Age and setting of dinosaur trackways, Ross River area, Yukon Territory (105F/15)

Darrel G.F. Long[1]
Laurentian University

Grant Lowey[2]
Yukon Geology Program

Arthur R. Sweet[3]
Geological Survey of Canada

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ABSTRACT

Chert-bearing clastic strata are a common component of Jurassic and younger terrestrial sequences in the Yukon. The discovery of dinosaur trackways in a small inlier of chert-bearing clastic strata within the Tintina Trench, 3 km west of Ross River, led to reevaluation of its sedimentary framework and previously assumed Eocene age. A mid-Cretaceous (middle Albian to early Cenomanian) age is inferred from a miospore assemblage that includes the angiosperms *Cupuliferoidaepollenites minimus*, *Retitricolpites prosimilis*, *Retitricolpites virgeus* and *Senectotetradites amiantopollis*. The trackways are preserved on at least three levels within the >427 m of section exposed along and north of the Robert Campbell Highway. They occur in splay deposits associated with small, sandy meandering rivers that flowed parallel to the direction of the Tintina Trench. Most trackways appear to be heading towards the southeast, suggesting systematic migration patterns during the wet season. Conglomeratic strata were deposited by wandering gravel-bed rivers that also flowed parallel to the trench. Individual channels were up to 12 m deep and more than 50 m wide.

RÉSUMÉ

On trouve souvent des strates clastiques cherteuses dans les séquences terrestres d'âge Jurassique et plus jeunes du Yukon. Des pistes de dinosaures ont été découvertes dans une petite enclave de strates clastiques cherteuses, dans le fossé de Tintina, à 3 km à l'ouest de Ross River, ce qui nous a amenés à réévaluer la structure sédimentaire de cette séquence, ainsi que son âge auparavant présumé de l'Éocène. Nous déduisons d'un assemblage de miospores, dont les angiospermes *Cupuliferoidaepollenites minimus*, *Retitricolpites prosimilis*, *Retitricolpites virgeus* et *Senectotetradites amiantopollis*, qu'elles datent du Crétacé moyen (entre l'Albien moyen et le Cénomanien précoce). Les pistes sont identifiables sur au moins trois niveaux de la section de plus de 427 m qui affleure en bordure, et au nord de la route Robert Campbell. Elles se trouvent dans des sédiments plats et divergents associés à de petits cours d'eau méandriques sablonneux qui s'écoulaient parallèlement à l'axe du fossé de Tintina. La plupart des pistes semblent se diriger vers le sud-est, indiquant des mouvements de migration systématiques durant la saison humide. Des strates conglomératiques furent aussi déposées par de petits cours d'eau sinueux au lit graveleux qui s'écoulaient aussi parallèlement à l'axe du fossé. Les chenaux atteignaient 12 m de profond et plus de 50 m de large chacun.

[1]*Department of Earth Sciences, Laurentian University, Sudbury, Ontario, Canada P3E 2C6, dlong@nickel.laurentian.ca*

[2]*glowey@gov.yk.ca*

[3]*Geological Survey of Canada, 3303-33rd St. NW, Calgary, Alberta, Canada T2L 2A7*

INTRODUCTION

Conglomerates and sandstones containing abundant chert and chert look-alikes are a common component of Jurassic and younger terrestrial sequences in the Yukon Territory. They include the Upper Jurassic(?) to Lower Cretaceous strata of the Tantalus Formation in the Whitehorse Trough (Long, 1982a,b, 1983, 1986; Bremner, 1988; Hart and Radloff, 1990; Allen, 1999; Allen and Weston, 2000) and Indian River area (Lowey, 1982, 1983a; Lowey and Hills, 1988); Upper Cretaceous strata in the Bonnet Plume basin (Norris and Hopkins, 1977; Long, 1978, 1986), the Eagle Plain Formation (Moorehouse, 1966; Mountjoy, 1967), and Moose Channel Formation (Young, 1975); and Tertiary strata in the Bonnet Plume basin (Long, 1978, 1986), Reindeer Formation (Mountjoy, 1967, Young, 1975, Norris, 1981) and along the trend of the Tintina fault zone near Dawson, Ross River and Watson Lake (Hughes and Long, 1980; Long, 1981; Long et al., 1990). The petrographic similarity of some of these sequences along the trend of the Tintina fault zone is shown in Figure 1. Most of the sandstones are sedlitharenites (Fig. 1a, c), containing abundant mudstone, carbonate and sandstone rock fragments, subordinate granitic rock fragments and only minor chert. The chert-like appearance of these sequences appears to be related to the abundance of fine-grained sedimentary rock fragments rather than true chert. Quartz types do not appear to be useful in distinguishing these strata (Fig. 1b).

Chert-bearing clastic strata located in a fault-bounded block within the Tintina Trench, beginning 2 km west of the townsite of Ross River (Fig. 2), were originally thought to be part of an 800- to 1100-m-thick Tertiary sequence of conglomerate and mudstone, with minor sandstone

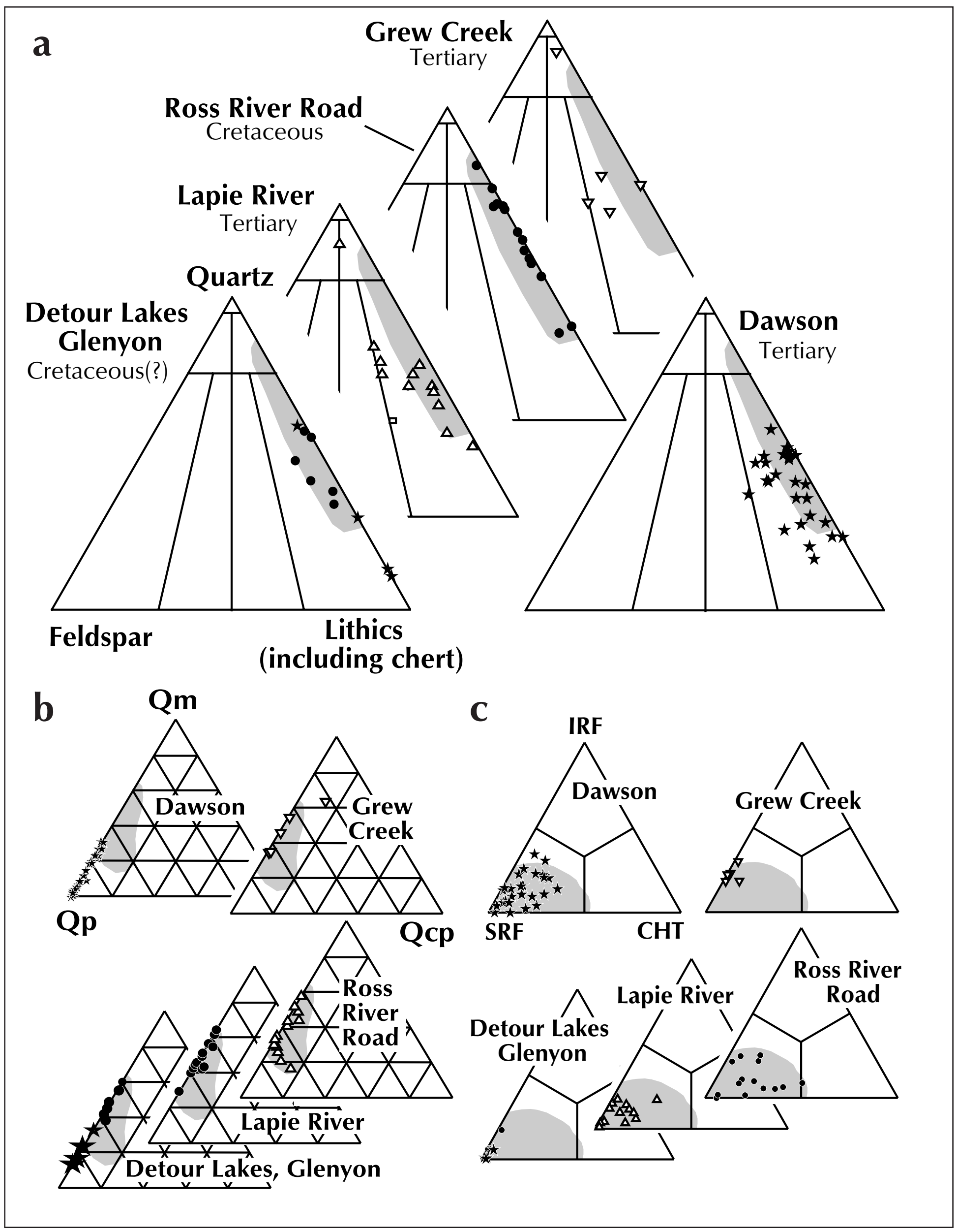

Figure 1. *(a) Petrography of framework grains in samples from localities along the Tintina Trench (minimum 700 framework grains per thin section); (b) Quartz grain-types (Qp = polycrystalline grains - fine; Qcp = coarse polycrystalline grains; Qm = monocrystalline quartz. Strained quartz was not present in significant amounts); (c) Petrography of rock fragments (IRF = igneous rock fragments; SRF = sedimentary rock fragments; CHT = Chert); Petrographic field of strata in the Ross River Road block is shaded.*

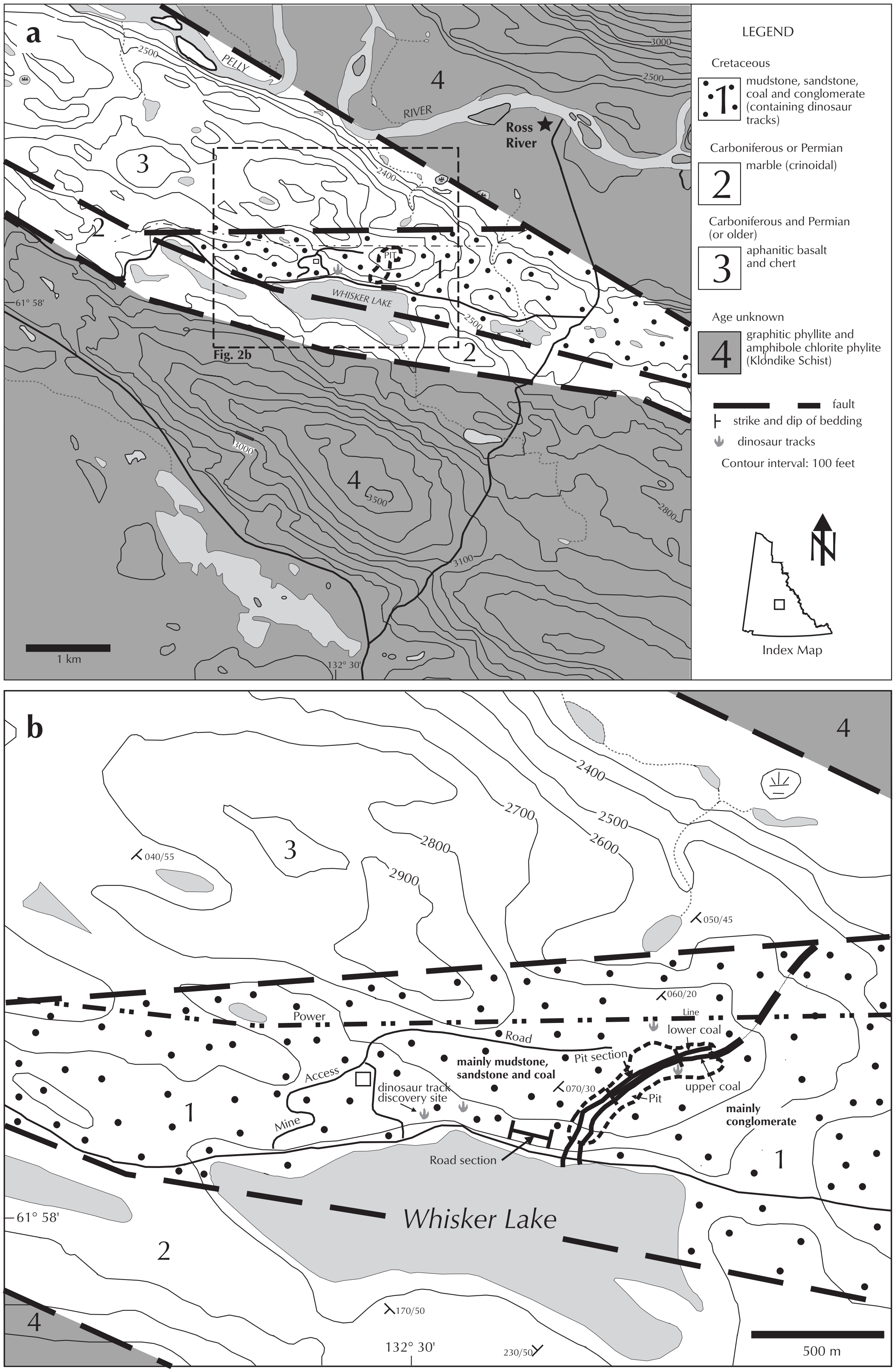

Figure 2. *(a) Geological map of the area near Ross River (modified from Tempelman-Kluit, 1977; Hughes and Long, 1980; Pigage, 1988). (b) Detailed geological map.*

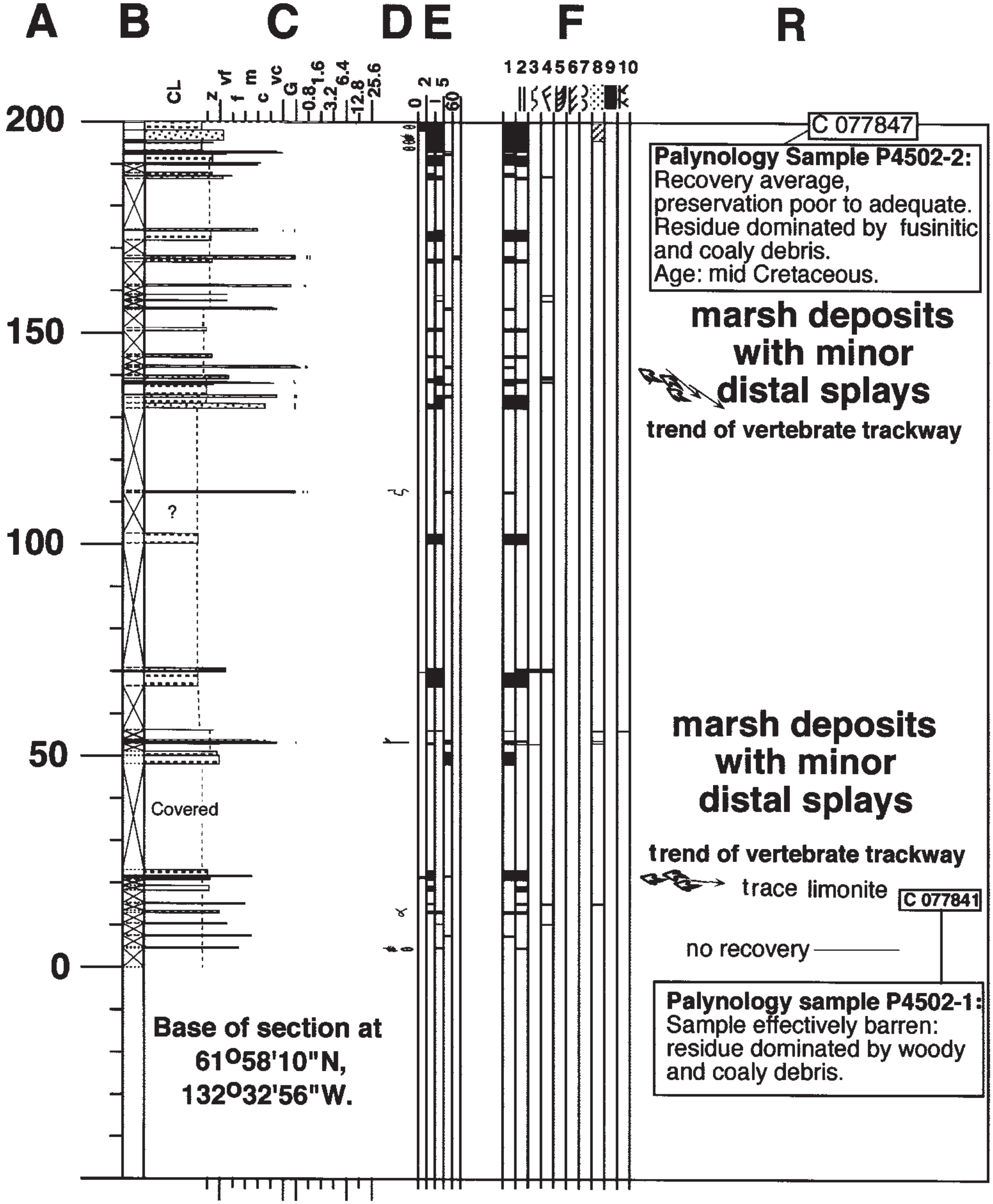

Figure 3. *Stratigraphy of the Ross River block, based on exposures adjacent to the Robert Campbell Highway, at Whisker Lake. A = elevation above base of section in metres. B = contacts, solid line = sharp, dashed line = transitional, dotted line = not seen, cross indicates no exposure. C = grain size: CL = claystone, M = mudstone, S = sandstone, z = siltstone, vf (very fine), f (fine), m (medium), c (coarse), vc (very coarse) = sandstone, G = granule conglomerate, number = grain size*

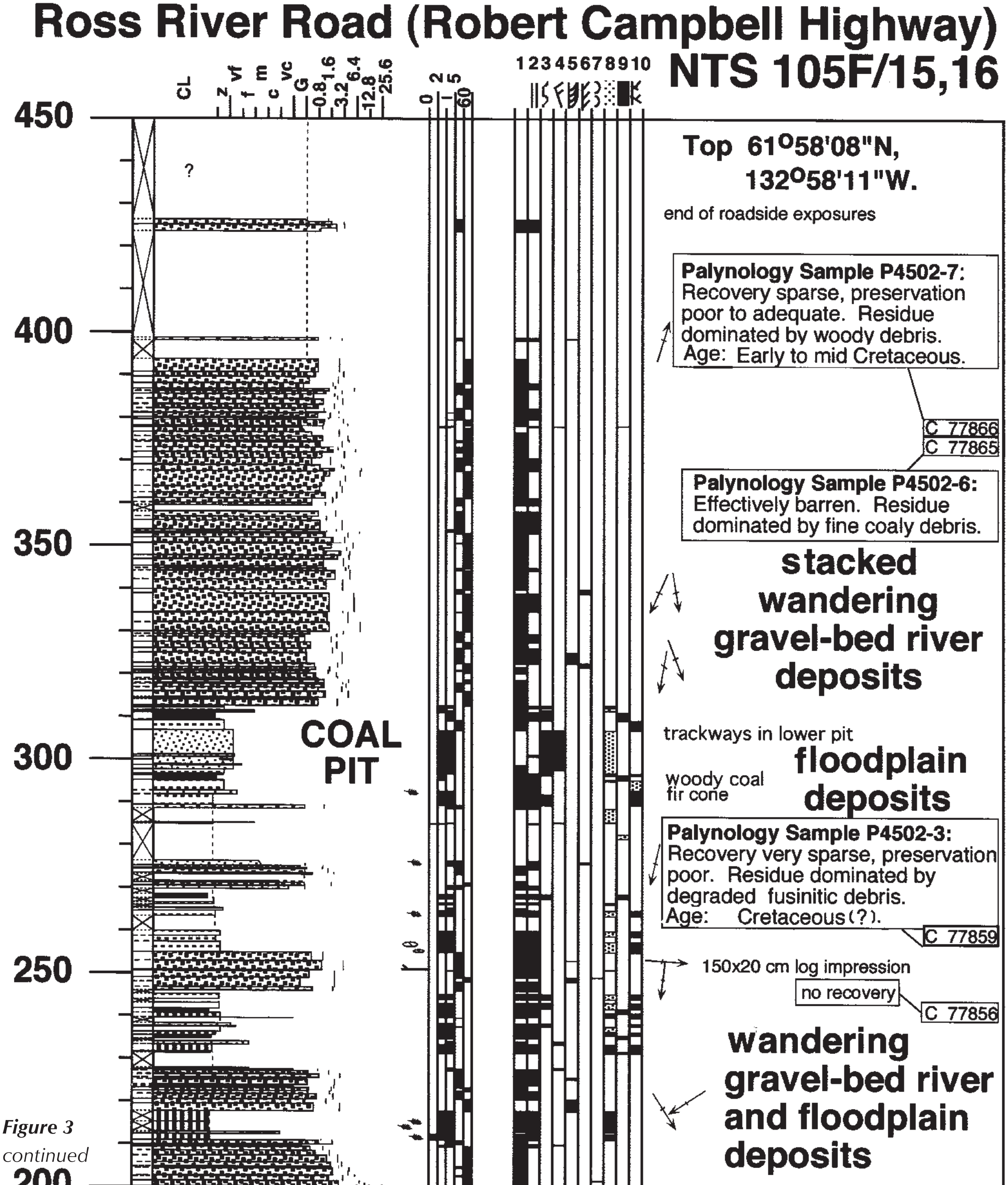

Figure 3 continued

in cm., p = pebble, g = granule. D = minor structures (concretions, plant leaves, logs). E = bed thickness (range in cm). F = sedimentary structures: 1 = appears massive; 2 = plane bedded; 3 = wavy bedded; 4, r = ripple cross-laminated; 5, t = trough cross-stratified; 6 = planar cross-stratified; h = horizontally laminated; w = wavy laminated; 7 = mudstone intraclasts; 8 = dispersed organic material; 9 = coal; 10 = traces of fossil plant roots; R = remarks. Arrows indicate paleoflow directions.

and coal (Kindle, 1946; Wheeler, et al., 1960; Milner and Craig, 1973; Tempelman-Kluit, 1977; Hughes and Long, 1980; Long, 1981; Long et al., 1990). While miospores in this block were found to be very poorly preserved due to thermal degradation, a Tertiary age was assumed because of the similarity of this strata to clastics in a second block at Lapie River, 7 km west of the Ross River townsite where Hopkins (1979) recovered a better preserved assemblage of palynomorphs. These included *Alnus*, which was taken as suggestive of an Early Eocence to late Middle Eocene age. A stratigraphic gap of about 200 m was estimated between the two sections based on vitrinite reflectance gradients (Hughes and Long, 1980). The subsequent discovery of dinosaur tracks in the Ross River block by Roland Gangloff and Kevin May of the University of Alaska (Pedersen, 1999; Gangloff et al., 2000) indicated that the original age assignment was in error. In order to determine the geological context of these tracks, the section was re-examined and re-sampled. Palynological samples collected in 1978 were re-processed and re-examined. Results of this study are outlined below.

GEOLOGICAL SETTING

The Ross River area is underlain by the Yukon-Tanana Terrane, an assemblage of polydeformed metamorphic rocks that is thought to be Paleozoic in age (Mortensen, 1990, 1992, 1996). According to Mortensen (1992), the Yukon-Tanana Terrane consists mainly of pelitic to quartzofeldspathic metasedimentary schist and gneiss with minor amounts of marble and mafic to felsic metavolcanic and metaplutonic rocks. It was juxtaposed with other terranes (i.e., Slide Mountain) by regional-scale thrust faulting in early Mesozoic time and structurally overlies the ancient continental margin of North America (Mortensen, 1990). The Yukon-Tanana Terrane is unconformably overlain by post-accretionary, mid- to Late Cretaceous sedimentary and volcanic rocks (Mortensen, 1996). Both the pre-accretionary and post-accretionary rocks are offset by at least 450 km of dextral movement along the Tintina fault zone, the displacement of which is thought to have occurred in the Late Cretaceous and Early Tertiary (Roddick, 1967; Long, 1981). The exact position of the Tintina fault zone in the area is uncertain. Tempelman-Kluit (1977) placed it about 2 km southwest of the rectangular area delineated on Figure 2, while magnetotelluric studies by Ledo, et al. (2000) indicate that the main crustal discontinuity may be east of the Ross River fault-bounded block. Ledo et al. (2000) also recognize a second crustal discontinuity further to the west, which coincides with the St. Cyr fault.

Tempelman-Kluit (1977) provides the most complete coverage of the bedrock geology in the Ross River area. The map by Roddick (1960) is dated but provides useful descriptive notes. Hughes and Long (1980) and Long et al. (1990) outline the geology and coal resource potential of the sedimentary rocks in the Ross River area, and a detailed map (1:2000 scale) of the area mined is included in the drilling report by Pigage (1988). The surficial geology has been discussed by Plouffe and Jackson (1995).

NEW OBSERVATIONS

Strata in the Ross River block consist of at least 427 m of mudstone, conglomerate and sandstone, with minor coal (Fig. 3). Most strata dip 20-30° to the southwest.

MUDSTONES AND COAL

Mudrocks dominate the lower 200 m of the section; they are predominantly dark grey to dark greenish grey claystones with minor siltstone. Most appear massive with a pseudo-brecciated appearance (cf. Fig. 4, lower unit), or exhibit faint horizontal stratification. Traces of plant roots are rare below the 200 m level and common between the 200 and 310 m levels (Fig. 3). Black, organic-rich mudrocks are developed locally in the lower 200 m of the section, but are more common in association with coals in the 200 to 310 m interval.

Coal forms a small but significant part of the sequence. Five seams of bituminous coal were recognized in the area prior to mining (Hughes and Long, 1980). Open-pit mining of the recessive interval below the upper conglomerate has exposed two of these seams from which Nadahini Mining Corporation extracted about 50,000 tonnes of coal (Pigage, 1988; Hunt, 1994). The lower of the two seams is a dull woody coal, 1.7 to 1.8 m thick, which rests on a 40-cm-unit of massive (pseudo-brecciated) organic-rich mudstone with abundant fossil plant roots. The upper seam is a dull woody coal, 1.5 to 1.8 m thick, which rests on an organic-rich mudstone, and is locally interbedded with wavy and ripple cross-laminated, fine to very fine sandstones. Further near-surface coal deposits may be present along strike to the northeast.

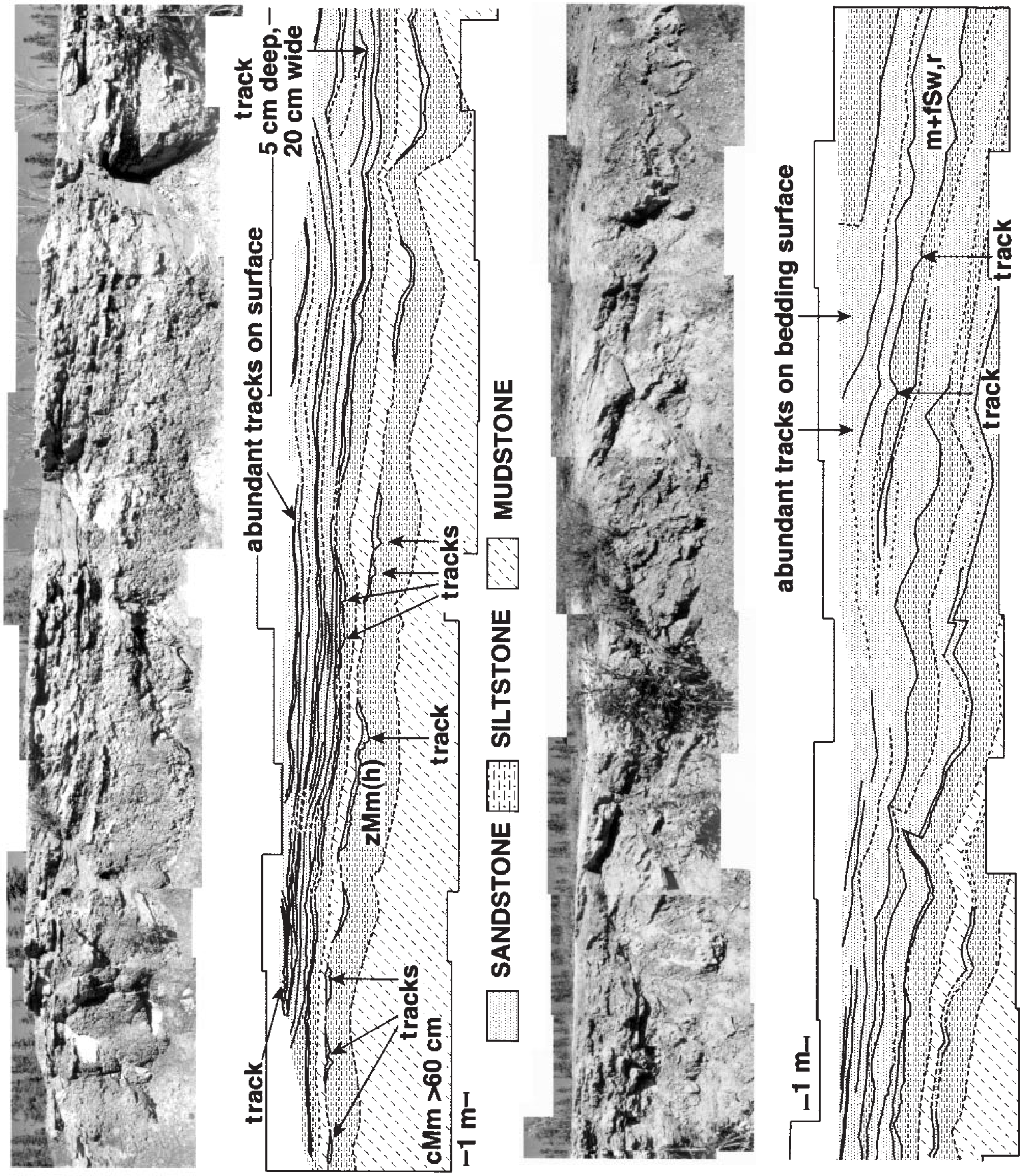

Figure 4. *Exposure of track-bearing mudstone and very fine- to medium-grained sandstones of probable splay origin, adjacent to Robert Campbell Highway north of Whisker Lake. See Figure 3 for explanation of abbreviations.*

SANDSTONES

Sandstones form a minor part of the sequence. All have a speckled (salt-and-pepper) texture due to the abundance of resistant lithic clasts (Fig. 1). They occur as thin sets (5-50 cm) of planar-laminated, wavy and ripple cross-laminated, silty fine- and very fine-grained sandstones; thin to thick co-sets (0.1-7 m) wavy and ripple cross-laminated, fine- to medium-grained sandstones; and minor massive and planar-laminated, poorly sorted to moderately poorly sorted, medium to granular, very coarse-grained sandstones in sets 0.15-1.3 m thick. Ripple cross-laminated medium- to very coarse-grained sandstones are found as thin layers within conglomeratic parts of the sequence. Finer grained sandstones are locally interbedded with siltstones and organic-rich mudstones, and may contain local (early) nodular siderite concretions (Fig. 5a). Large-scale bedforms include shallow scour surfaces and channels (Fig. 5b,c, 6). Epsilon cross-stratification is developed locally (Fig 5d, 6).

CONGLOMERATE

Conglomerates are conspicuous in the upper part of the sequence. They occur in stacked sequences a few metres to more than 90 m thick (Fig. 3) and as minor components of small channels in finer grained parts of the section (Fig. 7a). They consist predominantly of thick beds (5 cm - 5.5 m) of yellow-brown-weathering, framework-supported, moderately well sorted, small- to large-pebble conglomerate: sedlithrudite (Fig. 8). Clasts are typically rounded to subrounded, with a maximum observed clast size of 9 cm. In the section along the Robert Campbell Highway, most of the conglomerates appear to be massive

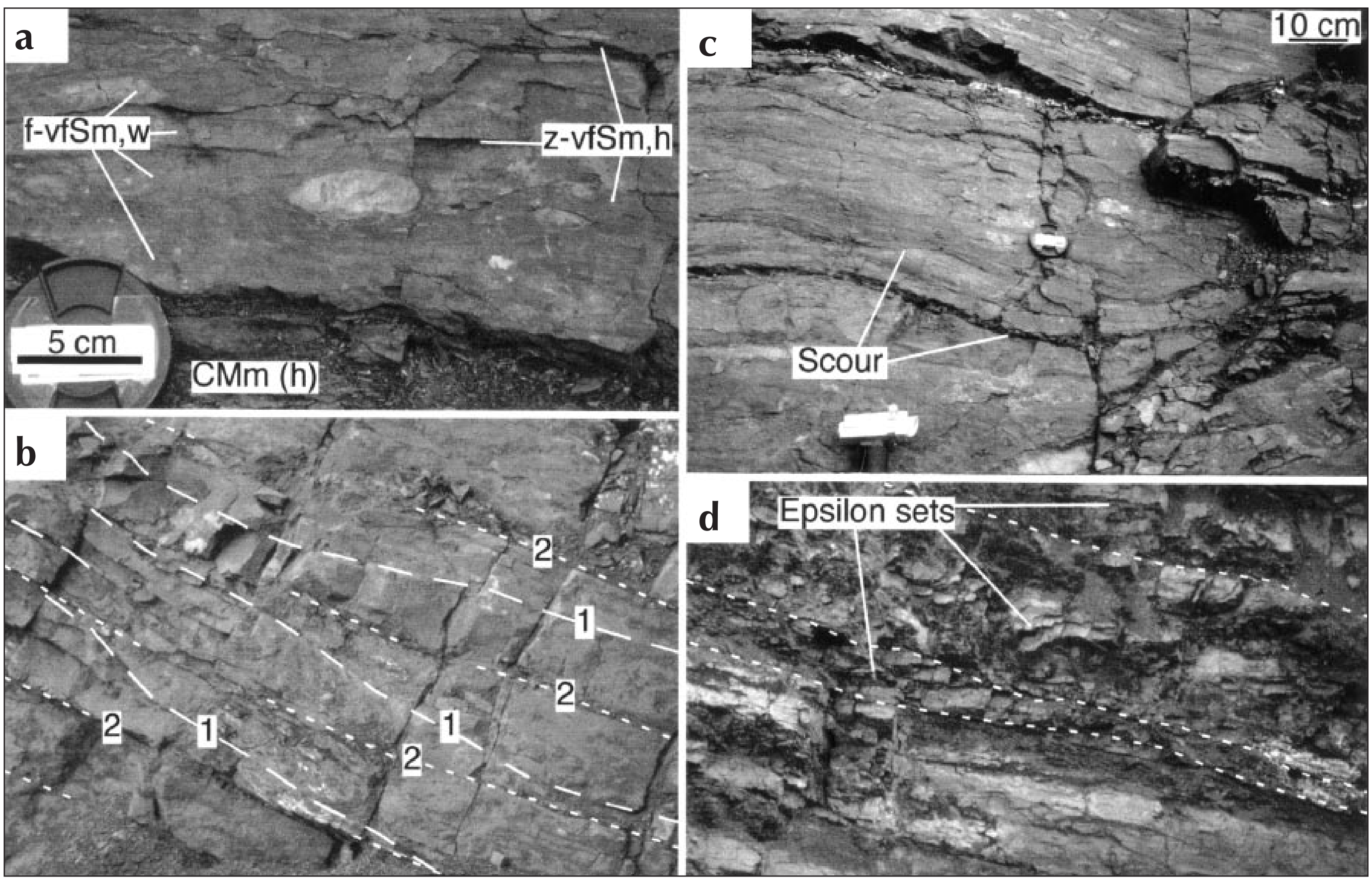

Figure 5. *Fine- to medium-grained sandstones: (a) Massive to wavy bedded fine- to very fine-grained sandstone with siderite nodules (in upper coal pit); (b) shallowly inclined co-sets of fine- to very fine-grained wavy laminated sandstone of levee-splay origin (upper coal pit); (c) local scour surfaces in fine- to very fine-grained flat to wavy laminated sandstones of levee-splay origin (upper coal pit); and (d) well developed epsilon cross-stratification, marked by alternating beds of fine- to very fine-grained sandstone and siltstone (below upper coal seam in upper pit). See Figure 3 caption for explanation of abbreviations.*

or planar-laminated (Fig. 7b). In the coal pit, this is seen to be an illusion as most of the strata are characterized by large-scale (1-5.5 m) planar and trough cross-stratification (Fig. 7c), with grouped sets occupying broad channels up to 12 m deep (Figs. 7d, 9). An unusual scalloped erosional contact was noted at the base of one conglomeratic unit at the north end of the upper pit (Fig. 7e).

DEPOSITIONAL FACIES

Clay-mudstones in the Ross River sequence are here interpreted as the products of deposition in overbank marsh and pond environments. Well developed planar lamination, characteristic of lake deposits was not seen. The grey colour is related to moderate dispersed organic content. The predominance of grey, rather than black mudrocks suggests marsh environments with the water table at or near the surface during part of the year. The brecciated appearance of many of the clay-mudstones (Fig. 4: lower unit) is due to the presence of numerous closely spaced, intersecting curved fracture surfaces. These slickensides are typically associated with a fluctuating water table (Try et al., 1984). In dry periods, the soil shrank and cracked, to swell again in wet periods. Rubbing of adjacent soil crumbs and blocks during repeated wetting and drying led to the production of grooved and polished surfaces, now represented by the slickensides (Donahue, et al., 1958; Fitzpatrick, 1980; Nadon, 1993). Siltstones are typically associated with both wavy to ripple cross-laminated sandstones and are interpreted as distal levee deposits. Organic-rich mudstones and coals were deposited in marsh and swamp environments, away from the main fluvial channels.

Finer-grained sandstones appear to have been deposited as overbank levee and splay deposits. The architecture (geometry) of some track-bearing splay deposits is shown

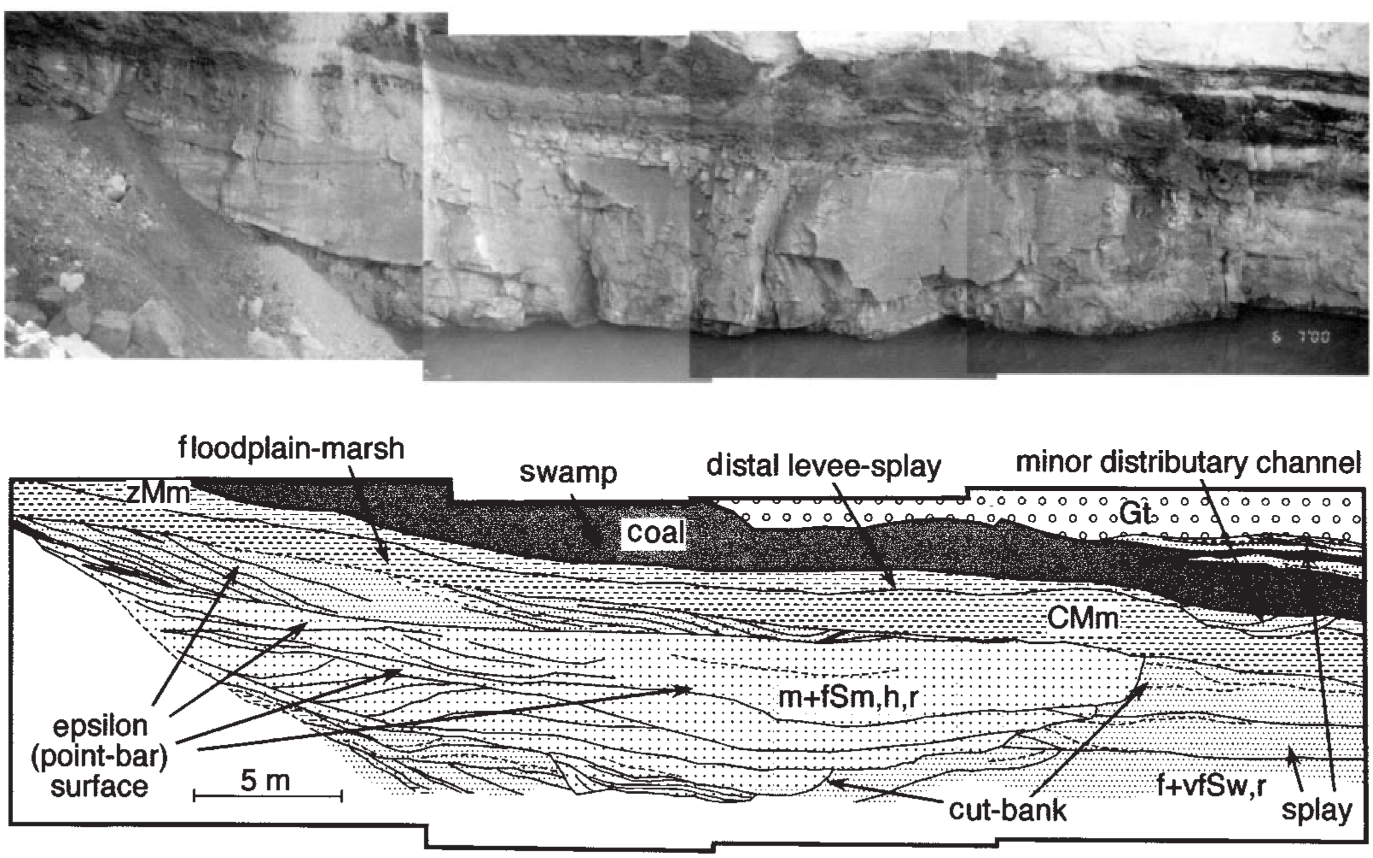

Figure 6. *High-constructive (stable) channel deposit, with stacked epsilon cross-stratification. Note minor distributary channel deposit at base of upper coal seam, and splay deposits at the top of the coal seam (lower pit). See Figure 3 caption for explanation of abbreviations. Patterns as in Figure 9.*

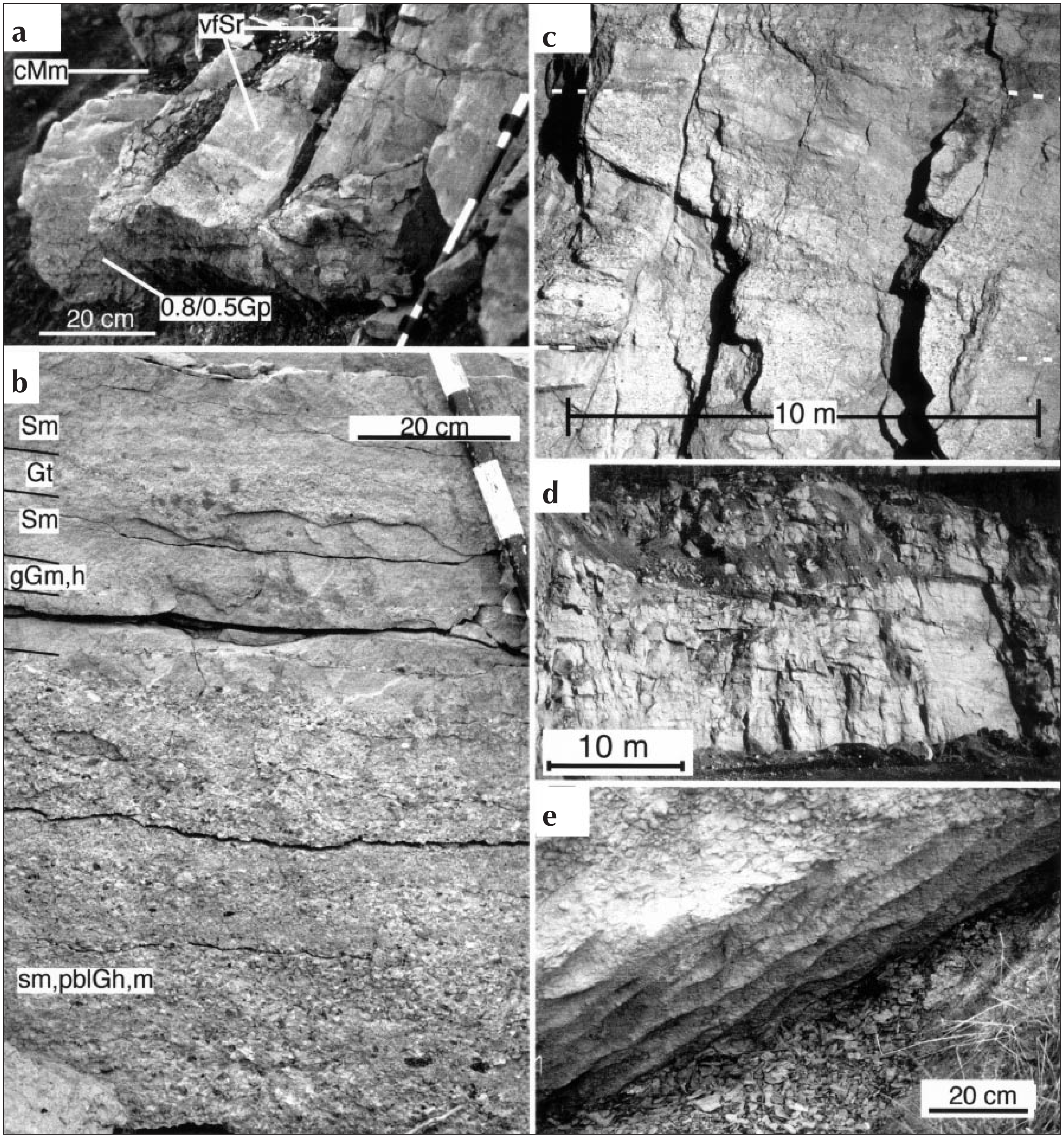

Figure 7. Conglomeratic strata: (a) Planar cross-stratified lens of small-pebble conglomerate in small, 8-m-wide channel in the upper coal seam, south end of upper coal-pit; (b) typical exposure of small-pebble conglomerate in the upper conglomerate adjacent to the Robert Campbell Highway; (c) a 5.5-m-thick composite planar cross-stratified small- to medium-pebble conglomerate (dashed lines indicate set boundaries); (d) large-scale channel (12 m thick), with local organic-rich mudstone and planar and trough cross-stratified conglomerate, upper coal-pit; and (e) scalloped surface at contact between medium pebble conglomerate and silty mudstone, north end of upper pit. See Figure 3 for explanation of abbreviations.

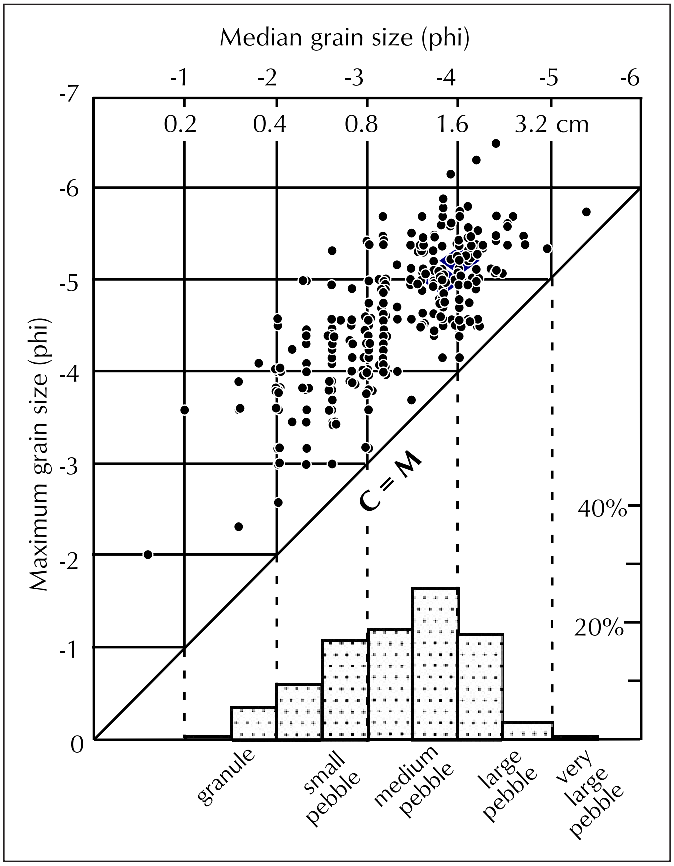

Figure 8. *Plot of maximum and median grain size of conglomeratic strata, based on 264 observations. Histogram at base shows a primary mode in the medium-pebble range.*

in Figure 4, which shows evidence of splay progradation over floodplain muds and silts. These appear to have supported lush vegetation as indicated by rare preserved plant roots, the crumbly, massive appearance of the mudstones due to soil-forming processes and root-bioturbation, and the occasional presence of well preserved plant leaves (Fig. 10f). Stacking of levee-splay sequences, as seen in the roadside section (Fig. 4) and in the coal-pit (Fig. 10) indicates an intimate association with stable stream channels. Local scour surfaces (Fig. 5c) may reflect scouring of levees during flood events. Low-angle inclined stratification (Fig. 5d) and epsilon cross-stratification may reflect lateral migration of crevasse channels or small streams. Lenticular sand bodies, such as those shown in Figures 6 and 7a, were deposited in low-gradient, high constructive stream systems, in which bank stability was probably maintained by dense plant growth (cf. Smith, 1976; Cairncross et al., 1988). The stacking of epsilon sets in these channel fills indicates that the streams had only a limited ability to erode channel walls. The paucity of channel deposits suggests that these were single channel systems, which changed position by avulsion, rather than being part of more extensive, multi-channeled anastomosed fluvial systems (cf. Nadon, 1993; Long, 2000).

Thicker conglomerate sequences in the Ross River fault-bounded block are all interpreted as products of deposition by wandering gravel-bed rivers (Forbes, 1983; Miall, 1996) rather than braided rivers. The roadside exposures appear to be dominated by massive to planar-laminated granule to small-pebble conglomerates, which would traditionally be interpreted as sheet-flood or longitudinal bar deposits of a high-gradient braided stream or alluvial fan (Long, 1981). The open-pit exposures show that the predominance of flat bedding is an artifact of the geometry of the roadside exposures. In the pit (Fig. 9), the sequence is dominated by large-scale (1 to 5.5 m) cross-stratification. These probably formed on side bars and in-channel bars in water depths of 2 to 12 m. Multiple scour and fill of older deposits has produced distinct channel deposits, some with complex sinusoidal geometry suggestive of deposition on point or side bars (Fig. 7d). This and the broad scatter of paleocurrents (Fig. 11), is suggestive of episodic migration of the river channels over the floodplain to produce extensive sheet-like bodies. Mudstones preserved in some of the channels reflect abandonment during avulsion. The section in Figure 9 is approximately normal to stream flow, so that the width of sedimentation units gives a minimum channel width of 30 to 80 m.

TRACKWAYS

To date, Gangloff et al. (2000) have documented over 150 individual tracks, produced by at least four taxa of dinosaurs in the Ross River block. Our investigation of the sedimentology of the area indicates that well preserved trackways occur on at least three levels within the sequence. These are all associated with fine-grained sandstones of overbank levee and splay origin, at the 20- and 140-m levels of the measured section (Fig. 3) in roadside exposures adjacent to the Robert Campbell Highway (Fig. 4), and at the 300-m level in the open-pit (Fig. 9) and in exposures along the power-line. Individual prints are between 20 and 50 cm long, and 15 to 35 cm wide and may include tracks of both herbivorous and carnivorous dinosaurs (Fig. 10). Where seen in cross-section, they resemble flute marks with relief of about

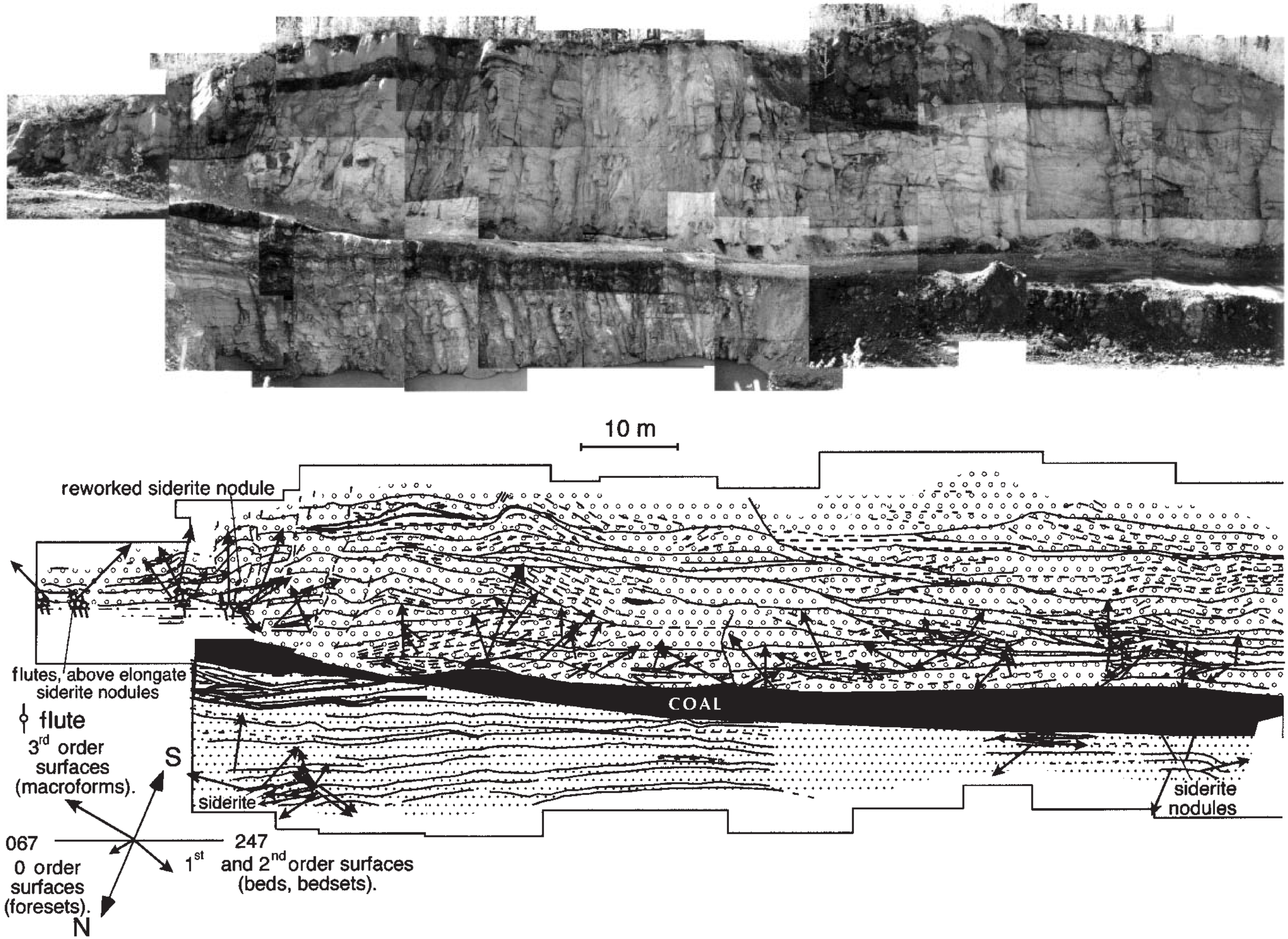

Figure 9. *Geometry and dip-corrected directional attributes of strata in the upper pit. Arrows directed above the horizontal indicate slopes dip away from the observer, those directed below the horizontal dip towards the observer (after correction for tectonic dip).*

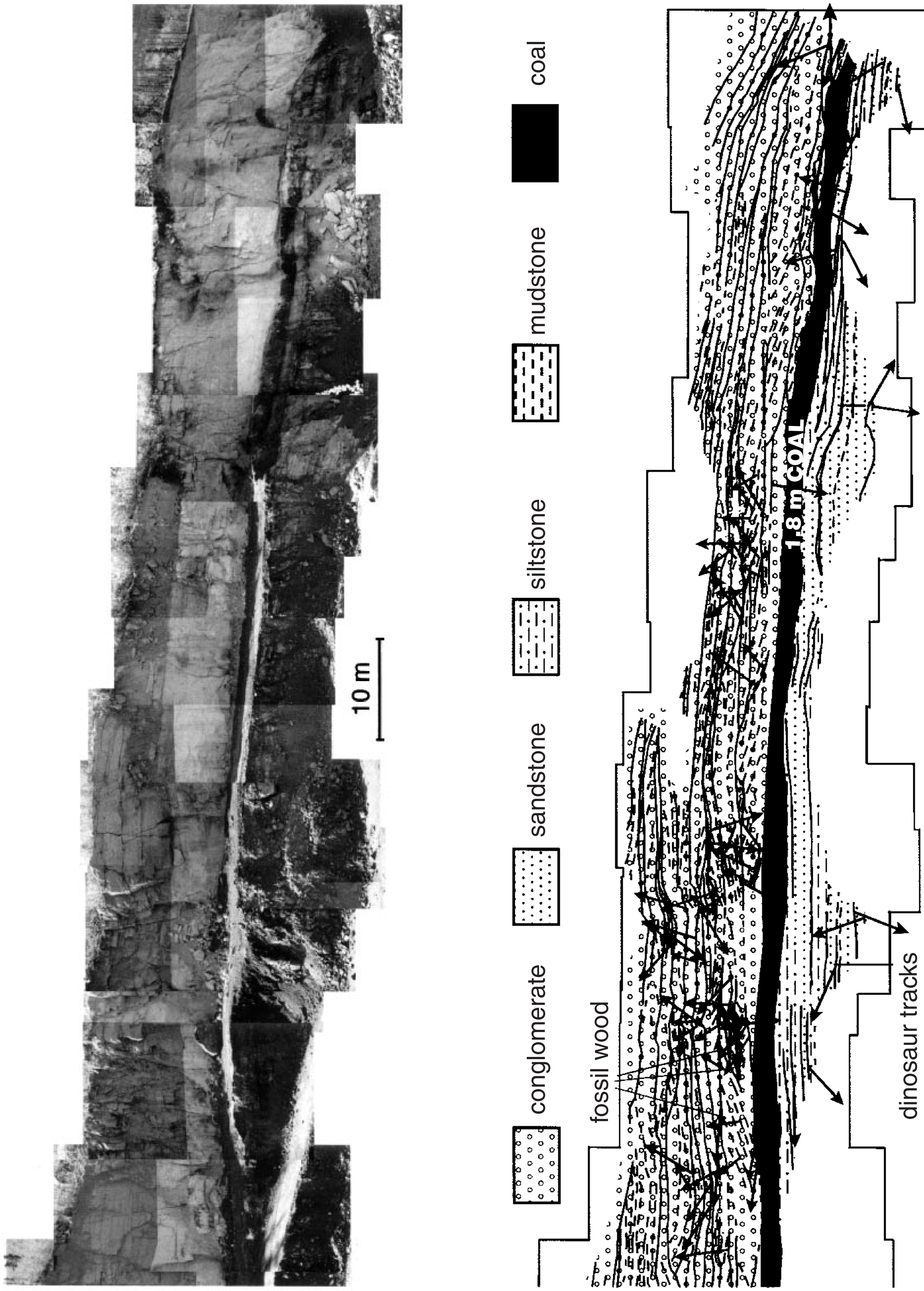

***Figure 9** continued.*

5 cm (Fig. 10e). Most of the tracks are filled with wave to ripple cross-laminated sandstone and only rarely with a thin film of mudstone. The trackways were probably produced and selectively preserved at times when the adjacent flood plains were submerged by seasonal floods. Also, the presence of (seasonal?) ponds is indicated by the degree of preservation of some of the plant fossils (Fig. 10f). Groups of herbivores may have walked on the submerged (distal) parts of sandy levees and splays associated with small high-constructive rivers, which flowed parallel to the axis of the modern Tintina Trench. A channel deposit of this type is exposed in the lower coal-pit (Fig. 6). The apparent consistent orientation of footprints suggests either seasonal migration during the

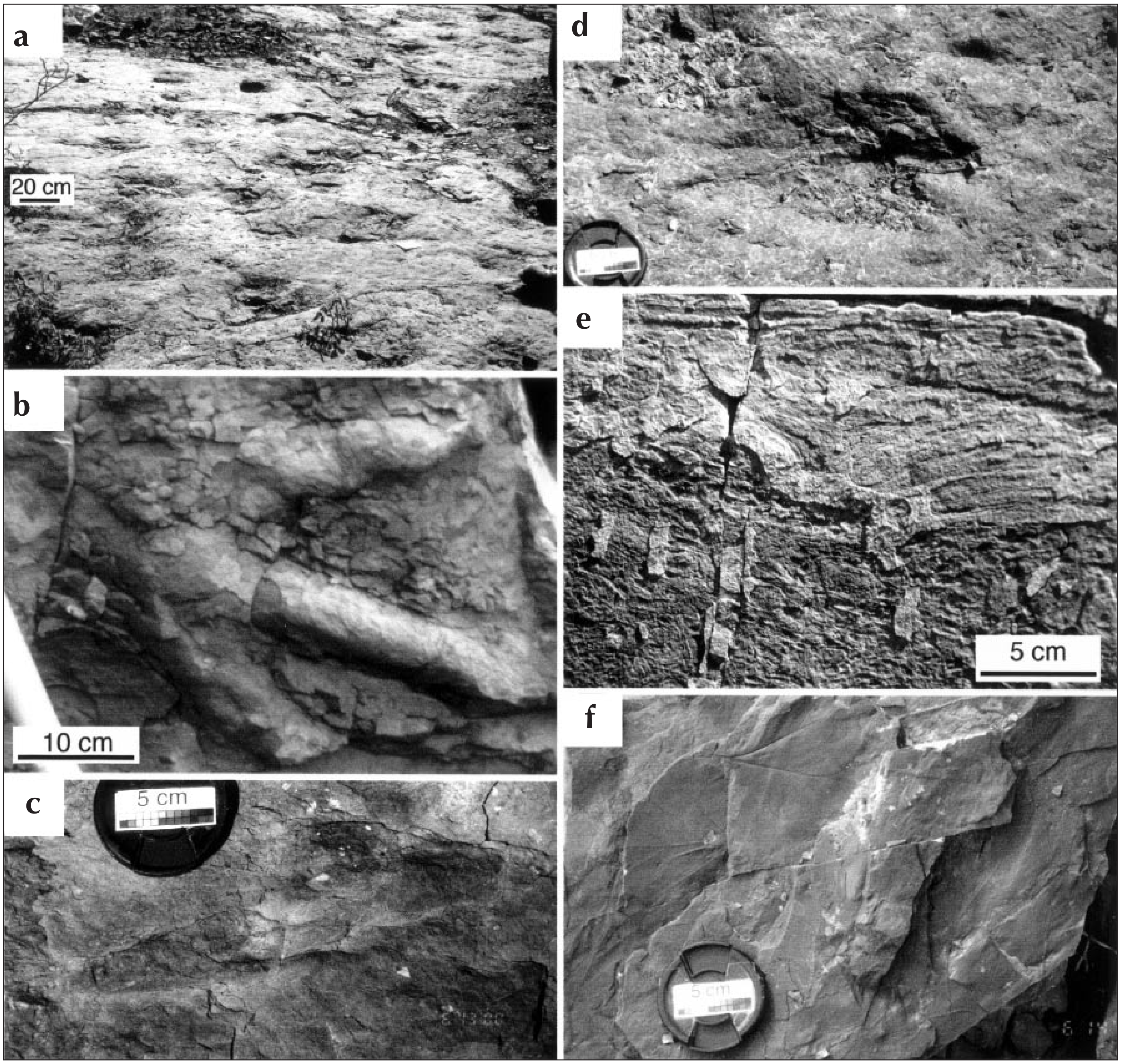

Figure 10. *Dinosaur trackways: (a) Trampled surface on top of section shown in Figure 4; (b) large prints from lower pit; (c) well preserved leaf impressions from siltstone interbeds in splay sandstone sequences, upper pit; (d) print from waste pile near upper pit; (e) print from trackway in (a); and (f) cross-section of track in upper pit with fill of ripple cross-stratified sandstone.*

wet season or easier transit along riverbanks during flood events. Nadon (1993) notes that wetlands associated with low-gradient fluvial systems were attractive areas for large herbivores, and that some species (including hadrosaurs) may have migrated to these areas during the wet season to escape large predators and lay eggs. Further observations are needed to test this hypothesis. The animals may have occupied the area during non-flood periods but left no lasting impressions. Vertebrate remains have yet to be recovered.

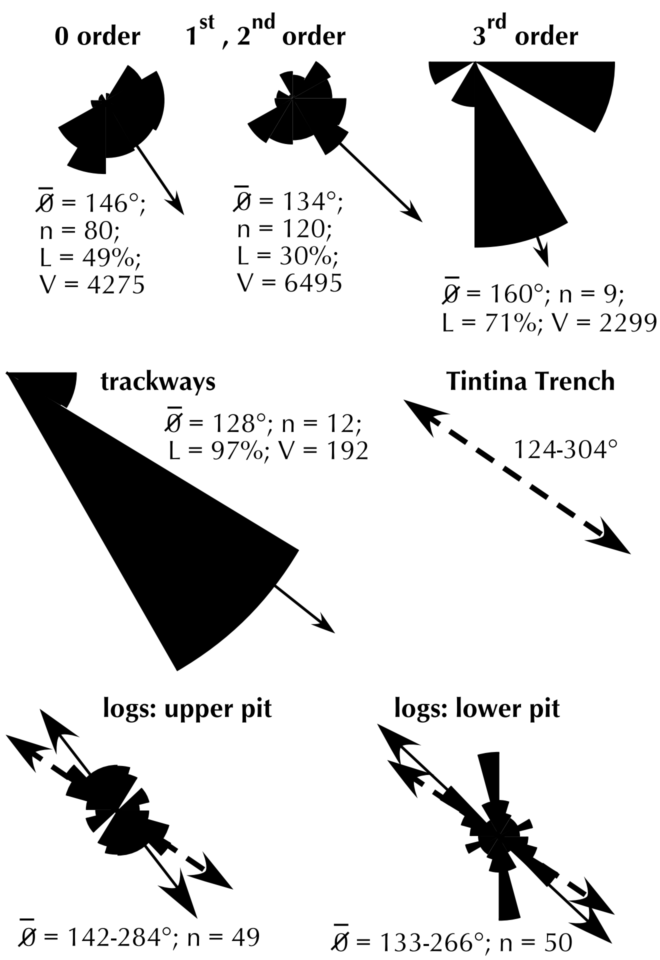

Figure 11. *Dip-corrected paleocurrent trends of 0 order (foresets), 1st and 2nd order (macroforms) and 3rd order and higher structures; dinosaur trackways, the Tintina Trench, and elongate logs from beneath the lower coal in the lower pit. Ø̄ = mean paleoflow direction; n = number of readings; L = one standard deviation; V = variance.*

PALYNOLOGY

Sweet (1999) conducted a palynological investigation of ten samples from the Ross River fault-bounded block. The quality of the preservation of miospores in these samples was typically poor due to their relatively high organic maturity. Two samples, however, contained a relatively rich flora that in combination included: *Appendicisporites sp., bisaccate pollen, Cerebropollenites mesozoicus, Cicatricosisporites sp., Clavatipollenites hughesii, Cupuliferoidaepollenites minimus, Cycadopites sp., Deltoidospora sp., Microreticulatisporites uniformis, Eucommiidites minor,* fungal spores, *Gleicheniidites sp., Laevigatosporites sp., Lycopodiumsporites sp., Osmundacidites sp., Retimonocolpites sp., Senectotetradites amiantopollis, Retitricolpites prosimilis, Retitricolpites virgeus, Zilvisporis sp., Cycadopites sp.* and *Stereisporites sp.*

Sweet (1999) concluded a mid-Cretaceous age, within the range of Middle Albian to possibly Cenomanian. The presence of tricolpate angiosperm pollen (*Cupuliferoidaepollenites minimus, Retitricolpites prosimilis, Retitricolpites virgeus*) and angiosperm pollen in obligate tetrads (*Senectotetradites amiantopollis*) precludes an age older than Middle Albian. The absence of more advanced forms of angiosperm pollen (tricolporate and triporate) argues against a late Cenomanian or younger age.

STRATIGRAPHY

While strata in the Ross River fault-bounded block appear to have been deposited in rivers which flowed parallel to the modern Tintina Trench, and are petrographically similar to Eocene strata at Lapie River, there is as yet no evidence that the paleovalley was controlled by the Tintina fault zone or the St. Cyr Fault, or that either fault was active during deposition of the late Early Cretaceous strata.

Correlation of strata containing dinosaur tracks in the Ross River area with lithostratigraphic units in southern Yukon is not certain at this time. However, strata in the Ross River area are lithologically and palynologically similar to strata in the Indian River area (Lowey, 1982, 1983 a,b; Lowey and Hills, 1988; Lowey et al., 1986). The Indian River area is located south of Dawson City and south of the Tintina fault zone. Strata in this area consist of interbedded sandstone, shale, conglomerate and coal that was assigned to the Tantalus Formation by Lowey and Hills (1988). It is informally subdivided into a lower, varicoloured chert-pebble conglomerate and sandstone unit (approximately 50 m thick) and an upper, quartz-vein pebble conglomerate and sandstone unit (approximately 450 m thick). The sedimentary rocks contain a rich and varied microflora assemblage that is dominated by terrestrial palynomorphs (such as *Appendicisporites crimensia*, *A. erdtmanii*, *A. potomacensis*, *A. unicus*, *Cicatricosisporites augustus*, *C. hallei*, *C. imbricatus, C. perforatus*, *Deltoidospora juncta*, *Gleicheniidites circinidites*, *Lycopodiumsporites expansus*, *L. reticulumsporites*), but also includes dinoflagellates (i.e., *Muderongia asymmetrica*, *M. sp.*; Lowey, 1984). Lowey (1984) concluded that the palynomorph assemblage indicates the sedimentary rocks in the Indian River area are Early Cretaceous (Middle to Late Albian) in age and were deposited principally in a fluvial or freshwater lacustrine environment with intervals of brackish or marine deposition.

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