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SEDIMENTOLOGY AND COAL RESOURCES OF THE EARLY OLIGOCENE AUSTRALIAN CREEK FORMATION, NEAR QUESNEL, BRITISH COLUMBIA

D.G.F. Long and P.S.W. Graham

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SEDIMENTOLOGY AND COAL RESOURCES OF THE EARLY OLIGOCENE AUSTRALIAN CREEK FORMATION, NEAR QUESNEL, BRITISH COLUMBIA

Abstract

Strata of the Early Oligocene Australian Creek Formation are characterized by marked lateral and vertical facies changes which complicate prediction of the distribution and character of coal deposits in the formation. In this paper, the Australian Creek Formation is interpreted as the product of the deposition of a valley-fill sequence, involving river channel, levee, splay, marsh, swamp, lake, and alluvial fan environments. Progradation of conglomeratic alluvial fans from the valley margins initiated low gradient conditions along the valley floor. This led to the development of a system of restricted lakes and an anastomosed system of fluvial channels and associated wetland environments. Conglomerates and channel-fill sandstones deposited by the parent stream were restricted to a limited part of the floodplain. The thick mudstone sequences that dominate the Australian Creek Formation accumulated as soils in levee and marsh settings, and as soils and pond deposits away from the distributary channels. The presence of well developed levees adjacent to the channels is indicated by the presence of abundant thin units of sandstone within much of the floodplain sequence. Coal deposits accumulated in rheotrophic swamp environments between and away from the main fluvial channels. The high ash content of these coals is a result of the frequent influx of mud into the swamps during flood events. The approximate locations where thick coal seams may have accumulated might be predicted using an anastomosed stream model, but many of these potential sites can be disregarded as they were eliminated by erosion during later stages of development of the Fraser River system. This, combined with deformation resulting from minor strike slip movement on the Fraser Fault system, means that coal in situ is of little economic significance, although some pockets may not have been removed by Miocene, Pliocene, Pleistocene and Recent river systems.

Résumé

Les strates de la Formation d'Australian Creek de l'Oligocène précoce sont caractérisées par d'importants changements de faciès latéraux et verticaux; ainsi, il est plus compliqué de prévoir la répartition et la nature des gisements de charbon dans cette lithologie. La présente étude porte sur l'interprétation de la Formation d'Australian Creek comme le produit du dépôt d'une séquence de remplissage de vallée, mettant donc en cause les milieux suivants : de chenal fluvial, de levée, de cône secondaire, de marais, de marécage, de lac et de cône de déjection. L'avancée de cônes de déjection conglomératiques depuis les marges de la vallée a été à l'origine des conditions de faible gradient au fond de celle-ci. Il en a résulté un ensemble de lacs à circulation fermée ainsi qu'un réseau de chenaux fluviaux anastomosés et de zones humides associées. Les conglomérats et les grès de remplissage de chenal déposés par le cours d'eau d'origine ont été confinés à une partie de la plaine d'inondation. Les épaisses séquences de mudstone qui dominent la Formation d'Australian Creek se sont accumulées, d'une part, à l'état de sols dans des levées et des marais et, d'autre part, à l'état de sols et de dépôts d'étang à une certaine distance des défluents. La présence de levées bien définies en position adjacente par rapport aux chenaux est indiquée par l'abondance de minces unités de grès dans la majeure partie de la séquence de plaine d'inondation. Les gisements de charbon se sont accumulés dans des milieux marécageux rhéotrophes entre les principaux chenaux fluviaux et à distance de ces derniers. La forte teneur en cendres de ces charbons est directement liée à l'apport fréquent de boue dans les marécages pendant les épisodes d'inondation. Bien qu'il serait possible de prevoír, à l'aide d'un modèle de cours d'eau anastomosés, le lieu approximatif d'accumulation des couches de charbon de grande épaisseur, nombre de ces sites identifiés pourraient être écartés car ils ont été détruits par l'érosion pendant les derniers stades de formation du réseau hydrographique du Fraser. Si on ajoute à cela la déformation due à un léger décrochement au niveau du réseau de failles du Fraser, on peut conclure que le charbon in situ offre peu d'intérêt économique, même si quelques poches ont pu être épargnées par les réseaux hydrographiques miocènes, pliocènes, pléistocènes, holocènes et récents.

Summary

Tertiary sedimentary and volcanic strata in the Fraser River valley near Quesnel, British Columbia, record a prolonged and varied drainage history, involving multiple re-occupation of a fault-controlled river valley, periodically blocked by lava flows during the past 50 million years. Coal-bearing strata of the Early Oligocene Australian Creek Formation rest with apparent angular unconformity on rocks of the Pennsylvanian to Permian Cache Creek Group, and are overlain by Middle Miocene conglomerate and sandstone of the Fraser Bend Formation.

Stratigraphic investigation of the Australian Creek Formation indicates that the lower 170 to 200 m of the formation are dominated by weakly consolidated sand and gravel; the middle 400 to 500 m are dominated by mudstone, with minor sandstone and conglomerate, and at least three major coal zones; and the upper 30 to 50 m of section consist mainly of coarse grained conglomerate and sandstone, with minor mudstone. The marked lateral and vertical facies changes that characterize the formation have made it difficult to predict the distribution and character of coal deposits in the middle member with any confidence.

Strata of the Australian Creek Formation form nine distinctive lithofacies assemblages. Conglomeratic strata can be divided into three major lithofacies based on their geometry in outcrop:

1. Thick bedded, crudely stratified, irregular sheets of pebble and cobble conglomerate which are interpreted as the products of sheet flood and channel processes (including minor slurry and debris flows) in the mid to distal parts of alluvial fans.

2. Thin to thick, massive and plane bedded, lenticular bodies of granule to large-pebble conglomerate which are interpreted as the products of avulsion controlled, high-constructive, channel-fill processes on an alluvial plain.

3. Thin sheets of conglomerate, which are found in intimate association with coarsening- or fining-upward sets of flat, wavy, and ripple crosslaminated units of very coarse to very fine grained sandstone, and are interpreted as proximal splay deposits. They may represent either sheet flood deposits developed on a splay surface, or lag deposits that accumulated in crevasse channels during times of flood.

Sandstones can be divided into two main lithofacies:

4. Stacked sequences of highly lenticular, massive or plane bedded sandstone, which show little or no evidence of systematic fining- or coarsening-upward. Ripple and planar cross-stratification are present locally, but are not common. Smaller sets are interpreted as deposits of minor fluvial distributary channels whose banks were stabilized by extensive vegetation, while thicker sets, with greater lateral continuity, are interpreted as deposits of moderately stable fluvial channels in which water flow was inadequate to transport conglomeratic material.

5. Thin sheets of laminated and ripple, crosslaminated, fine to very coarse grained sandstone occur in thinning- or thickening-upward sequences. Fining-upward sequences dominated by plane bedded or ripple laminated sandstone are most likely of splay origin. Those with abundant interbeds of mudstone may represent levee deposits.

Mudstones form more than half of the Australian Creek Formation, and can be divided into three lithofacies assemblages:

6. Massive to weakly laminated, organic-poor mudstone. In outcrop many contain carbonized plant roots, indicating deposition in a wetland or marsh setting where annual water levels did

not fall low enough to allow oxidation of buried plant remains. Where plant roots are not preserved, soil development is indicated by the presence of ped textures and abundant slickensides, which developed as the soils were compacted.

7. Massive to weakly laminated, organic-rich mudstone, which reflects the accumulation of organic material in marsh or levee marginal settings where groundwater levels remained high enough year-round to prevent the complete oxidation of plant material. These mudstones may grade laterally into organic-poor mudstones and lignites.

8. Laminated mudrocks and associated thin sands. The absence of abundant carbonized plant roots, combined with the frequent presence of even, parallel lamination indicate that thin sets of these deposits accumulated in semi-permanent floodplain ponds. Graded lamination within some deposits may reflect flood cycles. Thicker sequences, containing well preserved plant remains and minor intervals of poorly stratified very fine to very coarse grained sandstone, may represent deposition in larger bodies of water which developed on or in front of the floodplain.

Lignite, while locally abundant, forms only a minor part (one lithofacies) of the Australian Creek Formation.

9. Thick, highly lenticular, composite lenses of predominatly dull, flat to wavy laminated coal, with a high ash content. Minor bright bands of woody material occur, associated with tree stumps in growth position. The abundance of transitional lower contacts with massive to weakly laminated mudstones of Lithofacies 6 and 7, indicates that most of the coal seams accumulated in situ, as rheotrophic swamp deposits.

Rocks of the Australian Creek Formation are best interpreted in terms of a valley fill sequence. The earliest preserved deposits, represented by conglomerate and sandstone in the lower member, may reflect deposition from alluvial fans and braided rivers. The bulk of the overlying middle and upper members can be interpreted in terms of deposition on a floodplain characterized by swamp, marsh, floodpond, lake, channel, levee, and crevasse-splay environments, with minor deposition on alluvial fans that prograded from the valley walls.

The abundance of floodplain facies and the apparent stacked character of the channel-fill conglomerates, combined with the high ash content of the coals, all point to deposition in a fluvial system dominated by vertical rather than lateral accretion. This situation occurs in low gradient anastomosed fluvial systems where bank stability is high enough, due to the abundance of plant roots, to inhibit lateral migration of river channels across their floodplains. The presence of inclined stratification in some channel deposits and minor fining-upward sequences in others suggest limited channel migration. Most of the channel-fill conglomerates are interpreted as "shoestring-like" deposits of limited lateral extent. The presence of weakly developed planar stratification in these conglomerates is indicative of deposition on longitudinal in-channel bars, where grain size variation was controlled by flood cycles.

Highly lenticular coal deposits in the middle member of the Australian Creek Formation accumulated in rheotrophic swamp environments between and away from the main fluvial channels. The high ash content of these coals is directly related to the frequent influx of mud into the swamps during flood events. The approximate locations where thick coal seams may have accumulated might be predicted using an anastomosed stream model, but many of these potential sites can be disregarded because they have been eroded during later stages of development of the Fraser River system. This, combined with deformation resulting from minor strike slip movement on the Fraser Fault system, means that coal in situ is of little economic significance, although a few pockets may not have been removed by Miocene, Pliocene, Pleistocene and Recent river systems.

Sommaire

Dans la vallée du Fraser, près de Quesnel en Colombie-Britannique, les strates sédimentaires et volcaniques du Tertiaire témoignent d'une histoire de drainage longue et variée, comportant plusieurs réoccupations d'une vallée fluviale contrôlée par des failles et bloquée périodiquement par des coulées de lave depuis 50 millions d'années. Les strates charbonnières de la Formation d'Australian Creek de l'Oligocène précoce reposent en discordance angulaire apparente sur des roches du groupe pennsylvanien à permien de Cache Creek et sont sous-jacentes au conglomérat et au grès du Miocène moyen de la Formation de Fraser Bend.

L'étude stratigraphique de la Formation d'Australian Creek indique que les 170 à 200 mètres inférieurs sont dominés par du sable et du gravier peu consolidés; que les 400 à 500 mètres intermédiaires le sont par du mudstone, mais comprennent un peu de grès et de conglomérat et au moins trois grandes zones charbonnières; quant aux 30 à 50 mètres supérieurs, ils consistent surtout en des conglomérats et des grès grossiers, accompagnés d'un peu de mudstone. À cause des importants changements de faciès tant latéraux que verticaux qui caractérisent la formation, il est difficile de prévoir avec exactitude la répartition et la nature des gisements de charbon du membre intermédiaire.

Les strates de la Formation d'Australian Creek forment neuf assemblages de lithofaciès distincts. Les couches conglomératiques se divisent en trois grands lithofaciès selon leur géométrie en affleurement :

1. Épaisses couches irrégulières qui sont litées et grossièrement stratifiées; elles sont composées de conglomérat à cailloux et à galets et sont considérées comme le résultat du ruissellement en nappes et des processus de chenal (y compris de petites coulées de boue fluente et de débris) dans les parties centrales à distales des cônes de déjection.

2. Lentilles litées massives et planes de faible à forte épaisseur, composées de conglomérat allant de la granulométrie des granules à celle des gros cailloux; elles sont considérées comme les produits de processus très constructifs de remplissage de vallée, contrôlés par avulsion, dans une plaine d'inondation.

3. Couches minces de conglomérat étroitement associées à des ensembles à granoclassement inverse ou normal, composés d'unités de grès très grossier à très fin qui présentent des stratifications tant planes qu'ondulées ou obliques de rides; ces couches sont considérées comme des dépôts proximaux de cône secondaire. Il pourrait s'agir de dépôts de ruissellement en nappes formés à la surface d'un cône secondaire ou de résidus de déflation accumulés dans des chenaux en crevasse lors d'inondations.

Les grès se divisent en deux grands lithofaciès :

4. Empilements de grès fortement lenticulaire, massif ou en couches planes, où les indices de granoclassement normal ou inverse sont peu nombreux ou inexistants. Par endroits, s'observent des stratifications obliques ondulées ou planes. Les ensembles les plus minces sont considérés comme des dépôts de petits défluents fluviaux dont les rives ont été stabilisées par une végétation étendue, tandis que les ensembles plus épais, présentant une plus grande continuité latérale, sont interprétés comme des dépôts de chenaux fluviaux modérément stables, dans lesquels l'écoulement de l'eau n'était pas suffisant pour transporter les matériaux conglomératiques.

5. Minces feuillets de grès laminés et ondulés présentant des stratifications obliques; leur granulométrie est fine à grossière et ils s'observent en séquences s'amincissant ou s'épaississant vers le haut. Les séquences s'amincissant vers le haut et dominées par du grès à laminations

planes ou ondulées seraient des dépôts de cône secondaire, tandis que celles à interlits abondants de mudstone pourraient correspondre à des dépôts de levée.

Les mudstones constituent plus de la moitié de la Formation d'Australian Creek et se divisent en trois assemblages de lithofaciès :

6. Mudstones massifs à légèrement laminés, pauvres en matière organique; en affleurement, plusieurs d'entre eux contiennent des racines de plantes carbonisées, indiquant un dépôt dans un environnement de terres humides ou de marécages où les niveaux d'eau annuels ne baissaient pas suffisamment pour permettre l'oxydation des restes de plantes enfouies. Là où les racines des plantes n'ont pas été conservées, la formation de sol est indiquée par la présence de textures d'agrégat et de nombreuses surfaces de friction, apparues avec le tassement des sols.

7. Mudstones massifs à légèrement laminés, riches en matière organique; ils témoignent d'une accumulation de matière organique dans des milieux marginaux de marais ou de levée où les niveaux des eaux souterraines sont demeurés assez élevés à l'année longue pour empêcher l'oxydation complète de la matière végétale. Latéralement, il pourrait y avoir passage de ces mudstones à des mudstones et des lignites pauvres en matière organique.

8. Mudstones laminés associés à de minces couches de sable; les racines carbonisées peu abondantes et les laminations parallèles uniformes fréquemment observées indiquent que des ensembles minces de ces dépôts se sont accumulés dans des étangs de plaine d'inondation semi-permanents. Les laminations granoclassées de quelques dépôts peuvent être un indice de cycles d'inondation. Les séquences plus épaisses, contenant des vestiges de plantes bien conservées avec quelques petits intervalles de grès peu stratifié de granulométrie très fine à très grossière, pourraient témoigner d'une sédimentation dans de plus grands plans d'eau, dans la plaine d'inondation ou au niveau de sa zone frontale.

Le lignite, quoique abondant par endroits, ne constitue qu'une petite partie (un lithofaciès) de la Formation d'Australian Creek.

9. Épaisses lentilles composites fortement lenticulaires, composées surtout de charbon mat riche en cendres à laminations planes à ondulées; présence de petites bandes brillantes de matériel ligneux, dont notamment de souches d'arbre en position de croissance. L'observation fréquente de contacts inférieurs de transition avec des mudstones massifs à légèrement laminés associés aux lithofaciès 6 et 7 indique que la plupart des couches de charbon se sont formées in situ, en tant que dépôts de marécage rhéotrophe.

Les roches de la Formation d'Australian Creek constitueraient, selon toutes probabilités, une séquence de remplissage de vallée. Les plus anciens dépôts préservés, en l'occurrence les conglomérats et les grès du membre inférieur, indiquent qu'il s'agirait d'un dépôt dans des milieux de cône de déjection et de cours d'eau anastomosés. Le gros des membres intermédiaire et supérieur sus-jacents représenterait une sédimentation dans une plaine d'inondation, caractérisée par la présence de marécages, de marais, d'étangs d'inondation, de lacs, de chenaux, de levées et de crevasses mineures divergentes, avec de petits dépôts sur des cônes de déjection qui ont progressé à partir des versants de la vallée.

L'abondance des faciès de plaine d'inondation et l'empilement apparent des conglomérats de remplissage de chenal, combinés à la forte teneur en cendres des charbons, mènent à conclure à un dépôt dans un réseau fluvial dominé par une accrétion verticale plutôt que latérale. Cette situation est typique des réseaux fluviaux anastomosés à faible gradient où la stabilité des berges est assez grande, à cause de l'abondance de racines de plantes, pour empêcher la migration latérale des chenaux fluviaux en travers de leur plaine d'inondation. La présence d'une stratification inclinée dans certains dépôts de chenal et de petites séquences à granoclassement normal dans d'autres suggère que les chenaux ont peu migré. La plupart des conglomérats de remplissage de chenal seraient des dépôts «en forme de lacet» d'étendue latérale limitée. Dans ces conglomérats, la présence d'une stratification plane peu développée indique que des bourrelets de matériaux, dont la grosseur du grain reflète les cycles d'inondation, se sont déposés dans l'axe des chenaux.

Des gisements de charbon fortement lenticulaires du membre intermédiaire de la Formation d'Australian Creek se sont formés dans des milieux marécageux rhéotrophes, entre les principaux chenaux fluviaux et à distance de ces derniers. La forte teneur en cendres de ces charbons est directement liée à l'apport fréquent de boue dans les marécages pendant les épisodes d'inondation. Bien qu'il serait possible de prévoir, à l'aide d'un modèle de cours d'eau anastomosés, le lieu approximatif d'accumulation des couches de charbon de grande épaisseur, nombre de ces sites identifiés pourraient être écartés car ils ont été détruits par l'érosion pendant les derniers stades de formation du réseau hydrographique du Fraser. Si on ajoute à cela la déformation due à un léger décrochement au niveau du réseau de failles du Fraser, on peut conclure que le charbon in situ offre peu d'intérêt économique, même si quelques poches ont pu être épargnées par les réseaux hydrographiques miocènes, pliocènes, pléistocènes, holocènes et récents.

INTRODUCTION

Tertiary sedimentary and volcanic rocks in the Fraser River valley, near Quesnel, British Columbia (Fig. 1), record a prolonged and varied drainage history involving multiple re-occupation of a fault controlled river valley, which was periodically blocked by lava flows during the past 50 million years (Lay, 1940, 1941). Economic interest in this area is stimulated by the presence of lignitic coals and diatomaceous earths in Oligocene and Middle Miocene strata (Selwyn, 1872; Dawson, 1877; Reinecke, 1920; Galloway, 1924; Graham, 1978), and placer gold concentrations in Quaternary valley-fill sequences (Lay, 1940, 1941). Rouse and Mathews (1979) provided a comprehensive review of the Tertiary sequence in the vicinity of Quesnel and introduced new stratigraphic nomenclature that is followed in this report (Table 1).

Early Oligocene coal-bearing strata within the Tertiary sequence were named the Australian Creek Formation by Rouse and Mathews (1979). This formation consists predominantly of weakly consolidated mudstone, with lesser amounts of sandstone, conglomerate and lignite. Marked lateral and vertical facies changes make it difficult to predict the distribution of coal deposits in this formation with any confidence.

Dawson (1877) provided the first environmental interpretation of strata of the Australian Creek Formation (his "Lignite Series"). He used the presence of a well preserved suite of insect remains (Scudder, 1877) to suggest that at least some of the formation was deposited in a protected lacustrine setting. Dawson (1877, p. 257) suggested that the poor lateral continuity of coal seams in the unit could be explained by their deposition as "driftwood by somewhat rapidly flowing water".

Cockfield (1932) suggested that the "rapid changes from sand to gravel or sand to clay" which characterize the Australian Creek Formation could indicate deposition in nonmarine, swamp, lake or "basin" settings. Lay (1940) concurred, suggesting that deposits of his Australian member were of "unquestionable fresh water origin". Lay (1940, 1941) went on to deduce a complex fluvial drainage history for these and associated Tertiary to Recent strata along the Fraser River. McCallum (1969) suggested that equivalent strata, in the vicinity of Prince George, record a period of lacustrine, fluvial and paludal sedimentation in a humid climatic setting. This type of climate was confirmed by palynological observations by Mathews and Rouse (1963), Piel (1969, 1971), Rouse and Piel (1969), and Rouse and Mathews (1979).

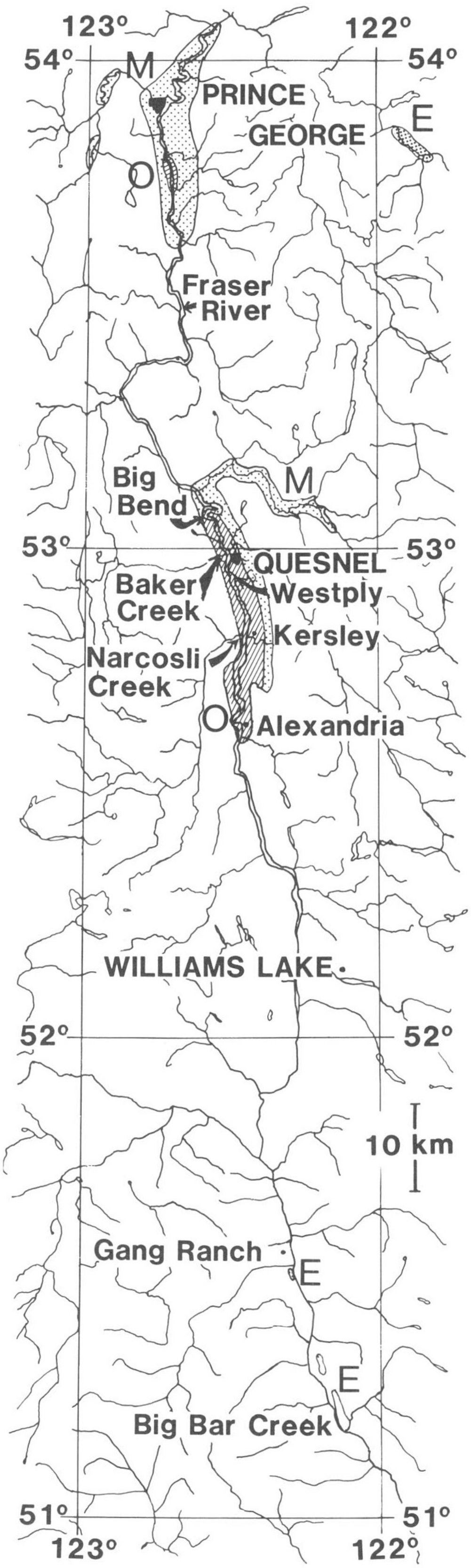

Figure 1. Location of Tertiary strata adjacent to the Fraser River, between Prince George and Big Bar Creek. E = Eocene; O = Oligocene; M = Miocene.

TABLE 1

Stratigraphic nomenclature for rocks in the Quesnel area

Lithology	Age	Lay (1940)	Tipper (1961)	McCallum (1969)	Graham (1978)	Rouse and Mathews (1979), and this paper
Olivine basalt, andesite	Late Miocene	Upper Volcanics	Endako Group	not studied	Upper Volcanics	Plateau Basalts
Diatomite clay, coal	Middle Miocene	Diatomite member	Fraser Bend Fm. of Reinecke (1920)	Tertiary C	Upper Fraser River Formation	Crownite Formation
Gravel, sand, clay		Gravel member		Tertiary B		Fraser Bend Formation
unconformity				unconformity		
Mud, gravel, sand, coal	Early Oligocene	Australian member		Tertiary A	Lower F.R.Fm.	Australian Creek Formation
unconformity						
Andesite tuff, breccia conglomerate	Middle Eocene	Lower Lavas	Unit 4 Tipper (1959)	Early Tertiary Volcanics	Lower Lavas	Kamloops Group Equivalent
unconformity						
Metasedimentary basalt, augite porphyry	Middle Jurassic-Triassic	Quesnel River Group (Tipper, 1978a)				
unconformity						
Metasedimentary chert, argillaceous greenstone	Pennsylvanian and Permian	Cache Creek Group (Tipper, 1959)				

Rouse and Mathews (1979) suggested that the Australian Creek Formation was deposited in a series of lakes, swamps and rivers that were confined to a lowland floodplain in a graben or half graben that paralleled the trend of the Fraser Fault. Rouse and Mathews used palynology to demonstrate the presence of mixed Mesophytic forests and shallow bodies of water during deposition of the Australian Creek Formation. They suggested that the formation accumulated in a marginal paratropical or submontane rain forest environment, comparable to modern examples in Central America and southern China, with mean annual temperatures in excess of 20°C, a mean annual temperature range of 11 to 13°C, and precipitation in the order of 1,800 to 2,000 mm a^{-1}.

This paper documents the depositional environment of Early Oligocene lignite-bearing strata of the Australian Creek Formation, utilizing core recovered during subsurface investigation of its coal resource potential (Graham, 1978, 1979), along with data from a limited number of surface sections. Preliminary results of this study, which was initiated to explain the marked lateral facies changes in the formation, are included in papers by Long (1981a–d).

GEOLOGICAL SETTING

The regional geological setting of Tertiary strata along the Fraser River is illustrated in maps by Tipper (1959, 1961, 1978a, b) and Tipper et al. (1979). Table 1 summarizes the geology of the Fraser River valley in the vicinity of Quesnel, as interpreted by Lay (1940), McCallum (1969), Graham (1978), Rouse and Mathews (1979) and others. The distribution of Paleogene strata south of Quesnel (Fig. 1) is controlled by a major fault, which is the northern extension of the Fraser Fault system (Trettin, 1961; Tipper, 1978a, b; Mathews and Rouse, 1984).

Tertiary strata within the Fraser River valley rest with apparent angular unconformity on rocks of the Pennsylvanian to Permian Cache Creek Group (Tipper, 1959). In the vicinity of Quesnel they abut Lower and (?)Middle Jurassic rocks of the Quesnel River Group (Tipper, 1978a; Tipper et al., 1979). Basal contacts of the sequence are rarely exposed, although an unconformable contact between conglomerates of the Miocene Fraser Bend Formation and quartzites of the Cache Creek Group is demonstrable at Big Bend on the Fraser River, 12 km north of Quesnel.

The Oligocene to mid-Miocene sequence (Fraser River Formation of Reinecke, 1920), in places overlies the Eocene volcanic sequence (Kamloops Group equivalents), and is divisible into three parts, which were renamed by Rouse and Mathews (1979) (Table 1). The lower unit (the Early Oligocene, Australian Creek Formation) consists mainly of mudrocks, with lesser amounts of sandstone, conglomerate and coal. This is overlain by a middle unit (the Middle Miocene, Fraser Bend Formation) of pebble and cobble conglomerates, with lesser amounts of sandstone and mudstone, which passes upsection through sandstones, siltstones, claystones, diatomaceous clays and minor lignites, into relatively pure diatomaceous earths of the Crownight Formation.

It should be noted that although Rouse and Mathews (1979) restricted the name Crownight Formation to the upper 12 m of Reinecke's (1920) Fraser River Formation, this does not correspond exactly to the earlier subdivisions by Lay (1940) or McCallum (1969) shown in Table 1. The Crownight Formation is conformably overlain by flat-lying olivine basalts and associated strata of Late Miocene to (?)Pliocene age. Deep post-Pliocene erosion is indicated by the presence of coarse fluvial conglomerates of Pleistocene and Recent age along the present trend of the Fraser River (Lay, 1940, 1941).

AUSTRALIAN CREEK FORMATION

Distribution, definition, and stratigraphy

Strata of the Australian Creek Formation, known previously as the Lignite Series (Dawson, 1877), lower Fraser River Formation (Graham, 1978), and Australian member (Lay, 1940), occur in a poorly exposed belt about 6 km wide, between Quesnel and Alexandria (Figs. 1, 2). Equivalent strata are present at Big Bend, on the Fraser River, 12 km north of Quesnel (Lay, 1940), on Tabor, Broadman and Haggith creeks; along the Fraser River south of Prince George (McCallum, 1969); and on the Blackwater River, 60 km northwest of Quesnel (Graham, 1978).

The type section of the Australian Creek Formation, as defined by Rouse and Mathews (1979, p. 427), is on Australian Creek (Fig. 2). This section (Appendix A, Section 1) is poorly exposed. It contains between 200 and 300 m of strata, which are for the most part stratigraphically higher than strata intersected in Geological Survey of Canada borehole Q1 (Graham, 1979; Appendix A), Cariboo Oil Company borehole Australian No. 1 (Lakes, 1930), and Sproule and Associates borehole Kersley No. 1 (Laurence, 1953). A tentative reconstruction of the stratigraphic relationships in the vicinity of Australian Creek is given in Figures 3 and 4. Using this reconstruction, the lower 170 to 200 m of the formation are dominated by weakly consolidated sand and gravel. The middle 400 to 500 m are dominated by mudstone, with minor sandstone and conglomerate and at least three major coal zones. The upper 30 to 50 m of section, exposed in the upper reaches of Australian Creek, are mainly coarse grained conglomerate and sandstone, with minor mudstone.

The Australian Creek Formation is exposed at several locations south of the type section and north of Diamond Island at Alexandria Ferry (Fig. 2). Most of these riverside exposures contain nonconglomeratic strata and may be correlated with the middle part of the formation in the type area. North of Australian Creek, exposures of the formation are present on both sides of the Fraser River, up to Fraser Bend (locally called the big bend), 11 km north of Quesnel (Fig. 1). The sections at Westply (Appendix A, Section 2) and Red Cliff, and in Geological Survey of Canada boreholes Q2 and Q3 (Appendix A) may be equivalent to the middle and lower parts of the section in the type area. Twenty metres of the (?)basal beds are exposed at Big Bend (Rouse and Mathews, 1979; Appendix A, Section 4). Distribution of other exposures is indicated by Rouse and Mathews (1979, Fig. 1C, p. 422). Some "greenish" gravel-rich beds, 11 km south of Quesnel, have been correlated with the upper part of the upper, coarse grained sequence by Rouse and Mathews (1979, p. 428) - these may be the same beds that Lay (1941, p. 39) considered predate the Australian Creek Formation.

Lithology

The Australian Creek Formation is composed mainly of weakly consolidated, massive and planar bedded mudstone, with lesser amounts of conglomerate, sandstone and coal. It can be divided into

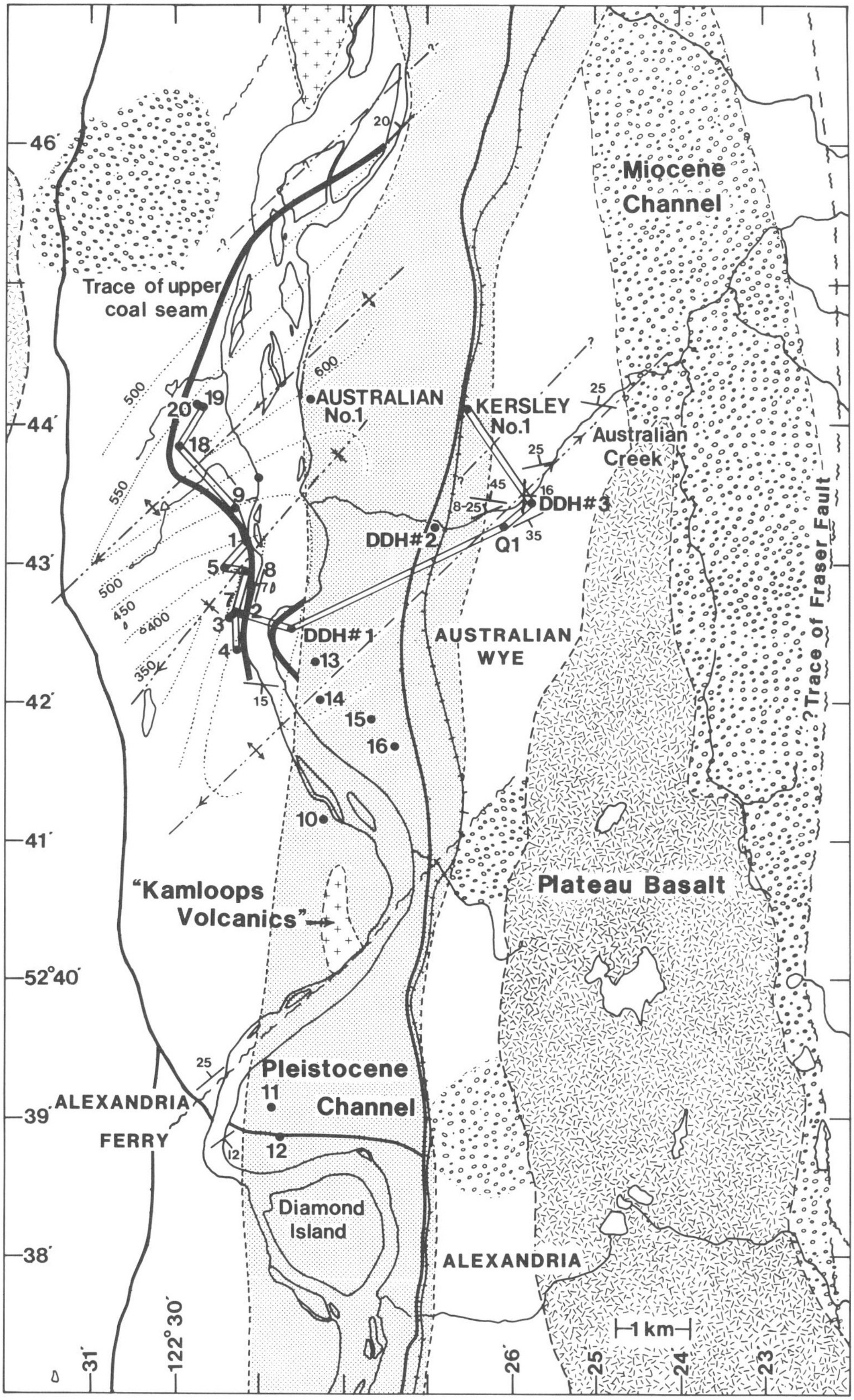

Figure 2. *Geology of the Australian Creek area. Trace of outcrop of main coal seam shown in black, structure contours dotted.*

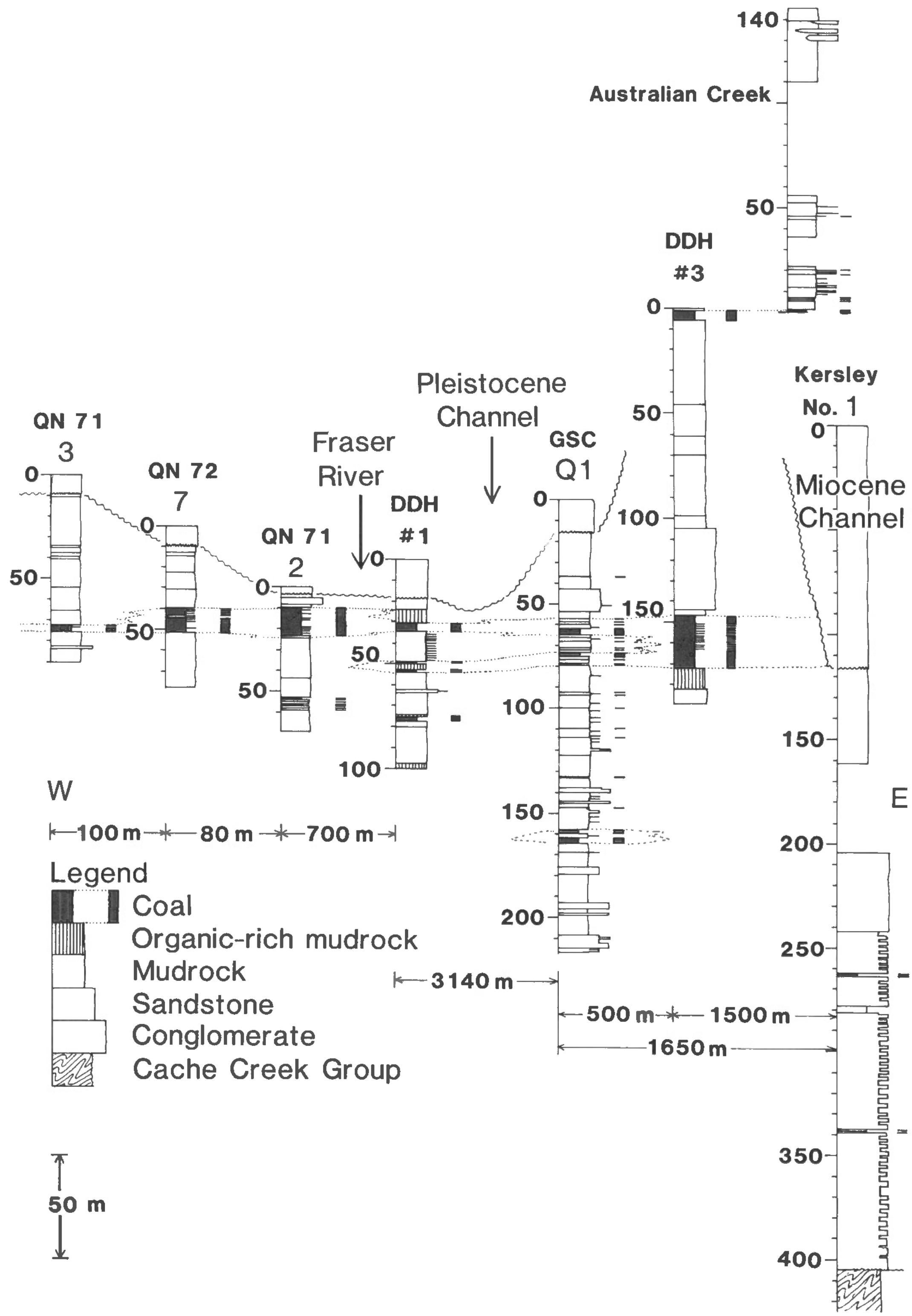

Figure 3. East-west correlation of strata in the Australian Creek Formation, near Australian Wye (Fig. 2). Note: For mudrock, sandstone and conglomerate, column width indicates rock type. [*Based on data from Yoon, 1972 (holes labelled QN); Lakes, 1930 (DDH 1, 3); and Laurence, 1953 (Kersley No. 1).*]

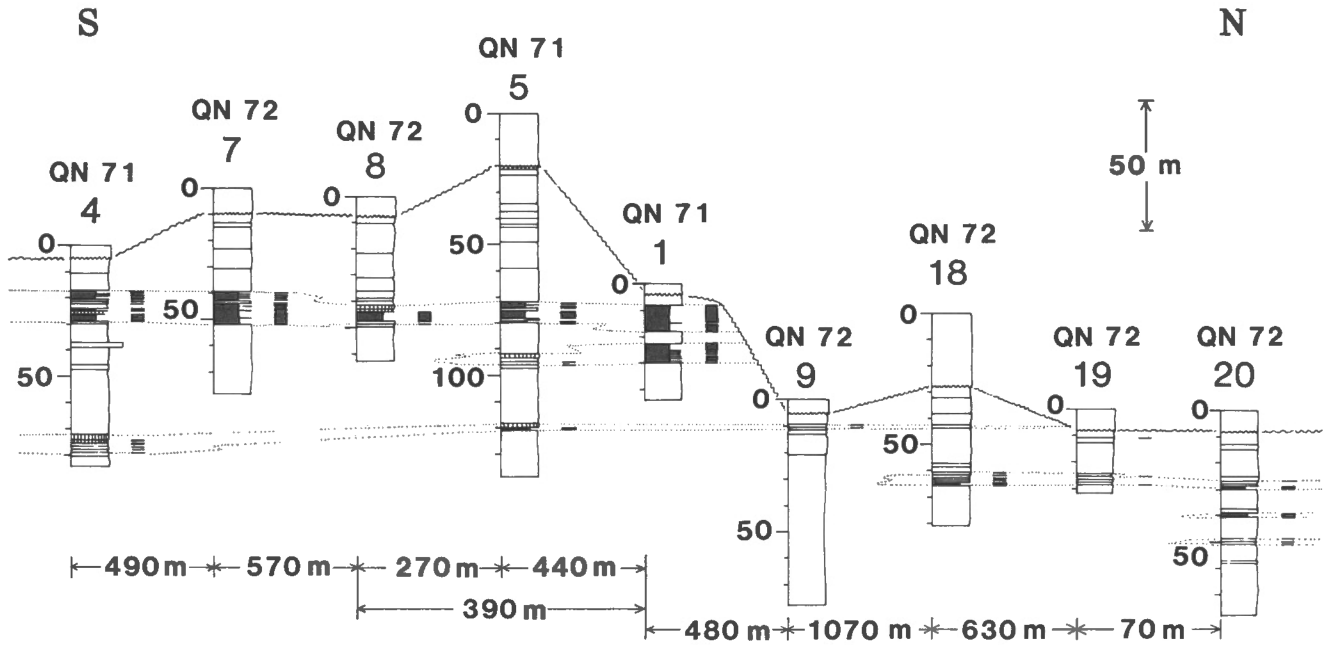

Figure 4. North-south correlation of strata on the west bank of the Fraser River, near Australian Wye (Fig. 2). See Figure 3 for legend.

nine distinctive lithofacies assemblages which are described below and in Table 2. Rock colours of wet samples were determined by comparison with the chart of Goddard et al. (1980). Detailed logs of selected surface sections, and Geological Survey of Canada boreholes Q1, Q2, and Q3 are provided in Appendix A.

Conglomerate

Conglomerates in the Australian Creek Formation are predominantly of granule to large-pebble grade. They form between 1 and 26 per cent of the middle part of the formation but may be more abundant in the lower and upper parts. Composition varies from metalithrudite to volcanilithrudite. Clasts in samples from Big Bend and Baker Creek are predominantly of metasedimentary origin, presumably derived from strata of the Cache Creek Group. Samples from Australian Creek, Alexandria Ferry, and boreholes Q1, Q2 and Q3, are dominated by volcanic debris, much of which can be matched to local sources.

Analysis of pebble grade clasts from 12 samples in borehole Q3 (Appendix B, Table 5) indicate an average of 79.1% volcanic rocks (range 37 to 94%), 6.2% quartz (0 to 13%), 8.7% chert (0 to 37%), and 5.5% sedimentary/metasedimentary (0 to 16%). Petrographic analysis of the sand to granule size fraction of 11 conglomerates from boreholes Q1 to 3 (Appendix B, Table 1) indicate an average of 10.9% quartz (range 4 to 18%), 2.4% feldspar (1 to 6%), and 86.6% rock fragments (77 to 94%). The last category includes an average of 9.2% chert, 9.5% sedimentary/metasedimentary, 12.9% metamorphic, 2.2% plutonic (granitic), and 52.9% volcanic grains (Fig. 5).

Conglomeratic strata in the Australian Creek Formation can be divided into three major lithofacies based on their geometry in outcrop: 1) thick bedded, crudely stratified irregular sheets; 2) thin to thick, massive and plane bedded lenticular bodies; and 3) thin sheets of massive and laminated conglomerate intimately associated with sandstone (Table 2, Lithofacies 1 to 3).

Sandstone

Sandstone forms a minor part of the Australian Creek Formation. It is present as thin interbeds between conglomerates of Lithofacies 1 in the upper and lower parts of the sequence, and constitutes from 4 to 30% of measured sections through the middle part of the formation, where it occurs in intimate association with both conglomerate of Lithofacies 2 and mudrock of Lithofacies 6, 7, and 8.

TABLE 2

Lithofacies of the Australian Creek Formation

CONGLOMERATE	
1 Thick bedded, crudely stratified, irregular sheets	Alluvial fan, braided stream and debris flow deposits
2 Thin to thick, massive, plane bedded, lenticular bodies	Alluvial channel fill
3 Thin sheets of massive and laminated conglomerate	Proximal splay deposits
SANDSTONE	
4 Stacked medium to very coarse, massive, laminated, rippled	Slack channel deposits
5 Laminated and rippled, fine to very coarse	Levee and splay deposits
MUDSTONE	
6 Massive, organic-poor	Marsh and floodpond deposits, soils
7 Massive to laminated organic-rich	Water saturated levee and marsh deposits
8 Laminated mudrocks	Lake and pond deposits
COAL	
9 Lignite	Swamp deposits

Petrographic analysis of 13 samples from the middle part of the formation (Appendix B, Table 1) indicates an average composition of 16.9% quartz (range 8 to 33%), 4.4% feldspar (1 to 9%), 78.5% lithic fragments (63 to 90%), and 0.2% accessories (0 to 1%). Rock fragments include an average of 9.2% chert, 4.9% sedimentary and metasedimentary rock fragments, 13.8% metamorphic rock fragments, 2% plutonic (granitic) rock fragments, and 48.8% volcanic rock fragments (Fig. 5).

Sandstones in the Australian Creek Formation range from very fine to very coarse sand grade. They can be divided into two main lithofacies (Table 2). These include stacked sequences of dark greenish grey (5Y 4/1) to bluish grey (5B 6/1) medium to very coarse grained sandstone of Lithofacies 4, and dark greenish grey (5GY 4/1) to sequences of pale olive (5Y 6/3), very fine to very coarse grained sandstones, which show coarsening- or fining-upward trends (Lithofacies 5).

Mudstone

Mudstone forms more than 50% of the Australian Creek Formation. It ranges in abundance from 5 to 10% in the upper and lower parts of the formation, to 55 to 92% in the middle part. Mudstones in the Australian Creek Formation are typically weakly consolidated. They range in colour from pale olive (5Y 6/4) to very dark grey (5Y 3/1) and black. Weathered samples tend to be lighter in colour, and may oxidize to olive-yellow (5Y 6/6) or brown (7.5YR 5/4). Analysis of mudrocks from the Australian Creek Formation (Appendix B, Tables 2, 3) indicates an average composition of 46% quartz, 8% feldspar, 17% chlorite + kaolinite, 10% illite, and 9% expandable and mixed layer clays.

Mudstones in the Australian Creek Formation can be divided into three main lithofacies, depending on the presence or absence of lamination, and their

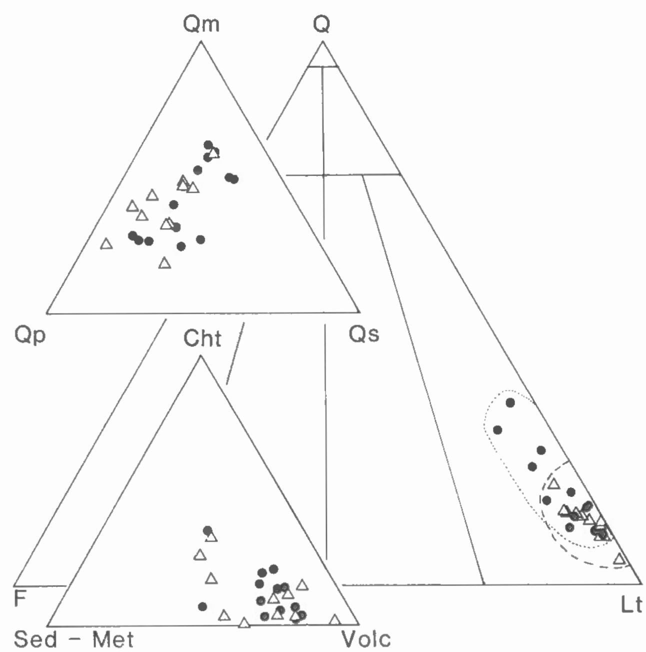

Figure 5. Petrography of the sand and granule fraction of samples from the Australian Creek Formation. Q = quartz; F = feldspar; Lt = lithic fragments, including chert. Daughter triangles indicate (upper left) the relative amounts of monocrystalline (Qm), polycrystalline (Qp) and strained (Qs) quartz; and (lower left) the relative amounts of chert (Cht), sedimentary and metamorphic (Sed-Met), and volcanic and plutonic (Volc) rock fragments. Triangles = conglomerates, dots = sandstones.

organic content (Table 2). Lithofacies 6 includes massive, organic-poor varieties, while Lithofacies 7 includes massive to weakly laminated organic-rich varieties. Lithofacies 8 includes laminated mudrocks and associated thin sands.

Coal

Lignite forms a minor part of the Australian Creek Formation. It occurs both in thick, composite lenses of predominantly dull, flat to wavy laminated coal, associated with massive to weakly laminated mudstones of Lithofacies 6 and 7, and as thin sheets associated with laminated mudrocks of Lithofacies 8.

Lithofacies of the Australian Creek Formation

Nine distinctive lithofacies are recognized in strata of the Australian Creek Formation (Table 2). These are described and interpreted below, beginning with the coarser grained rocks and ending with the coals.

LITHOFACIES 1: conglomerate sheets

Strata of Lithofacies 1 include laterally extensive irregular sheets of crudely stratified, pebble and cobble conglomerate. This type of deposit is best exposed in the upper part of the type section on Australian Creek (Fig. 6A). Other examples are exposed along the banks of Baker Creek (Rouse and Mathews, 1979, p. 428), at Big Bend (Appendix A, Section 4) and possibly in the +100 m thick section of McCallum's (1969, p. 10) gravel facies, exposed along the west bank of the Fraser River, 20 km south of Prince George.

At Big Bend (Fig. 6C) and in parts of Australian Creek (Fig. 6A, B, D), strata of Lithofacies 1 are characterized by weakly consolidated, massive to crudely stratified, buff to grey weathering, sandy, cobble and pebble conglomerate, interbedded with homogeneous, root-bearing claystone, siltstone and minor coal. Typically, the conglomerates occur as irregular, discontinuous sheets (Fig. 6D, E) 20 to 120 cm thick, with poorly developed planar or irregular stratification on a 1 to 5 cm scale. Width to depth ratios of the conglomerate bodies generally exceed 50:1. Lower contacts of the units are generally sharp planar surfaces (Fig. 6D) although irregular erosional contacts are present locally (Fig. 6E). Clasts within the stratified conglomerates include rounded to very angular forms, with angular and subangular forms predominant (Fig. 7). All of these features are consistent with deposition by sheet flood and channel processes in the mid to distal parts of an alluvial fan, below its intersection point (Blissenbach, 1954; Hooke, 1967; Bull, 1972; Hogg, 1982; Rust and Koster, 1984).

Within the upper part of the type section along Australian Creek, there is a noticeable upsection increase in both mean and maximum grain size, which corresponds to an increase in abundance of nonstratified (massive) deposits at the expense of stratified forms. In the upper reaches of Australian Creek, these massive deposits (Fig. 6A, D) are typically thick to very thick bedded (30 to 150 cm) and at best show only minor crude internal stratification. Inverse coarse-tail grading (Walker, 1975) is apparent in the basal parts of some units. Lower contacts of the massive units are generally sharp and irregular to sub-planar. Interbedded with these conglomerates are thin (1 to 5 cm) beds of organic-rich siltstone, which in places incorporate minor transported woody material (Fig. 6B). In one exposure, a tree stump in growth position appears to have been engulfed by the overlying conglomerate bed. Clasts in the massive conglomerates include rounded to angular forms. As with the stratified conglomerates, subangular and angular forms predominate, although there is a slightly greater abundance of angular forms.

Features of the massive conglomerates of Lithofacies 1 are consistent with deposition by slurry flow (Wasson, 1979) and debris flow processes in the proximal parts of an alluvial fan (Hooke, 1967; Bull, 1972; Pierson, 1980; Rust and Koster, 1984).

Mean grain size of strata of Lithofacies 1 is in the very coarse sand to large-pebble grades, with maximum grain size in the medium-pebble to cobble range. Grain size analysis of one massive (Australian Creek A) and two stratified conglomerates (Big Bend and Australian Creek A) are included in Appendix B, Table 4. The grain size distributions of these conglomerates do not appear significantly different to those of strata in Lithofacies 2, except that they tend to be mesokurtic to platykurtic, while those of the latter range from mesokurtic to leptokurtic (Appendix B, Table 4).

While angular clasts are slightly more abundant in strata of Lithofacies 1 (Fig. 7), the gross similarity in clast composition, shape and grain size distributions between Lithofacies 1 and 2 means that these facies can only be distinguished in core by their association with other rock types. Conglomerates below the 195 m level of borehole Q3 (Appendix A) may include some strata of alluvial fan origin. This is difficult to prove, but may be indicated by the paucity of associated

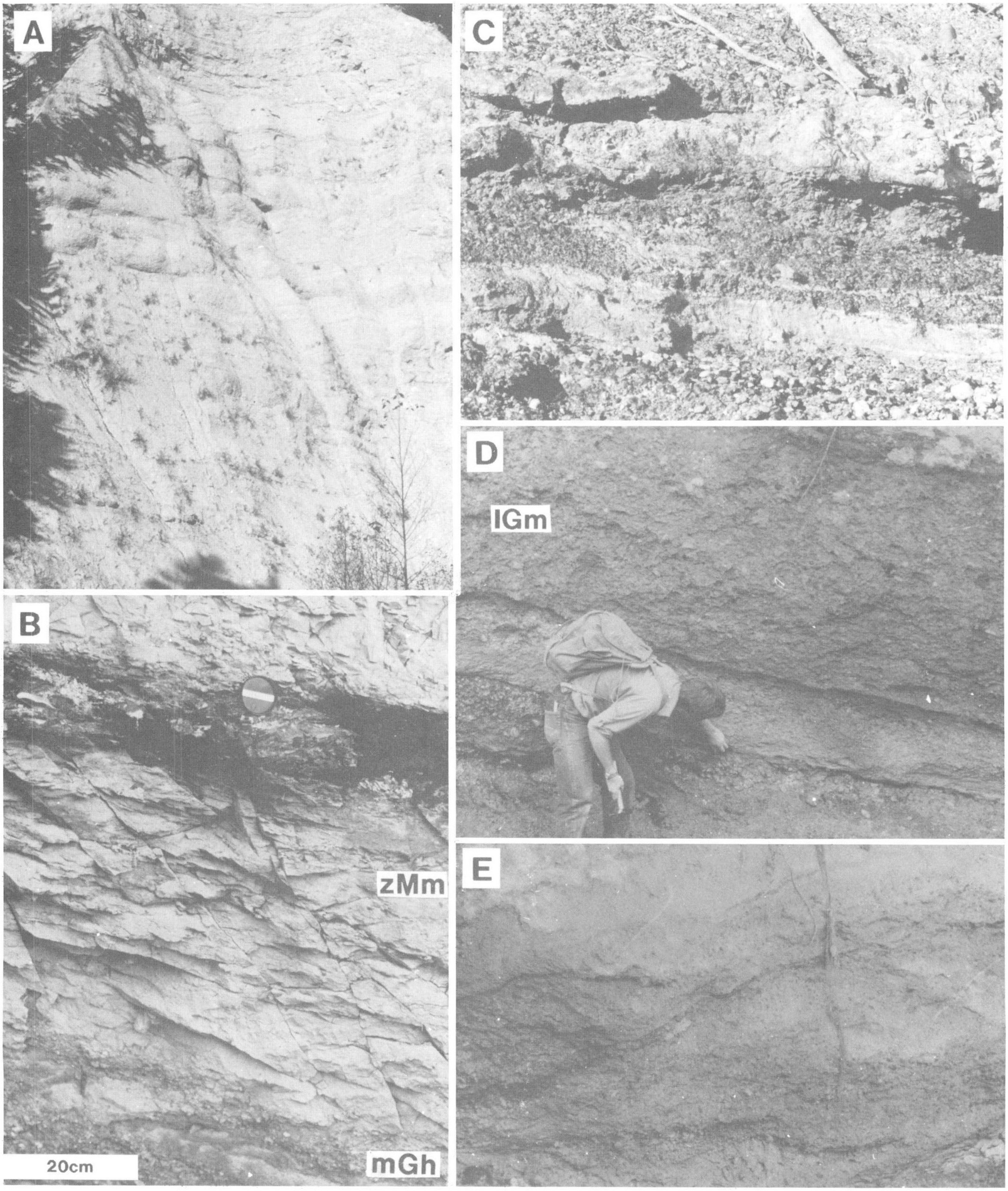

Figure 6. Conglomerates and associated strata.

A. Conglomerate with minor mudstone in alluvial fan deposits in the upper reaches of Australian Creek.
B. Beds of massive silty mudstone (zMm) and woody lignite (black) overlying a weakly stratified, small- to medium- to large-pebble conglomerate (mGh) of fan origin, Australian Creek.
C. Massive and stratified conglomerates of distal fan origin, Big Bend, Fraser River.
D. Thick bed of massive, poorly sorted, medium- to large-pebble conglomerate (lGm) of mass flow origin, overlying interflow lignite and mudstone, Australian Creek.
E. Lenticular channel-fill conglomerates of proximal fan origin, Australian Creek.

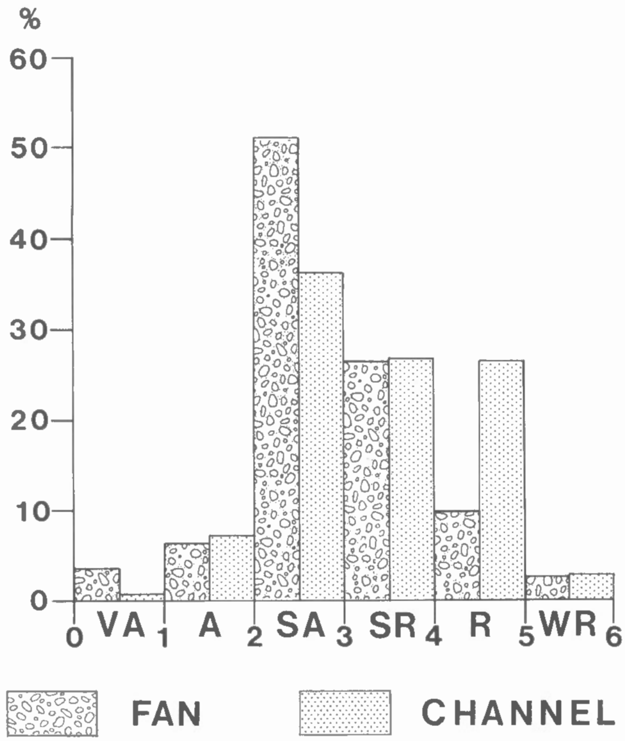

Figure 7. Distribution of Powers' (1953) roundness values (weight per cent) in alluvial fan and channel deposits. VA = very angular, A = angular, SA = subangular, SR = subrounded, R = rounded, WR = well rounded. Note that the mean roundness is lower for the fan sample (2.9 : Australian Creek, Sample A) than the channel sample (3.3 : borehole Q2, 144 m level).

sandstones and siltstones with fining-upward motifs in this part of the sequence, combined with the presence of poorly sorted strata of flood or mudflow origin.

LITHOFACIES 2: lenticular conglomerates

Thin to thick, massive and plane bedded lenticular bodies of granule to large-pebble conglomerate are conspicuous in outcrops at Baker Creek (Fig. 8) and Westply (Appendix A, Sections 2, 3). They are also present as a minor component in the type section at Australian Creek (Appendix A, Section 1) and at Alexandria Ferry (Appendix A, Section 5).

At Baker Creek (lat. 52°59′10″N; long. 122°32′W) a series of steep-walled channels, 1 to 5 m thick and 12 to 30 m wide, is exposed within a 12 m thick sequence of flat-lying mudrocks of Lithofacies 6 and 7 (Fig. 8A). The medium- and small-pebble conglomeratic channel-fill is typically massive or exhibits poorly defined plane bedding and shows no systematic coarsening or fining trends. The locally steep-walled conglomeratic bodies occur in a sequence of massive to weakly laminated mudrock with abundant slickensides and carbonized roots (Fig. 8B) and only minor sandstone. Local relief at the base of some channels is in excess of 1.4 m.

The poorly defined planar bedding that characterizes the conglomerates in the Baker Creek section is consistent with deposition on longitudinal in-channel bars (Ore, 1964; Smith, 1970). The high relief of the channel walls, combined with the abrupt lateral contacts between the conglomerates and adjacent mudrocks are indicative of deposition in a fluvial channel in which lateral channel migration was limited by vegetation (Smith, 1976). The absence of distinct fining-upward sequences, combined with the abrupt upper and lower contacts of the channels suggest that they were avulsion controlled, with little or no lateral migration (Try et al., 1984).

In the Westply sections (Appendix A, Sections 2, 3), channel-fill conglomerates are typically of granule to large-pebble grade, and may be associated with medium grained sandstones of Lithofacies 4 (Section 3: 45, 55 and 57 m levels). The conglomerates are typically massive to plane bedded, with minor planar and trough cross-stratification. Larger scale structures (Fig. 9A, B) may represent side or point bars, indicating at least some lateral migration of the river system. Individual conglomerate lenses are up to 3.2 m thick and may be more than 20 m wide.

In the Australian Creek section, conglomerate is confined to narrow channels (0.8 to 4 m wide and 0.3 to 0.97 m deep) which were partly eroded into associated mudrocks (Appendix A, Section 1: 12, 14, 20 and 46 m levels). The fill of these channels shows no evidence of sedimentary structures, other than weakly developed plane bedding. Typically the channel-fills are of uniform granule to small-pebble grade and show no evidence of coarsening- or fining-upward trends (Fig. 9C), suggesting deposition in small, fluvial, distributary channels where the walls were stabilized by vegetation (Smith 1976).

At Alexandria Ferry, granule conglomerate is confined to the base of one 35 m wide, sand-filled channel (Appendix A, Section 5). Conglomeratic strata are present at several levels in the three GSC boreholes (Appendix A). Because the grain size characteristics of strata of Lithofacies 2 are fairly similar to those of the conglomeratic alluvial fan deposits of Lithofacies 1 (Appendix B, Table 5), conglomerates cannot be used to distinguish channel and fan facies with any certainty. The presence of obvious stratification,

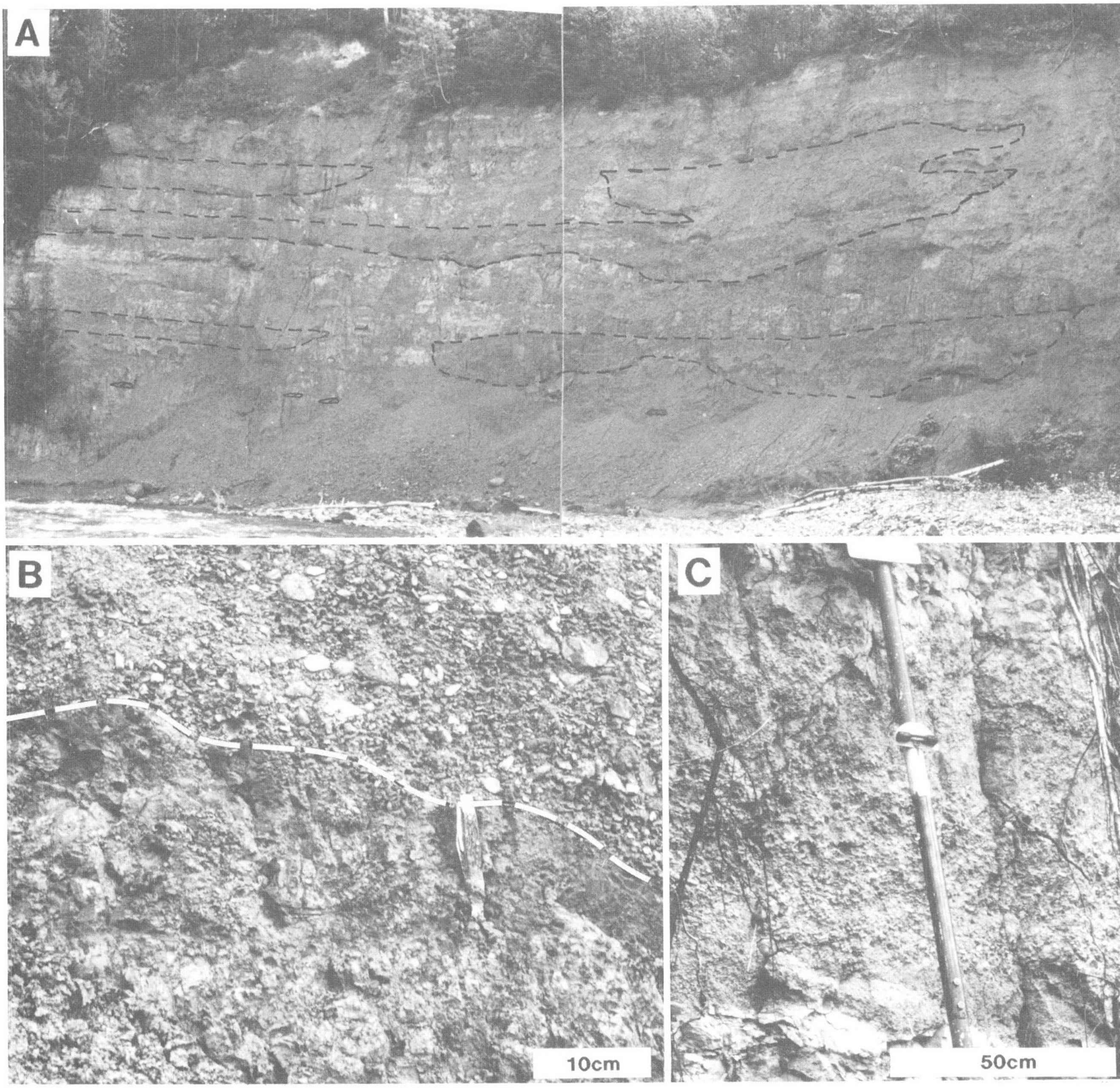

Figure 8. *Channel conglomerates.*

A. Stacked conglomeratic channels in a mudstone dominated sequence on Baker Creek (lat. 52°59' 10"N; long. 122°32' W).
B. Close-up view of the bases of the channels in the lower centre of Figure 8A. Note the crude planar stratification of the medium- to large-pebble conglomerates (top) and the stepped erosional contact (dashed) with hackly textured massive mudstones (base).
C. Details of the stratification in a channel-fill conglomerate in the lower reaches of Baker Creek (lat. 52°59' 13"N; long. 122°31' 44" W).

combined with small-scale variation in clast size within sets, permits the discrimination of proximal fan and channel deposits. A further useful criterion is the common association of abundant medium to very coarse grained sandstone with channel-fill conglomerates in surface sections. These sandstones were rarely seen in association with fan deposits. In borehole Q2, conglomeratic channel deposits and associated medium to very coarse sandstones at the 140 to 149 m level (Fig. 9D) show no systematic fining- or coarsening-upward trends, indicating deposition on in-channel bars, rather than point or side bars. In borehole Q3, similar deposits are present at the 78, 100 to 106, 111 to 143, 151 to 155, 160, 196 to 215, and 224

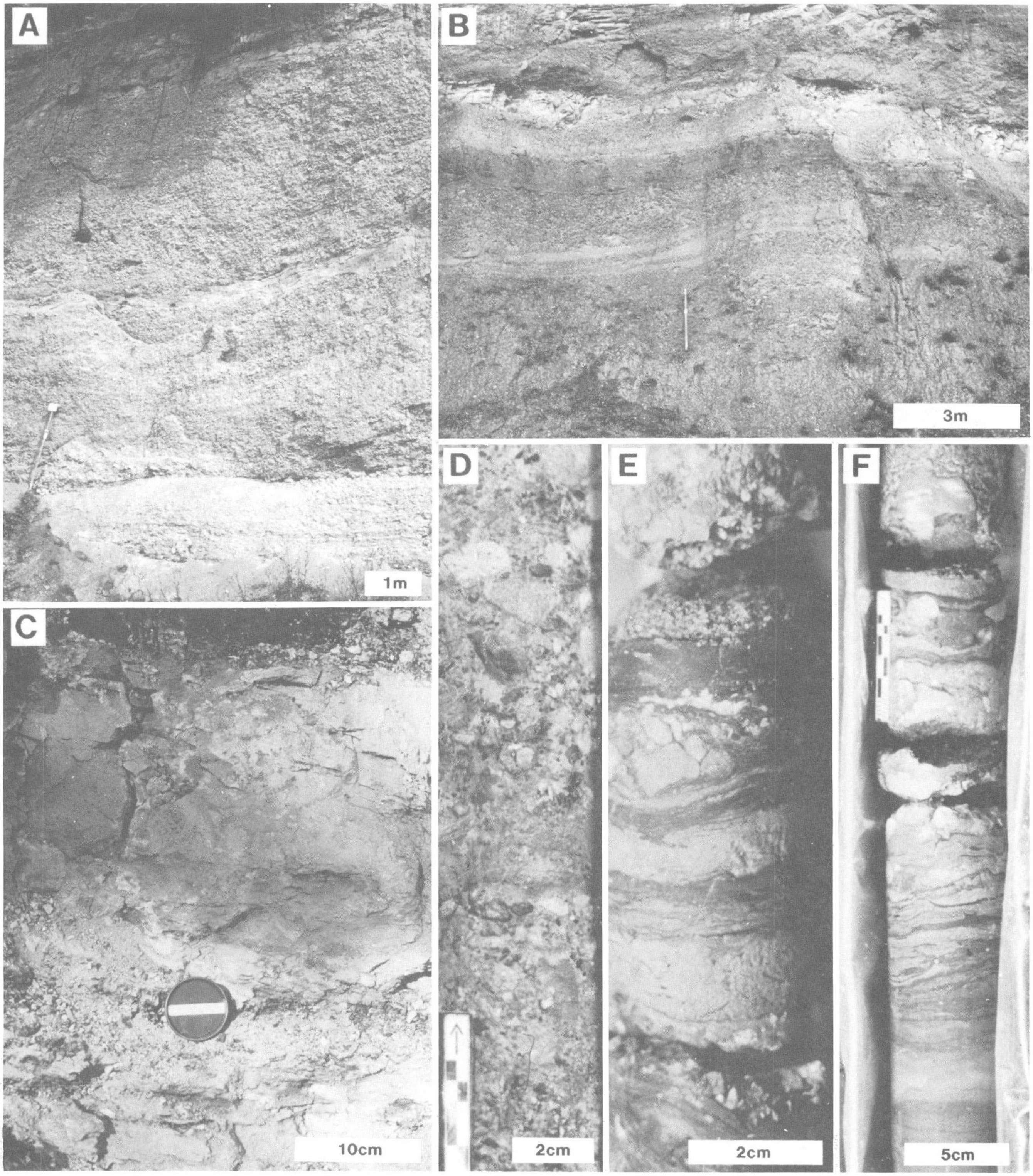

***Figure 9.** Outcrop and core examples of bar, splay, and channel deposits.*

A. *Inclined stratification of side bar origin at Westply (Section 3).*

B. *Inclined stratification of (?)point bar (+51 m) origin at Westply (Section 3).*

C. *Conglomeratic lag at the base of a sand-filled channel, Australian Creek (Section 1).*

D. *Stratified conglomerates in core from borehole Q2 (148 m level).*

E. *Part of a coarsening-upward splay sequence, containing sand (light), organic-rich muds (dark), and conglomerate (top), in core from borehole Q1 (196 m level).*

F. *Coarsening-upward sequence (bottom) of flat to wavy laminated mud (dark) and sand (light) at the base of a channel-fill conglomerate (top), in core from borehole Q1 (199.3 m level).*

to 230 m levels. Thinner conglomeratic sets, associated with fining-upward sequences at the 90 and 189 may represent the basal parts of point bar sequences.

In borehole Q1, conglomerates at the 210 and 214 m levels show a minor, nonsystematic fining-upward trend. As in the sequence at the 195 to 199 m level, these conglomerates are overlain and underlain by laminated mudrocks of either lacustrine or floodpond origin, or both, and could be interpreted as delta distributary channel deposits.

LITHOFACIES 3: thin sheet conglomerates

The thin beds of conglomerate, found in intimate association with coarsening- or fining-upward sets of flat, wavy and ripple crosslaminated units of very coarse to very fine grained sandstone at the 156 m level of borehole Q2, and the 124 and 201 m levels of borehole Q3, are here interpreted as proximal splay deposits. They may represent either sheet flood deposits developed on a splay surface, or lag deposits that accumulated in crevasse channels during flooding. The presence of mudstone drapes containing concentrations of organic material is consistent with either interpretation.

LITHOFACIES 4: stacked, lenticular sandstone

Strata of Lithofacies 4 are characterized by highly lenticular, stacked sets of massive or plane bedded sandstone in units 0.2 to 4.6 m thick. These show little or no evidence of systematic fining- or coarsening-upward (Fig. 10A). Ripple and planar cross-stratification are present locally, but are not common. Similarly, these sandstone units are found in association with conglomerates of Lithofacies 2 in exposures at Westply (Section 2: 3, 6, and 15 m levels; and Section 3: 10, 23, 30, 51, 45, 55, and 57 m levels) and Australian Creek (Section 1: 12 m level). They also occur as isolated units in exposures along Australian Creek (Section 1: 44, 45, and 48 m levels) and Alexandria Ferry (Section 5: 12, 13, 15, 16, and 18 m levels).

In the Australian Creek section, lenticular units of massive or weakly laminated, very fine to coarse grained sandstone are present as channel-fill units at the 12, 44, 45, and 48 m levels. These units are typically two to seven metres wide and less than one metre thick (Fig. 9C). They are surrounded by massive mudrocks with abundant slickensides and carbonized root fragments, suggesting deposition in minor fluvial distributary channels with banks stabilized by extensive vegetation (Smith, 1976).

Sandstones of Lithofacies 4 in the Alexandria Ferry section occupy channels up to 35 m wide, which are cut into laminated and ripple laminated sandstones of Lithofacies 5, and massive to weakly laminated mudrocks of Lithofacies 6 and 7. The channel-fill sandstones are of medium to very coarse granular sand grade and locally exhibit ripple and planar cross-stratification which is directed to the north (Fig. 10C). The absence of fining-upward trends or epsilon cross-stratification in these units indicates that they may have been deposited in moderately stable fluvial channels, in which water flow was inadequate to transport conglomeratic material. Similar slackwater, or low flow conditions may also be indicated by the presence of sandstones of Lithofacies 4 in intimate association with conglomerates of Lithofacies 2 in the Westply sections.

In the subsurface, strata of Lithofacies 4 are found in association with conglomerates in boreholes Q1 (119.8 m level), Q2 (139 and 144 to 150 m levels), and Q3 (86 to 143, 145 to 151, and 187 to 204 m levels). They are typically massive to plane bedded sandstones, with only minor ripple, planar and trough cross-stratification. As in the Westply sections, the sandstones occur in uniform stacked sets indicating deposition in minor or slackwater channels, or alternate with granule to medium pebble conglomerate, suggesting fluctuating energy levels in the major channels.

Thin (10 to 20 cm) sandstone units, representing minor channel deposits, similar to those in the Australian Creek section, are present in borehole Q1 at the 66.6, 111.2, and 113.8 m levels and in borehole Q3 at the 158.2, 171.6, and 174.3 m levels. Thicker sequences (47-100 cm) at the 139.5, 145 and 160.9 m levels in borehole Q1 have profiles that resemble channel-fill sandstones in the Alexandria Ferry section. The 4.3 m thick sandstone sequence at the 105 m level of borehole Q2 differs from the Alexandria Ferry channels in being capped by a fining-upward sequence, which may represent a splay or a channel abandonment sequence. Alternatively, this could be interpreted as the upper part of a point bar sequence.

LITHOFACIES 5: thin sheet sands

Sequences of laminated and ripple cross-stratified, fine to very coarse grained sandstones, which occur in thinning- or thickening-upward sequences, commonly

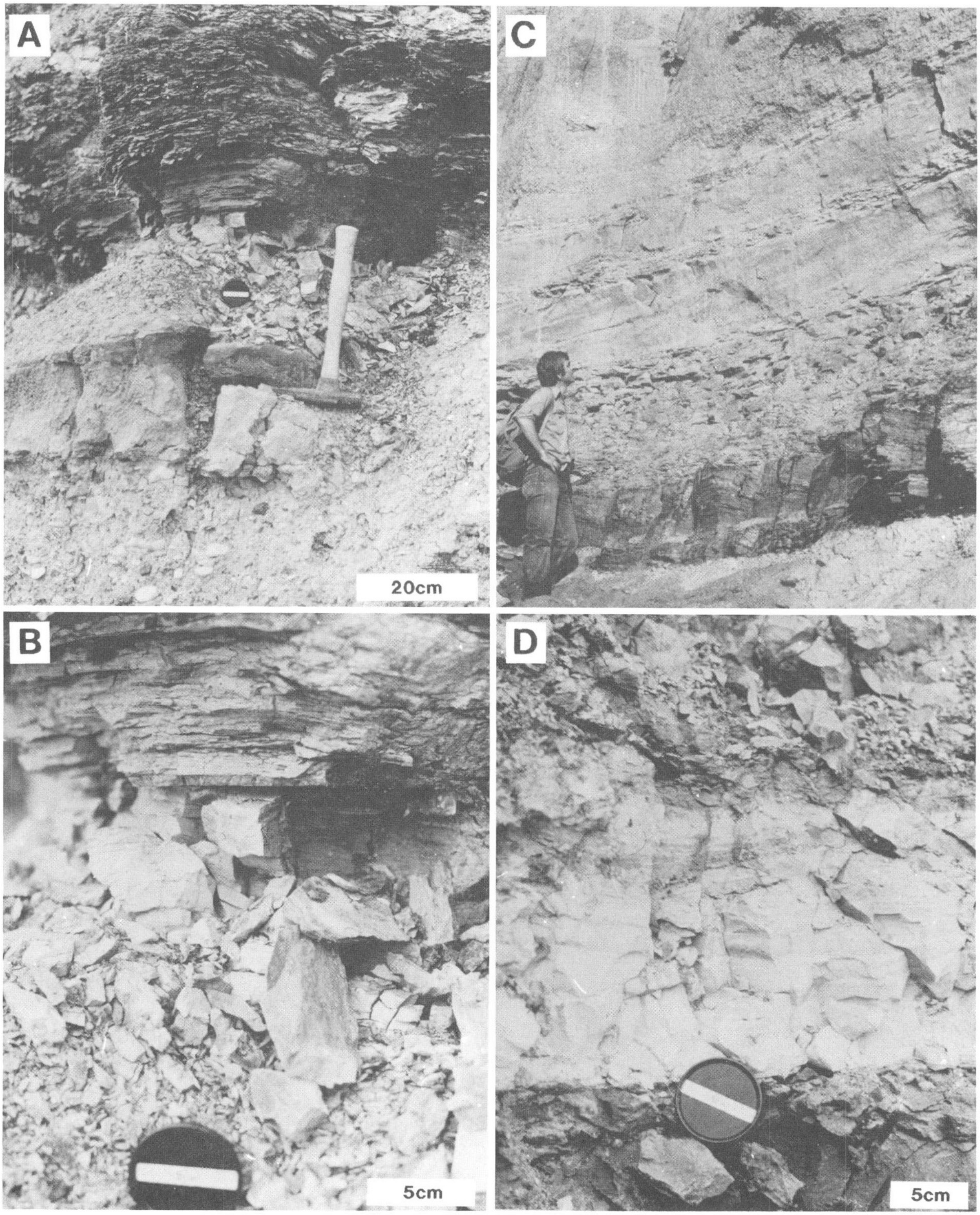

Figure 10. *Channel, levee and splay deposits.*

A. *Thin channel-fill sandstone (below hammer) in conglomeratic channel-fill conglomerate, capped by levee sands and muds (above hammer), Westply.*

B. *Close-up view of levee-splay sands shown in Figure 10A.*

C. *Cross-stratified channel-fill sands in a mudstone dominated sequence at Alexandria Ferry.*

D. *Ripple cross-stratified, splay sandstones (light) in mudstones, at Weldwood (Section 2). Note the sharp lower contact, and destruction by roots of textures in the upper part of the bed.*

associated with mud drapes and rooted sandstones and mudstones, can be interpreted as levee and splay deposits. Thin isolated sandstone units in exposures at Australian Creek (Section 1: 10, 15, 17, and 18 m levels) and Alexandria Ferry (Section 5: 19.4 m level) appear to have greater lateral continuity than associated channel-fill deposits, and are here interpreted as distal splay deposits. In the Westply sections, levee and splay sandstones are found either capping (Fig. 10B), or laterally adjacent to channel-fill sandstones and conglomerates (Section 2: 7, 14, and 16 m levels; and Section 3: 11, 13, 20, 24, 27, and 32 m levels). Fining-upward sequences dominated by plane bedded or ripple laminated sandstones (Fig. 10D) are most likely of splay origin, while those with abundant interbeds of mudstone may represent levee deposits.

In the subsurface, massive, plane, wavy and ripple crosslaminated sandstones of levee and splay origin are abundant, both as fining-upward sequences capping channel deposit (boreholes Q1: 119.5, 139, and 198.7 m levels; Q2: 100 to 104 and 141 to 143 m levels; and Q3: 75.9, 83 to 86, 93 to 95, 103, 107 to 110, 114.4, 116.5, 130.5, 159.2, 187, 190, 192, 193, 194.5, 209.6, and 215.7 m levels) and as coarsening-upward sequences underlying channel units [boreholes Q1: 145.2, 161, 196, 199.3, and 215 to 217 m levels (Fig. 9E, F); and Q3: 200.6, 206.5, and 212 m levels].

In the subsurface, distal splay deposits of Lithofacies 5 are found associated with organic-rich and organic-poor mudrocks of Lithofacies 6 and 7. They may show equant (boreholes Q1: 84.3, 106.3, 152, 166.2, 166.5, and 166.9 m levels; Q2: 108.5 and 132 to 137 m levels; and Q3: 154.7, 156.1, 158.2, 165.4, 168.5, 169.1, 216.8, 217.7, 218.6, 221.2, 221.8, 222.3, 222.5, and 222.9 m levels), coarsening-upward (boreholes Q1: 98.4, 149.6, 165.6, 168.2, and 173.2 m levels; and Q3: 155.3, 157.3, 157.6, 170, and 209.2 m levels) and fining-upward trends (boreholes Q1: 60.7, 93.4, 97.7, 100.6, 103.8, 107.4, 113, 113.5, 113.9, 115.3, 116, 120.3, 142, 143.8, 143.9, 148, 148.5, 153.6, 168.7, and 173.5 m levels; Q2: 82.5 m level; and Q3: 143.5, 156.7, 157, 158.8, 162, 163.3, 163.8, 164.8, 206, and 219 m levels), which can be interpreted in terms of changing discharge within individual flood cycles.

Thin sets of massive, plane and wavy laminated and ripple cross-stratified sandstones are found in intimate association with laminated mudrocks of Lithofacies 8, which are interpreted below as lake and pond deposits (Table 2, Lithofacies 8). They include proximal (borehole Q3: 97 m level) and distal splay deposits (boreholes Q1: 109.1, 167.7, 168.7, 172.2, and 173.4 m levels; and Q3: 92.2 and 92.8 m levels).

Thin sets of (bioturbated) flat to wavy laminated siltstone and flat, wavy and ripple laminated, very fine to very coarse sandstones in borehole Q1 (38 to 55, 122 to 128, and 169 to 175 m levels) are interpreted as lake marginal deposits. Sandstones at the 175 to 180 m level of borehole Q1 are interpreted as prodeltaic distributary lobe deposits.

LITHOFACIES 6: massive, organic-poor mudrocks

Massive to weakly laminated olive-grey (5Y 4/2) to pale olive (5Y 6/4) mudrocks dominate much of the Australian Creek Formation. In outcrop (Fig. 11C–E), many contain carbonized plant roots, indicating deposition in a wetland or marsh setting where annual water levels did not fall low enough to allow oxidation of buried plant remains. Most of the massive mudrocks are characterized by a hackly texture which reflects the presence of abundant slickensides (Fig. 11D, E). These grooved and polished surfaces are commonly considered to form in association with a fluctuating water table as naturally formed granules, blocks, crumbs or aggregates of soil (peds) rub against each other as they expand and contract in response to wetting and drying (Fitzpatrick, 1980). Soil textures are more pronounced where peds are outlined by thin laminae of clay minerals washed into place during eluviation of the soil, giving the mudrock a brecciated appearance (see borehole Q3: 63 to 74 and 173 to 176 m levels). These may reflect more intensive soil formation, developed on a slight rise formed by differential compaction of mudrocks over an older channel.

Massive to weakly laminated mudrocks containing few to no carbonized root fragments (Westply south: 15 to 18 and 33 to 38 m levels; Alexandria Ferry: 5 to 8 and 21 to 22 m levels; and borehole Q2: 52 to 53 and 57 to 59 m levels) may reflect deposition in temporary floodpond environments. Seasonally high water levels in modern floodponds of the Columbia River inhibit reed growth in areas away from the fringing marsh. While some lamination might be expected to develop in response to flood cycles (Smith and Smith, 1980), this can be destroyed by bioturbation (Smith, 1983) or by desiccation and pedogenesis during low water stages. Transitional contacts between floodpond and marsh deposits attest to the lateral equivalence of these facies. Minor, isolated, poorly sorted siltstones (borehole Q1: 97 and 104 m levels) very fine and very coarse grained sandstones (borehole Q1: 66.5 and 103 m levels) interbedded with massive mudrocks may reflect individual flood events.

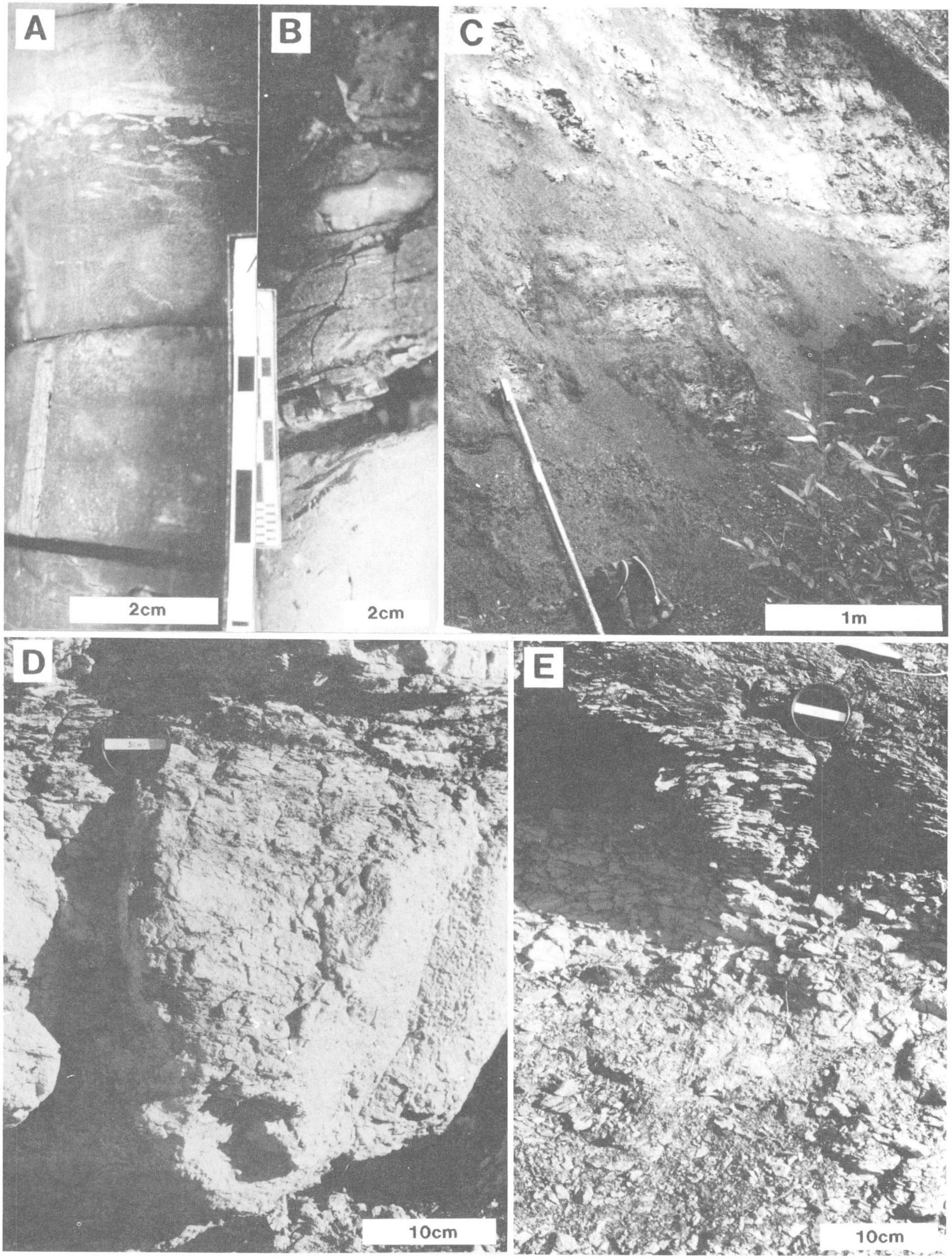

Figure 11. Core and outcrop examples of mudrock facies and lake deposits.

A. Laminated, bioturbated lake deposits in core from borehole Q1 (186 m level).
B. Contact between massive, organic-poor (base) and organic-rich mudrocks in core from borehole Q1 (103 m level).
C. Organic-rich (dark) and organic-poor mudrocks on Australian Creek.
D. Hackly textured mudrock on Australian Creek.
E. Upward transition from hackly textured organic-poor mudrock to coal (top) at Alexandria Ferry.

LITHOFACIES 7: massive to laminated organic-rich mudrocks

Very dark grey (5Y 3/1) to black, massive and weakly laminated mudrocks of Lithofacies 7 occur in intimate association with, and grade vertically and laterally into, lighter coloured mudstones of Lithofacies 6 and lignites of Lithofacies 9 throughout the Australian Creek Formation (Fig. 11B, D). The dark colours of mudrocks of Lithofacies 7 reflect accumulation of organic material in marsh or levee marginal settings where groundwater levels remained high enough year round to prevent complete oxidation of plant material.

LITHOFACIES 8: laminated mudrocks

Thin (0.3 to 3.8 m) sets of uniform, olive-grey (5Y 4/2) to black, massive to very fine laminated mudrocks containing a few well preserved plant remains were observed in outcrops at Westply (Section 2: 3 and 13 m levels) and Alexandria Ferry (Section 5: 10, 12.5, and 24 m levels), and in the subsurface (boreholes Q1: 143, 146, and 151 m levels; Q2: 65.5, 78, and 131 m levels; and Q3: 96 m level). The absence of abundant carbonized plant roots, combined with the frequent presence of even, parallel lamination (Fig. 12B, C) indicate that, unlike the floodponds discussed above (in Lithofacies 6), these deposits accumulated in semi-permanent floodplain ponds. Graded lamination within some deposits may reflect flood cycles (Smith and Smith, 1980).

Thicker sequences (1.5 to 38.9 m) of dark grey (5Y 4/1) to black (5Y 2.5/1), even, parallel laminated mudrocks containing well preserved plant remains and minor intervals of poorly stratified, very fine to very coarse grained sandstone were encountered in the subsurface in boreholes Q1 (15 to 55, 84 to 86, 123 to 128, 136 to 139, 166 to 193, and 196 to 208 m levels), Q2 (158 to 161 m level) and Q3 (80 to 84 m level). These thicker sequences of laminated mudrock may represent deposition in larger bodies of water that developed on or in front of the floodplain. A lacustrine origin is confirmed by the presence of bioturbation [boreholes Q1: 42 to 55, 123 to 133, 180 to 187 (Fig. 11A), 198, and 203 to 207 m levels; Q2: 157 to 161 m level; and Q3: 81 m level] and abundant thin-walled pelecypods (borehole Q1: 171 to 191 m level). The latter include unioid shell fragments (179.6 and 180.3 m) and *Sphärerium*? sp. (L.S. Russell, written communication, 1980).

LITHOFACIES 9: lignite

Lignite forms a minor, though important, part of the Australian Creek Formation. It is exposed locally along the banks of the Fraser River (Fig. 2) at Alexandria Ferry (Appendix A, Section 5), and along Australian Creek (Appendix A, Section 1). In most outcrops and in the subsurface, the lignites are predominantly dull in appearance. They are typically flat to irregular wavy bedded, with minor bright bands of woody material (vitrain), including tree stumps in growth position (Fig. 12A).

Typically coal seams are highly lenticular (Fig. 3, 4) and have a high ash content (Table 3). They are intimately associated with massive to laminated organic-rich mudstones of Lithofacies 7 and, to a lesser extent, with massive organic-poor mudstones of Lithofacies 6 (Section 1: 0 to 8 m level; Section 5: +10 to -31 m level; and boreholes Q1: 37, 56 to 82, 93 to 95, 100, 110, 133 to 136, 147 to 148, and 155 to 168 m levels; Q2: 32 to 48, 55 to 57, 66 to 77, 81 to 97, 109 to 124, and 150 m levels; and Q3: 91 to 92 and 178 m levels). Contacts may be sharp or transitional (Fig. 11E). The abundance of transitional lower contacts indicates that most of the coal seams accumulated in situ, as swamp deposits. Thin stringers of dull lignite in lake sediments at the 172.6 m level in borehole Q1 appear to represent leaf mats.

Palynology

Building on earlier observations by Piel (1969, 1971) and Rouse and Piel (1969), Rouse and Mathews (1979) noted a distinct relationship between palynofacies and lithofacies in muddy strata from the Australian Creek Formation. They defined three main palynofacies: an *Osmuda* facies, representing peaty swamps with periodic flooding; a *Parviprojectus* facies, representing shallow lake and pond environments; and a *Caraya* facies, representing stable bottomlands with ponds and backwater sloughs. These palynofacies correspond to Lithofacies 7, 8, and 6 respectively of this study (Table 2).

Palynological observations by W.S. Hopkins (written communications, 1978, 1981) confirm the presence of a large and varied floral assemblage during deposition of the Australian Creek Formation in Early Oligocene time. The flora observed is dominated by angiosperms, conifers with non-bladdered pollen grains, ferns, and lower plants, indicating a humid, warm temperate paleoclimate. While Hopkins' observations do not permit detailed correlation of strata in

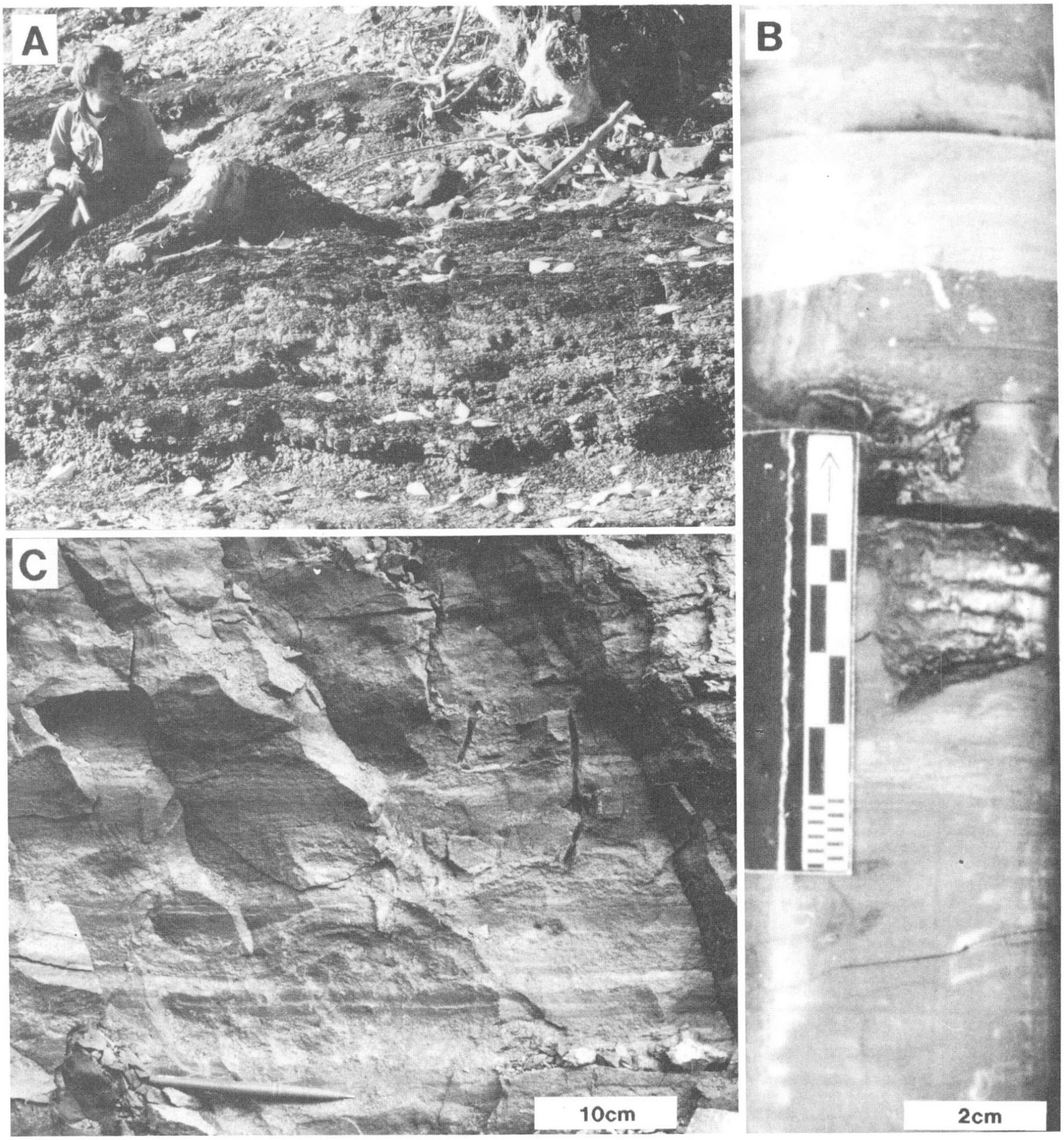

Figure 12. Outcrop and core examples of fine grained sediment and coal.

A. *Laminated mudstone of lake or semi-permanent pond origin at Westply.*
B. *Bioturbated contact between laminated mudstone (dark) and lighter coloured (?)ash bed in borehole Q1 (186 m level).*
C. *Coal seam exposed at Alexandria Ferry. Note the presence of interbedded mudstone, and the tree root in growth position.*

boreholes Q1, Q2 and Q3 (Fig. 13), they do appear to indicate an upsection decrease in the importance of Pineacea with respect to Angiosperms.

DEPOSITIONAL MODEL

Rocks of the Early Oligocene Australian Creek Formation are best interpreted in terms of a valley-fill sequence. The earliest preserved deposits, represented by conglomerates and sandstones in the Kersley No. 1 borehole (Fig. 2) (Laurence, 1953), may represent deposition from alluvial fans and braided rivers. The bulk of the formation overlies these deposits and can be interpreted in terms of deposition on a floodplain characterized by swamp, marsh, floodpond, lake, channel, levee, and crevasse-splay environments, with minor deposition on alluvial fans which prograded from the valley walls (Table 2).

TABLE 3

Proximate analysis of coal samples from the Australian Creek Formation

Borehole/depth m	Moisture %	Ash %	Volatiles %	Fixed Carbon %	Sulphur %	cal./g
Q1/62.13-64.62	31.6	22.0	24.1	22.3	1.88	3103
Q1/158.14-159.66	29.7	33.3	18.6	18.4	1.02	2386
Q1/161.90-163.7	40.2	26.1	19.3	14.4	1.00	2168
Q2/35.66-36.15	47.0	22.1	20.8	10.1	0.19	1953
Q2/45.72-46.18	49.9	18.5	18.6	13.0	0.17	2013

Data presented on an "as received" basis.

The abundance of floodplain facies and the apparent stacked character of the channel-fill conglomerates, combined with the high ash content of the coals, all point to deposition in a fluvial system dominated by vertical rather than lateral accretion. This situation occurs in low gradient fluvial systems where the abundance of plant roots stabilize banks sufficiently to inhibit lateral migration of river channels across their floodplains (Smith, 1976). In normal braided and meandering systems, rivers have enough competence to erode their banks and hence produce sheet sands or gravels (Fig. 14). While the presence of inclined stratification in some channel deposits (Fig. 9A, B), and minor fining-upward sequences in others (borehole Q3: 90 m level) suggest limited channel migration, the bulk of channel-fill conglomerates are interpreted as "shoestring-like" deposits with limited lateral extent. The presence of weakly developed planar stratification in these conglomerates is indicative of deposition on longitudinal in-channel bars.

Stable channel fluvial systems are of two types, those with interconnected multiple channel systems, (termed "anastomosed streams" by Smith and Smith, 1980), and those with single channel systems (termed "covered floodplain systems" by Melton, 1936). The abundance of channel-fill conglomerates and sandstones within the Australian Creek Formation is indicative of deposition in a multichannel, anastomosed system.

Modern anastomosed systems have been described in temperate (Smith and Smith, 1980; Smith and Putnam, 1980; Smith, 1983), tropical-savanna (Tanner, 1974; Smith, 1986), and arid regions (Rust, 1981; Rust and Legun, 1983). In all cases they are characterized by an interconnected network of channels, separated by extensive stable islands with pronounced levees, ponds, bogs and marshes. In intermontane settings the low gradients characteristic of anastomosed streams (8 to 12 cm km^{-1}) are created and maintained by cross-valley progradation of alluvial fans (Smith and Smith, 1980; Smith, 1986). These are represented in the Australian Creek Formation by strata of Lithofacies 1 (Table 2). When fan progradation is rapid, lakes (Lithofacies 8) may develop upstream of the fans. Consequent progradation of highly constructive elongate deltas may provide an initial framework for anastomosed stream development as levees adjacent to distributary channels become stabilized by vegetation. This scenario may be represented by conglomerates at the 195 and 214 m levels of borehole Q1, and prodeltaic sands at the 176 m level.

The abrupt lower and upper contacts of channel-fill conglomerates in the Australian Creek Formation suggest that they were avulsion controlled. The absence of marked vertical trends of decreasing grain size in all but a few of the channel deposits indicates that deposition on point bars, normally considered a characteristic feature of meandering systems, was not common. Most of the conglomerate within the channels appears to reflect deposition on in-channel (longitudinal) bars. The limited grain size range of conglomerates in these channel-fill deposits may indicate that flow conditions remained relatively constant during depositional (flood) cycles. Alternatively, grain size may be largely inherited from streams issuing from alluvial fans along the valley walls. Sandstone intervals within conglomeratic channel deposits reflect slackwater deposition, while non-conglomeratic channels may reflect deposition away from a local supply of coarse clastic material.

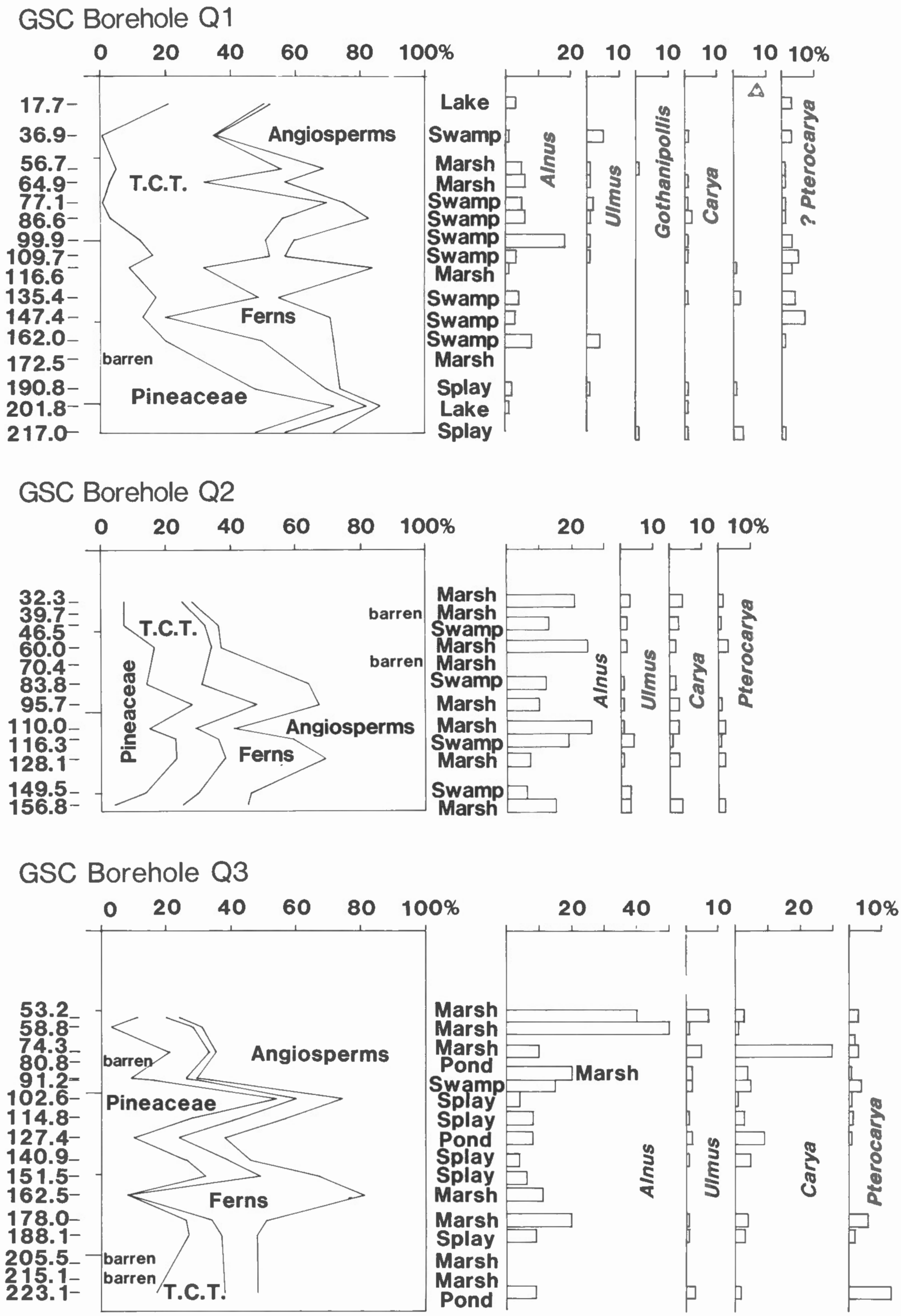

Figure 13. Relative abundance of groups of palynomorphs (left) and selected species (right) in GSC boreholes Q1, Q2, and Q3, based on observations by Hopkins (written communication 1981). T.C.T. = Taxodicceae, Cupressaceae and Taxaceae. Depth of samples is given in metres.

Splay deposits (Lithofacies 3 and 5) develop on the floodplain when flood waters overflow and cut a small channel through the levee to deposit a lobate sheet of sand in the adjacent wetland. Thinning- and fining-upward sequences reflect waning flood cycles or progressive abandonment of a splay as the crevasse becomes blocked by sediment, logs, or growth of vegetation in situ. Coarsening-upward sequences (Fig. 9E, F) are the hallmark of modern anastomosed systems (Smith, 1983). They are produced by the progressive progradation of splays into floodponds during one or more flood cycles. Continued enlargement of levee breaks may lead to the development of new channels (Smith and Smith, 1980) and produce sequences such as those in borehole Q1 at the 145, 165, and 215 m levels.

Smith (1983) noted that wetland facies form 60 to 90 per cent of modern intermontane anastomosed systems, while in the Australian Creek Formation they constitute 74 to 99 per cent of sections measured in the middle part of the formation (Lithofacies 3 and 5 to 8, Table 2). Peat bog facies in modern anastomosed systems contain up to 98 per cent organic material in units up to 1.5 m thick (Smith, 1983). High ash content in coals produced in this setting can be related to frequent inundation by muddy flood waters. In small intermontane systems such as the Mistaya and Alexandria rivers (Smith and Smith, 1980) peat bogs constitute 15 to 30 per cent of modern overbank facies and may occur throughout the floodplain. In larger systems, such as the Columbia River, peat bogs are less abundant and are normally confined to the margins of the valley (Smith, 1983, 1986). This may be directly related to a greater frequency of flooding in the interchannel areas than in swamps with only one side adjacent to a channel.

The predominantly dull appearance of coals in the Australian Creek Formation can be attributed to both a high, flood induced ash content and rapid accretion of predominantly non-woody plant litter in a rheotrophic (Moore, 1989) swamp setting, in which water levels remained sufficiently high to prevent their selective oxidation (Stach et al., 1982; Bustin et al., 1983; Moore, 1987). The presence of local stands of trees or woody shrubs is indicated by tree stumps in growth position (Fig. 12A) and thin bands of vitrain in the coals.

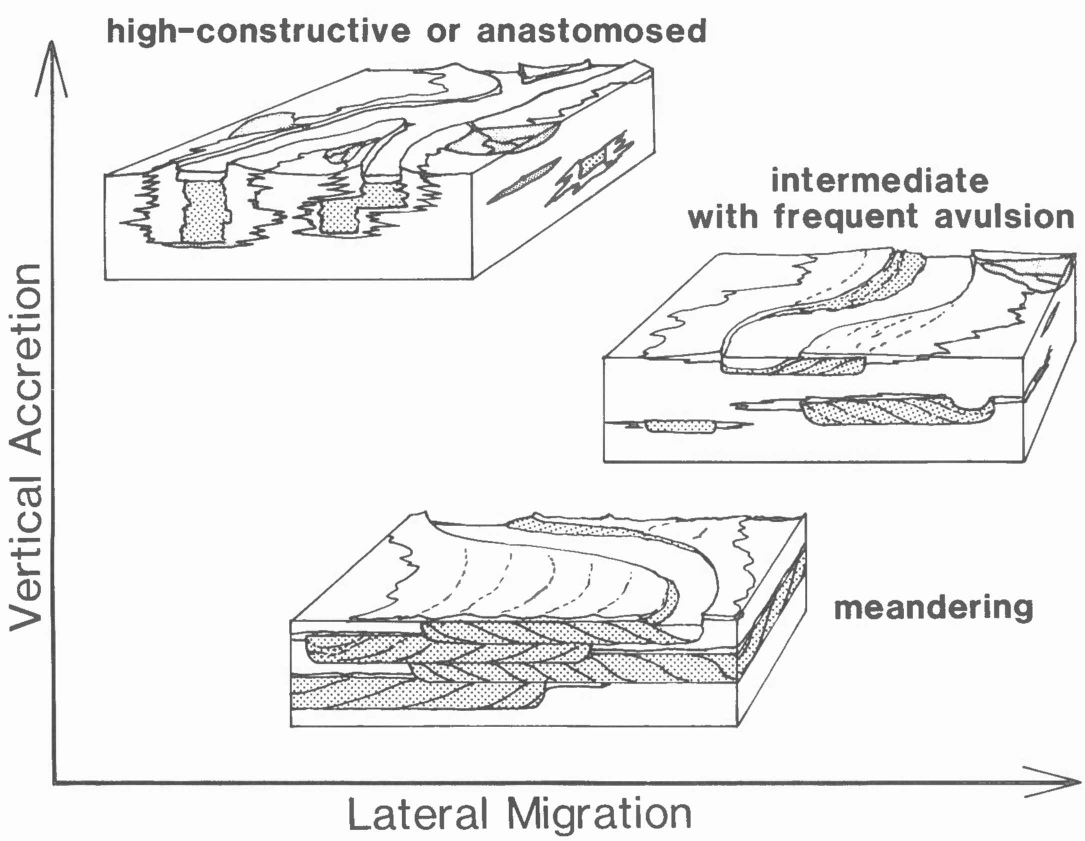

Figure 14. Effects of variations in the rates of vertical accretion and lateral migration on channel geometry in meandering and anastomosed river systems.

The range of average sedimentation rates in modern anastomosed rivers is 0.6 mm a^{-1} in the Mistaya River, 1.5 mm a^{-1} in the Saskatchewan River, 1.8 mm a^{-1} in the Alexandria River, and 3.8 mm a^{-1} in the Magdelena River, to 6 mm a^{-1} in the Columbia River (Smith, 1986). This requires comparable subsidence rates, or downstream grade control by cross-valley fan progradation in order to allow preservation. Smith (op. cit.) suggested that when sedimentation rates fall much below 1 mm a^{-1}, graded or meandering rivers will develop. Conversely, high subsidence rates do not appear to be conducive to the preservation of thick peat bogs in tropical–savanna settings (Smith, op. cit.); hence, the presence of thick coal seams in the Australian Creek Formation suggests subsidence (or fan aggradation) rates in the order of 1 to 2 mm a^{-1}.

SYNDEPOSITIONAL VOLCANISM

Volcanic rock fragments are a common framework component of both sandstone and conglomerate in the Australian Creek Formation. Dacitic and andesitic material appears to have been derived mainly from the Middle Eocene volcanic sequence (Kamloops Group equivalents). Other, more altered, coarse to fine grained, mafic to intermediate volcanic and plutonic rock fragments may have been derived from strata of the Quesnel River Group (Tipper, 1978a) and Cache Creek Group (Tipper, 1959). The presence of abundant, yellow-brown, isotropic glass fragments in samples collected from boreholes Q2 and Q3 (Vg in Appendix B, Table 1) may indicate a syndepositional volcanic source. These fragments, which locally form up to 3.6 per cent of the framework component of the sands, occur both as spherical grains and very angular tetrahedral fragments, suggesting that they originated as fragments of perlitic volcanic glass.

Further evidence of synvolcanic activity comes from the abundance of expandable and mixed layer clays (including montmorillonite) in all of the mudrocks analysed (Appendix B, Tables 2, 3). Light coloured bands within lake and pond deposits (Fig. 12B) may represent ash-fall horizons. The best evidence of this comes from the clay fraction of a 1 cm thick, pale yellow (5Y 7/3) layer from the 65.7 m level of borehole Q2, which contains 79 per cent expandable and mixed layer clays (predominantly montmorillonite) and 21 per cent kaolinite (Appendix B, Tables 2, 3).

COAL POTENTIAL

The potential for large tonnages of recoverable coal in the Australian Creek Formation is not high. The present distribution of coal beds is a function of both depositional and erosional events. The peat swamp precursors of the coal seams were probably lenticular, as indicated by the geometry of the coal zone west of Australian Creek (Figs. 2–4). Individual swamps may have been separated by a reticulate net of channels, comparable to the modern anastomosed reach of the Columbia River between Golden and Invermere (Smith and Putnam, 1980; Smith, 1983). In modern systems, uninterrupted peat development is most likely in parts of the floodplain that are close to the valley walls. Peat swamps in the central part of the floodplain are subject to constant inundation during flooding events, leading to lower quality coals and organic-rich mudrocks. Coal deposits away from the valley margin would have been highly susceptible to later erosion of the sequence both in Late Oligocene and Early Miocene times and during valley entrenchment in the Middle Miocene, Late Miocene, Pliocene, Pleistocene, and Holocene. Erosion of the Australian Creek Formation by later river systems has probably left very little coal in place. Several areas of limited economic interest are present (Graham, 1978) and will be discussed below.

Red Cliff

The Red Cliff area, immediately south of Quesnel townsite, derives its name from a cliff-like exposure of fire reddened clays on the east bank of the Fraser River. The red colour of the mudrocks (of organic-rich and organic-poor marsh facies) in this area is due to in situ combustion of adjacent coal seams. Subsurface investigations of local slumping (by the British Columbia Ministry of Highways, internal report, 1967) 560 m south of the cliff face, indicated a 30 m thick coal zone containing abundant claystone units. A similar clay-rich coal zone, 18 m thick, was penetrated by a water well, 800 m to the southeast and between the 32 and 94 m levels of GSC borehole Q2. Within this interval, individual coal seams have a high ash (clay) content and attain a maximum thickness of only 60 cm. It is difficult to suggest an exact correlation between the coal seams encountered along the highway and those in water wells, although a correlation between the highway seams and the 6 m thick coal-rich zone at the 84 m level of borehole Q2 is favoured. Borehole Q3 did not penetrate this coal zone, intersecting instead 180 m of channel-fill conglomerates, splay sandstones, and minor mudstones. Organic-rich swamp facies are only represented in the top few metres of the borehole (53 and 59 m levels). If this organic-rich unit is correlative with the above coal zone, the ash content increases drastically to the east, suggesting proximity to a high-constructive channel.

Alternatively, the coal zone may be missing from borehole Q3 because the hole was collared stratigraphically below this zone, or because of a lateral change from wetland to channel facies. Additional shallow water wells (maximum depth 60 m) east of the borehole Q3 site do not contain a record of any major coal seams.

Irrespective of the correlation between boreholes Q2 and Q3, the coal zone at Red Cliff appears to shale out in an easterly direction. To the west, this zone has been removed by erosion during the formation of the Pleistocene and Recent Fraser River channels.

West Australian Creek

Manalta Coal, under Masters Exploration, drilled 21 rotary holes in the vicinity of Australian Creek (Yoon, 1972). A thick coal seam is exposed along the west bank of the Fraser River, opposite Australian Creek (Fig. 2). Other seams are present, but are laterally discontinuous and rarely exceed 60 cm in thickness. Where encountered in the rotary drillholes (Fig. 3, 4) the main seam had a thickness of 3.4 to 13.2 m. The seam is split by numerous mudstone partings, few of which are thicker than 2 m. The coal zone appears to be lenticular, thinning from 10.5 to 3.4 m in the 150 m between holes QN-71-2 and -3 (Figs. 2–4). The percentage of coal in this zone ranges from 53 to 96 per cent, averaging 72 per cent, the remainder is waste rock.

Given the adverse topography of this area, in combination with the steep dips and complex structure of the Australian Creek Formation (Fig. 2), the amount of recoverable surface coal is limited (Table 4).

TABLE 4

Summary of coal resources, Australian Creek area (in millions of tonnes)

	Depth less than 46 m	Depth more than 46 m	total
Measured	3.3	0.9	4.2
Indicated	7.0	3.0	10.0
Inferred	5.2	9.3	14.5
		Total	28.7

East Australian Creek

The thickness and ash content of coal zones present in outcrops along Australian Creek and in boreholes between the Pleistocene and Miocene channels (Figs. 2–4) is highly variable. This variability, plus the complex structure, steeply dipping bedding, and thick overburden in this area result in a very low potential for the recovery of coal from shallow deposits.

Alexandria Ferry

Coal outcrops along the east bank of the Fraser River in an area just south of the old Alexandria Ferry (Appendix A, Section 5). The thickest seam reported in this section may contain up to 3.5 m of coal in a 4.7 m thick interval of coal and clay (Galloway, 1924). The extent of coal subcrop is limited by the erosion at the base of the Pleistocene channel to the east and the modern Fraser River to the west. Strata in this area dip at about 15°S. There may be some coal in strata east and south of the Ferry, but the complex structure of the Australian Creek Formation and the thick overburden make this an unattractive target.

Coal rank and quality

Although the rank of coal from the Australian Creek Formation has been reported previously as subbituminous B to C on a moisture/mineral matter free basis (Graham, 1978), more recent observations indicate that it is better considered as a lignite (Table 3). All coal seams analysed had a high inherent ash content (excluding partings) which averaged 20 to 30 per cent by weight on a moisture free basis. Given the low thermal value and high ash content of the coals, they appear to be of limited commercial value unless new, thick seams are found in settings amenable to surface mining

CONCLUSIONS

In the Early Oligocene, strata of the Australian Creek Formation accumulated in an intermontane valley whose geometry and subsidence history were controlled by the Fraser River Fault. The character of the earliest deposits in this basin (recorded in the Kersley No. 1 borehole, Fig. 3) may include braided stream and alluvial fan deposits. The progradation of alluvial fans from the sides of the valley provided local grade control, which promoted the development of lacustrine and high-constructive fluvial deposits of probable anastomosed stream origin. Coal accumulated in off-channel rheotrophic swamps, subject to frequent flooding. These floodplain swamps may have been preferentially concentrated toward the margin of the valley system, and were characterized by a predominance of non-woody plants, with only a limited tree cover.

Clastic material was supplied by tributary fan systems to a northerly flowing river system (Fig. 15) that drained an area to the east underlain by strata of the Quesnel River and Cache Creek groups. Less altered volcanic debris was provided by erosion of underlying and adjacent remnants of the Kamloops Group (Table 1) and by possible contemporaneous volcanism. The latter may have supplied the grains of light brown, isotropic, volcanic glass seen in some of the sandstones (Appendix B, Table 1) and the volcanic ash which diagenesis has converted into expandable clays (Appendix B, Tables 2 and 3).

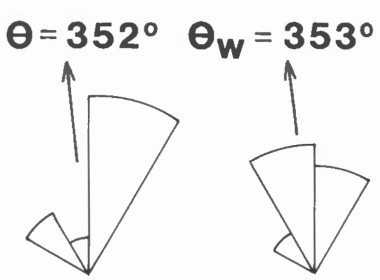

Figure 15. Unweighted (left: variance = 758) and weighted (right) paleocurrent rose diagrams for the Australian Creek Formation. Based on eight crossbed measurements.

The thick overburden, complicated structure and rapid facies changes noted would make coal recovery from the thick lignitic coal seams in the Australian Creek Formation difficult. Thicker seams appear to have had a better chance to develop in settings away from the main channels and close to the valley walls. As much of the original valley marginal sequence has been eroded by later Miocene, Pliocene, Pleistocene and Recent river systems, the probability for the discovery of thick coal seams is low.

ACKNOWLEDGMENTS

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APPENDIX A

Description of stratigraphic sections

Legend (for all sections)

Section 1. Australian Creek (incomplete section)

Section 2. Westply, north

Section 3. Westply, south

Section 4. Big Bend

Section 5. Alexandria Ferry

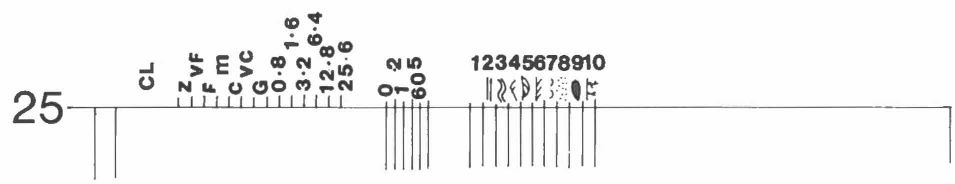
GSC Borehole Q1

GSC Borehole Q2

GSC Borehole Q3

LEGEND (for all sections).

A B C DE F G



A = **Elevation or depth in metres**

B = **Contacts: —— sharp; – – – transitional; · · · · · · not seen.**

C = **Grain size: CL = clay; Z = silt; VF, F, M, C, and VC = sand; G = granules; 0·8 - 25·6 = median grain size of gravel in centimetres. Line to right of column indicates maximum grain size.**

Special lithologies: coal; organic-rich mudrock; rooted mudrock

lenticular unit

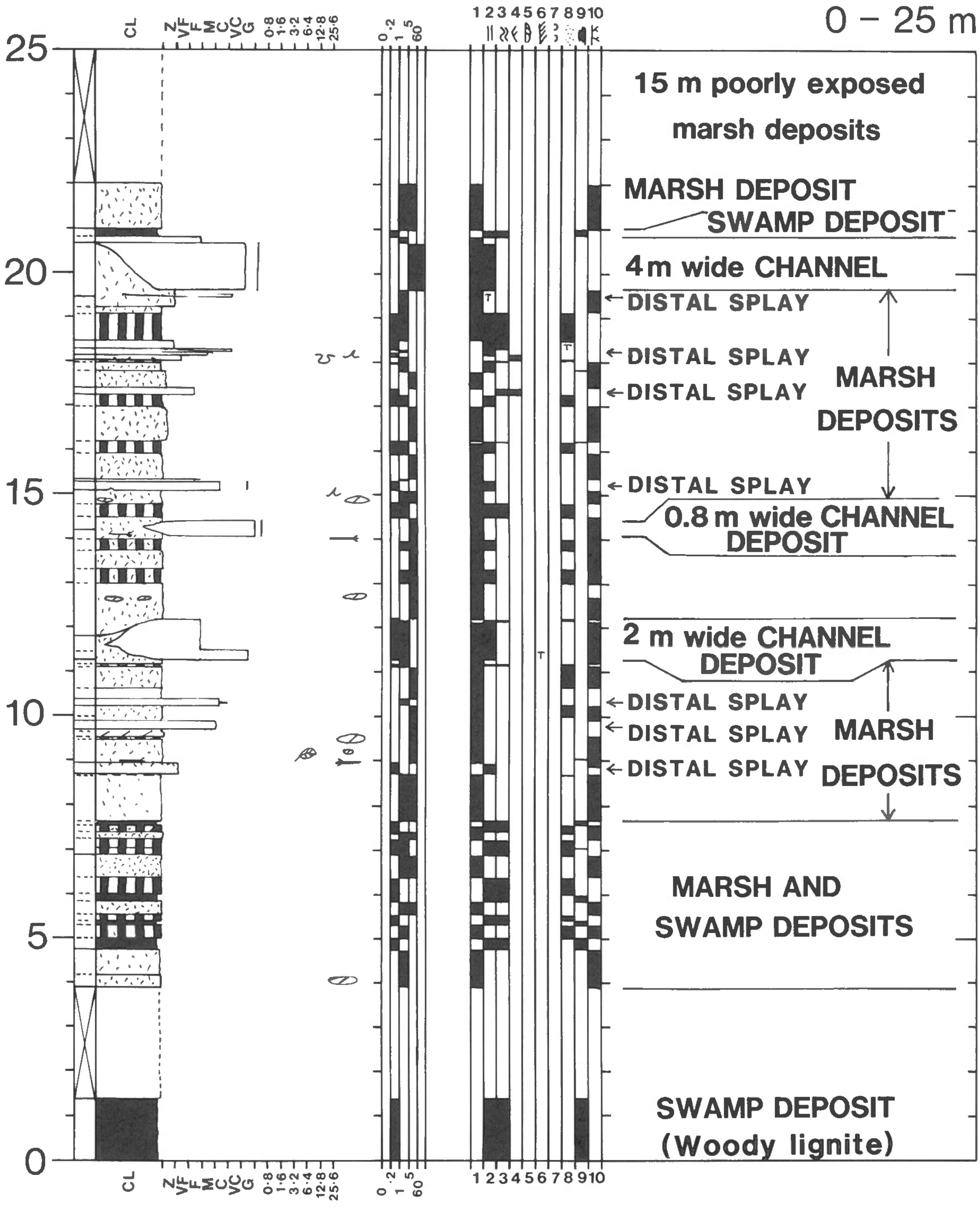
D = **Other features:** siderite concretion; fossil wood; fossil plants; bivalves; bioturbation; extensive ped textures; load structures; flame structures

E = **Bed thickness in centimetres**

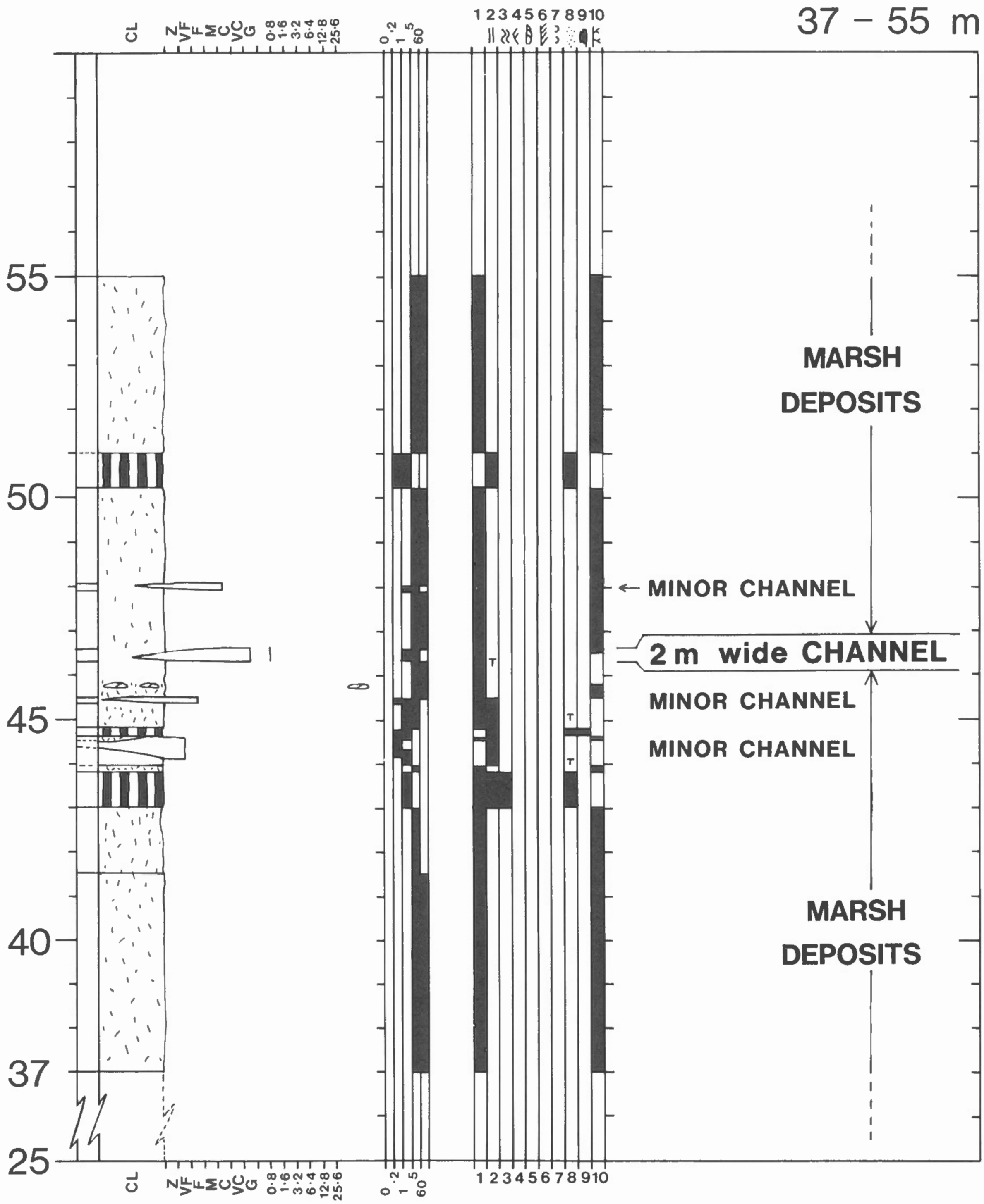
F = **Sedimentary structures: 1 = massive; 2 = plane bedded; 3 = wavy bedded; 4 = ripples; 5 = trough crossbedded; 6 = planar crossbedded; 7 = intraclasts; 8 = dispersed organics; 9 = coal; 10 = fossil roots**

G = **Remarks**

Section 1: Australian Creek 52°43'30"N, 122°26'20"W

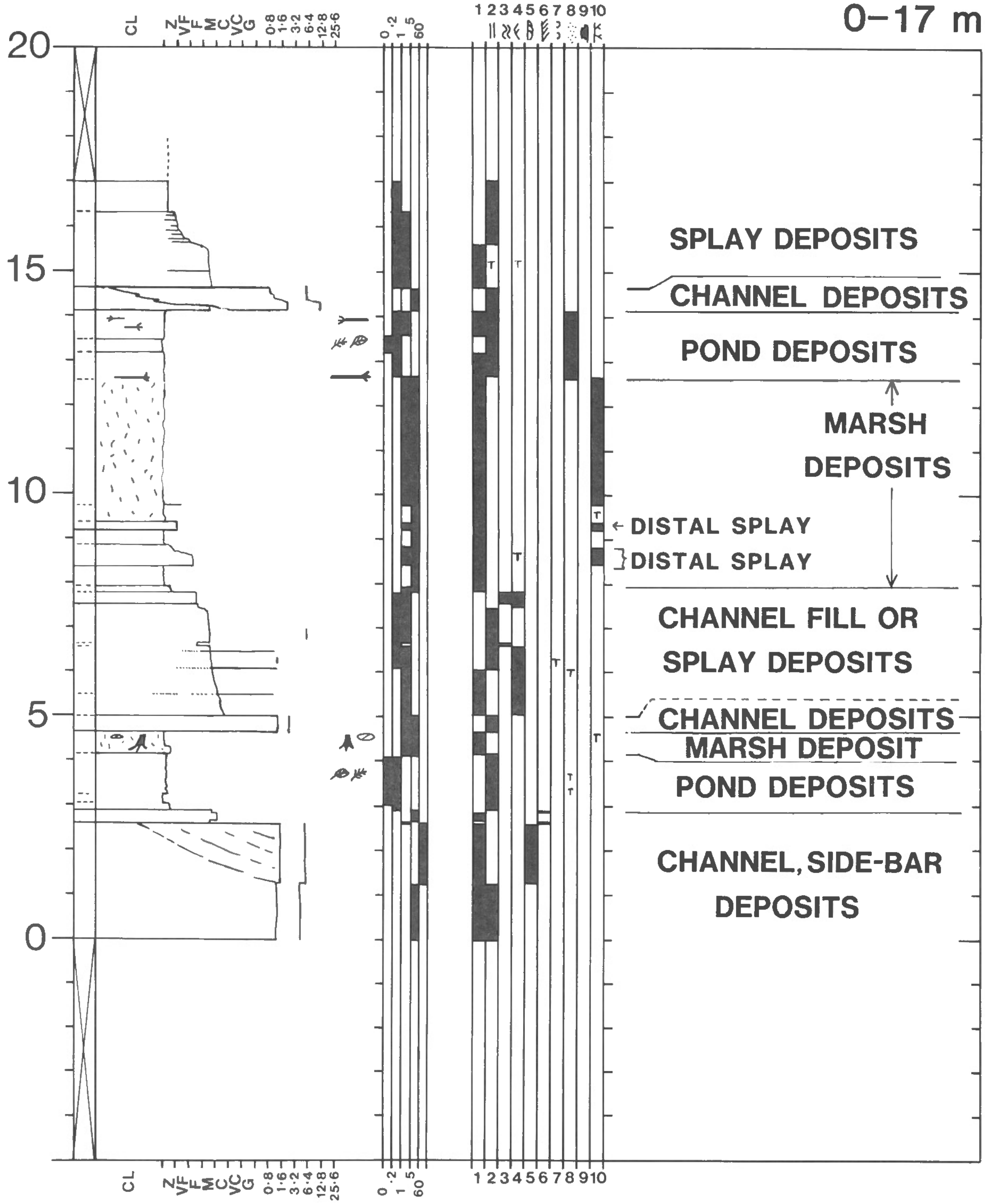


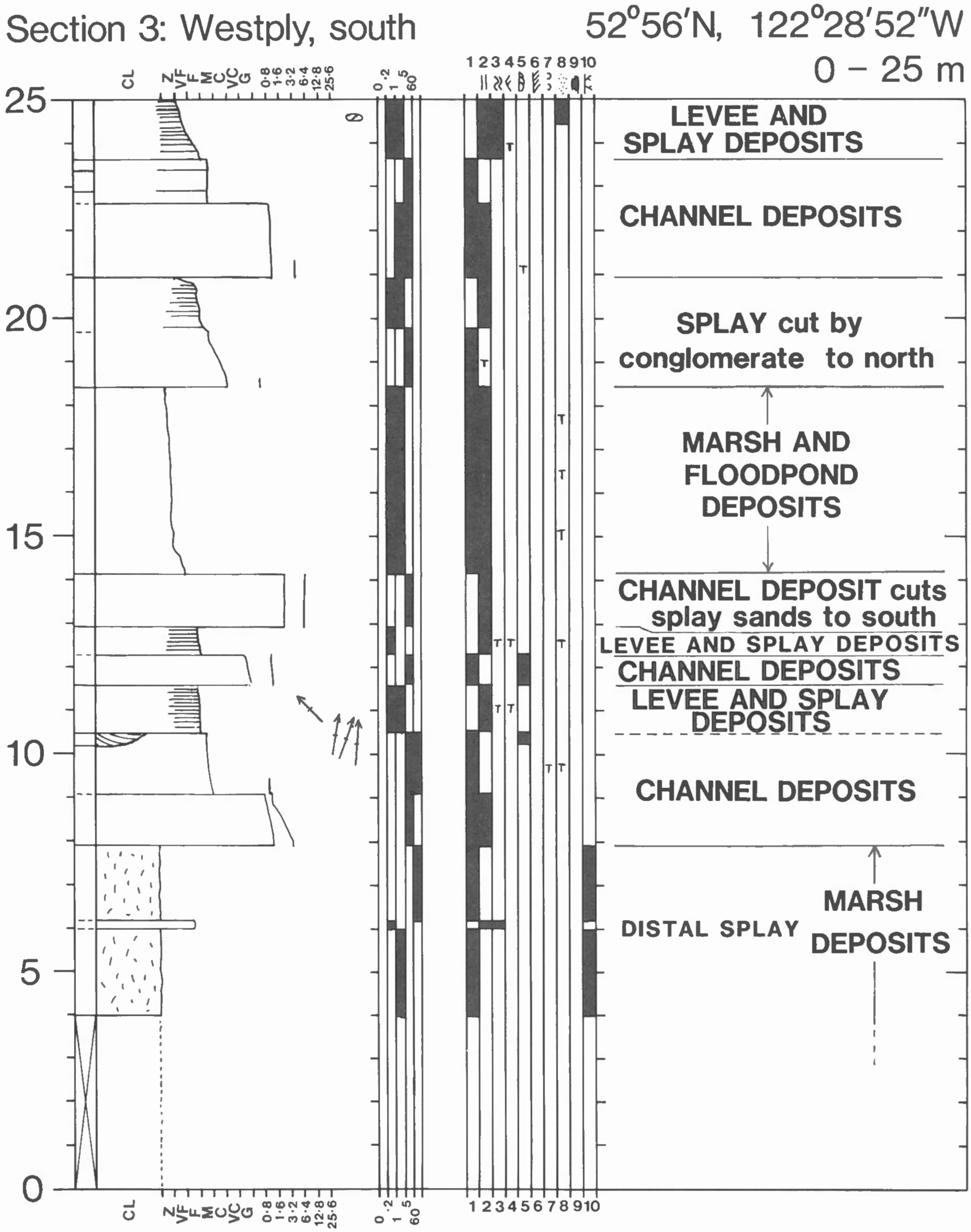
Section 1: Australian Creek



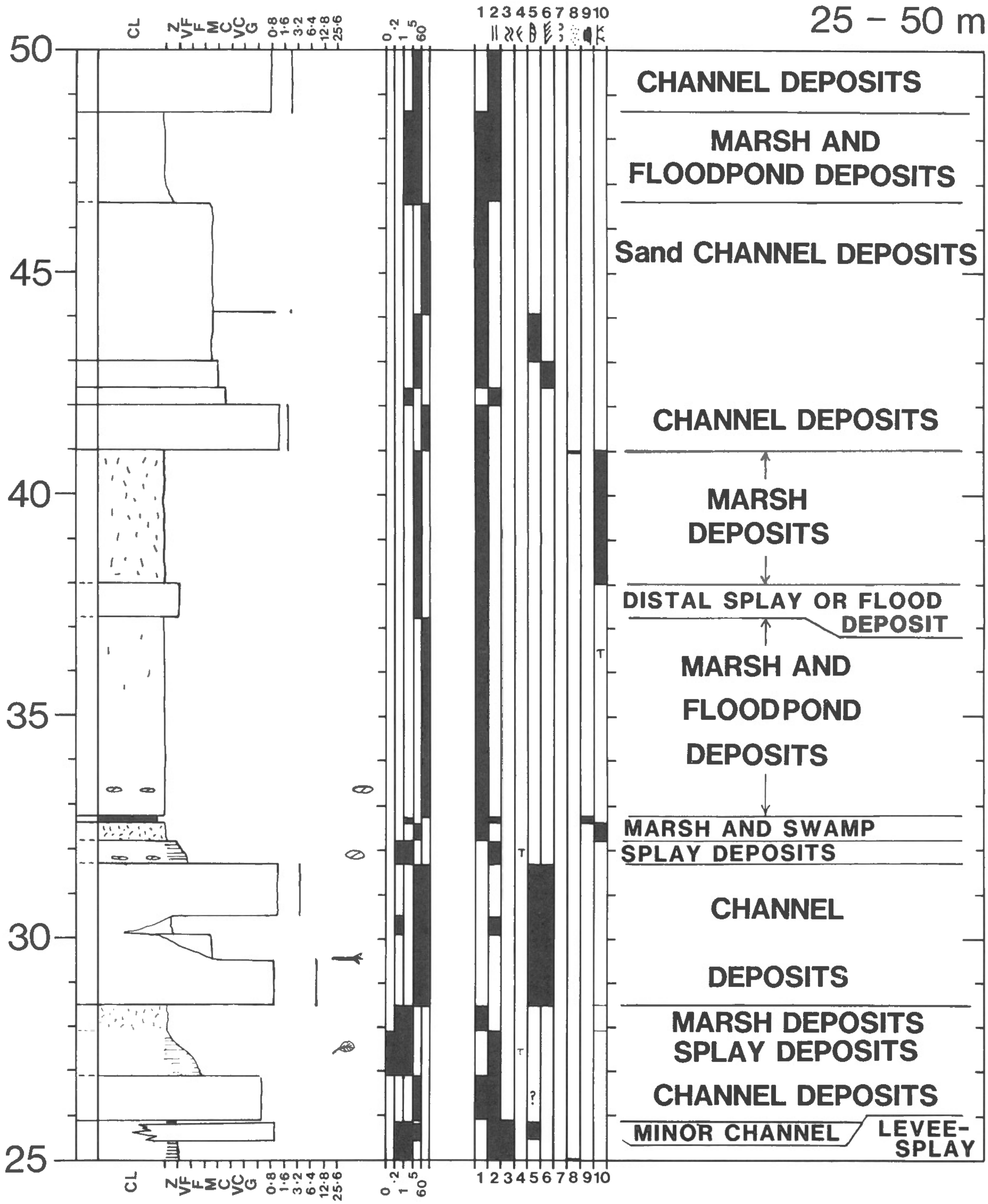
Section 2: Westply, north 52°56′15″N, 122°28′59″W

0–17 m

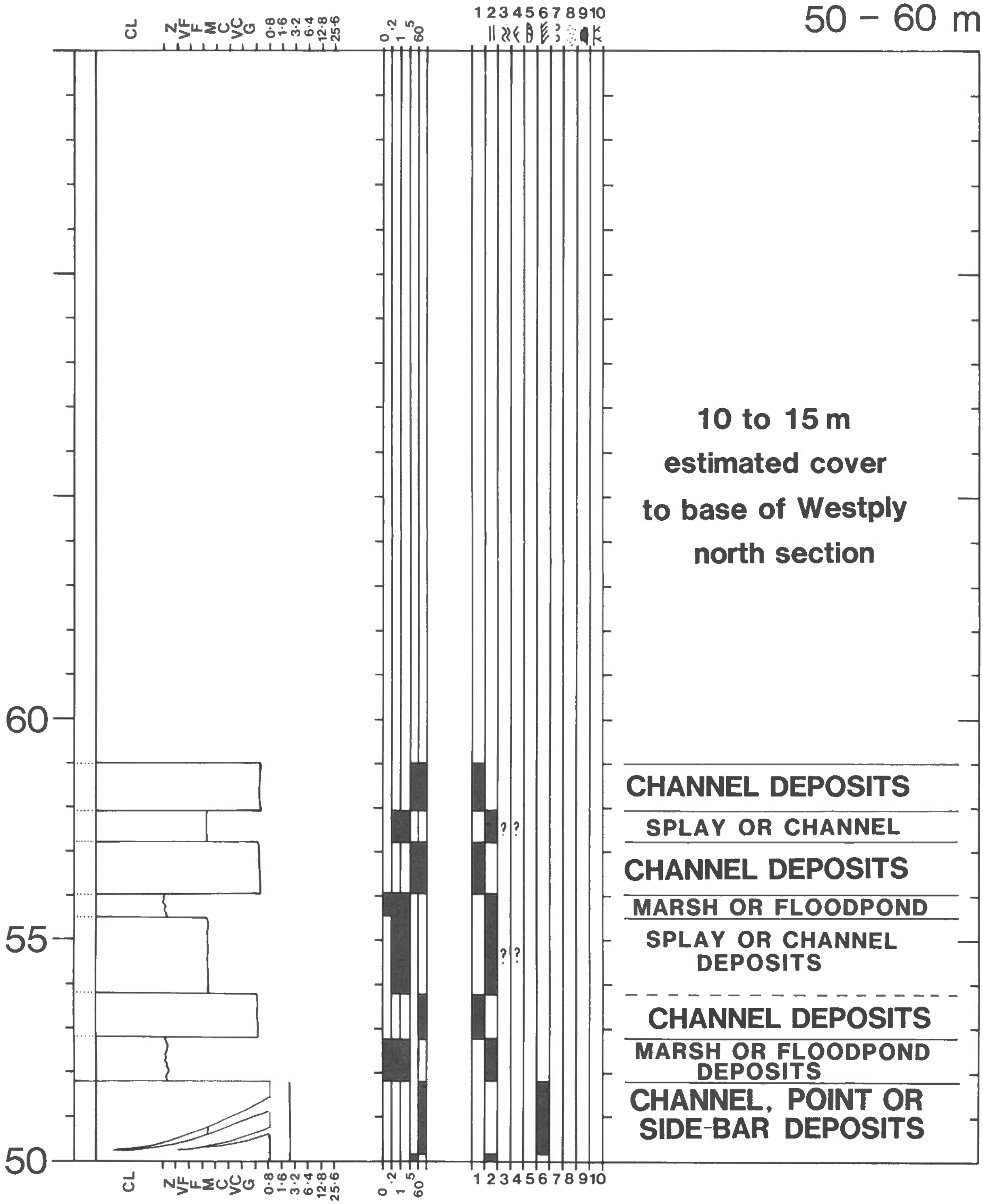



Section 3: Westply, south
52°56′N, 122°28′52″W
0 – 25 m
CL
Z VF F M C VC G 0·8 1·6 3·2 6·4 12·8 25·6
0 ·2 1 5 60
1 2 3 4 5 6 7 8 9 10
25
20
15
10
5
0
LEVEE AND SPLAY DEPOSITS
CHANNEL DEPOSITS
SPLAY cut by conglomerate to north
MARSH AND FLOODPOND DEPOSITS
CHANNEL DEPOSIT cuts splay sands to south
LEVEE AND SPLAY DEPOSITS
CHANNEL DEPOSITS
LEVEE AND SPLAY DEPOSITS
CHANNEL DEPOSITS
DISTAL SPLAY
MARSH DEPOSITS

Section 3: Westply, south



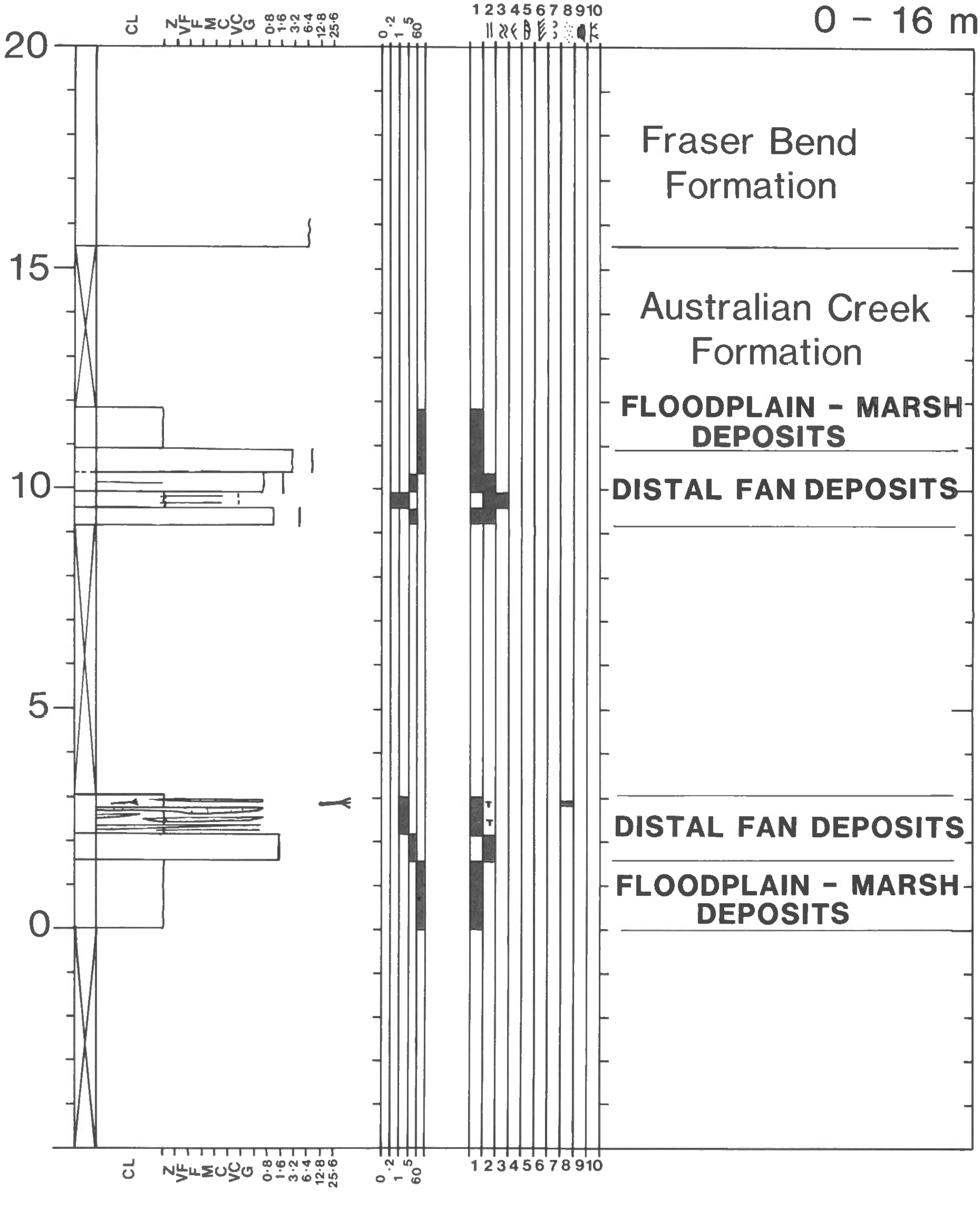
Section 3: Westply, south (Rich Bar I.R. No.4)



Section 4: Big Bend

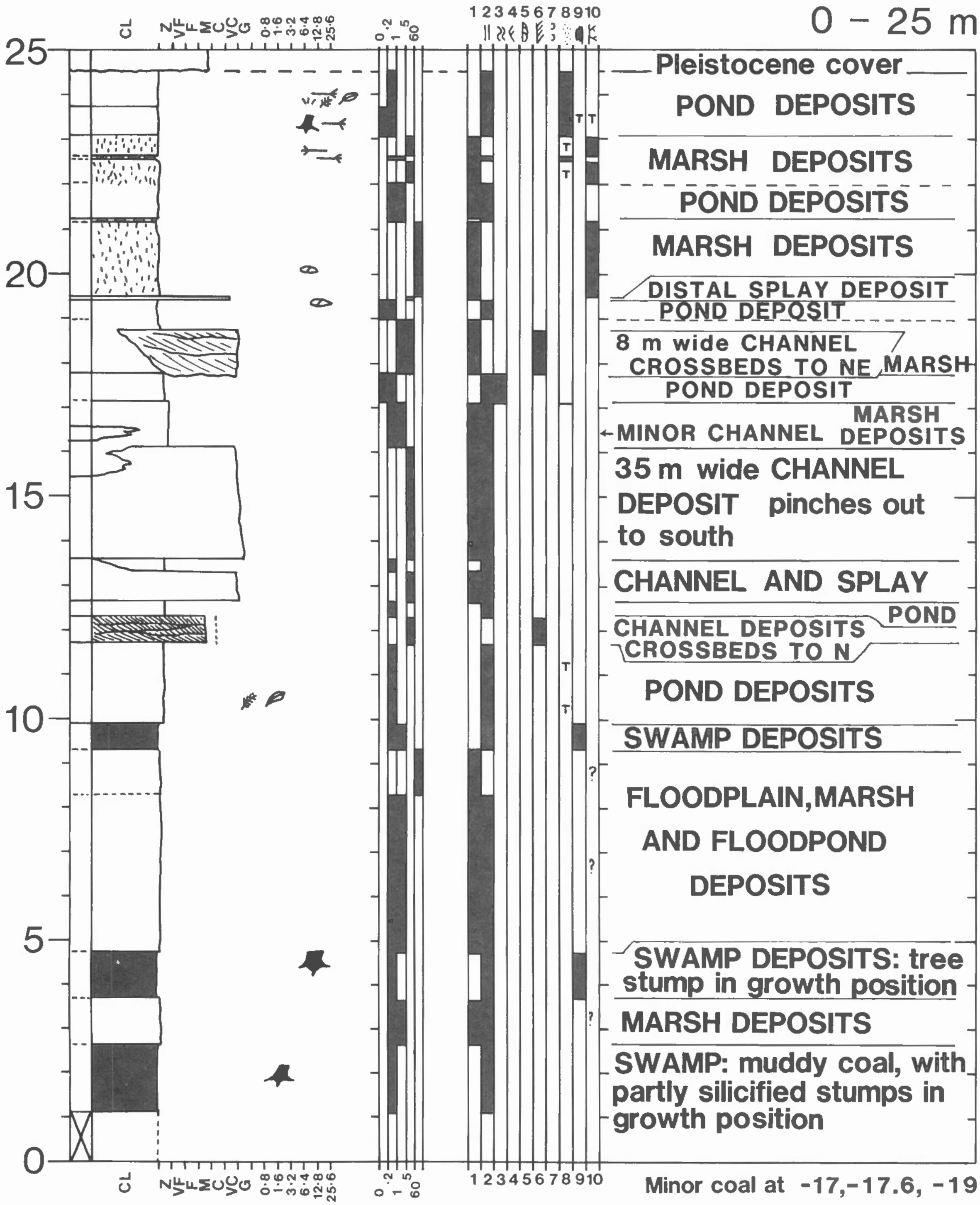
53°04′N, 122°35′W

0 – 16 m



Section 5: Alexandria Ferry 52°38′54″N, 122°29′33″W

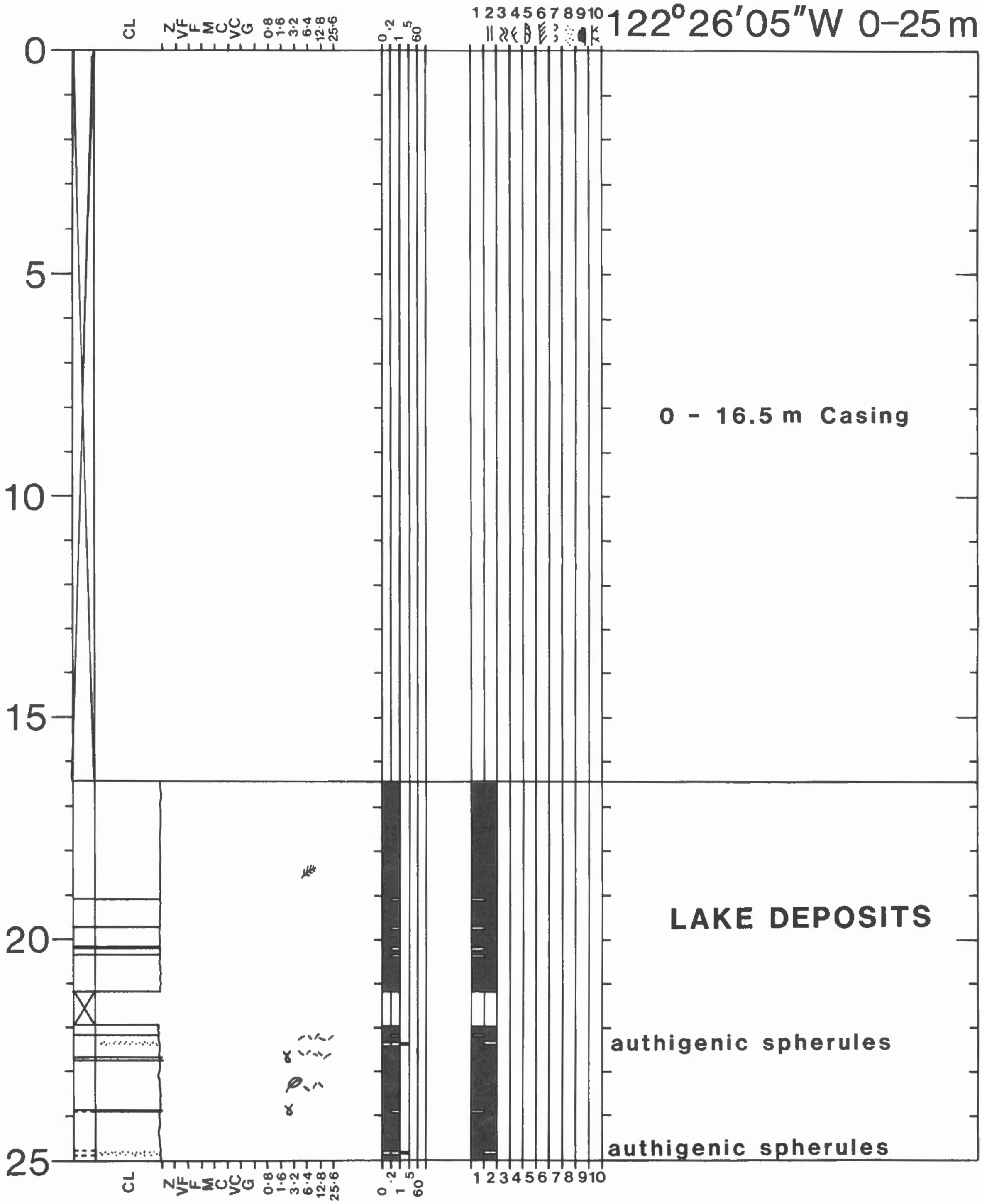
0 – 25 m



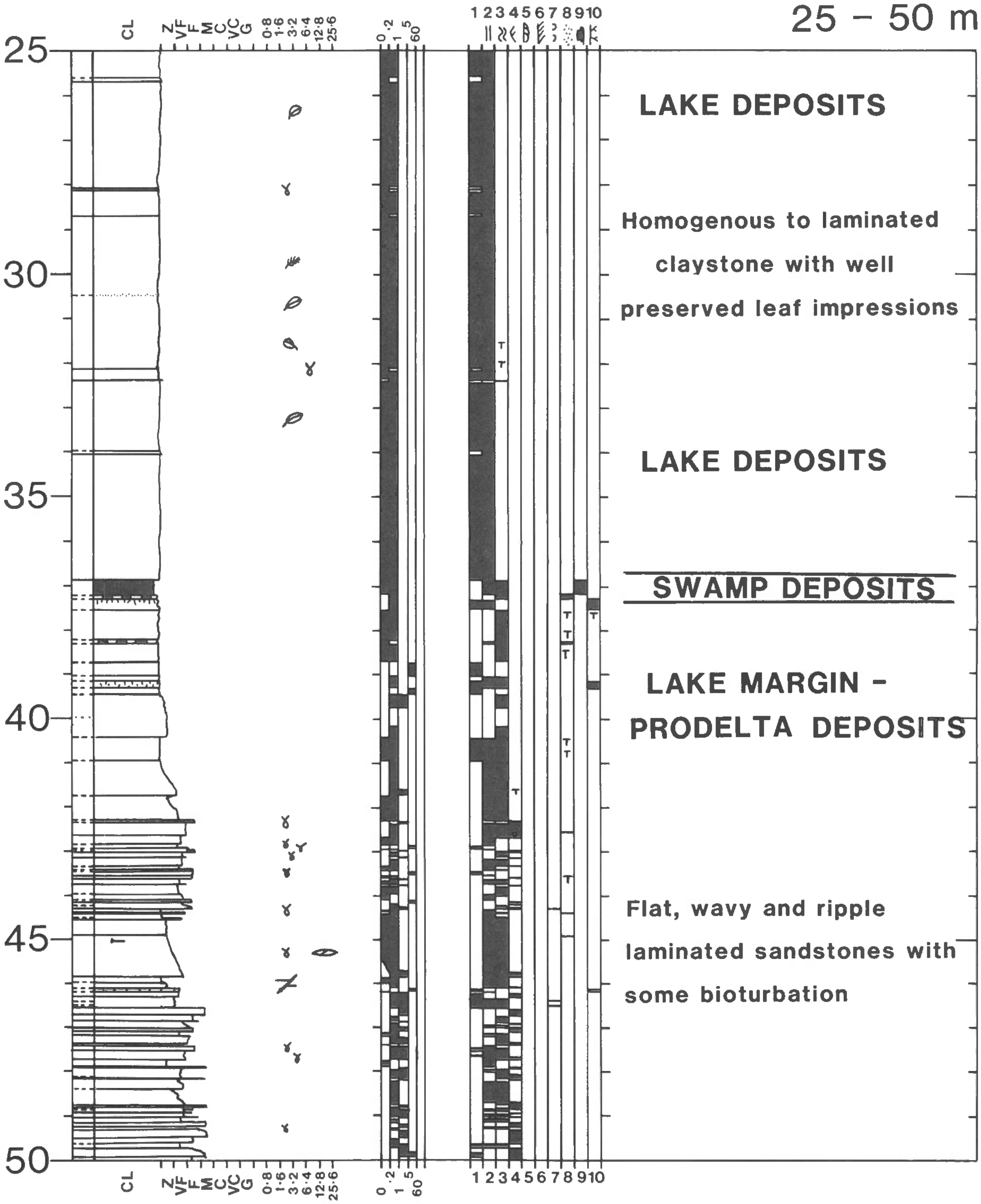
Underlying 32 m of section are very poorly exposed.

Minor coal at -17, -17.6, -19 and -31 m.

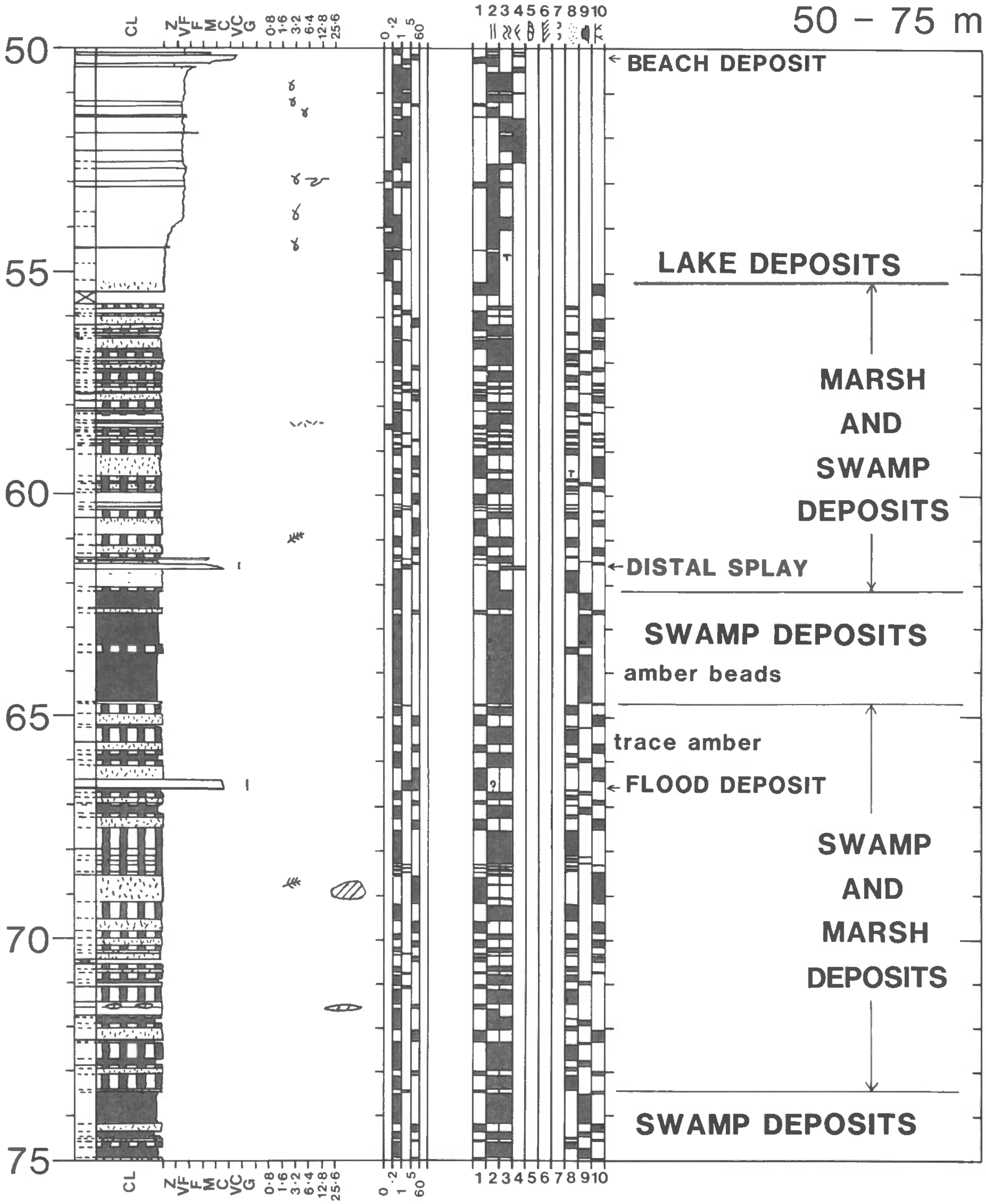
GSC Borehole Q1, Australian Creek 52°43′10″N, 122°26′05″W 0–25 m



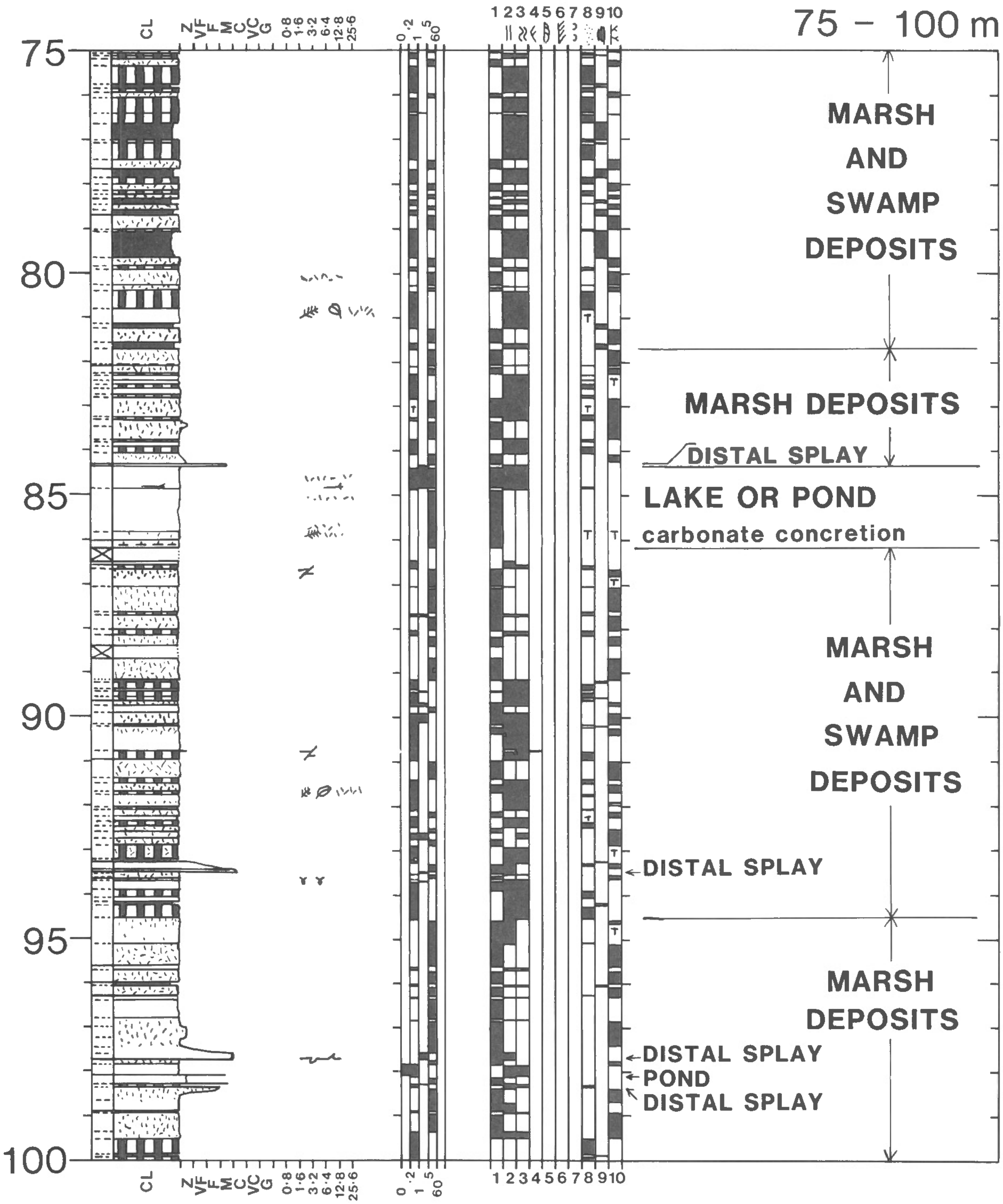
GSC Borehole Q1



GSC Borehole Q1



GSC Borehole Q1



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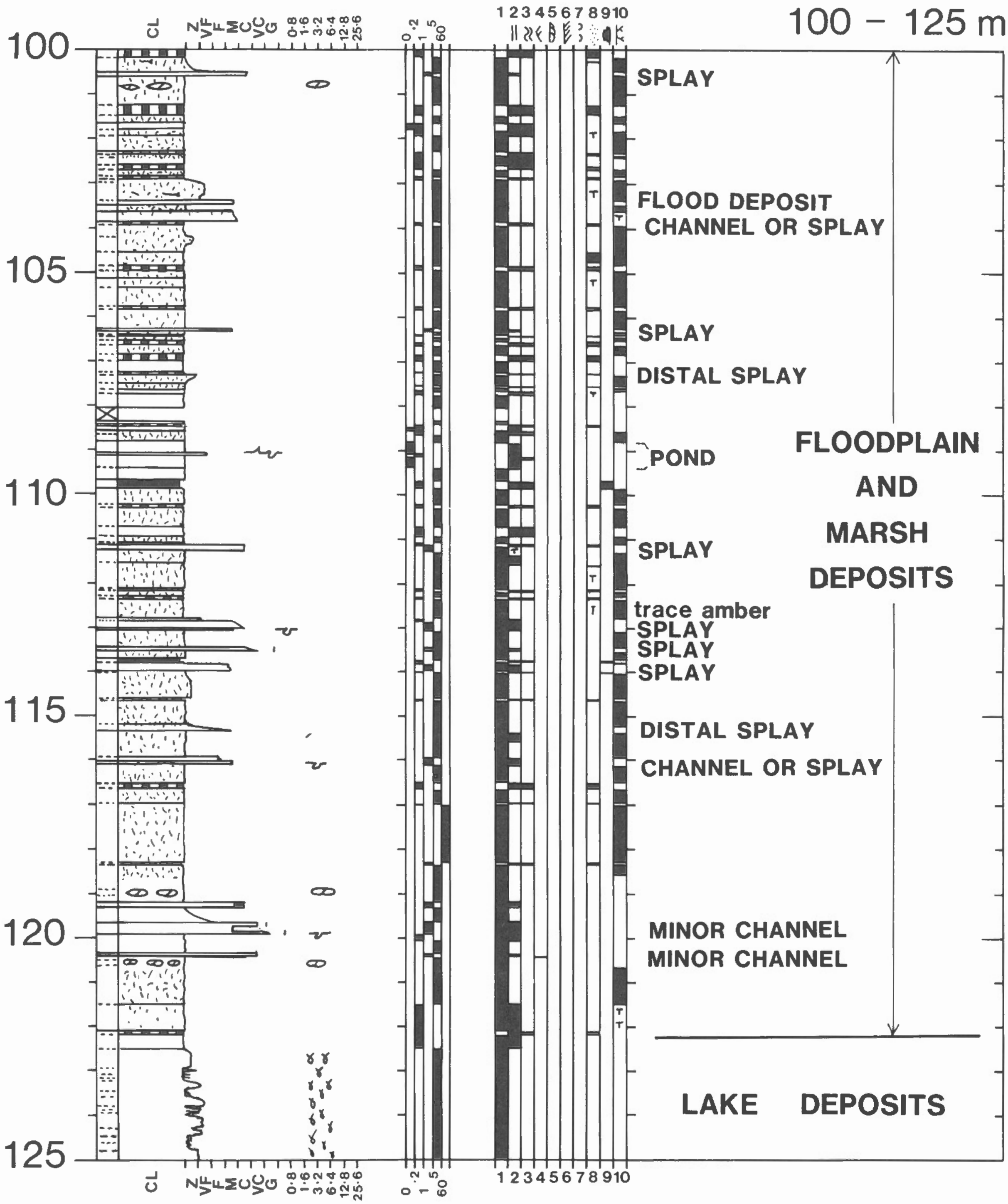
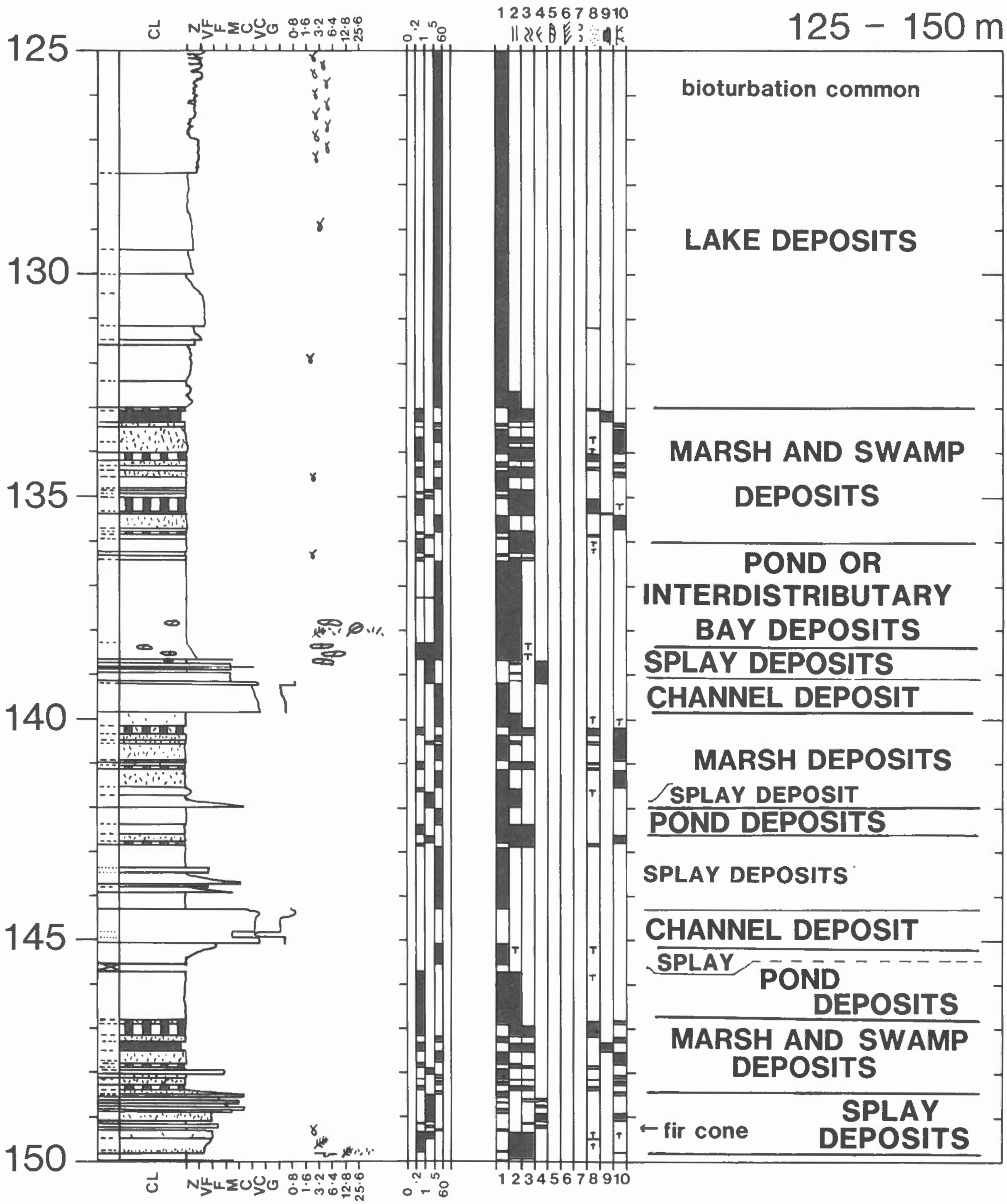
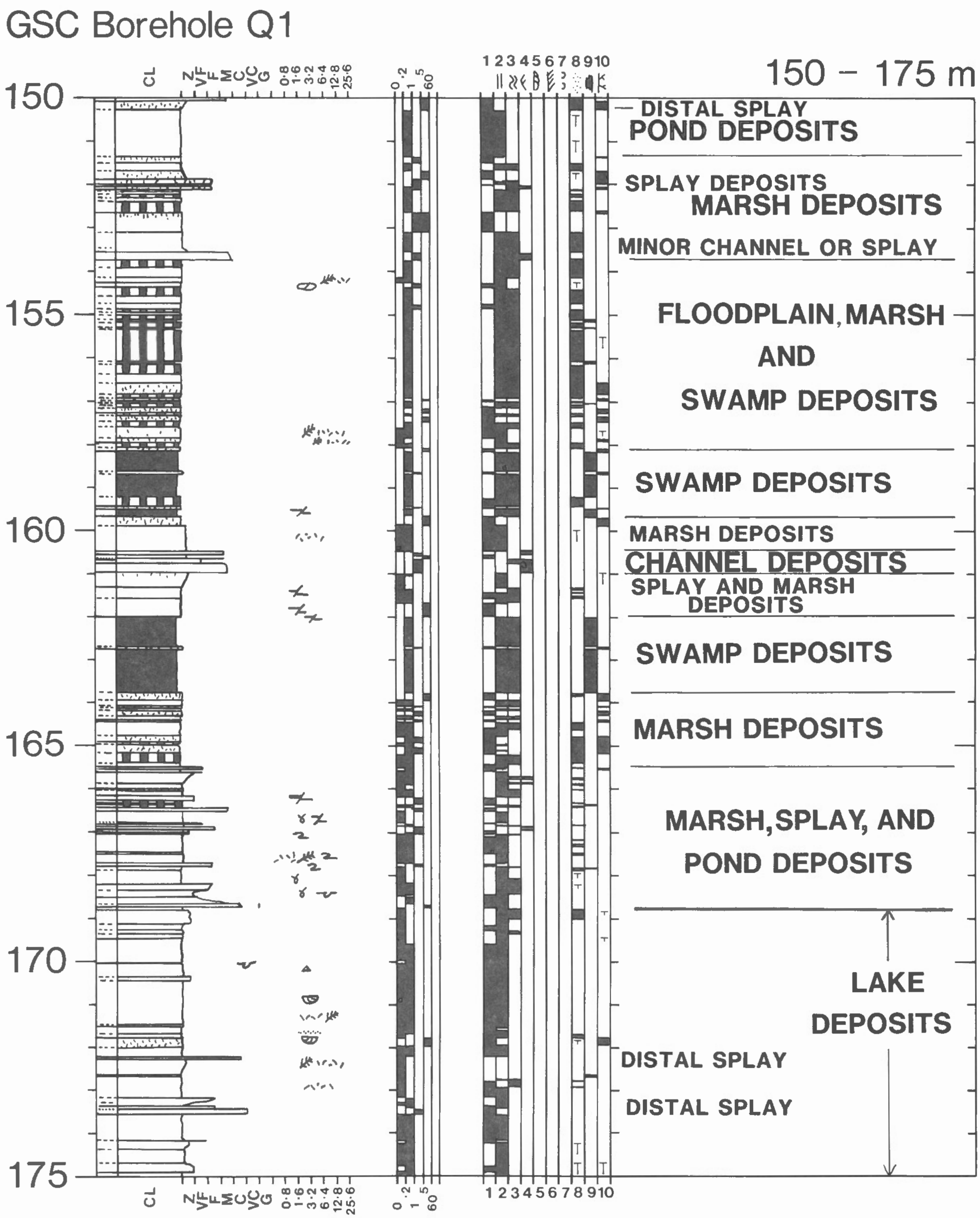
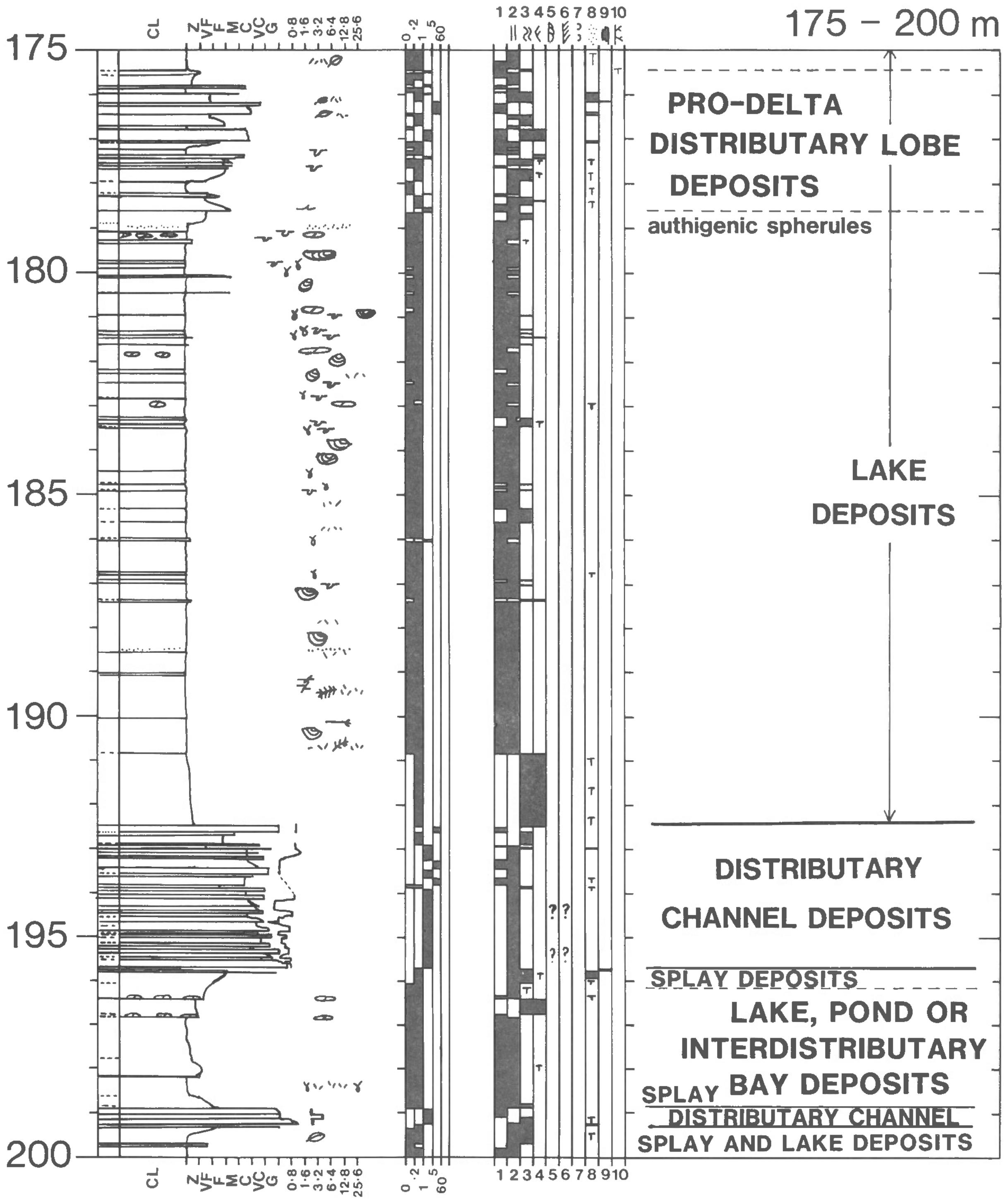


GSC Borehole Q1



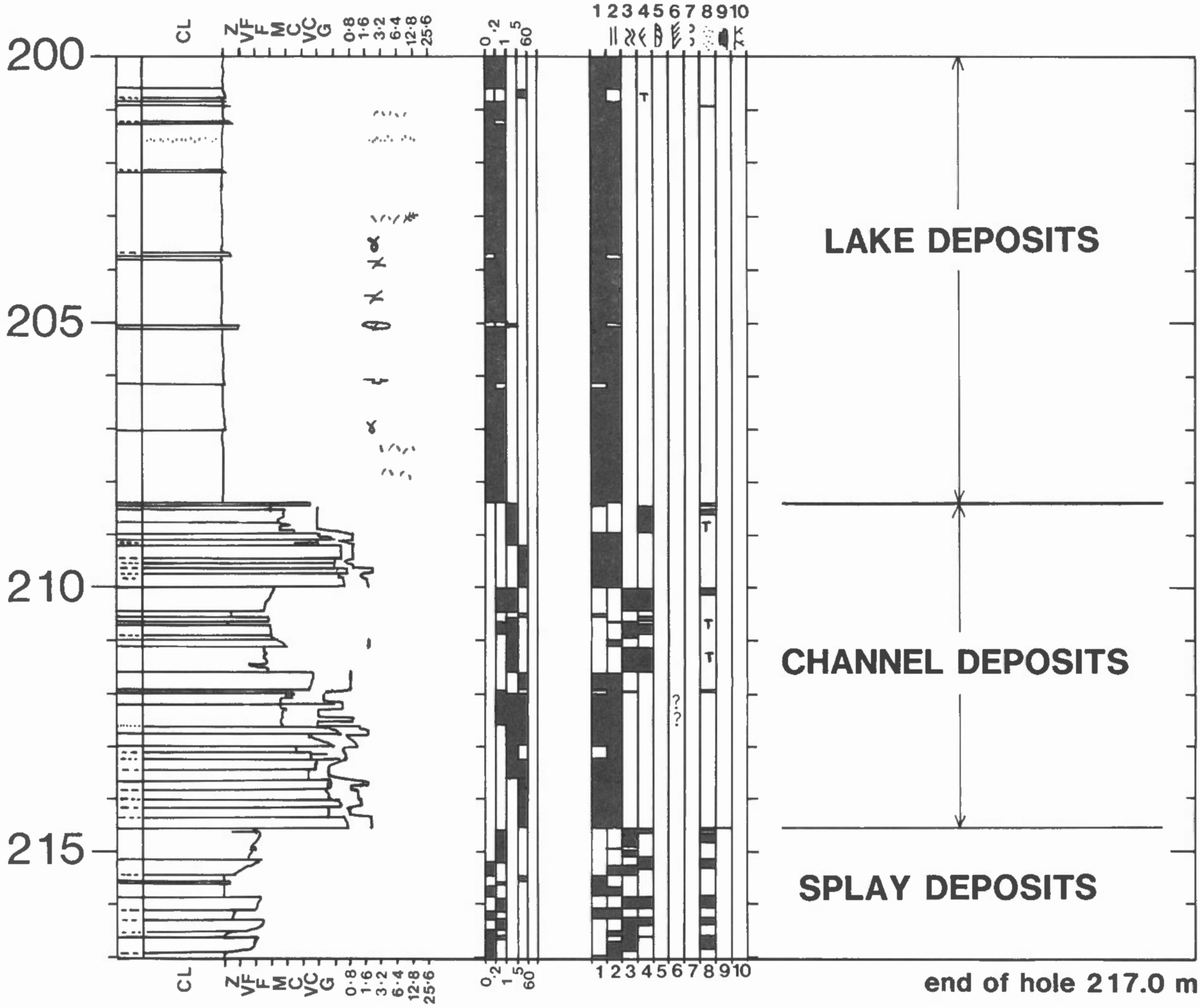

GSC Borehole Q1
150 – 175 m
150
155
160
165
170
175
CL
Z VF F M C VC G
0·8 1·6 3·2 6·4 12·8 25·6
0 .2 1 5 60
1 2 3 4 5 6 7 8 9 10
DISTAL SPLAY
POND DEPOSITS
SPLAY DEPOSITS
MARSH DEPOSITS
MINOR CHANNEL OR SPLAY
FLOODPLAIN, MARSH AND SWAMP DEPOSITS
SWAMP DEPOSITS
MARSH DEPOSITS
CHANNEL DEPOSITS
SPLAY AND MARSH DEPOSITS
SWAMP DEPOSITS
MARSH DEPOSITS
MARSH, SPLAY, AND POND DEPOSITS
LAKE DEPOSITS
DISTAL SPLAY
DISTAL SPLAY

GSC Borehole Q1

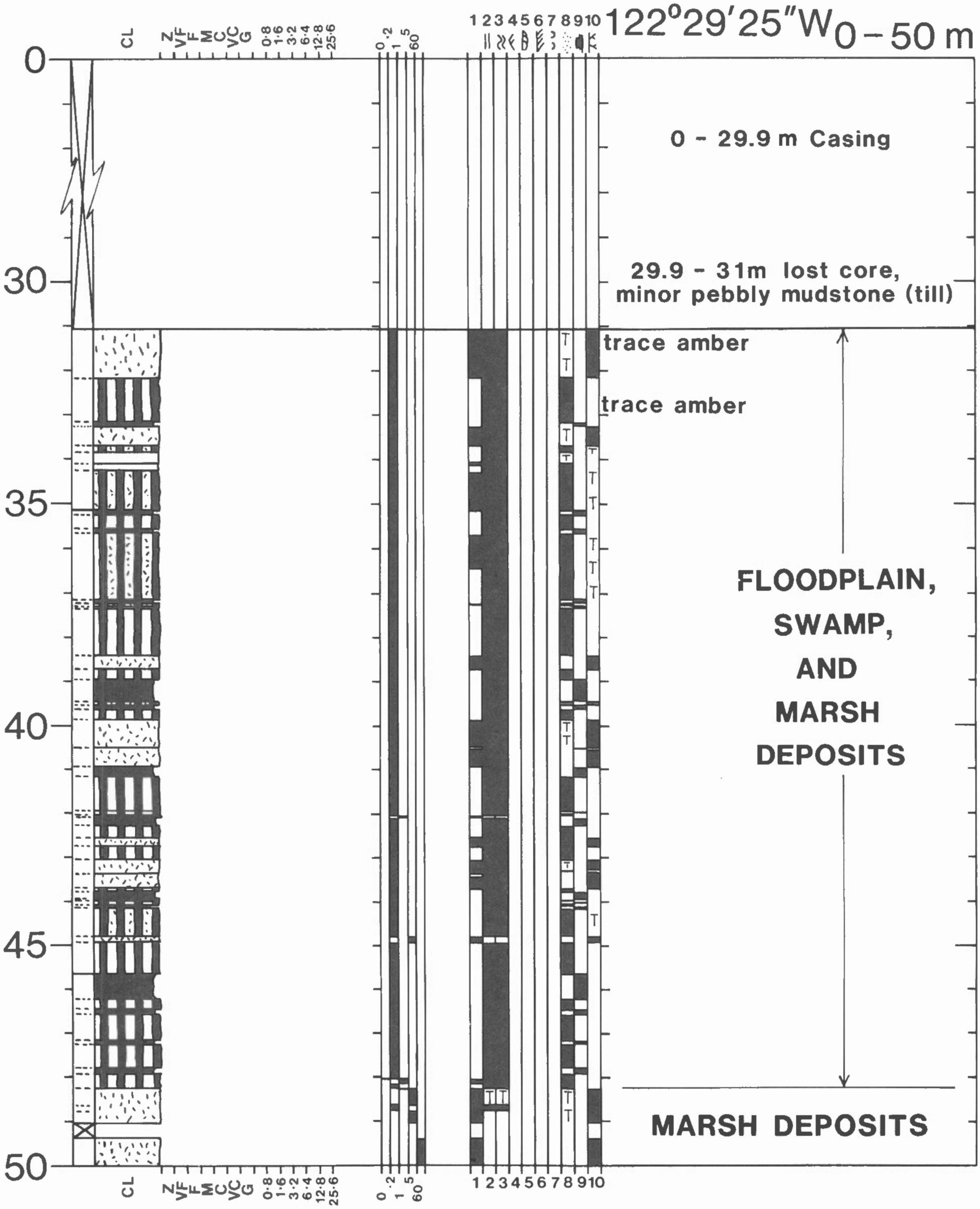


GSC Borehole Q1

200 - 217 m



GSC Borehole Q2, Red Bluff, Quesnel 52°57′48″N, 122°29′25″W 0 – 50 m



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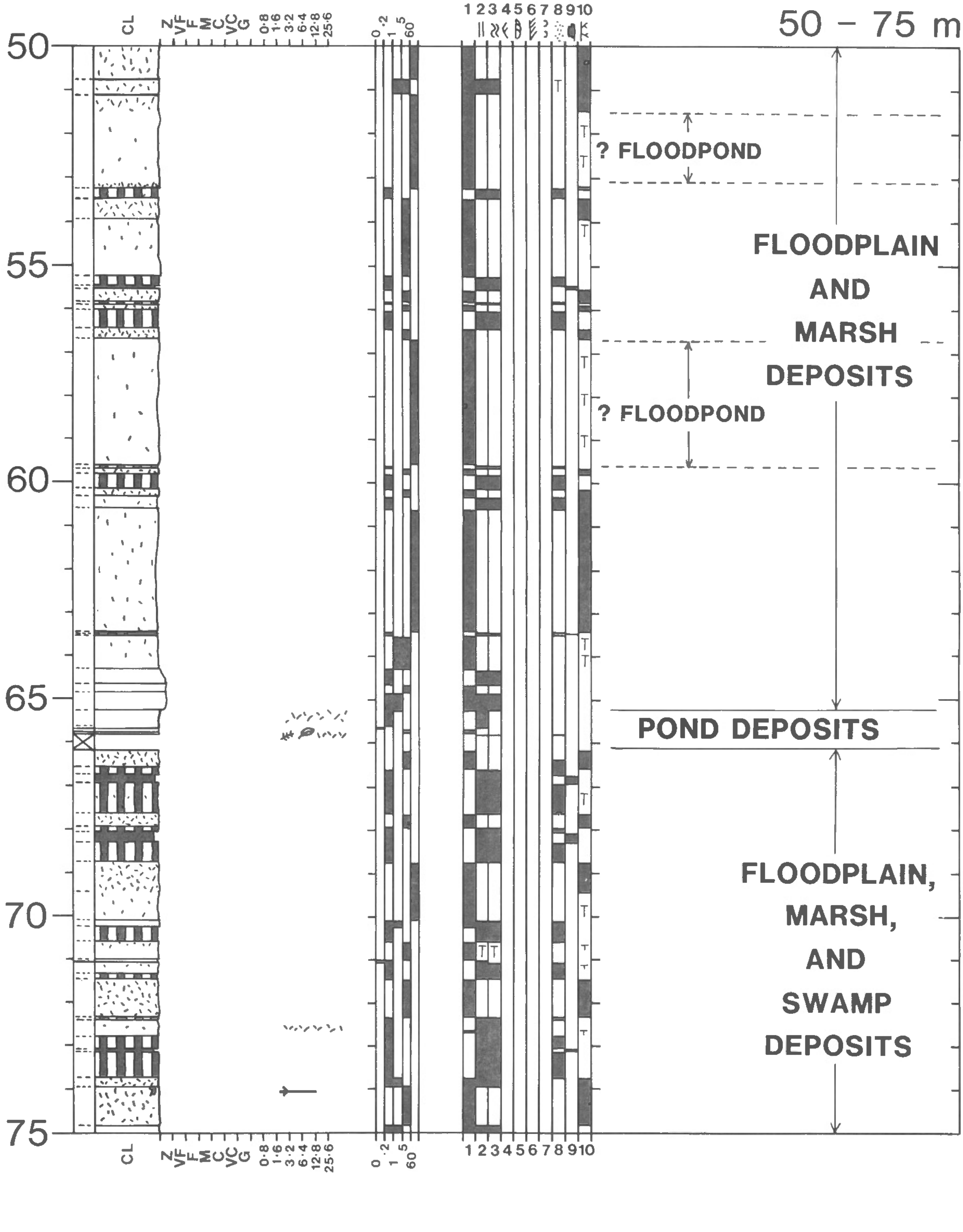

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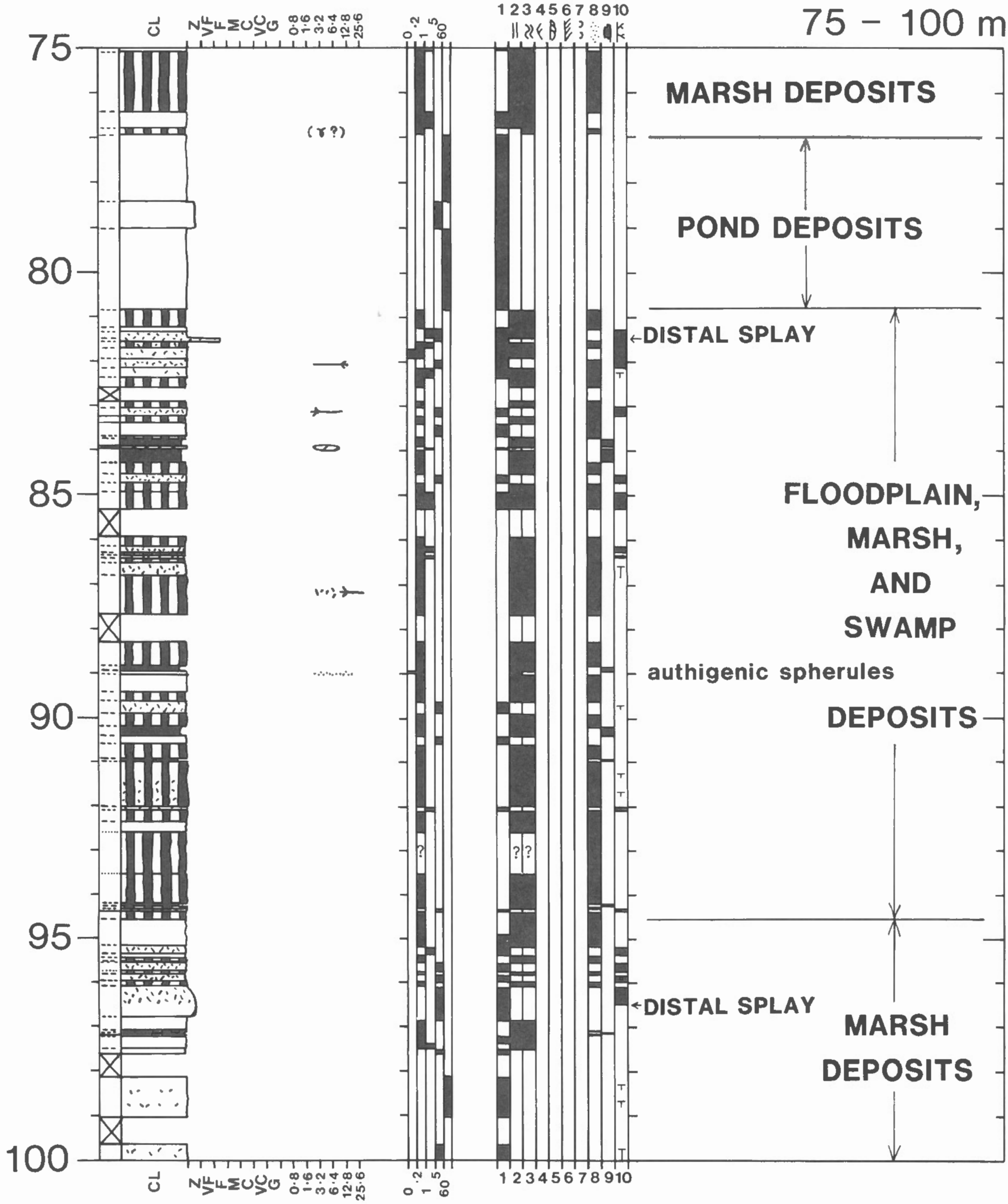
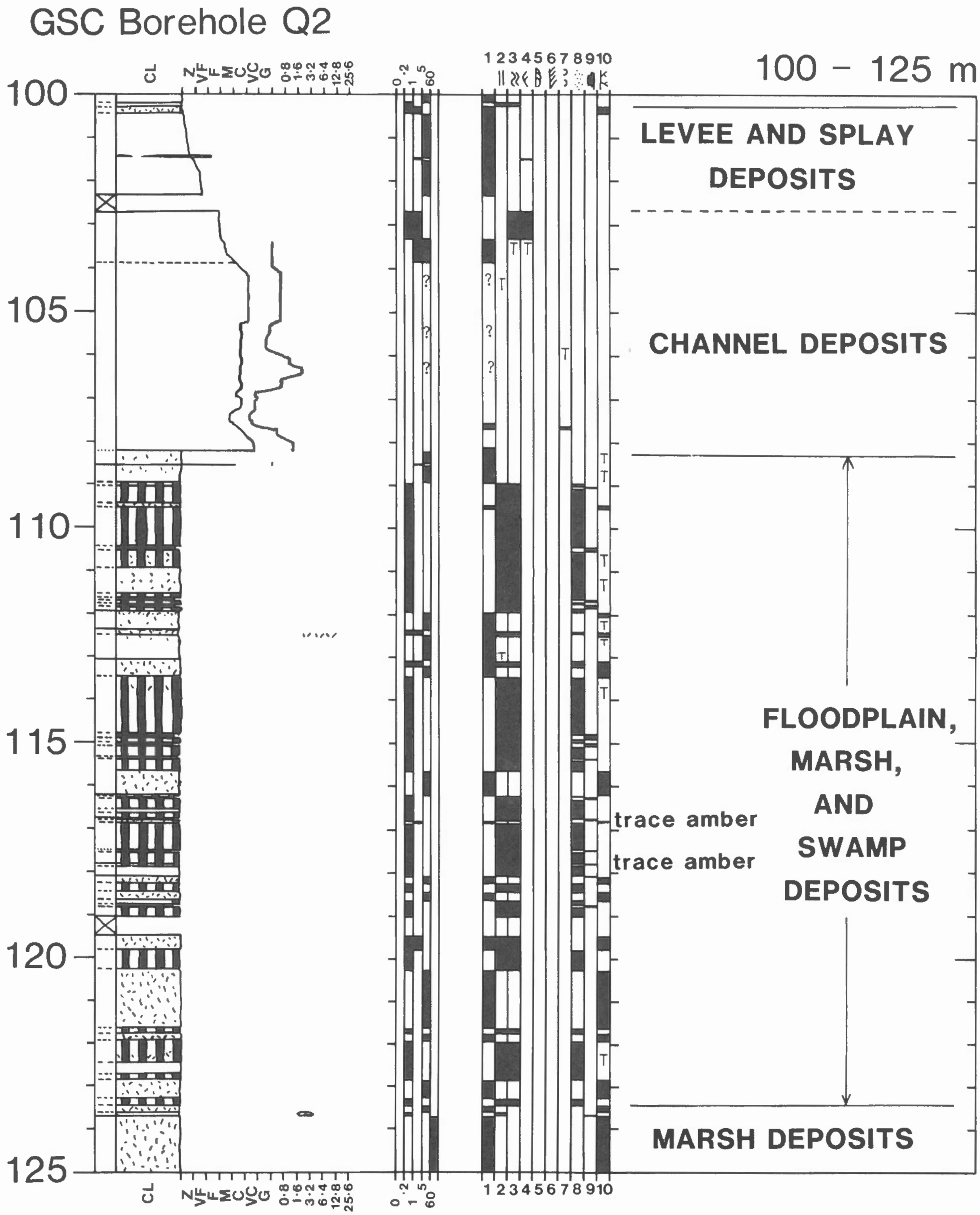
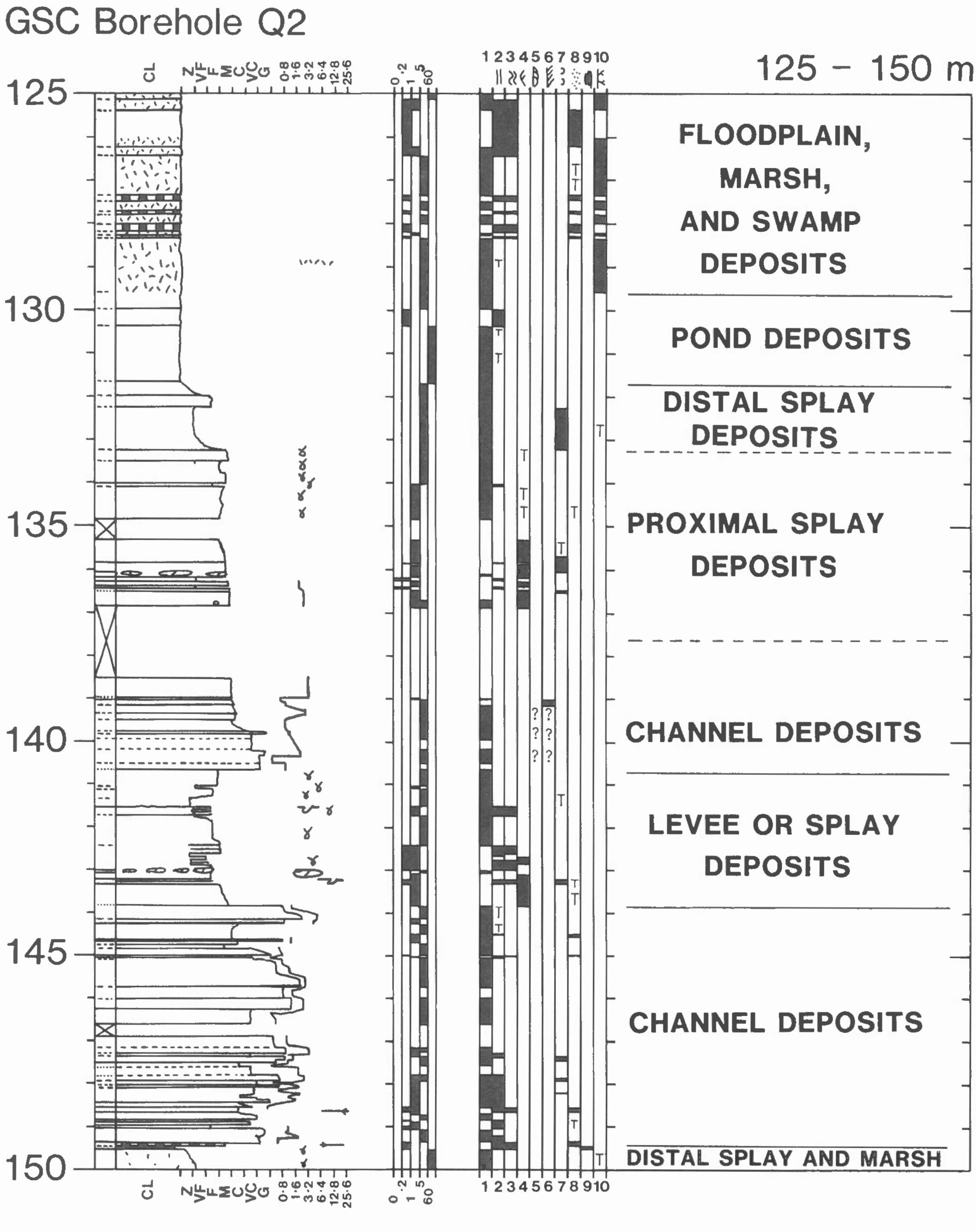
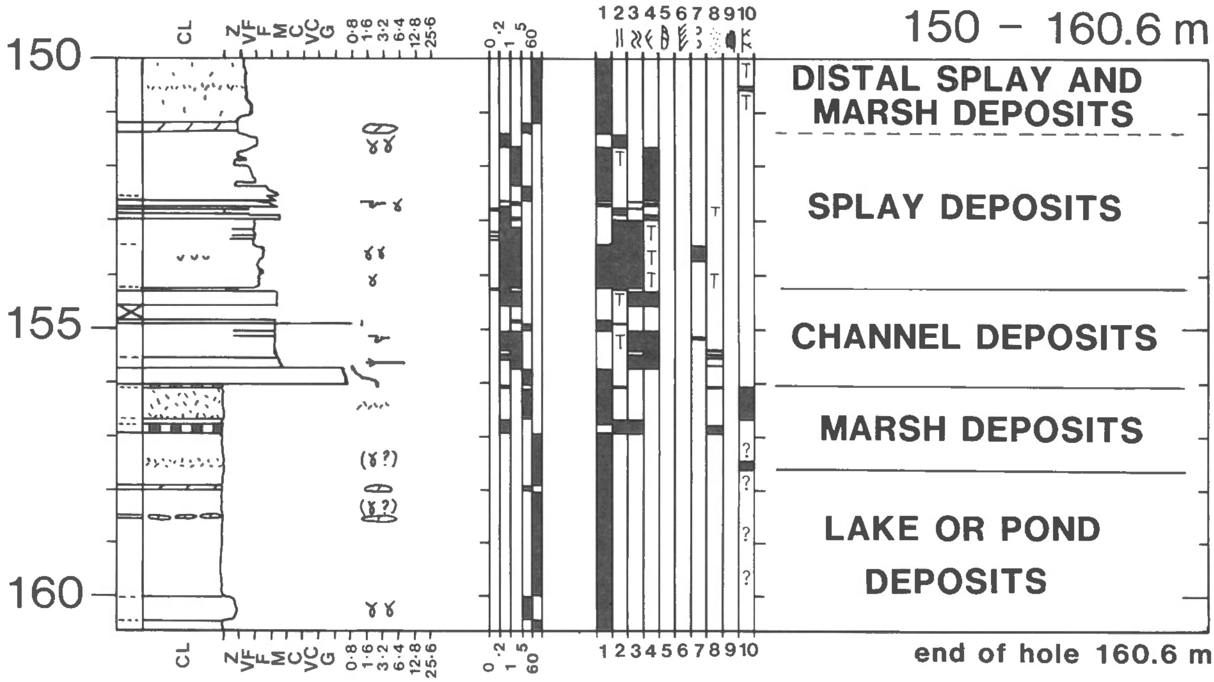



GSC Borehole Q2
100 - 125 m
LEVEE AND SPLAY DEPOSITS
CHANNEL DEPOSITS
FLOODPLAIN, MARSH, AND SWAMP DEPOSITS
MARSH DEPOSITS
trace amber
trace amber
100
105
110
115
120
125
CL
Z VF F M C VC G
0·8 1·6 3·2 6·4 12·8 25·6
0 .2 1 5 60
1 2 3 4 5 6 7 8 9 10

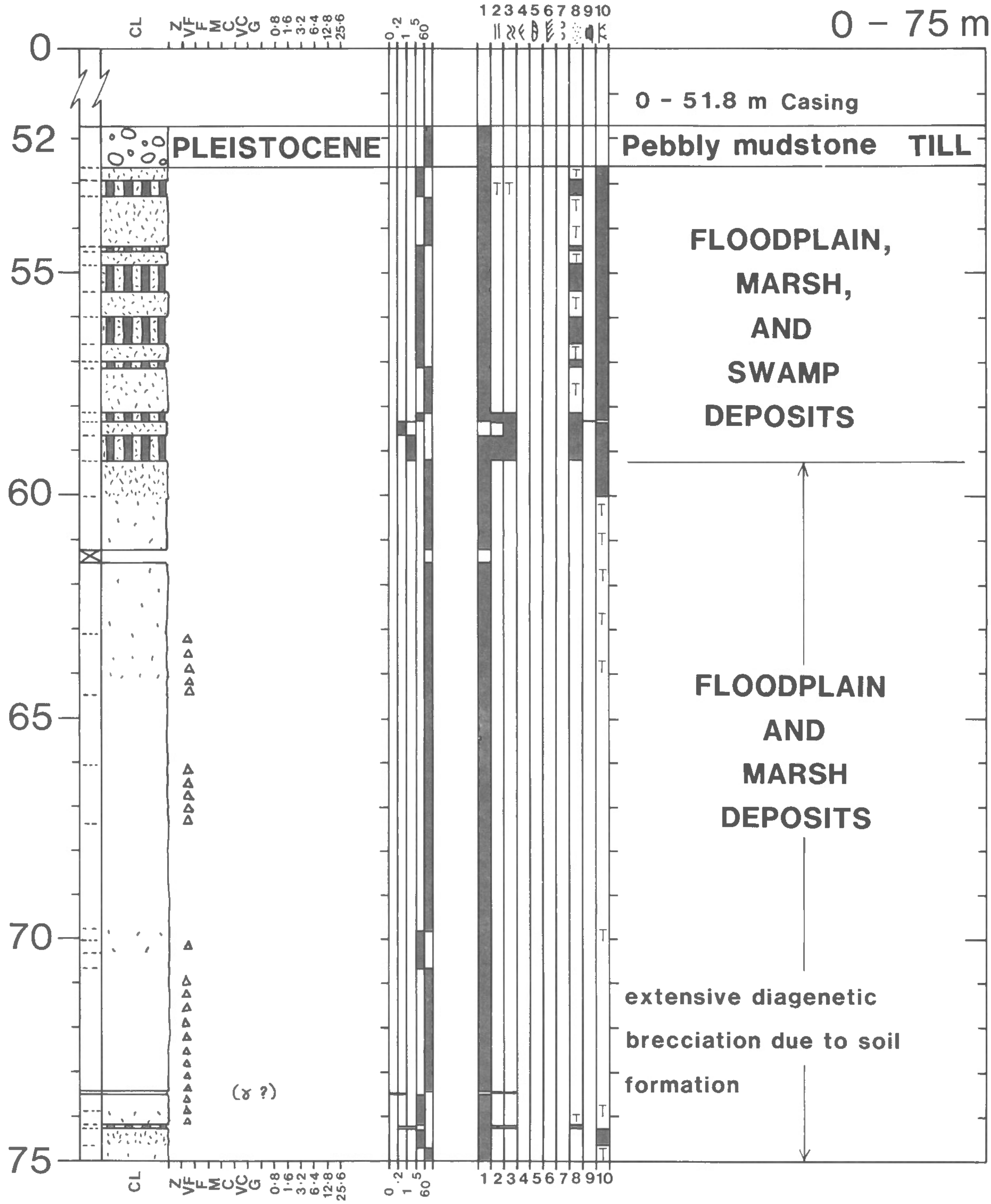


GSC Borehole Q2
125 - 150 m
125
130
135
140
145
150
CL
Z VF F M C VC G
0·8 1·6 3·2 6·4 12·8 25·6
0 ·2 1 5 60
1 2 3 4 5 6 7 8 9 10
FLOODPLAIN, MARSH, AND SWAMP DEPOSITS
POND DEPOSITS
DISTAL SPLAY DEPOSITS
PROXIMAL SPLAY DEPOSITS
CHANNEL DEPOSITS
LEVEE OR SPLAY DEPOSITS
CHANNEL DEPOSITS
DISTAL SPLAY AND MARSH

GSC Borehole Q2



GSC Borehole Q3, Quesnel 52°57′25″N, 122°29′25″W



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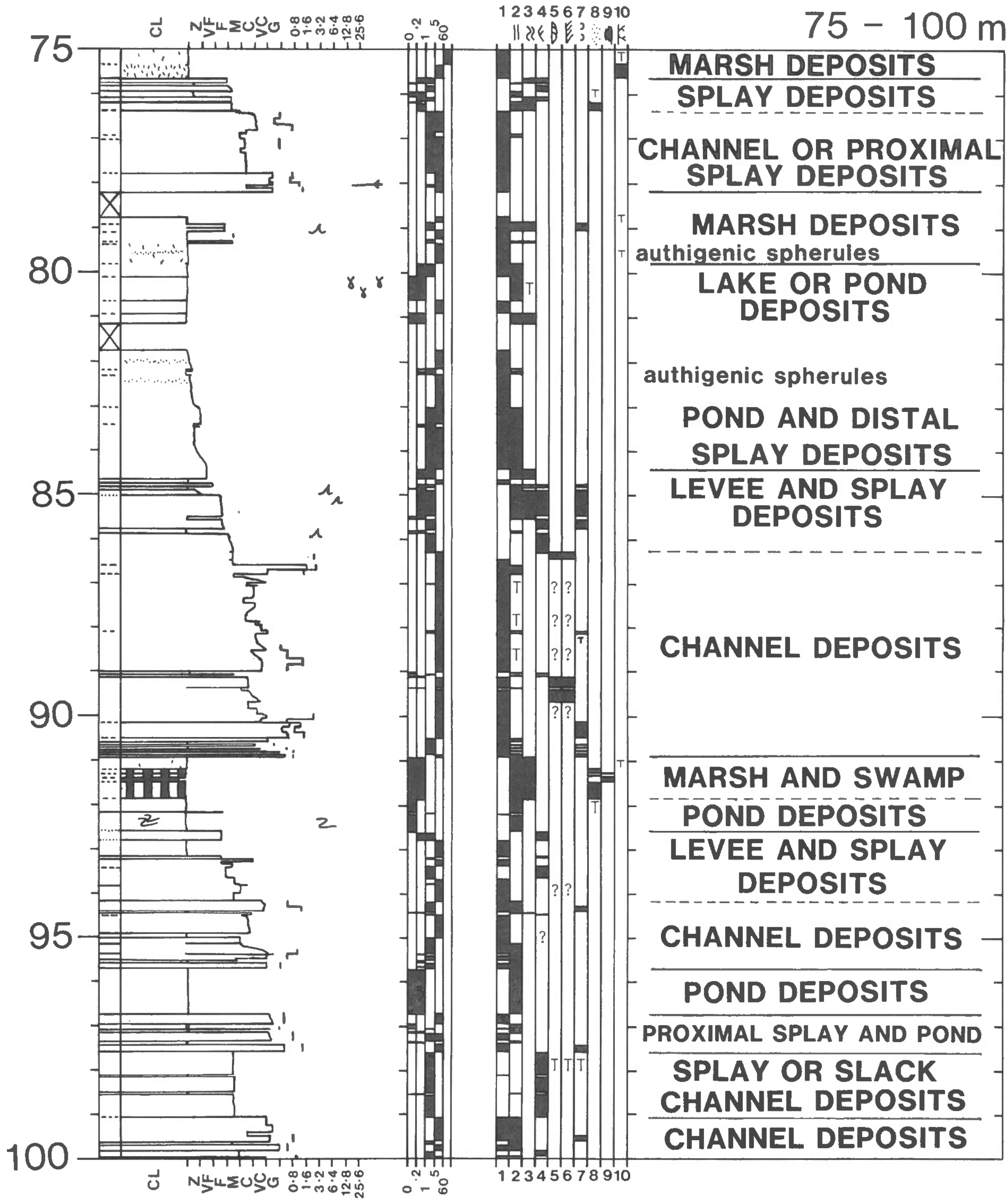

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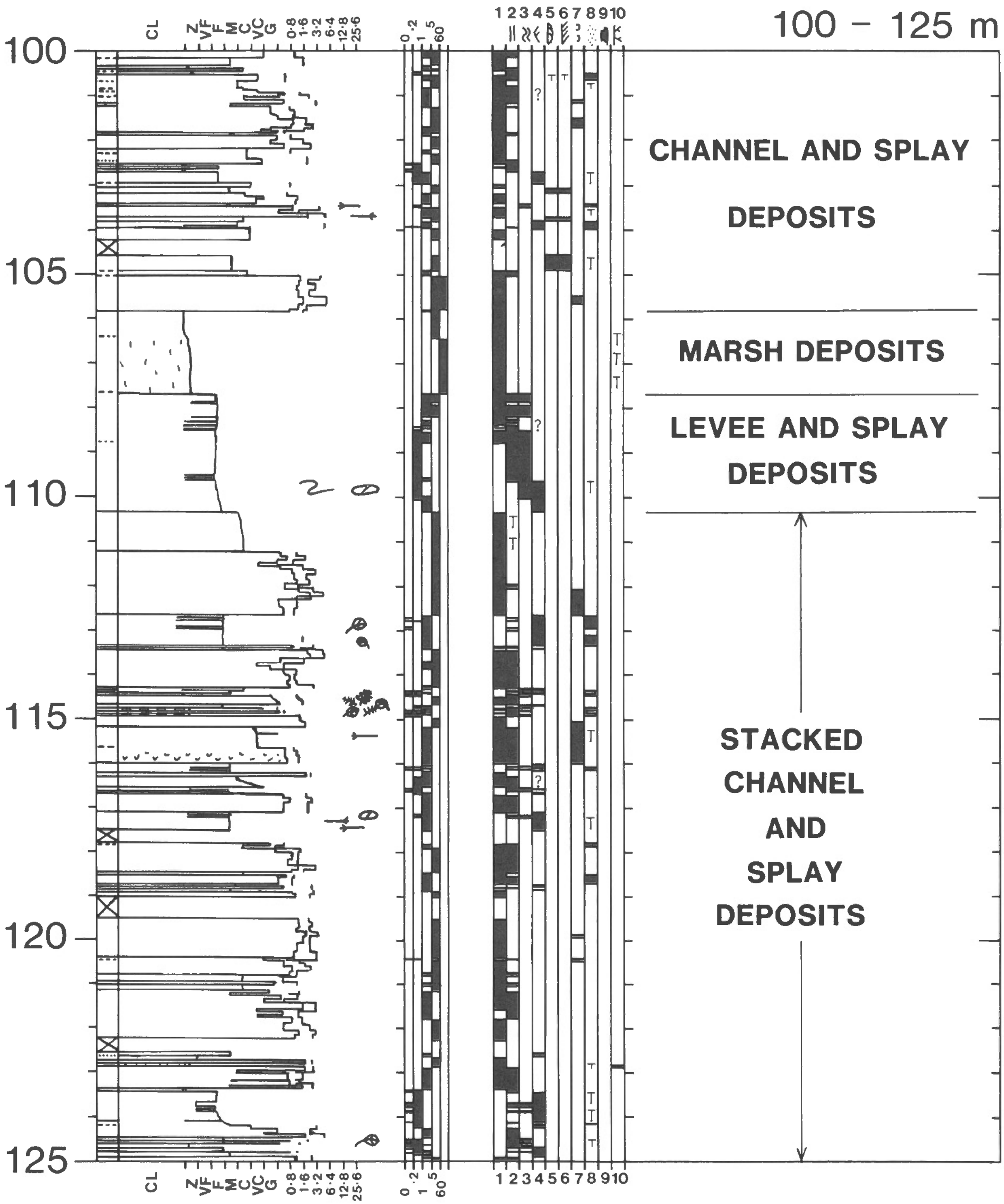
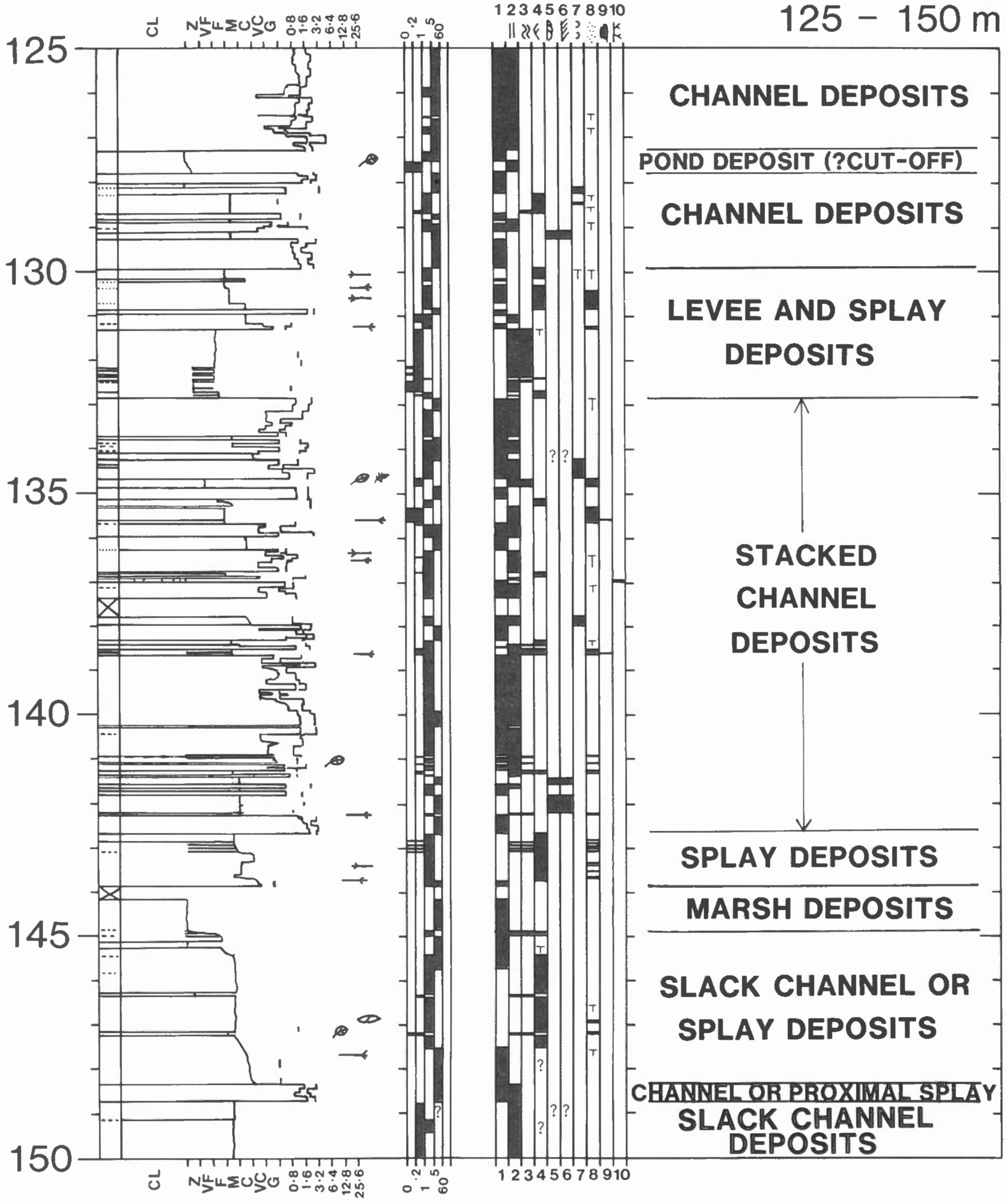


GSC Borehole Q3



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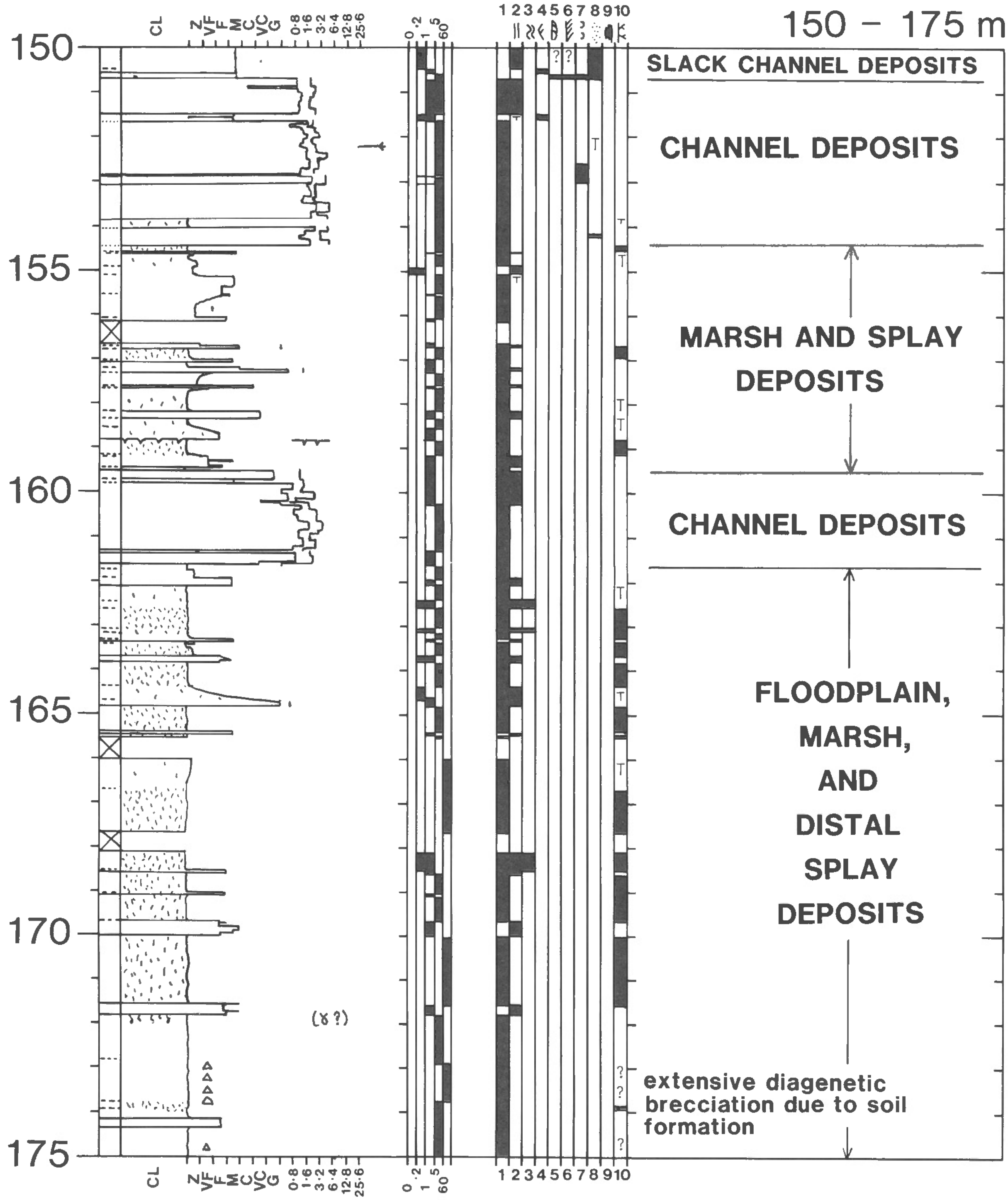

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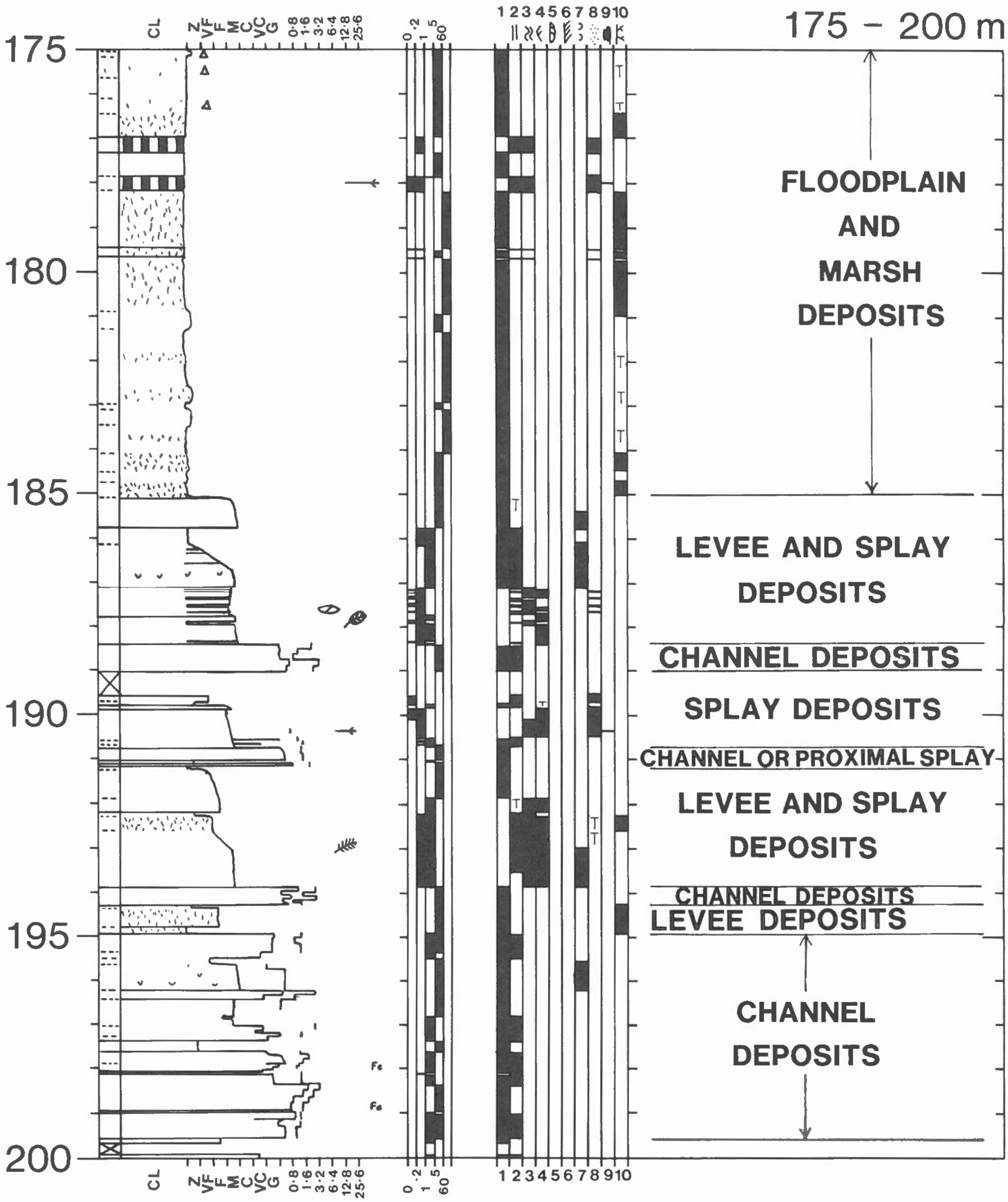

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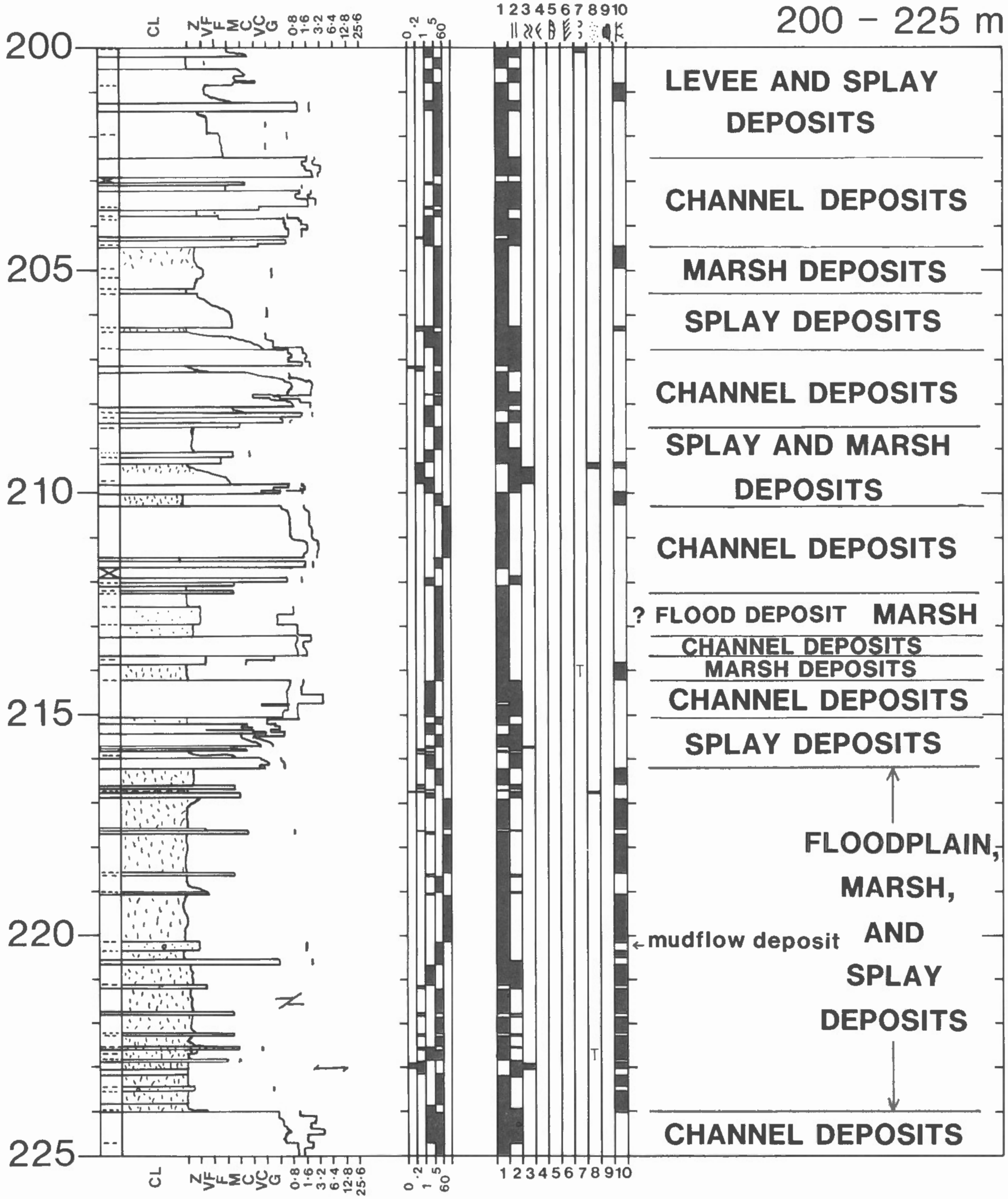

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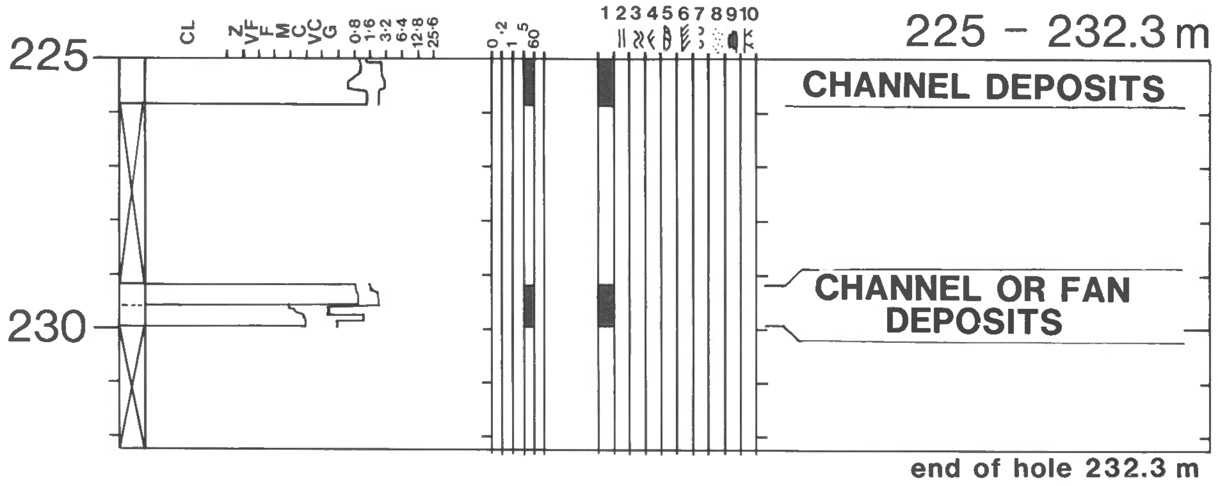

APPENDIX B

Petrographic and analytical data

TABLE 1

Petrography of framework components in sands (S) and gravels (G) of the Australian Creek Formation

Sample (borehole/ depth)	GS	Quartz M	Quartz P	Quartz S	Feldspar K	Feldspar Pl	Feldspar Mi	Lithic Fragments Cht	Sst	Met	Gnt	Vc	Vf	Vg	Accessories	n
SANDS																
Q1/49.32 m	mS	69	22	50	37	5	2	40	14	46	13	82	120	0		500
			(28.2%)			(8.8%)					(63.0%)					
Q1/50.35 m	mS	85	23	35	14	3	tr	17	23	23	4	24	177	0		428
			(33.4%)			(4.0%)					(62.6%)					
Q1/103.48 m	mS	20	27	25	19	10	1	12	59	61	32	59	228	0		553
			(13.0%)			(5.4%)					(81.6%)					
Q2/106.07 m	cS	16	33	12	8	13	0	80	39	46	7	180	59	2	Mux1	496
			(12.3%)			(4.2%)					(83.3%)				(0.2%)	
Q2/139.60 m	cS	19	40	11	2	5	0	84	13	61	0	177	78	8	Lx2	500
			(14.0%)			(1.4%)					(84.2%)				(0.4%)	
Q2/151.49 m	fS	15	20	12	11	2	0	30	60	141	4	164	37	2	Lx1, Six1	500
			(9.4%)			(2.6%)					(87.6%)				(0.4%)	
Q2/154.38 m	mS	53	18	36	14	17	0	18	9	72	4	120	117	18	Six1, Mux1, Hx2	500
			(21.4%)			(6.2%)					(71.6%)				(0.8%)	
Q2/155.60 m	mS	52	15	17	9	5	0	34	4	108	0	88	132	39	Lx1	504
			(16.7%)			(2.8%)					(80.4%)				(0.2%)	
Q3/62.48 m	mS	27	13	11	27	6	0	6	3	74	17	198	123	0	Hbx1	506
			(10.1%)			(6.5%)					(83.2%)				(0.2%)	
Q3/136.55 m	vS	20	40	9	5	3	0	61	9	87	20	184	57	0		495
			(13.9%)			(1.6%)					(84.4%)					
Q3/136.86 m	vS	10	18	12	3	7	0	159	59	75	4	125	27	1		500
			(8.0%)			(2.0%)					(90.0%)					
Q3/188.37 m	mS	69	25	28	9	10	0	48	5	53	12	139	95	6	Lx1, Ex1	501
			(24.4%)			(3.8%)					(71.5%)				(0.4%)	
Q3/196.60 m	mS	30	30	15	27	12	0	10	18	45	14	196	101	tr		498
			(15.1%)			(7.8%)					(77.1%)					
AVERAGE SANDSTONE																
n = 13		485	324	282	185	98	3	599	315	892	131	1736	1351	76	13	6481
%		7.5	5.0	4.4	2.9	1.5	tr	9.2	4.9	13.8	2.0	26.8	20.8	1.2	0.2	
			(16.9%)			(4.4%)					(78.5%)				(0.2%)	
GRAVELS																
Q2/140.21 m	gG	30	20	16	21	6	1	30	13	70	41	139	112	1		500
			(13.2%)			(5.6%)					(81.2%)					
Q2/155.91 m	sG	7	10	5	2	4	0	150	81	64	2	148	24	2	Mux1	500
			(4.4%)			(1.2%)					(94.2%)				(0.2%)	
Q3/135.03 m	mG	52	16	22	13	10	1	53	1	43	5	95	189	0	Hbx1, Bx1	502
			(17.9%)			(4.8%)					(76.9%)				(0.4%)	
Q3/135.94 m	gG	25	26	8	4	7	0	108	66	95	9	80	69	3		500
			(11.8%)			(2.2%)					(86.0%)					
Q3/142.68 m	lG	18	13	8	8	2	0	73	83	88	5	162	38	2		500
			(7.8%)			(2.0%)					(90.2%)					
Q3/153.31 m	gG	10	35	11	3	1	0	3	104	50	15	213	55	tr		500
			(11.2%)			(0.8%)					(88.0%)					
Q3/188.67 m	gG	18	25	4	2	1	1	49	42	31	14	258	54	1		500
			(9.4%)			(0.8%)					(89.8%)					
Q3/202.72 m	sG	29	20	13	11	4	0	10	10	67	11	265	59	1		500
			(12.4%)			(3.0%)					(84.6%)					
Q3/211.23 m	lG	18	27	7	3	3	0	4	1	33	4	379	21	0		500
			(10.4%)			(1.2%)					(88.4%)					
Q3/220.37 m	GM	21	29	15	13	6	0	12	25	75	9	240	55	0		500
			(13.0%)			(3.8%)					(83.2%)					
Q3/224.03 m	gG	11	30	3	6	1	0	15	94	92	4	217	27	0		500
			(8.8%)			(1.4%)					(89.8%)					
AVERAGE GRAVEL																
n = 11		239	251	112	86	45	3	507	520	708	119	2196	703	10	3	5502
%		4.3	4.6	2.0	1.6	0.8	0.1	9.2	9.5	12.9	2.2	39.9	12.8	0.2	0.	
			(10.9%)			(2.4%)					(86.6%)				(0.1%)	

GS = grain size, fS = fine grained sand, mS = medium grained sand, cS = coarse grained sand, vS = very coarse grained sand, gG = granule gravel, sg = small pebble gravel, mG = medium pebble gravel, lG = large pebble gravel, vg = very large pebble gravel; Quartz, M = monocrystalline, P = polycrystalline, S = strained; Feldspar, K = orthoclase, Pl = plagioclase, Mi = microcline; Lithic Fragments, Cht = chert, Sst = sandstone, Met = metamorphic, Gnt = granitic/plutonic, Vc = coarse volcanic and volcaniclastic, Vf = fine volcanic and volcaniclastic, Vg = volcanic glass; Accessories, Mu = Muscovite, L = lignite, Si = siderite, H = hematite, Hb = hornblende, E = epidote, B = biotite; n = number of points, tr = trace.

TABLE 2

Semi-quantative analysis of mudstone samples (Whole rock, by XRD)

Sample (borehole/ depth)	Quartz	Chlorite + Kaolinite	Illite	Feldspar	Calcite	Cristobalite	Mixed layer and/ or expandable clays	others
Q1/20.4 m Lake deposit (light band)	45%	19%	13%	11%	-	-	6%	siderite 6
Q1/22.3 m Lake deposit (light band)	47%	24%	13%	13%	-	-	3%	-
Q1/24.8 m Lake deposit (with authigenic spherules)	40%	15%	7%	11%	4%	7%	6%	pyrite 2 gypsum 2
Q1/33.4 m Lake deposit	39%	18%	11%	11%	-	8%	7%	siderite 6
Q1/34.0 m Lake deposit	50%	18%	11%	12%	3%	-	4%	dolomite 2
Q2/65.4 m Pond deposit (tr chlorite)	43%	21%(K)	9%	9%	-	12%	6%	-
Q2/65.7 m Pond deposit (volcanic ash band)	-	21%	-	-	-	-	79%	-
Q2/110.6 m Floodplain deposit (rooted marsh)	60%	14%	11%	5%	-	3%	6%	pyrite 1
Q2/128.2 m Floodplain deposit (rooted marsh)	48%	21%	10%	6%	-	15%	tr	-
Q2/128.5 m Floodplain deposit (oxidized marsh)	58%	9%(K)	7%	10%	-	12%	4%	-
Q2/130.1 m Pond deposit	53%	16%(K)	8%	6%	-	15%	tr	siderite 2
Q2/159.1 m Pond or marsh deposit	61%	12%	22%	4%	2%	-	tr	siderite 1
Q3/71.6 m Floodplain deposit (oxidized marsh)	56%	9%(K)	11%	5%	3%	13%	tr	dolomite 3

K = kaolinite only, tr = trace.

(analysis by J.N.Y. Wong)

TABLE 3

Composition of clay fraction in <2 micron component

Sample (borehole/ depth)	Quartz	α-Cristobalite	Illite	Chlorite + Kaolinite (C:K)	Expandable and/or mixed layer clays
Q1/20.4 m Lake deposit (light band)	5%	3%	12%	25% (C>K)	55% (M + C 2-1)
Q1/22.3 m Lake deposit (light band)	3%	-	19%	52% (2:1)	26% (M)
Q1/24.8 m Lake deposit (authigenic spherules)	5%	5%	12%	27% (1:1)	54% (M + C 2-1)
Q1/33.4 m Lake deposit	3%	-	9%	25% (1:1)	63% (M + C 2-1)
Q1/34.0 m Lake deposit	3%	-	13%	35% (1:1)	49% (M + tr C 2-1)
Q2/65.4 m Pond deposit	10%	12%	10%	53% (K)	15% (M + tr C 2-1)
Q2/65.7 m Pond deposit (ash)	-	-	-	17% (K)	83% (Ab M)
Q2/110.6 m Floodplain deposit (rooted marsh)	13%	-	26%	54% (1:2)	7% (tr M)
Q2/128.2 m Floodplain deposit (rooted marsh)	8%	18%	12%	53% (1:1)	9% (M + tr C 2-1)
Q2/128.5 m Floodplain deposit (oxidized marsh)	14%	13%	10%	44% (K)	19% (M + tr C 2-1)
Q2/130.1 m Pond deposit	10%	10%	9%	53% (K)	18% (M + tr C 2-1)
Q2/159.1 m Pond or oxidized marsh	9%	4%	28%	35% (2:3)	24% (M + tr C 2-1)
Q3/71.6 m Floodplain deposit (oxidized marsh)	9%	14%	15%	26% (K)	36% (M)

C:K = ratio of chlorite to kaolinite, C>K = chlorite more abundant than kaolinite, K = kaolinite only, M = montmorillonite, C 2-1 = chlorite 2-1 mixed layer silicate, Ab = abundant, tr = trace

(analysis by J.N.Y. Wong)

TABLE 4

Grain size characteristics of the Australian Creek Formation

Surface samples by location, lithofacies (and environment of deposition)

Percentile (C)	1	5	16	25	50	75	84	95	Mz	i	Ski	Kg
Australian Creek A, Lithofacies 1 (fan)	-4.86	-4.80	-4.05	-3.54	-2.30	-0.44	+0.87	+3.15	-1.83	2.4	0.33	1.08
Australian Creek B, Lithofacies 1 (fan)	-3.76	-3.30	-2.07	-1.55	-0.15	+1.40	+2.15	+4.30	-0.02	2.2	0.13	1.06
Big Bend Lithofacies 1 (distal fan, sheetwash)	-5.15	-5.09	-4.95	-4.80	-3.09	-1.25	-0.15	+2.15	-2.73	2.3	0.34	0.84
Weldwood Lithofacies 2 (main channel)	-4.40	-4.30	-3.51	-3.05	-2.08	-0.68	+0.70	+2.82	-1.63	2.1	0.35	1.23
Alexandria Ferry, Lithofacies 2 (channel)	-2.94	-2.45	-1.75	-1.40	-0.40	+0.71	+1.20	+2.40	-0.32	1.5	0.12	0.94

Subsurface samples by borehole number/depth, lithofacies (and environment of deposition)

Percentile (C)	1	5	16	25	50	75	84	95	Mz	i	Ski	Kg
Q1/50.1 m Lithofacies 5 (beach, berm)	-0.79	-0.09	+0.90	+1.58	+2.27	+3.45	+4.75	+6.80	+2.54	2.0	0.30	1.51
Q1/50.3 m Lithofacies 5 (beach, lower shoreface)	-2.01	+0.94	+1.60	+1.69	+2.04	+3.35	+4.70	+6.40	+2.78	1.6	0.66	1.35
Q1/51.2 m Lithofacies 5 (near shore, lacustrine)	+0.70	+1.42	+2.48	+3.25	+4.45	+5.80	+6.50	+7.80	+4.48	2.0	0.02	1.03
Q1/120.4 m Lithofacies 4 (minor channel)	-1.80	-1.55	-1.10	-0.83	-0.13	+0.80	+1.37	+2.30	+0.05	1.2	0.24	0.97
Q1/139.0 m Lithofacies 5 (splay)	-2.06	-1.02	-0.35	-0.07	+0.44	+2.40	+3.90	+6.80	+1.33	2.3	0.63	1.30
Q1/144.5 m Lithofacies 4 (channel)	-3.84	-3.63	-3.04	-2.81	-1.95	-0.47	+0.52	+2.53	-1.49	1.8	0.42	1.08
Q2/136.3 m Lithofacies 5 (proximal splay)	-3.55	-3.22	-2.63	-2.29	-1.30	+0.50	+1.90	+5.70	-0.68	2.5	0.49	1.31
Q2/140.3 m Lithofacies 4 (channel)	-4.12	-4.04	-2.47	-2.10	-0.60	+2.30	+4.00	+6.90	+0.31	3.3	0.40	1.02
Q2/144.0 m Lithofacies 2 (channel)	-4.89	-4.80	-4.23	-3.66	-2.47	-0.15	+1.55	+4.07	-1.72	2.8	0.43	1.04
Q2/154.4 m Lithofacies 5 (splay)	+1.40	+1.80	+2.10	+2.26	+2.55	+3.40	+4.10	+6.20	+2.92	1.2	0.60	1.58
Q2/155.6 m Lithofacies 5 (splay)	+1.32	+1.70	+1.95	+2.10	+2.60	+3.80	+5.00	+7.50	+3.18	1.6	0.63	1.40

Percentile (C)	1	5	16	25	50	75	84	95	Mz	i	Ski	Kg
Q2/156.0 m Lithofacies 2 (channel)	-4.38	-4.32	-4.29	-3.55	-2.36	-0.01	+1.65	+5.20	-1.67	2.9	0.46	1.11
Q3/135.0 m Lithofacies 5 (splay)	+0.85	+1.70	+2.40	+2.65	+3.15	+4.30	+5.00	+6.35	+3.52	1.4	0.40	1.15
Q3/135.9 m Lithofacies 5 (splay)	-2.10	-0.70	+0.15	+0.55	+1.30	+2.50	+3.75	+6.70	+1.73	2.0	0.41	1.56
Q3/136.6 m Lithofacies 2 or 3 (proximal splay or channel)	-4.60	-4.51	-1.90	-0.75	+0.75	+2.10	+3.75	+8.10	+0.87	3.3	0.11	1.81
Q3/136.8 m Lithofacies 2 (channel)	-4.55	-4.40	-3.71	-3.15	-1.60	+0.21	+1.60	+4.90	-1.24	2.7	0.30	1.13
Q3/142.6 m Lithofacies 2 (channel)	-4.85	-4.80	-4.50	-4.00	-2.60	+0.70	+2.00	+7.85	-1.70	3.5	0.53	1.10
Q3/158.3 m Lithofacies 2 (channel)	-4.85	-4.70	-4.10	-3.81	-2.90	-0.70	+0.70	+4.00	-2.10	2.5	0.54	1.15
Q3/187.5 m Lithofacies 5 (levee or splay)	+1.65	+1.92	+2.20	+2.34	+2.68	+3.40	+4.00	+6.40	+2.96	1.1	0.56	1.73
Q3/188.4 m Lithofacies 5 (levee or splay)	+0.15	+0.99	+1.32	+1.47	+1.75	+2.48	+3.15	+5.30	+2.07	1.2	0.59	1.75
Q3/188.7 m Lithofacies 2 (channel)	-3.20	-2.80	-2.35	-2.00	-1.02	+1.55	+2.90	+5.40	-0.53	2.6	0.53	0.95
Q3/196.6 m (Fan, flood or splay)	-2.70	-0.55	+1.65	+2.55	+5.00	+7.30	+8.40	+10.7	+5.02	3.4	0.01	0.97
Q3/203.7 m Lithofacies 6 (in channel pond or mudflow)	-2.70	-1.90	+1.35	+3.40	+5.80	+8.10	+9.15	+11.4	+5.43	4.0	-0.15	1.16
Q3/207.7 m Lithofacies 2 (channel)	-4.57	-4.20	-3.30	-2.60	-0.30	+4.40	+6.20	+10.1	+0.87	4.5	0.41	0.84
Q3/208.5 m Lithofacies 5 (splay or flood deposit)	+0.65	+1.38	+2.20	+2.30	+3.10	+4.00	+4.38	+5.15	+3.23	1.1	0.13	0.92
Q3/211.2 m Lithofacies 2 (channel)	-5.15	-5.05	-4.50	-4.05	-3.10	+0.50	+2.50	+5.70	-1.70	3.4	0.62	0.97
Q3/214.8 m Lithofacies 1 or 2 (channel, fan or braided stream)	-4.10	-3.90	-3.15	-2.50	-0.70	+2.25	+3.75	+6.60	-0.03	3.3	0.34	0.91
Q3/220.4 m Lithofacies 6 (mudflow or flood deposit)	-3.75	-2.05	+2.65	+4.50	+7.20	+10.0	?11.3	?12.5	+7.05	4.4	-0.16	1.08
Q3/229.5 m Lithofacies 1 or 2 (channel, fan or braided stream)	-4.06	-3.70	-3.00	-2.65	-1.15	+1.25	+2.75	+6.00	-0.47	2.9	0.42	1.02

Modern anastomosed rivers

Percentile (C)	1	5	16	25	50	75	84	95	Mz	i	Ski	Kg
Columbia River, British Columbia												
Channel (sidebar, above main outlet of fan at Golden, B.C.)	+1.26	+1.65	+1.87	+1.93	+2.19	+2.52	+2.61	+2.83	+2.20	0.4	0.11	0.82

Percentile (C)	1	5	16	25	50	75	84	95	Mz	i	Ski	Kg
Channel (sidebar, below main outlet of fan at Golden, B.C.)	-5.05	-4.90	-4.75	-4.29	-3.25	-0.95	+0.84	+2.43	-2.39	2.5	0.51	0.90
Splay (splay near Harrowgate, B.C.)	+0.75	+1.85	+2.20	+2.34	+2.59	+2.83	+2.99	+3.52	+2.59	0.5	0.06	1.40
Alexandria River, Alberta												
Channel (bar top sand, with linguoid ripples)	-1.89	-1.05	-0.18	+0.31	+0.96	+1.56	+1.65	+1.96	+0.81	0.9	-0.29	0.99
Channel (longitudinal in-channel bar, flat bedded)	-4.24	-3.78	-3.30	-3.05	-1.72	+0.30	+1.15	+2.12	-1.29	2.0	0.30	0.72
Upper Waterfowl Lake, Alberta												
Channel (bar side lag, flat bedded unit, about 2 mm thick)	-2.22	-1.43	-1.12	-0.68	+0.65	+1.96	+2.44	+3.28	+0.66	1.6	0.06	0.73
Channel (in-channel bar at confluence of two channels, massive, 10 cm thick)	-1.60	-0.90	-0.29	+0.18	+1.31	+2.10	+2.15	+2.92	+1.16	1.3	-0.16	0.82

Note: Percentile: (C) = weight per cent coarser than, in phi units
Graphic mean: Mz = (C16+C50+C84)/3
Sorting: i = (C84-C16)/4 + (C95-C5)/6.6
Skewness: $Ski = \frac{(C84+C16-2xC50)}{2x(C84-C16)} + \frac{(C5+C95-2xC50)}{2x(C95-2xC5)}$
Kurtosis: Kg = (C95-C5)/2.44x(C75-C25)

TABLE 5

Clast type analysis (percentage by weight)

Sample (borehole/ depth)	Quartz %	Volcanic %	Chert %	Sedimentary %
Q3/136.55 m	5.6	86.7	7.1	0.7
Q3/136.86 m	3.5	78.0	13.4	5.0
Q3/142.65 m	1.9	55.3	27.1	15.6
Q3/211.23 m	2.9	94.5	–	2.6
Q3/153.31 m	1.9	87.0	0.6	10.5
Q3/188.67 m	11.5	37.2	36.8	13.4
Q3/196.60 m	5.4	88.1	–	6.5
Q3/203.85 m	11.6	79.9	3.5	–
Q3/207.72 m	12.6	87.1	0.3	–
Q3/214.88 m	9.7	89.6	0.8	–
Q3/220.37 m	–	93.7	6.3	–
Q3/224.03 m	7.7	72.1	8.8	11.4
Average	6.2	79.1	8.7	5.5

Analyst: Clive Stephenson