Biostratigraphy and Sedimentary Provenance of Lower and Middle Triassic Natural Gas–Bearing Rocks in Northeastern British Columbia (parts of NTS 093P, 094A, B, K): Progress Report

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Introduction

The Triassic natural gas–bearing rocks of the Western Canada Sedimentary Basin (WCSB) in British Columbia have been the subject of a multiyear interdisciplinary study designed to improve the biostratigraphic correlation of the gas-producing formations and to assess changes in sediment distribution patterns within this biostratigraphic framework. Initially, the focus of the work was on surface outcrop equivalents to the subsurface gas-producing formations, but it has since extended to encompass subsurface sections as well. Biostratigraphic correlation has been conducted through the identification of conodonts, and to a lesser extent, ammonoids and bivalves. Changes in sediment transport, including the sediment source and direction of input, have been formulated by the dating of detrital zircons, which gives an age for the protoliths from which the sediment was derived. Although the majority of sediment entering the WCSB during the Triassic came from the North American craton to the east, it is becoming more apparent that at least some of the sediment was derived from rocks to the north and west, and that this began to occur during the Triassic. This has implications not only for the source of sediment and therefore for the transport pathways of that sediment into the basin, but also for the timing of terrane accretion along the western margin of ancestral North America. Evidence from detrital zircon analyses in the Yukon (Beranek, 2009) and in this study points towards Permo-Triassic accretion of the Yukon-Tanana terrane, as first suggested by Nelson et al. (2006). This is much earlier than the Jurassic age that has previously been accepted for this event (e.g., Monger and Price, 2002).

Keywords: *Triassic, Western Canada Sedimentary Basin, correlation, conodont, detrital zircon, sedimentary provenance, Doig phosphate zone, Williston Lake, Alaska Highway*

Previous progress reports on this study have described the sampling and analysis of samples from surface localities at South Halfway and Williston Lake (both in the Halfway River map area, NTS 094B), and subsurface samples from an oil well in the Dawson Creek map area (NTS 093P; Figure 1; Golding et al., 2010, 2011). These sections encompass an age range from the Smithian up to the Rhaetian. This report presents the results from those analyses, and describes a new round of fieldwork that was designed to build upon the results from previous field seasons. As such, outcrop was examined on the Alaska Highway in the summer of 2011, and six new subsurface cores were examined (Figure 1). The sections on the Alaska Highway cover an interval from the Anisian to Ladinian, which has previously been poorly covered by the sampling of this study. This time period was one of anomalous sediment thickness in the WCSB (Gibson, 1975) and also includes an unusual, highly phosphatic interval that is equivalent to the Doig phosphate zone in the subsurface. Additionally, these sections extend the area of study to the north. The extra subsurface sections cover an interval from the Spathian to the Anisian, and are therefore of a similar age to that from the previously studied borehole. They contain rocks belonging to the Doig phosphate zone, part of the Doig Formation that shows promise for producing natural gas (Walsh et al., 2006). Study of these cores will allow concepts derived from surface outcrop studies to be tested in the subsurface.

This interdisciplinary study has involved collaboration between the University of British Columbia, the University of Alberta, the Geological Survey of Canada, the BC Ministry of Energy and Mines, Geoscience BC and the petroleum industry.

Geological Setting

Triassic rocks of northeastern BC were deposited in the WCSB, along the western margin of the North American

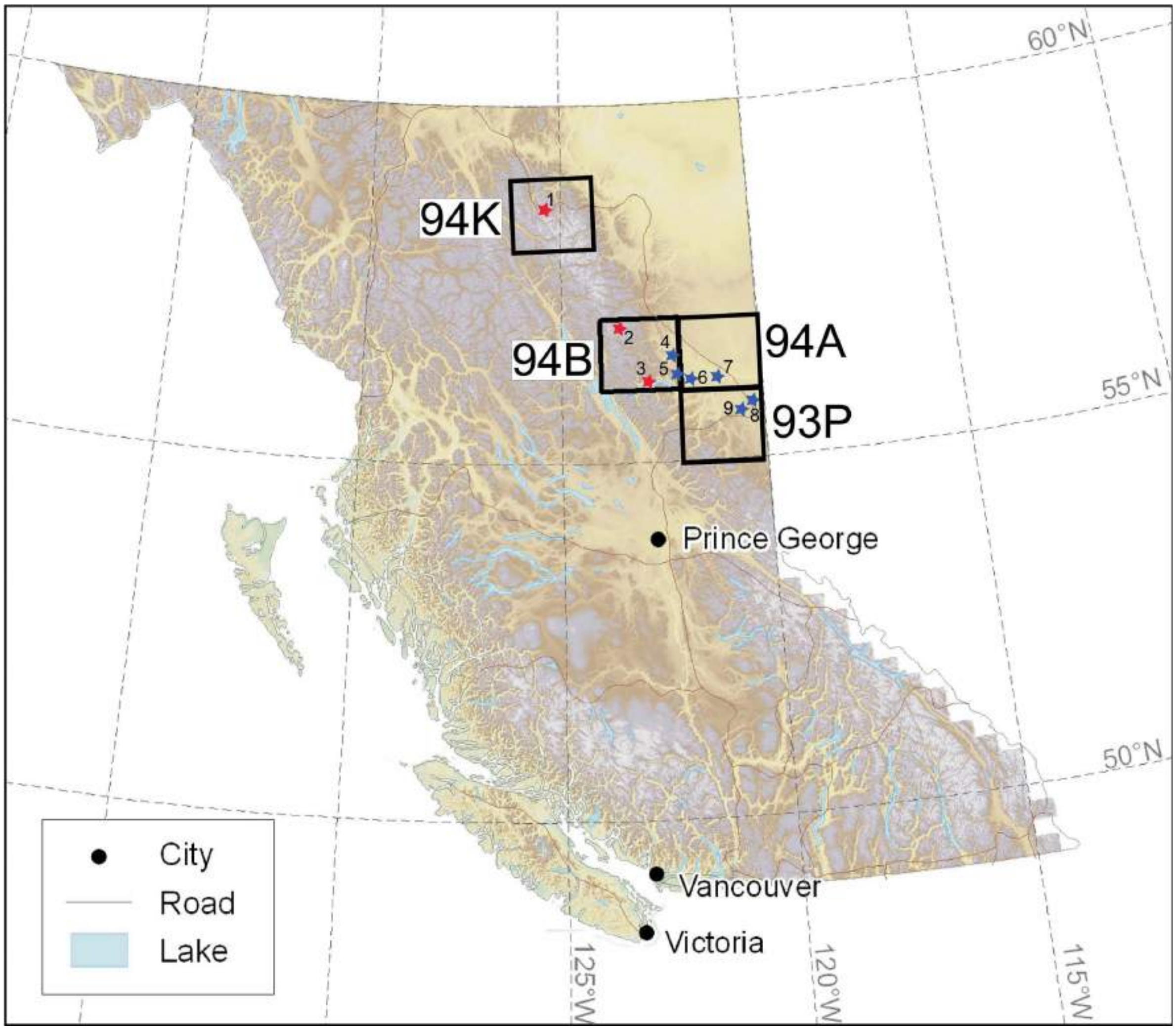


Figure 1. Location of map areas (NTS 093P, 094A, B, K), as well as the sampling localities: 1, Alaska Highway; 2, South Halfway; 3, Williston Lake; 4, Petro-Canada Kobes d-048-A/094-B-09; 5, Talisman Altares c-085-I/094-B-01; 6, Talisman Altares 16-17-083-25W6; 7, Rocor Monias 08-22-82-20W6; 8, Arc Dawson 07-13-79-15W6; and 9, Murphy Swan d-54-B/93-P-9. Red stars indicate outcrop localities, blue stars indicate subsurface wells.

continent. The WCSB at this time was at a latitude of around 30°N and the environment was arid (Davies, 1997). Sediment was deposited on the continental shelf, and consists primarily of a mixture of clastic and carbonate sediments. Windblown sediments are thought to have been a major constituent of the sediment deposited at this time (Davies, 1997), and storm reworking has been shown to have an important role in the distribution of sediment (Zonneveld et al., 1997). Although sediments were mainly deposited below normal wave base, some of the rocks show evidence of subaerial deposition (Zonneveld, 2010). Paleocurrent data is sparse for this time period, but that which is available indicates transport from the east, northeast and north (Pelletier, 1965).

Lithology varies from east to west, and from north to south along the belt of preserved Triassic rocks, as shown in Figure 2. In this study, rocks from the Toad, Liard, Baldonnel, Pardonet, Montney and Doig formations have been observed and sampled.

The oldest observed unit in the study area is the Toad Formation. This is exposed in surface outcrop, and consists of argillaceous to calcareous siltstone, silty shale, silty limestone and dolostone, as well as very fine grained sandstone (Thompson, 1989). It spans the Smithian to the Ladinian, and it is equivalent to the Montney and lower Doig formations in the subsurface (Zonneveld, 2010). Above the Toad Formation lies the Liard Formation, which consists of fine to coarse sandstone, calcareous and dolomitic siltstone and sandy to silty dolostone and limestone (Thompson, 1989). It ranges in age from the Ladinian to the Carnian, and is the surface equivalent of the upper Doig and Halfway formations (Zonneveld, 2010).

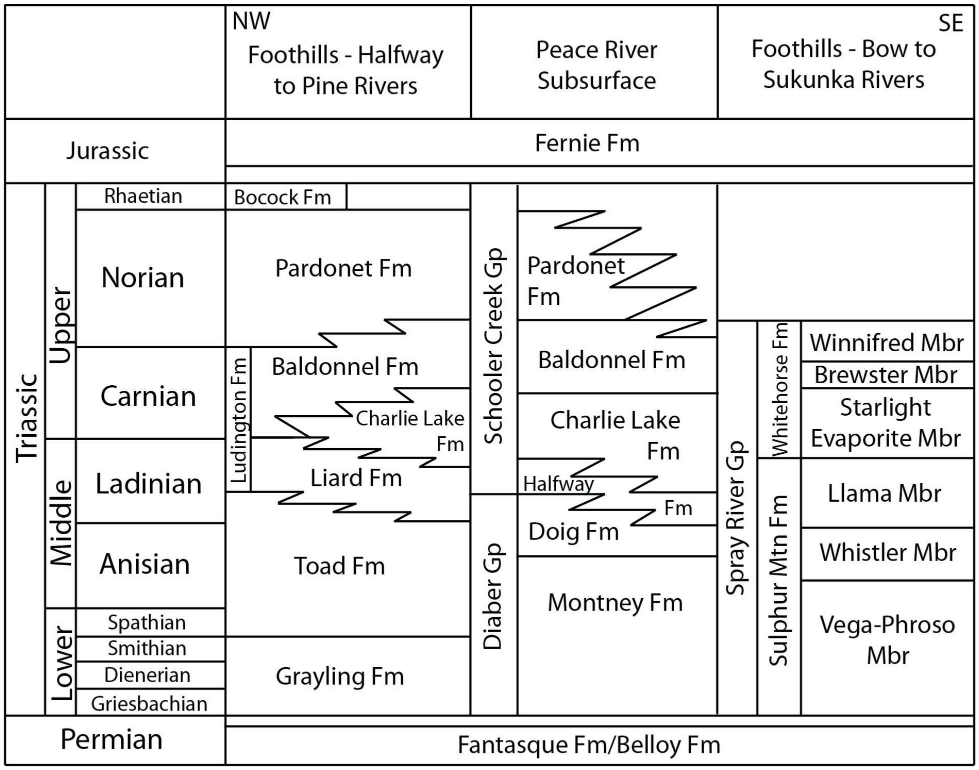


Figure 2. Triassic formations in British Columbia and their correlations with those in the subsurface and in southern Alberta. Modified from Ferri (2009). Abbreviations: Fm, Formation; Gp, Group; Mbr, Member; Mtn, Mountain.

The Baldonnel Formation, overlying the Liard Formation, is characterized by a sequence of limestone, dolostone and siltstone (Zonneveld, 2010). This unit is named after its subsurface equivalent. The age of this formation is diachronous and ranges from upper Carnian to lower Norian in the east, and from lower Carnian to upper Carnian in the west (Zonneveld, 2010). The Baldonnel Formation is typically succeeded by the Pardonet Formation, which consists of limestone, dolostone, calcareous silt and shale (Zonneveld, 2010). This unit can be traced into the subsurface, and it is Norian to Rhaetian in age (Zonneveld, 2010).

In the subsurface, shale and siltstone of the Montney Formation is overlain by the Doig Formation, with the boundary marked by a distinctive *Glossifungites* surface (indicative of a firmground surface). The basal part of the formation consists of a phosphatic pebble lag, which gives way to shale, siltstone, sandstone and occasional carbonate (Zonneveld, 2010). Deposition of this formation may extend as far back as the Spathian in age (Zonneveld, 2010) with its upper boundary in the Ladinian (Hunt and Ratcliffe, 1959). This makes it the subsurface equivalent of the upper part of the Toad Formation and the lower part of the Liard Formation.

Williston Lake Study Area (NTS 094B)

Williston Lake is located in the Halfway River map area (NTS 094B; Figure 1). In 2010, six sections were examined and sampled for conodont and detrital zircon geochronology (Golding et al., 2011; Tables 1, 2). From west to east, the sections are: Ursula Creek; Ne-parle-pas Point; Black Bear Ridge; Glacier Spur; East Carbon Creek and Beattie Ledge (Figure 3). These sections have been described and illustrated by Zonneveld (2010), and they range in age from Smithian to Rhaetian.

Results To Date

Ursula Creek

The Ursula Creek section contains shale and siltstone belonging to the Toad Formation. The sampled interval is Smithian to Ladinian. Four samples were collected for detrital zircon analysis, however, all were barren.

Ne-parle-pas Point

The Ne-parle-pas Point section contains shale, siltstone and sandstone of the Pardonet Formation. The sampled interval is Rhaetian. Three samples were collected for detrital zircon analysis, however, all were barren.

Black Bear Ridge

The Black Bear Ridge section contains siltstone and sandstone belonging to the Pardonet Formation. The sampled

Table 1. Detrital zircon samples collected from outcrop sites in the study area, northeastern British Columbia, in 2010 and 2011.

Outcrop sample number	Locality	Distance from base of section (m)	Formation	Analysis
MG-10-UC01	Ursula Creek	78.9	Toad	complete
MG-10-UC02	Ursula Creek	85.2	Toad	complete
MG-10-UC03	Ursula Creek	124.9	Toad	complete
MG-10-UC04	Ursula Creek	129.55	Toad	complete
MG-10-NPP01	Ne-parle-pas Point	41.2	Pardonet	complete
MG-10-NPP02	Ne-parle-pas Point	41.5	Pardonet	complete
MG-10-NPP03	Ne-parle-pas Point	51	Pardonet	complete
MG-10-BBR01	Black Bear Ridge	242	Pardonet	in progress
MG-10-GS01	Glacier Spur	122.6	Liard	complete
MG-10-GS02	Glacier Spur	149	Liard	complete
MG-10-GS03	Glacier Spur	255	Liard	complete
MG-10-GS04	Glacier Spur	293.8	Liard	complete
MG-10-GS05	Glacier Spur	304	Liard	complete
MG-10-ECC01	East Carbon Creek	76	Baldonnel	complete
MG-11-MP386-Z1	Mile Post 386	10.25	Toad	in progress
MG-11-MP386-Z2	Mile Post 386	17.5	Toad	in progress
MG-11-NTP-Z1	North Tetsa Phosphate	2.6	Toad	in progress
MG-11-NTP-Z2	North Tetsa Phosphate	2.7	Toad	in progress
MG-11-NTP-Z3	North Tetsa Phosphate	2.8	Toad	in progress
MG-11-NTP-Z4	North Tetsa Phosphate	10.6	Toad	in progress
MG-11-NTP-Z5	North Tetsa Phosphate	11.85	Toad	in progress
MG-11-OS-Z1a	Oyster Springs	3.3	Liard	in progress
MG-11-YB-Z1	Yellow Bluffs	1.7	Toad/Liard	in progress
MG-11-YB-Z2	Yellow Bluffs	3	Toad/Liard	in progress
MG-11-YB-Z3	Yellow Bluffs	3.75	Toad/Liard	in progress
MG-11-YB-Z4	Yellow Bluffs	10	Toad/Liard	in progress
MG-11-YB-Z5	Yellow Bluffs	13	Toad/Liard	in progress
MG-11-MP375W-Z1	Mile Post 375 West	n/a	Toad	in progress

interval is Rhaetian in age. Four samples were collected for conodonts, however, they contain only unidentifiable fragments. One sample was collected for detrital zircon analysis, and this contains Norian euhedral zircons. Work is ongoing to confirm the reliability of this result.

Glacier Spur

The Glacier Spur section contains sandstones and carbonate rocks of the Liard Formation, which span the Ladinian–Carnian boundary. Six samples were collected for conodonts, and all were productive. They contain a relatively abundant fauna, including representatives of *Budurovignathus mungoensis*, *Paragondolella inclinata*, *Metapolygnathus polygnathiformis* and *Neogondolella liardensis*. *Paragondolella willistonensis* was recovered for the first time from this section. These conodonts are indicative of the upper Ladinian and lower Carnian, which is in line with previous estimates for the age of this section. Five samples were collected for detrital zircon analysis, and all were productive. The lowest four samples are dominated by zircons of Proterozoic age, but also contain zircons of lower Paleozoic age. The highest sample is lacking the lower Paleozoic population.

East Carbon Creek

The East Carbon Creek section consists of siltstone, sandstone and carbonate belonging to the Baldonnel Formation. The sampled interval is Carnian. One sample was collected for detrital zircon analysis, and it contains zircons of Proterozoic and lower Paleozoic age.

Beattie Ledge

The Beattie Ledge section consists of sandstone and carbonate belonging to the Liard Formation and is Ladinian. Two samples were collected for conodonts, and although neither contain conodonts, they do contain an abundant icthyolith fauna. Work is ongoing to identify these elements and to determine their stratigraphic significance.

Discussion

The presence and spectra of detrital zircons of Proterozoic age is consistent with derivation from the North American

Table 2. Conodont samples collected from outcrop sites in the study area, northeastern British Columbia, in 2010 and 2011.

Outcrop sample number	Locality	Distance from base of section (m)	Formation	Analysis
MG-10-BBR02	Black Bear Ridge	242.8	Pardonet	complete
MG-10-BBR03	Black Bear Ridge	242.8	Pardonet	complete
MG-10-BBR04	Black Bear Ridge	243.8	Pardonet	complete
MG-10-BBR05	Black Bear Ridge	244.05	Pardonet	complete
MG-10-GS06A	Glacier Spur	129	Liard	complete
MG-10-GS06B	Glacier Spur	235	Liard	complete
MG-10-GS07	Glacier Spur	312.3	Liard	complete
MG-10-GS08	Glacier Spur	312.7	Liard	complete
MG-10-GS09	Glacier Spur	313	Liard	complete
MG-10-GS10	Glacier Spur	319.3	Liard	complete
MG-10-BL36	Beattie Ledge	36	Liard	complete
MG-10-BL48.5	Beattie Ledge	48.5	Liard	complete
MG-11-MP386-C1	Mile Post 386	3.5	Toad	in progress
MG-11-MP386-C2	Mile Post 386	8	Toad	in progress
MG-11-MP386-C3	Mile Post 386	12	Toad	in progress
MG-11-MP386-C4	Mile Post 386	14.1	Toad	in progress
MG-11-MP386-C5	Mile Post 386	17.5	Toad	in progress
MG-11-NTPW-C1	North Tetsa Phosphate West	n/a	Toad	in progress
MG-11-NTPW-C2	North Tetsa Phosphate West	n/a	Toad	in progress
MG-11-NTP-C0	North Tetsa Phosphate	-0.3	Toad	in progress
MG-11-NTP-C1	North Tetsa Phosphate	0.45	Toad	in progress
MG-11-NTP-C2	North Tetsa Phosphate	2.6	Toad	in progress
MG-11-NTP-C3	North Tetsa Phosphate	2.7	Toad	in progress
MG-11-NTP-C4	North Tetsa Phosphate	2.8	Toad	in progress
MG-11-NTP-C5	North Tetsa Phosphate	3.18	Toad	in progress
MG-11-NTP-C6	North Tetsa Phosphate	3.4	Toad	in progress
MG-11-NTP-C7	North Tetsa Phosphate	4.3	Toad	in progress
MG-11-NTP-C8	North Tetsa Phosphate	5.6	Toad	in progress
MG-11-NTP-C9	North Tetsa Phosphate	7.55	Toad	in progress
MG-11-NTP-C10	North Tetsa Phosphate	9.55	Toad	in progress
MG-11-NTP-C11	North Tetsa Phosphate	10.6	Toad	in progress
MG-11-NTP-C12	North Tetsa Phosphate	11.35	Toad	in progress
MG-11-NTP-C13	North Tetsa Phosphate	n/a	Toad	in progress
MG-11-OS-C1a	Oyster Springs	3.3	Liard	in progress
MG-11-OS-C4	Oyster Springs	17.9	Liard	in progress
MG-11-YB-C1	Yellow Bluffs	1.7	Toad/Liard	in progress
MG-11-YB-C2	Yellow Bluffs	1.7	Toad/Liard	in progress
MG-11-YB-C3	Yellow Bluffs	3	Toad/Liard	in progress
MG-11-YB-C4	Yellow Bluffs	3	Toad/Liard	in progress
MG-11-YB-C5	Yellow Bluffs	3.75	Toad/Liard	in progress
MG-11-YB-C6	Yellow Bluffs	3.75	Toad/Liard	in progress
MG-11-YB-C7	Yellow Bluffs	n/a	Toad/Liard	in progress
MG-11-YB-C8	Yellow Bluffs	10	Toad/Liard	in progress
MG-11-YB-C9	Yellow Bluffs	10	Toad/Liard	in progress
MG-11-YB-C10	Yellow Bluffs	8	Toad/Liard	in progress
MG-11-YB-C11	Yellow Bluffs	13	Toad/Liard	in progress
MG-11-YB-C12	Yellow Bluffs	13	Toad/Liard	in progress
MG-11-YB-Cfloat	Yellow Bluffs	n/a	Toad/Liard	in progress
MG-11-SL-C1	Sanitary Landfill	n/a	Toad	in progress
MG-11-SL-C2	Sanitary Landfill	n/a	Toad	in progress
MG-11-MP375W-C1	Mile Post 375 West	n/a	Toad	in progress
MG-11-MP375W-C2	Mile Post 375 West	n/a	Toad	in progress
MG-11-MP375W-C3	Mile Post 375 West	n/a	Toad	in progress
MG-11-MP375W-C4	Mile Post 375 West	n/a	Toad	in progress

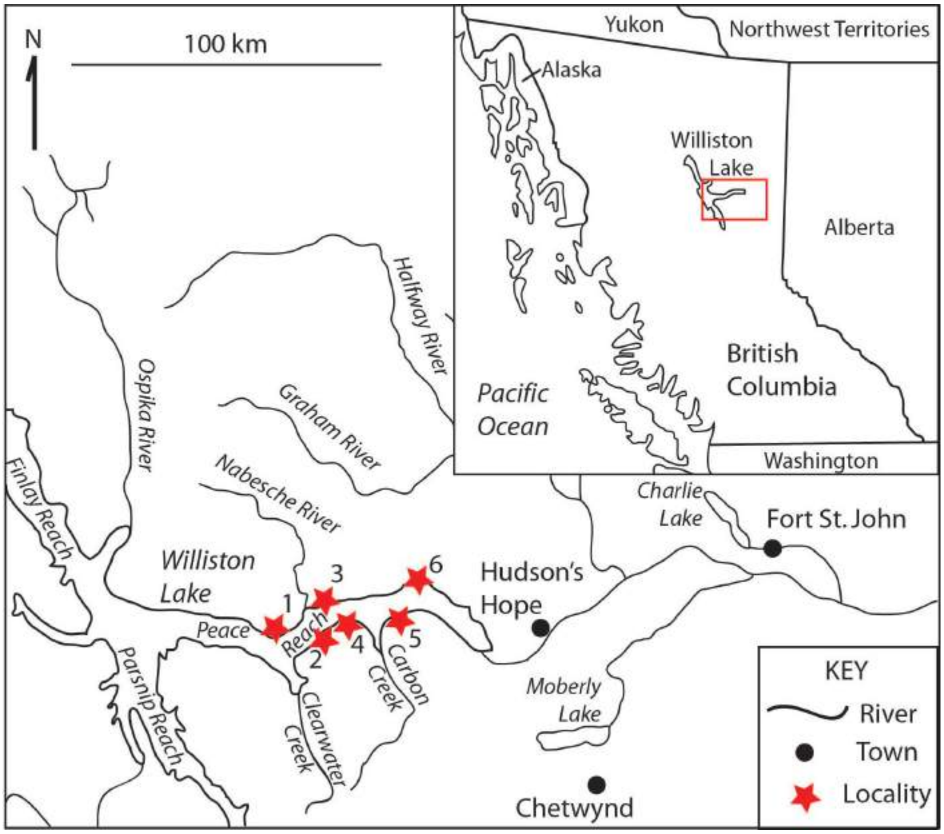


Figure 3. Location of Williston Lake sections: 1, Ursula Creek; 2, Ne-parle-pas Point; 3, Black Bear Ridge; 4, Glacier Spur; 5, East Carbon Creek; 6, Beattie Ledge. Modified from Zonneveld et al. (2001).

craton, and zircons of this age are present in all of the productive samples from Williston Lake. The detrital zircons of lower Paleozoic age (Ordovician–Devonian) imply initial derivation from the Innuitian/Ellesmerian Orogen to the north, likely by longshore drift. However, with the available data it is impossible to tell if these zircons were sourced directly from the orogen during the Triassic, or if they had been previously incorporated into older sediments near Williston Lake, before being reworked by more local systems during the Triassic. The zircons of Norian age from Black Bear Ridge could imply that pericratonic terranes with Triassic igneous rocks were in close proximity to the North American continent during the Rhaetian, and they were shedding some of this material into the WCSB. However, the euhedral nature of these zircons may suggest that they are primary, and represent deposition from contemporaneous volcanic activity during the Norian. This signal will be sought in other time equivalent sections on Williston Lake and elsewhere in northeastern BC. The absence of Mississippian and Permian detrital zircons is notable, as zircons of this age were identified in the Triassic of the Yukon by Beranek (2009), and interpreted as evidence for the Late Permian to Early Triassic accretion of the Yukon-Tanana terrane with North America. This conclusion is neither supported nor disproved by the data collected so far from BC.

Subsurface Correlation (NTS 093P)

In order to correlate the observations made at Williston Lake with equivalents in the subsurface, samples were collected from one subsurface core, taken from the Murphy Swan d-54-B/93-P-9 well. This is located to the southeast of the sections on Williston Lake and at South Halfway (Golding et al., 2011), in the Dawson Creek map area (NTS 093P; Figure 1, locality 9).

The Murphy Swan d-54-B/93-P-9 well intercepts the Montney and Doig formations, and eight core samples were processed for conodont and subsequent detrital zircon analysis (Tables 3, 4). These samples were processed for conodonts, and were productive, with the exception of material from 2556.90 m. The conodonts have not been identified to species level, but many appear to belong to the *Neogondolella constricta* group and are probably Anisian. Two of the samples (from 2551.80 and 2553.80 m) also produced enough detrital zircon to be dated, and as of November 2011 they were in the process of being analyzed.

These samples are slightly older than those that provided datable zircons from Williston Lake and South Halfway (Golding et al., 2011), and therefore may provide a test for the tectonic model suggested above. However, these are the most easterly of the samples studied so far, and may display

Table 3. Detrital zircon samples collected from subsurface wells in the study area, northeastern British Columbia, in 2010 and 2011.

Subsurface sample number	Locality	Distance from top of well (m)	Formation	Analysis
MG-10-JPZ1	d-54-B/93-P-9	2548.45	Doig	complete
MG-10-JPZ2	d-54-B/93-P-9	2549.66	Doig	complete
MG-10-JPZ3	d-54-B/93-P-9	2551.8	Doig	in progress
MG-10-JPZ4	d-54-B/93-P-9	2553.4	Doig	complete
MG-10-JPZ5	d-54-B/93-P-9	2553.8	Doig	in progress
MG-10-JPZ6	d-54-B/93-P-9	2556.25	Doig	complete
MG-10-JPZ7	d-54-B/93-P-9	2556.9	Doig	complete
MG-10-JPZ8	d-54-B/93-P-9	2557.3	Doig	complete
MG-11-C1	16-17-083-25W6	2258.30–2257.43	Montney	in progress
MG-11-C2	16-17-083-25W6	2256.22–2255.98	Doig	in progress
MG-11-C3	16-17-083-25W6	2255.30–2254.44	Doig	in progress
MG-11-C4	16-17-083-25W6	2248.52–2248.05	Doig	in progress
MG-11-C5	16-17-083-25W6	2247.75–2247.21	Doig	in progress
MG-11-C6	16-17-083-25W6	2245.79–2244.62	Doig	in progress
MG-11-C7	16-17-083-25W6	2242.35–2241.46	Doig	in progress
MG-11-C8	16-17-083-25W6	2239.75–2238.74	Doig	in progress
MG-11-C9	16-17-083-25W6	2237.05–2236.09	Doig	in progress
MG-11-C10	16-17-083-25W6	2234.57–2234.10	Doig	in progress
MG-11-C11	16-17-083-25W6	2233.61–2233.08	Doig	in progress
MG-11-C12	c-085-I/094-B-01	2374.17–2373.25	Doig	in progress
MG-11-C16	c-085-I/094-B-01	2315.22–2314.50	Doig	in progress
MG-11-C17	c-085-I/094-B-01	2310.89–2310.00	Doig	in progress
MG-11-C18	c-085-I/094-B-01	2306.82–2306.01	Doig	in progress
MG-11-C19	c-085-I/094-B-01	2295.92–2295.36	Doig	in progress
MG-11-C20	07-13-79-15W6	2056.35–2055.68	Montney	in progress
MG-11-C22	07-13-79-15W6	2054.30–2054.05	Doig	in progress
MG-11-C23	08-22-82-20W6	1779.61–1779.38	Doig	in progress
MG-11-C24	08-22-82-20W6	1778.98–1778.70	Doig	in progress
MG-11-C25	08-22-82-20W6	1775.20–1774.81	Doig	in progress
MG-11-C26	08-22-82-20W6	1774.16–1774.00	Doig	in progress
MG-11-C28	d-048-A/094-B-09	1968.25	Montney	in progress
MG-11-C29	d-048-A/094-B-09	1967.85	Montney	in progress
MG-11-C30	d-048-A/094-B-09	1967.50–1967.30	Doig	in progress
MG-11-C31	d-048-A/094-B-09	1967.00–1966.00	Doig	in progress
MG-11-C32	d-048-A/094-B-09	1965.90–1964.80	Doig	in progress
MG-11-C33	d-048-A/094-B-09	1965.40–1965.00	Doig	in progress

a detrital zircon signature dominated by the more proximal North American continent.

Alaska Highway Study Area (NTS 094K)

Seven sections were examined on the Alaska Highway during the summer of 2011 and sampled for detrital zircons and conodonts (Tables 1, 2). All sections are roadcuts on the Highway near to where it crosses the Tetsa River, and are situated in the Tuchodi Lakes map area (NTS 094K; Figure 4). From west to east, the sections are: Mile Post 386, North Tetsa Phosphate West, North Tetsa Phosphate, Oyster Springs, Yellow Bluffs, Sanitary Landfill and Mile Post 375 West. Of these sections, Mile Post 386, North Tetsa Phosphate, Yellow Bluffs and Mile Post 375 West have been studied before, although detailed logs were not available. Mile Post 375 West is the only one of these sections to have been mentioned in press (McLearn, 1946; Tozer, 1967). The North Tetsa Phosphate West, Oyster Springs and Sanitary Landfill sections are new. These sections span most of the Middle Triassic, from the Mulleri Zone (base Anisian) to the Meginae Zone (upper Ladinian).

Sampling

Mile Post 386

The Mile Post 386 section is located at mile post 386 on the Alaska Highway, with its base at Zone 10, 410890E,

Table 4. Conodont samples collected from subsurface wells in the study area, northeastern British Columbia, in 2010 and 2011.

Subsurface sample number	Locality	Distance from top of well (m)	Formation	Analysis
MG-10-JPZ1	d-54-B/93-P-9	2548.45	Doig	complete
MG-10-JPZ2	d-54-B/93-P-9	2549.66	Doig	complete
MG-10-JPZ3	d-54-B/93-P-9	2551.8	Doig	complete
MG-10-JPZ4	d-54-B/93-P-9	2553.4	Doig	complete
MG-10-JPZ5	d-54-B/93-P-9	2553.8	Doig	complete
MG-10-JPZ6	d-54-B/93-P-9	2556.25	Doig	complete
MG-10-JPZ7	d-54-B/93-P-9	2556.9	Doig	complete
MG-10-JPZ8	d-54-B/93-P-9	2557.3	Doig	complete
MG-11-C1	16-17-083-25W6	2258.30–2257.43	Montney	in progress
MG-11-C3	16-17-083-25W6	2255.30–2254.44	Doig	in progress
MG-11-C7	16-17-083-25W6	2242.35–2241.46	Doig	in progress
MG-11-C8	16-17-083-25W6	2239.75–2238.74	Doig	in progress
MG-11-C9	16-17-083-25W6	2237.05–2236.09	Doig	in progress
MG-11-C10	16-17-083-25W6	2234.57–2234.10	Doig	in progress
MG-11-C13	c-085-I/094-B-01	2370.61–2369.96	Doig	in progress
MG-11-C14	c-085-I/094-B-01	2368.88–2368.04	Doig	in progress
MG-11-C15	c-085-I/094-B-01	2366.75–2366.06	Doig	in progress
MG-11-C16	c-085-I/094-B-01	2315.22–2314.50	Doig	in progress
MG-11-C18	c-085-I/094-B-01	2306.82–2306.01	Doig	in progress
MG-11-C21	07-13-79-15W6	2054.68–2054.48	Doig	in progress
MG-11-C22	07-13-79-15W6	2054.30–2054.05	Doig	in progress
MG-11-C24	08-22-82-20W6	1778.98–1778.70	Doig	in progress
MG-11-C27	08-22-82-20W6	1773.65–1773.21	Doig	in progress
MG-11-C28	d-048-A/094-B-09	1968.25	Montney	in progress
MG-11-C29	d-048-A/094-B-09	1967.85	Montney	in progress
MG-11-C30	d-048-A/094-B-09	1967.50–1967.30	Doig	in progress
MG-11-C31	d-048-A/094-B-09	1967.00–1966.00	Doig	in progress
MG-11-C32	d-048-A/094-B-09	1965.90–1964.80	Doig	in progress
MG-11-C33	d-048-A/094-B-09	1965.40–1965.00	Doig	in progress

6503721N (NAD 83). It consists of 17.75 m of siltstone and sandstone belonging to the Toad Formation. Five conodont samples were collected (Table 2) and two detrital zircon samples were collected (Table 1). M. Balini (University of Milan) was present in the summer of 2011 and collected ammonoids from horizons at 8.0, 12.0 and 14.0 m above the base of the section, as well as from isolated outcrop 0.45 m above the top of the section. Previous unpublished ammonoid collections indicate that this section encompasses the Meginae Zone of the Ladinian.

North Tetsa Phosphate West

The North Tetsa Phosphate West section is located to the west of the North Tetsa Phosphate section and it consists of siltstone and sandstone belonging to the Toad Formation. Two conodont samples were collected, one from in situ, the other from talus. The in situ collection was also associated with ammonoids that were collected by M. Balini. The age of this section is uncertain.

North Tetsa Phosphate

The base of the North Tetsa Phosphate section is located at Zone 10, 416937E, 6503965N. It consists of 17.85 m of siltstone and sandstone belonging to the Toad Formation. This section contains a high proportion of phosphate, and is thought to be equivalent at least in part to the Doig phosphate zone that can be identified in the subsurface. Twelve conodont samples were collected from the section (Table 2). Another sample was collected from 0.3 m below the base of the measured section, and a final sample was collected from isolated outcrop above the top of the section. Five detrital zircon samples were also collected (Table 1). M. Balini collected ammonoids from horizons at 2.7, 3.18, 5.5, 17.2 and 17.5 m above the base of the section, as well as from one bed 0.3 m below the base of the section. Eight samples were collected from throughout the section for total organic carbon (TOC) analysis. Previous unpublished fossil collections indicate that this section is probably early Anisian in age.

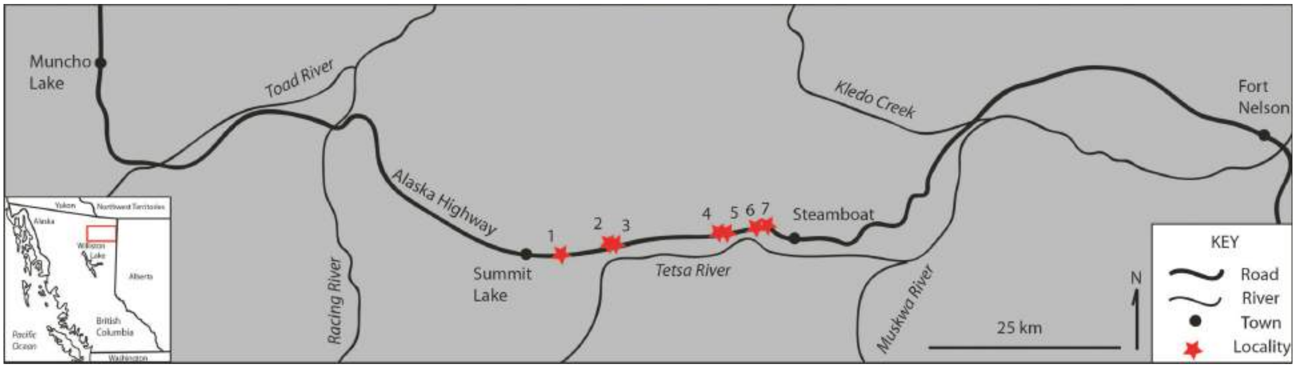


Figure 4. Location of Alaska Highway sections: 1, Mile Post 386; 2, North Tetsa Phosphate West; 3, North Tetsa Phosphate; 4, Oyster Springs; 5, Yellow Bluffs; 6, Sanitary Landfill; 7, Mile Post 375 West. Inset map modified from Zonneveld et al. (2001).

Oyster Springs

The base of the Oyster Springs section is located at Zone 10, 425012E, 6502735N and it consists of 18.53 m of siltstone, sandstone and carbonate belonging to the Liard Formation. Two conodont samples were collected (Table 2) and one detrital zircon sample was collected (Table 1). As this section has not been studied previously, its age is uncertain.

Yellow Bluffs

The base of the Yellow Bluffs section is located at Zone 10, 426835E, 6502265N and it consists of 92.5 m of siltstone and sandstone belonging to both the Toad and Liard formations. Eleven conodont samples were collected from the section (Table 2). A further two samples were collected from talus. Five detrital zircon samples were collected (Table 1). In the summer of 2011, M. Balini collected ammonoids from horizons at 1.7, 8.0 and 10.0 m above the base of the section. Previous unpublished fossil collections indicate that this section encompasses the Deleeni through Chischa zones of the Ansian.

Sanitary Landfill

The Sanitary Landfill section is located to the east of Yellow Bluffs near to an abandoned sanitary landfill. It consists of siltstone and sandstone belonging to the Toad Formation. Two conodont samples were collected, one from in situ and the other from talus (Table 2). The in situ collection was associated with ammonoids that were collected by M. Balini in the summer of 2011. The age of the section is uncertain.

Mile Post 375 West

The Mile Post 375 West section is located at mile post 375 on the Alaska Highway and is part of the Toad Formation. It was mentioned in Tozer (1967) and is the type section for the Caurus, Minor and Deleeni ammonoid zones. Four conodont samples were collected, one from Bed 1 of Tozer (1967), one from just above, one from Bed 2, and one from Bed 4 (Table 2). Bed 3 could not be located. One detrital zircon sample was collected from between the second and third conodont samples (Table 1). M. Balini also collected ammonoids from Bed 4. Previous fossil collections indicate that this section encompasses the Caurus, Hagei, Hayesi, Minor and Deleeni Zones of the lower, middle and upper Anisian.

Subsurface Studies (NTS 093P, 094A, B)

In order to improve the correlation between surface and subsurface, five cores from wells drilled in northeastern BC were logged and sampled for conodont analysis (Table 4). Detrital zircon samples were also collected in order to ascertain whether the results from the surface sections can be replicated from the subsurface farther to the east (Table 3). The cores were selected for their geographic coverage and also because they all covered the interval of the Doig phosphate zone. This part of the Doig Formation is poorly dated but economically important as a source rock. It is thought to be anywhere from Spathian to Anisian (Zonneveld, 2010), and therefore covers the interval in which Beranek (2009) discovered evidence for sediment being derived from pericratonic terranes to the west. Recognizing such a signal in the subsurface of BC would have implications for understanding the Doig Formation and would alter the current understanding of sediment input into the WCSB at this time. The samples collected span the same interval (the boundary between the Montney and Doig formations) as those processed from the Murphy Swan well (see above).The processing of these samples is currently underway. Well locations are shown on Figure 1.

Sampling Methodology

Talisman Altares 16-17-083-25W6 Well

From the Talisman Altares 16-17-083-25W6 well, 34.00 m of core were logged, from 2267.00 to 2233.00 m below the surface (Figure 5). Six conodont samples were collected (Table 4) and 11 samples were collected for detrital zircon analysis (Table 3). The conodont sample from 2258.30 to 2257.43 m comes from the Montney Formation, all of the other samples come from the Doig Formation. This well is located in the Charlie Lake map area (NTS 094A).

Talisman Altares c-085-I/094-B-01 Well

From the Talisman Altares c-085-I/094-B-01 well, 85.00 m of core were logged, from 2375.00 to 2290.00 m below the surface (Figure 6). Five conodont samples (Table 4) and five detrital zircon samples were collected (Table 3). All of these samples come from the Doig Formation. This well is located in the Halfway River map area (NTS 094B).

Arc Dawson 07-13-79-15W6 Well

From the Arc Dawson 07-13-79-15W6 well, 5.00 m of core were logged, from 2059.00 to 2054.00 m below the surface (Figure 7). Two conodont samples (Table 4) and two detrital zircon samples were collected (Table 3). The zircon sample from 2056.35 to 2055.68 m is from the Montney Formation, all of the others come from the Doig Formation. This well is located in the Dawson Creek map area (NTS 093P).

Rocor Monias 08-22-82-20W6 Well

From the Rocor Monias 08-22-82-20W6 well, 10.60 m of core were logged, from 1781.00 to 1770.40 m below the surface (Figure 8). Two conodont samples (Table 4) and four detrital zircon samples were collected (Table 3). All the samples are from the Doig Formation. This well is located in the Charlie Lake map area (NTS 094A).

Petro-Canada Kobes d-048-A/094-B-09 Well

From the Petro-Canada Kobes d-048-A/094-B-09 well, 9.80 m of core were logged, from 1970.00 to 1960.20 m below the surface (Figure 9). Six samples were collected, with each one to be processed for both conodonts and detrital zircons (Tables 3, 4). The two samples, at 1968.25 and 1967.85 m, are from the Montney Formation, all of the others come from the Doig Formation. This well is located in the Halfway River map area (NTS 094B).

Conclusions and Future Work

Detrital zircon ages collected from the Ladinian–Carnian boundary at Glacier Spur on Williston Lake indicate derivation of at least some of the sediment from the Ellesmerian/Innuitian Orogen to the north, supporting the hypothesis of Ross et al. (1997) and Beranek (2009). None of the sections have produced any Mississippian or Permian zircons, such as those found by Beranek (2009) in the Yukon, and so as yet the hypothesis of early pericratonic terrane accretion cannot be confirmed in BC. However, the Late Triassic dates from zircon recovered from Rhaetian rocks at Black Bear Ridge indicate the possibility of a nearby Triassic igneous rock source, or perhaps even primary volcanism in the region of BC during the latest Triassic. This is significant as there is no evidence for Triassic volcanism on the craton, and so would imply a source from a pericratonic terrane to the west, possibly the Yukon-Tanana terrane. The absence of a western detrital zircon signature in particular sections may therefore be due to the architecture of the WCSB, with these zircons not being transported to some parts of the basin.

All of this indicates a more complex pattern of sedimentation in the WCSB during the Triassic than has previously been assumed, it is not just a simple case of sediment being deposited from the east to the west. This has implications both for sedimentological analysis of the natural gas–bearing Montney and Doig formations, as well as for the tracing of facies within the basin.

Conodonts have already proved their worth in correlating beds within the Triassic (see Orchard and Tozer, 1997), and this study should contribute to a further refinement of the biostratigraphic scheme and enhanced correlation across the basin, improving the understanding of the timing of geological events during this period in BC.

The remainder of this study will focus on trying to find the Mississippian–Permian detrital zircon signal found in the Yukon. Work will be concentrated in the north of the province, to avoid the possible effects of entrainment by the Peace River embayment. This study will also try to confirm the Late Triassic detrital zircon signal found at Black Bear Ridge by examining and sampling other Rhaetian and Norian sections throughout the foothills. Analysis of whole rock geochemistry may help to determine the origin of the Late Triassic zircons; are they primary zircons from volcanic ash or are they reworked from older igneous intrusions on pericratonic terranes? The final goal of this study will be to improve the correlation of events between the surface and subsurface and further demonstrate the utility of this work in natural gas exploration.

This study provides the opportunity to understand the distribution of sedimentary facies in the WCSB in a way that is not possible simply by looking at subsurface core samples. Correlation between outcrop and the subsurface using biostratigraphy allows these facies to be traced into the subsurface where the equivalent formations contain important natural gas reserves. Understanding the distribution of sedimentary facies is important for the economic extraction of natural gas. The detrital zircon part of this study allows the provenance of the natural gas–bearing sediments to be determined. This in turn indicates the direction of transport of these sediments, which exerts an important control on the architecture of the sediments deposited in the basin. Understanding the direction of transport and therefore the architecture of the basin will also aid the extraction of natural gas. Finally, refinements that are being made to the biostratigraphic framework will allow more precise correlation of units both within the subsurface and from the subsurface to outcrop, which will in turn enable fine-scale mapping of facies across the basin and will also aid in finding more natural gas reservoirs of similar age to those already known.

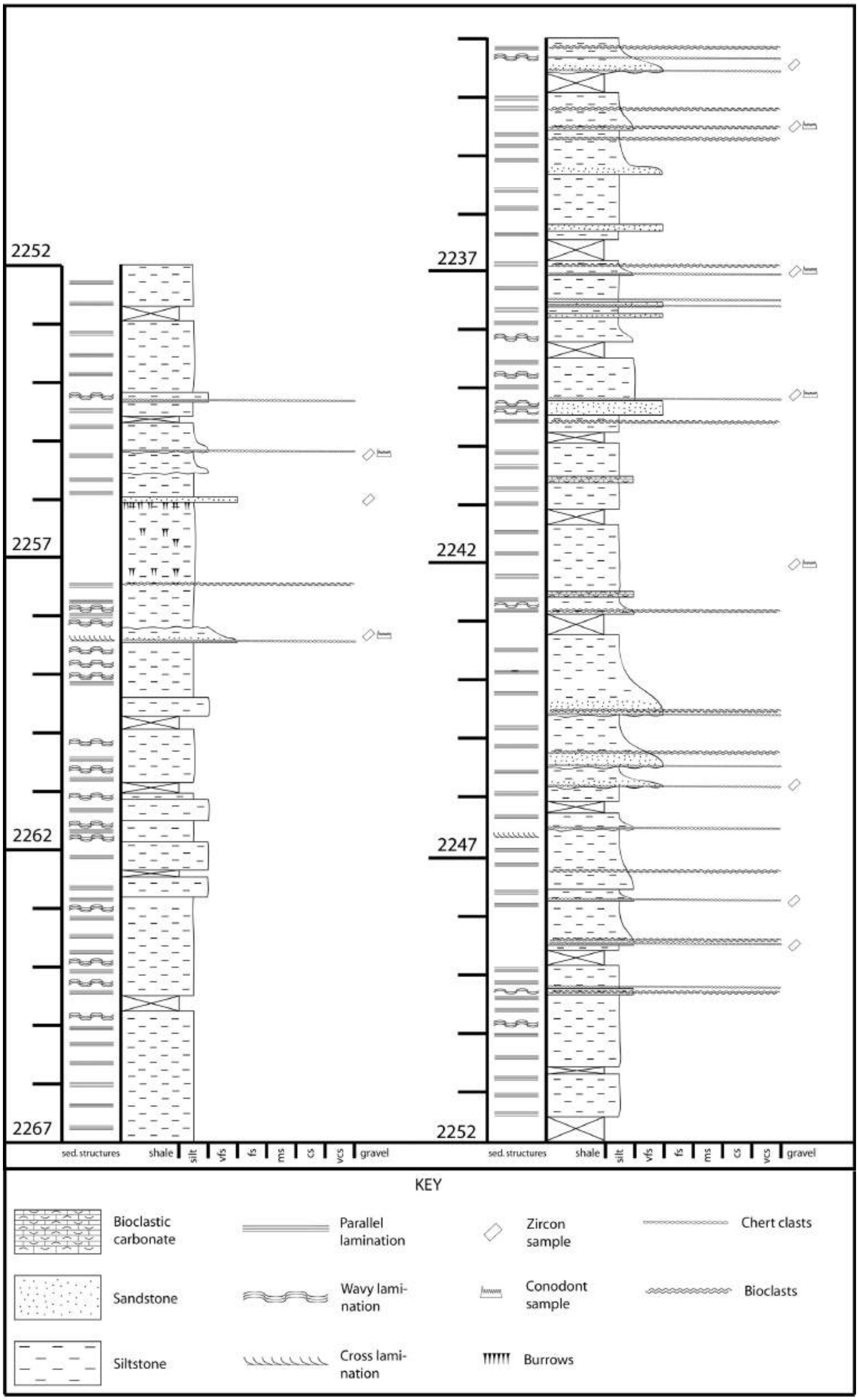
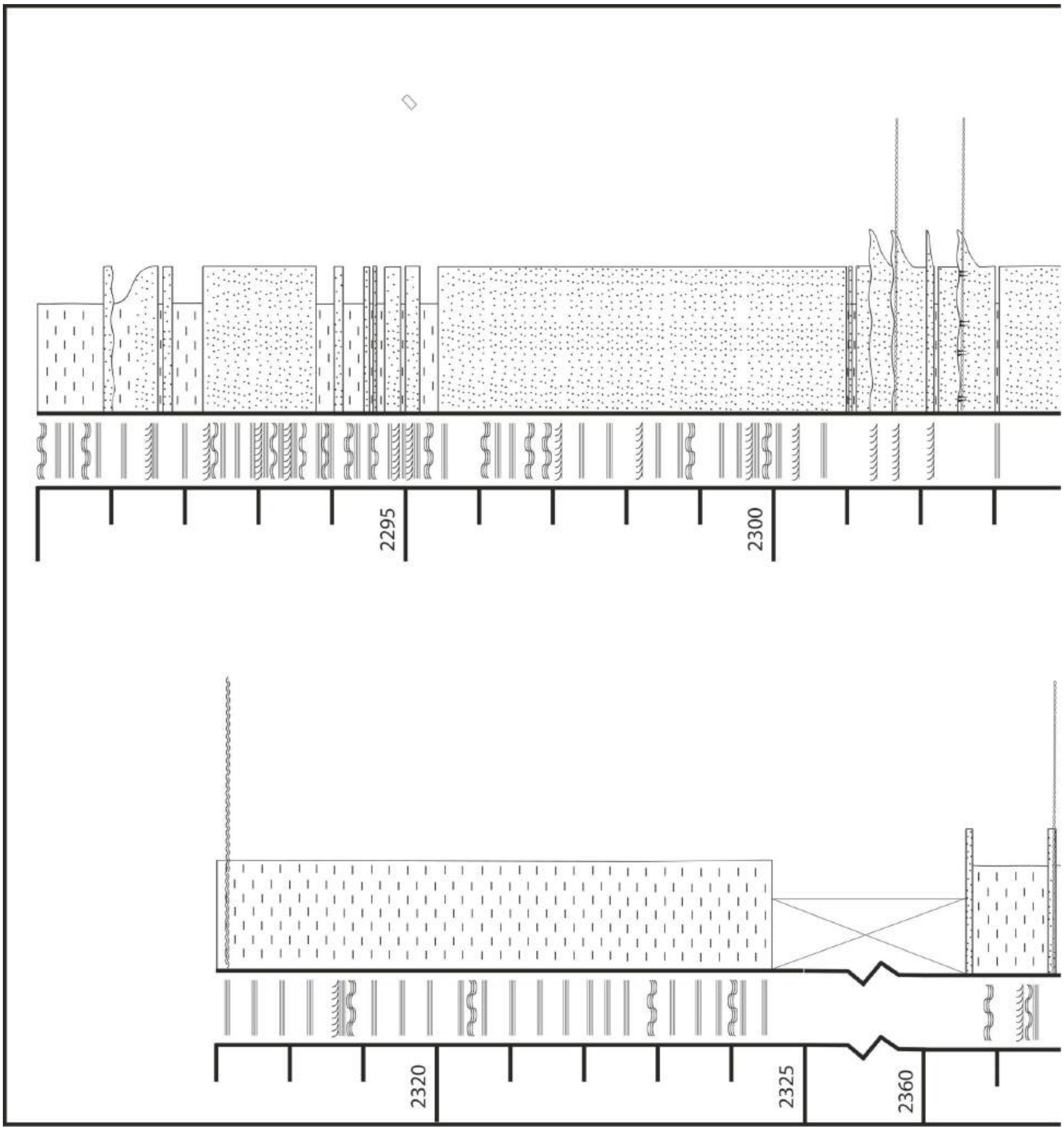


Figure 5. Sedimentary log of core from the Talisman Altares 16-17-083-25W6 well, showing location of sampled intervals. Vertical depths are shown in metres below surface. Abbreviations: cs, coarse-grained sand; fs, fine-grained sand; ms, medium-grained sand; sed, sedimentary; vcs, very coarse grained sand; vfs, very fine grained sand.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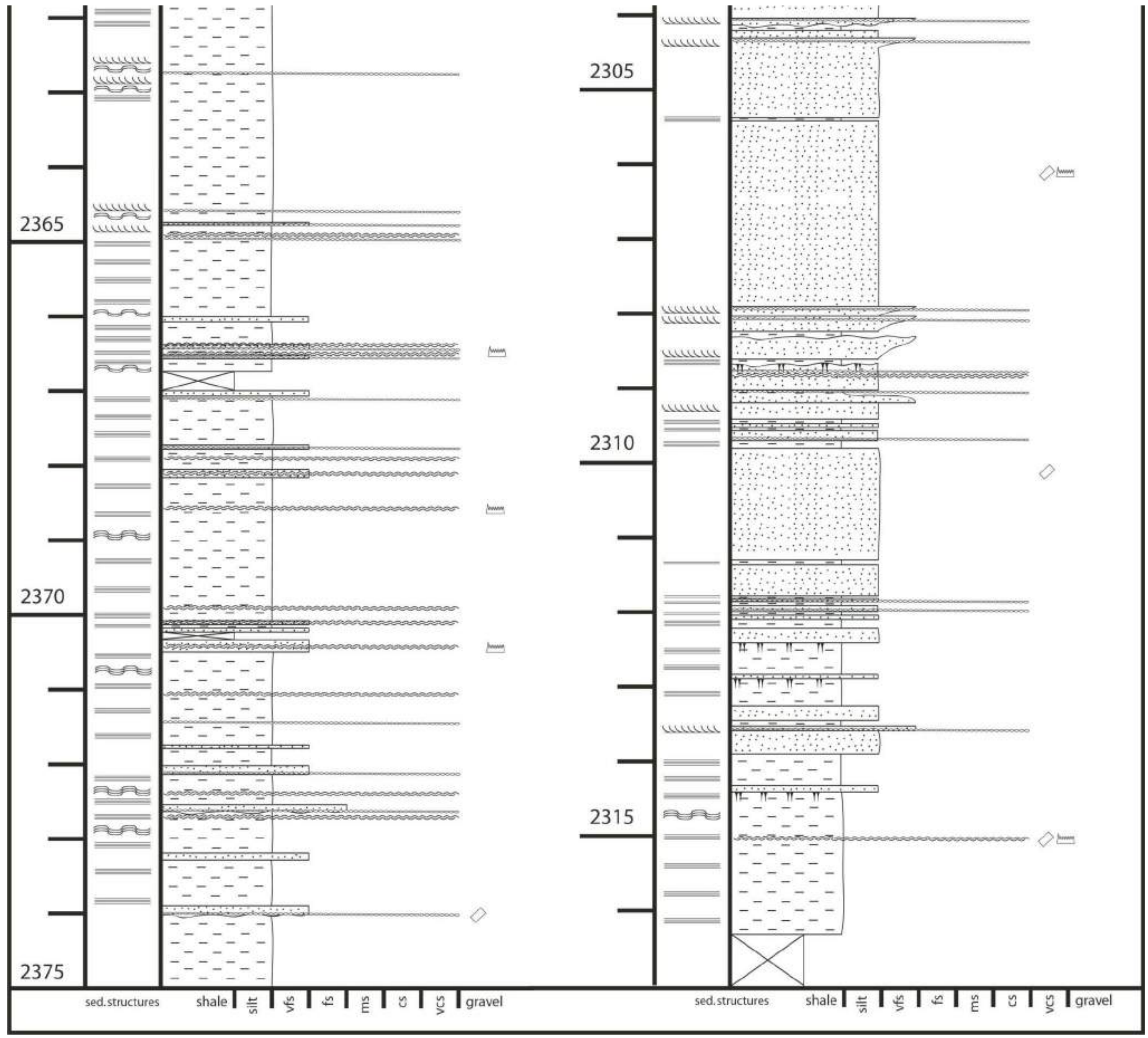

Figure 6. Sedimentary log of core from the Talisman Altares c-085-I/094-B-01 well, showing location of sampled intervals. Vertical depths are shown in metres below surface. See Figure 5 for the key to symbols. Abbreviations: cs, coarse-grained sand; fs, fine-grained sand; ms, medium-grained sand; sed, sedimentary; vcs, very coarse grained sand; vfs, very fine grained sand.

Acknowledgments

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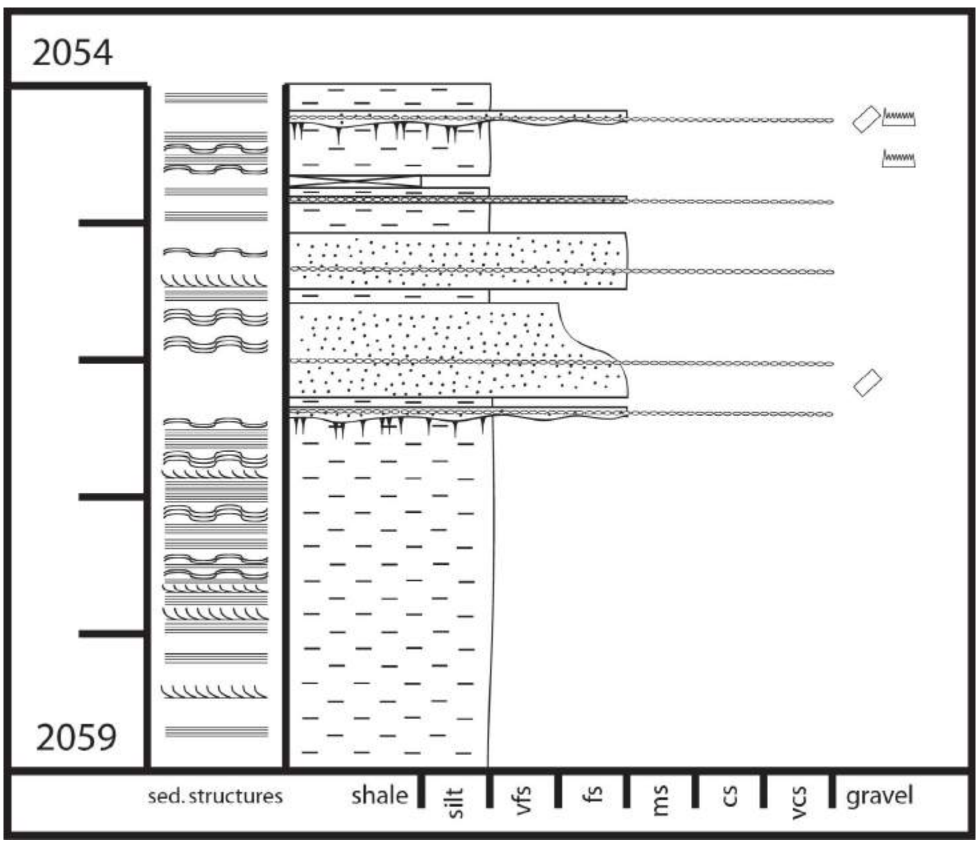

Figure 7. Sedimentary log of core from the Arc Dawson 07-13-79-15W6 well, showing location of sampled intervals. Vertical depths are shown in metres below surface. See Figure 5 for the key to symbols. Abbreviations: cs, coarse-grained sand; fs, fine-grained sand; ms, medium-grained sand; sed, sedimentary; vcs, very coarse grained sand; vfs, very fine grained sand.

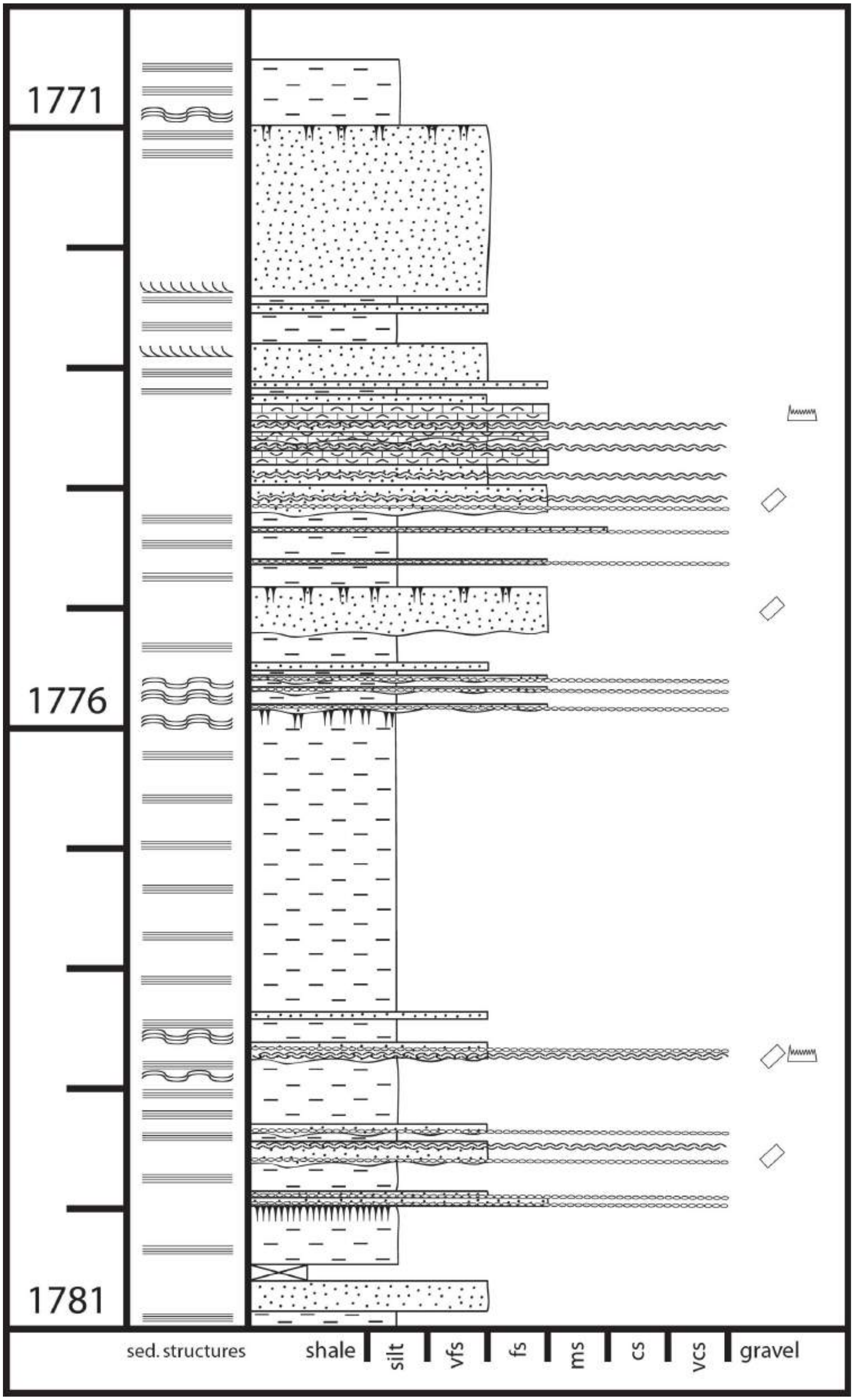

Figure 8. Sedimentary log of core from the Rocor Monias 08-22-82-20W6 well, showing location of sampled intervals. Vertical depths are shown in metres below surface. See Figure 5 for the key to symbols. Abbreviations: cs, coarse-grained sand; fs, fine-grained sand; ms, medium-grained sand; sed, sedimentary; vcs, very coarse grained sand; vfs, very fine grained sand.

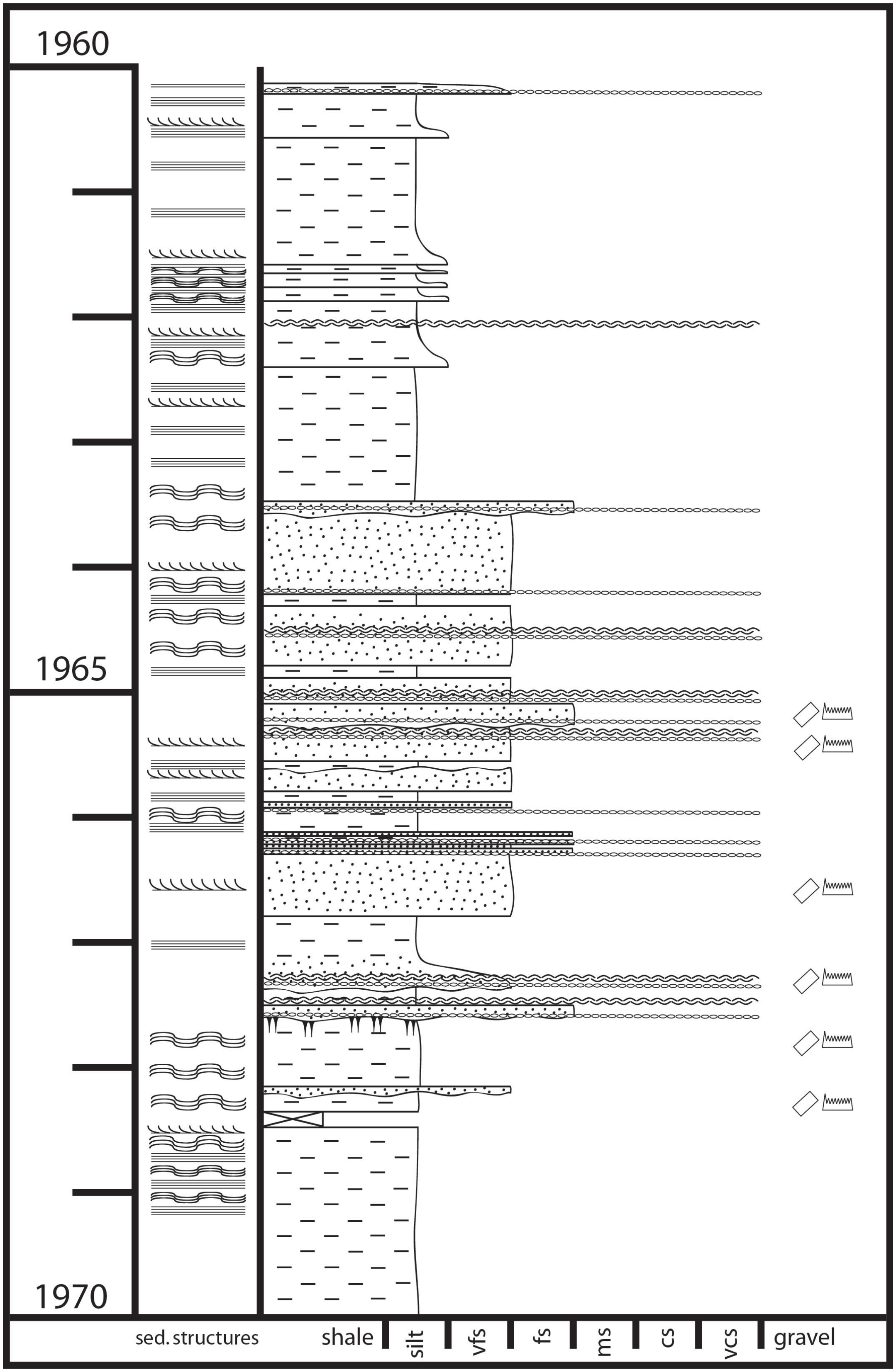

Figure 9. Sedimentary log of core from the Petro-Canada Kobes d-048-A/094-B-09 well, showing location of sampled intervals. Vertical depths are shown in metres below surface. See Figure 5 for the key to symbols. Abbreviations: cs, coarse-grained sand; fs, fine-grained sand; ms, medium-grained sand; sed, sedimentary; vcs, very coarse grained sand; vfs, very fine grained sand.

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