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A palynological investigation of the till succession from the Weyburn oilfield, Weyburn, Saskatchewan, Canada

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A palynological investigation of the till succession from the Weyburn oilfield, Weyburn, Saskatchewan, Canada

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Key words

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Foreword

This report represents the palynological study of twenty-four till samples from four boreholes drilled on the Weyburn oilfield, Saskatchewan, Canada. Dr Janet Campbell kindly commented on an initial draft of this report.

Contents

Summary

A palynological investigation of twenty-four samples from four boreholes drilled into the till on the Weyburn oilfield was undertaken. All samples produced abundant and well-preserved palynomorphs of Devonian, Carboniferous, Late Cretaceous and Quaternary age. The relative proportions of these elements proved relatively similar throughout; Late Cretaceous dinoflagellate cysts and pollen grains are the dominant elements, indicating that the principal sedimentary input to the till is from Upper Cretaceous (Campanian-Maastrichtian) units. Devonian, Carboniferous and Quaternary grains are consistently subordinate. The Devonian palynomorphs are from Manitoba to the north-east and the Late Cretaceous palynomorphs appear to be derived locally. The abundance of palynomorphs is testament to consistently high levels of sedimentary rock input to the till successions. The relative homogeneity of the kerogen and palynofloras from the till samples has not allowed the palynological differentiation of units

A and B. The four samples from the supposed 'bedrock clay' yielded similar palynofloras. These samples have high organic productivities, the highest levels of Devonian input, no Carboniferous spores, the lowest Cretaceous abundances, relatively high levels of both Quaternary taxa and non-age diagnostic palynomorphs. Because the palynomorph associations are so heterogenous and similar to the overlying unequivocal till the 'bedrock clay' is probably glaciogenic in origin.

1 Introduction

During 2001, soil gas monitoring of the Weyburn oilfield, Saskatchewan, Canada indicated separate small areas of elevated levels of thoron (^{220}Rn) and radon (^{222}Rn). This oilfield is the site of an enhanced oil recovery (EOR) operation using carbon dioxide and the soil gas monitoring is aimed at checking if the reservoir is leaking injected gas to surface (Riding et al., 2003). It was hypothesised that the small areas with slightly higher than normal thoron (^{220}Rn) and radon (^{222}Rn) are underlain by till which is especially rich in granitic material. Granite, and other crystalline rocks, emanate both thoron (^{220}Rn) and radon (^{222}Rn) upon weathering.

In order to test this hypothesis, four strategically-located boreholes were drilled through the till at the Weyburn field and have been subjected to several geoscientific tests. A palynological study should give an indication of possible heterogeneity of the till, the input of sedimentary rock to this glaciogenic deposit and its provenance. Different till sheets typically have different organic signatures and the allochthonous palynomorphs can provide evidence as to which areas the glacier traversed (Lee et al., 2002).

The initial advance of the Late Wisconsin ice to its maximum (at *c*. 23ky BP) was from the north-east towards the south-west (Dyke and Prest, 1987a,b; Dyke et al., 2002; Klassen, 1989). As the ice front began to retreat, the ice along the margin thinned and the Weyburn ice lobe formed (at *c*. 14ky BP). Ice flow shifted to the south-east along the south-western margin of the Laurentide ice sheet, fed by the Athabasca ice stream from the north-west (Christiansen, 1956; Dyke and Prest, 1987a,b; Klassen, 1989; Dyke et al, 2002). The ice flow in the region at this time was in part confined by the ice-free Missouri Coteau and Moose Mountain uplands. Both ice flow directions are recorded in the streamlined landforms with the later north-west-south-east as the dominant direction preserved.

2 Sample Details

The table below lists all the twenty-four samples studied. The columns are, respectively, the (informal) sample number, the BGS micropalaeontological registration number (prefixed MPA), the core number, the depth below surface in metres, the lithostratigraphical unit of Matthuis (2003) and the lithology. Corehole logs are given in Matthuis (2003).

2.1 COREHOLE NUMBER B23 [LOCATION: 589487E/5479941N (NAD 83) (GPS)]

No.	BGS Reg. No.	Core No.	Depth (m)	Unit	Lithology
1	MPA 52457	Core 1	1.37-1.42	A	grey-brown, sandy till
2	MPA 52458	Core 3	3.42-3.48	A	brown, clay-rich till
3	MPA 52459	Core 5	6.40-6.46	A	light grey, clay-rich till
4	MPA 52460	Core 6	7.65-7.70	A	dark grey, sandy till
5	MPA 52461	Core 8	11.17-11.26	A	mid grey, clay-rich till
6	MPA 52462	Core 9	13.41-13.45	'bedrock'	dark brown clay

2.2 COREHOLE NUMBER A13 [LOCATION: 58916.1E/5481155N (NAD 83) (GPS)]

No.	BGS Reg. No.	Core No.	Depth (m)	Unit	Lithology
7	MPA 52463	Core 2	1.79-1.85	A	light brown till

8	MPA 52464	Core 3	3.27-3.31	A	light brown till
9	MPA 52465	Core 4	5.56-5.61	A	grey/brown, sandy till
10	MPA 52466	Core 5	7.48-7.52	A	grey/brown, sandy till
11	MPA 52467	Core 7	10.48-10.54	bedrock	mid grey clay
12	MPA 52468	Core 9	12.30-12.34	bedrock	mid grey clay

2.3 COREHOLE NUMBER B46 [LOCATION: 588825.9E/5479939N (NAD 83) (GPS)]

No.	BGS Reg. No.	Core No.	Depth (m)	Unit	Lithology
13	MPA 52469	Core 2	2.60-2.67	A	brown, sandy till
14	MPA 52470	Core 4	5.94-6.00	A	grey till
15	MPA 52471	Core 5	6.67-6.72	A	grey till
16	MPA 52472	Core 7	9.34-9.39	A	grey, sandy till
17	MPA 52473	Core 11	15.34-15.39	B	grey, sandy till
18	MPA 52474	Core 12	16.98-17.03	B	grey, clay-rich till

2.4 COREHOLE NUMBER A8 [LOCATION: 589836.9E/5481156N (NAD 83) (GPS)]

No.	BGS Reg. No.	Core No.	Depth (m)	Unit	Lithology
19	MPA 52475	Core 2	2.97-3.02	A	light brown, sandy till
20	MPA 52476	Core 3	3.56-3.60	A	light brown, sandy till
21	MPA 52477	Core 4	6.05-6.09	A	mid grey, sandy till
22	MPA 52478	Core 5	6.36-6.40	A	mid grey, sandy till
23	MPA 52479	Core 6	8.40-8.43	A	mid grey, sandy till
24	MPA 52480	Core 7	10.08-10.12	bedrock	grey silty clay

3 Palynology

In this section, the palynology of the twenty-four samples is described below. Because of the relative homogeneity of the material, the four boreholes are not treated separately. Full listings of palynomorphs, including quantitative data, are held on the respective BGS micropalaeontology/palynology data sheets, which have been archived. Tables 1 to 4 illustrate the proportions of palynomorphs in age-related groupings.

3.1 GENERAL

All twenty-four samples produced generally similar kerogen and palynomorph associations. The kerogen is mostly wood-dominated, but occasionally, amorphous organic material is present in significant proportions. Other plant tissues than structured wood are also present consistently. Palynomorphs of Devonian, Carboniferous, Cretaceous and Quaternary age are present, in addition to forms that are not age-diagnostic. No material of pre-Devonian, Permian to Jurassic and Palaeogene/Neogene age was identified. Of the biostratigraphically significant forms, Devonian and Carboniferous spores are consistently rare, generally accounting for less than 5% of the overall palynoflora. The most numerous palynomorph group are Cretaceous forms. These comprise both miospores and dinoflagellate cysts and typically account for between 30% and

50% of the palynofloras. Spores and pollen typical of the Quaternary are also present in moderate proportions (5-15%).

3.1.1 Devonian

Devonian spores are consistently rare and somewhat sporadic (Tables 1-4). These largely comprise the highly distinctive genus *Ancyrospora* but also include *Cristatisporites* spp., *Retispora lepidophyta* and undifferentiated Devonian spores. This association is typical of the Middle and Upper Devonian formations of Canada (McGregor and Owens, 1966; McGregor and Camfield, 1982; McGregor and Playford, 1992). The genus *Ancyrospora* was recorded in the majority of the samples and is characteristic of the Middle and Upper Devonian (Richardson and McGregor, 1986). *Retispora lepidophyta* was recovered from samples 11 and 24; this distinctive spore is a reliable regional marker for the latest Devonian (McGregor and Playford, 1992, fig. 7).

The relatively small percentages of Middle and Upper Devonian spores in the samples studied are interpreted to have been sourced from outcrops south of the Canadian Shield. The likely source for these Devonian palynomorphs is from the north-east of Weyburn, where Middle and Upper Devonian limestones outcrop in southwestern Manitoba. These units are the Winnipegosis and Souris River formations. The till composition data of Garrett and Thorleifson (1995) also show an east to north-east influence of carbonate material in the tills in southern Saskatchewan, suggesting a regional south-westerly flow during the advance of the ice. On a regional scale, the percentage of carbonate in the matrix and percentage of brown carbonate clasts decreases westward. Other Canadian sources such as those in north-western Canada (Yukon/District of Mackenzie/northern Alberta) or Arctic Canada (northern islands in the District of Franklin) are too distant to have contributed to this till. Sources local to Weyburn, i.e. the partly latest Devonian (latest Fammenian) Bakken Formation are precluded as this unit is deeply buried.

3.1.2 Carboniferous

Spores of Carboniferous age are also rare throughout (Tables 1-4). They mainly comprise the genus *Densosporites*. Other forms were also recorded in smaller proportions and include *Lycospora pusilla*, *Murospora* sp., *Radiizonates* spp., *Simozonotriletes intortus*, *Triquitites* spp. and undifferentiated forms. This association is most characteristic of the Namurian-Westphalian interval. The provenance of these spores is, like that of the Devonian input, assumed to be from outcrops immediately south of the Canadian Shield. Local Carboniferous sources may be ruled out as these units are deeply buried in the Weyburn area.

3.1.3 Late Cretaceous

Cretaceous palynomorphs comprise the majority of the allochthonous component of these samples. These forms account for between 5.7% (sample 6) and 68.8% (sample 22). Most samples yielded between 40% and 50% Cretaceous species. These forms include both marine and terrestrial-derived taxa. Marine dinoflagellate cysts include *Alterbidinium* spp., *Cerodinium diebelii*, *Chatangiella* spp., *Circulodinium* spp., *Cribroperidinium* spp., *Dinogymnium* spp., *Isabelidinium microarmum*, *Isabelidinium* spp., *Odontochitina operculata*, *Oligosphaeridium* spp., *Palaeoperidinium pyrophorum* and *Phelodinium* sp. This association is characteristic of the Late Cretaceous; forms such as *Alterbidinium* spp., *Cerodinium diebelii*, *Chatangiella* spp., *Dinogymnium* spp., *Isabelidinium* spp. and *Palaeoperidinium pyrophorum* indicate probable derivation from the Santonian to Maastrichtian interval. The associations are similar to those reported by Ioannides (1986) from Arctic Canada and Nøhr-Hansen (1996) from West Greenland. Cretaceous miospores recorded throughout include *Aequitriradites* sp., *Appendicisporites* spp., *Aquilapollenites* spp., *Cicatricosisporites* spp., *Cranwellia* sp., *Impardecispora apiverrucata*, *Mancicorpus* spp., *Integricorpus/Triprojectus* spp., *Wodehousia*

spinata and *Wodehousia* spp. The spore genera such as *Appendicisporites* and *Cicatricosisporites* are relatively long-ranging. Other long ranging Mesozoic spores recorded include *Cibotiumspora juriensis*. However, the angiosperm pollen are highly characteristic of the Late Cretaceous; these forms include *Aquilapollenites* spp., *Mancicorpus* spp., *Integricorpus/Triprojectus* spp. and *Wodehousia* spp. These forms are especially characteristic of the Maastrichtian (Srivastava, 1972; 1981; Evitt, 1973; Nøhr-Hansen, 1996).

The most likely source of these Late Cretaceous miospores are Campanian-Maastrichtian outcrops. These palynomorths are consistent with local and up-ice bedrock of the Upper Bearpaw, Riding Mountain, Eastend, Whitemud, Battle and Frenchman formations. The Bearpaw and Riding Mountain formations form the underlying bedrock surface immediately to the north and east of the Weyburn area. Advance of the Late Wisconsin ice sheet from the northeast would undoubtedly have incorporated palynomorphs from these formations into these glaciogenic sediments found around Weyburn.

3.1.4 Quaternary

Spores and pollen grains typical of the Quaternary are consistently present throughout in moderate numbers. These include bisaccate pollen grains, *Inaperturopollenites hians* and *Laevigatosporites* and are recognised by their preservational style and pale colour. These grains may have been incorporated into the till from local or distant sources; the nature of these low diversity associations does not permit detailed provenance analysis.

3.1.5 Non age-diagnostic palynomorphs

This group of palynomorphs represents a major component of the associations. The group comprises forms which are stratigraphically long-ranging such as *Cyathidites* spp., pre-Quaternary bisaccate pollen and *Tasmanites*. Many are likely to be of Cretaceous age because the Cretaceous is well represented throughout.

3.2 THE 'BASAL CLAY UNIT'

Four samples, numbers 6 (from borehole B23), 11 (A13), 12 (A13), and 24 (A8) are from presumed bedrock clays. Samples 6 and 12 especially have yielded similar palynofloras. Samples 6, 11, 12 and, to a lesser extent 24, have relatively high productivities. Furthermore, they have the highest levels of Devonian input, no Carboniferous spores (except sample 11), generally the lowest Cretaceous abundances, relatively high levels of Quaternary elements and non-age diagnostic palynomorphs. This signature may be locally biostratigraphically significant.

The mixed nature of these samples is interesting. Normal non-glaciogenic rock units do not exhibit such disparate associations. If this sediment represents *in-situ* Cretaceous clay, it would not contain such high proportions of Devonian and Cretaceous palynomorphs. Contamination of the core is not likely. This indicates that the 'basal clay unit' is probably a clay-rich till unit.

3.3 THE DIFFERENTIATION OF TILL UNITS A AND B OF MATTHUIS (2003)

Of the 20 till samples all except numbers 18 and 17 are from unit A of Matthuis (2003). Samples 18 and 17 are from borehole B46 and are from unit B of Matthuis (2003). The two units were differentiated on the basis of carbonate content, unit A having a lower carbonate content than unit B (Matthuis, 2003, fig. 10). These samples are relatively low in palynological productivity and are extremely low in Palaeozoic spores (Table 3). Other than the latter two considerations, these samples are not significantly different to samples from unit A. In fact, samples 18 and 17 have widely differing proportions of Cretaceous and non-age diagnostic palynomorphs (Table 3). Because of the low numbers of samples from unit B, and their relative

similarity to those from unit A, further work is needed to attempt to distinguish these till units on the basis of palynology.

4 Conclusions

A palynological investigation of twenty-four samples from four boreholes drilled into the till on the Weyburn oilfield was undertaken. All samples produced abundant and well-preserved palynomorphs of Devonian, Carboniferous, Late Cretaceous and Quaternary age. The relative proportions of these elements proved relatively similar throughout; Late Cretaceous dinoflagellate cysts and pollen grains are the dominant elements, indicating that the principal sedimentary input to the till is from Upper Cretaceous (Campanian-Maastrichtian) units. Devonian, Carboniferous and Quaternary grains are consistently subordinate. The Devonian palynomorphs are from Manitoba to the north-east and the Late Cretaceous palynomorphs appear to be derived locally. The abundance of palynomorphs is testament to consistently high levels of sedimentary rock input to the till successions. The relative homogeneity of the kerogen and palynofloras from the till samples has not allowed the palynological differentiation of units A and B. The four samples from the supposed 'bedrock clay' yielded similar palynofloras. These samples have high organic productivities, the highest levels of Devonian input, no Carboniferous spores, the lowest Cretaceous abundances, relatively high levels of both Quaternary taxa and non-age diagnostic palynomorphs. Because the palynomorph associations are so heterogenous and similar to the overlying unequivocal till the 'bedrock clay' is probably glaciogenic in origin.

5 Raw data

The data generated in this study is presented below in four tables.

Sample no.	Reg. No. (MPA)	Grains counted	Dev. spores	Carb. spores	Cretaceous	Quaternary	Non age-diagnostics
1	52457	129	…	39 (30.2%)	49 (38.0%)	15 (11.6%)	26 (20.2%)
2	52458	779	1 (0.1%)	34 (4.4%)	435 (55.8%)	39 (5.0%)	270 (34.7)
3	52459	540	…	27 (5.0%)	261 (48.3%)	69 (12.8%)	183 (33.9%)
4	52460	473	1 (0.2%)	11 (2.3%)	191 (40.4%)	42 (8.9%)	228 (48.2%
5	52461	373	4 (1.1%)	11 (3.0%)	131 (35.1%)	55 (14.7%)	172 (46.1%)
6	52462	348	6 (1.7%)	…	20 (5.7%)	58 (16.7%)	264 (75.9%)

Table 1. Table illustrating the numbers and percentages of palynomorphs per microscope slide from six samples (numbers 1 to 6) of Till from Weyburn Till corehole number B23. The overall palynomorph counts slide are given; these are then broken down into counts/percentages of allochthonous Devonian spores, Carboniferous spores, Cretaceous palynomorphs and ?autochthonous Quaternary pollen and spores and non-age diagnostic palynomorphs. If a palynomorph group was not observed, is represented by three dots (…).

Sample no.	Reg. No. (MPA)	Grains counted	Dev. spores	Carb. spores	Cretaceous	Quaternary	Non age-diagnostics
7	52463	551	…	3 (0.5%)	325 (59.0%)	29 (5.3%)	194 (35.2%)
8	52464	707	…	17 (2.4%)	317 (44.8%)	35 (5.0%)	338 (47.8%)
9	52465	685	…	16 (2.3%)	278 (40.6%)	76 (11.1%)	315 (46.0%)
10	52466	288	…	4 (1.4%)	135 (46.9%)	9 (3.1%)	140 (48.6%)
11	52467	832	10 (1.2%)	49 (5.9%)	375 (45.1%)	64 (7.7%)	334 (40.1%)
12	52468	675	23 (3.4%)	…	137 (20.3%)	61 (9.0%)	454 (67.3%)

Table 2. Table illustrating the numbers and percentages of palynomorphs per microscope slide from six samples (numbers 7 to 12) of Till from Weyburn Till corehole number A13. The overall palynomorph counts slide are given; these are then broken down into counts/percentages of allochthonous Devonian spores, Carboniferous spores, Cretaceous palynomorphs and ?autochthonous Quaternary pollen and spores and non-age diagnostic palynomorphs. If a palynomorph group was not observed, is represented by three dots (…).

Sample no.	Reg. No. (MPA)	Grains counted	Dev. spores	Carb. spores	Cretaceous	Quaternary	Non age-diagnostics
13	52469	502	4 (0.8%)	7 (1.4%)	310 (61.7%)	50 (10.0%)	131 (26.1%)
14	52470	591	8 (1.4%)	3 (0.5%)	295 (49.9%)	53 (9.0%)	232 (39.2%)
15	52471	393	1 (0.3%)	4 (1.0%)	162 (41.2%)	20 (5.1%)	206 (52.4%)
16	52472	483	2 (0.4%)	17 (3.5%)	199 (41.2%)	76 (15.7%)	189 (39.2)
17	52473	220	…	…	111 (50.5%)	24 (10.9%)	85 (38.6%)
18	52474	214	1 (0.5%)	…	37 (17.3%)	34 (15.9%)	142 (66.3%)

Table 3. Table illustrating the numbers and percentages of palynomorphs per microscope slide from six samples (numbers 13 to 18) of Till from Weyburn Till corehole number B46. The overall palynomorph counts slide are given; these are then broken down into counts/percentages of allochthonous Devonian spores, Carboniferous spores, Cretaceous palynomorphs and ?autochthonous Quaternary pollen and spores and non-age diagnostic palynomorphs. If a palynomorph group was not observed, is represented by three dots (…).

Sample no.	Reg. No. (MPA)	Grains counted	Dev. spores	Carb. spores	Cretaceous	Quaternary	Non age-diagnostics
19	52475	1035	1 (0.1%)	25 (2.4%)	592 (57.2%)	31 (3.0%)	386 (37.3%)
20	52476	483	1 (0.2%)	5 (1.0%)	177 (36.7%)	30 (6.2%)	270 (55.9%)
21	52477	723	…	5 (0.7%)	430 (59.5%)	106 (14.6%)	182 (25.2%)
22	52478	570	1 (0.2%)	5 (0.9%)	392 (68.8%)	67 (11.7%)	105 (18.4%)
23	52479	291	…	5 (1.7%)	143 (49.2%	33 (11.3%)	110 (37.8%)
24	52480	292	5 (1.7%)	…	139 (47.6%)	45 (15.4%)	103 (35.3%)

Table 4. Table illustrating the numbers and percentages of palynomorphs per microscope slide from six samples (numbers 19 to 24) of Till from Weyburn Till corehole number A8. The overall palynomorph counts slide are given; these are then broken down into counts/percentages of allochthonous Devonian spores, Carboniferous spores, Cretaceous palynomorphs and ?autochthonous Quaternary pollen and spores and non-age diagnostic palynomorphs. If a palynomorph group was not observed, is represented by three dots (…).

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