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THE HAY RIVER FORMATION AND ITS RELATIONSHIP TO ADJACENT FORMATIONS, SLAVE RIVER MAP-AREA, N.W.T.

G.K. WILLIAMS

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THE HAY RIVER FORMATION AND ITS RELATIONSHIP TO ADJACENT FORMATIONS, SLAVE RIVER MAP-AREA, N.W.T.

Abstract

The Upper Devonian (Frasnian) Hay River Formation, composed of about 400 m (1300 ft) of shale, is mappable over an area of about 26 000 km^2 (10 000 sq miles) in the southern Northwest Territories and northern Alberta. Hay River strata are underlain by the Slave Point Formation, a widespread carbonate-evaporite unit, generally considered to be entirely of Middle Devonian age, and are overlain by the Twin Falls Formation, composed of interbedded limestone, siltstone and shale, of Frasnian age. The Hay River Formation is equivalent partly to the following shale units: Waterways, Ireton, Muskwa, Fort Simpson and Horn River Formations. Carbonate units equivalent to parts of the formation occur in the Grosmont reef-complex and the Swan Hills pinnacle reefs.

This study provides evidence that, contrary to majority opinion, there was continuous subsidence across the Middle-Upper Devonian boundary, i.e. the Slave Point and Hay River Formations have a gradational contact. Clinoforms within the Hay River Formation slope westward; the western 'toes' of the clinoforms become radioactive black shale layers. Several such radioactive layers merge to form the Muskwa Formation. The following deductions are made: 1) The shale of the Hay River Formation was deposited primarily by lateral sedimentation as a stacked series of westward-advancing mud banks. 2) The Muskwa Formation is a starved-basin, relatively deep water deposit equivalent to most of the Hay River Formation. 3) Subsidence at a rate faster than that of clastic deposition is indicated in areas where the Muskwa and Slave Point Formations are in contact.

The belief that there was a regional uplift prior to deposition of the Hay River Formation stems largely from evidence derived from outcrop areas at Gypsum Cliffs in northeastern Alberta and Windy Point on Great Slave Lake. At Gypsum Cliffs, the karst-like contact between the Slave Point and Waterways Formations and the missing faunal zones could have been produced by solution of previously deposited evaporites by less saline, deepening water. At Windy Point, fossil evidence does not rule out the possibility that the recrystallized reef mass includes rocks equivalent to the Slave Point Formation.

Résumé

La formation de Hay River, du Dévonian supérieur (Frasnien), composée d'environ 400 m (1300 pieds) de schistes argileux, se retrouve sur une superficie d'environ 26 000 km^2 (10 000 milles carrés) dans le sud des Territoires du Nord-Ouest et le nord de l'Alberta. Les couches de Hay River recouvrent celles de la formation de Slave Point, formation d'une grande étendue, constituée d'évaporites et de roches carbonatées, généralement considérée comme étant entièrement du Dévonien moyen et sont recouvertes par la formation de Twin Falls, constituée de calcaires, de siltstones et de schistes argileux en couches alternées (Frasnien). La formation de Hay River correspond en partie aux unités schisto-argileuses suivantes: les formations de Waterways, d'Ireton, de Muskwa, de Fort Simpson et de Horn River. Des formations de roches carbonatées correspondant à certaines sections de la formation de Hay River se trouvent dans le complexe récifal de Grosmont et dans les récifs a clochetons de Swan Hills.

Cette étude montre que, contrairement à l'opinion de la majorité, il y a eu subsidence continue lors du passage du Dévonien moyen au Dévonien supérieur; c'est à dire que le contact entre les formations de Slave Point et de Hay River est progressif. Les structures monoclinales de la formation de Hay River plongent vers l'ouest; les plongements occidentaux de ces structures passent latéralement à des couches de schistes argileux noirs radioactifs. Plusieurs de ces couches radioactives se confondent pour constituer la formation de Muskwa. On deduit que: 1) les schistes argileux de la formation de Hay River se sont d'abord déposés par sédimentation latérale sous forme de séries empilées de talus de boue s'avançant vers l'ouest; 2) la formation du Muskwa est un dépôt de bassin sous-alimenté, relativement peu profond, contemporain de la plus grande partie de la formation de Hay River; 3) une subsidence a eu lieu, à une vitesse plus grande que la vitesse de sédimentation des dépôts clastiques et est manifesté dans les zones où les formation de Muskwa et de Slave Point sont en contact.

La croyance qu'il y a eu un soulèvement régional avant le dépôt de la formation de Hay River provient en grande partie des indications fournies par les affleurements de Gypsum Cliffs dans le nord-est du l'Alberta et de Windy Point, au bord du Grand lac des Esclaves. A Gypsum Cliffs, le contact de type karstique entre les formations de Slave Point et de Waterways et l'absence de certaines zones de faune, sont peut-être dus à la dissolution par des eaux moins saturées et plus profondes, des évaporites deposées auparavant. A Windy Point, les manifestations paléontologiques n'excluent pas la possibilité que la masse récifale recristallisées contienne des roches contemporaines de celles de la formation de Slave Point.

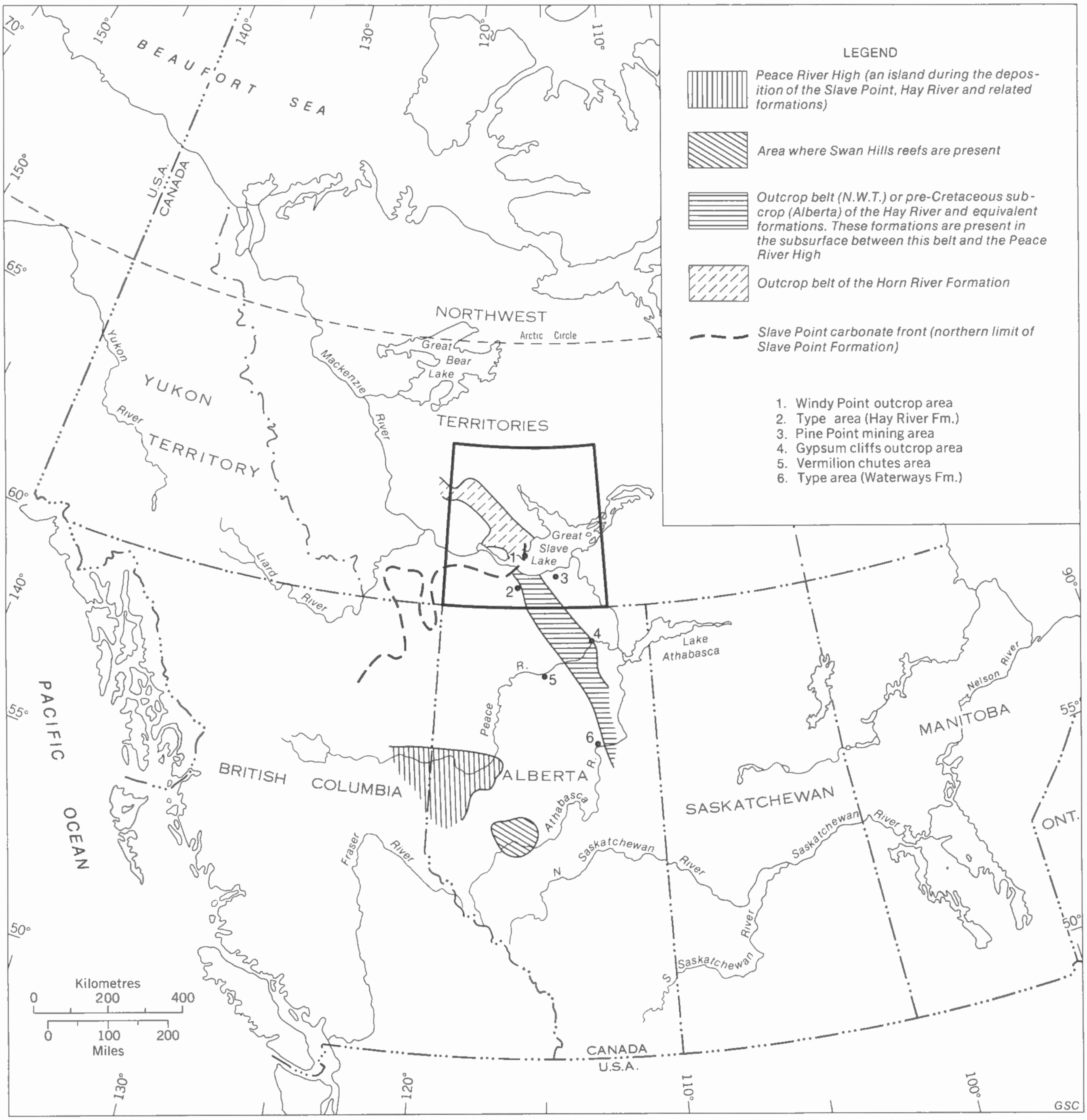

FIGURE 1. Index map showing the main geologic features and geographic areas

THE HAY RIVER FORMATION AND ITS RELATIONSHIP TO ADJACENT FORMATIONS, SLAVE RIVER MAP-AREA, N.W.T.

INTRODUCTION

Slave River map-area (NTS 85) is in the southern part of the District of Mackenzie, Northwest Territories; the southern edge is the northern boundary of Alberta (Fig. 1).

The purpose of this report is to review our knowledge of the geology of the Hay River Formation; to bring together in one report various data, some of which are unpublished, to reconcile conflicting concepts as far as possible and to present a theoretical model for the sedimentary processes that produced the Hay River and related formations.

This is primarily a subsurface investigation and information is derived, mainly, from a detailed study of geophysical well logs. Given some prior knowledge of the lithology, correlation patterns derived from geophysical logs can indicate shallow, intermediate and relatively deep water environments and, in some instances, can show how rocks of one environment correlate with time-equivalent rocks deposited in a different environment.

PREVIOUS WORK

The history of nomenclature, full lithological descriptions, and a discussion of macropaleontology of the Hay River Formation are given by Belyea and McLaren (1962). In their report, the name Escarpment Member was introduced for the upper part of the formation. Correlation of the limestone units which form the two falls on Hay River, including the outcrops and escarpments northwest of the falls, was first correctly explained by Harding (1955); unfortunately, his work remained largely unknown or unheeded. Jamieson (1967) studied the above limestone units and independently arrived at Harding's correlation. Jamieson has suggested that the term "Escarpment Member" be discarded; she has introduced also several new member names, one of which, the Louise Falls Member, could be adapted for subsurface use.

Subsurface terminology of northern Alberta was revised by Leavitt (1966), whose suggestions were followed by Hemphill *et al.* (1970). The Beaverhill Lake Group, as that term now is used in northern Alberta, includes, from the base up, the Fort Vermilion, Slave Point, Swan Hills and Waterways Formations (Fig. 10). The Waterways Formation is equivalent to the lower part of the Hay River Formation; the shaly strata of the Waterways cover, and are in part equivalent to, the Swan Hills reefs.

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Publications by A.W. Norris, who mapped the geology of areas in northern Alberta (Norris, 1963) and in the Slave River map-area (*ibid.*, 1965), are basic to any discussion of the Hay River and related formations. An up-to-date review of the Paleozoic geology of northeastern Alberta is given by Norris (1973).

Other reports involving or touching on the Hay River Formation are too numerous to mention. Of special importance, however, are those of Bassett and Stout (1967) and Griffin (1965); the former provides the regional geological setting, the latter discusses lithology and well-log correlation in the area immediately south of the Slave River map-area. The unpublished work of Richmond (1965) is a comprehensive investigation of the surface and subsurface geology of a region which includes the Slave River map-area.

The concept of undaform, clinoform and fondoform bedding was formulated by Rich (1951). Oliver and Cowper (1963) applied these concepts to well-log data of the Ireton Formation in an area near Edmonton. Sheasby (1971) made a similar study of the Waterways Formation in the Swan Hills area of Alberta.

ACKNOWLEDGMENTS

The lithological descriptions of wells in the map-area are mainly the work of H.R. Belyea and E.J. Tassonyi. D. Morrow and A.W. Norris critically reviewed the original manuscript and their helpful suggestions for improvement are gratefully acknowledged. These readers do not agree with all the conclusions and these remain the responsibility of the writer.

LITHOLOGICAL SUMMARY

The stratigraphic position of the Hay River Formation is illustrated diagrammatically in Figure 2. The underlying Slave Point Formation is a widespread carbonate-evaporite deposit about 60 m (200 ft) thick (as used here, the term includes the Fort Vermilion anhydrite). To the northwest, the Slave Point Formation is entirely carbonate, and mainly limestone; to the southeast, in northeastern Alberta, it is mostly anhydrite. The northwestern limit is an abrupt carbonate front; equivalent shaly strata are part of the Horn River Formation.

Overlying the Hay River shale is the Twin Falls Formation, composed of shallow-water calcarenite which is variably sandy with many shaly layers. A thin biostromal layer, the Alexandra Member, forms the basal unit.

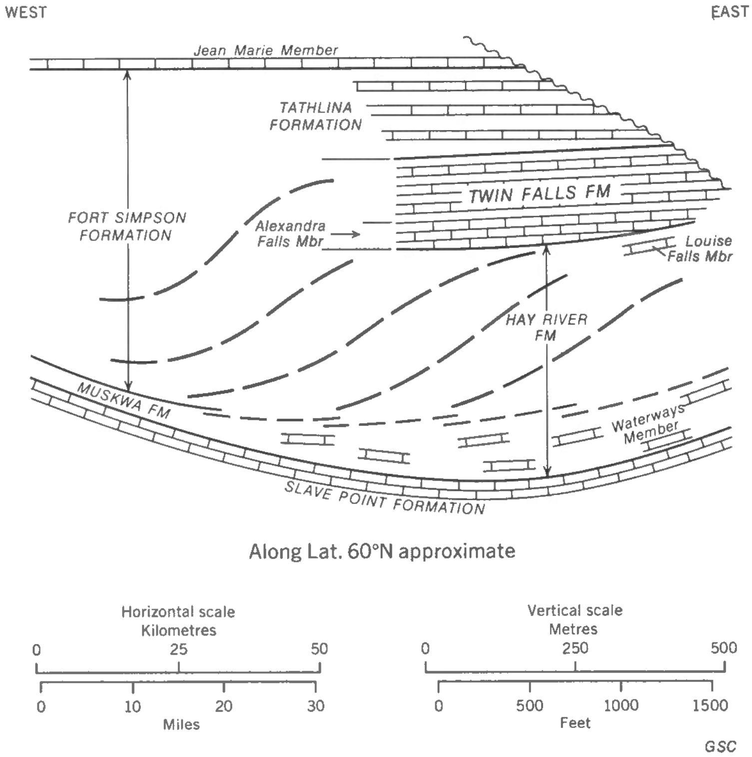

FIGURE 2. Schematic cross-section illustrating nomenclature

The Hay River Formation consists primarily of grey-green, fissile marine shale. Carbonate cement, detrital fossil debris and silt or very fine sand are present in amounts which vary from place to place and throughout the section. In the type area, the upper part of the formation contains several thin layers of limestone. This limestone may be shaly, silty or sandy or, rarely, nearly free of terrigenous material; it is variably fossiliferous, ranging from calcilutite with shelly fauna to coral-stromatoporoid biostromes. This occurrence of limestone within the upper part of the formation is confined to a narrow north-northwest trending belt, including the type area. The facies northeast from this belt is unknown because this part of the section has been eroded (Fig. 1); southwest from this belt, the upper part of the section is almost entirely shale with only a few thin bands of calcilutite.

In the south-central part of the Slave River map-area, the lower part of the Hay River Formation - that part which is equivalent to the Waterways Formation - also contains intercalated, thin beds of limestone. These limestone beds are variably argillaceous and silty, grading from marl to, rarely, a pure limestone. Fossils and fossil fragments occur in variable concentrations, in some places forming a thin bioclastic layer, but more often are present only as traces. The most common fossils are brachiopods, gastropods, ostracodes, and tentaculitids. Pyrite is common, and usually finely disseminated. Bituminous shale layers occur throughout the Waterways Member in part of the map-area; they are not present in the south-central area, but become increasingly abundant to the north and to the west. To the west, these bituminous shales merge to become part of the Muskwa Member.

CORRELATION

PROBLEMS AT THE TYPE AREA

The history of nomenclature in this area is rather complex; it is reviewed by each of the authors quoted in this section. Only that part of the history that is pertinent to an understanding of the term "Escarpment Member" is reviewed here.

The Upper Devonian of the Slave River map-area consists of two main divisions: an upper division, comprising several formations, which is dominantly limestone; and a lower division, the Hay River Formation, which is nearly all shale. The regional strike is northwest, the dip southwest. The Hay River flows northeast, cutting progressively deeper into the section.

Where the Hay River cuts through the transition from limestone to shale, there are two waterfalls: the Alexandra Falls, and the lower and smaller Louise Falls (*see* Fig. 3). Both falls are formed by resistant limestone units, separated by a few metres of shale. The top contact of the Hay River Formation is placed at the base of the limestone forming Alexandra Falls, which is known as the Alexandra Falls Member of the Twin Falls Formation.

Resistant limestone units at or near the upper contact of the Hay River Formation form a line of low but prominent escarpments which extend northwest from the river for about 48 km (30 miles) (Fig. 3). Outcrop is not continuous, and the correlation from the river section to the escarpments has been interpreted in different ways. One result of miscorrelation has been confusion regarding the Escarpment Member.

Harding (1955) indicated a correlation between the biostrome which forms the escarpment near Heart Lake (Fig. 3) with the bedded, non-reefal limestone unit that forms the Alexandra Falls. The latter falls-forming limestone unit, then known as the Alexandra Formation, is now known as the Alexandra Member of the Twin Falls Formation (Belyea and McLaren, 1962). Harding (1955) also concluded that the limestone beds forming Louise Falls (Fig. 3) were correlative with the low escarpment formed by reefal limestone near Escarpment Lake. Belyea and McLaren (1962) arrived at a different correlation; they considered the reef at Heart Lake to be correlative with the limestone forming Louise Falls, thus the Heart Lake reef was thought to lie within, and near the top of, the Hay River Formation. The name "Escarpment Member" was given by Belyea and McLaren (1962) to the upper one quarter, approximately, of the Hay River Formation, which includes the Heart Lake reef, the Louise Falls limestone, the thin reefal limestone near Escarpment Lake, other similar bioclastic or reefal lenses, as well as the enclosing shale. House and Pedder (1963) suggested that the Escarpment Member be elevated to formational rank, that the term "Hay River Formation" be discarded, and that the shale section be relegated to the Fort Simpson Formation.

Jamieson (1967) presented convincing lithostratigraphic, biostratigraphic and topographic evidence that Harding's (1955) correlation was correct. The escarpment at Heart Lake is formed by reefal rocks

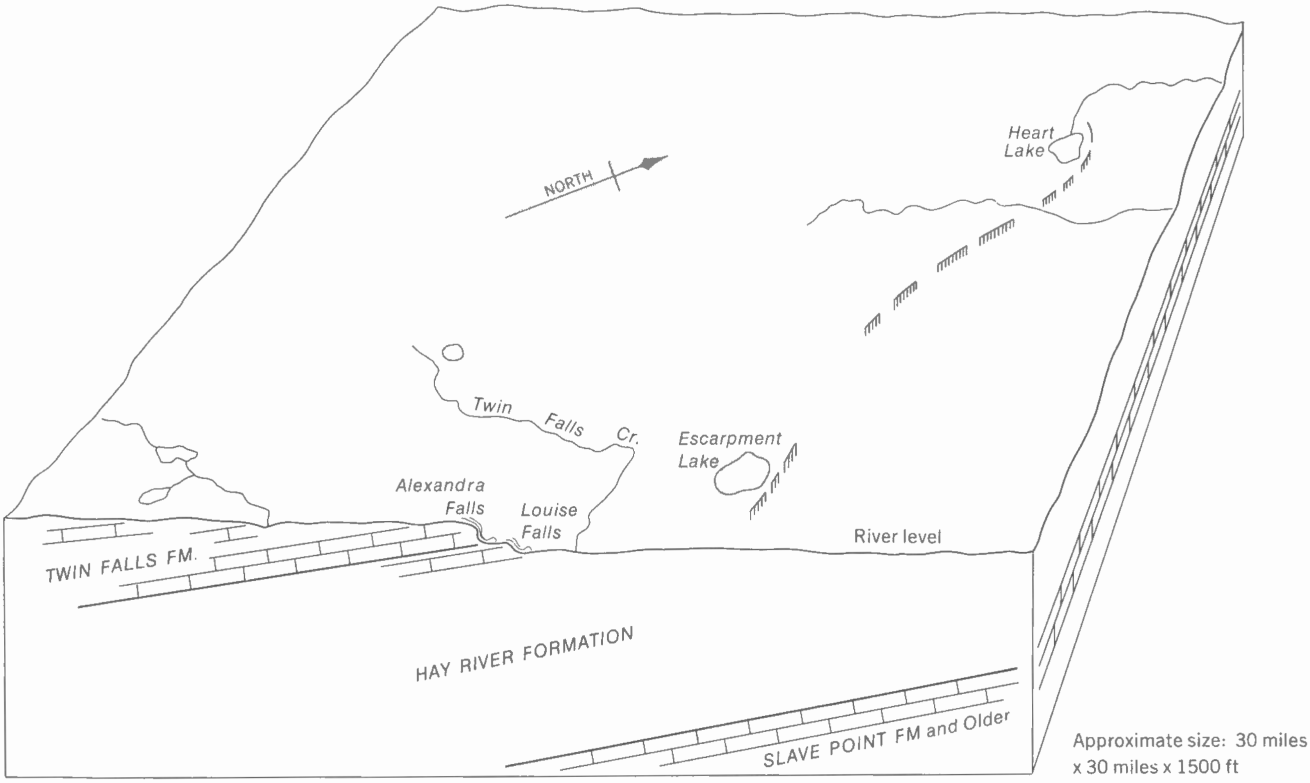

FIGURE 3. Schematic block diagram, type-area of Hay River Formation

equivalent to the bedded non-reefal limestone of the Alexandra Member of the Twin Falls Formation; the limestone forming the escarpment at Escarpment Lake correlates with the Louise Falls Member of the Hay River Formation. The term 'Escarpment Member' is therefore invalid and, as suggested by Jamieson (1967), should be dropped. The name is still used on the latest map of the area (Douglas, 1974); however, it is used to denote only the single lens of limestone which forms Louise Falls and the escarpment near Escarpment Lake.

SURFACE TO SUBSURFACE CORRELATION

Precise correlation from surface to subsurface cannot be established with absolute confidence. Although several wells have been drilled near the type section, correlation is difficult due to lack of geophysical logs of the upper part of the hole, poor samples, and facies changes. Given good well samples, which do not exist at present, one might be able to recognize the fine divisions of the upper part of the Hay River Formation described and named by Jamieson (1967). For subsurface mapping, a geophysical log marker must be used. The one selected to mark the top of the formation coincides very nearly with the stratigraphic horizon marking the top of the formation as defined in outcrop, but probably excludes the uppermost few metres of limestone and sandstone which are present at the top of the Hay River Formation below Alexandra Falls.

The Hay River-Twin Falls contact, as recorded on Figure 14, is picked on the geophysical logs where they indicate a downward change from predominantly limestone to predominantly shale or shaly limestone. As can be seen on Figures 11 and 12, the point chosen on the log is arbitrary. Union Alexandra Falls No. 6 well (Fig. 9) is located near Hay River about 6.4 km (4 miles) downstream from Louise Falls; the limestone between the depths of 95 and 135 feet (29-41 m) must be the Louise Falls limestone. A limestone unit in a similar position is present in nearby wells to the south but, as seen in the Canso *et al.* Grumbler J-13 well (Fig. 9), there are several such limestone units.

CORRELATION WITH NORTHERN ALBERTA

Figure 9 illustrates the nature of geophysical log correlation. Union Alexandra Falls No. 6 well is located near Hay River in the type area. The southernmost well is near Vermilion Chutes on Peace River, an area mapped by Norris (1963). Figure 10 provides a correlation tie to an area studied by Leavitt and Fischbuch (1968).

It has been recognized for a long time that the Hay River Formation contains, in its lowest part, rocks equivalent to the Waterways Formation of northeastern Alberta; the log sections (Figs. 9, 10) illustrate the nature of the relationship. The Waterways Formation, unlike the Ireton, contains several thin but laterally persistent limestone layers. The upper contact apparently is not a persistent marker, but drops very gradually downsection from south to north and from east to west. Also, the number and thickness of limestone beds decreases from south to north. In the north, the Waterways equivalent, where it is recognizable, can be considered a member of the Hay River Formation.

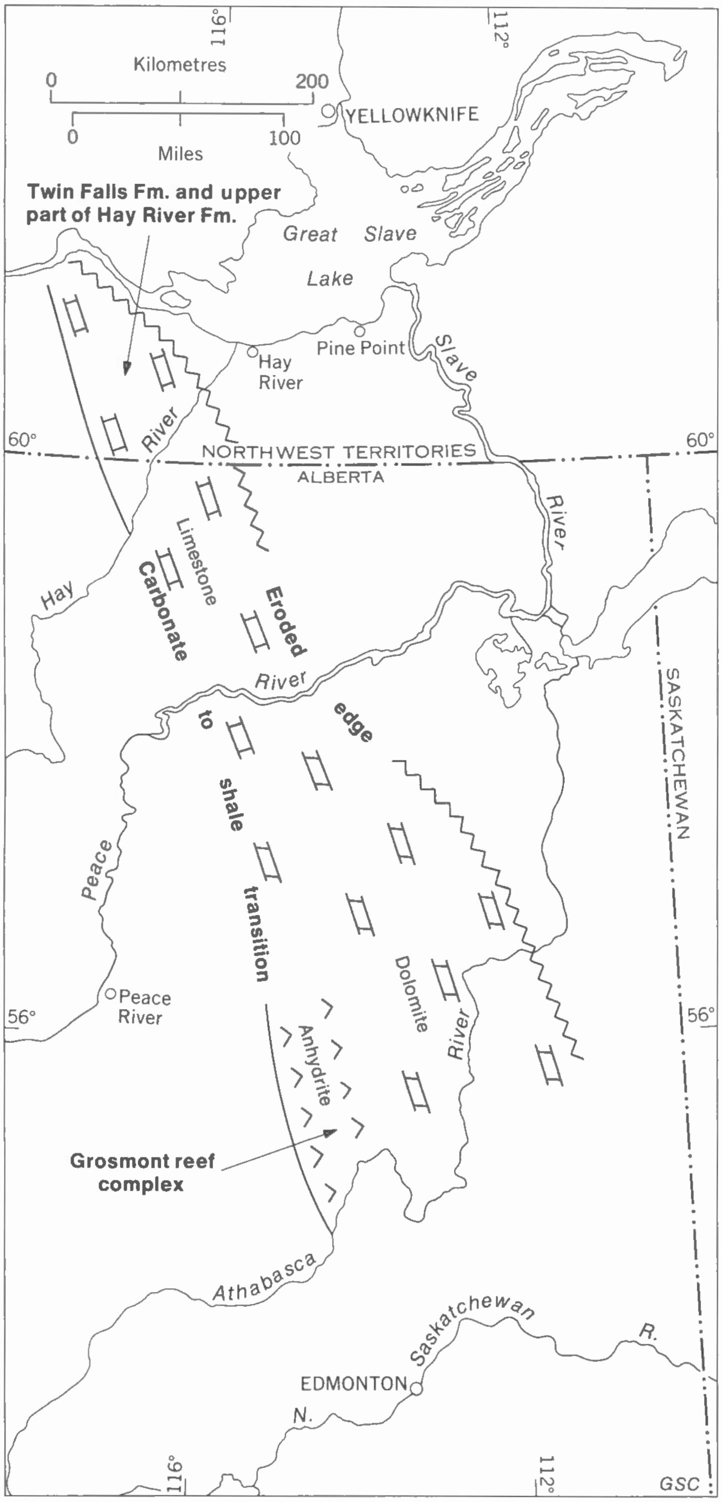

FIGURE 4. Illustration of relationship of Grosmont Formation to Twin Falls and Hay River Formations [modified from Fig. 6-12 (H.R. Belyea) *in* McCrossan and Glaister, 1964]

In northeastern Alberta, the Grosmont Formation is a reef complex up to 170 m (550 ft) thick (Belyea, 1952). In the Vermilion Chutes area, only the lower part of the formation survived pre-Cretaceous erosion. Figure 9 shows that it is not possible to correlate individual beds; but it is obvious that the Grosmont Formation is equivalent to the upper part of the Hay River Formation as well as a part, at least, of the Twin Falls Formation. Figure 4 illustrates the regional relationship.

CLINOFORM MARKERS WITHIN THE HAY RIVER SHALE

In the 1950's, a favourite exploration method in the Slave River map-area was the drilling of shallow structure test holes. Well log markers within the predominantly limestone section, later known as the Tathlina and Twin Falls Formations, were found to be reliable and persistent, but markers within the Hay River shale section appeared to be erratic. A log marker in one test hole would be identical to a marker in an adjacent test hole but lie at a higher or lower level. Although it was recognized that some of these markers could be interpreted as giant cross-bedding, their significance was not evident. Somewhat similar markers had been noted in the Upper Devonian shales of Alberta by McCrossan (1961). Oliver and Cowper (1963) applied the concepts of Rich (1951) in a study of the Ireton Formation in central Alberta; they interpreted a series of rapidly diverging well log markers as west-sloping clinoforms. Sheasby (1971) found a similar pattern within the Waterways Formation in the Swan Hills area. The hitherto apparently erratic markers of the Hay River Formation can be interpreted in a similar fashion.

Evidence of clinoforms within the Hay River Formation is presented in Figures 11 and 12. In several other regions of the Slave River map-area and in northern Alberta, markers occur, common to a few adjacent wells, which can be interpreted as clinoforms. Reliability of the correlation ranges from indisputable, as in the central logs on Figure 11, to highly subjective, as on Figure 12.

Figure 5 illustrates a summary of the evidence from several such areas. The contour lines are isopachs of an interval from a clino marker to an overlying marker at, or parallel to, a formation boundary. The several isolated areas are isopaches of different intervals; no clino marker common to the entire map-area can be identified. The isopachs, which represent the geometry of bedding slopes modified by compaction, consistently indicate a north-northwest strike and a slope to the west. Dips are between 3 and 13.5 m (10-45 ft) per mile.

RELATIONSHIP OF HAY RIVER FORMATION TO ADJACENT FORMATIONS

RELATIONSHIP TO OVERLYING FORMATIONS

This relationship varies but, in general, the vertical change in lithology indicates a progressive upward shallowing. At the type area, the upward change is from shale to shale with thin limestone layers, one of which is reefal, to interbedded shale,

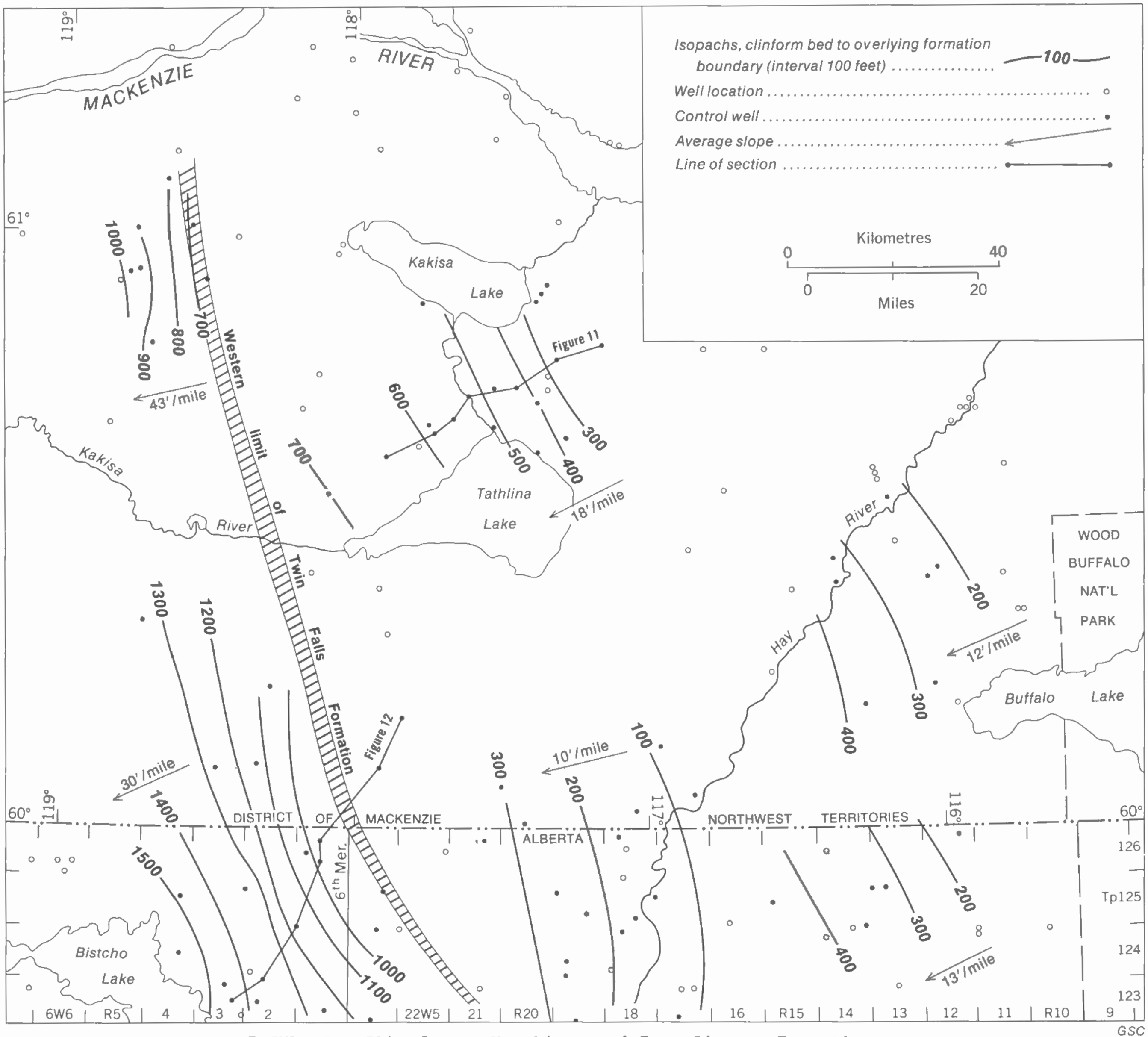

FIGURE 5. Clinoforms; Hay River and Fort Simpson Formations

sandstone and sandy limestone. The contact with the overlying Alexandra reef-complex is sharp.

South of the type area, there is a narrow belt in which conditions are similar, although there appear to be more and thicker limestone units within this upper part of the formation. As shown in Figure 9, this zone merges with the lower part of the Grosmont reef-complex.

It is interesting to speculate on what conditions were like to the east, in the belt now eroded. Perhaps the Alexandra reef and the carbonates of the upper Hay River Formation are tongues of a Grosmont-type reef complex, now destroyed by erosion (*see* Figs. 4, 8).

In the subsurface, judging from the well logs plus rather poor quality samples, the upper contact of the Hay River Formation is gradational. For the sake of consistency, the same marker was traced, as far as possible, in all wells, even though the change from predominantly shale to predominantly limestone shifts slightly up- or downsection from place to place (Figs. 11, 12, 14).

To the west, beyond the shale-out of the Twin Falls Formation, the Hay River becomes the basal part of the Fort Simpson Formation. On the evidence of the clinoform markers shown on Figure 11 and other cross-sections, the 390 m (1300 ft) of Hay River shale of the type area are equivalent to a much thinner interval within the basal part of the Fort Simpson and upper part of the Muskwa shales; farther west, the Hay River shale may be equivalent to only the upper few feet of the Muskwa Formation (Fig. 2).

RELATIONSHIP TO THE SLAVE POINT FORMATION

A discussion of this relationship raises several questions. Is the age of the Slave Point Formation entirely Middle Devonian or does it, in places, extend into the Upper Devonian? Is there a regional unconformity at the Slave Point-Waterways contact or are these formations gradational and, to some extent, intertongued? Is there a regional unconformity at the base of the Muskwa Formation? Is there a regional unconformity marked by uplift, warping and erosion which marks the Middle to Upper Devonian boundary?

The range of opinion can be illustrated by a selection of quotes. The following are listed chronologically. In reports up to 1970, read "Waterways" for "Beaverhill Lake".

Kent (1964, p. 62) [Great Plains of western Canada]

> There is little or no evidence to suggest that a period of stillstand was initiated at the close of the last interval*. On the other hand there is evidence that a major change in the tectonic pattern did occur near the close of it. (*Slave Point and Fort Vermilion Formations)

Murray (1965, p. 315) [northeastern Alberta]

> A number of new brachiopods make their first appearance in the Waterways but relict Middle Devonian elements persist.

Griffin (1965, p. 31) [northeastern British Columbia, northern Alberta]

> ... the Beaverhill Lake Formation was eroded before the deposition of the overlying Muskwa Formation.

McGill (1966, p. 104) [north-central Alberta]

> Comparison of several (ostracode) species with their counterparts from the Givetian of the Urals, U.S.S.R. and Europe suggests that the Slave Point Formation may be latest Givetian in age and that the Frasnian-Givetian boundary occurs at the contact between the Slave Point and overlying Beaverhill Lake Formation.

Braun (1966, p. 257) [Bear Biltmore No. 1 well; 7-11-87-17W4; representative of north-central and northeastern Alberta]

> From a microfaunal point of view the Slave Point Formation, therefore, is Givetian in age and not Upper Devonian, as sometimes suggested. In contrast, the ostracodes of the Beaverhill Lake Formation are closely related to mid- and late Frasnian faunas of Western Canada, and they differ substantially from the Slave Point or older Givetian assemblages. Such drastic changes within an important fossil group can be best explained by postulating different seas for the late Middle Devonian and early Upper Devonian, and consequently unconformable relationship at the boundary.

Griffin (1967, p. 813) [northeastern British Columbia]

> The deposition of the lower part of the Beaverhill Lake Formation is believed to have taken place contemporaneously with the accumulation of the Slave Point Formation ...

Bassett and Stout (1967, p. 714) [western Canada]

> ... a withdrawal of the sea accompanied by uplift and truncation occurred in latest Givetian time ...
>
> ... there can be no debate regarding the regional proportions and significance of that [a significant inter-regional unconformity] at or near the Middle-Upper Devonian boundary.

Bassett and Stout (1967, p. 744) [western Canada]

> The Waterways, up to 700 feet thick in east-central Alberta, thins westward to nil in northeastern British Columbia primarily by onlap onto the underlying top Middle Devonian unconformity.

Leavitt (1968, p. 317) [Carson Creek area, central Alberta]

> There is no evidence known to the writer that the off-reef basinal areas were subaerially exposed. [re Swan Hills reefs]

Hemphill, Smith and Szabo (1970, p. 56) [Swan Hills area, central Alberta]

> The Late Devonian Beaverhill Lake transgression began with the deposition of Slave Point carbonate ...
>
> Author's note: Beaverhill Lake here used as a group, and includes Slave Point and Waterways.

Belyea (1971, p. 31) [Slave River map-area]

> The close of Slave Point time was accompanied by uplift, erosion and a complete change in tectonic style. The succeeding Upper Devonian rocks are black and grey shales that thin westward by onlap or condensation or a combination of the two.

Johnson (1971, p. 3273) [western North America]

> The Taghanic [latest Givetian, earliest Frasnian] was the largest single transgressive event of the Kaskaskia Sequence ...

The questions listed at the beginning of this section are treated below under the following headings: the Slave Point Formation-Waterways Formation contact, the Muskwa Formation, and the Middle-Upper Devonian boundary.

Slave Point Formation-Waterways Member contact

Outcrop areas at Gypsum Cliffs on Peace River in northern Alberta and near Windy Point on Great Slave Lake provide the strongest evidence of the existence of an unconformity at the top of the Slave Point Formation. Subsurface evidence is equivocal, and the contact can be interpreted either as a transition or as an unconformity.

Outcrops at Gypsum Cliffs

This area was described by Norris (1963). The upper surface of the Slave Point Formation is irregular, and contains cavities, widened joint fissures and sink holes; in some of these are remnants (from recent erosion) of Waterways shale and limestone. According to Norris (*ibid.*, p. 62), fossils from the Slave Point indicate a Middle Devonian age, while those from the Waterways indicate a Late Devonian age. Thus, there is evidence suggesting a break, with karst-type erosion, between the Slave Point and Waterways Formations. Does this break indicate a widespread withdrawal of the Middle Devonian sea?

The Slave Point Formation is composed entirely of carbonate in the northwest but, southeastward, anhydrite becomes increasingly common in the lower part of the formation, eventually forming the Fort Vermilion Formation. Richmond (1965) has demonstrated that the percentage of anhydrite within the Slave Point-Fort Vermilion interval steadily increases toward Peace River (*see* Richmond, 1965, p. 175, Fig. 31). Gypsum Cliffs lies within this belt wherein evaporite predominated over carbonate deposition, and probably near the eastern limit of carbonate deposition.

The fact that the contact between the Slave Point Formation (restricted, evaporitic environment of deposition) and the Waterways Formation (normal marine environment of deposition) shows evidence of a missing section and of solution is not proof of a widespread withdrawal of the sea. Both the missing section and the karst-like contact could be the effects of transgression without a preceding regression. Suppose, for example, that gypsum or other evaporites were being deposited in response to a very slow rise of sea level. This area, which is remote from the open sea, would be covered by a thin layer of saturated brine. A relatively rapid increase in the rate of sea level rise would result in a thicker layer of water of decreased salinity, and some of the evaporites would be dissolved. A layer of evaporites of modest thickness, which were later dissolved, conceivably could represent considerable time. Dissolved evaporites would result in brecciation of any interbedded carbonates. If the postulated change in the rate of sea level rise was coupled with, or followed by, conditions favouring clastic deposition, the result could be a karst-like contact of marine shale with brecciated carbonate and interbedded anhydrite, with evidence of a missing section. The effects of transgression over evaporites is discussed by Shaw (1964, p. 23). An example, somewhat similar to the above supposition, is described by Richter-Bernberg (1973) from the Messinian evaporites in Sicily.

Outcrops at Windy Point

Slave Point is a prominent geographic feature on the north shore of Great Slave Lake, after which the Slave Point Formation was named. A few kilometres to the north is Windy Point (Figs. 14, 15), where there is an extensive exposure of a reef-like mass of carbonate, in part altered to coarsely crystalline dolomite. The reef-complex is identical, lithologically, with the ore-bearing reef-complex at Pine Point, with which it has always been correlated (Cameron, 1918; Norris, 1965). Flanking the dolomite at Windy Point on the west side is a thin veneer of fossiliferous limestone; about 3 m (10 ft) are exposed, but up to 24 m (80 ft) occur in nearby diamond-drill holes. The capping limestone, according to Norris (1965, p. 83) "... appears to unconformably overlie the Presqu'ile Formation ..." and he also states (*ibid.*, p. 85) that the strata "... undoubtedly correlate with the Firebag Member of the Waterways Formation ... Since these beds are early Upper Devonian they are excluded from the Slave Point Formation".

There are three points to note here: 1) the exclusion of the uppermost limestone from the Slave Point Formation on paleontological grounds; 2) the presumed unconformity between the limestone and the dolomite; and 3) the presumption that the coarsely crystalline dolomite is a time-rock unit. The first point appears to violate the definition of a formation. Limestone outcrops, which had been included in the Slave Point Formation by Cameron (the man who named the formation) as well as by others, were removed and placed in the Hay River Formation. With regard to the second point, a complete reading of Norris' (1965) lithologic descriptions reveals that the limestones are interbedded, in places, with the dolomite and, thus, the evidence for an unconformity must depend on the last point.

In the past, the Presqu'ile Formation has been considered to be a time-rock unit - a facies of the Sulphur Point Formation - lying between the Slave Point carbonate above and the Pine Point carbonate below (*see* Norris, 1965, Figs. 3, 6). It is now becoming increasingly evident that the Presqu'ile-type dolomite (i.e. very coarse dolomite) is a diagenetic facies not limited to any definite horizon or any one original type of carbonate (Skall, 1975). In the Slave River map-area, the Presqu'ile facies is found at any horizon from the Keg River platform to high in the Slave Point Formation. Furthermore, the Presqu'ile facies tends to migrate upsection from south to north. Along the carbonate front in the Slave River map-area, there are several wells where the Slave Point is, in part (in one case entirely), altered to a Presqu'ile facies, some 60 m (200 ft) stratigraphically higher than the position of the Presqu'ile facies at Pine Point.

A similar situation has long been recognized along the gas-bearing parts of the carbonate front in northeastern British Columbia (Gray and Kassube,

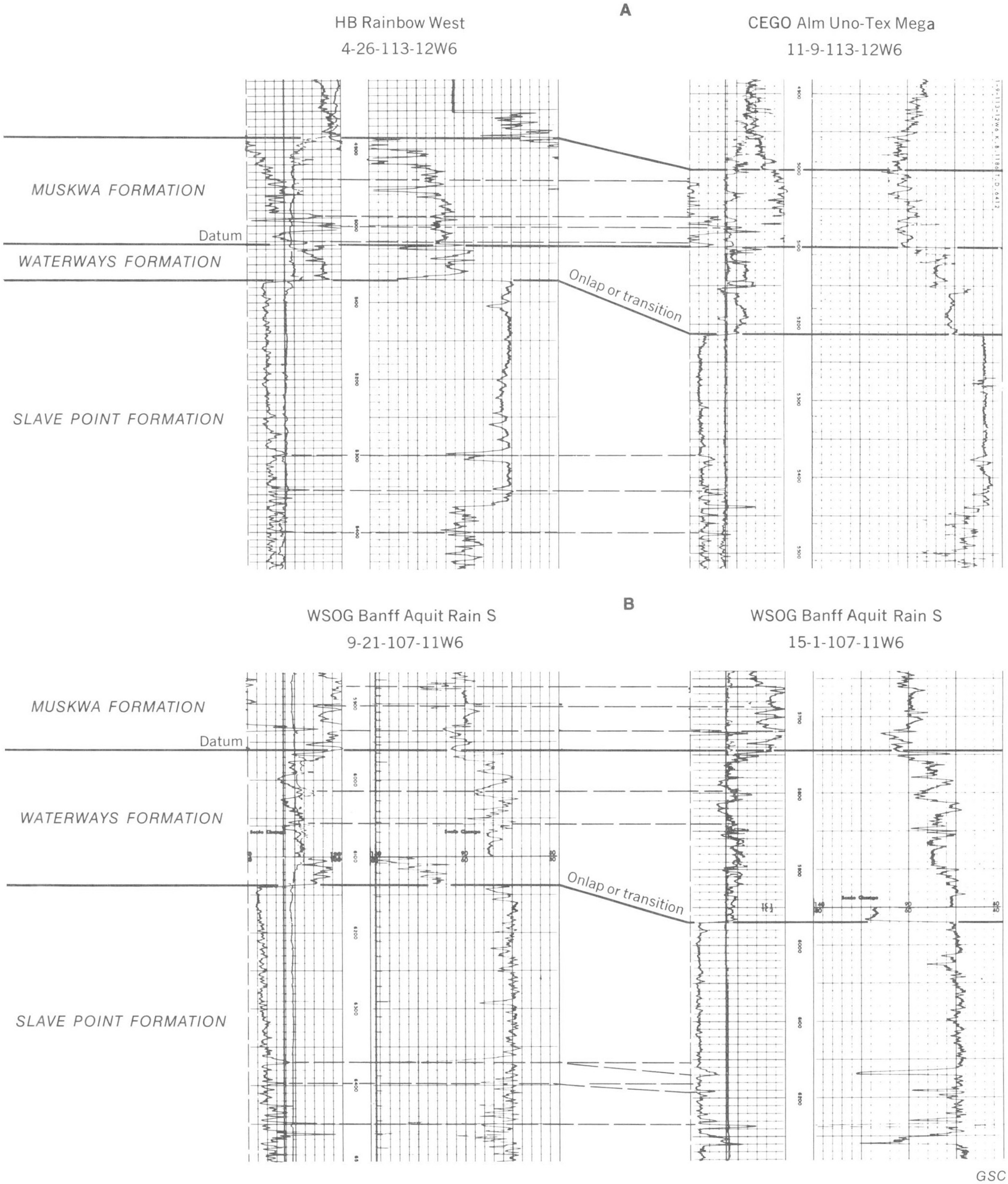

FIGURE 6. Waterways Formation-Slave Point Formation subsurface contact, northern Alberta:
(A) between Sec. 9, Tp. 113, Rge. 12W6 and Sec. 26, Tp. 113, Rge. 12W6;
(B) between Sec. 1, Tp. 107, Rge. 11W6 and Sec. 21, Tp. 107, Rge. 11W6.

1963). Should fate have conspired to keep the Windy Point outcrops hidden, and the same stratigraphic sequence had been encountered first, say in 1970, in an exploratory well, any well-site geologist, armed with current isopach and lithofacies maps, would almost certainly have considered the top of the limestones to be the top of the Slave Point Formation. He would have noted that the Slave Point Formation was dolomitized to within 3 m (10 ft) of its top. Or, had he cut cores of the carbonate, and noted the fossils, he might have considered this to be a dolomitized Swan Hills reef.

It should be noted that, ten years ago, Richmond (1965) came to the conclusion that the dolomitized reef at Windy Point included, at its top, beds equivalent to the Slave Point Formation.

To summarize, at Windy Point there is no evidence, one way or the other, regarding an unconformity anywhere in the section (the overlying shales are not exposed). The uppermost beds of the Windy Point carbonate complex bear fossils indicating correlation with the basal member of the Waterways Formation of Alberta. Thus, the field evidence can be interpreted to indicate that the Slave Point-Waterways contact is transitional and diachronous, and that the contact moves upsection from south to north.

Subsurface

In comparison with the surface sections, the subsurface data from well logs are equivocal. The nature of the Slave Point-Waterways contact is illustrated on Figures 6, 7 and 9 to 12. The log-sections may be interpreted in different ways: as an onlap over a tilted surface, as favoured by Bassett and Stout (1967), or as a transitional contact, as favoured by Griffin (1965). In Figure 9, the contact has been interpreted in the latter fashion in the light of the Windy Point evidence. Skall (1975) found no evidence for erosion at the Hay River-Slave Point contact in any of the cores from diamond-drill holes in the Pine Point area.

Muskwa Formation-Waterways Member relationships

In northeastern British Columbia, the Muskwa Formation is a thin, distinctive unit consisting predominantly of radioactive dark shale with minor interbeds of non-radioactive shales, and rare limestone lenses. This unit becomes less radioactive eastward into northern Alberta and, therefore, less distinctive on the well logs, but it appears to overlie a westward-thinning wedge of the Waterways Formation. Griffin (1965) explained the above relationship by postulating a regional unconformity; uplift, tilt to the east, subaerial erosion cutting progressively downsection from east to west, and renewed subsidence followed by deposition of the Muskwa shales. Griffin's (*ibid.*, Fig. 6) evidence comes mainly from well-log correlations; the evidence is tenable but not convincing. No undoubted truncation can be demonstrated at the base of the Muskwa Formation. On the contrary, there are examples from closely spaced wells where thickness changes of Waterways strata are almost certainly a result of irregularities or facies changes at the base, rather than at the top, of the formation, as shown in Figures 6 and 7. Also, the Muskwa-Waterways contact becomes rather indistinct, especially in the northernmost part of Alberta.

In the Slave River map-area, which is immediately north of the area studied by Griffin, the situation is somewhat comparable but with an important difference: the Muskwa and Waterways lithologies appear to be interbedded. This is illustrated on Figure 13. In the Fina Gulf Trainor Lake B-24 well, the westernmost well, typical Muskwa shale overlies the Slave Point Formation. A few kilometres to the east in H.B. Shell W. Cameron Hills F-24 well, a few feet of non-radioactive beds lie above the Slave Point limestone and, since these wells lie along the projected strike of the feather edge of the Waterways in Alberta, these two wells could be considered to delineate that edge. However, the remaining wells shown in Figure 13 suggest that the Muskwa Formation splits into several thin radioactive shale units which occur throughout the Waterways Member. The radioactivity of these shale units decreases from west to east: east of Longitude 117°W, there are no radioactive markers within or above the Waterways Member. The highest radioactive marker appears to peel-off to the east, rising in the section at a rate comparable to a gentle clinoform marker; such markers are present on Figures 11 (2500 ft in K-48) and 12 (4112 ft in C-22).

Thus, the well-log evidence from the southern Slave River map-area does not support the concept of an erosional unconformity at the base of the Muskwa shale; rather the evidence suggests that the Muskwa radioactive shale is a condensed section equivalent to part of the Waterways Member as well as to part of the overlying Hay River shale.

The Middle-Upper Devonian boundary

An interpretation of the mode of origin of the Hay River Formation, to be given later, involves continuous subsidence across the Middle-Upper Devonian boundary. This interpretation is incompatible with prevailing concepts which have been derived in part from studies within the Hay River map-area. Therefore, although the subject has been treated partly elsewhere in this report, a review is in order.

At Gypsum Cliffs in northern Alberta (Norris, 1963), there is evidence for a hiatus with some erosion at the Middle-Upper Devonian boundary. This break coincides with the Slave Point-Waterways contact. As previously stated, a hiatus in this evaporitic environment is not, in itself, evidence for a regional unconformity.

A similar interpretation has been given for the outcrop-area at Windy Point (Norris, 1965), with the implication that perhaps 60 m (200 ft) of section are missing below a pre-Upper Devonian unconformity. As discussed in a previous section, this same evidence can be re-interpreted and taken to indicate that:

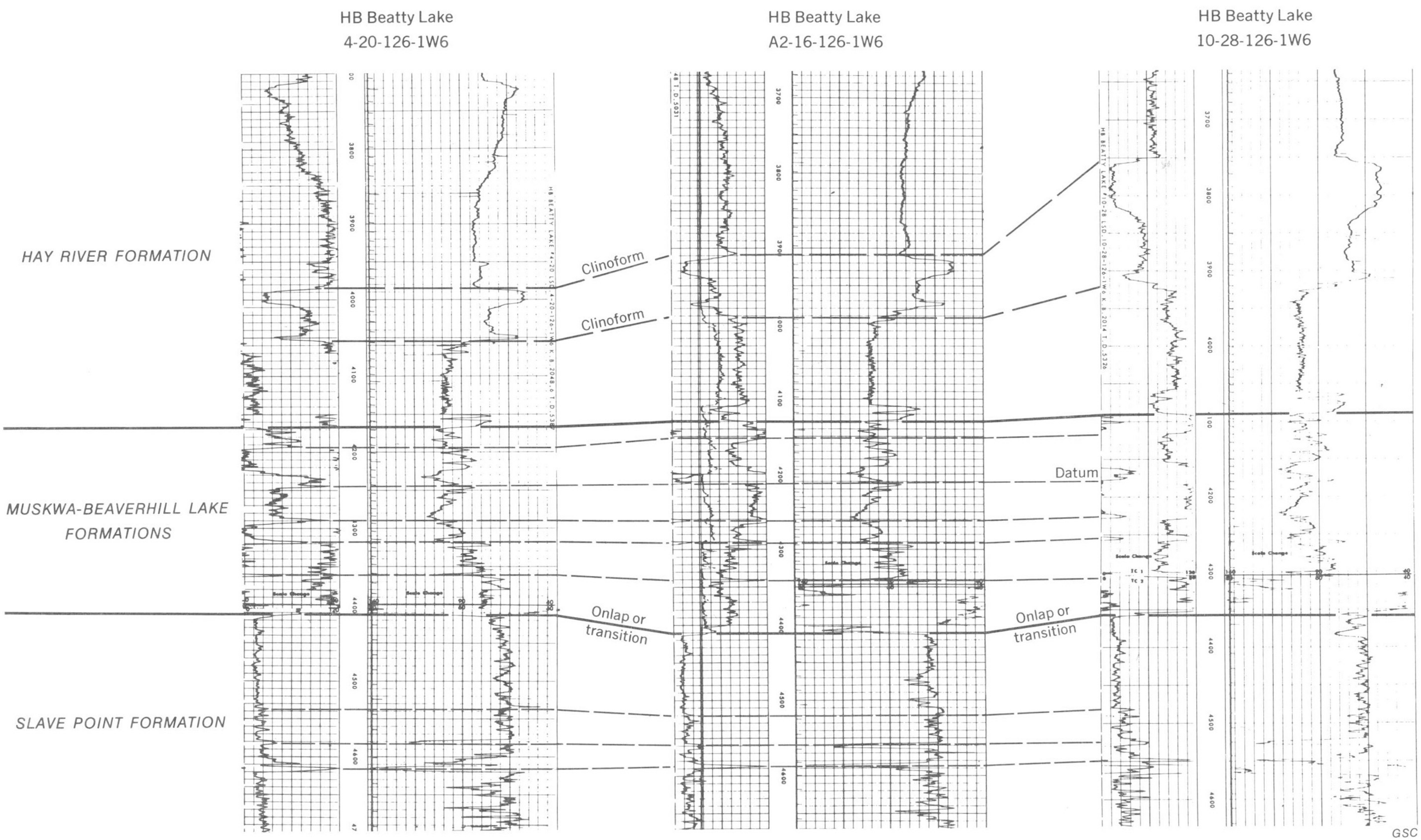

FIGURE 7. Waterways Formation-Slave Point Formation subsurface contact, northern Alberta: between Secs. 16, 20 and 28 of Tp. 126, Rge. 1W6.

- the Slave Point Formation, in this area near the carbonate front, extends into the Upper Devonian;
- the Slave Point and Waterways Formations are gradational and to some extent equivalent; and
- there is no evidence, one way or the other, regarding an unconformity at the top of the Slave Point or at the Middle-Upper Devonian boundary.

Braun (1967, p. 632, Fig. 8) indicates an unconformity at the Hay River-Slave Point contact in Frobisher Hay River No. 4 well. He (*ibid.*, p. 633) states that:

> Relatively few feet of shales seem to represent the Calmut Member. The rest of the Waterways strata, or their equivalents, either were eroded or else were not deposited in this region.

It is important to note that Braun's ostracode collections come from the Hay River shale only and he (*ibid.*, p. 619) records that "the underlying Givetian Slave Point limestone did not yield any fauna". So it would seem to be quite in order to suggest that here, as at Windy Point, the missing Firebag interval might be represented by a limestone facies, in other words the Slave Point Formation extends into the Upper Devonian.

The Swan Hills reefs in Alberta are considered to be, for the most part at least, equivalent to the basal part of the Waterways Formation (Uyeno, 1974; Leavitt and Fischbuch, 1968; and several others). In the Swan Hills reefs, therefore, the Middle-Upper Devonian boundary lies within a carbonate succession. Fischbuch (1968) noted indications of erosion at several horizons within the reef complex, one of which, on faunal grounds, was selected as the probable representative of a regression of the Middle Devonian sea. A reef-complex, by its nature, is almost bound to have been exposed at various times. An erosional break within a reef, with or without a faunal break, cannot in itself be taken as evidence for a widespread regression of the sea.

Within the Slave River map-area, parts, and in a few cases all, of the Slave Point Formation has been cored in numerous wells. Unfortunately, except in the Pine Point mining area, there are no cores through the Hay River-Slave Point contact. Within the carbonate section, no significant breaks have been noted, other than the Watt Mountain-type breccia at the base of the formation.

RELATIONSHIP TO THE HORN RIVER FORMATION

The Horn River Formation was redefined by Norris (1965, p. 43) as:

> ... a unit consisting largely of dark shales variably interbedded with limestones, which overlies the Lonely Bay Formation or lower part of the Pine Point Formation, and is unconformably overlain by green shales of the Fort Simpson or Hay River Formation ...

Norris (*ibid.*, p. 44) states that:

> The upper contact (subsurface) is drawn arbitrarily where the color of the shale changes to green ...

Since the above was written, much new subsurface information has become available. The Horn River Formation is a wedge of argillaceous sediments occupying the paleotopographic depression north and east of the Slave Point carbonate front (*see* isopach map, Fig. 15). Adjacent to the front, the formation consists of shale indistinguishable lithologically from Hay River shale, but including interbeds of argillaceous limestone and dark, bituminous shale. To the northwest, the formation thins and becomes predominantly dark radioactive shale, thicker but otherwise indistinguishable from the Muskwa shale.

In constructing the isopach map (Fig. 15), the criteria for determining the top of the formation vary from place to place. In the old wells east of the Deep Bay carbonate bank, for which there are no logs, the top is placed at the highest occurrence of dark bituminous shale. West of the Deep Bay bank, the well-log top is taken at the point where there is an indicated change from shale devoid of markers to shale with numerous, fairly widespread carbonate markers. Farther west still, the top is placed where there is a change from normal shale to highly radioactive dark shale. On the basis of the above criteria, the Horn River Formation is readily mappable in the subsurface using either well-logs or lithology. On the other hand, if the formation is considered to be entirely Middle Devonian, as defined, and separated from overlying shales by an unconformith, the formation is not mappable.

The criteria described above are identical with those used in placing the tops of the Waterways Member or the Muskwa Formation; the Horn River Formation, as shown on the isopach map, Figure 15, undoubtedly contains the equivalents of these two units. Also shown on Figure 15 are isopachs of the Waterways and Muskwa shales. These units extend up to the carbonate front; they are unlikely to cease abruptly at the front and to be replaced by identical but older units.

Thus, the well-log evidence indicates that the basal part of the Hay River Formation (Waterways Member), as well as the partly equivalent Muskwa Formation merge northward into the upper part of the Horn River Formation. This interpretation is not new. As the term was used in northeastern British Columbia by Gray and Kassube (1963), the Horn River Formation included the Muskwa Member. Recently, Fuller and Pollock (1972), in the area immediately west of the Slave River map-area, have reported Frasnian conodonts to within a few feet of the base of the Horn River black shale.

INFLUENCE OF MAJOR TECTONIC FEATURES

There are two prominent basement features underlying Paleozoic rocks of the Slave River map-area: a swarm of northeast-trending faults roughly parallel with the Hay River, and the Tathlina Arch (*see* de Wit *et al.*, 1973, p. 201, Fig. 8 and p. 195, Fig. 6, respectively).

The basement faults presumably are related to the East Arm Fold Belt (Hoffman, 1968) and the Athapusco Aulacogen (Hoffman *et al.*, 1974). Their presence is manifest mainly as sub-Devonian topographic irregularities, although some have caused minor structural breaks in Devonian rocks. The influence, if any, of these basement faults on the deposition of the Hay River Formation must have been very subtle. Isopachs of the formation (Fig. 14) tend to parallel the fault northwest of Tathlina Lake; this is one of the faults that cuts Devonian rocks. Near the southern border of the map-area there are two wells, Cameron Hills E-69 and H-34, in which the upper contact of the formation is anomalous. There, either an extra 9 to 12 m (30-40 ft) of limestone are present in the Twin Falls Formation, or a Louise Falls-type of limestone unit is developed at the top of the Hay River Formation. Perhaps this stratigraphic anomaly is somehow related to underlying basement topography, or to slight movement during deposition.

The Tathlina Arch is an ancient topographic high; it formed an island during much of Early Devonian time. By Slave Point time, the island was entirely submerged. The Arch can be delineated by isopachs, either of individual units, or of the total Slave Point and older section. Belyea (1971) concluded that periodic differential movement occurred during early Middle Devonian time. Whether or not the Arch was ever independently active after Slave Point time is an unsolved question.

Isopachs of the Hay River Formation (Fig. 14), the Waterways-Muskwa interval, and the Horn River Formation (Fig. 15), all indicate thinning of the units to the west, and the region where they are thinnest coincides with the apex of the Tathlina Arch. An isopach map of the Fort Simpson Formation and equivalents (not included) confirms this coincidence; the westward thinning of the Fort Simpson Formation is illustrated on Figure 2. One obvious way to interpret the isopach maps is to invoke tectonic movements after Slave Point deposition, either by uplift of the Tathlina Arch, or by differential subsidence on its flanks before or during deposition of the Upper Devonian shale. This tectonic interpretation conflicts with the evidence of the clinoform markers which dip toward this supposedly high area (*see* Figs. 2, 5). If the significance of clinoforms (to be discussed in the next section) has been interpreted correctly, either the movement of the Tathlina Arch postdated the deposition of the clinoform-bearing shale, or the coincidence of the isopach "thin" with the arch is due to some reason other than tectonic movement.

GEOPHYSICAL LOG MARKERS AS INDICATORS OF DEPOSITIONAL ENVIRONMENTS

Given some knowledge of lithology, geophysical log markers can yield additional information on conditions of deposition. In the various cross-sections (Figs. 9-13), the log markers fall into several distinct categories:

1. Point-for-point correlation, over several tens of kilometres, with little variation in character or interval, within a mixed carbonate and shale section;
2. Clinoform markers within a shale section;
3. Shale section devoid of markers; and
4. Radioactive markers.

Point-for-point log correlation is characteristic of the Tathlina and Twin Falls Formations, and these units contain relatively shallow water limestone. Therefore, this category of marker can be a product of shallow deposition.

Clinoform markers form an oblique angle with the top and base of a formation. If the formation boundaries represent the approximate regional slope during the epoch of deposition, and the clinoforms represent the sediment/water interface at an "instant" of time, then the slope of clinoforms provides a qualitative measure of bottom relief and depth of water during deposition. Within the Hay River Formation, the average slope of clinoforms is about 6 m per kilometre (20 ft per mile), the pre-compaction slope possibly was twice as great. These Hay River markers can be traced laterally over distances of about 32 km (20 miles). The depth of water over the base of the depositional slope must have been several hundred feet. The existence of clinoforms demonstrates two conditions: 1) a previous rise of sea level at a rate sufficiently rapid that sedimentation did not keep pace; and 2) the sediment spread laterally to fill the "void" created by the sea level rise.

Clinoform markers occur within the Hay River shale which, from evidence farther south, abutted against the Grosmont carbonate bank. Clinoform markers occur within the Fort Simpson shale in the belt abutting the western limit of the Twin Falls carbonates (Fig. 12). Farther west, the Fort Simpson shale is devoid of markers. The clinoform markers appear to be caused by variations in the amount of carbonate in shale, whether as cement or fine detritus is unknown (they are not caused by sand-size or coarser detritus). Tentatively, the presence of clinoforms can be taken as evidence of a "shoreward" position and the proximity of a carbonate-producing environment; the absence of clinoforms suggests a seaward position.

The distal ends of clinoforms tend to flatten (decrease in angle of dip) and become radioactive. Several such radioactive markers, spread through a section of normal shale with thin lutite beds, appear to merge seaward into a much thinner interval that is composed predominantly of radioactive shale (Fig. 13). From this geometry, and given the assumptions previously made regarding clinoforms, the radioactive shale was deposited in relatively deep water and represents the highly condensed equivalent of considerably thicker sections of normal shale deposited in "shoreward" positions (Fig. 11).

The sequence in which marker categories occur also tells something of the depositional history. A carbonate succession like the Slave Point Formation obviously was produced in shallow water. When such a carbonate unit is overlain directly by a radioactive shale, drowning is indicated followed by very slow deposition, suggesting a position remote from the clastic source. Where such a carbonate is overlain by a mixed shale-carbonate section exhibiting point-for-point correlation, a near-source position might be the explanation, with

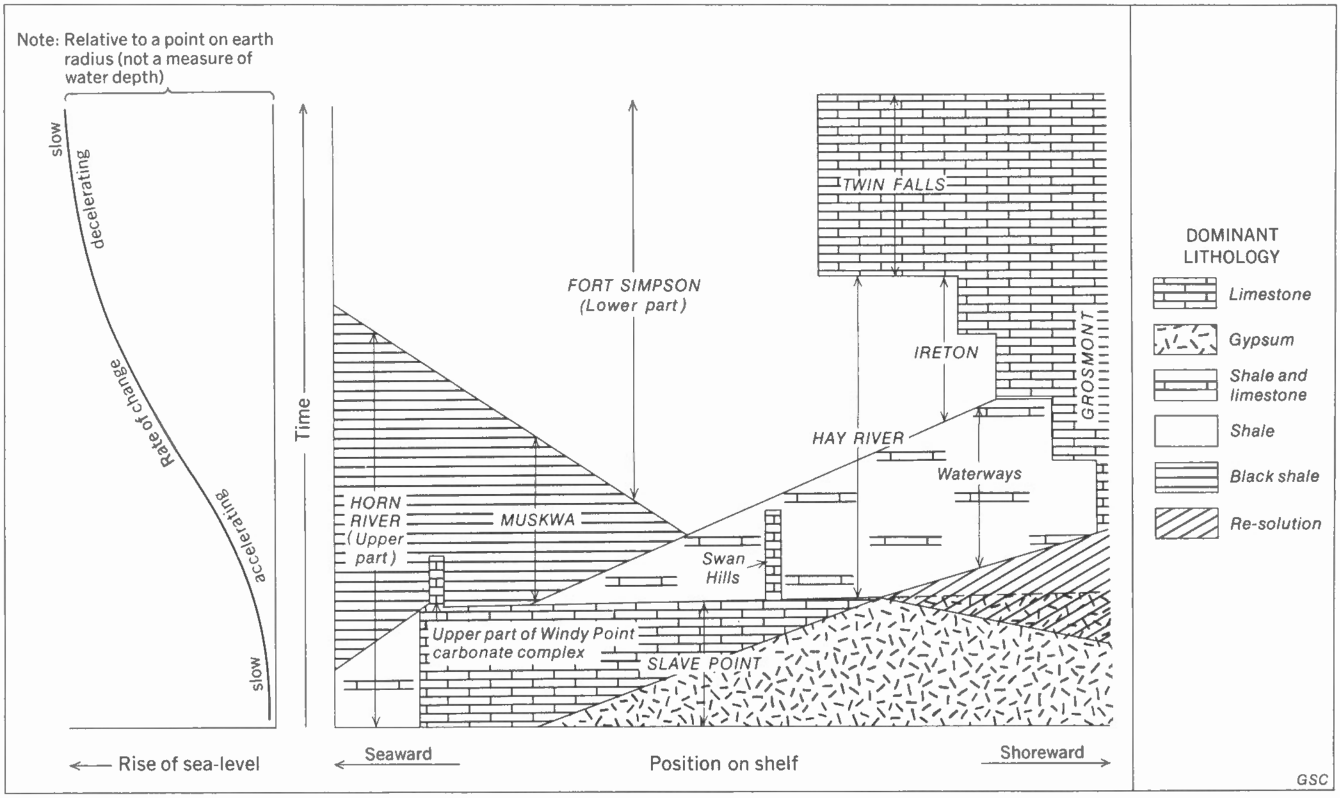

FIGURE 8. Correlation chart relating dominant lithology to position on shelf and rate of sea level rise

deposition more or less keeping pace with the rise in sea level.

Where clinoform shales are overlain by a section with point-for-point correlation, it is reasonably certain, even without lithologic control, that this indicates a progressive shallowing of the water. The final stages in such a cycle may be a biostrome, or an evaporitic layer, followed by a karstic surface.

INTERPRETATION OF SEDIMENTARY ENVIRONMENTS

The concept of a single transgressive event suffices to explain the nature of the Hay River Formation and its relationship to underlying, overlying and equivalent formations. There is no need to postulate any large-scale sea level fluctuations leading to widespread withdrawals of the sea, or to postulate other than local, minor, differential tectonic movements. The epeirogenic changes that gave rise to the suite of sediments (of which the Hay River Formation is only a small part) can be attributed to a cycle of sea level rise, illustrated by the graph on the left side of Figure 8. It is postulated that, beginning from a condition of still-stand, there began a progressively accelerating rise of sea level. This acceleration culminated after a rise of several hundred feet and was followed by a continued rise at a much slower rate. The sedimentary response to changing conditions was a function of the position of the shelf (Fig. 8) and the rate of influx of clastic material.

The Slave Point Formation was the initial blanket deposit formed in shallow water during the initial slow sea level rise. Normal marine carbonate rocks were deposited in the northwest, grading through more restricted carbonate strata to mostly anhydrite in the southeast. The positions of the northern and western rims of this carbonate were inherited largely from an earlier carbonate edge.

Accelerating sea level rise resulted in a variety of sedimentary responses. The simplest situation occurred in the west where carbonate production ceased because of the rapidly deepening water and, being remote from source, the only sediment that accumulated was black mud of the basal Muskwa Formation. In certain areas, reef-building organisms held their own and bioherms developed (the Swan Hills reefs and the upper part of the Windy Point carbonate complex), their tops keeping pace with the rising sea level. As water of normal salinity spread over the evaporitic portion of the Slave Point Formation, some solution occurred, resulting in a karst-like contact. To the east, near the clastic source, mud accumulated keeping the sediment surface near enough to the water surface so that carbonate layers could develop periodically (the Waterways Fm.).

During the interval of relatively rapid sea level rise, the western area remained sediment starved and the reefs were drowned. To the east, in a belt now destroyed by erosion, there probably was a north-south trending carbonate bank - a northern continuation of the Grosmont Formation. This belt remained a site of carbonate deposition throughout the entire cycle. Clastic sedimentation was episodic; longshore currents may have moved the clastics from north to south, but the accumulation pattern was from east to west. During episodes of clastic influx, mudbanks formed adjacent to the Grosmont carbonate bank. These built vertically to near water level, then spread westward to form the Ireton and Hay River Formations. Between episodes of clastic influx, carbonates developed in the clear shallow water over the mud banks, thus the Grosmont Formation spread westward in a series of steps. The Twin Falls Formation is the highest of these steps.

The last phase of the cycle was a slowdown in the rate of sea level rise. The Twin Falls limestone continued to form in the east, and episodic clastic sedimentation continued in the west. Eventually, the entire shelf was buried with mud, forming the Fort Simpson Formation.

RECONCILING CONFLICTING OPINIONS (A SUMMARY)

This study of the Hay River and related formations brings together ideas expressed by various authors and fits them into a consistent sedimentary model. This model is in conflict in some important respects with views held by numerous workers in the area.

The most fundamental assumption underlying the new model, or what might be termed the 'revisionist view' is as follows. Geological conditions, including depth of water, salinity, current strength, rate of clastic influx, and others, were not uniform at any instant of geologic time, but varied significantly from place to place. They were related fundamentally to the geographical location, i.e. the position on the shelf (seaward, shoreward, relation to clastic supply, etc.). The belief that a sedimentary event recorded in one area (or well) must be recorded in all areas is a view not taken seriously by anyone, yet its insidious influence can be seen in the attempts by some authors to find the stratigraphic point marking the supposed withdrawal of the Middle Devonian sea.

An advantage of the 'revisionist view' is that apparently conflicting interpretations can be reconciled so that, in effect, everyone's views are correct, at least within a limited area.

According to the 'revisionist view', there was continuous subsidence across the Middle-Upper Devonian boundary. This interpretation is implicit in the nomenclatural revision set out by Hemphill *et al.* (1970) wherein the Beaverhill Lake was elevated to group status to include the Fort Vermilion, Slave Point and Swan Hills Formations as well as overlying shales equivalent to the Hay River Formation. Thus, a transitional contact between the Waterways and Slave Point Formations is reasonable (Griffin, 1967). It is not surprising that relict Middle Devonian fauna occur in the Waterways Formation (Murray, 1965) or that Late Devonian fossils occur in the highest carbonates of the Windy Point complex. The carbonate-shale contact is not a time marker since carbonate sedimentation continued in certain areas into the Upper Devonian. The Swan Hills reefs are a special example of the above (Fischbuch, 1968, and others).

Continuous subsidence does not by any means imply continuous sedimentation. The profound faunal changes, in places associated with an abrupt change from carbonate to black shale certainly do document a significant unconformity (Bassett and South, 1967). There is undoubtedly an unconformity at the contact between the Muskwa and Slave Point Formations (Griffin, 1965), at least locally, but this unconformity (or unconformities) could be the result of non-deposition or submarine erosion, rather than regional uplift. An unconformity may divide, in certain areas, Middle from Upper Devonian rocks, as at Gypsum Cliffs (Norris, 1963) but this would be a coincidence related to geography, not geology.

The second tenet of the 'revisionist view' is the degree of diachronism at certain formation or member contacts. That Devonian shales can be strongly diachronous was demonstrated by Oliver and Cowper (1963). However, it may be more difficult to believe that a few feet of Muskwa shale represent the time equivalent of most of the Hay River Formation, or that the Horn River Formation, only 60 m (200 ft) thick, is the time equivalent of more than 600 m (2000 ft) of a nearby section including rocks older than the Slave Point Formation to younger than the Hay River Formation. Such strong diachronism is suggested by clinoform markers. This interpretation, however, renders compatible such statements as that the Horn River Formation is entirely of Middle Devonian age (Norris, 1965) with the statement that Frasnian conodonts occur in the lower part of the Horn River Formation (Fuller and Pollock, 1972).

A third belief of the interpretation presented here is that the Presqu'ile dolomite is a diagenetic facies not confined to any one formation. The idea that the Presqu'ile (or at least the Presqu'ile-Sulphur Point) is a formation in the conventional sense, more or less a time-rock unit, has persisted in spite of the knowledge that the facies can occur high in the Slave Point Formation, as in northeastern British Columbia (Gray and Kassube, 1963) or in the Slave River map-area (Belyea, 1971). Recently, Skall (1975, p. 32) has used the term "Presqu'ile" in the type-area at Pine Point "regardless of environmental conditions or time period of original carbonate deposition". At Windy Point, fossiliferous Upper Devonian limestone overlies "Presqu'ile"-type dolomite (Norris, 1965). The "Presqu'ile" at Windy Point probably embraces strata equivalent to part of the Slave Point Formation (Richmond, 1965). By using the term "Presqu'ile" as shorthand for a particular diagenetic dolomite, the above statements are not in conflict.

RECOMMENDATIONS ON NOMENCLATURE

Some modification and standardization of existing nomenclature are desirable. No new names are needed.

As stated by Jamieson (1967), the term "Escarpment Member" should be abandoned. Continued use of the term can only cause confusion. Informal names such as "Louise Falls limestone" are useful locally but, because of the rather rapid facies changes in the type area, it is not considered advisable to subdivide formally the upper part of the Hay River Formation. It is conceivable that a finer breakdown of the Hay River Formation may become useful within a small part of the Slave River map-area southeast of the Hay River. When this need arises, the Alberta nomenclature can be used; from the top down this includes the Grosmont (with informal members), Ireton and Waterways Formations.

If it is accepted that the Waterways Member and the Muskwa shale are in part correlative, and that the top of the Muskwa shale is highly diachronous, then the selection of the appropriate nomenclature will reveal a maximum amount of lithologic information. The lower part of the Hay River Formation can be termed, progressing from east to west: 1) the Waterways Member, denoting shale with thin limestone bands; 2) the Muskwa-Waterways Member, denoting the above, plus interbeds of radioactive shale; and 3) the Muskwa Member, denoting predominantly radioactive shale. For reasons to be discussed later, the Muskwa should be promoted to a formation in the area west of the Twin Falls Formation shale-out.

North of the Slave Point carbonate front, the term Hay River Formation should not be used, as there is no satisfactory way to map the base. Equivalent beds are contained in the basal part of the Fort Simpson and the upper part of the Horn River Formation. The term Horn River Formation should be used in the sense put forward by Gray and Kassube (1963) for northeastern British Columbia, whereby the formation spans the Middle-Upper Devonian boundary and includes beds equivalent to the Waterways and Muskwa Members of the Hay River Formation. As defined by Gray and Kassube (1963), the Muskwa is the upper member of the Horn River Formation; in most wells drilled in the Slave River map-area, the Muskwa Member is not mappable as a discrete part of the Horn River Formation.

North of the carbonate front, Belyea and McLaren (1962) placed the contact between the Fort Simpson and Horn River Formations at the change, downward, from normal shale to radioactive shale. South of the front, they placed the lower contact at the top of the Slave Point Formation, thus including the Muskwa (then unnamed) as a basal black shale member of the Fort Simpson Formation. To be consistent, the usage of Gray and Kassube (1963) should be followed and the base of the Fort Simpson Formation placed at the top of the highest regionally mappable radioactive shale - the Horn River Formation north of, and the Muskwa Formation south of the carbonate front.

The term "Muskwa" should be used as follows: as the upper member of the Horn River Formation in parts of northeastern British Columbia and the Northwest Territories (where it can be recognized) north of the Slave Point carbonate front; and as the basal member of the Hay River Formation in part of the Slave River map-area. In the intervening area, the Muskwa should be promoted to a formation, between the Fort Simpson and Slave Point Formations.

There remains one small problem area, that north of the carbonate front, east of the shale-out but west of the eroded limit of the Twin Falls Formation (*see* Fig. 14). The layer of shale between the Twin Falls and Horn River Formations cannot be called Hay River because that formation overlaps the Horn River Formation. It could be called the Fort Simpson Formation if that unit were redefined. Belyea and McLaren (1962) placed the top of the Fort Simpson at the base of the Jean Marie Member of the Redknife Formation. This definition is satisfactory over a large area but it creates problems in northeastern British Columbia (*see* Pelzer, 1966, p. 316, Fig. 16). No attempt is made in the report to redefine the top of the Fort Simpson Formation because most of the problems lie outside of the Slave River map-area.

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