AN EARLY CARBONIFEROUS RIVER-DOMINATED REGRESSIVE FACIES IN SOUTHERN IRELAND[1]

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ABSTRACT

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The Early Carboniferous Kinsale Formation contains a distinctive sand dominant unit in western County Waterford known as the Crows Point Member. This is built up by epsilon cross-stratified grey sandstones with minor thin claystone and heterolithic intercalations. Six rhythmically diminishing lithofacies, organised into four sequential facies associations, are distinguished. Facies analysis shows it to be the record of high-energy pulses of fluvial sediment influx via distributary channels from the ESE. These were modelled by fluctuations in river stage; an overall allocyclic mechanism may have been responsible for the interpreted progressive shallowing of the distributaries through time, accompanied by an increased tidal influence in response to a north-easterly regional transgression. The member provides additional support for a positive source area lying off the southeastern margin of the Munster Basin during the Early Carboniferous. This together with its relationship to adjacent facies, indicates a NE-SW axial drainage pattern within this basin at this time.

INTRODUCTION

In the most recent analysis of the Devonian – Carboniferous Munster Basin (GARDINER, 1975) four major depositional episodes were distinguished. The final episode involved marine breaching at the southern margin, the resulting sediment wedge (Kinsale and Courtmacsherry Formations) displaying a marked south-westerly thickening (Fig. 1). As a result of more recent work (GARDINER & HORNE, 1976; MACCARTHY ET AL., 1978) the shape of the wedge proposed by GARDINER (1975) has been modified (Fig. 1). In the Cork Harbour – South Ringabella area, the Kinsale Formation (Early Carboniferous) records deposition in a muddy, shallow marine platform on which sandy shoals developed (DE RAAF ET AL., 1977) while further southwest at Galley Head, an offshore subtidal environment has been interpreted (GRAHAM, 1975) (Fig. 2). To the east, at Hook Head, a time equivalent sequence is represented by estuarine facies (Fig. 2) (Gardiner, pers. comm.). This paper is concerned with the intervening zone (Figs. 2 and 3) and documents a distinctive transitional facies within the Kinsale Formation (the Crows Point Member of MACCARTHY ET AL., 1978) (Fig. 3).

The Crows Point Member outcrops at Helvick Head, County Waterford on the southern limb of the Dungarvan Syncline (Fig. 4) and also on the flanks of the adjacent Ardmore Syncline to the south. This analysis is confined to the better exposed Helvick occurrence. It comprises pale grey, fine to coarse quartzarenites (92%) and grey claystone (4%) and siltstone (4%). A 1.5 m red mudstone occurs close to the base of the exposed 50 m sequence at Helvick (Fig. 5). A well exposed part of the member adjacent to Helvick Pier was chosen for detailed analysis. The succession was logged vertically and laterally in order to establish the multi-dimensional facies relationships. Six lithofacies are recognized. These recur in a partially repetitive manner resulting in four preferred associations (Fig. 5).

The facies are:

Facies A: thick epsilon cross-stratified sandstones.
Facies B: large-scale, trough-, cross-stratified sandstones.
Facies C: thin grey and red mudstones.
Facies D: large-scale tabular, cross-stratified sandstones (two sub-facies recognized).
Facies E: Rippled siltstones.

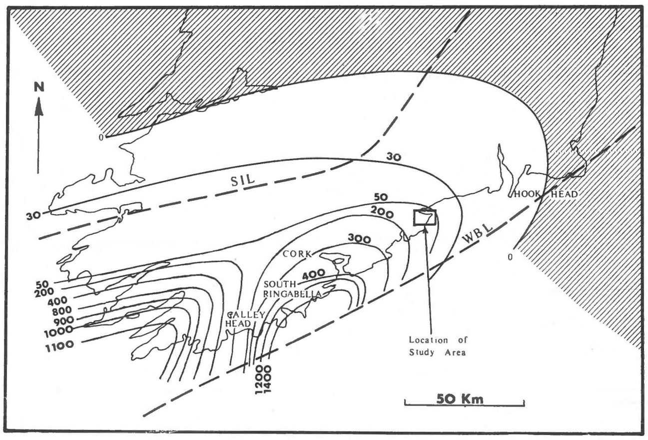

Fig. 1
Isopach map of sediments deposited during Episode 4 (Kinsale and Courtmacsherry Formations). Modified from Gardiner (1975). Isopachs shown in metres. SIL-South Ireland Lineament; WBL-Wexford Boundary Lineament.

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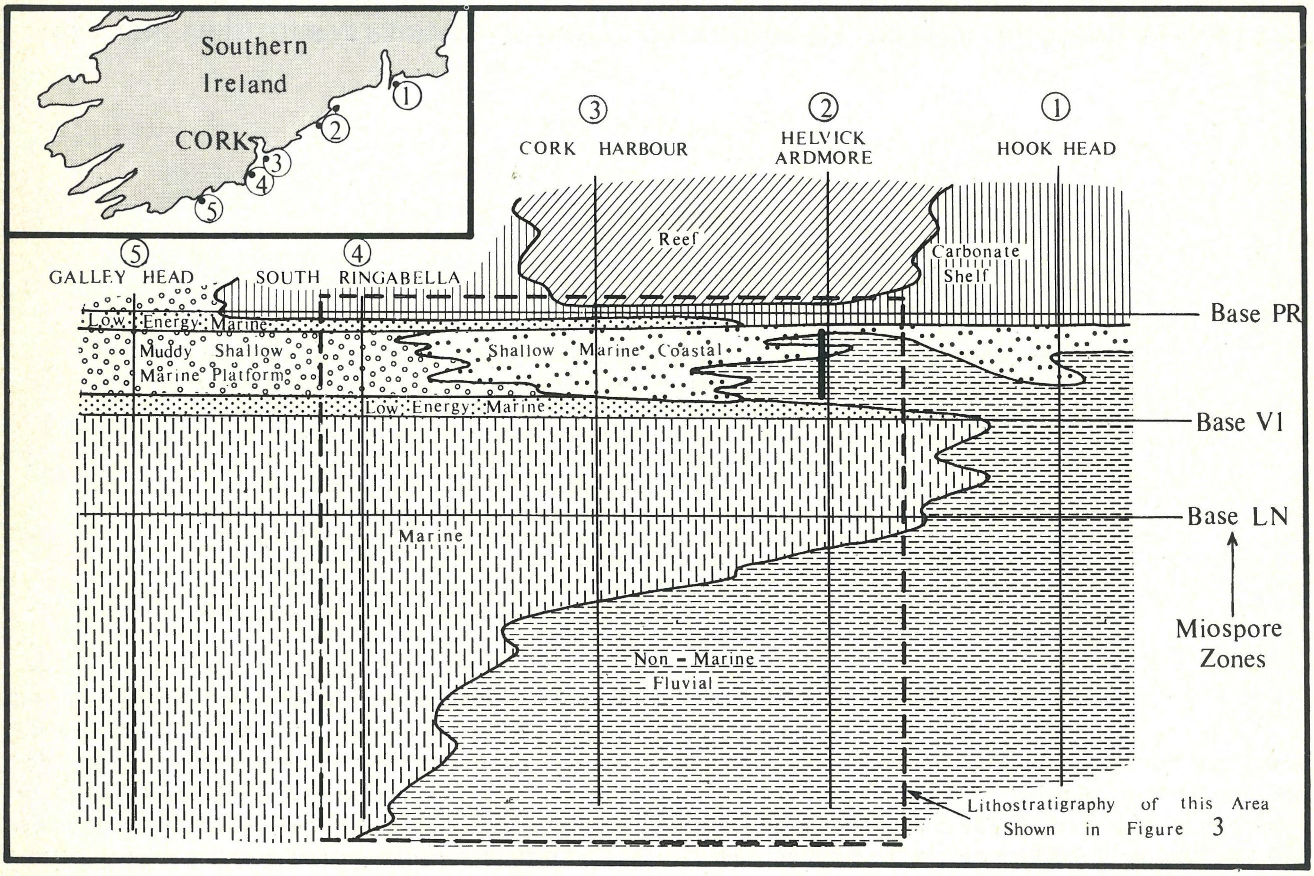


Fig. 2
Simplified cross-section through part of the Munster Basin showing major environmental distribution in the Late Devonian – Early Carboniferous and location of studied section (vertical black bar). No stratigraphical thickness implied. Data for South Ringabella, Galley Head and Hook Head from De Raaf et al. (1977), Van Gelder (1974), Graham (1975) and Gardiner (1975).

Facies F: Thinly bedded sandstones.

As shown below the Crows Point sequence departs significantly from other cross-stratified sandstone facies interpreted as being the product of marine shoal (DE RAAF ET AL., 1977), shallow marine (HOBDAY & READING, 1972; HARMS ET AL., 1975; JOHNSON, 1977; VOS & HOBDAY, 1977) and prograding shorelines (HARMS ET AL., 1975). None of the facies contains any of the features described from modern tidal deltas or washover fans (DICKENSON ET AL., 1972) nor of migrating barriers (KUMAR & SANDERS, 1974; HARMS ET AL., 1975). Nor are there features comparable to prograding distributary mouth bars (GOULD, 1970; COLEMAN AND GAGLIANO, 1965) nor to inter-distributary bay crevasse-lobes described by ELLIOTT (1974, 1975, 1976) and LEEDER (1974). The sequence is, however, comparable with channel-fill deposits of riverine and estuarine parts of distributary channels.

FACIES DESCRIPTIONS

Facies A

This occurs as thick (4-9 m) composite units each with an irregular (up to 2 m) cross-cutting base. Each unit persists laterally for at least 200 m and consists of gently inclined, cross-cutting epsilon foresets which are either laminated internally or contain uniformly directed intrasets (up to 2 m thick) of large-scale, tabular cross-stratification. Epsilon foresets are up to 10 m in length and are typically tangential, grading to horizontal toesets. In all cases the current flow appears to have been directed down the epsilon foresets suggesting that they are not lateral accretion features. Epsilon toesets pass downcurrent into flaser-bedded sands and thence to a basal intraformational conglomerate comprising mudstone and sandstone clasts dispersed throughout horizontally bedded claystone-laminated sandstone (Fig. 6). Internal foresets are up to 2.3 m thick and commonly normally graded with irregular concave-up bases. Thin (less than 2 mm) mud drapes intervene between some foresets. Internal gently inclined cross-cutting surfaces, analogous to reactivation surfaces (COLLINSON, 1970), occur throughout the facies. Palaeocurrents are directed uniformly from the ESE (Fig. 5).

Facies B

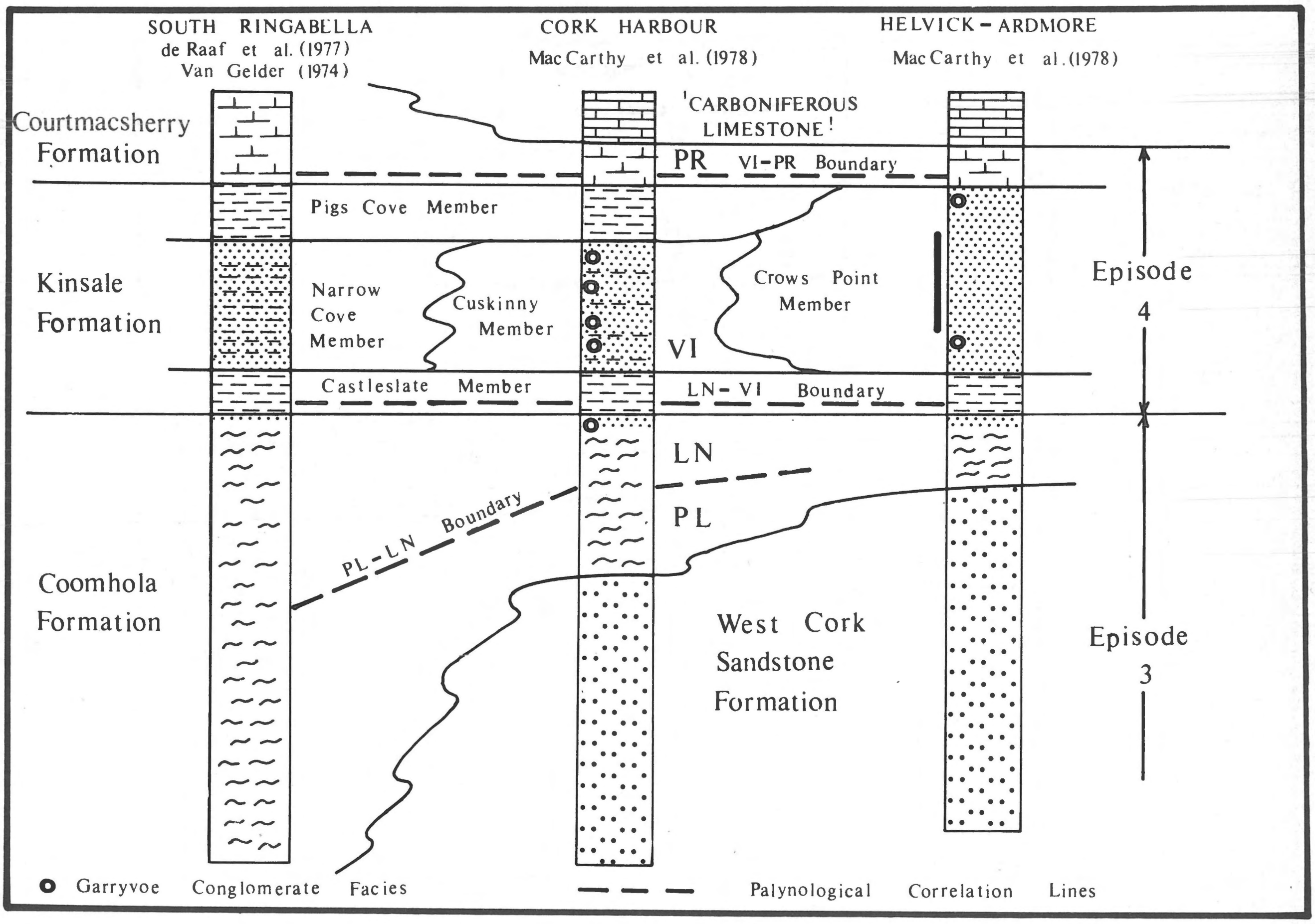


Fig. 3
Schematic illustration of lithostratigraphical relationships with Cork Harbour and South Ringabella and delimitation of Depositional Episodes 3 and 4 of Gardiner (1975). No stratigraphical thickness implied. Palynological correlations taken from Gardiner & Horne (1976) and Van der Zwan (in press).

This facies comprises thin (0.2-1.5 m) cosets of large-scale, trough cross-stratified sandstones overlying Facies A and D (Fig. 5). Prominent mud drapes occur between the foreset laminae, imparting an heterolithic character to the large-scale sets. Intraformational conglomerates commonly line the base of troughs or are concentrated above the basal cross-cutting surface of the facies. In such cases the conglomerates pass upward to sandstone through a transitional zone. Palaeocurrent directions are approximately normal to those of Facies A, being bipolar NNE/SSW with the NNE mode dominating.

Facies C

This consists of thin (0.1-2.5 m) impersistent grey and red massive claystone units, becoming thinner upwards in the sequence (Fig. 5). These units rest on planar horizontal surfaces and are truncated at their upper boundary by sandstones of the succeeding facies in the main westerly direction of drainage. This precludes an assessment of the original geometry or degree of lateral persistence of the facies.

Facies D

This consists of horizontal, parallel-sided and lenticular sets of large-scale, tabular cross-stratified sandstones (Figs. 7 and 8) containing a high proportion of clay drapes between the foresets (Fig. 9). The facies is divided into two sub-facies on the basis of set thickness; D1 consisting of thick (1-2 m) sets and D2 consisting of thin (less than 1 m) sets. Individual sets are traceable for up to 70 m in the downcurrent direction. At isolated levels foresets flatten when traced axially, becoming horizontal. In such cases the horizontal beds are individually composed of thin (less than 10 cm) tabular sets whose current directions are consistent with those of the large-scale structures of the same facies.

An interesting association occurs between Facies D2 and the heterolithic Facies E at 32 m in figure 5. At this level large-scale epsilon foresets, individually composed of small tabular sets (D2), interdigitate with the heterolithic sediments of Facies E (Fig. 5). The palaeocurrent directions in Facies E are

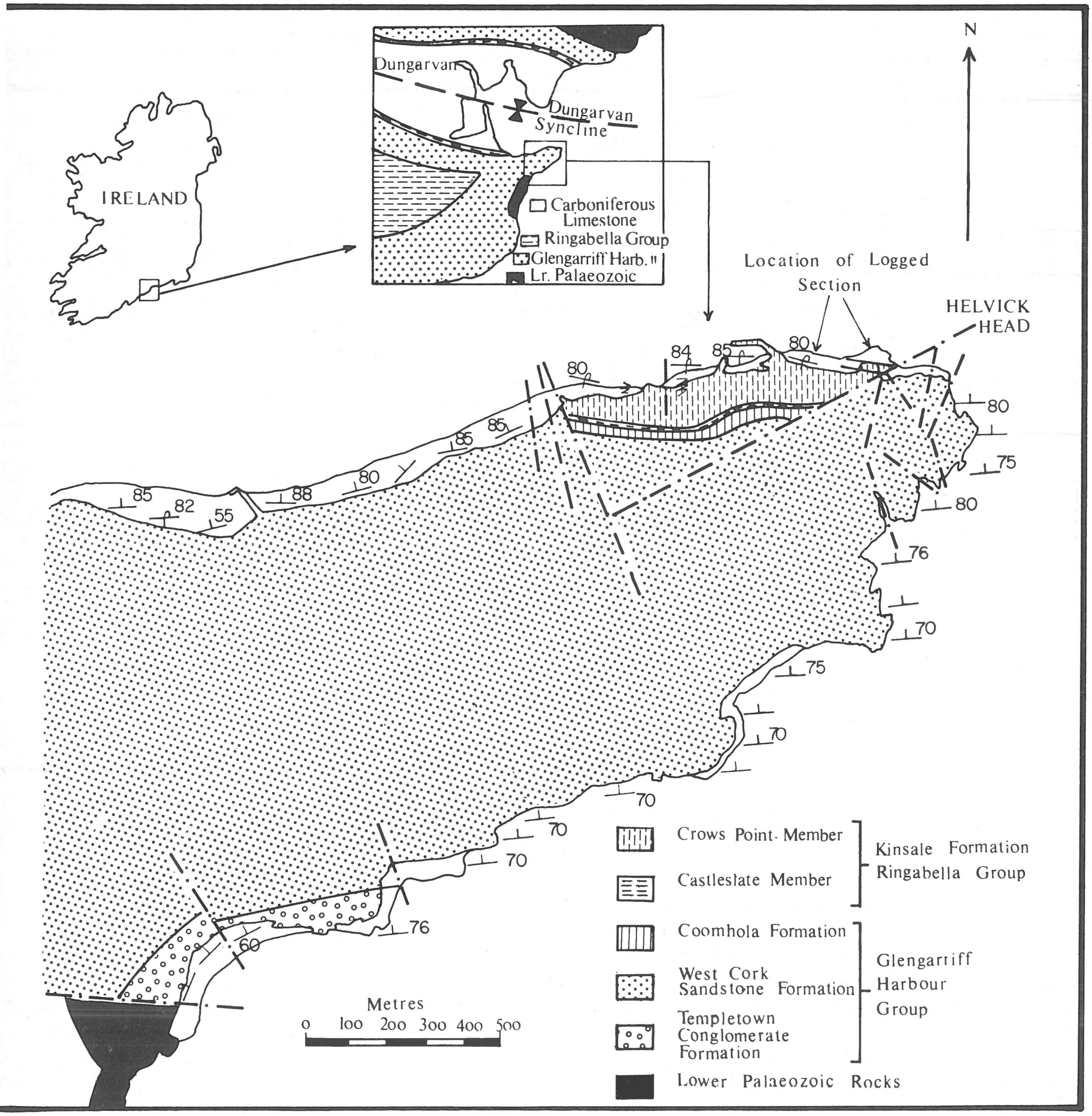


Fig. 4
Map showing the location of Helvick Head and its geological setting.

here opposed to those indicated by Facies D2 which are as in Facies A, i.e. from the ESE.

Facies E

This facies consists of (a) siltstones containing thin sand laminae and thick (0.8 m) lenticular erosively-topped sand units and (b) lenticular heterolithic (linsen) units. The siltstones are confined to a single occurrence at the base of Facies Association 3 (Fig. 5) and contain current-generated small-scale climbing sets and oppositely directed large-scale, low-angle, current-generated cross-lamination in the sandstones. This siltstone unit is erosively overlain by an heterolithic unit which records the earliest development of wave generated structures (Fig. 10). Succeeding heterolithic units occur as lenticular bodies. The lower occurrence of Facies E interdigitates with, and is erosively overlain by, large-scale sets of Facies D2.

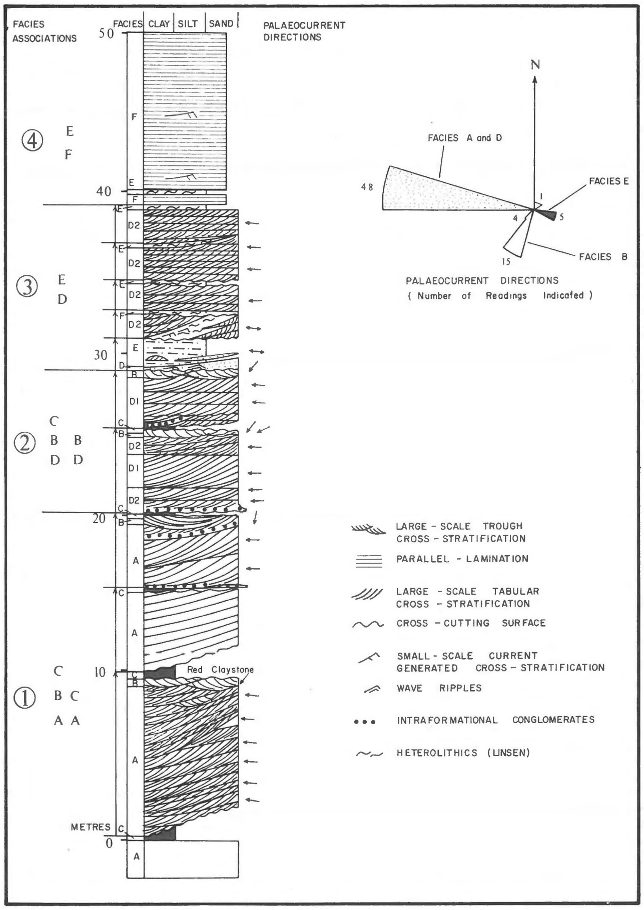


Fig. 5
Log of the Crows Point Member showing facies, facies associations and palaeocurrents.

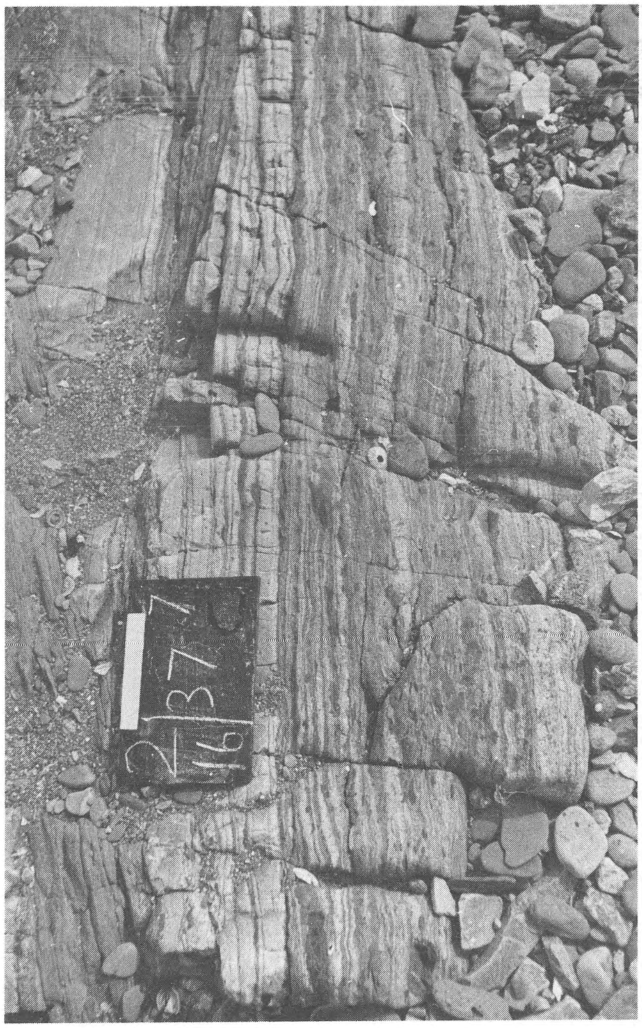


Fig. 6
Facies A: Bedded intraformational conglomerate at 18.6 m consisting of thin, coarse, parallel-sided sandstones alternating with thin claystones containing randomly dispersed, rounded and angular clay fragments. Sequence youngs to the left. White bar scale on slate measures 10 cm in all photos.

Facies F

This facies comprises parallel-sided sheet units of parallel-laminated and small-scale, cross-laminated fine to medium grained sandstones containing occasional mud drapes.

FACIES INTERPRETATIONS

Facies A

There are no features in this nor in any other facies which would suggest deposition in any other than an aqueous medium. The facies is interpreted as reflecting relatively high energy influxes from which sediment accreted on slip faces analogous to micro-deltas examined experimentally by JOPLING (1965). The micro-deltas migrated down the inclined epsilon surfaces. The tangential concave-up character of the foresets indicates deposition from a high-energy influx to a standing body of water. Thin mud drapes between foresets indicate that tranquil episodes of suspension sedimentation punctuated the high-energy sand influxes. Deposition of intraformational conglomerates presumably resulted from partial reworking of mud on the bottomsets. Such reworking of mud drapes and bottomset sands by currents at the reattachment point of the form sets, analogous to that proposed by MACCABE (1977) to explain massive sands at the base of distributary channels, may also be invoked for the bottomset beds here. The superimposition of inclined (epsilon) erosional planes bounding the tabular sets appear to be reactivation surfaces (COLLINSON, 1970) pointing to a periodic fall in base level. On this basis each reactivation episode was then followed by increased water depth during the next high stage, resulting in renewed bed-load transport and the construction of further micro-deltas on the inclined reactivation surfaces. Water depth must have been at least as great as the

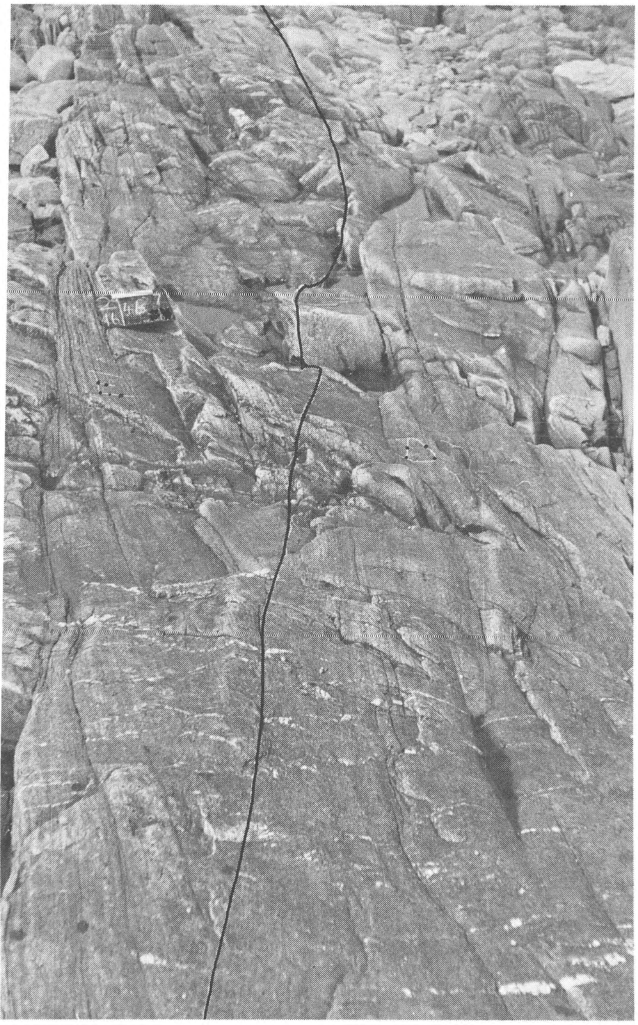


Fig. 7
Facies D1: Two large-scale tabular cross-stratified sets at 27 m showing tangential character of foresets. Boundary separating sets shown by black line. Sequence youngs to the right.

(epsilon) set thickness, i.e. 5-8 m (JOPLING, 1965). The dominance of repeated high-energy, uniformly directed microdelta construction in Facies A matches the process of transverse bar development within channels described by SMITH (1970) within the Platte River. The downcurrent-inclined epsilon surfaces of this model differ significantly from those generated by lateral accretion within fluvial (ALLEN, 1970) or estuarine (REINECK & SINGH, 1973) environments. The inferred absence of lateral accretion suggests that the channels represented by Facies A were essentially straight or slightly sinuous. The lateral extent of individual levels indicates that the channels were not less than 100 m wide and probably greater than 300 m. This model suggests that the facies represents transverse bars with epsilon slip faces generated during falling stage.

SMITH (1970) has shown that the proportion of tabular cross-stratification in the Platte braided river increases downstream with a corresponding decrease in horizontal stratification. Comparison with this model would place Facies A within a distal setting of the fluvial drainage network, comparable to fluvial-tidal reaches of channels in The Netherlands (TERWINDT, 1970). The association between transverse bar growth within channels and regular suspension sedimentation between periods of bar growth (mud drapes) suggests either channel switching with quiet water traps or that this was an area of weak tidal influence of the fluviotidal zone. The regularity of fines supports the latter interpretation.

Facies B

The troughs apparently represent phases of shallow channeling by strongly erosive currents followed by the development of sinuous megaripple trains. Ripple migration was periodically interrupted by episodes of suspension-dominated sedimentation.

Channeling into Facies A followed by dune migration and the upward passage to (abandoned channel) Facies C suggests an in-channel setting. The rapid alternation of traction and suspension conditions indicates that dune migration alternated with low-energy episodes. Facies B is thought to represent the topset beds of major bars probably deposited during low stage. The rapid intra-set energy alternation may have been a function of weak tidal influence.

Palaeocurrent variance between heterolithic low-stage dunes (i.e. Facies B) and high-stage bars (i.e. Facies A) could be explained by postulating that the high-stage bedforms resembled those of straight-crested ripples with long wave lengths analogous to sand waves. At low stage, drainage would preferentially follow the troughs of these bedforms which were orientated normal to the main channel axis; hence, the current reversal. Low-stage drainage of this type would imply relatively wide channels.

Facies C

The muds are thought to have accumulated from suspension and therefore represent low-energy conditions. The absence of shrinkage cracks suggests permanent water cover. This hydrodynamic situation, coupled with the abrupt basal contact of the facies overlying distributary sands (Facies A and B) indicates an abandoned channel-fill for this facies.

Facies D

Apart from the variation in set thickness, the facies is similar to the internally cross-stratified parts of Facies A and a similar hydrodynamic interpretation is envisaged for individual sets. The large-scale sets compare well with those generated by migrating straight-crested transverse bars on horizontal surfaces within distributary channels similar to tabular units of Facies A. The water depth, approximated by the set height

Fig. 8
Facies D1: Large-scale tabular set at 23 m. Individual foresets are graded and separated by thin mud drapes. Base of set shown by white line. Sequence youngs to the right.

(JOPLING, 1965), however, is significantly less than in Facies A. The rapid alternation of clay and sand grade sediment between the foreset laminae indicates that bar growth took place in the zone of tidal influence. However, the superimposition of several bar units may suggest that termination of bar growth was controlled by successive rises in base level, in contrast to fluctuations in river stage which controlled earlier facies development (e.g. Facies A). Such rises are thought to have been responsible for suspension sedimentation on each successive set with resultant absence of reactivation surfaces which occur in Facies A. Suspension muds and bedload sands were partially reworked into basal intraformational conglomerates during succeeding high-energy transverse bar growth. The progressive upward decrease in preserved set thickness within Facies D (D1 replaced by D2) points to progressive shallowing of distributary channels.

Facies E

The lower siltstone unit of this facies is thought to have accumulated downstream of transverse bars (Facies D1) in a relatively low energy setting in which currents transported sediment from the WNW. Oppositely directed currents are indicated by lenticular cross-stratified sandstones. These are interpreted as the product of migrating fluvial sand bars possibly generated downcurrent of prograding bars (Facies D2) and reworked partly by oppositely directed tidal currents. The irregular erosive upper surface to sandstone units may reflect storm surge processes. Linsen units represent alternation of slack water during which muds accumulated from suspension with periods of high-energy deposition from a traction load within a wave influenced area. The bipolar current pattern in the siltstone/sandstone units represents the first indication of tidal currents capable of transporting a bed load. This, together with its relationship to distributary channels (Facies D2), suggests deposition in a tidally influenced channel zone.

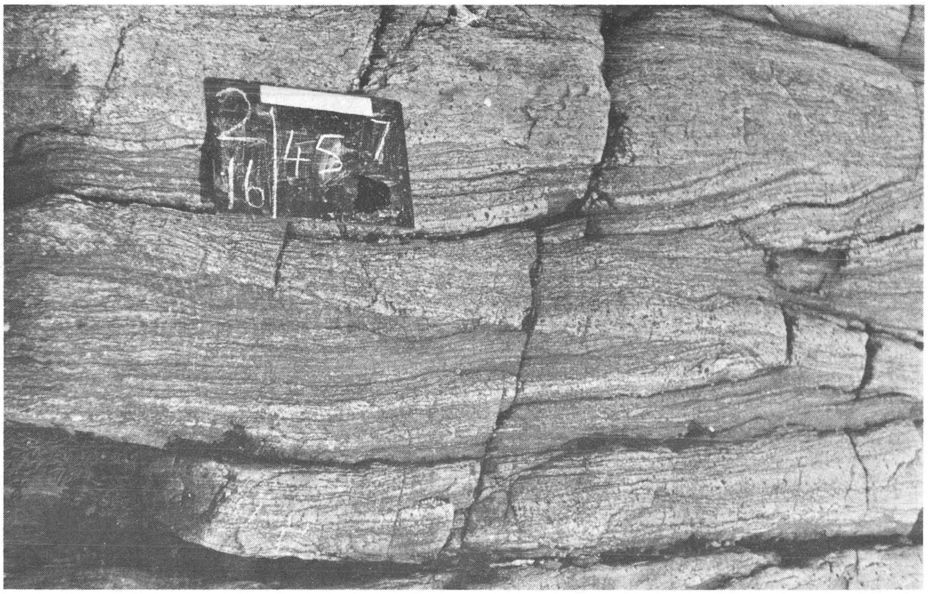
Facies F

The parallel-laminated sheet sand units show no parting lineation and are interpreted as low-energy products. The minor phases of ripple development may have been the product of fall out following storm episodes in a protected marine setting. The association with tidally influenced Facies (E) and shallow distributary channels Facies D2 suggests deposition seaward or lateral to the main feeder channels.

FACIES ASSOCIATIONS: DESCRIPTIONS AND INTERPRETATION

The six facies described above relate in a vertically rhythmic pattern grouped into four associations (Fig. 5) with an upward progressive loss of particular facies. Superimposed on these associations four trends are evident. These are:

(1) A bulk upward decrease in rhythm thickness and grain size.
(2) An upward thickness decrease in Facies A and C.
(3) An upward increase in the proportion of intra-foreset mudstone, within Facies A, B and D.
(4) Rapid upward increase in thickness of Facies F.



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'acies D1: Large-scale tabular sets with tangential foresets showing intra-set alternations of mud and sand grades at 26 m. Sequence youngs ipwards.

The succession of facies associations and superimposed rends point to a progressive change in the style of sedimen-tation, suggestive of gross allocyclic control of facies deve-opment.

Facies Association 1 is comparable with riverine distribu-ary models developed by MACCABE (1977) for Carboniferous sequences in northern England. Apart from scale differences n set thickness the major deviation from these models is the absence here of the 'unlaminated massive beds' at the base of channels. MACCABE (1977) has suggested that these massive beds represent reorganisation of sediment within the troughs of bedforms at the reattachment point on the leeside of 'al-ernate bars'. The absence of this facies from the Crows Point sequence is possibly a function of a lower energy flow at the reattachment point of shallower bars. The intraformational conglomerates at the base of some channels may, however, have been generated by a similar mechanism.

Facies Association 1 indicates a rhythmic pattern of sedi-ment input in which relatively high-energy bars migrated from the ESE within essentially straight, broad, deep distri-butary channels which experienced weak tidal influence. Fa-cies development was modelled by reductions in water depth within the channels following each main flood episode. Fluctuations in river stage, considered here to have played an important role in facies development, may have been at least partially controlled by spring/neap tidal oscillations. Each major increment of channel sediment was followed by low-stage dune migration approximately normal to the channel axes. The abrupt contact between Facies B and C implies channel abandonment rather than a lateral shift in the chan-nel axes which would have resulted in lateral accretion surfaces within a fining upwards motif (ALLEN, 1970). Such abandonment points either to a repeated transgressive ten-dency or to a rapid switching of the drainage pattern. The apparent absence of major crevasse lobes and the uniform palaeocurrent pattern here favours the former mechanism.

The upward change to Facies Association 2 and 3 records an important change in the style of sedimentation. A distinc-tive flood-dominated tidal influence makes its first appearan-ce at the inception of Facies Association 3 indicating a shift to a more distal setting within the drainage network. The superimposition of erosively based Facies D2 on the lowest occurrence of Facies E points to a renewal of river-domina-ted distributary growth. Deposition, however, proceeded in shallower tidally influenced parts of these distributary chan-nels. Successive bar growth was initiated by successive deepening, possibly in response to marine influences, indica-ting that river dominance was waning and that the distribu-tary gradient was much reduced. Each major pulse of fluvial distributary construction was followed by rapid aban-donment in favour of distal distributary conditions in which wave processes and suspension/traction alternations predo-minated (Facies E).

Distributary growth was terminated in Facies Association 4 which is thought to represent a low-energy protected en-vironment where deposition may have occurred, following storm surge processes across a barrier.

The bulk upward decrease in rhythm thickness and the upward thickness decrease in Facies A and C testify to a time-progressive reduction in channel depth while the up-ward reduction in grain size and the progressive upward in-crease in intra-foreset mudstone in Facies A, B and D is consistent with a shift to a more distal tide-influenced setting in the drainage system. The rapid increase in the thickness of Facies F indicates either a major lateral shift of distributary channels to another area or a final waning of channelisation in favour of less restricted marine conditions. The absence of crevasse-splay and/or inter-distributary bay sediments in the upper part of the sequence (Facies Association 4) favours the latter interpretation. This appears to indicate an allocyclic mechanism as having been the major controlling factor in modelling the sequence of facies associations.

PALAEOGEOGRAPHICAL IMPLICATIONS

Two recent regional palaeogeographical models which incorporate the investigated sequence area have been proposed. NAYLOR ET AL. (1974, p. 89) suggested that this sequence was deposited – following a regional northerly transgression some 10 km south of an east-west trending shoreline – in a setting of 'offshore subtidal and prodelta environments with interactions of shelf and inshore subtidal sediment' and 'tidal channel deposits'. In contrast, GARDINER (1975) considered that the general setting was that of a tidal plain which had encroached onto the south-east flank of what was a totally internal continental Munster Basin (Fig. 11) following southerly marine breaching in the Late Devonian. This study permits an assessment of these two differing regional palaeogeographical settings as well as evaluating the local environment in more detail.

The repeated occurrence of wide, straight, river-dominated distributary channels in this area coupled with tidal influence and the rhythmic development of channel-abandonment conditions suggests that the Crows Point succession represents a major phase of river-dominated distributary growth, in a coastal setting, from the ESE in response to a major regressive event. The upward shallowing of distributary channels and the gradual upward increase in tidal and shallow marine influence indicates a progressive waning of river dominance. From its inception, therefore, this member records a progressively waning phase of progradation, at the margins of a river-dominated coastline, due to facies migration in response to a regional easterly transgression. The sequence therefore provides evidence of the unusual association of river-dominated processes in a coastal area which appears to have simultaneously responded to transgressive processes. The coastline must at least locally, have been orientated NNE-SSW, a feature which would seem to have been inherited from the pre-Crows Point Member palaeogeography (Fig. 11).

The regional significance of the Crows Point Member lies also in its lateral southwestward gradation to the Cuskinny and Narrow Cove Members (Kinsale Formation) which contain the distinctive Garryvoe Conglomerate Facies (MACCARTHY ET AL., 1971; GARDINER & HORNE, 1976). These sequences accumulated in a wave-dominant shallow marine setting (GRAHAM, 1975; DE RAAF ET AL., 1977). Analysis of the Garryvoe Conglomerate Facies has shown this to have been the product of high-energy influxes from a stable, low-relief area of plutonic igneous and metamorphic rocks located on the south-eastern flank of the Munster Basin (MACCARTHY ET AL., 1971). The present analysis, therefore, provides cogent support for this important source area during Carboniferous times. The member appears to lie in an intermediate, transitional fluvial-marine setting.

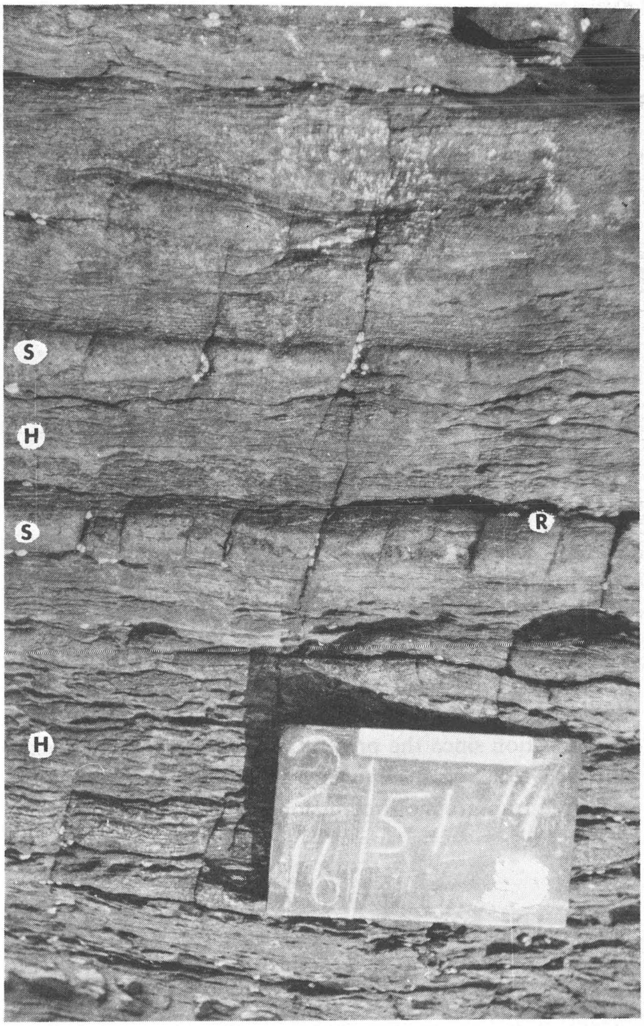

Fig. 10
Facies E: Detail of laterally impersistent heterolithic unit at 32 m showing heterolithic levels (H) alternating with parallel-laminated sandstones (S) of which some show evidence of reworking of their upper surface (R). Sand levels within heterolithic units are mostly wave rippled. Sequence youngs upwards.

The spatial arrangement of these facies and the present detailed analysis of the Crows Point Member support the Late Devonian – Early Carboniferous configuration of the basin proposed by GARDINER (1975) (Figs. 1 and 11) and suggests a southwestward regional axial drainage pattern. This study indicates that the basin experienced a significant influx from a positive southeastern flank at least in the Helvick area

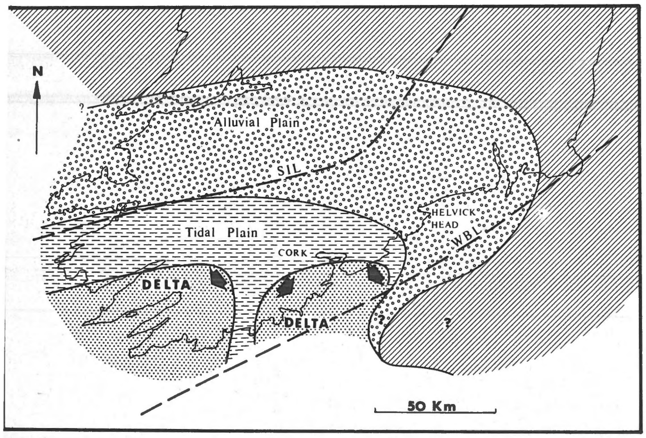

Fig. 11
Palaeogeography of the Munster Basin preceeding deposition of the Crows Point Member. Modified from Gardiner (1975). Arrows indicate main drainage pattern.

and that the configuration of the basin envisaged by NAYLOR ET AL. (1974) with a regional southward directed drainage system and a northerly regional transgression in the Early Carboniferous is incorrect. The generalised tidal plain environment of GARDINER (1975), however, appears an oversimplification since the present analysis shows a complex of differing local environments associated with possibly widespread transgression/regression at this level.

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