Small Carbonaceous Fossils from the Earlie and Deadwood Formations (Middle Cambrian to Lower Ordovician) of Southern Saskatchewan

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Abstract

The subsurface Earlie and Deadwood formations of southern Saskatchewan encompass a broad expanse of mixed siliciclastic strata of probable middle Cambrian to earliest Ordovician age. The scarcity of both macrofossils and traceable carbonate horizons in the Saskatchewan subsurface has hindered biostratigraphic correlation, but the discovery of abundant, often exceptionally well-preserved "small carbonaceous fossils" (SCFs) promises significantly greater stratigraphic resolution, along with unprecedented insights into Cambrian palaeobiology. Low-manipulation HF processing of Earlie/Deadwood mudstones from 12 widely separated drillcores has yielded thousands of SCFs, including diverse remains of "soft-bodied" algae and animals, as well as taphonomically demineralized brachiopods and paraconodonts. Substantial stratigraphic and regional variations are becoming apparent as the study proceeds; we tentatively distinguish middle and late Cambrian SCF assemblages, and contrast shallow- and deep-water biotas across the Western Canada Sedimentary Basin.

Keywords: *Cambrian, SCFs, Saskatchewan, Alberta, Western Canada Sedimentary Basin, Williston Basin, Earlie Formation, Deadwood Formation, Burgess Shale, palaeobiology, palynology.*

1. Introduction

Cambrian to early Ordovician rocks occur in the southern half of Saskatchewan as a subsurface succession of interbedded sandstones, siltstones, and shales with minor carbonates and flat-pebble conglomerates, together comprising the Basal Sandstone Unit (BSU), Earlie Formation, and Deadwood Formation (*sensu* Dixon, 2008). These strata represent the Inner Detrital Facies, deposited in a shallow sea inboard of the Laurentian passive margin on an eroding Precambrian shield (Slind *et al*., 1994). Locally up to 500 m thick, they form a westwards-thickening unit that extends southwards into similar deposits in North Dakota and Montana, and westwards into deeper-water deposits of Alberta (Dixon, 2008). Comparisons with these better-known successions suggest an age range in Saskatchewan of middle Cambrian (Series 3) through late Cambrian (Furongian) and early Ordovician, although detailed correlations and direct age constraints are lacking.

In the subsurface of Alberta, data from trilobites, conodonts, and traceable carbonate horizons provide comparatively good correlations with the thick outcrop successions of the Cordillera (Hein and Nowlan, 1998). In Saskatchewan, however, stratigraphic resolution is limited by both the scarcity of carbonate horizons and an overall paucity of fossils: no trilobites have been documented from the BSU/Earlie/Deadwood sequence, with biostratigraphic tiepoints limited to preliminary reports of middle to late Cambrian conodonts (*e.g.*, Nowlan, 1999) and a single documented occurrence of late Cambrian brachiopods (Robson *et al*., 2003). Correlations and internal divisions have therefore relied on evidence from geophysical logs, sedimentary facies exposed in drill cuttings and cores, and isopach data.

In 1996, Binda *et al*. investigated the potential for palynological resolution of these strata and recovered a significant range of organic-walled microfossils, extending an earlier study that had identified sphaeromorphic/coccoidal acritarchs (Stasiuk, 1994). On the basis of these preliminary results, we initiated a more extensive sampling of the Earlie and Deadwood formations in the subsurface of Saskatchewan, focussing specifically on "small carbonaceous fossils" (SCFs); *i.e.*, organic-walled fossils too large and/or delicate to be recovered using conventional palynological techniques, but too small to be recognized on bedding surfaces (see Butterfield and Harvey, 2012).

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The aims of our research are:

1) to extend the stratigraphic and geographic scope of the initial Binda *et al*. (1996) study;
2) to establish the biological affinities and ecological significance of the recovered SCFs; and
3) to identify patterns in SCF distribution that might help to subdivide and correlate the sampled succession.

2. Existing Stratigraphic Framework

Various schemes have been proposed for the internal division and wider correlation of the subsurface Cambrian to Ordovician succession in Saskatchewan (Slind *et al*., 1994; Dixon, 2008) and Alberta (Hein and Nowlan, 1998). Recent discussion has centred on whether the BSU and Earlie Formation can be usefully distinguished from the Deadwood Formation: whereas Greggs and Hein (2000) and Potter (2006) both employ an expanded concept of the Deadwood Formation, Dixon (2008) argues for the retention of both the BSU and Earlie formations in Saskatchewan. We have provisionally adopted the latter scheme here, which is consistent with the nomenclature used by Binda *et al*. (1996).

Dixon (2008) distinguishes the Earlie Formation as a shale-dominated interval that overlies the coarse-grained BSU and is separated from the overlying, sandier Deadwood Formation by a subtle sequence boundary. In the far southwest of Saskatchewan, the succession is more uniformly shale-rich and the Earlie and Deadwood are not easily distinguished; towards the east, however, the succession thins and is occupied entirely by a sandy facies of the Deadwood Formation. As such, the base of the succession appears to be highly diachronous, reflecting onlap of shoreface sediments in an easterly direction throughout the middle and late Cambrian (*ibid.*).

Age constraints for the Saskatchewan subsurface are largely set by biostratigraphic data from Alberta and the Williston Basin of the northern United States. The lower part of the succession in western Saskatchewan is likely to be middle Cambrian in age, based on lithostratigraphic correlation to trilobite-bearing horizons in the subsurface of Alberta (see Slind *et al*., 1994; Hein and Nowlan, 1998). The top of the succession is defined by an erosional surface with the uppermost units probably no younger than earliest Ordovician, based on correlative units in the northern United States (reviewed in Binda *et al*. 1996).

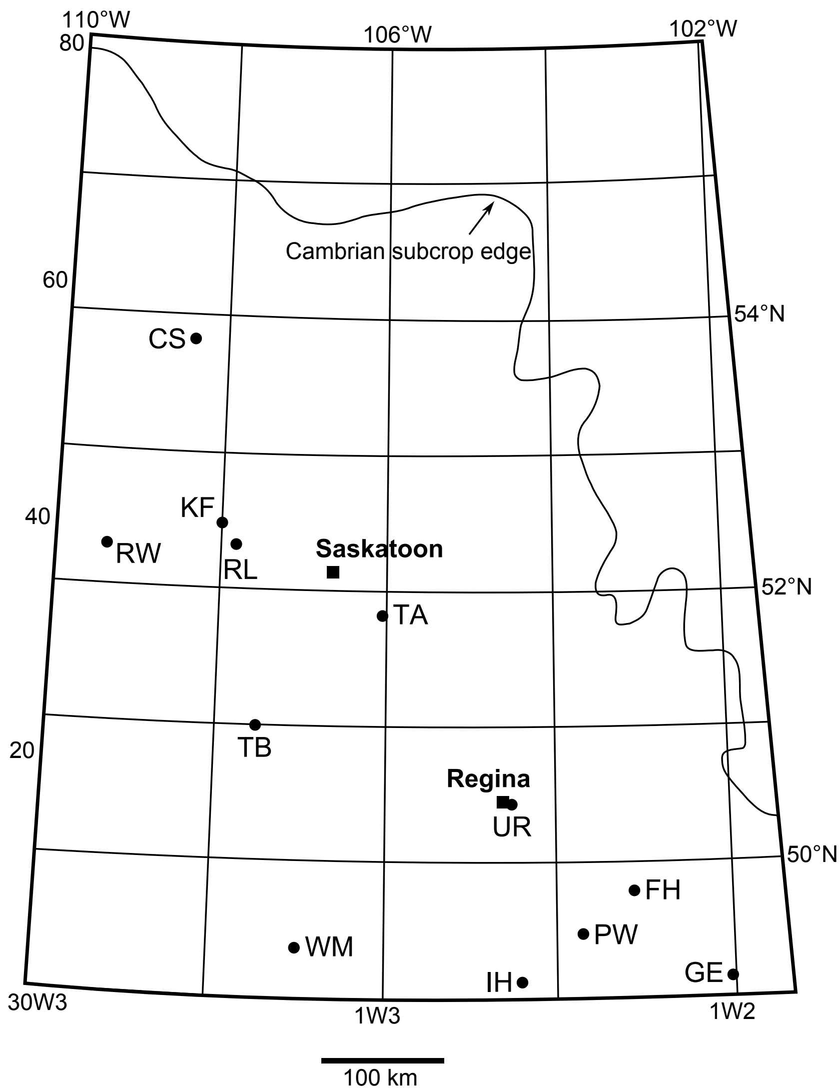

Figure 1 – Locations of sampled wells in central and southern Saskatchewan. For well name abbreviations and other details, see Table 1.

3. Materials and Methods

This study is based on cored intervals from 12 wells located across central and southern Saskatchewan (Figure 1; Table 1). The wells are distributed in a broad band running northwest-southeast between Canadian Seaboard Divide No. 2 (07-14-056-17W3), in the Meadow Lake region, to Husky Glen Ewen (16-23-002-01W2) near the border with Manitoba, a distance of

Table 1 – Details of sampled well localities, core intervals, and numbers of samples processed, with selected "small carbonaceous fossil" (SCF) distributions and tentative assemblage zone assignments (E, "Earlie assemblage"; LD, "lower Deadwood assemblage"; and UD, "upper Deadwood assemblage"). Samples in square brackets yielded no SCFs. Note that cored interval depths are given in feet for cores taken prior to metrication in Canada.

Well Name	Label	Locality	Well Licence	Core	Core Interval	Samples Processed	"Mahto-type" radulae	*Wiwixia* sclerites	"Crescent" radulae	Anostracans	Copepods	Paraconodonts	"Problematicum A"	Priapulid scalids	SCF assemblage zone
Husky Glen Ewen	GE	111/16-23-002-01W2	97I438	3	2775 to 2793 m	7						x	x	x	UD
CPEC et al Hartaven	FH	142/12-01-010-09W2	98E189	3	2443 to 2450 m	2						x	x	x	UD
CVE Weyburn DD	PW	141/04-16-006-13W2	97G483	3	2887.6 to 2894.7 m	[1]									
Imperial Hummingbird	IH	101/06-13-002-19W2	57G023	18	10,320 to 10,370 ft	3								x	
U of R Regina	UR	131/03-08-017-19W2	78L010	3	2067 to 2085 m	8						x	x		UD
Tide Water Allan Crown No. 1	TA	101/04-10-033-01W3	54J085	37	4,900 to 4,905 ft	[1]									
CVE Mankota	WM	101/10-03-005-08W3	61I046	1 and 2	8,368 to 8,438 ft	2		x				x		x	
Tide Water Beechy Crown No. 1	TB	101/01-29-023-11W3	54J036	13 to 33	6,143 to 6,506 ft	1						x			
Ceepee Riley Lake	RL	101/03-04-039-13W3	58H014	14	5,724 to 5,754 ft	6		x						x	
				13	5,365 to 5,390 ft	23 + [1]		x	x	x	x			x	LD
				12	5,065 to 5,095 ft	2							x	x	UD
Ceepee Keppel Forest	KF	101/08-03-040-14W3	58F050	14	5,488 to 5,513 ft	7								x	
				13	5,203 to 5,210 ft	1								x	
				12	4,990 to 5,015 ft	1									
Canadian Seaboard Divide No. 2	CS	101/07-14-056-17W3	56A041	10	3,787 to 3,806 ft	5		x	x	x	x			x	LD
Ceepee Reward	RW	101/04-28-038-24W3	58E063	17	6,192 to 6,227 ft	1	x								E
				16	6,018 to 6,043 ft	6	x			x					E
				15	5,808 to 5,833 ft	8		x						x	LD
				14	5,565 to 5,590 ft	2		x						x	LD
				13	5,384 to 5,409 ft	5									

around 700 km. We have resampled the productive intervals identified by Binda *et al*. (1996) in two wells located west of Saskatoon – Ceepee Reward (04-28-038-24W3) and Ceepee Riley Lake (03-04-039-13W3) – along with the nearby Ceepee Keppel Forest (08-03-040-14W3). The remaining wells have been selected for their broad geographic and sedimentological range across a largely uninterrupted depositional basin, avoiding the very sandy shoreface Deadwood facies in the east and northeast, and also the condensed successions associated with Swift Current basement highs in the southwest (see Dixon, 2008).

Sampling focussed on fine-grained lithologies with low carbonate content and minimal evidence of oxidation or deformation. Individual samples range from pale grey-green to dark grey and from fissile shales to siltstone – all commonly interbedded with conspicuously bioturbated glauconitic sands, and supporting the interpretation of a variably muddy, shallow-marine setting. To date, 93 horizons from 12 drillcores have been processed, with the majority coming from Ceepee Riley Lake (32), Ceepee Reward (22), Ceepee Keppel Forest (nine), U of R Regina (eight), Husky Glen Ewen (seven), and Canadian Seaboard Divide No. 2 (five) (see Table 1).

Ten to 50 g of each sample was processed for SCFs using a gentle HF maceration procedure, with individual fossils picked from aqueous suspensions by pipette (see Butterfield and Harvey, 2012). In contrast to conventional palynological procedures, this technique permits the recovery of substantially larger and/or more delicate carbonaceous fossils (SCFs), although it misses specimens smaller than *ca.* 25 µm.

4. Results

Ninety of the 93 processed samples yielded SCFs, with typical yields in the range of tens of specimens per gram; several thousand specimens have been mounted on *ca.* 300 glass slides. The recovered sample assemblages vary markedly in composition and quality of preservation, ranging from low-diversity collections of acritarchs and simple filaments, to arrays of strikingly complex SCFs, including exceptionally well-preserved metazoan body parts (Figures 2 and 3). Many specimens represent new fossil taxa of uncertain anatomical and phylogenetic affinity. Nevertheless, most forms can be identified to at least a broad biological category through analysis of large populations (including rare semi-articulated specimens), underlying microstructure, and comparisons with modern and fossil counterparts.

a) Non-metazoan SCFs

Non-metazoan SCFs include sphaeromorphic acritarchs of presumed algal origin (Figure 2A) and cyanobacterial affinity (*e.g.*, *Gloeocapsomorpha*; Figure 2B), along with simple unbranched filamentous fossils interpreted as benthic cyanobacterial sheaths (Figure 2C). At least five distinct taxa of larger (30 to 150 µm diameter) acanthomorphic acritarchs (*e.g.*, Figure 2D) are demonstrably eukaryotic but, by definition, do not preserve sufficient characters to identify their more specific affinities. Also problematic are regularly recurring reticulate structures originally identified by Binda *et al*. (1996, pl. I, image 19). By contrast, populations of branching, septate tubes (Figures 2E and 2F) are reliably assigned to the siphoncladalean green algae (Chlorophyta) on the basis of their diagnostic cell morphology. This is the second-known fossil occurrence of this algal group (*cf.*, *Proterocladus* from the Neoproterozoic Svanbergfjellet Formation of Spitsbergen; Butterfield *et al*., 1994) and represents an important new record of benthic photosynthesis in the early Palaeozoic.

b) Metazoan SCFs

Metazoan SCFs include representatives of at least six phyla, greatly augmenting the occasional macrofossil remains of brachiopods and “graptolites” observed on bedding surfaces (pers. obser.). HF-extracted fragments of pterobranch/graptolite periderm (Figure 2G) and organo-phosphatic branchiopod shell are significantly more widespread than their macrofossil counterparts, and reveal finer-scale structures. More surprisingly, some horizons have yielded diverse assemblages of flattened, demineralized paraconodonts (Figures 2H to 2L) – a group known almost exclusively as three-dimensional phosphatic microfossils from carbonates, and only sporadically documented in Saskatchewan (*e.g.*, Nowlan, 1999). This previously undocumented style of preservation substantially enhances the biostratigraphic potential of paraconodonts in siliciclastic facies, and offers novel insights into their structure, function, and taxonomic affiliations (*cf.*, Müller and Hinz, 1991). Commonly co-occurring with the conodonts are ornamented sheets, possibly de-mineralized, of uncertain metazoan affinity (“Problematicum A”; Figure 2M).

Originally non-biomineralizing metazoans in the Earlie/Deadwood SCF assemblages are represented by a range of disarticulated elements, including *Wiwaxia* sclerites (Figures 2Q and 2R) and a diversity of scalids and teeth from priapulid-like worms (Figures 2N to 2P). Although the whole-organism morphology of such forms is limited to exceptionally preserved biotas like the Burgess Shale, it is the disarticulated SCF record that documents their larger-scale patterns of distribution (Butterfield and Harvey, 2012). Soft-bodied molluscs were also common constituents, with series of tooth-like structures (Figure 2S) first noted by Binda *et al*. (1996) and subsequently identified as elements of molluscan radulae – directly comparable to populations in the early Cambrian Mahto Formation of Alberta (Butterfield, 2008). Assemblages from Ceepee Riley Lake and Canadian Seaboard Divide No. 2 contain a second type of radular element, distinguished by crescent-shaped rows of pointed teeth (Figures 2T and 2U).

In terms of evolutionary significance, the most important SCFs recovered in this study are the exceptionally well-preserved remains of crustacean arthropods. Specimens from three boreholes (Ceepee Reward, Ceepee Riley Lake, and Canadian Seaboard Divide No. 2) include readily identifiable appendages and mouthparts of both anostracan branchiopods (“fairy shrimps”) and copepods (Figure 3), by far the earliest on record (Harvey *et al*., 2012). These strikingly modern-looking and ecologically sophisticated crustaceans contrast with the trilobites and other “archaic” arthropods that dominate Cambrian shelly assemblages and Burgess Shale–type biotas. Along with comparable populations in the epicratonic Mount Cap Formation, NWT (Harvey and Butterfield, 2008), the widespread occurrence of crustacean SCFs in the Earlie and Deadwood formations of Saskatchewan suggests that shallow-marine environments served as a nursery for early arthropod evolution.

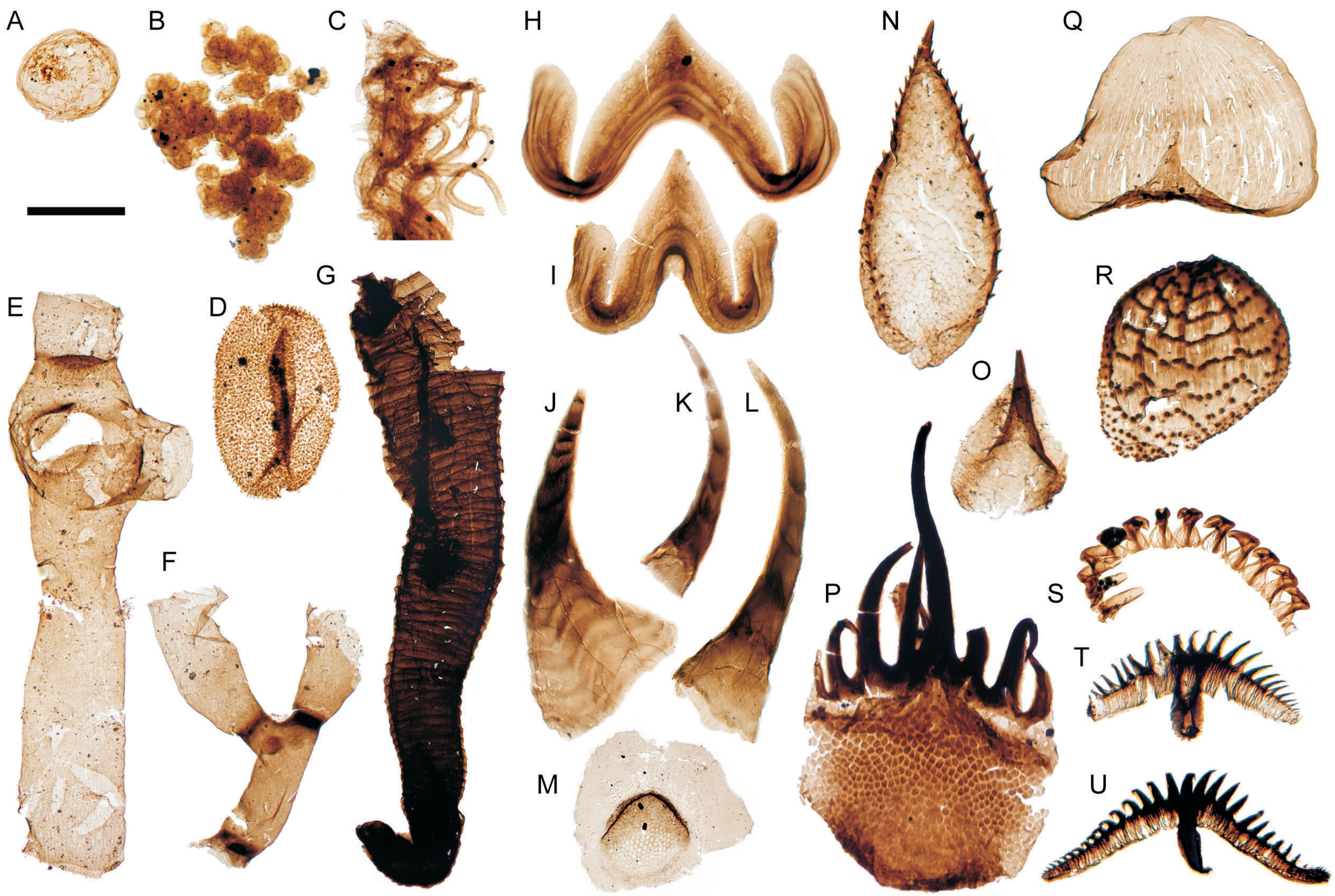

Figure 2 – Selected "small carbonaceous fossils" (SCFs) from the Earlie and Deadwood formations of Saskatchewan. Specimen labels are in the format: "well label (Table 1)+core–box–horizon (= centimetres below boxed top)–slide number–England Finder co-ordinates"[1] (except for UR, where 'horizon' is given as total borehole depth in metres). A) Large sphaeromorphic acritarch, CS10–1–23–02–M39, scale 100 µm. B) Acritarch cluster cf. **Gloeocapsomorpha**, *WM1–2–90–01–W43, scale 100 µm. C) Cyanobacterial filaments, RL13–4–110–16–M22, scale 75 µm. D) Large acanthomorphic acritarch, RW14–6–70a–P27, scale 67 µm. E) and F) Siphonocladalean green algae, scale 50 µm; E) RL13–1–120[91–ST–10]c–O17 and F) RL13–1–120[91–ST–10]c–K23. G) Pterobranch tube, CS10–1–40–01–T9, scale 300 µm. H) to L) Paraconodonts including* **Westergaardodina** *sp. and coniforms, scale 75 µm; H) UR3–12–2083.60–04–M24; I) UR3–12–2083.60–02–L39; J) UR3–12–2083.55–02–R7; K) UR3–12–2083.60–02–T23; and L) UR3–12–2083.60–03–J34. M) Ornamented sheet ("Problematicum A"), FH3–4–65–01–W44, scale 150 µm. N) to P) Priapulid-type scalids, scale 50 µm; N) CS10–2–140–03–K30; O) CS10–1–40–01–M47 and P) RW15–1–43a–S34. Q) and R)* **Wiwaxia** *sclerites, scale 50 µm; Q) CS10–2–140–04–P32 and R) CS10–1–23–01–N9. S) to U) Molluscan radulae, scale 50 µm; S) "Mahto-type" radula, RW16–6–45c–O28; T) and U) "Crescent" radulae, RL13–4–50–02–J9 and RL13–4–60–03–-F32, respectively.*

[3] The England Finder is a glass slide marked so that the referenced position of a specimen can be read relative to the locating edges. This allows relocation of the specimen by any microscopist examining the sample.

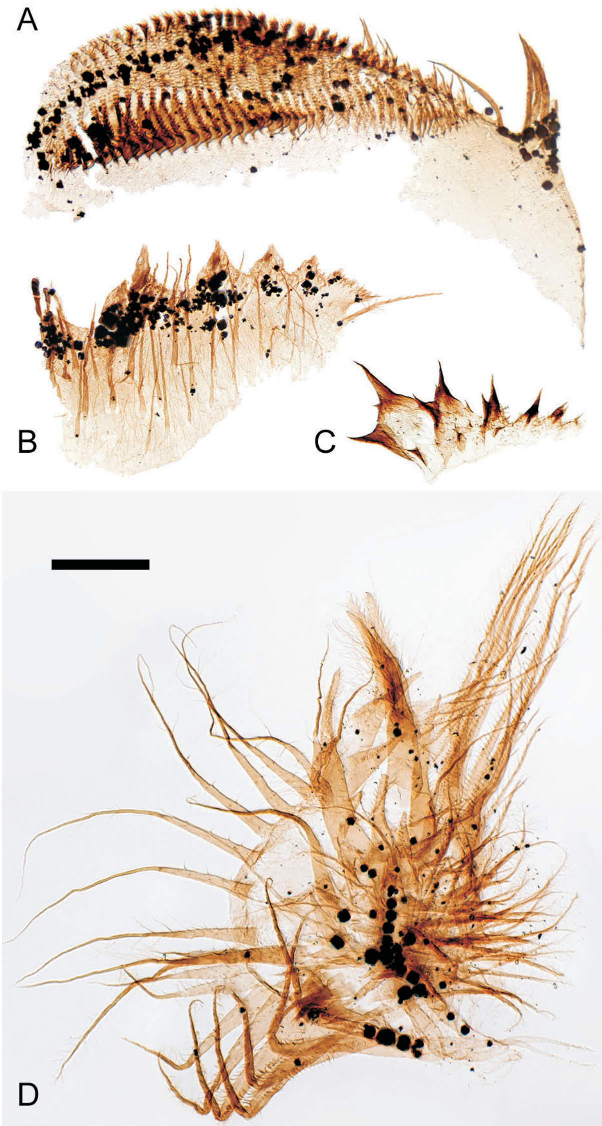

Figure 3 – Selected crustacean "small carbonaceous fossils" (SCFs) from the Earlie and Deadwood formations of Saskatchewan. Specimen labels are in the format: "well label (Table 1)+core–box–horizon (centimetres below boxed top)–slide number–England Finder co-ordinates". A) Grinding (molar) surface of the mandible (jaw) of an anostracan branchiopod crustacean, RL13–4–90a–P32, scale 50 µm. B) and C) Biting mandibles of copepod crustaceans, scale 50 µm; B) RL13–4–60–01–J48 and C) RL13–4–110–04–K49. D) Part of a filtratory limb of a branchiopod crustacean, RW–16–6–45–K38, scale 20 µm.

5. SCF Distribution

Cambrian SCFs are widely distributed in the subsurface of Saskatchewan and offer a novel source of biostratigraphic and palaeoenvironmental data. As with all fossil assemblages, local expression is highly variable, but larger-scale patterns are beginning to emerge as regional and global datasets accrue.

a) Biostratigraphic Potential

Although many SCF "taxa" persist through the entire Earlie to Deadwood interval (*e.g.*, acritarchs, algae, priapulids, and reticulate problematica), there appears to be sufficient stratigraphic differentiation in the constituent assemblages to distinguish three SCF-based biozones.

From the lower part of the sequence – best expressed in the Ceepee Reward well (cores 16 and 17; Table 1) – we tentatively recognize an "Earlie assemblage" characterized by problematic spines and abundant Mahto-type radulae. This latter form occurs widely in early and middle Cambrian units in western Laurentia (see Butterfield and Harvey, 2012), but has yet to be recovered from younger Deadwood strata. This pattern corroborates lithostratigraphic evidence for a middle Cambrian age for the Earlie Formation in Saskatchewan (*e.g.*, Dixon, 2008).

The succeeding "lower Deadwood assemblage" – based on a densely sampled interval from Ceepee Riley Lake (core 13; Table 1) and comparable biotas in Canadian Seaboard Divide No. 2 (core 10) – is distinguished by the presence of abundant copepod remains and crescent-shaped radulae, along with a distinctive suite of undescribed cuticular spines and *Wiwaxia* sclerites. Because *Wiwixia* is otherwise known only to occur in lower to middle Cambrian strata (see Butterfield and Harvey, 2012), its presence in the "lower Deadwood assemblage" either represents its first reported occurrence in upper Cambrian strata (*cf.*, Dixon 2008), or a late middle Cambrian age for this interval.

A potentially distinct "upper Deadwood assemblage", which occurs towards the top of the succession in wells from southeast Saskatchewan (Husky Glen Ewen, U of R Regina, and CPEC et al Hartaven; Figure 1), is characterized by a rich assemblage of paraconodonts and distinctively ornamented sheets ("Problematicum A"), but lacks *Wiwaxia* sclerites, radulae, and many types of priapulid scalid (Table 1). The middle to late Cambrian age of the paraconodonts (G. Nowlan, pers. comm., 2012) and absence of *Wiwaxia* (Butterfield and Harvey, 2012) supports the assignment of these strata to the upper Cambrian.

b) Palaeoenvironmental Distinctions

Although the interplay between stratigraphic and environmental distribution can be difficult to distinguish, SCFs are beginning to provide evidence for spatial partitioning among Cambrian biotas. Notably, they reinforce a picture from co-occurring macrofossils of an unusually low diversity "shelly" biota in the Saskatchewan strata. There is no evidence at either scale for trilobites, chancelloriids, or hyoliths, despite the prevalence of these groups in macrofossil faunas of the Middle Carbonate Shoal and Outer Detrital facies in the Rocky Mountains, as well as their widespread preservation as SCFs in the Little Bear biota of the Mount Cap Formation, middle Cambrian, NWT (Butterfield and Nicholas, 1996). Conceivably, these differences relate to the conspicuously more proximal and, at least locally, more shallow-water settings of the Saskatchewan strata.

A similar level of palaeoenvironmental distinction is emerging from the distribution of "soft-bodied" metazoans. Both *Wiwaxia* and priapulid worms, for example, exhibit a wide distribution in western Canada (and worldwide), ranging from the Outer Detrital setting of the Burgess Shale to mud-cracked environments of the Pika Formation (see Butterfield and Harvey, 2012). In contrast, deep-water biotas, including the exceptionally rich Burgess Shale, preserve no evidence of modern (*i.e.*, crown-group) crustaceans at either the micro- or macroscopic scales, despite their conspicuous presence in Saskatchewan and similarly epicratonic shale facies in the subsurface of Alberta (Harvey *et al*., 2012) and the NWT (Harvey and Butterfield, 2008). Combined with the prevalence in Saskatchewan of radulae, paraconodonts, and various problematica, all of which appear to be rare or unknown in deeper settings, it is clear that shallow-water SCFs provide a distinctive new window onto Cambrian life.

6. Conclusions

- SCFs have been recovered from 90 samples from the subsurface Earlie and Deadwood formations (middle Cambrian to lower Ordovician), from 12 wells located across central and southern Saskatchewan. In contrast to the paucity of co-occurring macrofossils, the SCFs are abundant, diverse, and remarkably widespread.

- The Saskatchewan SCFs represent a wide diversity of prokaryotic, algal, and metazoan organisms, often in an excellent state of preservation. Many forms have not previously been described, including arthropod mouthparts that provide the earliest known evidence for anostracan and copepod crustaceans.

- Emerging patterns of SCF distribution in space and time across western Canada suggest possible distinctions between middle *vs.* late Cambrian assemblages, and shallow- *vs.* deep-water biotas, offering improved correlations and novel insights into Cambrian palaeobiology.

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