CARDIUM OUTCROP STUDY: SEEBE-KANANASKIS AREA

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ABSTRACT

Contained herein is a field guide for Cardium outcrops at Seebe Dam, Horseshoe Dam and Kananaskis River locations. The guide is based on Roger Walker's work (1988). Photographs of allomembers at each location and stratigraphic sections are included. Bedding structures, ichnofossils and faults are identified. The Economic importance of the Cardium is discussed.

TABLE OF CONTENTS

LIST OF FIGURES

PRODUCTION (Mossop & Shetsen, 1994)

Gas Production

Gas production is concentrated in southwest Alberta adjacent to the disturbed belt. There are 12 Cardium gas fields with initial established gas reserves of over 1,000 E^6 m^3 (35 Bcf). Gas is closely associated with oil production and both are often produced from the same reservoir.

Oil Production

There are 14 Cardium oil fields with initial established recoverable reserves of over 1 E^6 m^3 (6 MM Bbls). The Cardium Pembina field is Canada’s largest oil field. All fields occur in stratigraphic traps in sandstone and conglomerate deposited in thin sheets as at Pembina or in elongate marine scours as at Garrington and Crossfield.

Gas Production from the Cardium

Gas production from the Cardium is concentrated in southwestern Alberta adjacent to the disturbed belt. As well, minor gas production occurs in western Saskatchewan. Included are fields producing from the Cardium in Alberta and the St Walburg Sand in Saskatchewan.

There are 12 Cardium gas fields with Initial Established Marketable Gas Reserves of over 1000 x 10^6m^3 (35 BCF). The ten largest Cardium gas fields, listed in order of Initial Established Marketable gas reserves, are shown in Table 1. Cumulative production data for Alberta are updated to the end of 1990.

Table 1. Ten Largest Cardium Gas Fields (in units of 10^6m^3).

No.	Field	Formation	No.of Pools	Initial Established Marketable Reserves	Initial Established In-place Volume	Cumulative Production	Discovery Year
1	Pembina	Cardium	5	20,566	113,714	15,165	1953
2	Ferrier	Cardium	26	18,333	34,931	14,431	1956
3	Ricinus	Cardium	49	16,538	22,441	2,303	1968
4	Willesden Green	Cardium	8	5,946	24,743	3,388	1962
5	Minehead	Cardium	6	3,390	5,644	277	1965
6	Ansell	Cardium	8	3,076	14,910	393	1976
7	Kakwa	Cardium	6	2,878	4,423	178	1978
8	Caroline	Cardium	10	2,654	8,070	1,413	1965
9	Edson	Cardium	12	2,025	4,124	1,081	'1963
10	Hanlan	Cardium	5	1,263	1,642	0	1969

Much of the gas production from the Cardium is closely associated with oil production, with both often being produced from the same field.

Total recoverable gas reserves in the Cardium are estimated at 88.3 x 10^9m^3, of which 30.8 x 10^9m^3 have already been produced. Initial Established In-Place Volume of Cardium gas reserves totals 263 x 10^9m^3. There are a total of 289 Cardium gas pools, with an average 305 x 10^6m^3 recoverable gas reserves/pool. Table 2 lists the distribution of Cardium gas reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Cardium Gas Pools (in units of 10^6m^3)

In-Place Pool Size Class	No.of Pools	Recoverable Reserves	Cumulative Production
1.0 to 10	8	28	5
10 to 100	134	3,977	572
100 to 1000	124	20,465	2,338
1000 to 10000	18	16,728	3,711
over 10000	5	47,087	24,148
Total	289	88,285 x 10^6m^3	30,774 x 10^6m^3

Figure 1: Cardium Gas Production (Mossop & Shetsen, 1994, p. 376).

Oil Production from the Cardium

Oil production from the Cardium is concentrated in southwestern Alberta adjacent to the disturbed belt. Pembina, Canada's largest oil field, produces from the Cardium and is truly a giant oil field.

There are 14 Cardium oil fields with Initial Established Recoverable Oil Reserves of over 1×10^6 m^3 (6 MMBbls). The ten largest Cardium oil fields, listed in order of Initial Established Recoverable Reserves, are shown in Table 1. Cumulative production data for Alberta are updated to the end of 1990.

Table 1. Ten Largest Cardium Oil Fields (in units of 10^6m^3).

No.	Field	Formation	No. of Pools	Initial Established Marketable Reserves	Initial Established In-place Volume	Cumulative Production	Discovery Year
1	Pembina	Cardium	20	231.3	1187.2	172.1	1953
2	Willesden Green	Cardium	9	25.8	124.7	18.0	1954
3	Ferrier	Cardium	12	12.3	77.5	7.4	1954
4	Ricinus	Cardium	49	6.6	49.8	4.1	1968
5	Cyn-Pem	Cardium	16	5.5	18.8	3.8	1962
6	Carrot Creek	Cardium	23	3.9	17.3	1.6	1963
7	Garrington	Cardium	14	3.5	34.7	3.1	1953
8	Crossfield	Cardium	3	3.1	26.1	3.0	1956
9	Caroline	Cardium	10	2.4	10.5	1.8	1961
10	Kakwa	Cardium	6	2.1	9.3	1.2	1957

All of these fields occur in stratigraphic traps, in sandstones and conglomerates deposited in thin sheets as at Pembina or in elongate marine scours as at Garrington and Crossfield. All fields contain light to medium gravity oil.

Total recoverable oil reserves in the Cardium are estimated at $305.0 \times 10^6m^3$, of which $220.9 \times 10^6m^3$ have already been produced. Pembina alone comprises over 75 percent of the recoverable reserves. Initial Established In-Place Volume of Cardium oil reserves totals $1648 \times 10^6m^3$. There are 297 Cardium pools in 42 fields, with an average $1027 \times 10^3m^3$ recoverable oil reserves/pool. When Pembina is deleted from this calculation, the average drops to $266 \times 10^3m^3$. Table 2 lists the distribution of Cardium oil reserves according to In-Place Pool Size.

Table 2 - Size Distribution of Cardium Oil Pools (in units of 10^6m^3)

In-Place Pool Size Class	No. of Pools	Recoverable Reserves	Cumulative Production
less than 0.1	76	0.40	0.19
0.1 to 1	174	5.04	2.54
1.0 to 10	37	20.25	12.74
10.0 to 100	8	22.59	15.47
100.0 to 1000	1	25.73	17.93
over 1000	1	231.00	171.99
Total	297	$305.00 \times 10^6m^3$	$220.86 \times 10^6m^3$

Figure 2: Cardium oil production (Mossop & Shetsen, 1994, p. 376).

GEOLOGIC SETTING

Structural Setting (Walker, 1988)

The Cardium formation outcrops along the rocky mountain foothills; it is here that the formation has been brought to surface by multiple juxtaposed east verging thrusts. In the plains region of Alberta, the Cardium is confined to subsurface, forming a 200 km long terrigenous, muddy, sandy and conglomeratic clastic wedge which thins into the basin's interior.

Alberta can be divided into two parts: the undeformed and essentially flat lying Plains and the Deformed Belt (Figure 1) The Deformed belt consists of two main parts: 1) the Foothills, characterized at the surface and immediate subsurface by many westward-dipping thrusts and some folds, and affecting mostly Cretaceous sandstones and shales; and 2) the Front Ranges, characterized by major westward dipping thrusts that displace Paleozoic (Cambrian and Devonian) carbonate rocks. The junction between the Front Ranges and the Foothills is marked by the McConnell Thrust, which emplaces the Middle Cambrian Eldon Formation on top of the Upper Cretaceous Belly River Formation (Figure 2). The McConnel thrust lies just north of the Seebe area.

The Turonian Cardium Formation lies within the Foothills structural belt (Figures 1 and 2). Bedding dips gently westward at about 10 – 20^{o}. The outcrop is slightly disrupted by small thrust faults (Figure 3) which dip westward at 10 – 15^{o} steeper than bedding. Lateral displacements are northeastward and slickensides have an average trend of 048^{o}. The bedding and thrust faults are cut by six younger normal faults (Figure 3) that are essentially parallel, trending 120 – 300^{o}. All except N4 are downthrown to the east, with offsets up to about 5 m. N5 is probably the same fault as N6 and N4 is a splay of N3. The only fault downthrown to the west is N4, with an offset of 7m.

Stratigraphic Setting

The Cardium overlies 200 m of the Blackstone Formation’s marine mudstones and is overlain by 400 m of similar marine mudstones of the Wapiabi Formation. In the southern and central plains of Alberta, the Cardium is in the Colorado Group. In plan view, the Cardium covers an arc 1000 km’s long from Waterton Lakes National Park to Dawson Creek B.C.

Sedimentological Setting (Walker, 1988, p. 7)

Cardium deposition took place in the Western Interior Seaway of Alberta during the Turonian and Coniacian stages of the Late Cretaceous along the western margin of the Alberta Foreland basin. This seaway occupied a late Jurassic and Cretaceous Foreland Basin, between the actively rising Cordillera to the west, and the stable craton to the east. The bulk of the Cardium consists of interbedded bioturbated marine mudstones and hummocky cross stratified (HCS) sandstones, indicating a depositional environment below fairweather wave base, in a storm-dominated open marine setting (Wright and Walker, 1981; Krause and Nelson, 1984). To the west and southwest, the sea was at times bordered by strandplain, barrier and lagoonal environments (Plint and Walker, 1987).

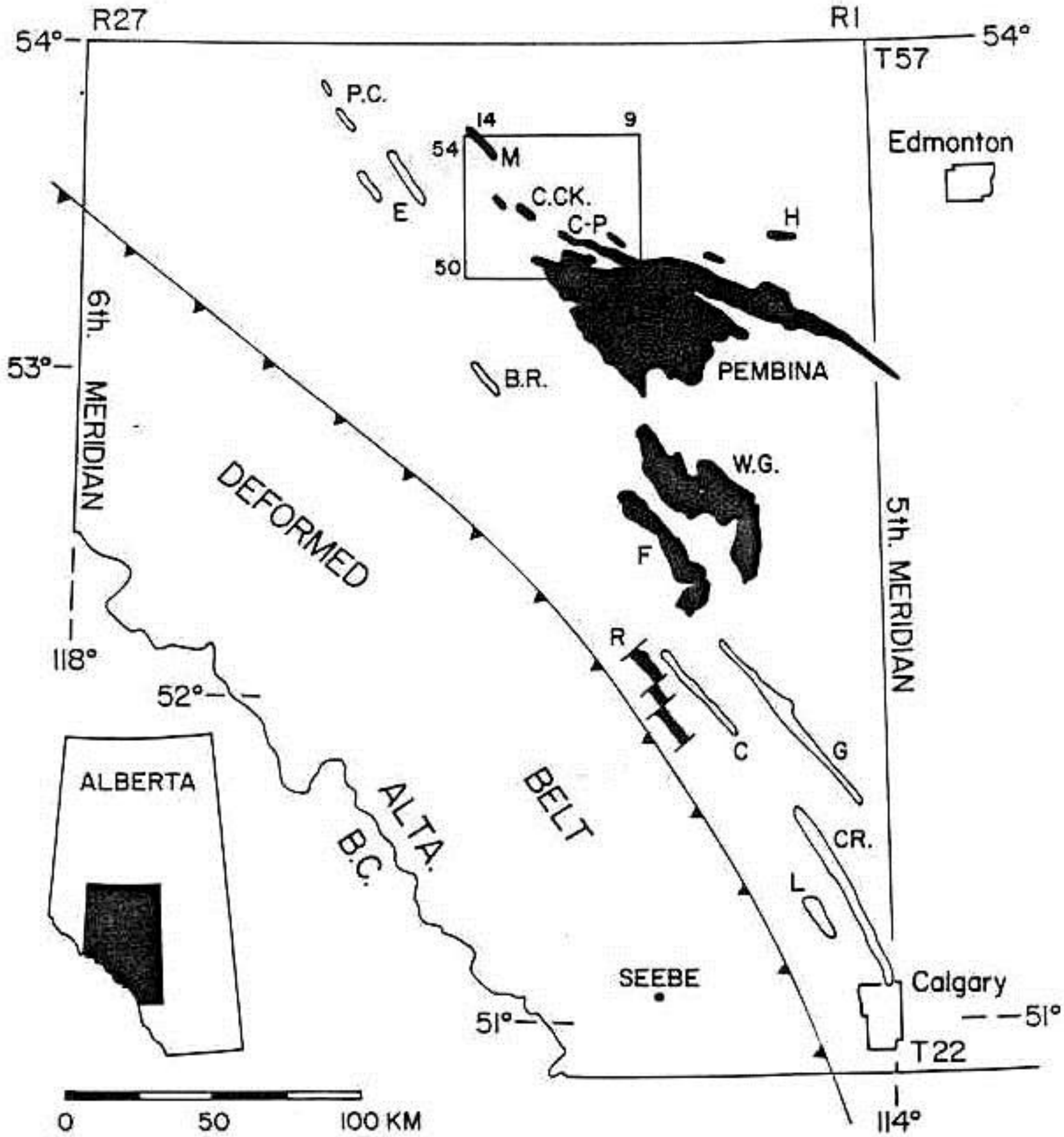


Figure 3: Subsurface oil and gas fields in Alberta. Fields associated with erosion surface E5 are black, and fields associated with E4 are white. P.C.-Pine Creek; E-Edson; M-Mcleod; C.Ck.-Carrot Creek; C-P Cyn-Pem; H-Highvale; B.R.-Brazeau River; W.G.-Willesden Green; F-Ferrier; R-Ricinus; C-Caroline; G-Garrington; L-Lochend (Walker,1988, p. 3).

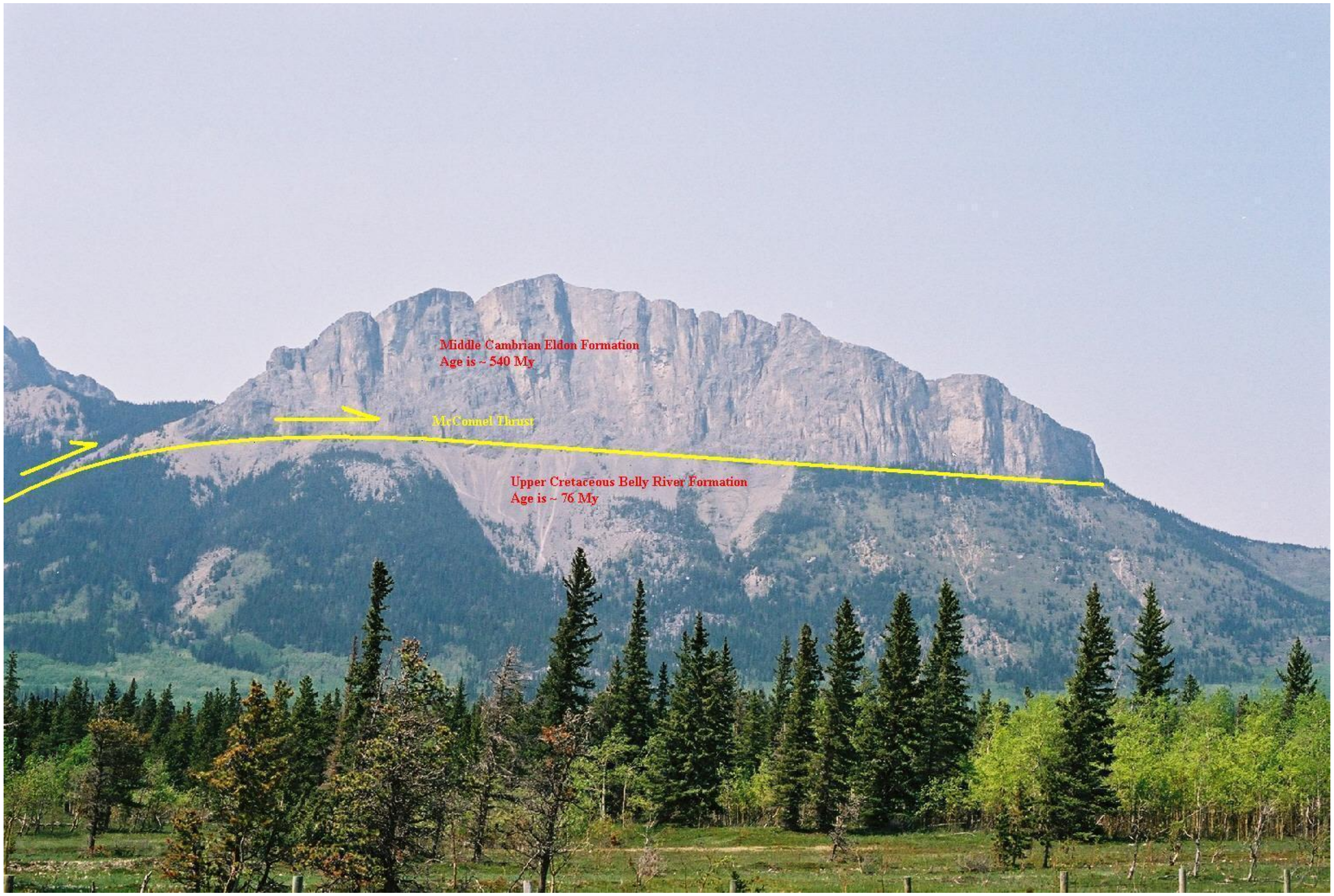


Figure 4: Yamnuska, elevation 2545 m, also called Mt. Laurie. The McConnel Thrust runs along the base of the cliff which is 350 m high and marks the junction between the Front Ranges and the Foothills. Here the Middle Cambrian Eldon Formation is emplaced on top of the Upper Cretaceous Belly River Formation.

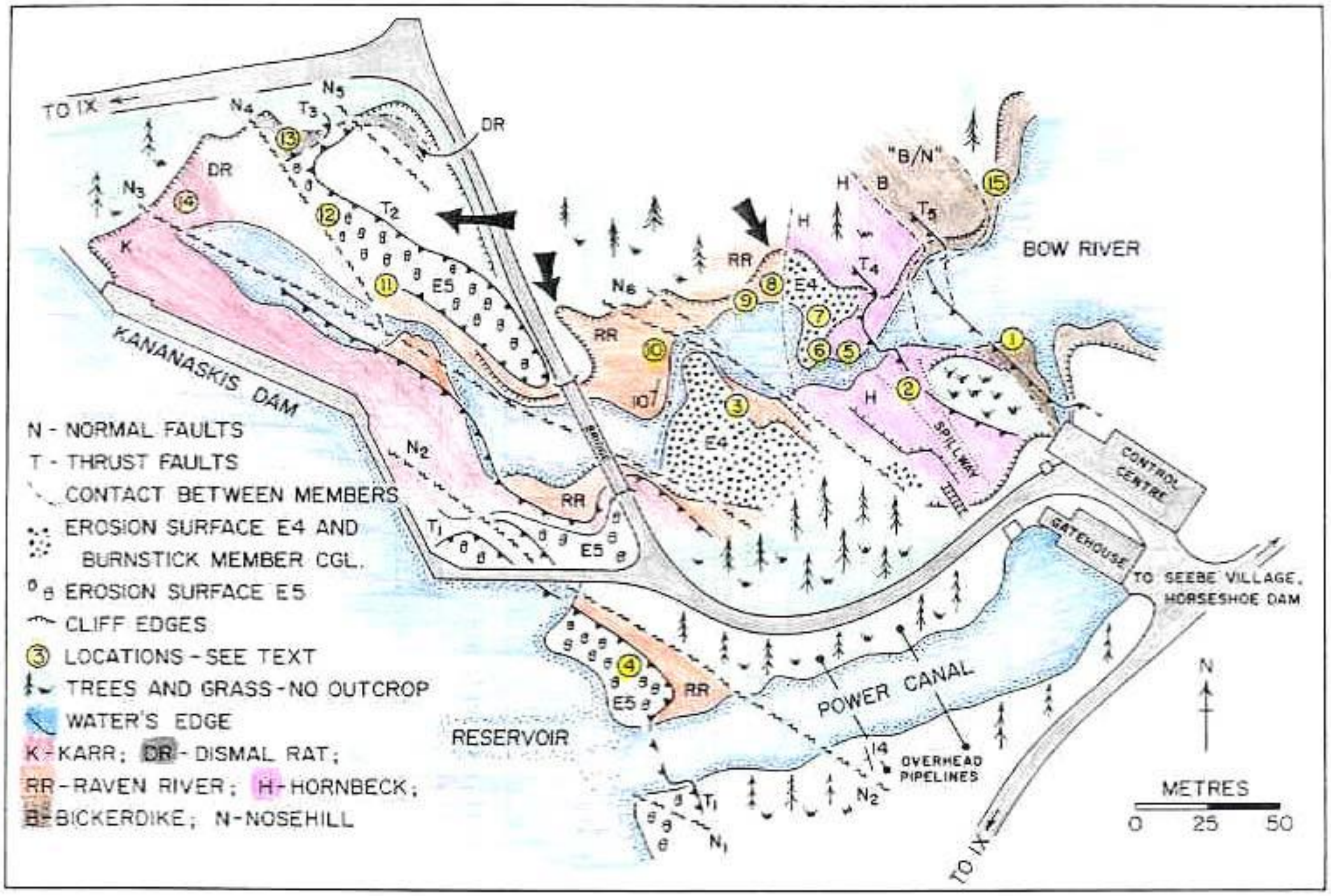


Figure 5: Field map of the Seebe area. Reference locations are numbered and highlighted with yellow. Cardium allomembers are color coded for outcrop locations. Faults and contacts are identified (Walker, 1988, p. 9).

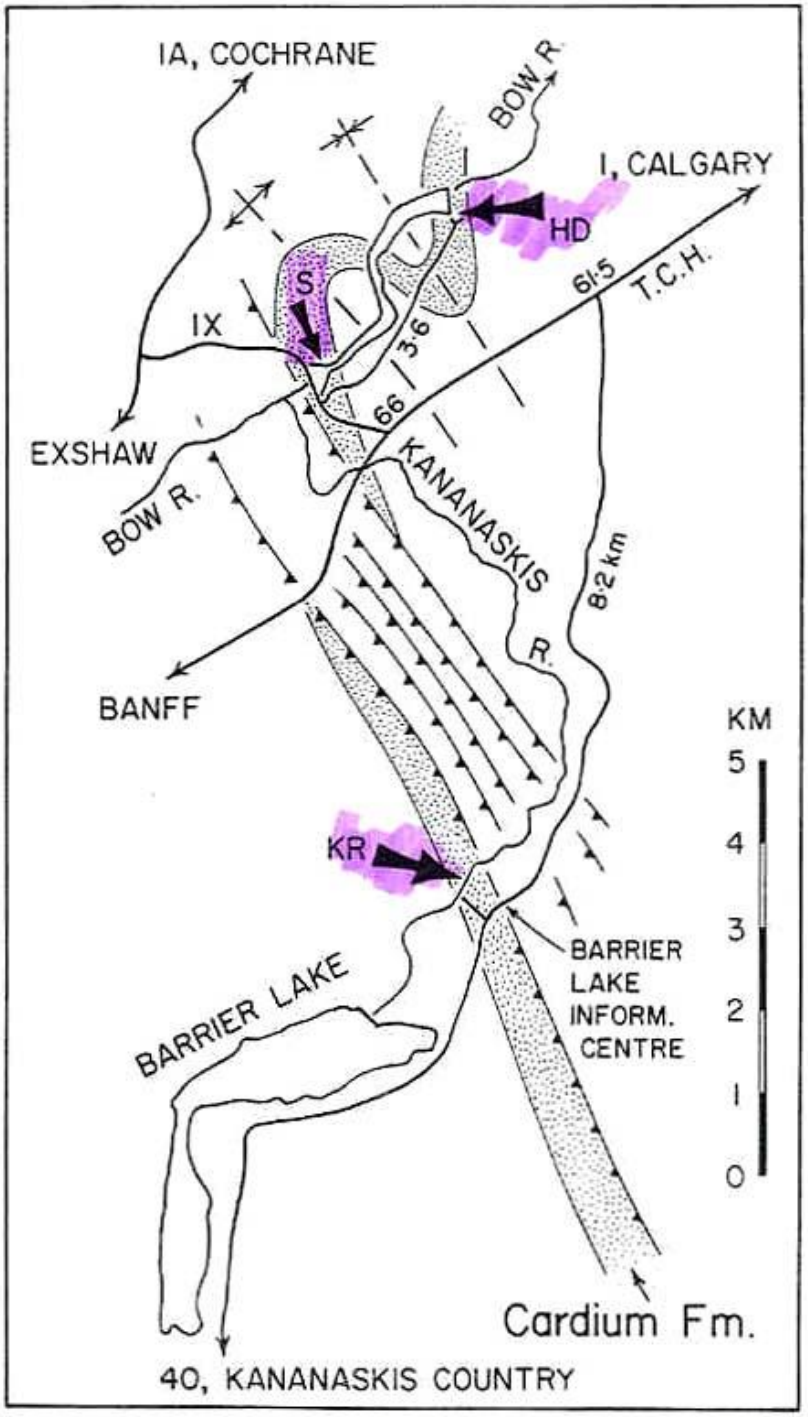


Figure 6: Outcrop locations in the Seebe-Kananaskis area. Note that Seebe (S) and Horseshoe Dam (HD) locations have two folds between them – a syncline anticline sequence. Also note the number of thrust faults between Seebe and Kananaskis River (KR) locations (Walker, 1988, p. 4).

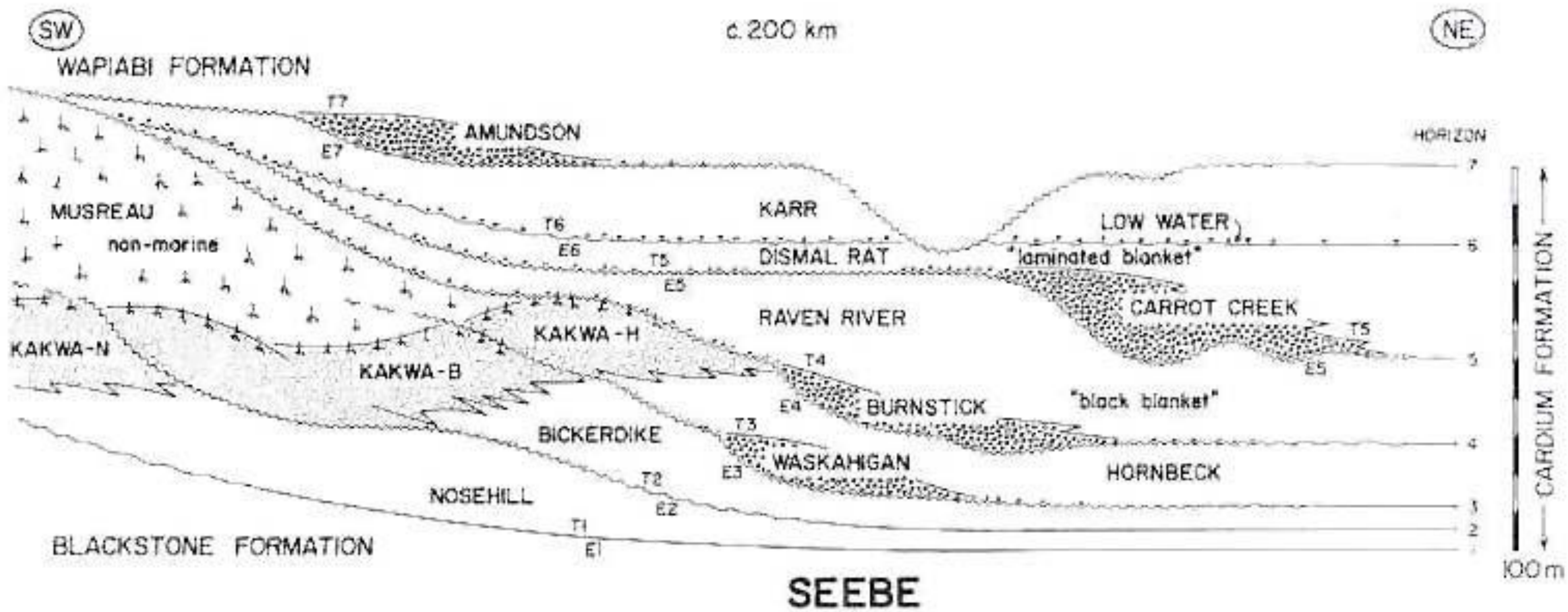


Figure 7: Allomember terminology for the Cardium Formation in subsurface. The erosive (E) and transgressive (T) surfaces are bounding discontinuities that define the allomembers. In the Seebe-Kananaskis area, neither the shoreface (Kakwa) nor nonmarine (Murrael) parts of lthe Cardium crop out. The erosive surfaces die out basinward into correlative conformities (Horizons 1 through 7). The thick conglomerates in the subsurface (Waskahigan, Burnstick, Carrot Creek and Amundson) are represented in outcrop by thin pebble veneers, except at Kananaskis River, where the Amundson conglomerate is about 3 m thick (Walker, 1988, p.11).

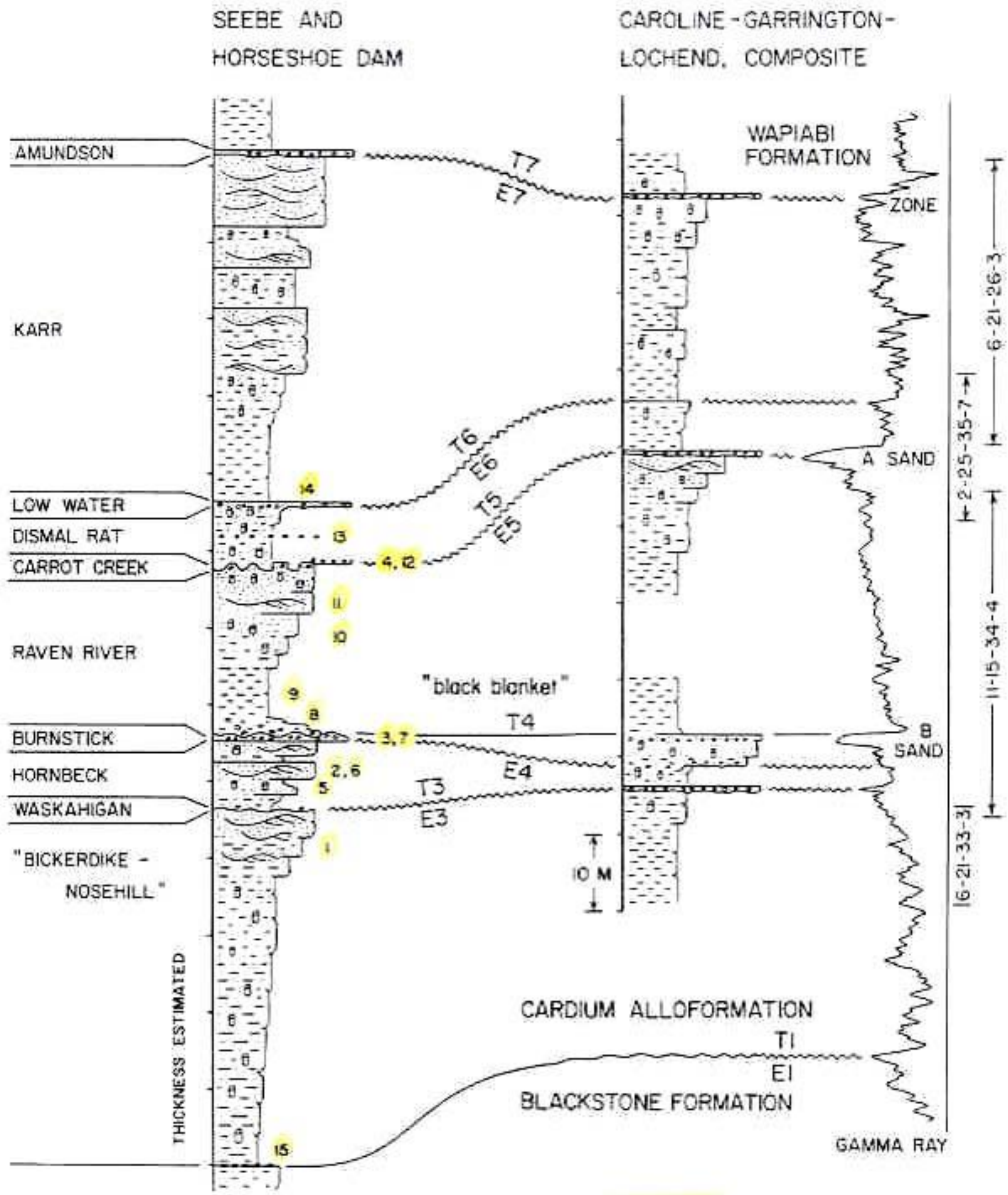


Figure 8: Measured section at Seebe (up to basal Karr Member) and Horseshoe Dam (Karr and Amundson Members; from Wright and Walker 1981), correlated with the closest possible composite subsurface section from the Garrington – Caroline – Lochend area (compiled by Guy Plint from Walker's (1983c) data; Plint et al., 1988). Diagram also shows gamma ray log, with Cardium "zone" log marker, and A and B sands (Walker, 1988, p. 12).

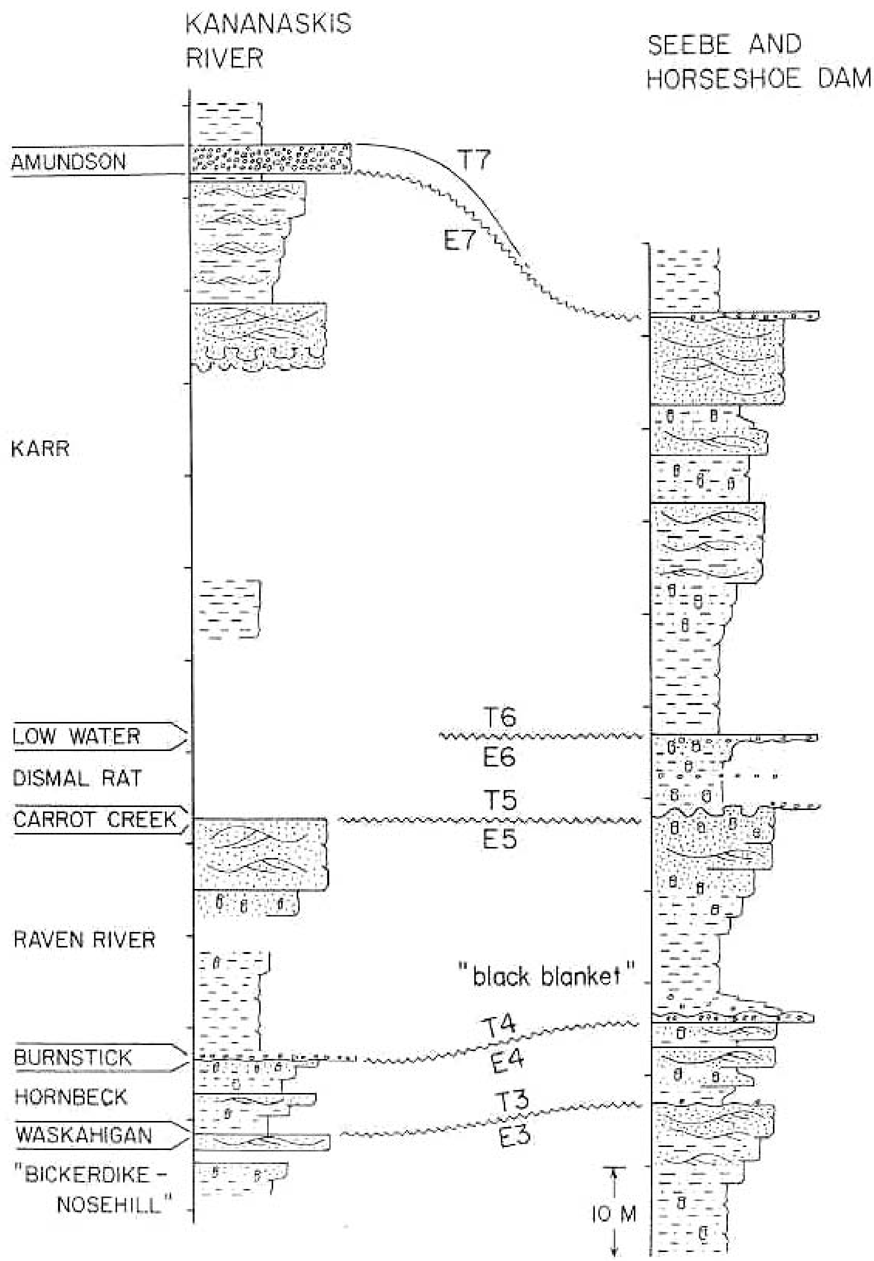


Figure 9: Measured section of the Kananaskis River compared with the section at Seebe. The covered interval in the Karr Member may have been overestimated; deep erosion on surface E7 is not necessarily implied (Walker, 1988, p. 32).

Figure 10: Panoramic photograph taken while standing on E4 at location 02 looking northwest toward Seebe dam. The Hornbeck and Raven River members are visible from this vantage point. Note also that E4 repeats here: Normal fault N6 bisects these two surfaces, causing them to repeat.

Figure 11: Hummocky cross stratification (HCS) in the Raven River Member just east of location 11. This sedimentary structure occurs in the lower shoreface region (below storm weather wave base).

Figure 12: Erosional surface 5 (E5) at location 12. Relief is up to 1.5 m on this surface. The Carrot Creek conglomerate (Cardium A) overlies this surface and is up to 20 m thick in the subsurface. At this location, the Bow River has eroded the conglomerate away, leaving the erosional surface exposed.

Figure 13: Dismal Rat Member at location 13.

Figure 14: Dismal Rat Member in center faulted section and Low Water Member to the left. Location 14.

Figure 15: Panoramic photograph taken just above Horseshoe Dam looking northwest. Immediately behind the dam is the Karr member which has a mudstone base and becomes sandier-upward. Looking at the sandy top of the Karr Member, we see that it dips to the left.

Figure 16: Panoramic photograph taken just below Horseshoe Dam looking northwest.

Figure 17: Amundson member at Kananaskis River. Here the conglomerate is 3 m thick. Note also the sandier-upward sequence in the upper part of the Karr Member.

Figure 18: Close view of the Amundson Member conglomerate at Kananaskis River.

DEPOSITIONAL SEQUENCES AND SEQUENCE BOUNDARIES

Walker (1988) describes the depositional sequences and sequence boundaries as follows:

Nosehill and Bickerdike Members

- Single sandier upward sequence grades from bioturbated mudstones, through HCS sandstones interbedded with bioturbated mudstones into amalgamated HCS sandstones.
- Depositional sequence is interpreted as offshore facies and reflects progradation of the shoreface farther to the southwest.
- The sideritic horizon is probably the disconformity bounded allostratigraphic member of the Cardium Alloformation.
- Location 1 displays this sequence well.

Hornbeck and Burnstick Members

- A progressively sandier-upward sequence which begins with bioturbated mudstones and is overlain by HCS sandstone. The sequence ends with amalgamated HCS sandstones.
- E4 surface is the bounding unconformity which defines the top of the Hornbeck Member.
- E4 is overlain by up to 20 cm of clast-supported conglomerate with symmetrical ripples.
- Conglomerate is stratigraphically equivalent to the Burnstick Member in the subsurface.
- T4 is a transgressive surface and separates the Burnstick Member from the overlying Raven River Member.

Raven River and Carrot Creek Members

- The Raven River comprises an overall sandier-upward sequence, beginning with pebbly mudstones (location 8). The pebbles decrease in quantity upwards for three metres at which point the facies becomes a pebble and sand free non-fissile dark mudstone.
- At location 9 we see the facies grades upward into progressively more and more burrowed and sandier facies. Because of the extent of the burrowing, preserved HCS sandstones are rare at Seebe in the Raven River Member and can only be seen at location 11. In contrast, in the subsurface, HCS dominates the upper part of the Raven River.
- Location 4 displays *Rhizocorallium*, *Zoophycos*, and large horizontal structures. Pemberton and Frey (1983) believe these horizontal burrows were caused by *Thalassinoides*.
- Erosively truncated by E5 (location 12) with 1.5 m of relief and shows a series of “elongate spurs and rounded lumps”. These features are siditerized.
- Pebbles can be seen on the E5 surface at Horseshoe Dam; this veneer is correlative with the Carrot Creek Member in subsurface.
- Overlying transgressive surface T5 is interpreted as erosional.

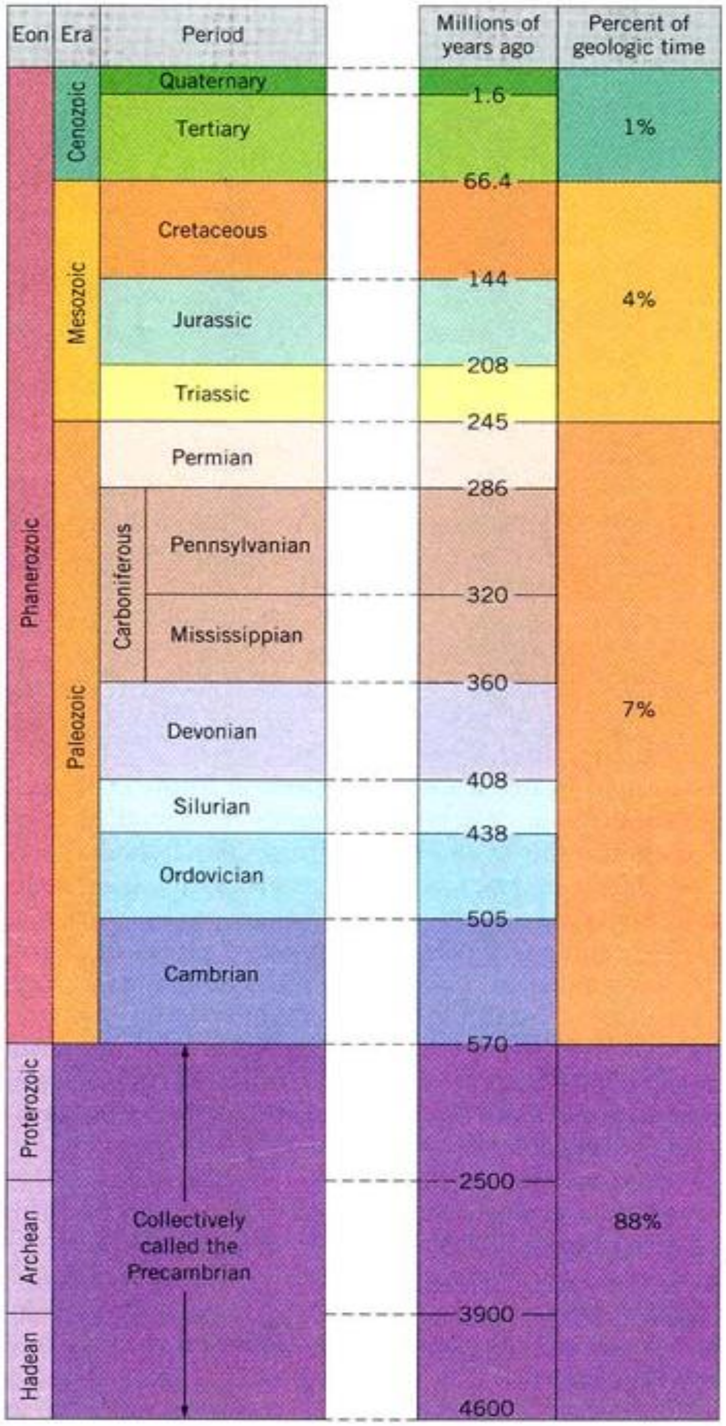
Dismal Rat and Low Water Members

- Dismal Rat Member is thin (6-7 m) and muddy. In the subsurface it is composed of laminated mudstones.
- Low Water Member is faulted down to the west and can be seen at location 14. It consists of dispersed pebbles in a muddy matrix, with many irregularly-shaped siderite nodules.
- Transgressive surface T6 represents the top of the member and is characterized by very dark somewhat fissile mudstones of the Karr Member.

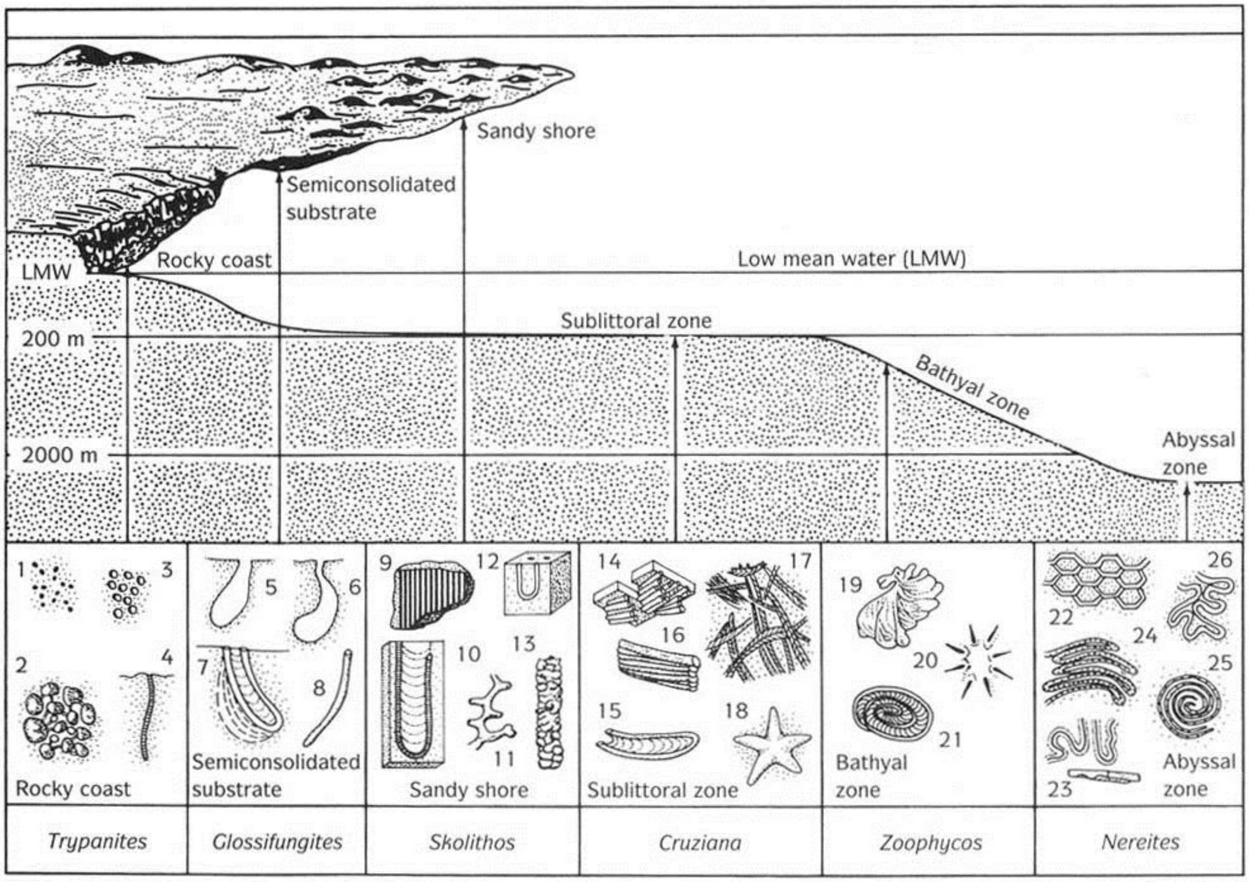
Karr and Amundson Members

- These members do not crop out at Seebe, but can be seen in general view across the river at Horseshoe Dam.
- The sequence coarsens upward from dark mudstones, via prominent, continuous HCS sandstone beds, into amalgamated HCS sandstones.
- At the top of the Karr Member there are no mudstone partings and the facies closely resemble swaley cross stratification (SCS; Leckie and Walker, 1981). McCrory and Walker (1986) indicate that SCS represents a storm-dominated shoreface environment.
- The Amundson Member consists of a veneer of pebbles at Horseshoe Dam, but is 3 m thick at the Kananaskis River outcrop.
- The top of the Karr Member differs at Kananaskis River from Seebe. At Kananaskis River, the Karr contains a 1 m interval of dark mudstone overlain by the Amundson Member.

APPENDIX A: The Geologic Time Scale (Dolgoff, 1996, p. 28).



APPENDIX B: Trace Fossils and Ichnofacies



Summary diagram of the most common trace fossils and ichnofacies. Traces numbered as follows: 1=*Caulostrepsis*; 2=*Entobia*; 3=unamed echinoid borings;4=*Trypanites*; 5-6=*Gastrochaenolites* or related ichnogenera; 7=*Diplocraterion*; 8=*Psilonichnus*; 9=*Skolithos*; 10=*Diplocraterion*; 11=*Thalassinoides*; 12=*Arenicolites*; 13=*Ophiomorpha*; 14=*Phycodes*; 15=*Rhizocorallum*; 16-*Teichichnus*; 17=*Crossopodia*; 18=*Asteriacites*; 19=*Zoophycos*; 20=*Lorenzinia*; 21=*Zoophycos*; 22=*Paleodictyon*; 23=*Taphrhelminthopsis*; 24=*Helminthoida*; 25=*Spirorhaphe*; 26=*Cosmorphe* (Frey & Pemberton. (1984). Trace Fossil Facies Models, in R.G. Walker, ed., Facies Models, pp. 189-207).

APPENDIX C: Glossary

All definitions are from: **Jackson, J. A. & Bates, R. L. (1997). Glossary of Geology Fourth EditionVirginia: American Geological Institute.**

aggradation The building of the Earth's surface by deposition.

alloformation The fundamental allostrigraphic unit.

allomember The formal allostratigraphic unit next in rank below an alloformation.

allostratigraphy Stratigraphy defined and identified on the basis of bounding discontinuities.

anhydrite A mineral consisting of anhydrous calcium sulfate: CaSO4. It represents gypsum without its water of crystallization, and it alters readily to gypsum, from which it differs in crystal form.

anthracite coal Coal of the highest metamorphic rank, in which fixed-carbon content is between 92-98%(on a dry mineral-matter-free basis).

bituminous A sedimentary rock that is naturally impregnated with, contains, or constitutes the source of bitumen.

calcareous shale A shale containing at least 20% calcium carbonate in the form of finely precipitated materials or small organically-fixed particles.

chalk A limestone of marine origin consisting almost wholly (90-99%) of calcite.

clast An individual constituent, grain, or fragment of a sediment or rock, produced by the mechanical or chemical disintegration of a larger rock mass.

coal A readily combustable rock containing more than 50% by weight and more than 70% by volume of carbonaceous material including inherent moisture, formed from compaction and induration of variously altered plant remains similar to those in peat.

discontinuity Any interuption in sedimentation, whatever its cause or length, usually a manifestation of nondeposition and acompanying erosion; an unconformity.

dolomitic limestone A limestone containing 10-50% dolomite and 50-90% calcite and having an approximate magnesium-carbonate equivalent of 4.4-22.7% or a limestone whose Ca/Mg ratio ranges from 4.74-60.

dolostone A carbonate sedimentary rock containing more than 90% dolomite and less than 10% calcite, or having an approximate MgO equivalent of 19.5-21.6% or magnesium-carbonate equivalent of 41.0-45.4%.

downwarp Subsidence of a regional area of the Earth's crust.

emergence A change in the levels of water and land such that the land is relatively higher and areas formerly under water are exposed; it results either from an uplift of the land or a fall of the water level.

eustatic Pertaining to worldwide changes of sea level that affect all the oceans. Eustatic changes may have various causes, but the changes dominant in the past few million years were caused by additions of water to, or removal of water from, the continental icecaps.

facies A distinctive rock type, broadly corresponding to a certain environment or mode of origin.

foreland The exterior area of an orogenic belt where deformation occurs without significant metamorphism. Generally the foreland is closer to the continental interior than other portions of the orogenic belt.

foreland basin A linear sedimentary basin at a forland.

friable A rock or mineral that crumbles naturally, or is easily broken.

geosyncline A mobile downwarping of the crust of the Earth, either elongate or basinlike, measured in scores of kilometres, in which sedimentary and volcanic rocks accumulate to thicknesses of thousands of metres.

hummocky cross stratification (HCS) A type of cross stratification in which lower bounding surfaces of sets are erosional and commonly slope at angles less than 10^{o}; though dips can reach 15^{o}; laminae above above these erosional set boundaries are parallel to that surface or nearly so; the hummocks range in scale from 1 – 5 m in wavelength. It is thought to be formed by storm-wave surges on the shoreface.

incision The process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley.

limestone A carbonate sedimentary rock containing more than 95% calcite and less than 5% dolomite. Common minor constituents include silica (chalcedony), feldspar, clays, pyrite, and siderite.

nodule A small, irregularly rounded knot, mass, or lump of a mineral or mineral aggregate, normally having a warty or knobby surface and no internal structur, and usually exibiting a contrasting composition from the enclosing sediment or rock matrix in which it is embedded.

progradation Outward or basinward building of a shoreline occuring when the rate of sediment supply at the shoreline exceeds the rate of relative rise in sea level.

regression The retreat or contraction of the sea from land areas, and the consequent evidence of such withdrawl (such as enlargement of the area of deltaic deposition).

sandstone A medium-grained (1/16 mm < medium-grained < 2 mm) clastic sedimentary rock composed of abundant rounded or angular fragments of sand size with or without a fine grained matrix (silt or clay) and more or less firmly united by a cementing material (commonly silica, iron oxide, or calcium carbonate). The sand particles are predominantly quartz and the term sandstone when used without qualification, indicates a rock containing about 85-90% quartz.

sandy shale A shale with a higher percentage of sand / medium-grained clasts (33-50%).

shale A laminated, indurated rock with > 67% clay-sized (<= 1/256 mm) minerals.

shaly sand A sandstone with a higher percentage of shale / clay-sized matrix (15-50%).

siltstone An indurated silt having the texture and composition of shale but lacking its fine lamination or fissility. At least two thirds is material of silt size (1/256mm < silt size < 1/16 mm).

tectonic A branch of geology dealing with the broad architecture of the outer part of the Earth, that is, the regional assembling of structural or deformational features, a study of their mutual relation, origin, and historical evolution.

transgression The spread or extension of the sea over land areas, and the consequent evidence of such advance (such as strata deposited unconformably on older rocks).

transgressive lag A sedimentary deposit, commonly less than 2 ft. thick, of relatively coarse-grained material composed of shells, shell fragments, clay rip-up clasts, calcareous nodules, siliciclastic gravel or pebbles. This material derives from underlying strata by shoreface erosion during a marine transgression.

winnowing The selective sorting, or removal, of fine particles by wind action, leaving the coarser grains behind. The term is often applied to removal by or sorting in water, but the term washing is more appropriate.

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