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STRATIGRAPHY AND SEDIMENTOLOGY OF THE LOWER CRETACEOUS GETHING FORMATION, CARBON CREEK COAL BASIN, NORTHEASTERN BRITISH COLUMBIA

D.W. GIBSON

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STRATIGRAPHY AND SEDIMENTOLOGY OF THE LOWER CRETACEOUS GETHING FORMATION, CARBON CREEK COAL BASIN, NORTHEASTERN BRITISH COLUMBIA

Abstract

The Gething Formation in the Carbon Creek basin of northeastern British Columbia comprises a predominantly nonmarine, interstratified sequence of sandstone, siltstone, mudstone, conglomerate and coal, with a composite stratigraphic thickness of at least 1036 m (3400 ft), making the Gething in the area the thickest yet recorded in northeastern British Columbia and northwestern Alberta. The contact with the underlying Cadomin Formation is gradational and placed at the top of the uppermost thick sandstone of the Cadomin containing lenses or pockets of chert-pebble conglomerate. The contact with the overlying Moosebar Formation was not observed in borehole cores in the Carbon Creek area but is assumed to lie not far above the thick sandstone capping borehole 72-13.

The Carbon Creek basin contains in excess of 100 seams of coal ranging in thickness from a few centimetres to 4.3 m (14 ft), with sixty-one of these seams greater than 0.3 m (1 ft) in thickness and 10 seams ranging between 0.9 and 4.3 m (3-14 ft) thick. The coal grades in rank between high volatile bituminous near the top of the Gething Formation, to medium volatile bituminous near the base.

Evidence in the form of facies, facies relationships, sedimentary structures and coal sulphur concentrations suggests that strata of the Gething Formation of the Carbon Creek coal basin were deposited in two major deltaic environments. The lower half of the formation contains features typical of modern upper deltaic plain and possible minor alluvial valley environments while, in contrast, the upper half or remaining strata of the Gething Formation contain evidence of deposition in a lower deltaic plain environment.

Résumé

La formation de Gething du bassin de Carbon Creek dans le nord-est de la Colombie-Britannique comprend une séquence interstratifiée de grès, de silstone, de mudstone, de conglomérat et de charbon, tous d'origine principalement non marine. L'épaisseur stratigraphique totale est d'au moins 1036 m (3400 pieds), ce qui fait que la Gething de cette région est la plus épaisse dans le nord-est de la Colombie-Britannique et le nord-ouest de l'Alberta. Il existe une surface de contact progressive avec la formation de Cadomin sous-jacente; elle se situe au sommet du grès épais le plus élevé de la formation de Cadomin, lequel contient des lentilles ou des poches de conglomérat de galets de chert. La surface de contact avec la formation de Moosebar sus-jacente n'a pas été observée dans les carottes de sondage de la région de Carbon Creek, mais devrait se trouver au-dessus de l'épaisse couche de grès qui coiffe le trou de forage 72-13.

Le bassin de Carbon Creek renferme plus de 100 filons houillers dont l'épaisseur varie de quelques centimètres à 4,3 m (14 pieds); soixante-et-un de ces filons ont plus de 0,3 m (1 pied) d'épaisseur et 10 ont une épaisseur qui varie de 0,9 à 4,3 m (3 à 14 pieds). Le charbon varie de la houille bitumineuse à haute teneur en matières volatiles près du sommet de la formation de Gething à celle à moyenne teneur en matières volatiles près de sa base.

Les faciès, les liens entre les faciès, les structures sédimentaires et les concentrations de soufre de houille laissent supposer que la formation de Gething du bassin houiller de Carbon Creek se serait accumulée dans deux milieux deltaïques importants. La moitié inférieure de la formation de Gething contient des éléments caractéristiques de l'amont d'une plaine deltaïque récente et possiblement de petites vallées alluviales tandis que la moitié supérieure aurait été déposée dans la partie aval d'une plaine deltaïque.

STRATIGRAPHY AND SEDIMENTOLOGY OF THE LOWER CRETACEOUS GETHING FORMATION, CARBON CREEK COAL BASIN, NORTHEASTERN BRITISH COLUMBIA

INTRODUCTION

The Carbon Creek coal basin lies approximately 32 km (20 miles) west of the W.A.C. Bennett Dam and Peace River canyon in northeastern British Columbia, encompassing an area of approximately 115 km^2 (72 square miles) (Figs. 1, 2). The Carbon Creek area has been of economic interest since 1911 when coal was first noted by Messrs. Cowper Rochfort, David Barr, and George McAllister at the confluence of Carbon Creek and Peace River (Mathews, 1947). Coal leases were acquired but there was little exploration or development activity. In subsequent years, geological mapping surveys were conducted in the area by Galloway (1924), Mathews (1947), and Stott (1968, 1969, 1973). However, it was not until 1971 when demand for coking coal began to exceed current supplies in Canada that Utah Mines Limited of Vancouver obtained coal leases in the Carbon Creek area. They began a detailed drilling program to determine the distribution, quality, and reserves in the area.

In 1973, Utah Mines extended to the Geological Survey of Canada the opportunity to examine some of the cores from their drilling program. The surface stratigraphy of the Gething Formation in northeastern British Columbia and west-central Alberta has been extensively studied by D.F. Stott of the Geological Survey (Stott, 1967, 1968, 1969, 1973). Little was known, however, of the Gething Formation in the Peace River district in the western Rocky Mountain Foothills west of Peace River canyon (Fig. 1), and the opportunity to examine and study the core provided the Geological Survey and the writer with needed information in this area. It was anticipated that the study would complement and provide additional data in support of the field investigations of Stott (*op. cit.*).

The following report is based on field work undertaken during the summer of 1974. Thirty-three rotary cores were examined and sampled in detail as a means of providing data on 1) the facies and facies relationships, and 2) the distribution, thickness, and continuity of coal seams in the Gething Formation within a very limited area of the western Foothills. Sedimentary structures and other sedimentological data were also recorded to aid in describing and interpreting the depositional environments and history of deposition in the area.[1]

Acknowledgments

The writer thanks Utah Mines Limited for providing the opportunity to examine the core and providing pertinent geological data from the Carbon Creek area. D.S. Fullerton and N. LeNobel of Utah Mines guided the writer around the property and provided information on borehole and core locations, correlation of coal seams, coal analyses, and other confidential geological data. Able assistance was rendered in the field by J.M. Ward. Additional thanks are extended to colleagues of the Geological Survey, A.R. Cameron, P.A. Hacquebard and P.R. Gunther[2] for coal rank and reflectance analyses, D.A. Neuert[2] for laboratory assistance in the computation and compilation of coal seam rank data, and drafting and assembling figures for this report, and W.O. McEwan for making several thin sections. All megafossils and microfossils collected from the core were identified and dated where possible by J.A. Jeletzky and J.H. Wall.

STRATIGRAPHY

General

The predominantly nonmarine, fluvial-deltaic Gething Formation of the Bullhead Group in northeastern British Columbia and west-central Alberta, with its type section at Peace River canyon (Fig. 1), can be traced in outcrop from Smoky River in west-central Alberta to Tetsa River in northeastern British Columbia (Stott, 1968, 1973). The Gething correlates to the southeast and east with the Gladstone Formation of the Blairmore Group in the Alberta Foothills, and with strata of the McMurray Formation and other units of the Lower Mannville Group of the Alberta Plains. The Gething Formation is overlain by marine shales of the Moosebar or Buckinghorse formations of the Fort St. John Group, and is underlain by sandstone and conglomerate of the Cadomin Formation. To the northwest the formation is underlain by an erosional unconformity at the top of the Triassic Schooler Creek Group (Stott, 1972).

Carbon Creek Coal Basin

Lithology

In the Carbon Creek area of this report, the economically important Gething Formation consists of an interstratified sequence of predominantly nonmarine sandstone, siltstone, mudstone, and coal, with lesser sporadic intervals of both pebble and intraformational conglomerate. The succession attains a cumulative thickness of at least 1036 m (3400 ft), making the formation in the Carbon Creek area the thickest yet recorded for the Gething. The type section at Peace River canyon (Fig. 1) at 549 m (1800 ft) was previously considered to be the thickest occurrence of the Gething Formation in the Peace River District (Stott, 1969).

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[1]Since completing this study, a suggestion has recently been made in a preliminary report by Stott and Gibson (1980) concerning coal in the Minnes Group in northeastern British Columbia, that perhaps the thick coal-bearing succession in the Carbon Creek basin described in the following report may not be the Gething Formation as proposed by earlier workers, including the writer, but may consist predominantly of strata of the Minnes Group. However, recent field work by Stott in 1981 in the adjacent Mount Rochfort area to the west, indicated an error in the identification of part of the Minnes Group succession. Strata formerly assigned to the Minnes succession are now considered to be the Gething Formation (Stott, pers. comm., 1982). Thus, the thick coal-bearing succession of the Carbon Creek basin, which is described in this report, is still identified as mainly strata of the Gething Formation and correlates with the thick coal-bearing succession of the adjacent Mount Rochfort area described by Stott and Gibson (*op. cit.*).

[2]Formerly of the Geological Survey of Canada.

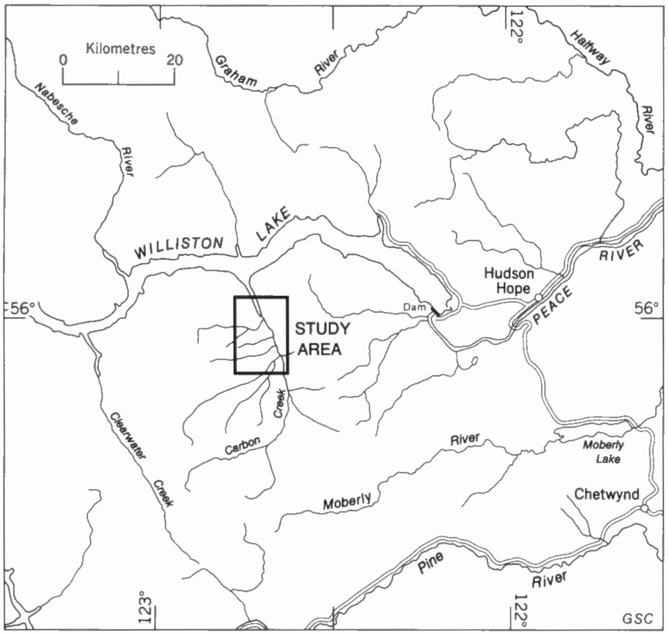

Figure 1. *Index map showing location of study area (shaded).*

Sandstone is one of the most common rock types in the formation. It is moderately to well sorted, well indurated, and ranges from predominantly very fine to less commonly coarse grained. Conglomerate lenses and "floating" pebbles of chert occur sporadically in some of the thicker units in the upper one third of the formation (Pl. 2, A, B, D, and Fig. 4). The sandstone ranges from medium to light grey but may be dark grey in the finer grained, more carbonaceous facies. Quartz and chert predominate, with chert most abundant in coarser grained units. Lithic grains of silicified shale, siltstone, and quartzite form a minor fraction of the rock. Grains are angular to well rounded. Cement consists of silica and less commonly dolomite, calcite, and clay minerals. Grains of collophane, glauconite, muscovite, and rare orthoclase and plagioclase feldspar were also noted in thin sections. The sandstone occurs mainly as inconspicuous thin beds and thin to thick laminations interbedded and interlaminated with siltstone (Pl. 5, E). Less commonly but more conspicuously, however, the sandstone occurs as thick units, up to 47 m (155 ft) thick (Sec. 71-4, Fig. 4), which have proven most helpful in correlating boreholes within the area. These thicker sandstone units are cleaner, better sorted, and commonly coarser grained than the thin beds and laminations cyclically interbedded with siltstone. It must be emphasized that coarse grained sandstone, although present as thick and conspicuous beds, forms but a minor part of the Gething Formation in the Carbon Creek area. Most sandstones, particularly the thinner, finer grained beds, display regular wavy, or lenticular, darker grey, carbonaceous silt laminations (Pl. 5). Graded bedding is common in some of the thicker units (Pl. 4, A).

Small- to medium-scale festoon and planar crossbeds are abundant, with the festoon type most common (Pl. 3, A). Also abundant are ripple and ripple drift laminations (Pl. 4) and contorted or convolute laminations (Pl. 6).

A typical thick sandstone in the lower Gething Formation can be described as follows. An erosional base with relatively coarse grains contains, in places, scattered, well rounded chert pebbles or angular siltstone or mudstone clasts. Overlying is a thin interval with small-scale festoon crossbedding. The crossbedded interval is followed by a unit of finer grained sandstone with ripple laminations, then by a zone of climbing ripples or ripple drift laminations (Pl. 4). The sandstone may or may not be capped by contorted or convolute laminations (Pl. 6).

Horizontal and vertical burrow structures are found in many of the finer grained sandstones, especially those interbedded with siltstone and mudstone in the upper half to third of the formation (Pls. 8, 9). The burrows are of two types. One type consists of vertical and sometimes horizontal to oblique channels or tubes ranging in diameter between 1.3 and 2.5 cm (0.5-1.0 in). These burrows may also be found in some of the coarser grained sandstone units. Another structure found with fine grained, commonly graded sandstones, siltstones and mudstones is subaqueously formed, shrinkage or syneresis cracks (Donovan and Foster, 1972). These unusual, but relatively common, burrow-like, sedimentary structures are filled with sand or silt and rarely exceed 1.3 cm (0.5 m) in diameter and 2.5 cm (1 in) in length (Pl. 8, B). Other structures noted but rare in occurrence are stylolites and small cut-and-fill channels (Pl. 2, D; Pl. 7, D). These are found mainly in the coarser grained, clean and well sorted sandstones.

Medium to dark grey siltstone in units up to 7 m (22 ft) thick form another common lithofacies in the Gething. The siltstone is carbonaceous-argillaceous, and characteristically very sandy. The sand concentration is such, that at times it is difficult to classify the rock as either a very fine grained sandstone or sandy siltstone without a detailed laboratory size analysis. Carbonate forms a relatively high concentration in some of the siltstone, so that the rock may be classed as a silty limestone or dolostone. In addition to the association with very fine grained sandstone, the siltstone commonly occurs with mudstone (Figs. 3-9), where it is generally darker grey, more carbonaceous, and contains a relatively high concentration of macerated plant material. Mineralogically, the siltstone is similar to the sandstone except that chert is much less common in the siltstone. Sedimentary structures are similar to those found in the finer grained sandstones, and include parallel to wavy, light grey, sand laminations; dark grey to black, organic, carbonaceous laminations (Pl. 5); small- to micro-scale, festoon crossbedding; and ripple and ripple drift laminations. Sand-filled, large and small, vertical to horizontal burrow structures are common in the upper third of the formation (Pls. 8, 9). Contorted or convolute laminations are common in both siltstone and sandstone units (Pl. 6). Cut-and-fill structures were noted but in general are rare.

Mudstone and claystone (Folk, 1964) form conspicuous components of the Gething Formation in the report area. The mudstone, which may in part be classed as claystone or siltstone depending on the concentration of clay and silt, is medium dark to dark grey, rarely calcareous or dolomitic, and forms thick units in excess of 5 m (18 ft).

Two main types of mudstone have been recognized: vegetal-matter rich, and vegetal-matter free. The first type is carbonaceous, silty to sandy, and contains a high concentration of macerated plant material (phytoclasts). These mudstones display in places parallel to wavy and well developed lenticular laminations. The second type is darker grey and appears to contain a high concentration of clay minerals. In contrast to the first type, very little to no vegetal matter is found, and sand-silt laminae are rare. With X-ray or chemical analysis, some of these rocks may prove to be claystones. These mudstones may contain reddish to orange-brown, lenticular, ferruginous laminations and ferruginous nodules, the latter up to 2.5 cm (1 in) in

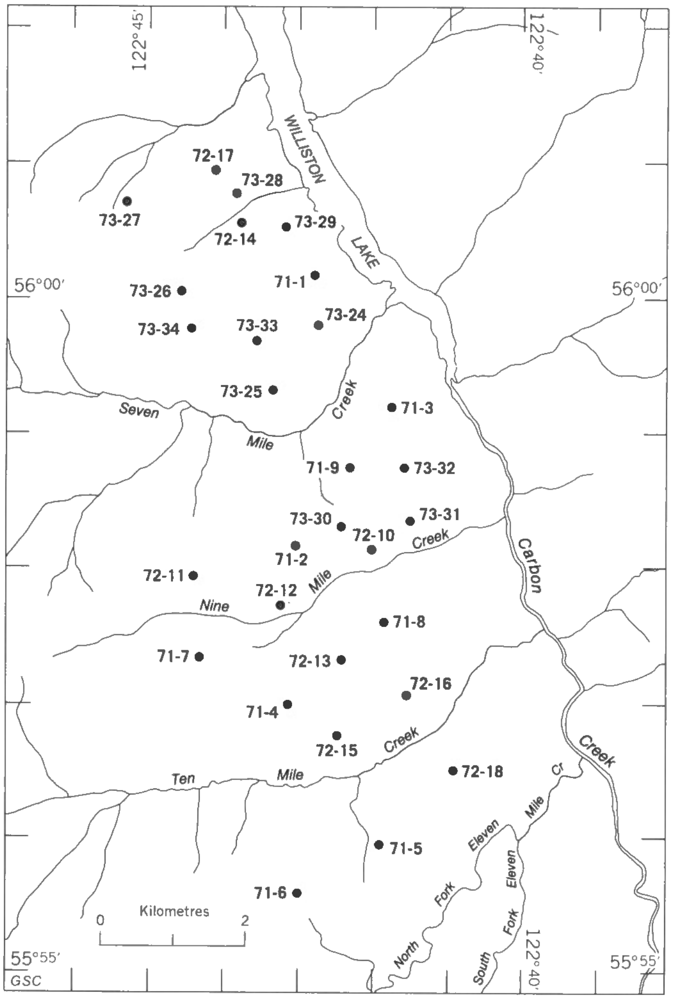

Figure 2. Location of boreholes used in study.

diameter. The dense, generally silt-free mudstone of the second type displays a characteristic subconchoidal fracture, and contains most of the megafossils collected from the area. Small silt- and sand-filled burrows and bioturbate mottling are common in some units, particularly in the upper half of the formation.

Conglomerate, the most conspicuous but least common lithotype of the area, occurs as thin to thick beds or as lenticular pockets, commonly associated with or contained within the thicker fine- to coarse-grained sandstone (Figs. 3, 4, 10). Two types have been observed. The first and most common is chert-pebble conglomerate, which is well developed in the massive sandstone marker facies near the top of the formation and illustrated in Figure 4. The conglomerate consists of well rounded pebbles and granules of both light and dark grey chert, light grey quartzite, and dark grey, siliceous mudstone or shale, ranging in size up to 5 cm (2 in) in diameter (Pl. 2, A, B) with the average size approximately 0.6 cm (0.25 in). The matrix and cement are composed of fine- to coarse-grained quartz and chert sandstone. The second conglomeratic lithotype is intraformational conglomerate, which consists of angular, elongate, dark grey siltstone and mudstone clasts up to 18 cm (7 in) long by 4 cm (1.5 in) wide in a matrix of medium- to coarse-grained, quartz-chert sandstone (Pl. 2, C). The angular clasts are most commonly oriented parallel or subparallel to the bedding.

Facies Variations

Stott (1968, 1973) has documented some of the major facies variations in the Bullhead Group and Gething Formation between Smoky River in west-central Alberta and Tetsa River of northeastern British Columbia. The Carbon Creek basin (Fig. 2) affords an opportunity to examine the nature of facies changes that occur within a small sedimentary basin. Figures 3 to 9 contain five east-west and two north-south cross-sections, illustrating lithofacies and lithofacies variations, both transverse and parallel to the structural trend of the region. Major coal seams and other readily correlatable seams have been designated with letters to simplify the discussion that follows.

It is apparent from an examination of the cross-sections that the only obvious facies changes are those of the major sandstones (including conglomerates), mudstones and coals. The most distinctive facies variation is illustrated by the thick sandstone in the upper Gething Formation, shown in Figure 4. This unit is up to 47 m (155 ft) thick and can be traced throughout the southern part of the study area. Lower in the section is another major sandstone that can be traced between boreholes and is shown in Figures 3 and 4. This unit illustrates the rapid thinning and intertonguing with siltstones to the west, demonstrating the rapidity of a lateral facies change. For example, the sandstone thins from approximately 14 m (46 ft) in borehole 72-18 (90.8 m below top) (Fig. 3) to approximately 1.8 m (6 ft) in borehole 71-6 (65.2 m below top) (Fig. 3) in a lateral distance of 2.9 km (1.8 miles). In boreholes 71-4 and 71-7 (Fig. 4) to the north, the same sandstone unit thickens to over 26 m (85 ft) in borehole 71-4 (230 m below top). In adjacent borehole 72-15, 0.8 km (0.5 miles) away, the sandstone thins to approximately 7.6 m (25 ft). Also noteworthy is the distribution of thin and thick beds and lenses and pockets of pebble and intraformational conglomerate adjacent to and associated with the thicker sandstones. Stott (1973) reported thick conglomerate units with well rounded pebbles of chert up to 7.6 cm (3 in) in diameter in the Gething Formation of Peace River canyon. In the Carbon Creek area, conglomerate is uncommon, but where observed contains well rounded pebbles or angular clasts up to 5 cm (2 in) in diameter, with most however, averaging between 0.6 cm (0.25 in) and 1.3 cm (0.5 in). Furthermore, in the Peace River canyon area, Stott (1973) indicated that the coarse grained sandstones and pebble conglomerates were found mainly near the base of the Gething Formation. This observation contrasts with the occurrence of the conglomerates and coarser grained sandstones in the Carbon Creek area, where they occur mainly in the upper third of the formation (Figs. 3, 4, 10).

Another distinctive lateral facies variation is illustrated by the major sandstone overlying Seam C, that is evident in the boreholes in Figure 5. This sandstone unit is lenticular, pinching or thinning to almost zero in borehole 71-9, then reappearing in borehole 73-31. Sandstone facies are poorly represented throughout borehole 71-9.

Rapid variations in abundance and thickness of mudstones can be seen in figures (especially 3 and 4) illustrating both the upper and lower parts of the Gething Formation. Mudstone is common in the upper strata of the formation and occurs as units up to 9 m (30 ft) thick. In the lower Gething Formation (Figs. 6, 7), mudstone is less abundant and occurs as thinner units.

Stott (1968, 1969, 1973) has published accounts of the regional facies variations in the Gething Formation.

Age

Although relatively common, very few fossil collections from the Gething Formation in west-central Alberta and northeastern British Columbia have proven useful in dating the strata. Recently, Chamney (in Stott, 1973) identified foraminifera from localities that include the Peace River canyon and assigned an age of late Neocomian (Barremian-Aptian) to Early Albian. Bell (in Stott, 1973) dated a Gething macroflora as Aptian and/or Early Albian. In the same report, McGregor suggested an age for the microflora ranging from Valanginian to Aptian, with the possibility that the formation may be younger than Barremian.

Very few identifiable macrofossils were obtained from cores. Those recovered by the writer and examined by Jeletzky were mainly indeterminate pelecypods and gastropods. However, two important collections were made from boreholes 71-8 and 72-11 (Figs. 4, 5) from mudstones 154 m (506 ft) and 76 m (249 ft) respectively, from the top of the wells in the upper quarter of the Gething Formation. *Aucellina aptiensis* (d'Orbigny) Pompeckj and *Aucellina caucasica* (Abich) were identified, and, according to Jeletzky, are of considerable biochronological importance. The occurrence of this fauna indicates an Aptian age for the upper Gething strata in the Carbon Creek and other areas of west-central Alberta and northeastern British Columbia. In addition, *Unio* (Elliptio) cf. *biornatus* McLearn was recovered from borehole 73-24 (Fig. 2) 116 m (380 ft) above the base of the borehole (Fig. 6, 10). The age is suggested by Jeletzky to be possibly Aptian. The *Unio* collection comes from strata of the lower half to quarter of the Gething Formation. Other fossils collected include *Astarte* s.l. sp., *Corbula* s.l. sp., and cf. *Sphaerium onestiae* McLearn. No age was assigned to these fossils.

Contacts

Stott (1968, 1973) placed the contact between the Gething and underlying Cadomin Formation "at the top of the uppermost thick conglomerate which is separated from the basal conglomerates by no more than a few tens of feet of finer sediments". In addition, he also stated that "the lower contact of the Gething forms no persistent stratigraphic horizon but lies above different conglomeratic beds of the Cadomin from place to place". In the Carbon Creek area of this report only one borehole 72-17 (Figs. 7, 10) penetrated the Cadomin Formation. The Cadomin contains strata in the Peace River area not unlike those found in the lower Gething Formation. In borehole 72-17 (Figs. 7, 10) the upper Cadomin consists of interbedded sandstone, siltstone, mudstone and minor coal. The sandstones are up to 12 m (40 ft) thick, and contain lenses of chert-pebble conglomerate with well rounded pebbles up to 2.5 cm (1 in) in diameter, although averaging 0.6 cm (0.25 in). Coal seams are sparse and thin in comparison to those in the Gething. In keeping with the contact criteria used by Stott (*op. cit.*) in his surface studies of the Gething Formation, the writer places the lower contact at the top of the uppermost thick sandstone containing lenses of conglomerate. In borehole 72-17 another major sandstone occurs 30 m (100 ft) above the defined contact. However, this sandstone is very fine- to fine-grained and does not contain conglomerate. Accordingly, it is herein considered a facies of the Gething Formation.

No boreholes were spudded into the overlying Moosebar Formation of the Fort St. John Group in the Carbon Creek drilling program. Personal communication with N. LeNobel, project co-ordinator of Utah Mines, suggests that the bed that occurs at the top of borehole 72-13 (Fig. 10) may be close to the contact with the Moosebar Formation. Stott (1968) states that the contact with the Moosebar is distinct and probably disconformable. In the Peace River canyon area he draws the contact at the top of a massive or thick bedded sandstone, which in some areas is gritty and contains chert pebbles on the upper surface. This sandstone underlies a thick succession of generally recessive weathering dark grey mudstone to shale, containing reddish brown weathering concretions. In borehole 72-13 (Fig. 10) no chert pebbles or evidence of the composition of the overlying strata were observed by the writer. The contact is tentatively placed at the top of the borehole. This placement of the upper contact as shown is also based upon local outcrop observations by N. LeNobel (pers. comm.) in the area adjacent to borehole 72-13, where mudstones and shales similar in appearance to the Moosebar Formation were observed.

Composite Section and Formation Thickness

Stott (1968, 1973) described the Gething Formation in northeastern British Columbia as ranging in thickness from zero at its eastern limit of convergence (see Stott, 1973, p. 15), to a maximum of 549 m (1800 ft) at the type locality in Peace River canyon. In a well 24 km (15 miles) east of the canyon area, Stott (1968) recorded a thickness of 257 m (843 ft) for the Gething, while 288 km (180 miles) southeast of Peace River canyon, at Wolverine Creek, the Gething is 206 m (677 ft) thick. North of Peace River the maximum thickness recorded by Stott (1973) was 396 m (1300 ft) at a locality on Fiddes Creek. Thus, it can be seen that the Peace River canyon area was considered by Stott to represent the site of maximum deposition for the formation.

Figure 10 is a composite section of the Gething Formation in the Carbon Creek basin. It has been compiled to show how the Gething Formation in the Carbon Creek area compares in thickness to the Gething Formation of other areas in Alberta and British Columbia described by Stott (*op. cit.*). The section is composed of seven boreholes (71-1, 71-4, 72-13, 72-17, 72-31, 73-24, 73-25), representing a complete stratigraphic cross-section of the area. Each borehole has associated or corresponding gamma ray and resistivity logs (not shown), which were provided to the writer by Utah Mines Limited. The seven overlapping borehole sections have been correlated using the geophysical logs, stratigraphic position of major and minor coal seams, and the relative position of prominent lithofacies such as major sandstone units. As can be seen in Figure 10, the correlation between borehole sections 71-4, 72-13, and 73-31 using major and minor coal seams and major sandstone bodies is good. The correlation is also supported by the gamma ray and resistivity logs. The relationship between borehole sections 73-25 and 73-31 is based mainly on the correlation of seams A and H (Figs. 5, 6). At first glance this relationship may appear unreliable because of the small interval of section overlap between the two wells. However, adjacent borehole sections 71-2 and 73-30 (Fig. 2) and the geophysical log traces, when used in conjunction with borehole data of sections 73-25 and 73-31, support the proposed correlation. Correlation of borehole sections 73-24 and 73-25 is based mainly upon coal seam C (Fig. 6) and the major sandstone located approximately 23 m (75 ft) below the seam. As with other paired boreholes in the composite section, the implied correlation is supported by similar gamma ray and resistivity log traces for the major coal and sandstone units. Adjacent wells drilled by Utah Mines Limited near borehole sections 73-24 and 73-25, but not included in this study, support the suggested correlation. Borehole sections 71-1 and 73-24 are correlated using coal seam C (Fig. 9) and the prominent sandstone immediately overlying the coal. Again, the gamma ray and resistivity trace over the coal and sandstone and in adjacent borehole section 72-14 support the correlation. The greatest difficulty in compiling the composite section occurred between borehole sections 71-1 and 72-17, the latter representing the deepest stratigraphic penetration in the Carbon Creek area. Examination of the lowest two boreholes in Figure 10 at first glance suggests no apparent lateral lithological or geophysical relationship. However, when considered in conjunction with borehole section 72-14 (Fig. 9) a reasonable correlation pattern emerges, based mainly upon the occurrence of coal seam B (Fig. 7), and a similar coal reflectance value of 1.28 between coal seams in the two boreholes. It can readily be seen that the lithofacies units below marker seam B differ markedly between the two borehole sections. However, if Figure 7, which includes borehole sections 72-14, 73-27 and 73-29 is closely examined, a more meaningful correlation can be made, which is not readily apparent in the two boreholes 71-1 and 72-17 of Figure 10. It is interesting to note that the two major seams, C and D of 71-1 (Fig. 7), have a widespread distribution in the area but do not extend into borehole section 72-17. It is this unusual lateral facies change or disappearance of the two major coal seams in borehole 72-17 which initially made correlation difficult, causing concern in arriving at a realistic Gething Formation thickness value in the Carbon Creek area. Figure 7 illustrates the lateral disappearance of seam C in borehole 72-17. Coal seam D of 71-1 (Fig. 7) unfortunately was not penetrated in borehole 72-17 during the drilling program, because the bedrock surface occurred at a stratigraphic level below that at which seam B would occur.

If the composite section compilation is correct as shown, and no major structural complications occur in the area (none have been detected in any core samples), then a cumulative thickness of at least 1036 m (3400 ft) is obtained for the Gething in the Carbon Creek coal basin. As discussed previously, the level of the upper contact with the Moosebar Formation of the Fort St. John Group is uncertain, although it is assumed to lie not far above the capping sandstone of borehole 72-13 (Fig. 10). The Gething Formation in the Carbon Creek coal basin is thus the thickest known occurrence of the formation in northeastern British Columbia and west-central Alberta.

COAL

Introduction

The coal of the Gething Formation has long been recognized and has been described and discussed by such workers as McLearn and Irish (1944), Mathews (1947), McLearn and Kindle (1950), and Stott (1968, 1972, 1973). Only Mathews (1947) provided any detailed information on seam quality, thickness, and distribution in the Carbon Creek area. He reported 14 seams in excess of 0.9 m (3 ft) thick from the Eleven Mile Creek area in the southern part of the basin (Fig. 2). The possibility that some of the seams represent structural repetitions was suggested. The coal rank was determined to be mainly medium volatile bituminous and not of sufficient quality to be of use in the manufacture of coke but was acceptable as steam coal for local use. Utah Mines Limited began an extensive exploration and drilling program in the Carbon Creek coal basin and adjacent areas in 1971 so that the distribution and quality could be accurately assessed. Much of this information is confidential, however, and cannot be documented in this report.

Proximate analyses of selected coal samples by Utah Mines and petrographic coal reflectance analyses by the Geological Survey of Canada indicate coal seam ranks ranging between high volatile bituminous A near the top of the formation and medium volatile bituminous near the base.[1] One analysis indicates a rank of semi-anthracite. This rank designation (shown in Fig. 3, 71-6), according to Cameron (pers. comm.), is anomalous and may indicate an error in analysis or transcription of data, or a coal of unusual composition (i.e. one high in maceral inertinites).

Seam Thickness and Correlation

The 1036 m (3400 ft) thick section of Gething strata in the Carbon Creek basin contains in excess of 100 coal seams, ranging in thickness from a few centimeters to 4.3 m (14 ft). Sixty-one of these seams are greater than 0.3 m (1 ft) thick, while ten range between 0.9 m (3 ft) and 4.3 m (14 ft) (Figs. 3-10). Stott (1973), in his surface investigations of the Gething Formation elsewhere in Alberta and British Columbia, reported that coal seams in the Gething Formation change markedly in thickness and quality within relatively short lateral distances. This characteristic is particularly evident in the Gething Formation of the Carbon Creek area, as shown by the stratigraphic columns in Figures 3 to 9. This lateral variability in thickness makes correlation of seams difficult, especially for those less than 0.6 m (2 ft) thick.[2]

The lower quarter of the Gething Formation is characterized by two major coal seams, C and D (Fig. 7), which can be traced throughout most of the northern part of the basin. The distribution of these marker seams in the southern part of the basin is unknown because drilling there did not penetrate to this level in the formation. Seam C ranges in thickness from a minimum of 1.5 m (5 ft, 73-29) to a maximum of 2.7 m (9 ft, 71-1), with an average of approximately 2.1 m (7 ft) in four boreholes used in this study. Figure 7 illustrates the variability in thickness and the correlation problems that can develop even when using major marker seams. It can be seen that seam C grades laterally in a distance of 0.8 km (0.5 miles) into a coaly, carbonaceous mudstone or shale (72-17). Seam D, the next overlying coal marker in the lower Gething Formation, ranges from 1.6 m (5.4 ft, 73-27) to 3.1 m (10.2 ft, 72-14) thick, and averages 2.4 m (8.0 ft).

Seam A of Figure 5 and seam H of Figure 6 are correlative and represent the next overlying, regionally distinctive marker seam. It has been penetrated by many boreholes throughout the Carbon Creek basin. However, as can be seen in Figure 5, there are 15 less distinct but correlatable seams between seam H (Fig. 6) and seam D of Figure 7. The majority of these seams do not exceed 0.6 m (2 ft) thick, and those that are thicker do not maintain any lateral thickness continuity between the illustrated boreholes. Seam A-H (Figs. 5, 6) ranges in thickness in the boreholes examined by the writer from a minimum of 0.6 m (2.0 ft) in borehole 71-2 (Fig. 2) to a maximum of 2.4 m (7.8 ft) in borehole 73-25 (Fig. 6). Seam A-H averages 1.5 m

[1] The ranks illustrated in Figures 3 to 9 are a mixture of directly determined reflectances and those calculated from proximate analyses using curves of Kötter (1960) and McCartney and Teichmüller (1972).

[2] Note that correlations in Figures 3 to 9 are shown by joining lines, the seams in each figure are lettered upward beginning with A, and similarity of letters from figure to figure does not imply correlation of coal seams.

(5.0 ft) thick. Seam B in Figures 3, 4 and 5 is the next overlying major, and economically important, coal marker. It has been penetrated in most boreholes of the central and southern part of the Carbon Creek basin. It is interesting to note that very few seams of significant thickness occur between seam A-H (Figs. 5, 6) and seam B (Figs. 3, 4, 5). Seam B ranges in thickness from 0.7 m (2.4 ft) in borehole 72-18 (Fig. 3), to 2.1 m (6.9 ft) in borehole 71-5 (Fig. 3), and averages 1.5 m (5.0 ft).

Seam D (Figs. 3, 4) and correlative seam G of Figure 5 were penetrated by most boreholes in the southern part of the basin. Between seam B (Figs. 3, 4, 5) and the next major overlying marker seam D (Figs. 3, 4) and G (Fig. 5) are five correlatable coal seams ranging from less than 0.3 m (1 ft) to 1.2 m (4.1 ft) in thickness. The coal ranges in thickness from 0.5 m (1.7 ft) in borehole 72-11 (Fig. 5), to 2.1 m (7.0 ft) in borehole 71-4 (Fig. 4), and averages 1.2 m (4.0 ft).

Twelve to fifteen metres (40-50 ft) above seam D is seam E (Fig. 4), which is another distinctive coal marker in the southern part of the Carbon Creek basin, attaining a maximum thickness of 2 m (6.8 ft) in borehole 71-2 (Fig. 2). Seams F through G and the unlettered seam between them in Figure 4, and the upper three unlettered, thick seams of borehole 71-11 (Fig. 5), represent the next major coal seam interval in the upper Gething Formation. The seams range in thickness from a minimum of 0.3 m (1.1 ft) in borehole 72-16 (Fig. 4), to a maximum of 3.6 m (11.7 ft) in borehole 71-8 (Fig. 4), while averaging 1.5 m (5.0 ft). Overlying seam G (Fig. 4) is an unusually thick, relatively coal-free interval of sandstone and sandy conglomerate, ranging in thickness from approximately 33 to 58 m (110-190 ft). This lithofacies interval serves as a distinctive marker unit in the upper Gething Formation of the area.

Overlying the sandstone-conglomerate is the last of the major marker seams. Because the wells were spudded below the upper 76 to 91 m (250-300 ft) of the Gething, information as to the marker seam distribution and thickness in this part of the section is limited to the area between Nine and Ten Mile creeks (Fig. 2). Three, and locally four, good marker seams occur within this stratigraphic interval. They are illustrated in Figure 4 as seams H, I and J, and the thick unlettered seam at the top of borehole sections 71-4 and 71-8. The seams range in thickness from 0.4 m (1.3 ft) to 2.6 m (8.6 ft) in borehole 71-8. The average thickness of these seams in the four boreholes examined for this study (which includes 72-13, Fig. 10) is 1.2 m (4.0 ft).

Coal Reflectance

Hacquebard and Donaldson (1974) used coal samples from the Crowsnest Pass area of southwestern Alberta and southeastern British Columbia and from the Peace River canyon area of northeastern British Columbia to demonstrate that the rank of coal seams in the Foothills and Rocky Mountains increases with stratigraphic depth. It was shown that the increase in rank was mainly a function of depth of burial and not related to geologic age, depth of mining, or degree of tectonism. In addition, they demonstrated that some major seams could be correlated from area to area using reflectance values from the coal maceral vitrinite. Graham et al. (1977) demonstrated a similar relationship between rank and depth using reflectance values from coals of the Kootenay Formation in the upper Elk River valley of southeastern British Columbia. Such consistency in coal rank led the writer to anticipate that reflectance values would be useful in correlating coal seams of the Gething Formation, and that a vertical reflectance trend could be established that would assist in placing boreholes and their contained seams into their proper stratigraphic position in the formation.

Mean maximum reflectance values (R_o), obtained by measurement from a few core samples and by calculation from proximate analyses, have been plotted along the right and left margins respectively of their respective stratigraphic columns in Figures 3 to 9. Correlation of seams by means of measured reflectance values, even where boreholes are closely spaced, does not appear to be practical, as can be seen from an examination of values in Figure 7. However, with additional sample analyses and data, correlation of seams may be possible.

An increase in reflectance values (R_o) with depth is apparent in boreholes 72-14 and 72-17 (Fig. 7). A similar down hole increase is apparent in borehole 72-15 (Fig. 4). However, systematic increase in reflectance values with depth does not always occur in the Carbon Creek area, for example, in borehole 71-3 (Fig. 6), although higher values do occur in the lower third of the borehole. The reasons for the apparently erratic nature of coal reflectance values in this area is unknown. Further study and additional values from coals in adjacent wells are needed to resolve the problem.

Proximate analysis data were provided by Utah Mines for many of the major coal seams in the report area. These data were corrected to the dry, mineral matter-free basis using the standard A.S.T.M. formula (A.S.T.M., 1973). Reflectance values for the coals were then obtained using volatile matter-reflectance curves from Kötter (1960) and McCartney and Teichmüller (1972). This was done to determine what, if any, difference there may be between calculated reflectance values and those measured directly on vitrinite. It was hoped that a relationship between the two methods of reflectance determination could be established in the area, and that with the additional data a meaningful correlation of coal seams could be established. It can readily be seen that in most observations no comparable lateral or systematic vertical relationship exists between or within the boreholes in the area. As with values calculated from vitrinite measurements, a general trend can be seen in reflectance values from top to bottom in some boreholes, with the lower reflectance values found in general at the top and the higher values near the base. Many exceptions are apparent. It is recognized that reflectance values calculated from proximate analyses are generally less accurate than those obtained from direct measurements on vitrinite, but it was not anticipated that differences of the magnitude shown in Figures 3 to 9 would exist.

According to A.R. Cameron (pers. comm.), a major reason for differences is that while reflectance measurements done directly on the coal are restricted to the group maceral vitrinite, proximate analysis data are determined on the whole coal, and reflectance values calculated from such proximate results will tend to be distorted by differences in the contents of the other maceral groups, such as exinite and inertinite, which differ chemically from vitrinite. In addition, another important factor which may account for some of the differences between the two coal reflectance determination techniques is the type and content of mineral matter in the coal samples being analysed. For example, coals with a relatively high concentration of carbonate minerals will give distorted volatile matter concentrations which in turn will distort the calculated reflectance values. It is apparent that the relationship between chemical data and reflectance values for these coals needs to be explored further. Additional data and a more comprehensive analysis and discussion of this problem will be presented at a later date.

DEPOSITIONAL ENVIRONMENTS

Stott (1968, 1973), in his regional surface studies of the Bullhead Group in west-central Alberta and northeastern British Columbia, described three major depositional environments for strata of the Gething Formation: between Pine and Smoky Rivers, a continental alluvial plain; in the vicinity of and including Peace River, a fluvial-deltaic environment; and northward between Peace and Tetsa rivers, a deltaic-marine environment. The following discussion of depositional environments in the Carbon Creek basin provides additional sedimentological data in support of some of the environmental interpretations by Stott (*op. cit.*). The interpretations presented here are based upon lithologic facies, facies relationships, sedimentary structures, megafossil collections, and proximate coal analyses. The data, however, were obtained from a restricted region, and the following discussion is presented as a preliminary account only.

The Gething Formation of the Carbon Creek basin comprises a thick clastic wedge of predominantly deltaic strata deposited during the initial phase of a narrow, southerly transgressing, boreal sea (Stott, 1973). The seaway, during Gething time, paralleled the present northwest-southeast structural trend of the Rocky Mountains and was connected in the north to a major sea in the area occupied by the present Arctic Ocean. The northern connection is indicated by the occurrence of *Aucellina aptiensis* and *A. caucasica*, which were collected from upper Gething strata in boreholes 71-8 and 72-11 (Fig. 2). This fauna has a restricted distribution and is found only in time equivalent rocks in northern or Arctic Canada and northeastern Siberia (Jeletzky, pers. comm.). According to Stott (1973), the transgression of this boreal sea extended southward as far as Cadomin, Alberta, approximately 440 km (275 miles) southeast of Carbon Creek.

The analysis of sedimentary facies and structures, megafossils, and sulphur concentration (from coal and not pyritiferous shale) suggests that the strata of the Gething Formation may have been deposited in two deltaic environments. The upper half of the formation, approximately 579 m (1900 ft), displays sedimentary characteristics typical of a lower deltaic plain, whereas the lower half, approximately 457 m (1500 ft), has the characteristics of an upper deltaic plain environment. Stott (1973) recognized a similar two-fold division in the Gething Formation in surface exposures in the vicinity of Peace River canyon, to the east. His division is not specifically assigned to any particular stratigraphic level in the formation, and, furthermore, the division is based on different sedimentological criteria than those used by the writer. No conclusive evidence has yet been uncovered in core samples from the Carbon Creek area to suggest the presence of any extensive or major units of strata typical of exclusively open marine or nonmarine depositional environments.

Upper Deltaic Plain

The upper deltaic plain environment includes subenvironments that are similar in character to those of an alluvial plain, except that the delta plain may contain indigenous freshwater faunas and floras, and is generally characterized by finer grained sediments (Bernard et al., 1973). The upper limit of the upper deltaic plain is the junction with the terminus of the alluvial valley; the lower limit is commonly defined by a line marking the first occurrence of a brackish to marine flora and fauna or marine sedimentary facies.

Strata of the basal Gething Formation were deposited on fluvial-alluvial fan strata of the Cadomin Formation (Stott, 1973; McLean, 1976, 1977) during an early pulse of the transgressing boreal sea. Evidence for this transgression is known in the Peace River canyon area, where Chamney (in Stott, 1973) identified brackish to marine foraminifera from the lower Gething Formation. The first transgressive pulse, however, may not have reached the Carbon Creek area, where to date no evidence of a marine to brackish water fauna in the lower Gething has been obtained.

Coal as a lithotype is of use in the recognition of certain deltaic and alluvial plain depositional environments (Riegel, 1977; Collins, 1977; Weimer, 1977; and Horne and Ferm, 1976). For example, coal containing low sulphur concentrations is generally considered to have been formed from peat deposited under the influence of nonmarine to marginally brackish water conditions in alluvial and upper deltaic plains. Conversely, coals of the lower deltaic plain are higher in sulphur because of marine or brackish water contamination.

In order to test the usefulness and significance of coal seam sulphur concentration as a possible environmental indicator, sulphur values from proximate coal analyses were examined for many major seams in the 34 boreholes used in the present study. The sulphur concentration values ranged from a low of 0.32 per cent to a high of 7.20 per cent. Examination of the values when plotted against their respective stratigraphic positions, indicate a conspicuous trend at a stratigraphic level approximately 457 m (1500 ft) above the base of the formation. The level is indicated in borehole 73-25 (Fig. 10), 99 m (325 ft) above the base of the hole. The coal seam at this level possesses a sulphur concentration of 1.38 per cent. Below this stratigraphic level, sulphur values rarely exceed 1.25 per cent, and, in most analyses, never exceed 1.0 per cent (Fig. 10). Seams above the 99 m (325 ft) level of borehole 73-25 display varying sulphur concentrations, with most lower than 1.0 per cent, but many in excess of 1.38 per cent. The sulphur concentration (not illustrated) from all major seams in Figure 7 indicates, without exception, values equal to or less than 1.0 per cent. Marine or brackish water megafossils or microfossils have not as yet been identified from the lower Gething Formation in the Carbon Creek area. Pelecypods have been collected from core samples, but for all collections Jeletzky reports them to be characteristic of nonmarine environments. If one accepts a value of 1.25 or 1.30 per cent sulphur in the Gething coal as a reference or marker value for subdividing nonmarine from marine to brackish water coals, then the 99 m (325 ft) level noted in Figure 10 of well 73-24 is an appropriate level at which to draw a reference boundary between lower and upper deltaic plain depositional environments. Additional coal and microfossil analyses from the Carbon Creek area are necessary to more accurately support or disprove this postulated depositional boundary.

Many depositional subenvironments within the upper deltaic plain may be proposed. For example, the thick, light grey, medium- to very fine-grained sandstone near the base of borehole 73-25 (Figs. 6, 10) may be interpreted to represent a major distributary channel. A prominent scour surface truncating the underlying strata lies at the base of this sandstone, which is characterized by medium- to small-scale festoon crossbedding (Pl. 1), and also displays fining-upward graded bedding. The sandstone can be traced laterally into boreholes 71-3 and 73-24, and grades westerly into carbonaceous mudstone and siltstone (Fig. 6). In borehole 71-3 (Fig. 6), the sandstone contains angular clasts of mudstone-siltstone (Pl. 2C), and distinctive bands of climbing ripples are evident near the top (Pl. 4). Such sedimentary structures, when found capping, or in association with major sandstone bodies, are commonly considered to represent fluvial point bar sequences (Coleman and Gagliano, 1965), a feature of upper deltaic plain-fluvial depositional environments.

Overlying many of the thicker sandstones are thin units of interbedded mudstone and siltstone which are interpreted as subaerial levees formed during a flood stage. Another typical upper deltaic distributary channel sandstone is that adjacent to the top of borehole 73-24 (Fig. 6). The lower part contains small- to medium-scale, planar crossbedding and lenses of pebble conglomerate, overlain by climbing ripple laminations, followed in turn by a thin unit of silty sandstone with well developed, contorted laminations (Pl. 6). Capping this sandstone, however, is a unit of mudstone with abundant plant debris and small ferruginous nodules, representing a probable flood basin swamp-lacustrine environment. The thinner, laterally discontinuous sandstones illustrated in the cross-sections of Figures 3, 4 and 10, represent probable crevasse splays, deposited in the flood basin environment. These splay sandstones are characterized by ripple and ripple drift laminations (Pls. 3C, 4), and contorted laminations, and are commonly associated with thin to thick seams of coal or very carbonaceous to coaly mudstone, of the swamp or marsh environment. Associated and interbedded with the crevasse splay facies are thin to thick units of alternating sandstone, siltstone and mudstone, commonly capped by thick to thin seams of coal. This facies combination represents an upper deltaic flood basin, which includes the deposits of freshwater swamps, marshes, and lakes, and occurs adjacent to the major distributary channel deposits. Strata of this subenvironment are characterized by an abundance of ripple drift and very fine ripple laminations, lenticular and wavy bedding (Pls. 3C, 4, 5), contorted laminations (Pl. 6), and a few large and small burrows. The occurrence of lenticular and wavy bedding suggests that the freshwater lake area of the flood basin was subjected to periods of strong current, wave, and/or flood activity, alternating with periods of quiescence when the suspended muds, silts, and fine grained sands were deposited. Similar sedimentary alternations may also be found in the upper Gething strata of the lower deltaic plain environment. The thick, silt- and sand-free carbonaceous mudstones probably represent lacustrine deposits, whereas those with high concentrations of plant and woody material were formed in freshwater swamps and marshes. As noted previously, coal seams may be used in conjunction with other evidence to indicate paleoenvironments. For example, in the upper deltaic plain-alluvial plain environment, seams are mainly thin, but locally thick, and tend to be discontinuous and difficult to correlate from area to area. The two major seams, C and D, shown in Figure 7, are exceptional in being traceable throughout much of the northern area. It must be emphasized, however, that the area under discussion in this report is relatively small, and it may be that these seams are not recognizable beyond the Carbon Creek basin, e.g. Peace River canyon. The coal seams illustrated in Figures 6 and 7, typical of the upper deltaic plain are numerous and thin in comparison to those found in the lower deltaic plain characteristic of the upper half of the Gething Formation. The paucity of seams in the lower part of borehole 72-17, near the Cadomin Formation contact, may be interpreted to be a result of deposition in an alluvial plain depositional environment. A similar scarcity of seams has been described by Gibson (1977) for strata of the Elk Member of the Kootenay Formation of southwestern Alberta and southeastern British Columbia.

Lower Deltaic Plain

The lower deltaic plain (Bernard et al., 1973), as defined for this report, consists of that part of the deltaic plain periodically subjected to marine or brackish water inundations because of proximity to the open sea. Strata of the lower deltaic plain consist of lithofacies similar to those of the upper deltaic plain, but generally are finer grained, and usually contain brackish water to marine faunas. As noted previously, a stratigraphic level was discovered in the Gething Formation, below which coal sulphur concentration values rarely exceeded 1.0 per cent. This level (1.38%) is indicated in borehole 73-25 (Fig. 10). The concentration of sulphur in major coal seams above this stratigraphic level varies considerably between a low of 0.5 per cent to a high of 7.2 per cent. No consistent concentration trend was detected in the upper Gething Formation. The variable sulphur concentrations in coal seams of the upper Gething Formation therefore suggest that coal-forming peats were deposited under freshwater, brackish and probable marine conditions, all of which are found in a lower deltaic plain environment.

In addition to the sulphur concentration, the thickness, distribution and lateral continuity of coal seams in the upper Gething Formation also suggest deposition in a lower deltaic plain, possibly in floodplain levee, swamp and marsh, interdistributary bay, and/or abandoned distributary channel subenvironments. Most coal in the upper Gething probably formed in large flood basin swamps and marshes, environments which presumably bordered the major distributary channels in the area. Near the distributary mouths, these swamps and marshes could be expected to be of wide areal extent, ultimately, in some areas, merging with the interdistributary bay and connecting with the brackish or brackish marine environment. Coals typical of this environment are those illustrated in the cross-sections of Figures 3 and 4, and are associated with the numerous intervals of mudstone and siltstone.

The major seams of the southern part of the basin can readily be correlated and are thin and variable in thickness: typical thicknesses are 0.9 to 1.2 m (3-4 ft), but over short lateral distances the seams may thin to less than 0.3 m (1 ft) or disappear. Rapid shifting of distributary channels and associated subenvironments in the lower deltaic plain would account for the general lack of thick coal deposits. During the lateral shifting and abandonment of these channels, and during subsequent flooding, some of the channels may have been filled with fine grained sand, silt, mud, and ultimately thin deposits of peat. One possible example of a channel-fill coal seam is that in borehole 72-16 (Fig. 4), where the small channel sandstone 12 m (40 ft) above the base is overlain by a thin unit of siltstone and mudstone capped by a thin seam of coal.

Most megafossil collections from the upper Gething Formation were identified by Jeletzky as being mainly of nonmarine to possible brackish water origin. However, two important collections, recovered from boreholes 71-8 and 72-11 (Fig. 2), included the marine pelecypods *Aucellina caucasica* and *A. aptiensis*. The occurrence of this fauna provides the best evidence for marine inundations in the Carbon Creek area. It is interesting to note that the major coal seams immediately underlying the fossil collections contain high sulphur values (4.1 and 3.6 per cent).

Sedimentary features of the upper Gething Formation, illustrated in Figures 3, 4 and 10, are typical of those found in modern lower deltaic plain environments. The most conspicuous facies, other than coal, are the major distributary channel sandstones. They are commonly thick, display graded bedding and become finer grained toward the top. They contain well developed fine- to medium-scale festoon and planar crossbedding near the base, followed by ripple and ripple drift laminations toward the top (Pls. 3, 4). The bases of the sandstone units are erosional. Well rounded pebbles and angular lithoclasts may occur, as in the thick sandstone near the base of borehole 71-4 (Fig. 4). The angular clasts, lenses, and beds of conglomerate represent the deepest part of the distributary channel. Large coal spars are common in the lower few metres of some sandstones. These major channel sandstones grade laterally into siltstones and mudstones, and locally into thin to thick seams of coal. Burrows, although present, are not common. A good example of a distributary channel is the thick sandstone shown between seams B and C in Figure 3.

The prominent, thick sandstone and conglomerate unit characteristic of the upper Gething Formation between seams G and H (Fig. 4) may represent the main distributary of the Gething delta. However, immediately below and above this sandstone are coal seams containing relatively high concentrations of sulphur. This would suggest that the sandstone was deposited adjacent to, or in contact with, a marine to brackish depositional environment, probably close to sea level or near the mouth of the distributary channel. The occurrence of lenses and thin to thick beds of chert-pebble conglomerate, with occasional well rounded pebbles up to 4 cm (2 in) in diameter, is difficult to explain in a distributary channel of the lower deltaic plain and near the channel mouth. Coarse grained sediments of this grade are not customarily found in this subenvironment so close to sea level. An alternative explanation may be that the sandstone-conglomerate represents a possible beach facies. For example, crossbedding is present but not common, as is evident in boreholes 71-8 and 72-16 (Fig. 4). Shallow dipping crossbedding, a structure common in recent beach lithofacies, could be present but was not detected in the boreholes. Climbing ripples are rare, with the exception of the upper few metres in boreholes 71-4 and 72-16 (Fig. 4). Burrowing is rare, although some burrow traces up to 2.5 cm (1 in) in diameter were noted. If the sandstone is characteristic of a beach then it has developed on a mudstone of an interdistributary bay, perhaps as part of the transgression during a momentary stillstand of the sea. The sandstone was then later onlapped by more mudstone and siltstone of the interdistributary bay or flood basin environment. Since the lateral extent of the massive sandstone is not known in the area, one cannot substantiate either environmental interpretation.

Certain fine- to coarse-grained sandstone lithofacies associated with the mudstone and siltstone units may represent small distributary mouth bars. These sandstones grade laterally into, and interfinger with, mudstones and siltstones. Small- to medium-scale festoon crossbedding may be common as well as climbing ripple laminations. Contorted laminations and burrow structures may be found along the flanks of these bar facies. The sandstones are characterized by gradational lower contacts in contrast to the erosional contacts found at the base of major distributary channels. Similar features have been described by Horne and Ferm (1976) for Carboniferous sandstones of eastern Kentucky and southern West Virginia.

Interdistributary bay and flood basin environments are represented by the association of mudstone, siltstone, and very fine grained, interbedded sandstone (see Figs. 3, 4, and boreholes 71-4, 72-13, 73-31 in Fig. 10).

In the Carbon Creek area, the interdistributary bay strata of the upper Gething Formation consist mainly of thin to thick units of mudstone, grading vertically into thin units of siltstone and, locally, very fine grained sandstone. Mudstone and siltstone with marine and possible brackish water pelecypods, and associated with high sulphur coal, represent deposition in interdistributary bays with open channels or tidal inlets to the sea. The mudstone-siltstone is dark grey, very carbonaceous and argillaceous, and commonly contains abundant, large and small burrows and subaqueously formed syneresis cracks (Pls. 8, 9). Thin, lenticular to wavy, very fine grained sandstone, coarse siltstone, and thick sandstone laminations (Pls. 6C, D), are typically present and represent quiet water environments that were periodically subjected to wave or current activity. The sedimentary structures and lithofacies relationships just described are similar to those described earlier for the flood basin lacustrine subenvironment of the upper deltaic plain environment, in which, however, burrowing is conspicuously less abundant. It can be seen in Figures 3, 4 and 10, that the finer grained lithofacies of the interdistributary bay contains thin units of siltstone and sandstone, characterized by ripple, ripple drift, and contorted laminations (Pls. 3, 4, 6). These coarser grained units represent probable crevasse splay deposits.

Flood basin deposits display similar sedimentary facies, facies relationships, and sedimentary structures to those of the interdistributary bay sediments. It is in the flood basin swamp, marsh, and fresh to brackish water lakes that the major accumulations of peat occur, eventually resulting in some of the thick, laterally discontinuous coal seams. The main distinguishing features of the flood basin sediments are the absence of a marine and brackish water flora and fauna, and the associated relatively low sulphur coal.

The Gething is overlain by a thick succession of marine mudstone and shale of the Moosebar Formation, which represents the final, totally marine conditions resulting from transgression in the Carbon Creek area.

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PLATES 1 - 9

Illustrations of lithology and sedimentary and biogenic structures

PLATE 1

Medium grained, crossbedded, channel sandstone erosionally truncating finer grained sandstone, siltstone and mudstone. Note well developed lenticular (ripple) and flaser bedding and burrowing in finer grained facies. ISPG Photo No. 1016-37.

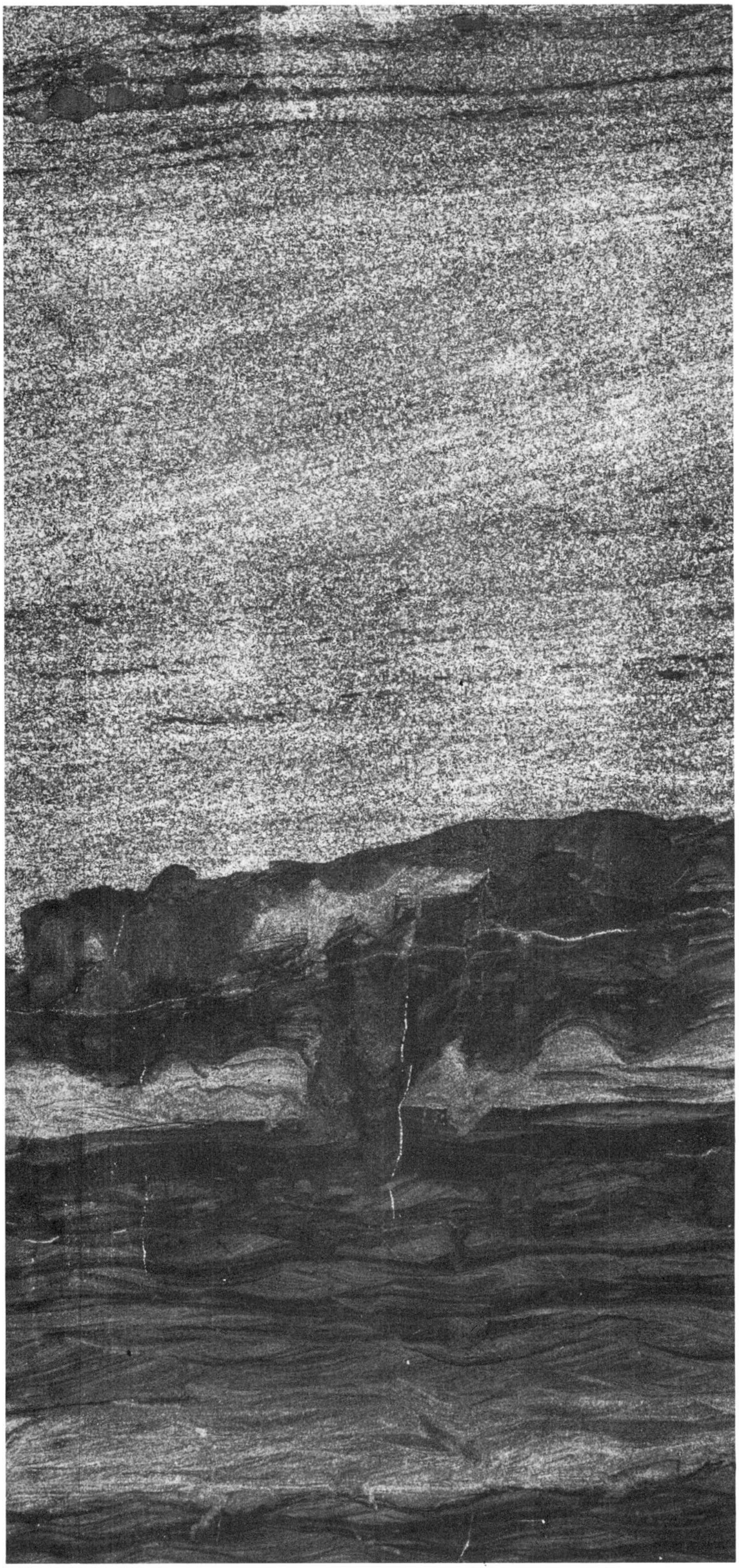

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PLATE 2

A. Conglomeratic sandstone with well rounded pebbles of light and dark grey chert, quartzite and silicified mudstone. Note distorted carbonaceous lamination near base. ISPG Photo No. 1016-6.

B. Conglomeratic, coarse grained sandstone with well rounded pebbles and granules of chert, quartzite, and mudstone. Note small-scale crossbedding. ISPG Photo No. 1016-9.

C. Intraformational conglomerate with angular clasts of carbonaceous siltstone in medium- to coarse-grained sandstone. ISPG Photo No. 1016-4.

D. Fine- to medium-grained sandstone with well rounded "floating" pebbles of light and dark grey chert, and silicified mudstone. Note fine, black, carbonaceous laminations, small-scale crossbedding and stylolitic contacts. ISPG Photo No. 1016-20.

E. Alternating fine- to coarse-grained sandstone with well developed, ripple laminations. Note thin, black, wavy, carbonaceous laminations. ISPG Photo No. 1016-7.

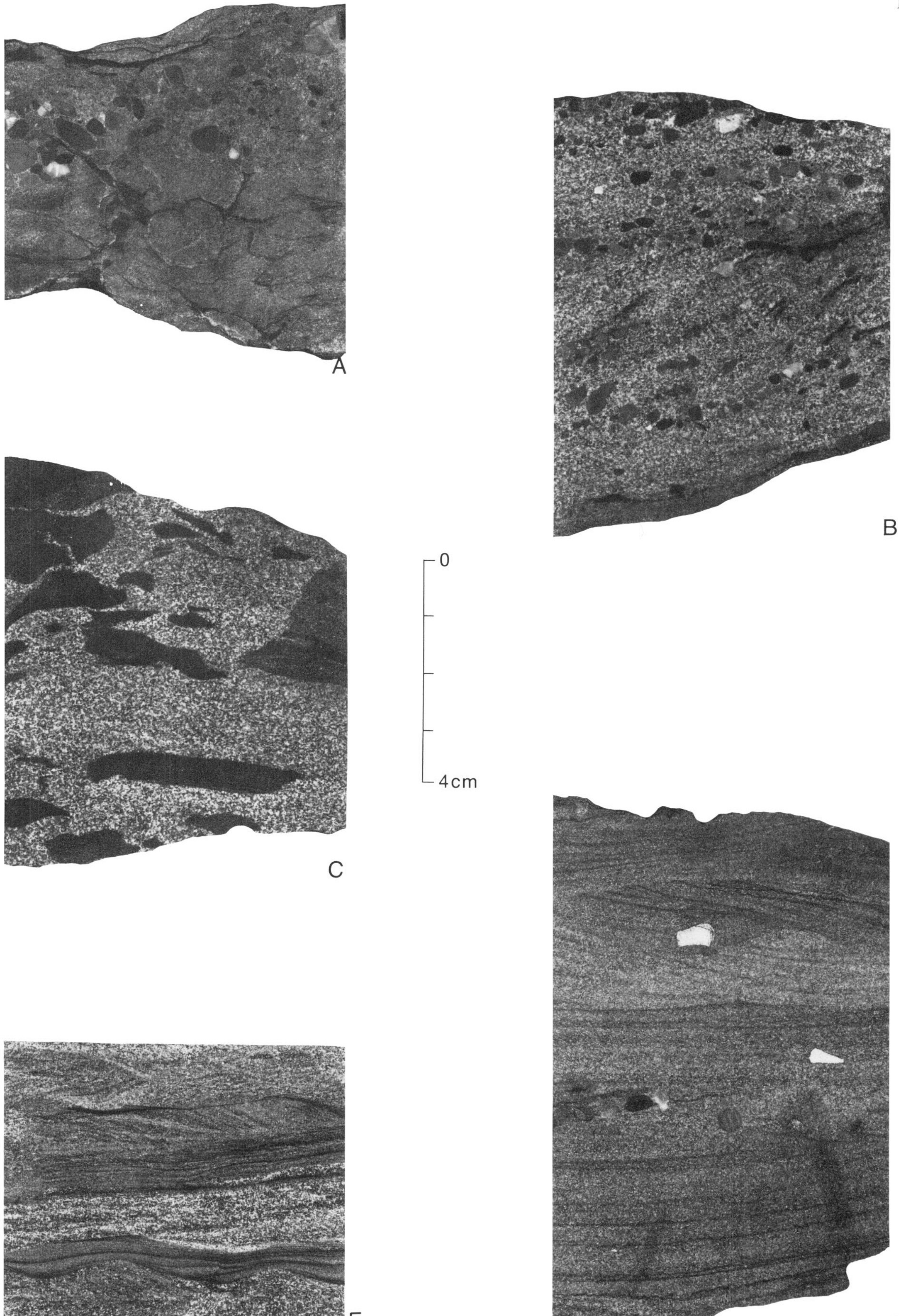
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PLATE 3

A. Small- to medium-scale, festoon, crossbedding. ISPG Photo No. 1016-24.

B. Intraformational, conglomeratic sandstone and fine grained, laminated sandstone; note ripple drift laminations and erosional contact between lithofacies. ISPG Photo No. 1016-36.

C. Well developed ripple laminations in fine grained sandstone. Note poorly developed flaser bedding. ISPG Photo No. 1016-38.

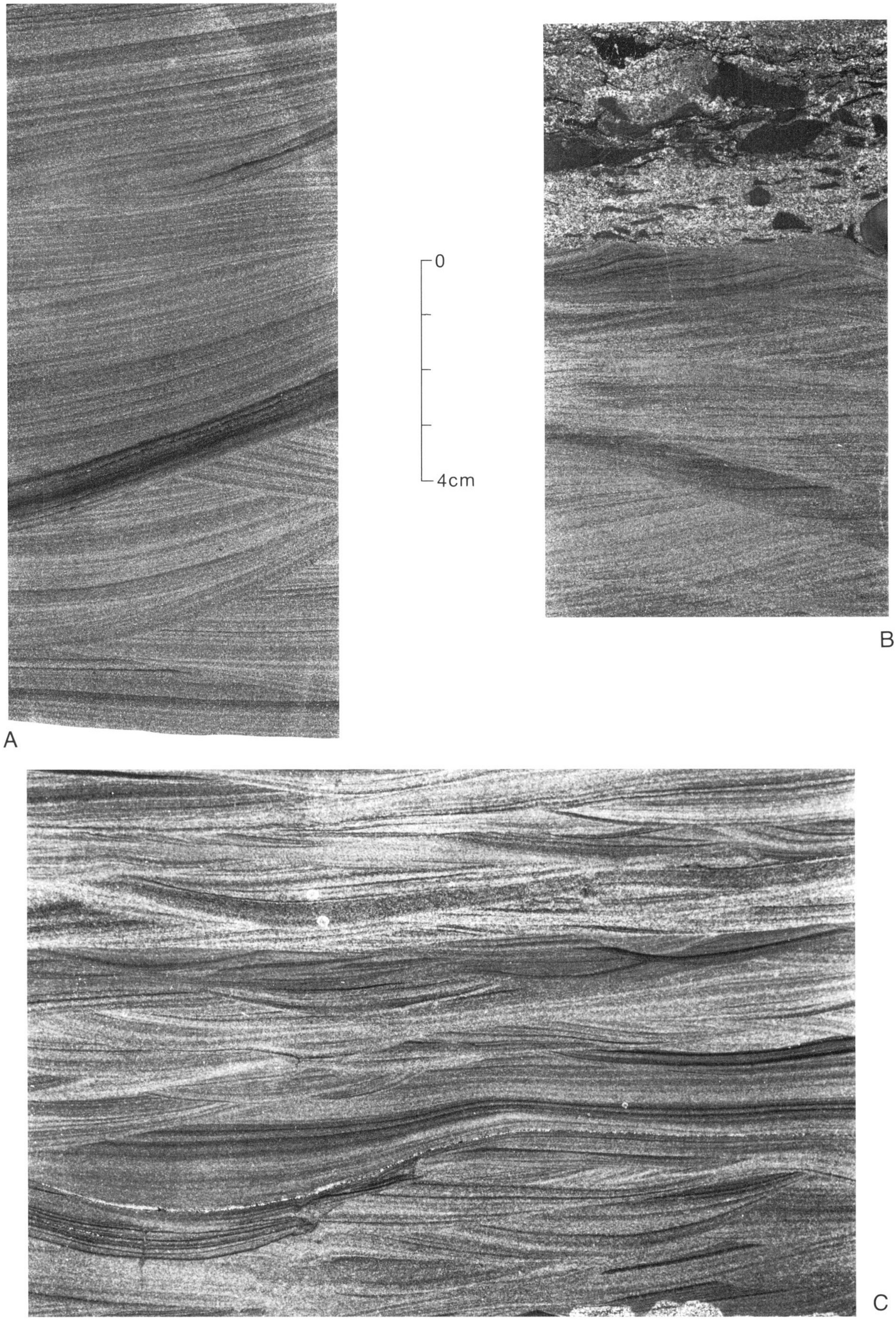
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PLATE 4

A. Well developed, climbing ripple (ripple drift) laminations in medium- to very fine-grained sandstone. Note well developed, graded bedding and large burrow structure. ISPG Photo No. 1016-40.

B. Climbing ripple laminations with small burrows near top. ISPG Photo No. 1016-41.

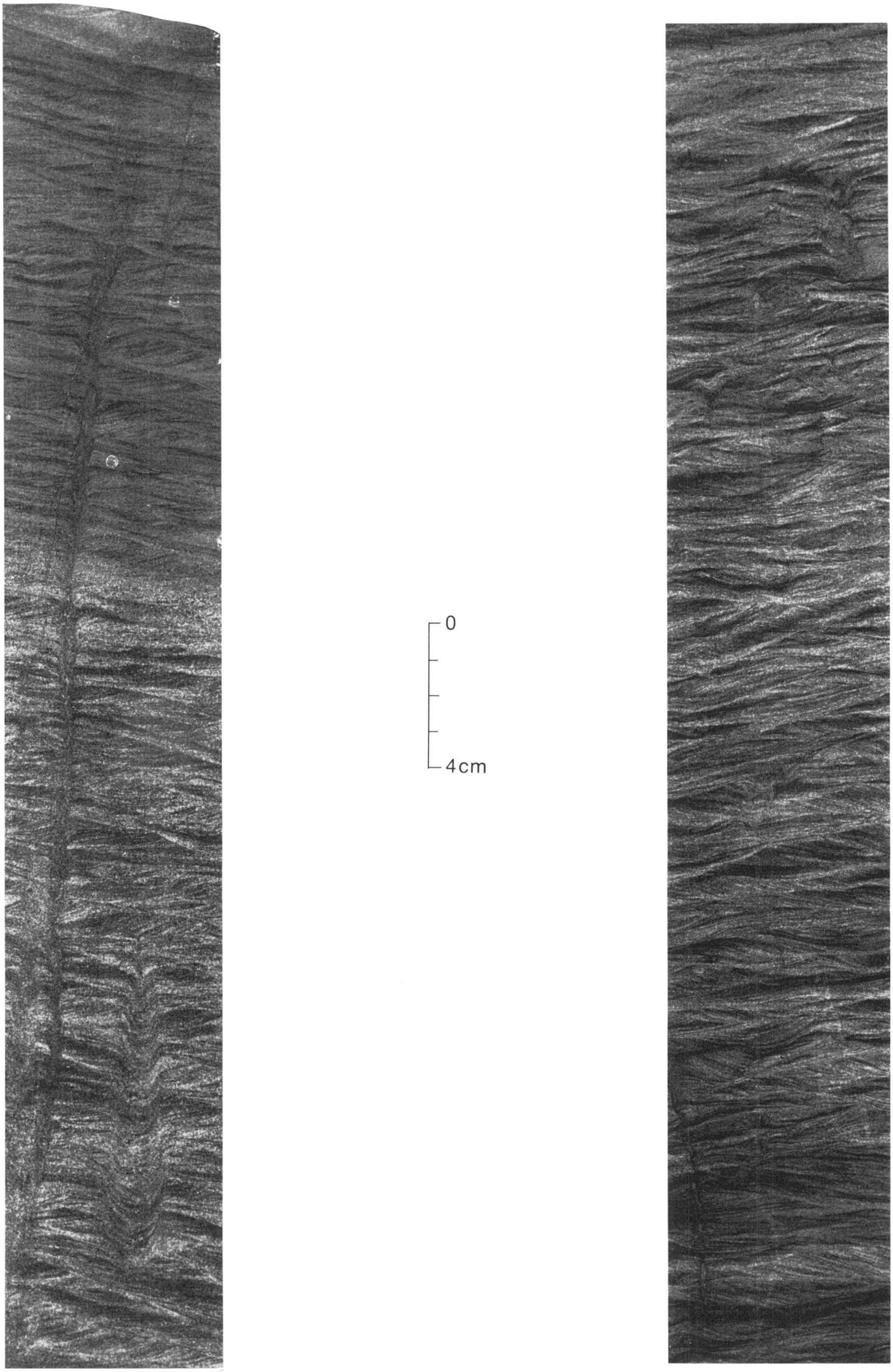

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PLATE 5

A. Well developed, lenticular bedding with isolated lenses (ripples) of very fine- to fine-grained sandstone. Note small burrow structure. ISPG Photo No. 1016-39.

B. Wavy to lenticular laminations in alternating succession of sandstone, siltstone and mudstone. ISPG Photo No. 1016-5.

C. Regular, wavy, and lenticular laminations and bedding in alternating succession of fine-grained sandstone and siltstone. Note small- to micro-scale crossbedding. ISPG Photo No. 1016-15.

D. Alternating sandstone, siltstone and minor mudstone laminations and thin beds. Note dark grey, carbonaceous laminations and small, sand-filled burrows. ISPG Photo No. 1016-14.

E. Alternating sandstone and siltstone laminations; lenticular and wavy bedding and ripple laminations are evident in thin beds. ISPG Photo No. 1016-10.

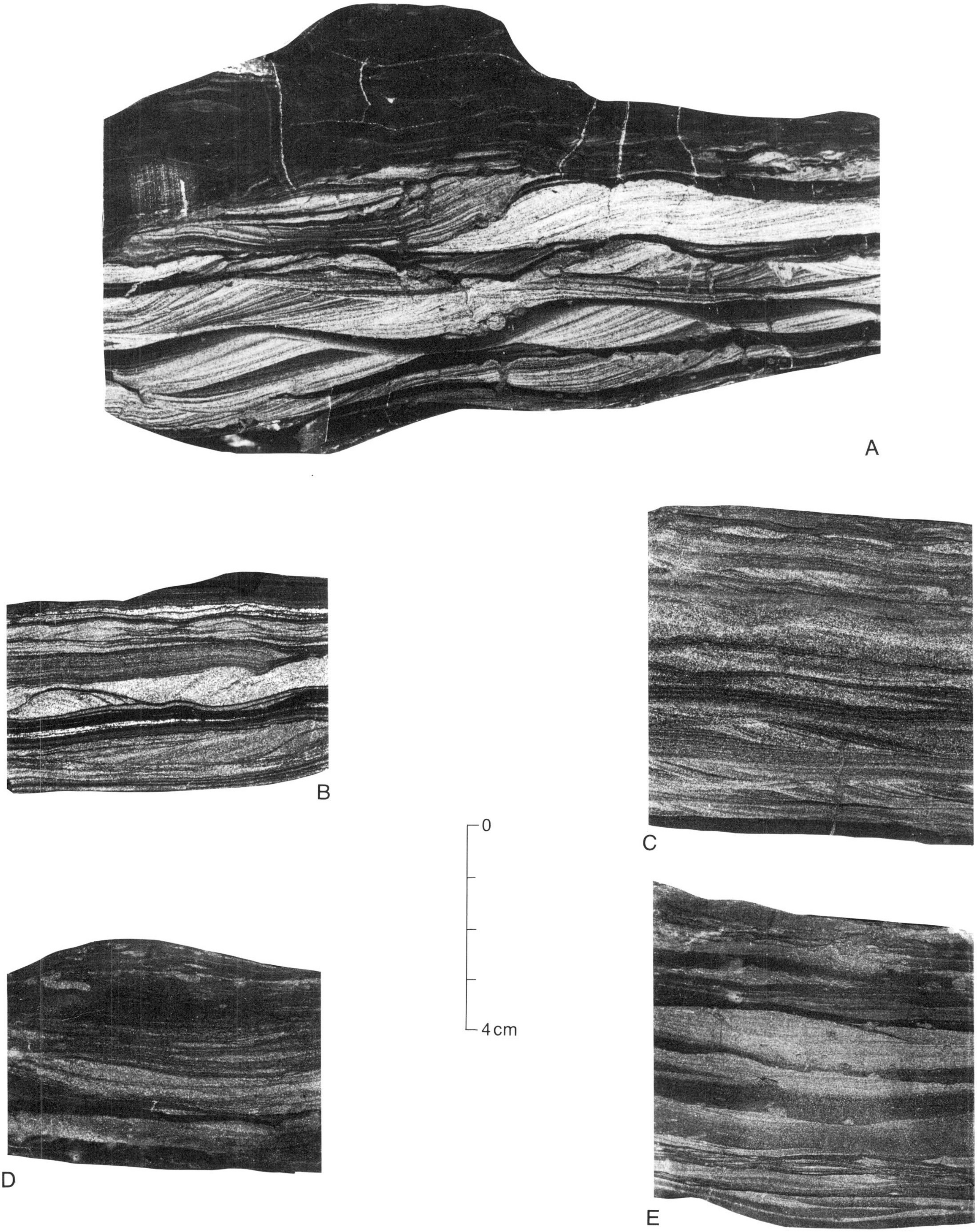
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PLATE 6

A. Contorted laminations in very fine- to fine-grained sandstone. ISPG Photo No. 1016-26.

B. Contorted laminations in fine- to very fine-grained sandstone. Note well developed ripple laminations at base. ISPG Photo No. 1016-23.

C. Lenticular bedding in sandy to silty mudstone with well developed, contorted laminations near base. ISPG Photo No. 1016-2.

D. Wavy to lenticular bedding and laminations in fine- to very fine-grained sandstone, convolute or contorted laminations at base. ISPG Photo No. 1016-16.

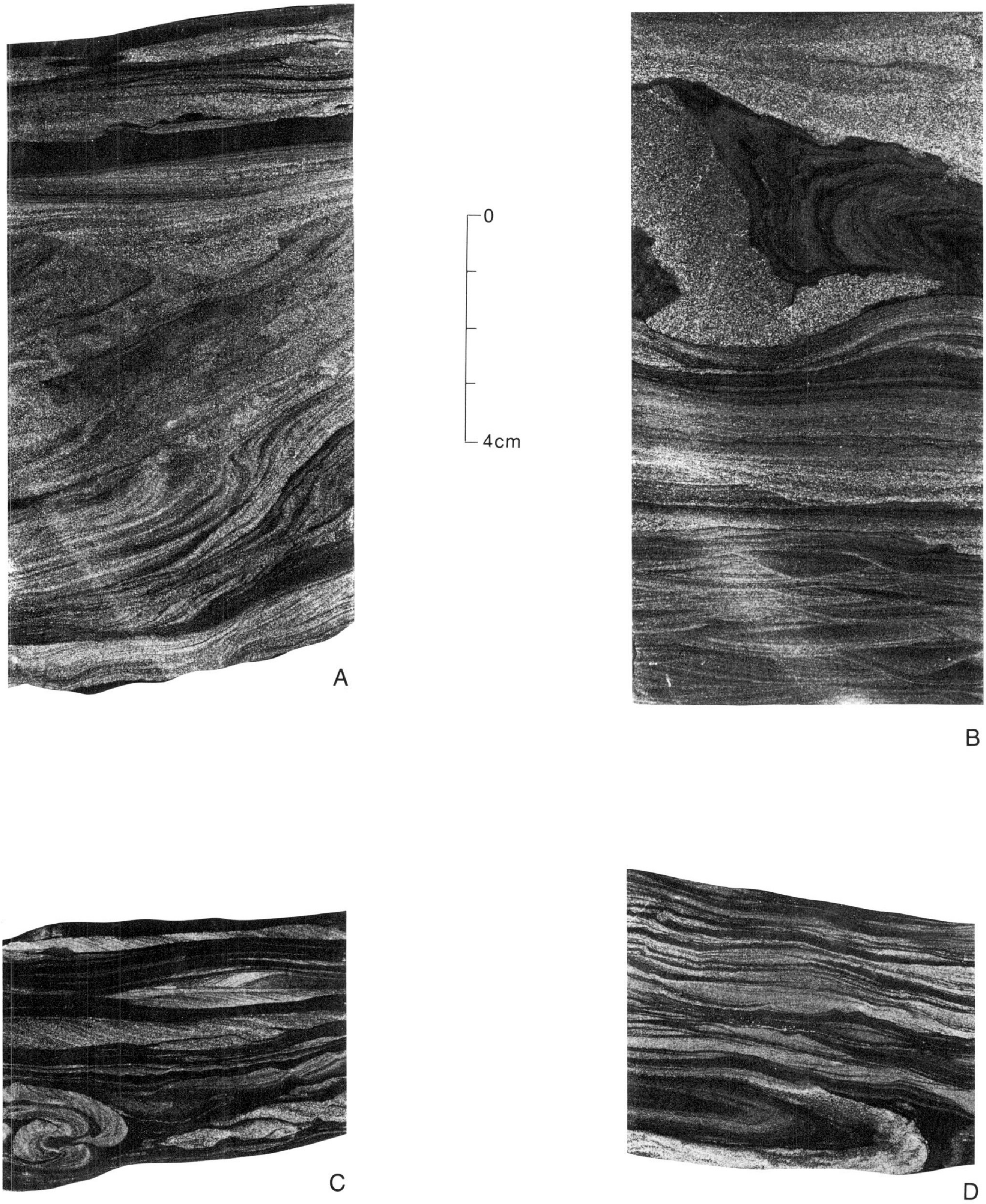
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PLATE 7

A. Well developed ripple laminations in fine-grained sandstone. ISPG Photo No. 1016-31.

B. Alternating sandstone and siltstone beds and laminations. Note small-to micro-scale crossbedding in coarser grained sandstone and ripple laminations near top. ISPG Photo No. 1016-36.

C. Bioturbate mottling in fine-grained sandstone. ISPG Photo No. 1016-35.

D. Very fine- to coarse-grained sandstone with small cut-and-fill structures at base. ISPG Photo No. 1016-30.

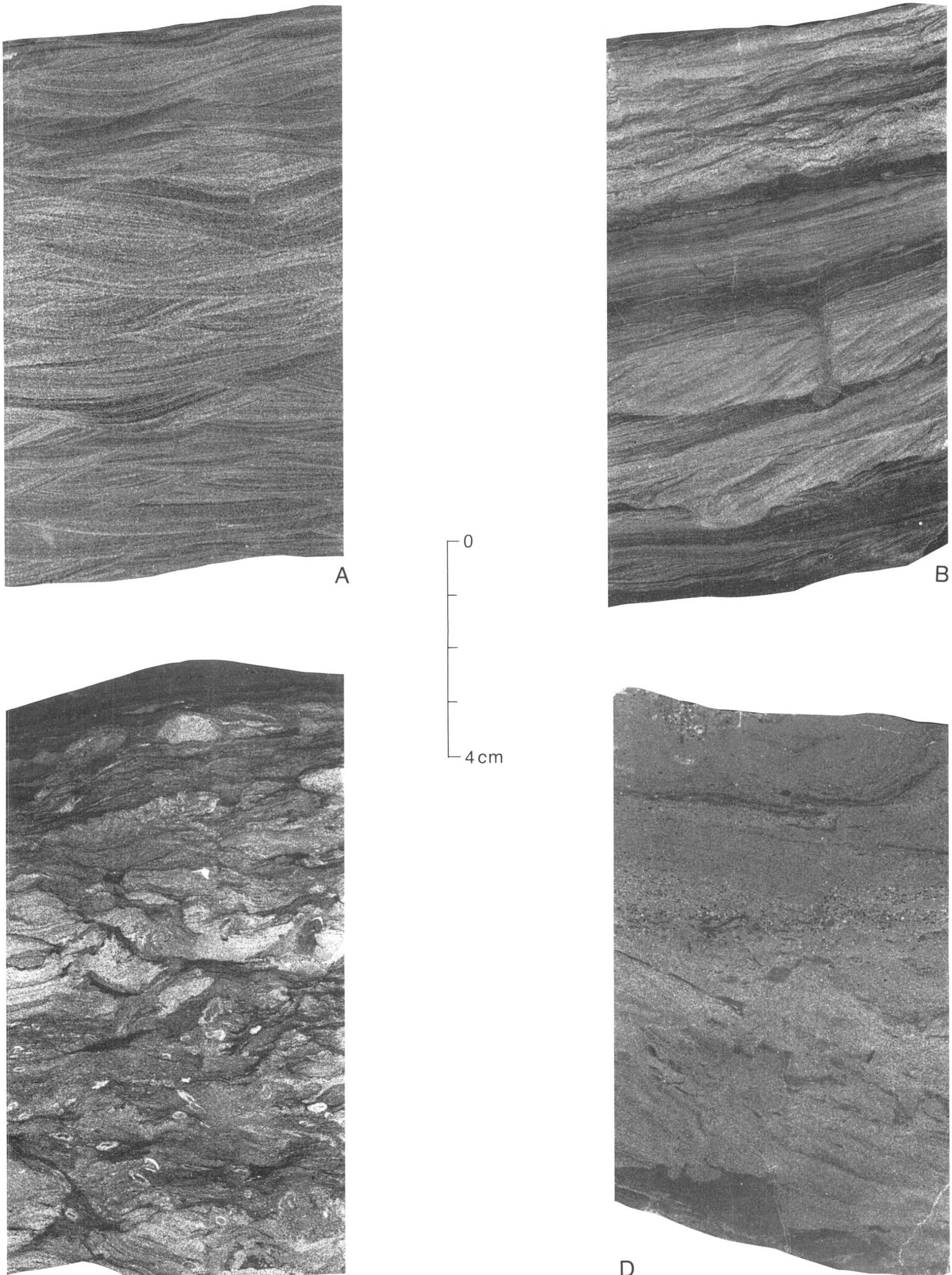
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PLATE 8

A. Vertical burrows in very fine grained sandstone and siltstone. ISPG Photo No. 1016-1.

B. Syneresis cracks in alternating beds and laminations of sandstone, siltstone and mudstone. Note similarity to burrow traces. ISPG Photo No. 1016-18.

C. Large horizontal and vertical burrows in thin bedded sandstone and siltstone. ISPG Photo No. 1016-3.

D. Small horizontal burrows in alternating thin beds and laminations of very fine grained sandstone and siltstone. Note well preserved sandstone ripple. ISPG Photo No. 1016-17.

E. Sand-filled burrows developed in alternating units of sandstone and siltstone. Note presence of small, sand-filled, syneresis cracks. ISPG Photo No. 1016-11.

F. Horizontal and vertical burrows in very fine grained sandstone. Note lenticular bedding near base. ISPG Photo No. 1016-29.

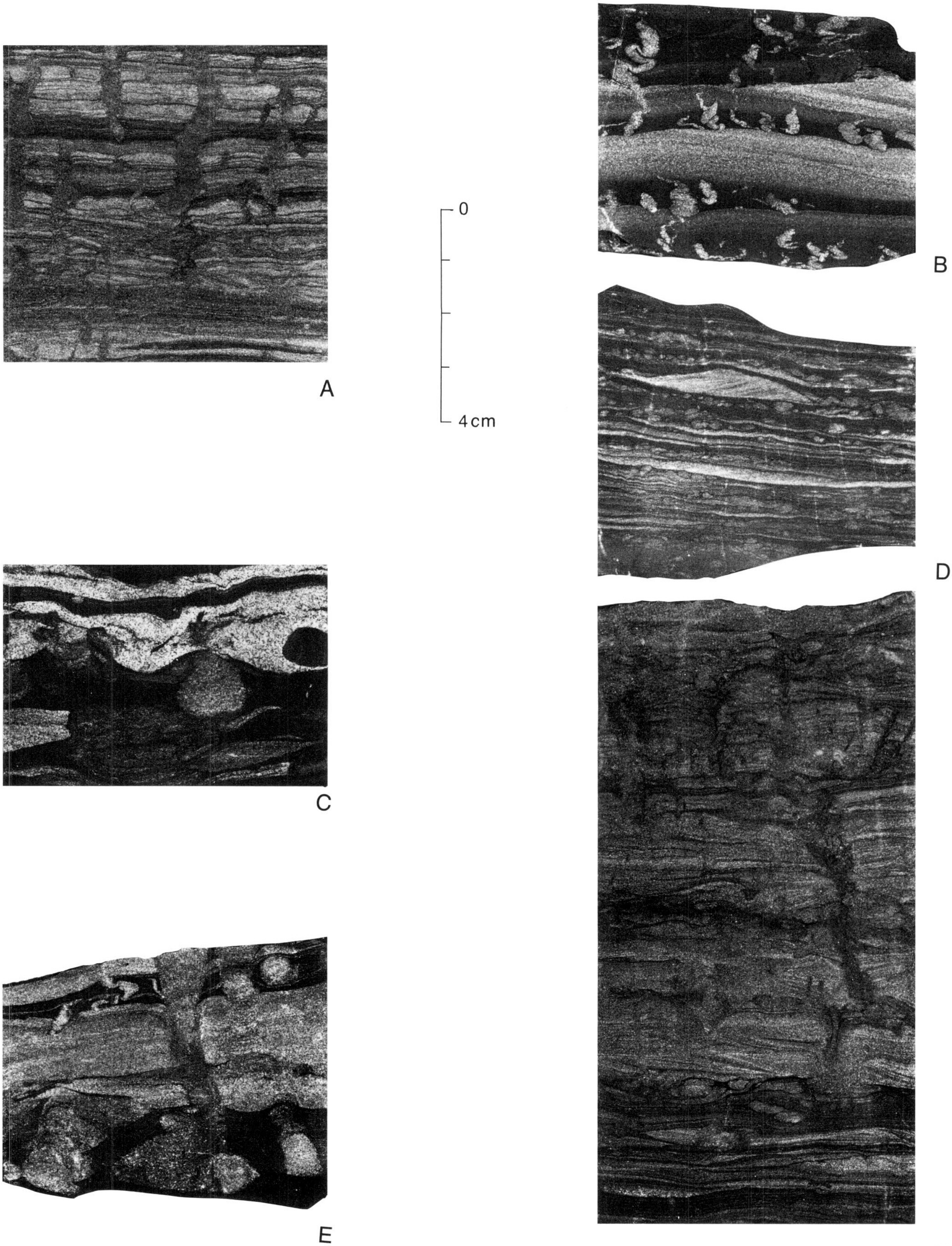
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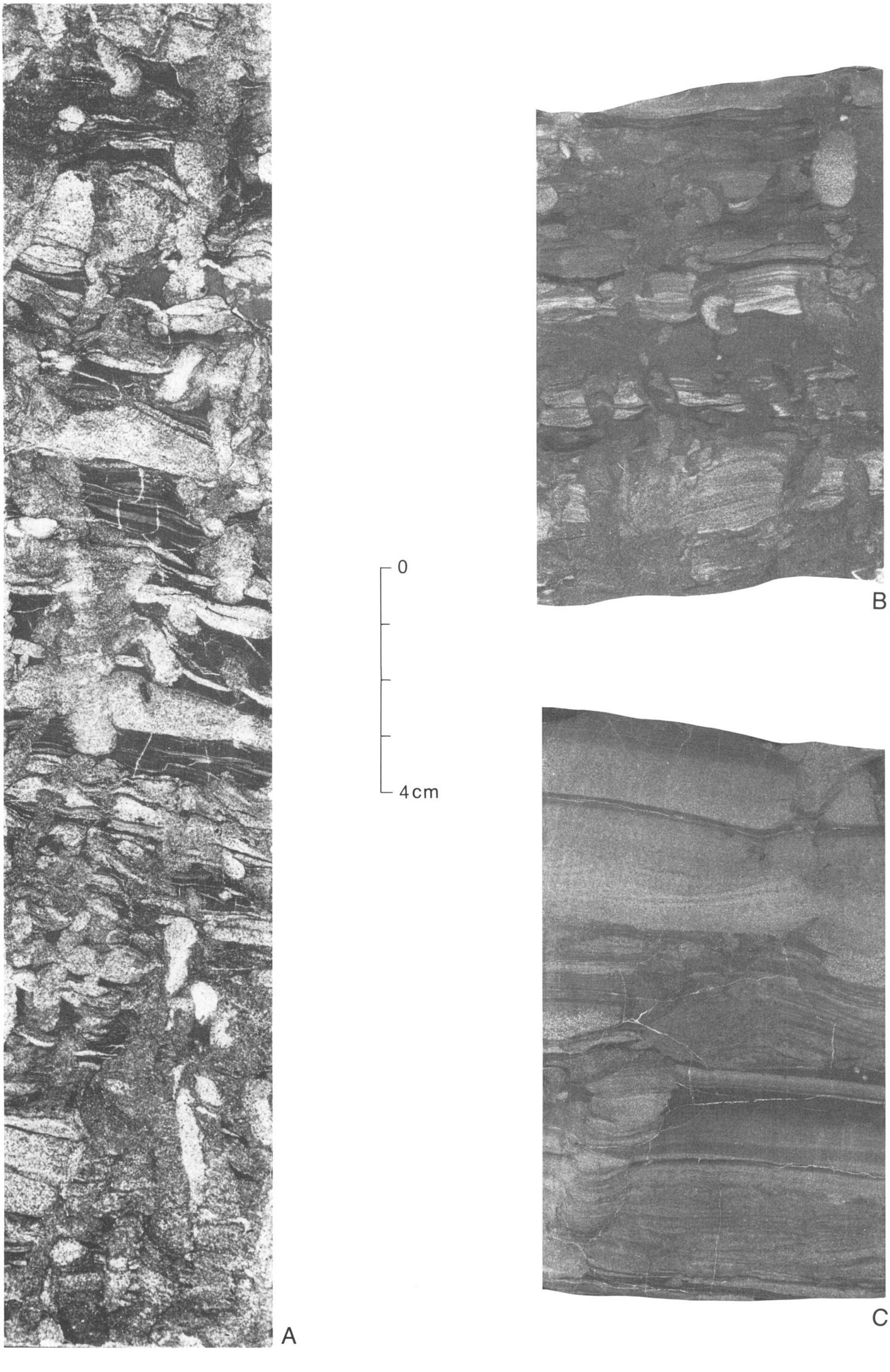
PLATE 9

A. Well developed, vertical, oblique, and horizontal burrows in alternating succession of fine-grained sandstone, siltstone and mudstone. ISPG Photo No. 1016-42.

B. Large and small burrows in very fine- to fine-grained sandstone. ISPG Photo No. 1016-34.

C. Large, vertical, sand-filled burrow in very fine-grained sandstone and siltstone facies. ISPG Photo No. 1016-32.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