3, Table 2) and barrier islands (Facies Succession 1 and 6, Table 2) (Bhattacharya and Walker, *this volume*). Associated distributary channels are back filled during transgression, resulting in estuarine facies successions (Facies Succession 5; Table 2, Bhattacharya, 1989b). As in allomember E, nonmarine facies increase in proportion northwestward. The facies in the reference well (6-11-62-3W6, Fig. 8) are typical. D3 is represented by the lower portion of a coarsening-upward and probably deltaic unit (Facies Succession 3, Table 2) truncated by a possible TSE. The overlying prograding barrier island succession in D2 includes a tidal inlet (Facies Succession 6, Table 2) capped by lagoonal facies associated with shingle D1 (these lagoonal facies are
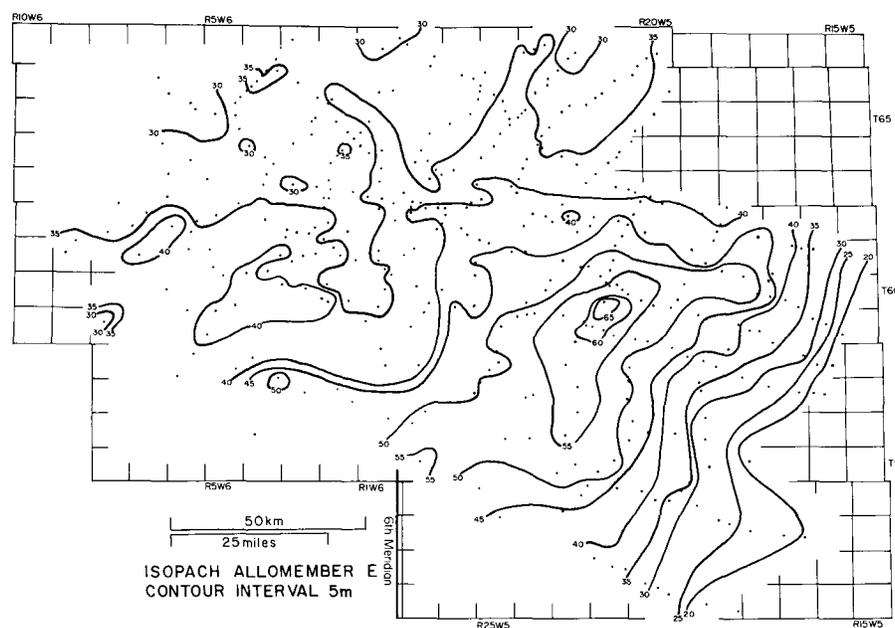
Fig. 13. Isopach of allomember E showing a pod-shaped geometry. The thickest area (centring on Bigstone in T60, R21W5) coincides with deposition of a major lowstand delta lobe (modified from Bhattacharya, (*in press*)).

also illustrated in Fig. 7). The D1 RSE surface is thought to correlate with the rooted zone at 14.6 m in Figure 8 (base of Facies 2C).

Production from allomember D is mostly from reservoirs in estuarine channels from shingle D1 in the Waskahigan and Ante Creek areas (e.g., well 6-18-64-23W5, Fig. 5).

ALLOMEMBER C

Allomember C extends throughout the map area, ranging from about 1 m to 40 m in thickness (Fig. 15). The reference well is 10-13-63-3W6, 6800 to 6820 ft. (2072-2079 m) (Fig. 9). A prominent depositional break separates the northwestern and southeastern parts of the isopach map (Fig. 15). In the northwest, allomember C varies in thickness from 1 to 10 m, except for a single bullseye in T61 R27W5, which is associated with the preserved remnant of an incised sand body interpreted as a channel. To the southeast, allomember C thickens up to 40 m.

There are two major shingles consisting of several offlapping sand bodies that lie dominantly in the southeast. They are truncated by a transgressive surface of erosion (TSE) to the northwest of the depositional break. The reference well (Fig. 9) illustrates the nature of this TSE in the northwest, where allomember C is quite thin. The lower allomember-bounding MjF surface, at 0.7 m in Figure 9, is marked by a sharp transition from pervasively bioturbated sandy mudstone (Facies 3A) into the overlying bioturbated marine shaly mudstone (Facies 1). This same contact is also illustrated in Figures 7 and 8. In the reference well (Fig. 9), allomember C coarsens upward into rippled silty mudstones (Facies 2B) but is truncated at

about 4.9 m by the TSE followed by about 2 m of pervasively bioturbated sandstone (Facies 4H). This sandstone is characterized almost exclusively by large *Ophiomorpha nodosa* burrows and represents a widespread marker bed (the *Ophiomorpha* bed). Commonly, the *Ophiomorpha* burrows are seen to penetrate the underlying mudstones where the lining becomes indistinct and thus become *Thalassinoides* (Fig. 10). The loss of their lining may indicate that the underlying mudstones were relatively firm during the transgression and consequent burrowing. Burrowed firmgrounds, such as this, represent the *Glossifungites* ichnofacies (Frey and Pemberton, 1984; MacEachern et al., 1990). The sand is interpreted as a transgressive sand sheet effectively representing a transgressive lag. The sharp contact between this sandstone and the overlying marine shales (Facies 1) at 6.2 m (Fig. 9), represents the upper allomember-bounding MjF surface.

Important producing sandstones in allomember C include estuarine channel fills (Facies Association 5) in the Giroux area (e.g., well 10-31-65-22W5, Fig. 5).

ALLOMEMBER B

Allomember B is confined to the northwestern half of the map area. It has an irregular shape but thins from about 8 m in the northwest to zero southeastward (Fig. 16). It comprises a single sand body that dips toward the southeast and downlaps onto the top of allomember C (Fig. 4). In most cores through allomember B in the southeast, pervasively bioturbated sandy mudstones (Facies 3A) overlie stratified silty mudstones (Facies 2A). The reference well is 10-13-63-3W6 (Fig. 9). It shows a coarsening-upward facies succession (similar to
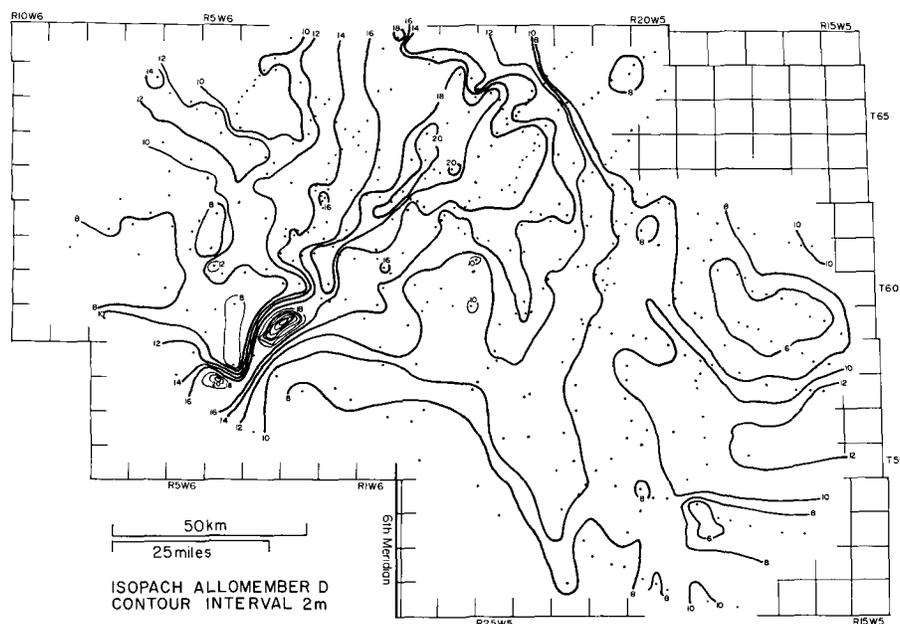
Fig. 14. Isopach of allomember D displaying an irregular geometry. The thickest portion in the southwest coincides with development of a channel. Dots indicate data points.
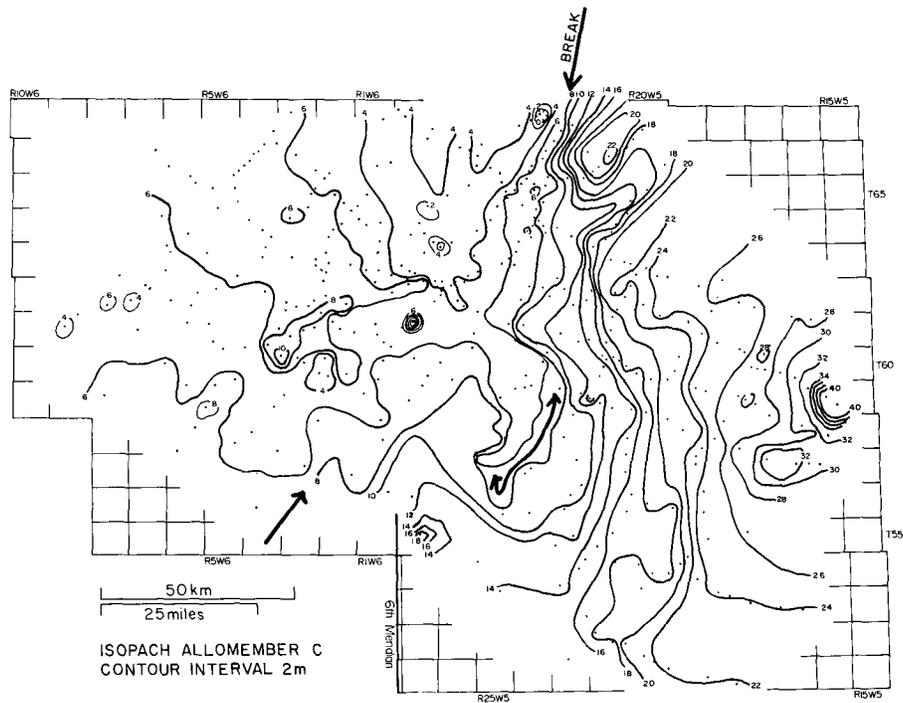
Fig. 15. Isopach of allomember C is more monoclinal in shape and contains a distinct depositional "break" indicated with the thick arrows. Southeast of this break there is a dramatic increase in thickness, although the sediments within this thicker portion are shale dominated. Dots indicate data points.
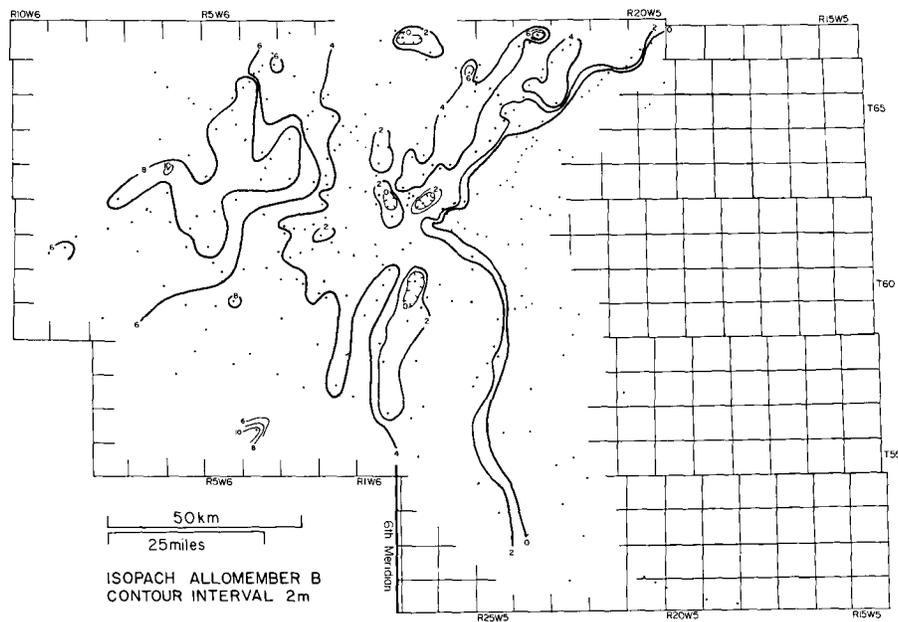
Fig. 16. Allomember B isopach displaying an irregular shape but confined to the northwest. Dots indicate data points.

Facies Succession 3, Table 2) bounded by MF surfaces above and below at 12 and 6.3 m (6782 to 6800 ft. on well log, Fig. 9).

No production is known from allomember B.

ALLOMEMBER A

In the northwestern part of the area, allomember A is wedge shaped (Fig. 4) and thickens to a maximum of about 22 m (Fig. 17). Over most of the southeastern portion of the map area, it is an undulating blanket that ranges from 5 to 10 m in thickness. It contains two shingled sand bodies, each of which pinches out into shales toward the southeast. In contrast to the other allomembers, toplap was not observed and both shingles thicken toward the northwest. The lower shingle (A2) contains several channelized sand bodies that have been intepreted as estuarine in nature (Bhattacharya, 1989a). Only one is traversed by the cross-section (Lator area) and is shown in the reference well 10-13-63-3W6, at 15 m (Fig. 9). Channels were not seen in the upper shingle (A1).

In the reference well (Fig. 9), the lower MjF surface is marked at 12 m by an abrupt transition from rippled sandstone (Facies 4B) into burrowed to stratified silty mudstone (Facies 2A). The upper surface, at 21 m, represents a transition from pervasively bioturbated silty mudstone (Facies 3A) into bioturbated marine shales (Facies 1) belonging to the basal Kaskapau Formation. Except for the thin estuarine channel at 15 m, allomember A is dominated by silty mudstones in the reference well. The main producing pools include estuarine sand bodies of shingle A2 in the Lator and Jayar areas (Fig. 1).

INTERPRETATION OF THE ALLOSTRATIGRAPHY

The lower portion of the Dunvegan Formation records the overall progradation of a complex series of deltaic and shallow marine depositional systems. A rapid fall of eustatic sea level has been tentatively interpreted to correlate with the incision of the Simonette channel in shingle E1 (Bhattacharya, 1988, 1989a). This results in the formation of a type 1 unconformity in sequence stratigraphic terminology (Posamentier *et al.*, 1988). This was followed by progradation of shingle E1 and allomembers D and C, which have been interpreted as being deposited during the ensuing lowstand (Bhattacharya, 1988; Bhattacharya, 1989a).

The widespread surface of erosion (TSE) that terminates the progradational phase of allomember C represents a transgressive unconformity, which has been interpreted to correlate with the global rise of sea level (at 93.5 Ma) that terminated the earlier lowstand. The overlying allomembers A and B were deposited during the early phases of the ensuing transgression that culminated in deposition of the Kaskapau shales. Peak transgression is probably related to the development of the radioactive shales including the Doe Creek marker (a condensed section) and the Second White Speckled Shale.

The overall progradation of the Dunvegan was punctuated by the shorter-term allomember-bounding transgressive events. The extent of the allomember-bounding MjF surfaces also suggests control by a basin-wide rise in relative sea level. This deepening was probably an **allocyclic** process, and has
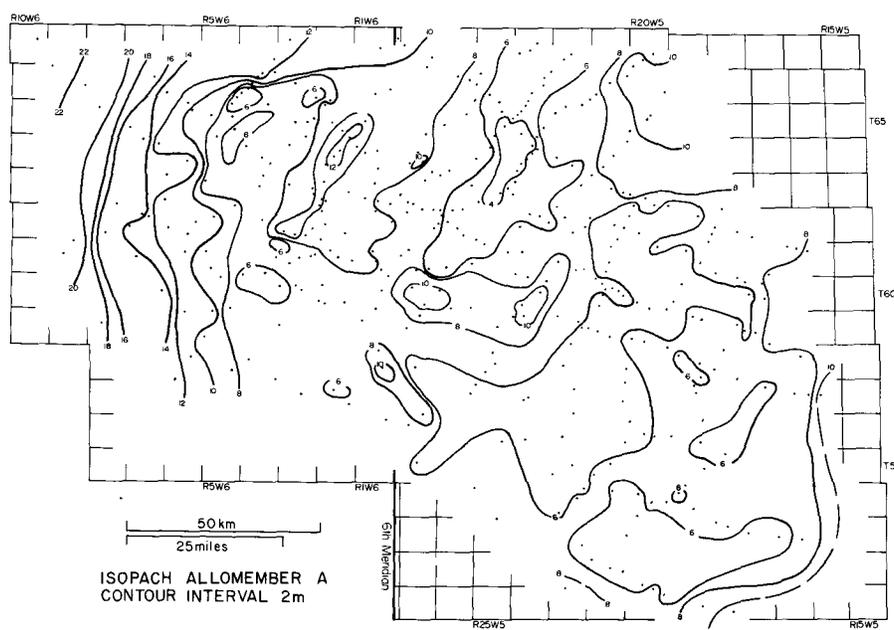
Fig. 17. Isopach of allomember A, wedge shaped in the west but more irregular to the southeast. Dots indicate data points.

been interpreted as being related to pulses of tectonically-induced subsidence resulting from rejuvenated thrusting in the adjacent cordillera, rather than reflecting a eustatic control (Bhattacharya, 1988,1989a).

Detailed mapping and facies analysis suggest that in general, the sandier-upward facies successions in the shingles are the result of prograding marginal marine and shallow marine depositional systems (Bhattacharya, 1988, 1989a,b, and *in press*; Bhattacharya and Walker, *this volume*). The regressive surfaces of erosion (RSE's), overlain by fining-upward successions, suggest that the shingles were fed by rivers. Thus the shingles are interpreted as prograding deltaic lobes (Bhattacharya, *in press*). The switching from one shingle to another was probably largely the result of **autocyclic** processes, such as river avulsions (Bhattacharya, 1988, 1989a, and *in press*). Channels in units older than shingle E1 may also be candidates for the sequence boundary discussed above. This illustrates the difficulty in distinguishing sequence boundaries from autocyclic channels in offlapping sedimentary units in foreland type settings, where subsidence (*i.e.*, accommodation) is higher in a landward position.

RELATIONSHIP OF LITHOSTRATIGRAPHIC AND ALLOSTRATIGRAPHIC UNITS

DUNVEGAN AND SHAFTESBURY FORMATIONS

In this section we illustrate how the new allostratigraphic scheme clarifies the genetic relationships of the previously defined lithostratigraphic units. The sandstones within each allomember die out southeastward, with the sandstones in allomembers G and F disappearing before those in allomembers E, D, and C (Fig. 4). Conventional lithostratigraphy defines the base of the Dunvegan Formation at the first thick sandstone overlying the shales of the upper Shaftesbury Formation. Such a base is diachronous, gradational, and passes obliquely through prograding depositional units. The shales in our allomembers E, F and G grade into and become indistinguishable from the shales of the upper Shaftesbury Formation to the southeast, indicating an interfingering relationship between the Shaftesbury and Dunvegan formations. Chronostratigraphically, in the southeastern portion of the study area, most of the upper Shaftesbury Formation is in fact the shaly, basinal equivalent of Dunvegan Formation sandstones to the northwest. Our correlations (Fig. 4) suggest that shales of the upper Shaftesbury Formation of the Fort St. John area in northeast British Columbia, belonging to the *T. alcesensis* Zone (Caldwell *et al.*, 1978), pinch out and are completely absent to the southeast as they downlap onto the FSU marker. These relationships help to account for the loss of this zone to the southeast and explain the nature of the regional paraconformity described by Caldwell *et al.* (1978) at the Fish Scales Horizon, which is indistinguishable from the FSU horizon farther to the south.

The allostratigraphic relationships defined in cross-section (Fig. 4) show that units within the upper portion of the upper Shaftesbury Formation and lower portion of the Dunvegan

Formation downlap onto the FSU marker. The base of the FSU marker therefore represents a widespread bounding discontinuity (a regional downlap surface) overlain by a significant condensed section.

In the Peace River area, north of this study area, there are two cored wells that penetrate the FSU marker. These are Imperial Spirit River #1, 12-20-78-6W6 and Imperial Claremont #1, 16-25-72-5W6. In the Spirit River well the FSU marker lies at 548.6 m (1800 ft.), 53 m above the base of the Fish Scales Marker. In the Claremont well the FSU marker lies at 1044.5 m (3427 ft.), 38 m above the base of the Fish Scales. Examination of these cores shows a dramatic lithological change across the FSU boundary. Dark greenish black, fish-scale bearing, bentonitic shales underlie the FSU marker. Above, the sediments comprise sideritic, rippled, silty mudstones (Facies 2B) lacking fish scales and with clear evidence of deposition above wave base. This transition is thought to mark a change from deep water marine conditions into shallower water brackish conditions (J.H.Wall, pers. comm.). This facies change confirms that the sediments above the FSU marker are probably related to progradation of Dunvegan deltaic depositional systems, whereas those below are not genetically related to the Dunvegan Formation and are probably related to a time of peak transgression of the upper Shaftesbury seaway.

The FSU marker merges with the Fish Scales to the southeast where, as described above, it becomes paraconformable. The paraconformable nature to the southeast, in combination with the facies changes across it, indicates that the FSU marker represents a significant stratigraphic break within the upper Shaftesbury Formation.

THE DUNVEGAN AND KASKAPAU FORMATIONS

Sandstones in upper allomembers B and A also die out to the southeast where they pass into the shales of the Kaskapau Formation, although the downlapping nature so prominent in the lower allomembers is not pronounced. These sandstones do not prograde as far as sandstones in the underlying allomembers E, D and C. In conventional lithostratigraphy the base of the Kaskapau Formation is defined as the first thick marine shale overlying the Dunvegan Formation, although the formations have been been described as interfingering (ASPG Lexicon, 1960, p. 187). As illustrated above, in any given core, this contact is commonly sharp rather than gradational (*i.e.*, it coincides with an MjF surface). But in cross-section (Fig. 4), this contact is also diachronous and passes obliquely through the upper allomembers of the Dunvegan.

As interpreted above, the major transgression in the Dunvegan Formation is interpreted as being represented by the TSE in allomember C. Allomembers A and B are interpreted as having been deposited during the ensuing transgression that culminated in deposition of widespread shales in the Kaskapau seaway. Allomembers A and B are therefore interpreted to be genetically related to shales of the Kaskapau Formation (*i.e.*, the transgressive phase) and not directly related

to the sediments of the underlying progradational lowstand phase.

These relationships have also been recognized in outcrop studies of the Dunvegan Formation. Stelck, *et al.* (1958) recognized a similar three-fold subdivision of the Dunvegan Formation along the Beatton River in northeastern British Columbia. This included a lower marine to brackish unit, a middle nonmarine unit containing fluvial channels (arkosic division) and an upper "deltaic" unit. Without detailed correlations between our study area and Dunvegan outcrop, however, we regard attempts to recognize our allomembers in outcrop as premature.

Finally, we emphasize that the allostratigraphic and lithostratigraphic schemes are parallel stratigraphies.

We believe that the allomembers defined above form a better basis for the description and interpretation of the sedimentology, paleogeographic evolution, and genetic relationships than a purely lithostratigraphic scheme. Examples of the types of paleogeographic reconstructions made possible using this approach are illustrated in Bhattacharya and Walker (*this volume*) and Bhattacharya (*in press*).

CONCLUSIONS

1. Seven allomembers are defined within the Dunvegan and associated upper Shaftesbury and lower Kaskapau formations designated, from youngest to oldest, A through G.

2. Each allomember consists of one or more overlapping lens-shaped units, termed shingles, which progressively offlap southeastward and downlap onto the underlying allomember. Landward, the shingles may be represented by fluvial channels underlain by regressive surfaces of erosion whereas seaward, most of the shingles are characterized by a sandier-upward facies succession capped by a minor marine flooding surface.

3. The allomember boundaries are represented by major marine flooding surfaces (MjFS), which separate the offlapping sets of shingles.

4. The lower allomembers downlap onto a regionally persistent marker horizon forming a prominent condensed section within the upper Shaftesbury Formation (the FSU marker) that has been recognized as far north as the Peace River. The shales of the upper Shaftesbury Formation above the FSU marker are interpreted as being genetically related to the progradational sandy phase of the Dunvegan Formation to the northwest, whereas the shales below the FSU marker are not related to the Dunvegan.

5. A major transgressive surface of erosion (TSE) in allomember C terminates the dominantly progradational phase of the Dunvegan Formation and is marked by a widespread sandy *Ophiomorpha* bed. The TSE is interpreted as the first indication of the Kaskapau transgression.

6. The overlying allomembers B and A pass laterally southeastward into shales of the Kaskapau Formation implying a genetic relationship between the lower Kaskapau and the upper portion of the Dunvegan Formation.

7. The progradational phase of the Dunvegan Formation is thought to be driven in part by a third-order eustatic fall of sea level (Bhattacharya, 1988). We suggest that the third-order sequence boundary may lie at the base of shingle E1, although it is hard to distinguish from some of the other channelized erosional surfaces in units above and below.

8. Each allomember is interpreted as representing the progradation of sandy, shallow marine and marginal marine environments. Each progradation is terminated, probably rapidly, by a widespread transgression that produces the thin transgressive unit bounded above by the MjF surface, which defines each allomember.

9. The shift from one shingle to another is interpreted as being the result of an **autocyclic** process; however, the extent of the allomember-bounding MjF surfaces suggests an **allocyclic** control. This is interpreted as a relative rise of sea level, induced by regional tectonics.

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