A Revised Stratigraphic Architecture and History for the Horseshoe Canyon Formation (Upper Cretaceous), Southern Alberta Plains*

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Abstract

A revised stratigraphy for the paralic-to-continental Horseshoe Canyon Formation (265 m thick; Upper Cretaceous; Alberta plains) highlights the varying influences of changes in relative sea level, tectonism, and climate. Five units are recognized:

- Unit 1: marine-to-nonmarine transitions; very coaly; east-west cross sections below a bentonite datum are tabular and thicken weakly to the west; cross-sections above the datum are strongly wedge-shaped, and thicken to the west, indicating an increase in sediment supply and subsidence.
- Unit 2: reduced bed thicknesses; marine transgression; evidence for a seasonally dry climate. These features indicate a rise in sea level coincident with a reduction in both sediment supply and accommodation, and an absolute reduction in subsidence.
- Unit 3: stacked shoreline sandstones and alluvial sandstones ubiquitously cemented with iron carbonate, suggestive of a highstand systems tract.
- Unit 4: non-coaly; subequal paleochannel-overbank representation; non-amalgamated channel deposits; coarse-grained volcanic ash; These features indicate resurgent tectonic activity with increased sediment supply to the plains.
- Unit 5: two coal zones; multistoried fine-to-medium grained alluvial sandstone bodies with localized lags of extraformational pebbles. These features suggest foredeep rebound, a return to a wetter regional climate, and decreasing accommodation in the plains.

Conclusions:
1) A newly recognized bentonite-rich zone in Unit 1 serves as an effective stratigraphic datum in the plains region.
2) Decreasing rates of subsidence in Unit 2 are most likely due to a forebulge rise in response to overthrusting and mountain building, which requires the transgressive event to be interpreted as a global-eustatic rise in sea level.
3) The co-occurrence in Unit 2 of seasonal dryness and tectonic uplift suggests that climate change was driven by regional uplift and a rain-shadow effect.

4) Although three sandstone-rich zones may have hydrocarbon potential (top of Unit 1, Unit 3, and Unit 5), Unit 5 has the best potential for exploitation.

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ROYAL TYRRELL MUSEUM

- coal
- coal bed methane
- variety of fossils
- superb outcrop geology (e.g., Drumheller)

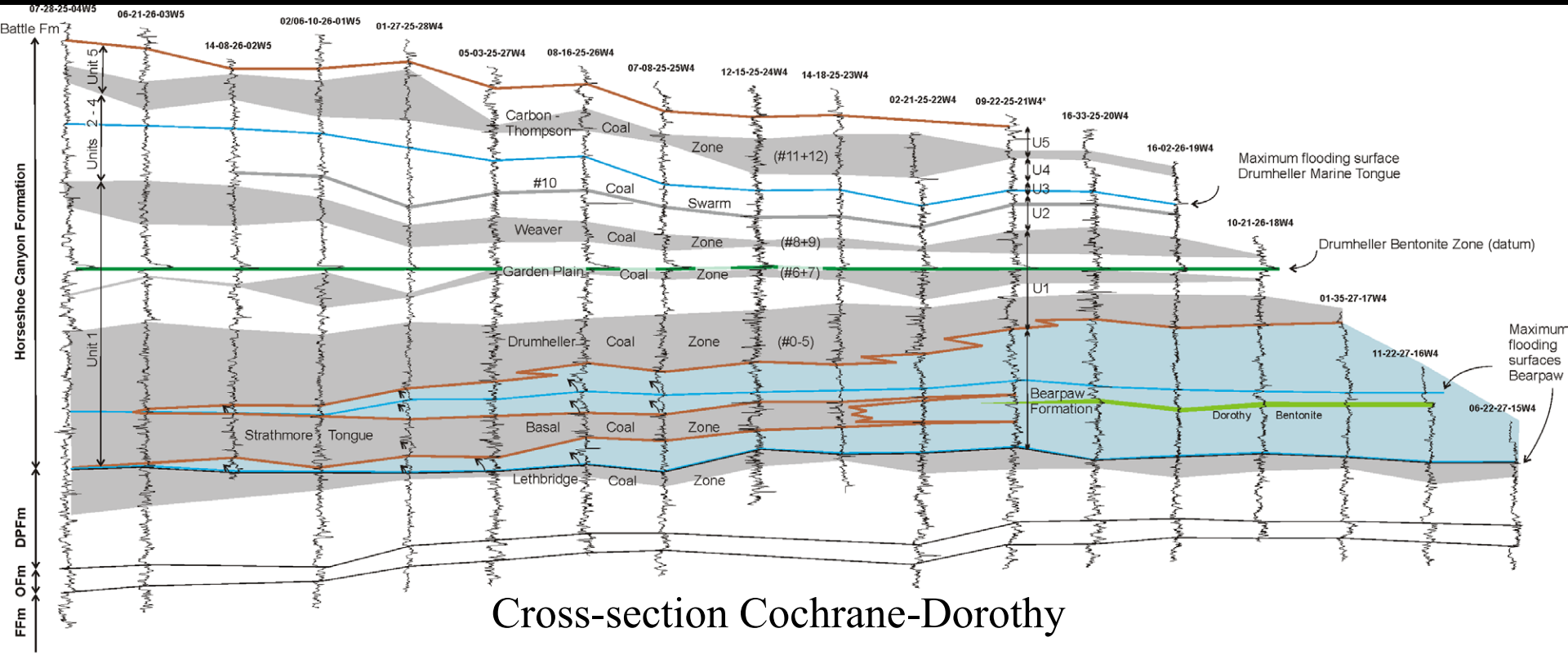
Wapiti Fm

Horseshoe Canyon Fm bedrock

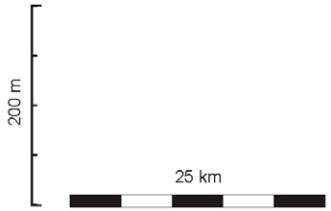
St Mary River Fm

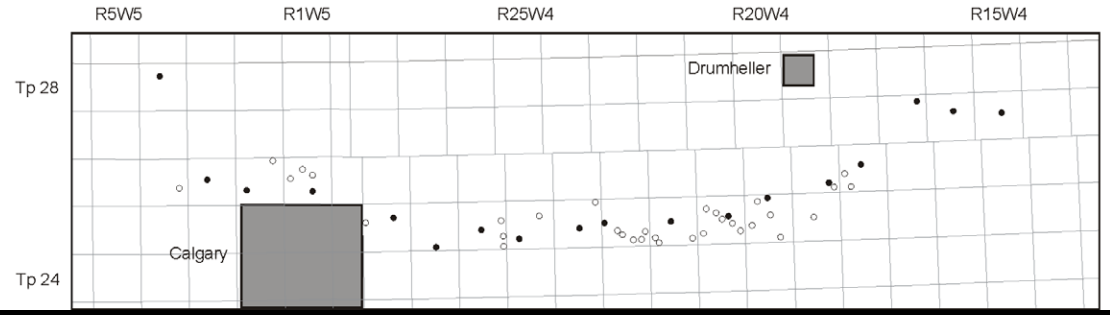
Jerzykiewicz & Sweet 1988; Nadon 1988; Fanti & Catuneanu 2010

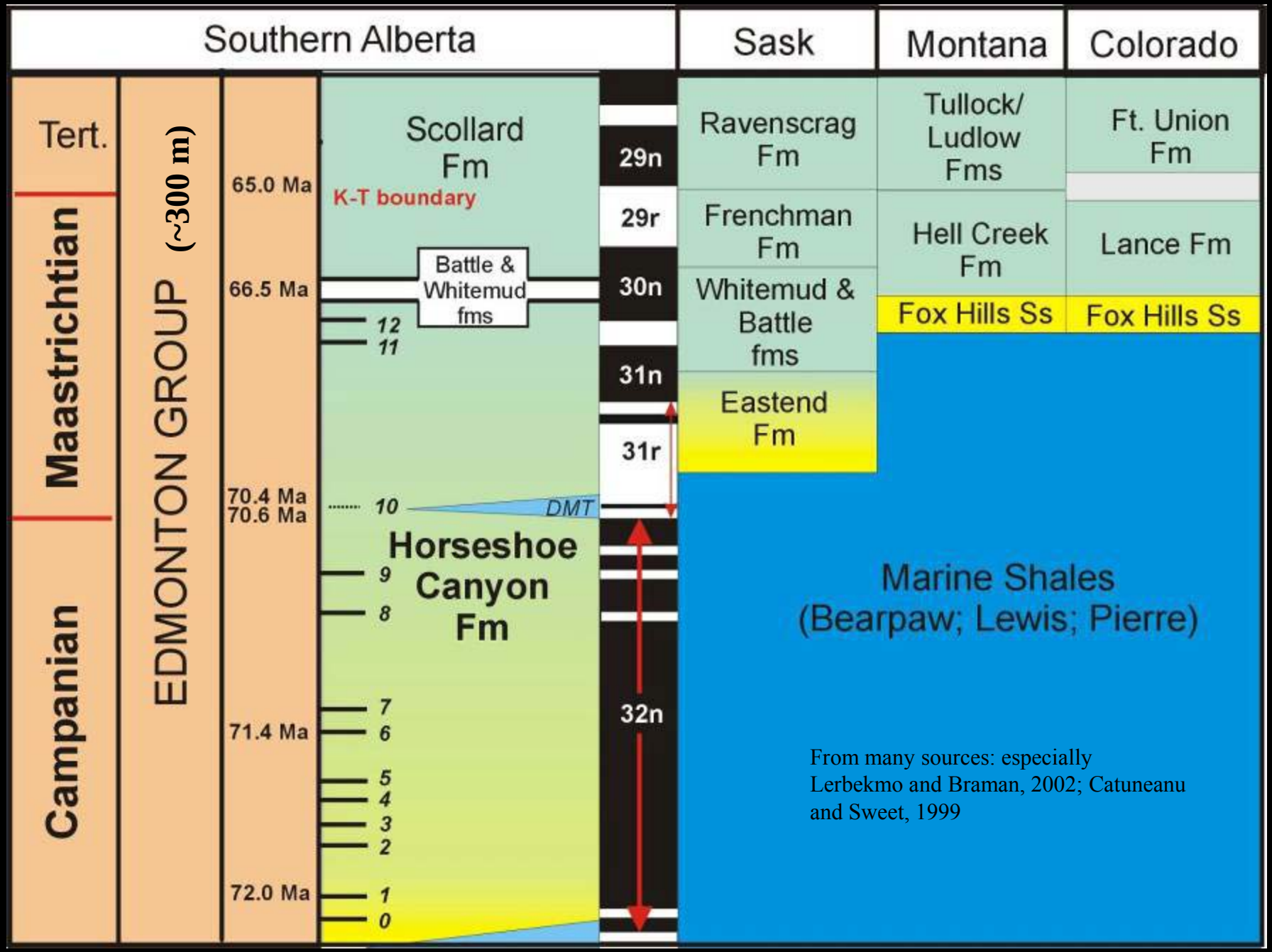
- Overall regressive unit (3rd order) above the Bearpaw/Belly River
- Records the onset of the withdrawal of Western Interior Seaway



Cross-section Cochrane-Dorothy






Southern Alberta
Sask
Montana
Colorado
Tert.
Maastrichtian
Campanian
EDMONTON GROUP (~300 m)
65.0 Ma
66.5 Ma
70.4 Ma
70.6 Ma
71.4 Ma
72.0 Ma
Scollard Fm
K-T boundary
Battle & Whitemud fms
12
11
10
DMT
Horseshoe Canyon Fm
9
8
7
6
5
4
3
2
1
0
29n
29r
30n
31n
31r
32n
Ravenscrag Fm
Frenchman Fm
Whitemud & Battle fms
Eastend Fm
Tullock/ Ludlow Fms
Hell Creek Fm
Fox Hills Ss
Ft. Union Fm
Lance Fm
Fox Hills Ss
Marine Shales (Bearpaw; Lewis; Pierre)
From many sources: especially Lerbekmo and Braman, 2002; Catuneanu and Sweet, 1999

Stratigraphy, depositional history, and architecture are mostly understood in the context of "downstream" influences (changes in relative sea level)

"Upstream" influences (tectonics and climate) poorly understood/documented.

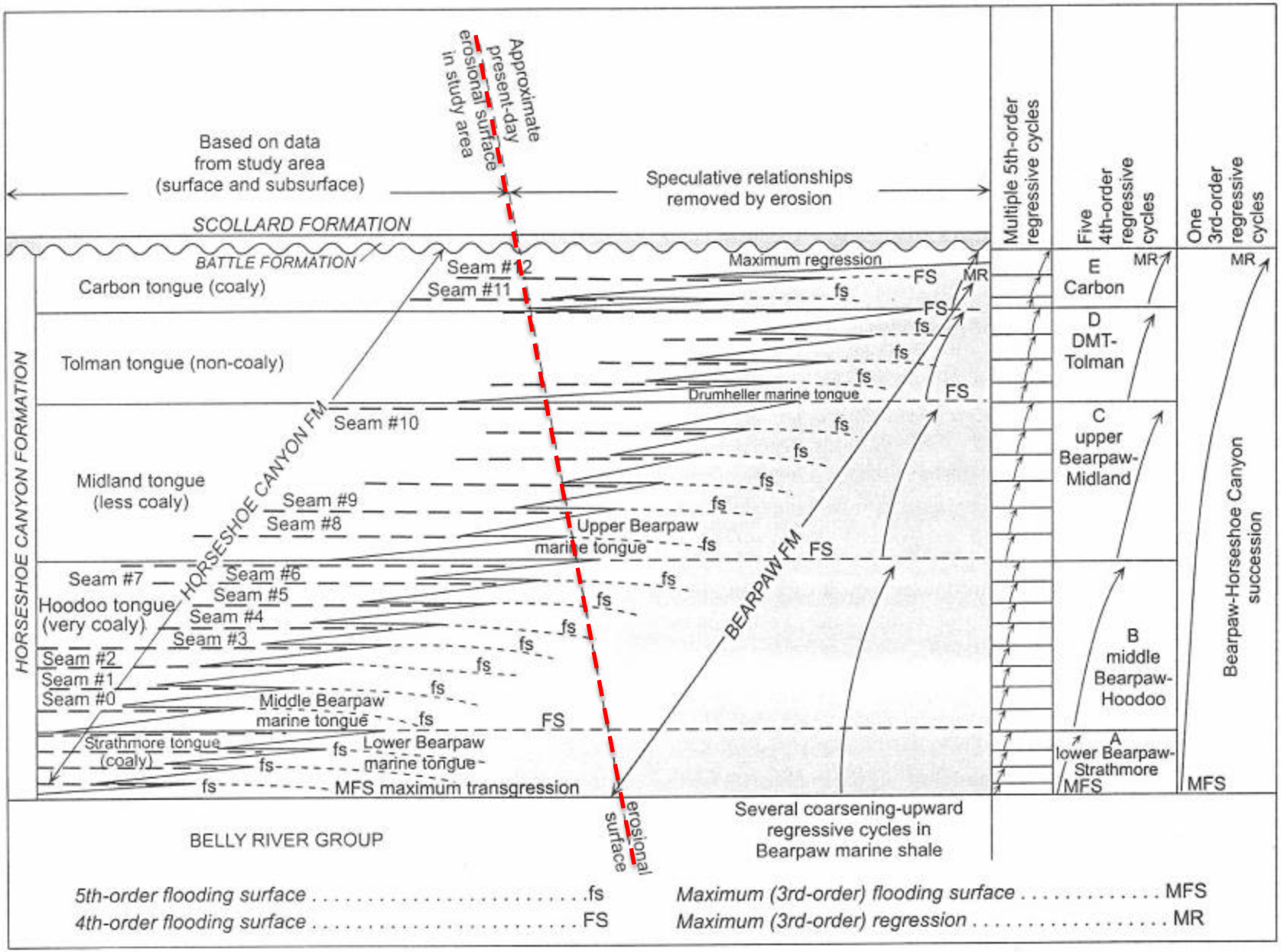


Figure 80. *Schematic conceptual northwest-southeast cross-section of Bearpaw Formation-Horseshoe Canyon Formation depositional system, illustrating stratigraphic architecture and interpretive framework, and relation of coal seams to multiple transgressions in south-central Alberta.* From Hamblin (2004)

Purpose of talk: make a case for "upstream" influences

Evaluate/frame the evidence in terms of

a) the classic 2-phase foreland basin model (e.g., Heller et al. 1988; Eberth and Hamblin 1993; Heller and Paola, 1996; Catuneanu and Sweet, 1999)

b) basic "accommodation" concepts (Shanley and McCabe 1994; Catuneanu 2006; Fanti and Catuneanu 2010)

Compiled:

16 measured sections (Drumheller area)

~200 well logs (T52 - south)

Examined/Utilized

- Coals
- Lithostratigraphy
- Grain sizes
- Ss/mudstone ratios
- Paleochannel size & architecture
- Ss stacking patterns
- Volcanic ashes
- Climate indicators (e.g., paleosols; vertebrates; plants)
- Marine/nonmarine seq strat concepts
- Foreland basin modeling concepts

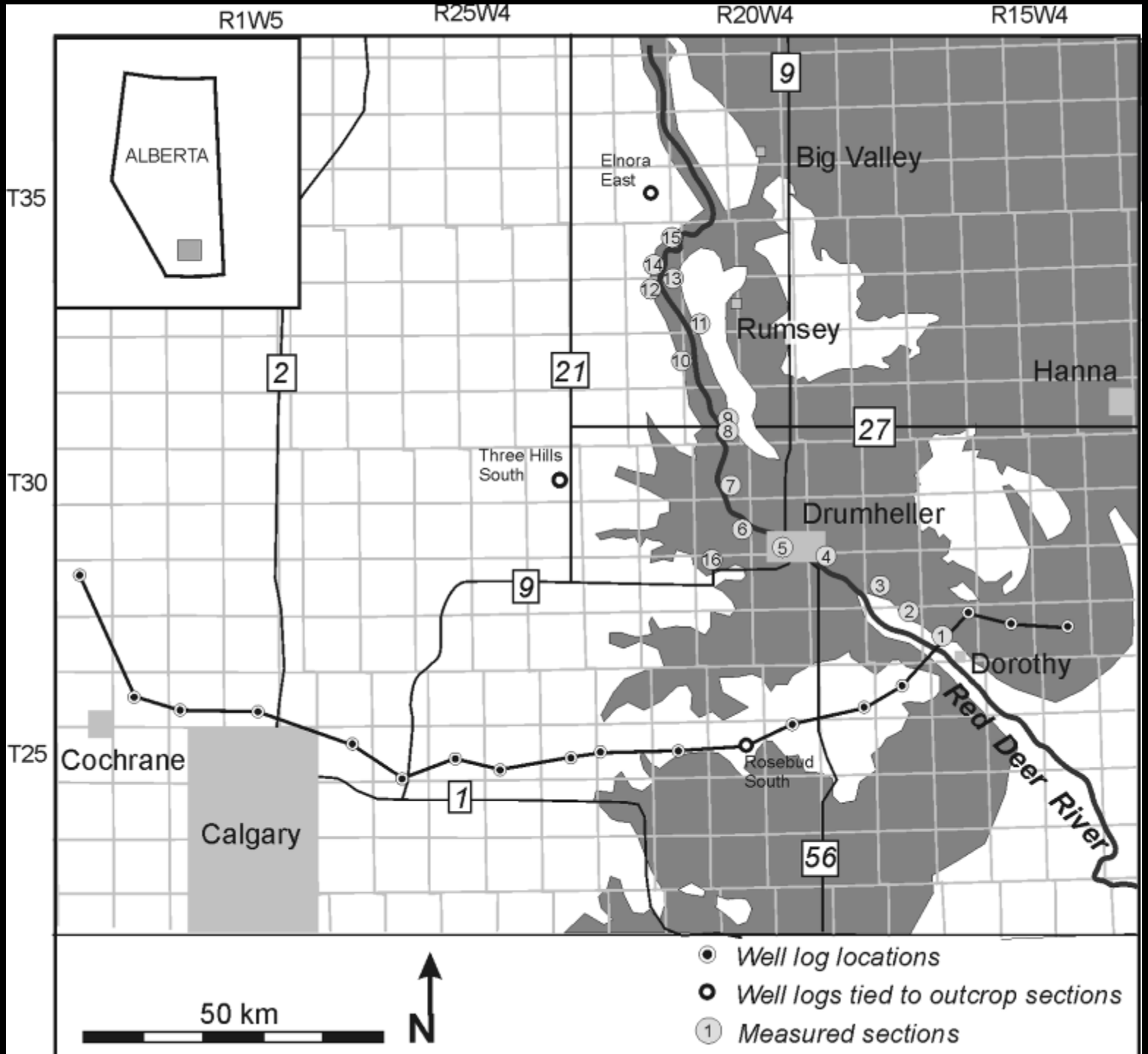
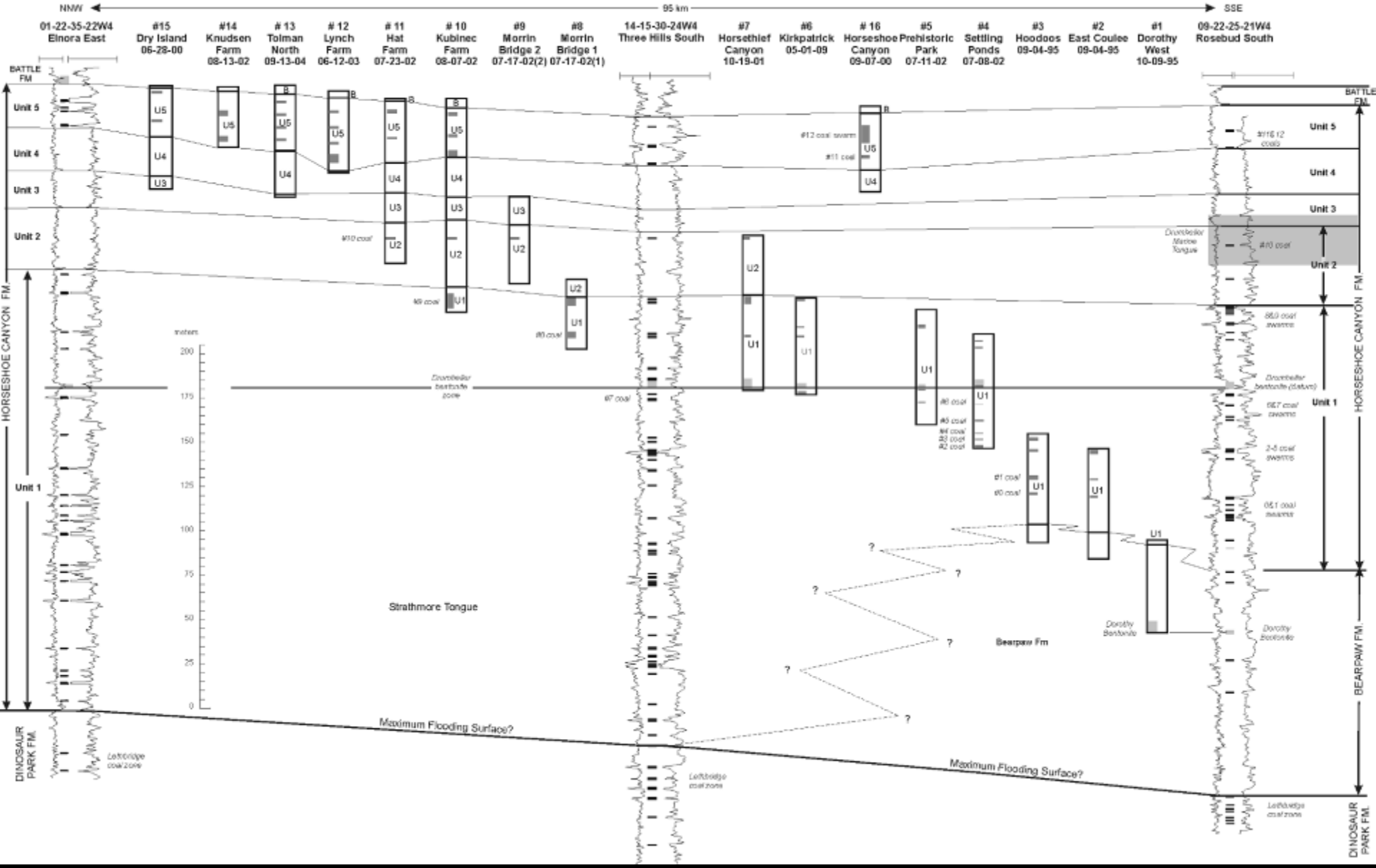
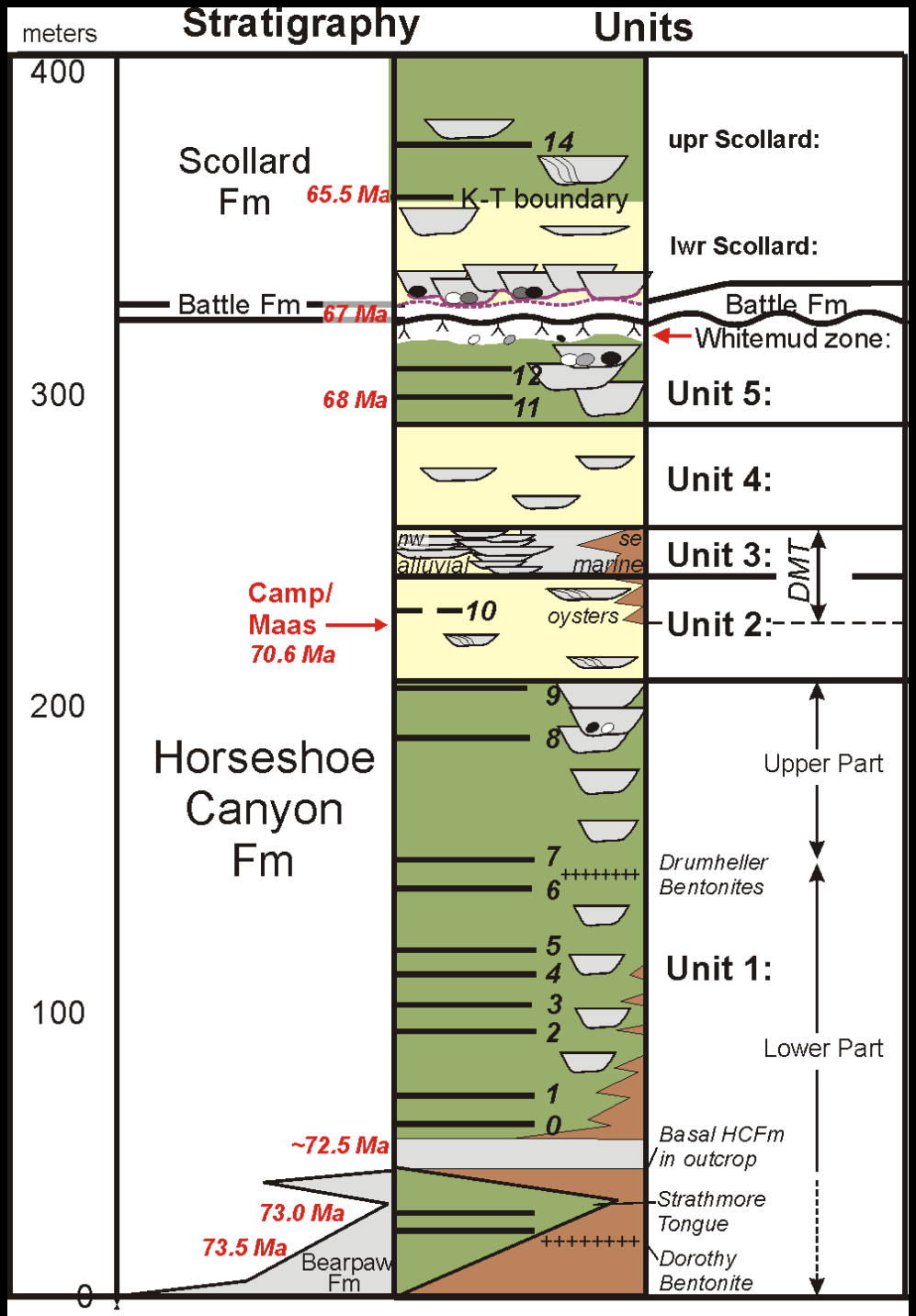

R1W5
R25W4
R20W4
R15W4
ALBERTA
T35
T30
T25
9
Big Valley
Elnora East
15
14
13
12
11
Rumsey
10
Hanna
2
21
27
9
8
Three Hills South
7
Drumheller
6
5
4
16
3
2
1
Dorothy
Red Deer River
Cochrane
Rosebud South
1
Calgary
56
50 km
N
Well log locations
Well logs tied to outcrop sections
Measured sections

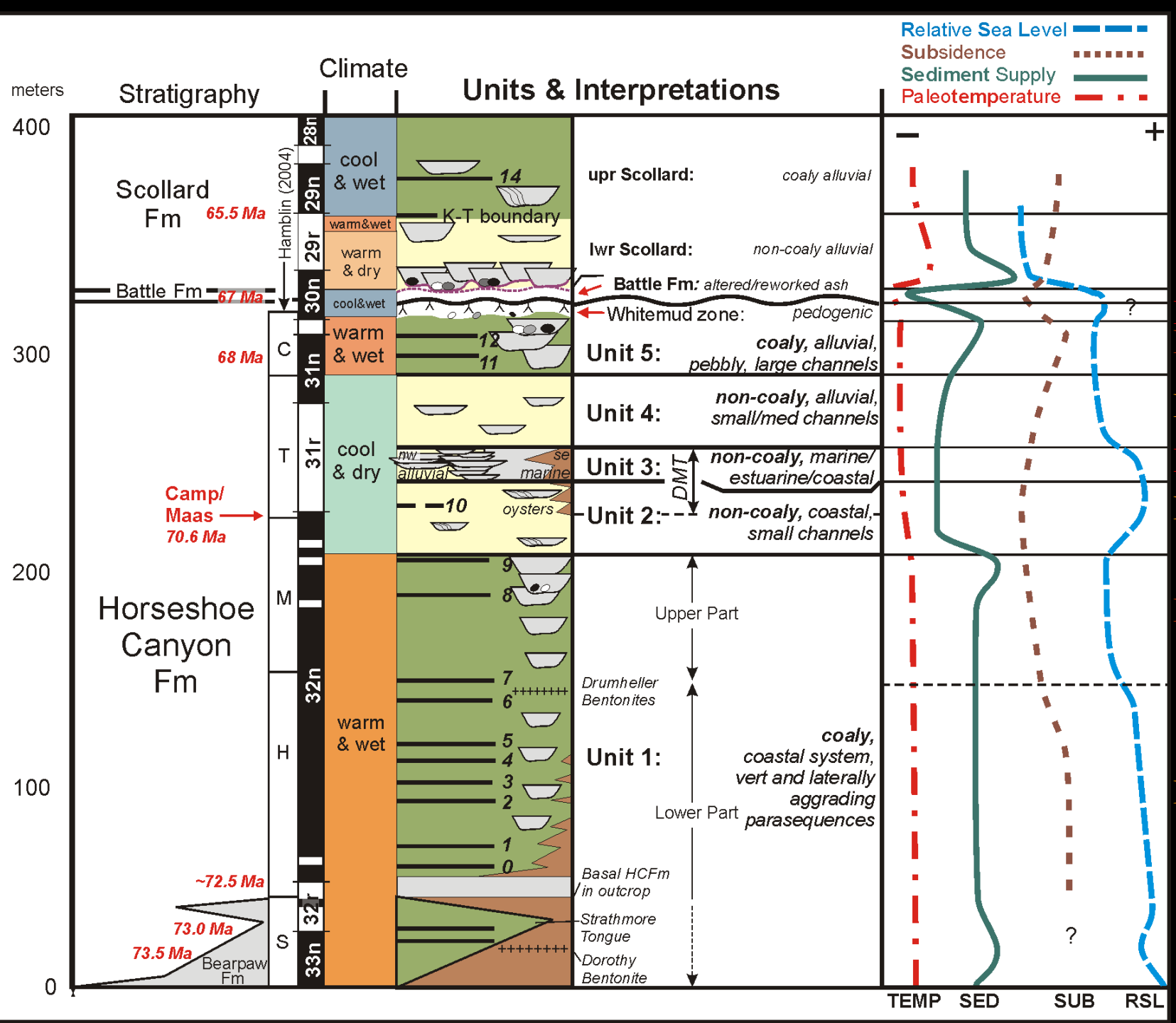
Figure 2


NNW
95 km
SSE
01-22-35-22W4 Elnora East
#15 Dry Island 06-28-00
#14 Knudsen Farm 08-13-02
13 Tolman North 09-13-04
12 Lynch Farm 06-12-03
11 Hat Farm 07-23-02
10 Kubinec Farm 08-07-02
#9 Morrin Bridge 2 07-17-02(2)
#8 Morrin Bridge 1 07-17-02(1)
14-15-30-24W4 Three Hills South
#7 Horsethief Canyon 10-19-01
#6 Kirkpatrick 05-01-09
16 Horseshoe Canyon 09-07-00
#5 Prehistoric Park 07-11-02
#4 Settling Ponds 07-08-02
#3 Hoodoos 09-04-95
#2 East Coulee 09-04-95
#1 Dorothy West 10-09-95
09-22-25-21W4 Rosebud South
BATTLE FM
Unit 5
Unit 4
Unit 3
Unit 2
Unit 1
HORSESHOE CANYON FM
BEARPAW FM
DINOSAUR PARK FM.
Drumheller bentonite zone
Drumheller Marine Tongue
Strathmore Tongue
Bearpaw Fm
Dorothy Bentonite
Maximum Flooding Surface?
Lethbridge coal zone
#10 coal
#9 coal
#8 coal
#7 coal
#6 coal
#5 coal
#4 coal
#3 coal
#2 coal
#1 coal
#0 coal
#12 coal swarm
#11 coal
#16 12 coals
88.0 coal swarm
88.7 coal swarm
2-5 coal swarms
85.1 coal swarm
meters
200
175
150
125
100
75
50
25
0

Conclusions

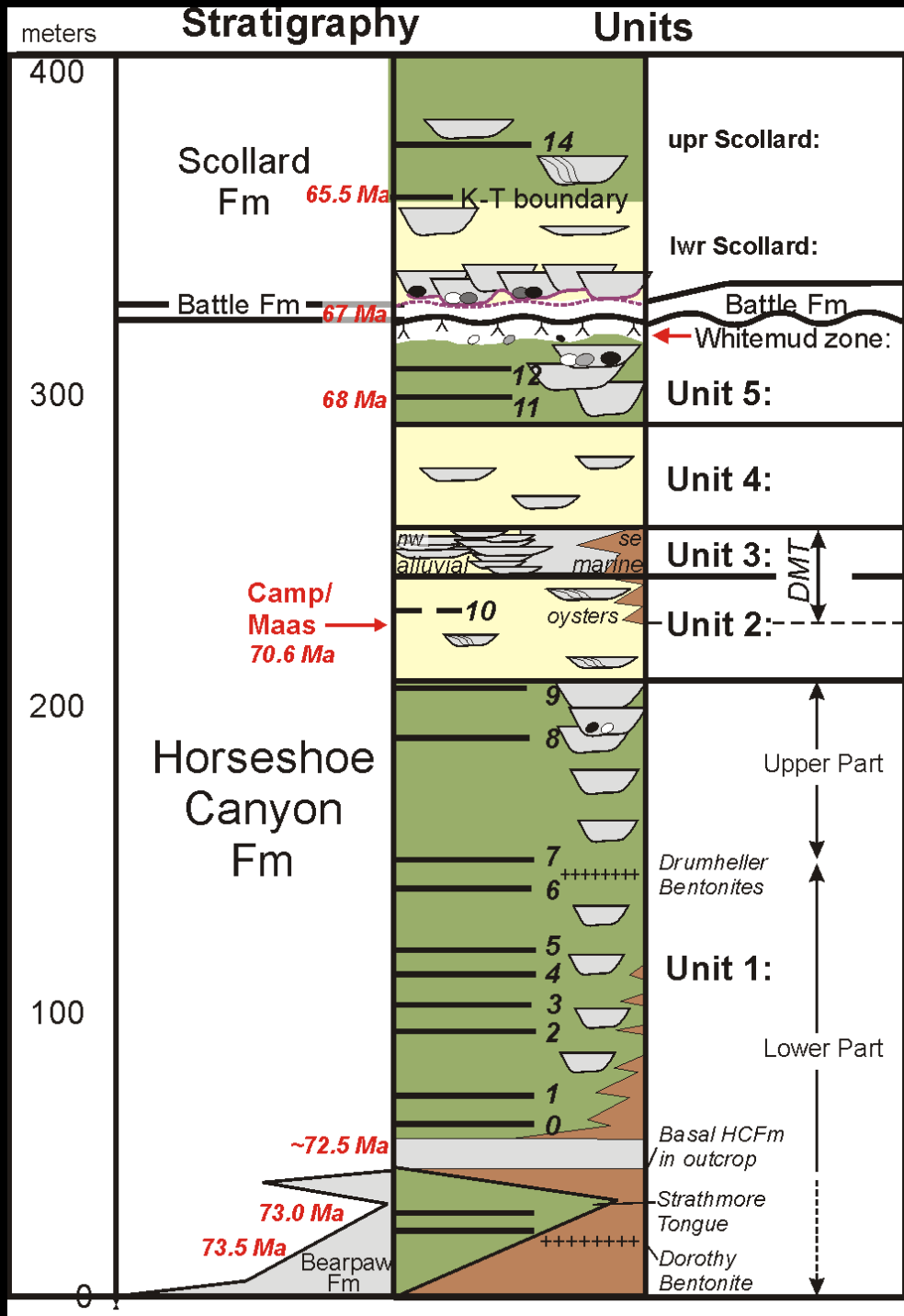
- 5 definable and mappable lithostratigraphic "units"
- each includes evidence for varying degrees of upstream influences
- upstream influences increase (become more obvious) upsection
- considerations of resource potential (especially upsection) should include evaluations of upstream influences




meters
Stratigraphy
Climate
Units & Interpretations
Relative Sea Level
Subsidence
Sediment Supply
Paleotemperature
400
300
200
100
0
Scollard Fm
65.5 Ma
Hamblin (2004)
Battle Fm
67 Ma
68 Ma
Camp/ Maas
70.6 Ma
Horseshoe Canyon Fm
~72.5 Ma
73.0 Ma
73.5 Ma
Bearpaw Fm
28n
29n
29r
30n
31n
31r
32n
32r
33n
C
T
M
H
S
cool & wet
warm&wet
warm & dry
cool&wet
warm & wet
cool & dry
warm & wet
K-T boundary
nw alluvial
se marine
oysters
upr Scollard: coaly alluvial
lwr Scollard: non-coaly alluvial
Battle Fm: altered/reworked ash
Whitemud zone: pedogenic
Unit 5: coaly, alluvial, pebbly, large channels
Unit 4: non-coaly, alluvial, small/med channels
Unit 3: non-coaly, marine/ estuarine/coastal
DMT
Unit 2: non-coaly, coastal,- small channels
Upper Part
Drumheller Bentonites
Unit 1: coaly, coastal system, vert and laterally aggrading parasequences
Lower Part
Basal HCFm in outcrop
Strathmore Tongue
Dorothy Bentonite
TEMP
SED
SUB
RSL
Relative Accom.
Low
Mod-Low
Mod
Low
Mod
Mod-Low
Mod

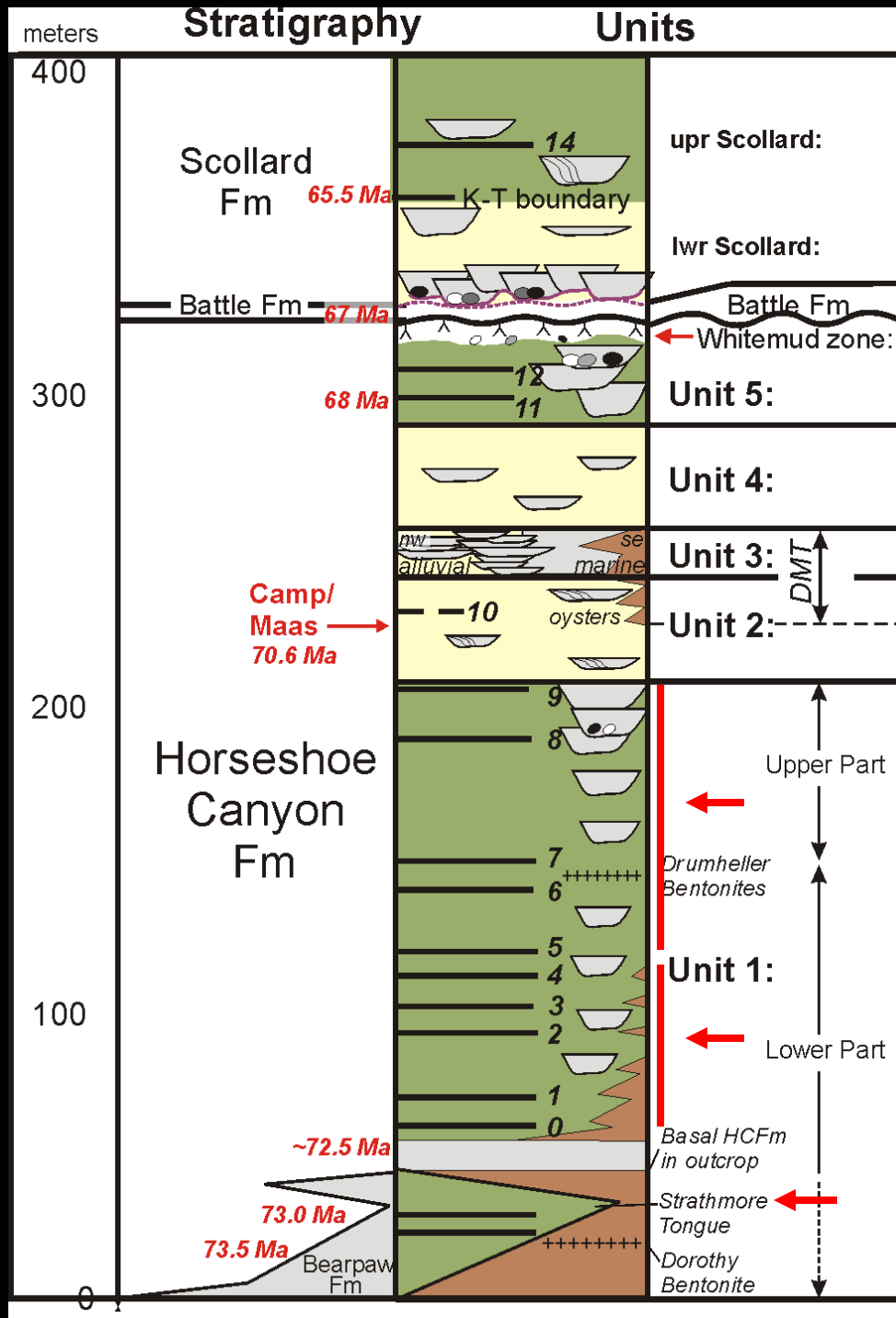
Unit 1: Notable Features

- 3 discrete intervals different geometries
- volcanic ash horizon: Drumheller bentonite zone
- thick, abundant, coarser paleochannels at top of Unit 1

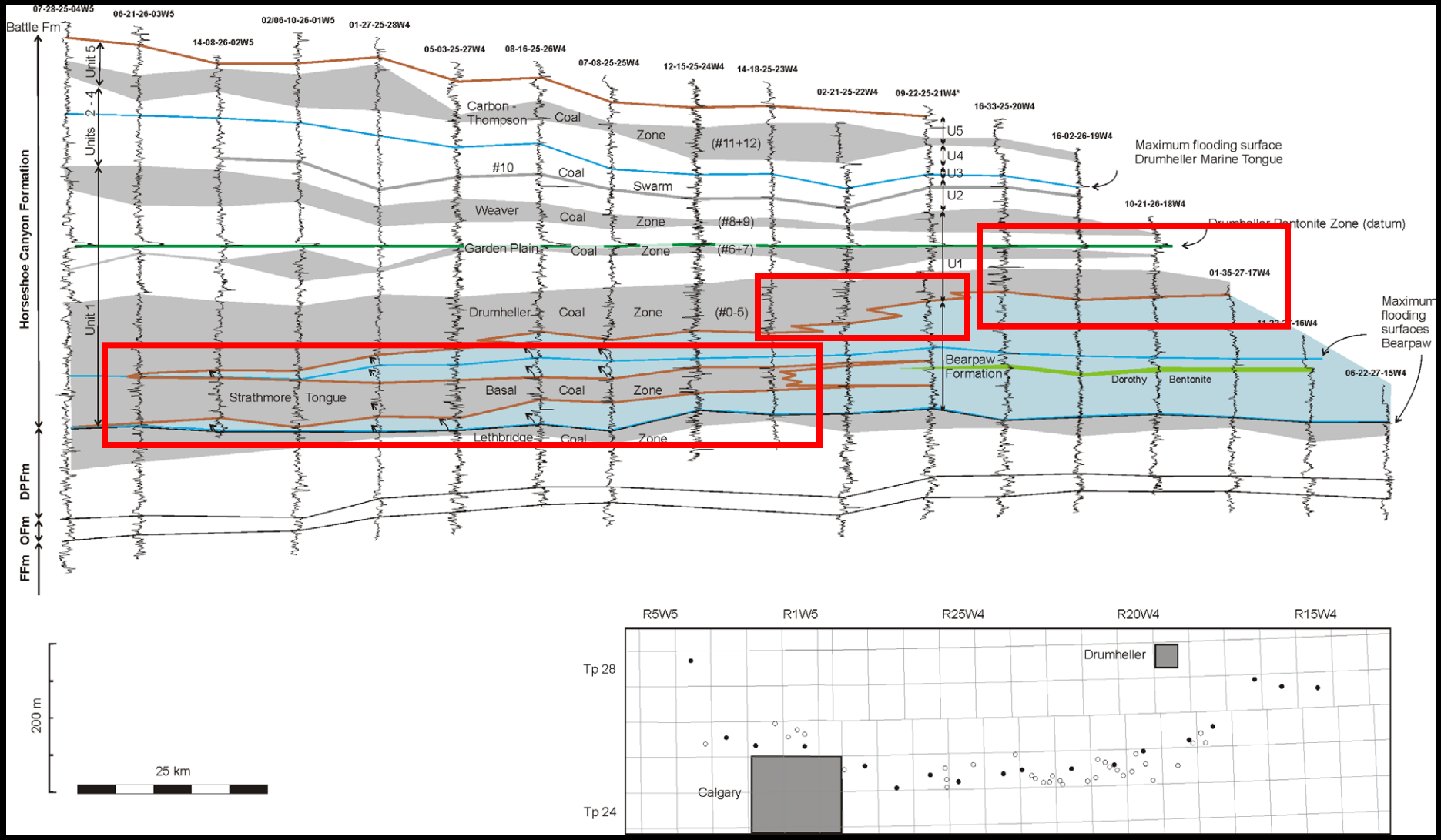


Unit 1: Notable Features

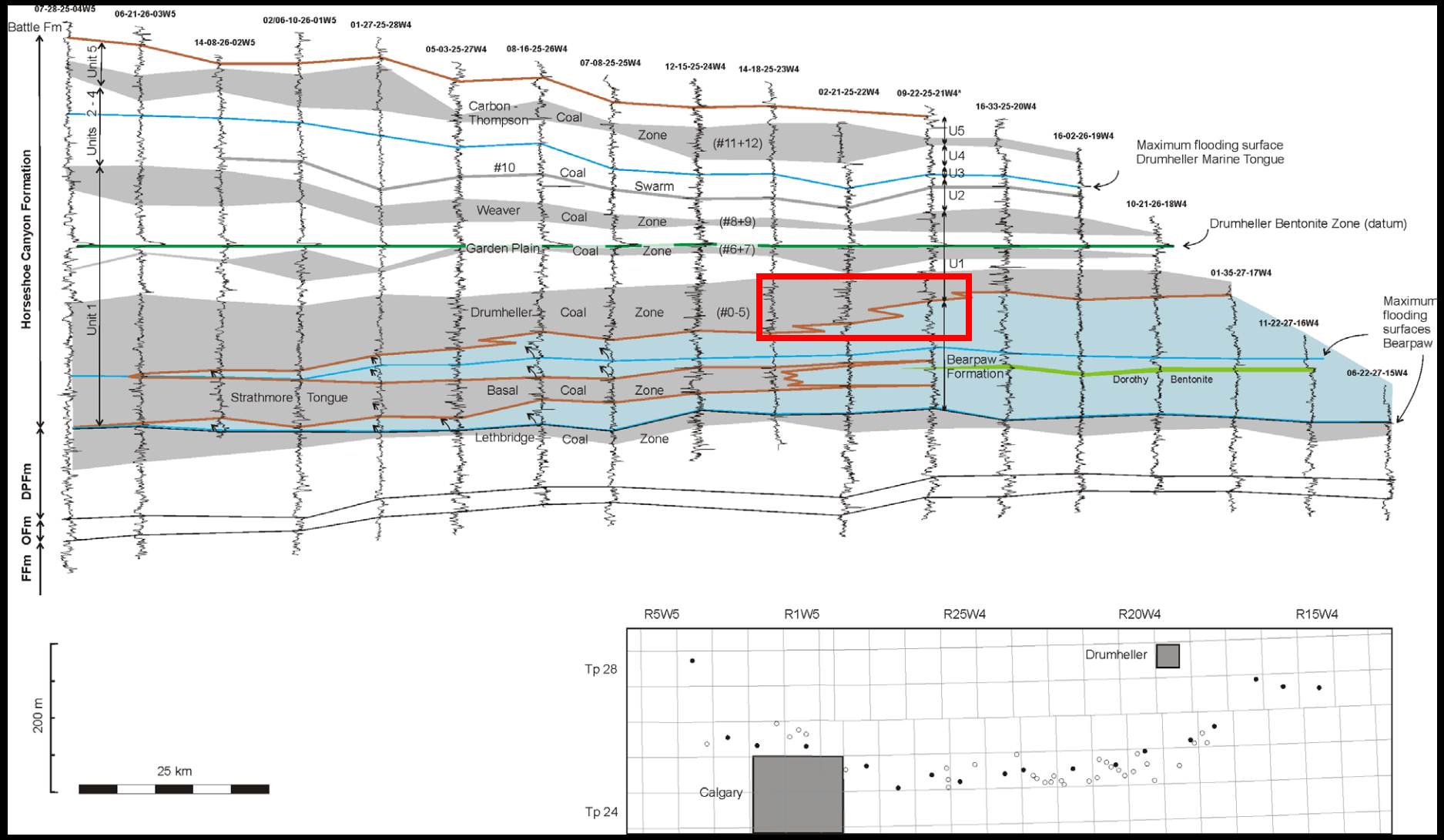
- 3 discrete intervals different geometries
  - ✓ strathmore tongue (R/T; Hamblin 2004)
  - ✓ vertical aggradation (#0-4 coals)
  - ✓ significant progradation (#5-9 coals)



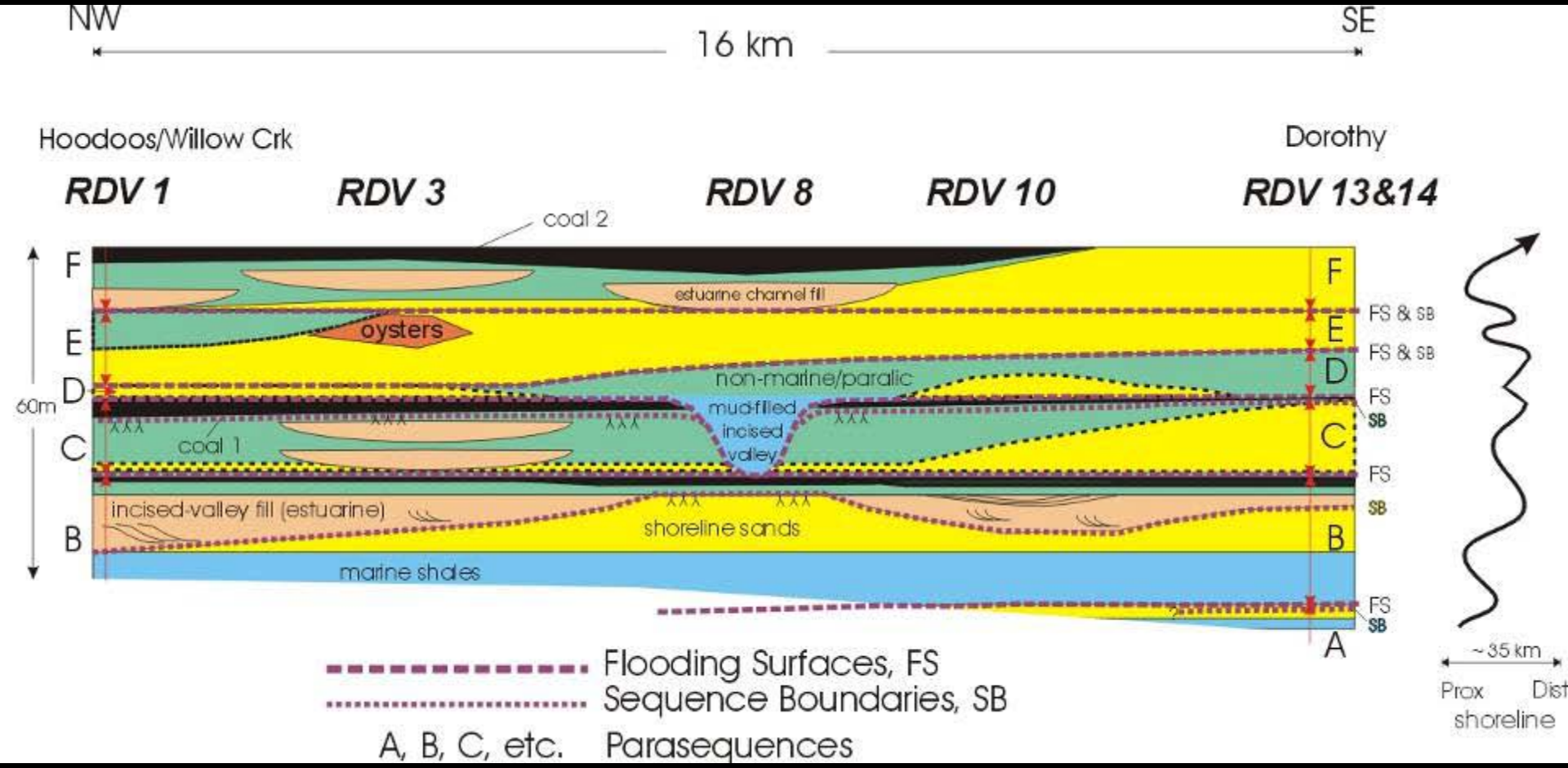
Cross-section Cochrane-Dorothy



vertically aggrading portion (#0-4 coal swarms)

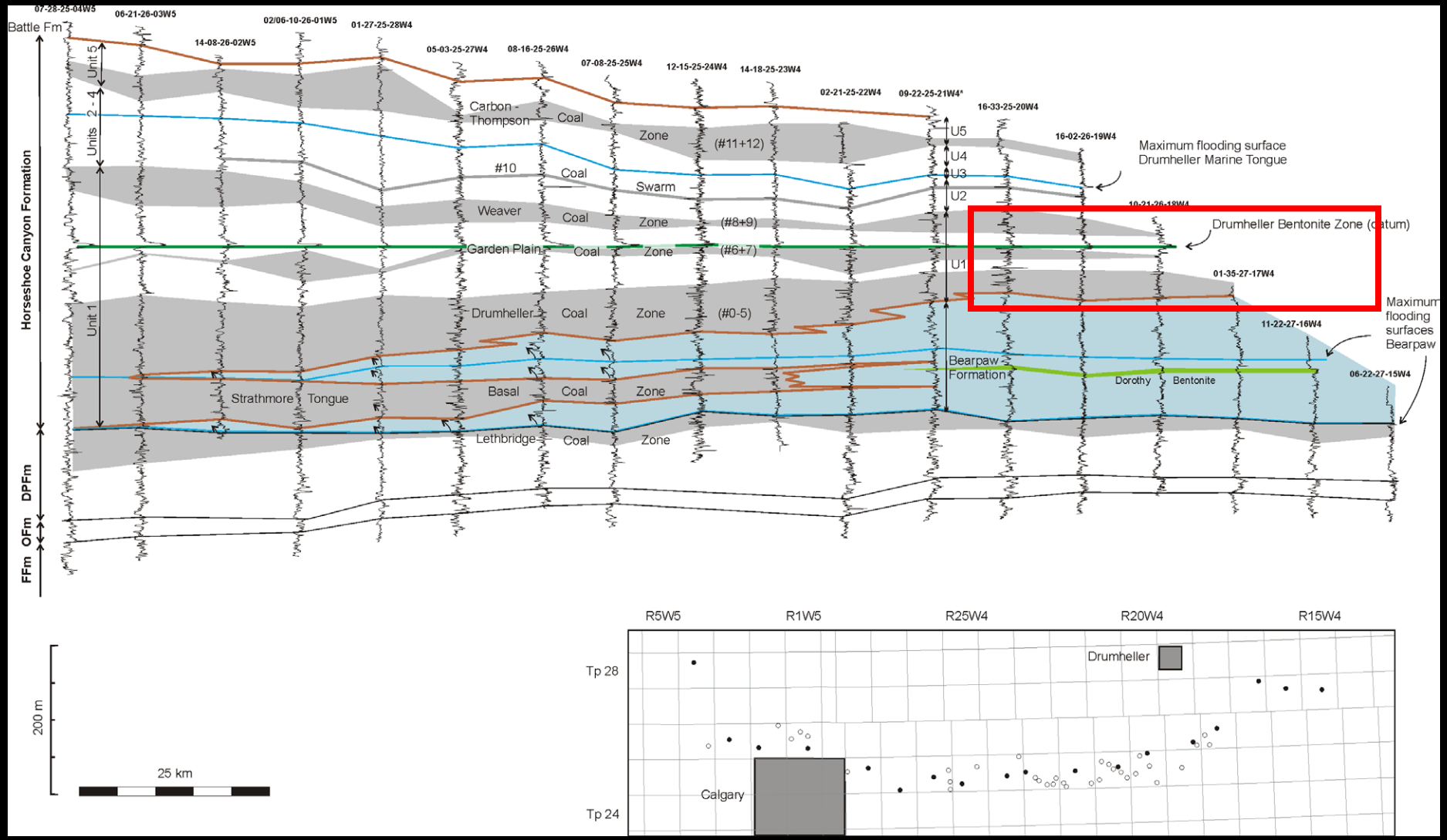


NW-SE migrating shorelines, coal swarms 0-2, Unit 1

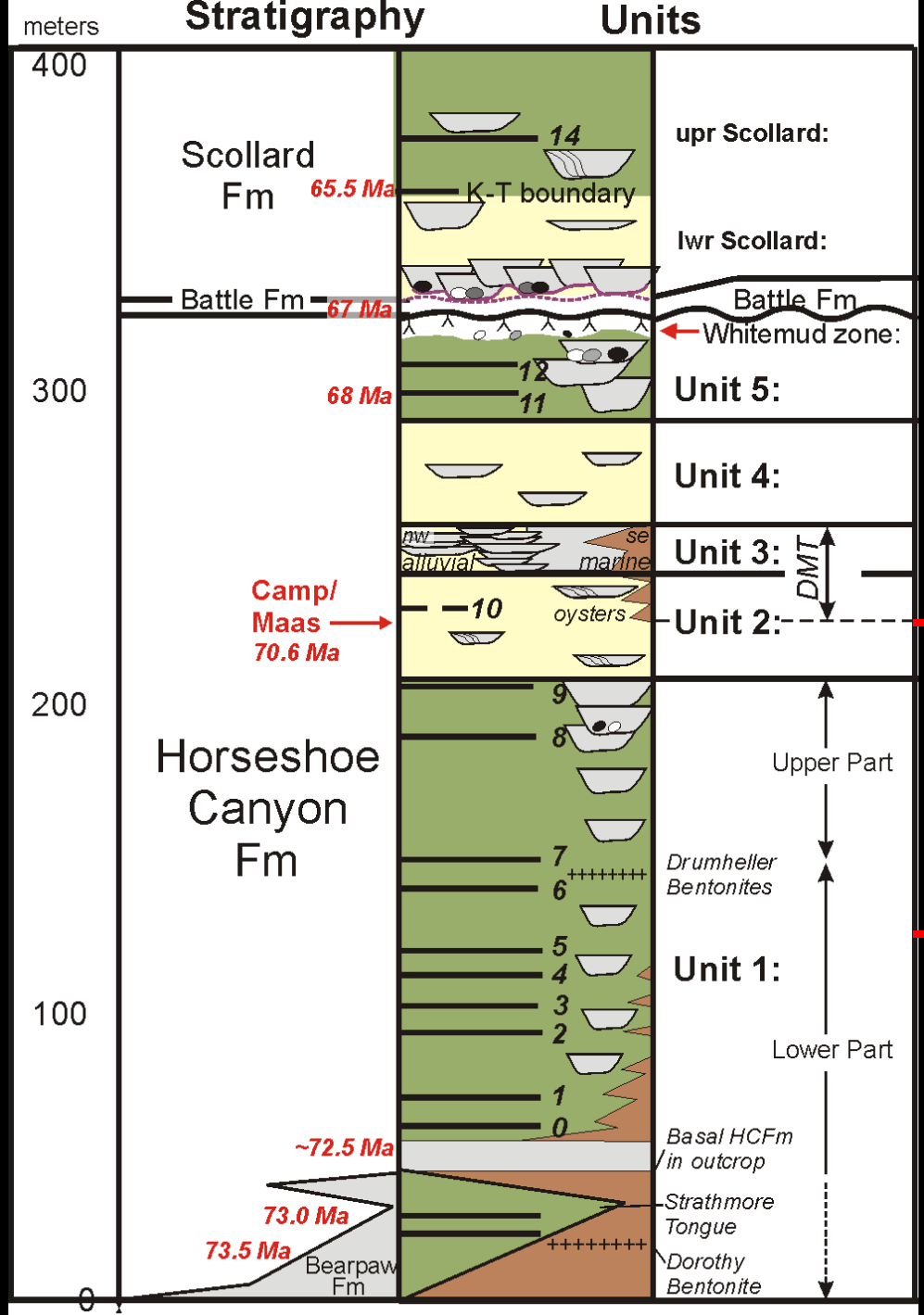


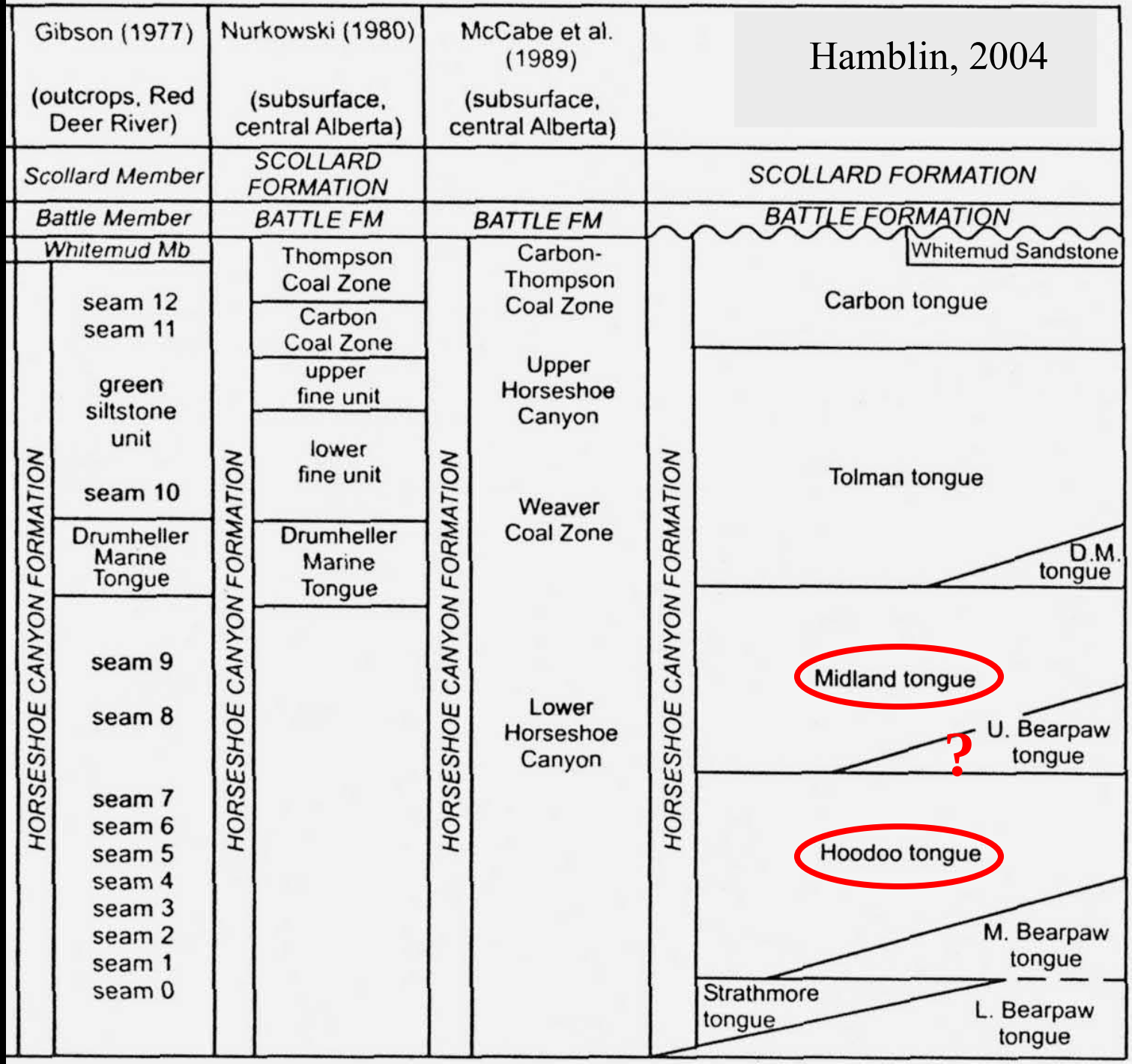
modified from Rahmani 1983; Ainsworth 1994

- prograding portion (#5-9 coal swarms)
- shoreline steps basinward >75 km



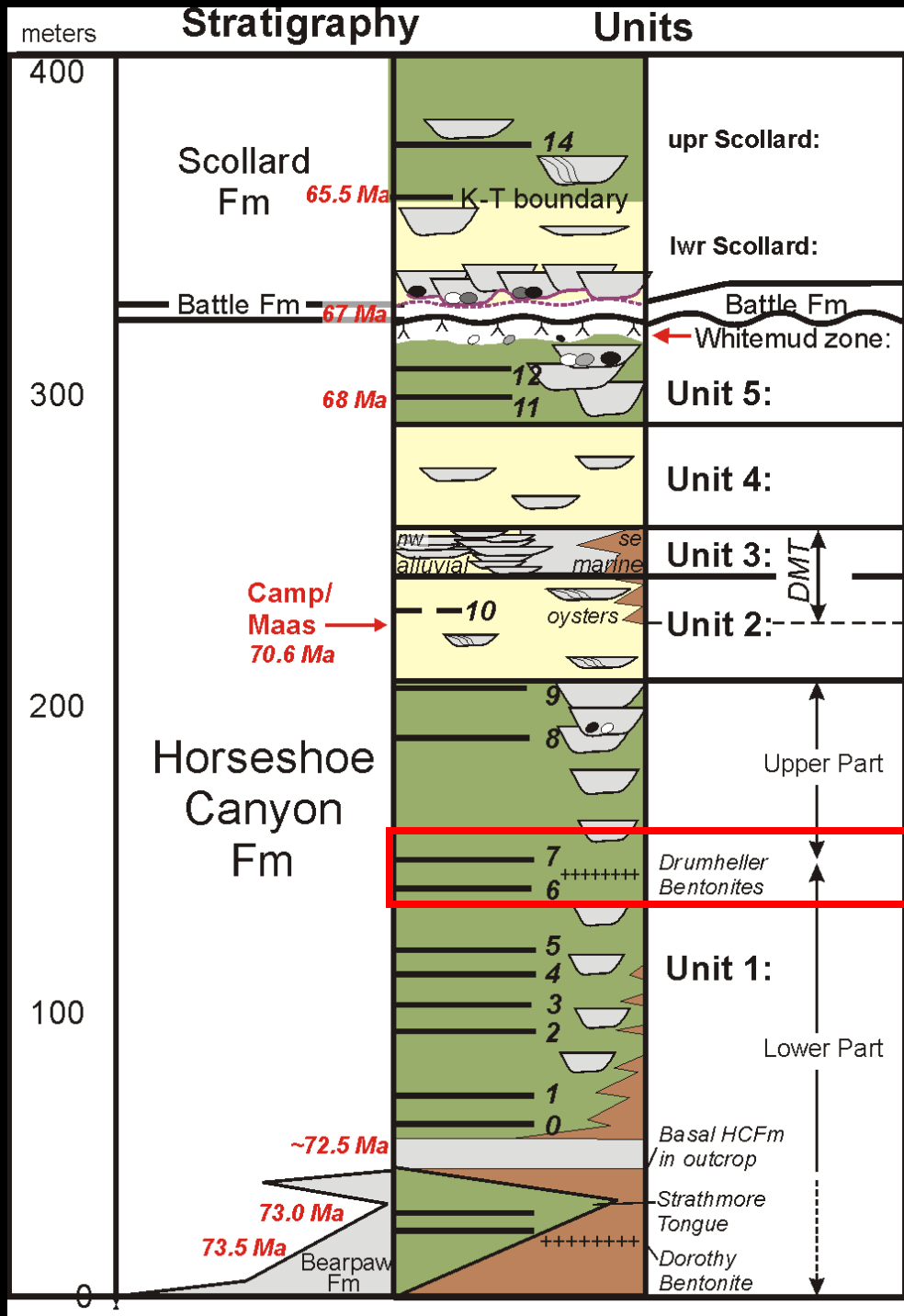

Hanna, AB, Canada
Sheerness, AB, Canada
~75 km
Drumheller, AB, Canada
Bihl (1970): no marine microfossil indicators above the 6-7 coals at Sheerness
© 2010 Google
Image © 2010 TerraMetrics
Image © 2010 DigitalGlobe
31 km
Google
12 U 435473.32 m E 5709197.50 m N
Eye alt 106.62 km

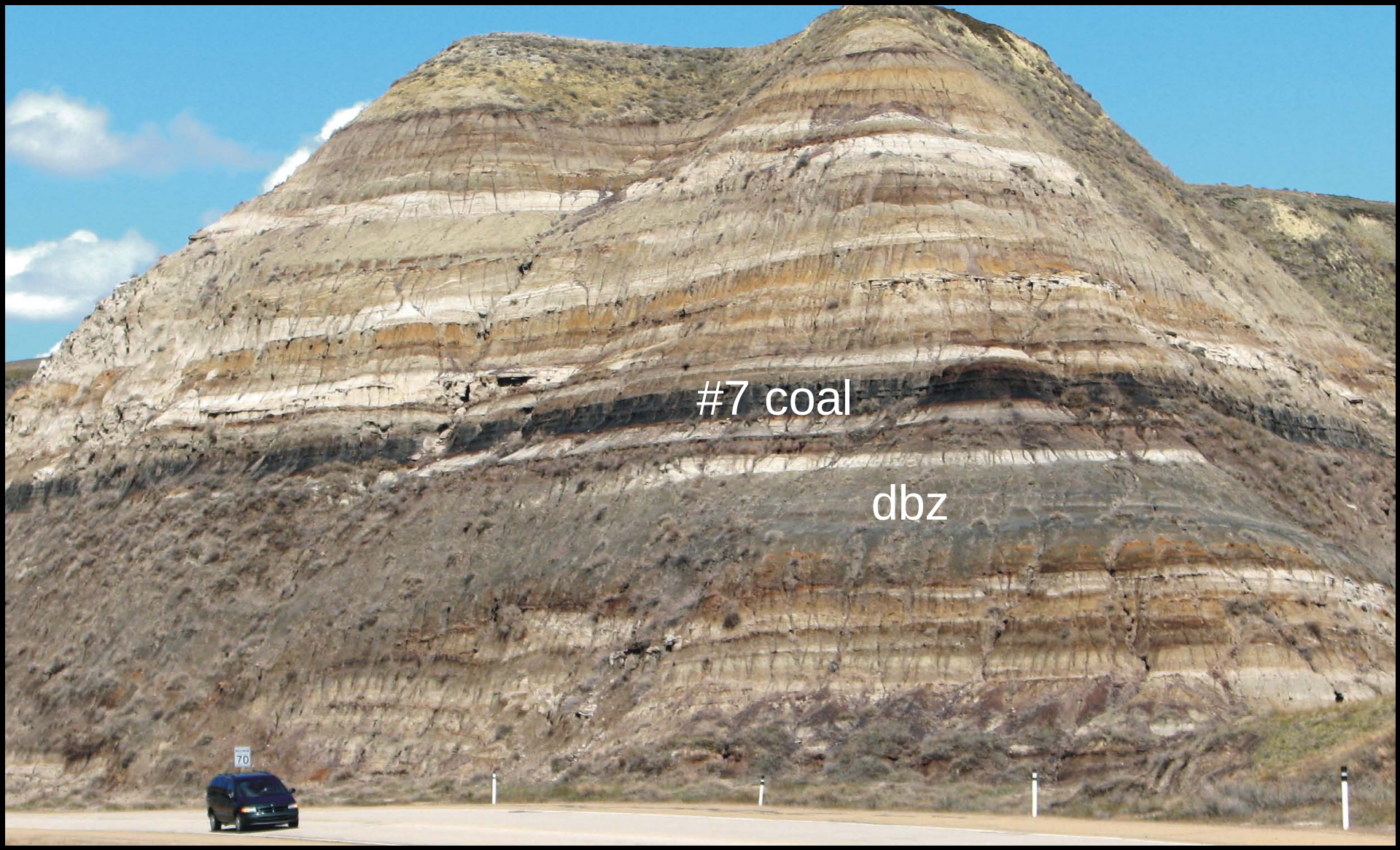

meters
Stratigraphy
Units
400
300
200
100
0
Scollard Fm
65.5 Ma
Battle Fm
67 Ma
68 Ma
Camp/ Maas
70.6 Ma
Horseshoe Canyon Fm
~72.5 Ma
73.0 Ma
73.5 Ma
Bearpaw Fm
14
K-T boundary
12
11
10
9
8
7
6
5
4
3
2
1
0
nw
alluvial
se
marine
oysters
upr Scollard:
lwr Scollard:
Battle Fm
Whitemud zone:
Unit 5:
Unit 4:
Unit 3:
Unit 2:
DMT
Upper Part
Drumheller Bentonites
Unit 1:
Lower Part
Basal HCFm in outcrop
Strathmore Tongue
Dorothy Bentonite
nonmarine
marine indicators

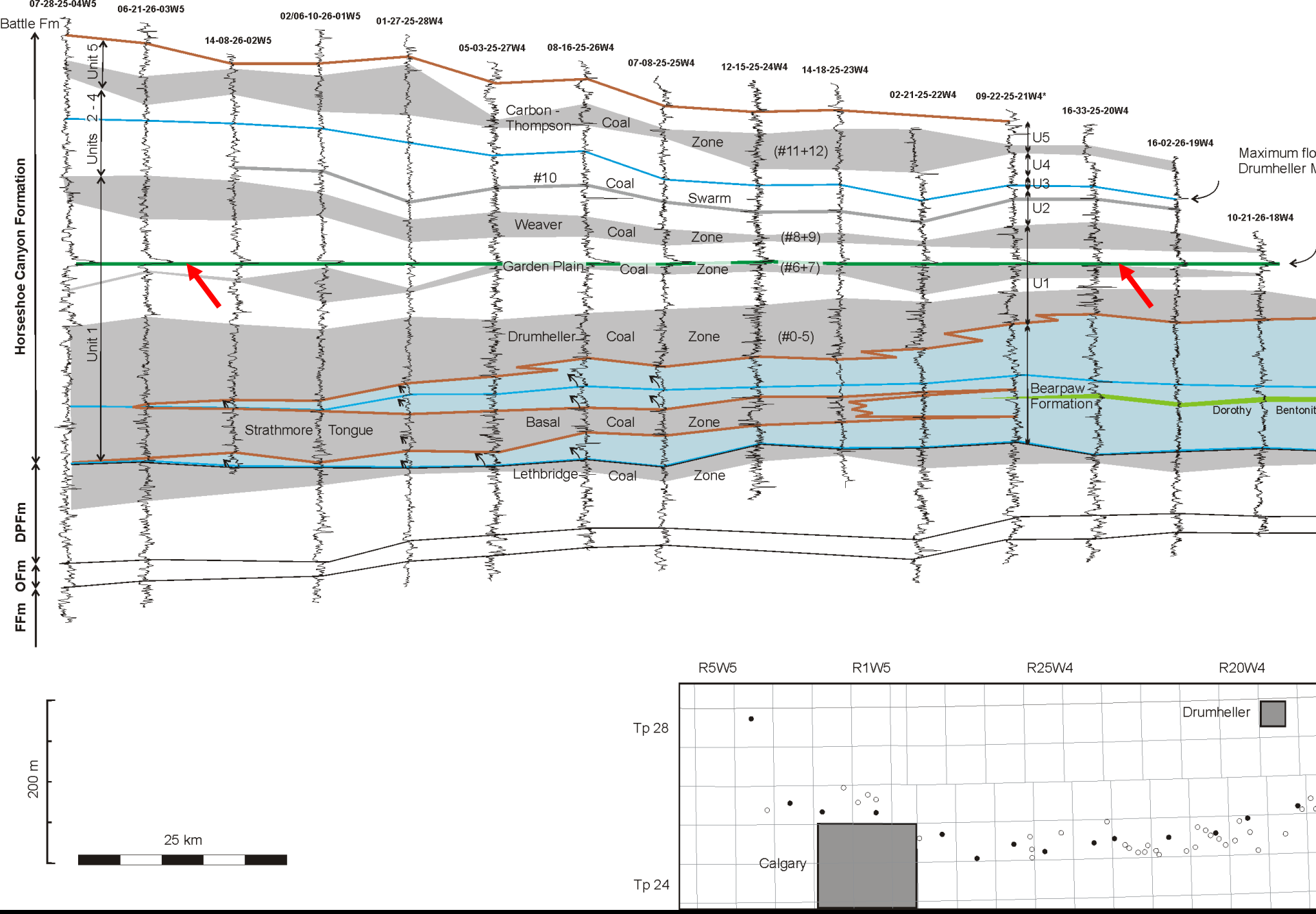

Gibson (1977)
(outcrops, Red Deer River)
Nurkowski (1980)
(subsurface, central Alberta)
McCabe et al. (1989)
(subsurface, central Alberta)
Hamblin, 2004
Scollard Member
SCOLLARD FORMATION
SCOLLARD FORMATION
Battle Member
BATTLE FM
BATTLE FM
BATTLE FORMATION
Whitemud Mb
HORSESHOE CANYON FORMATION
seam 12
seam 11
green siltstone unit
seam 10
Drumheller Marine Tongue
seam 9
seam 8
seam 7
seam 6
seam 5
seam 4
seam 3
seam 2
seam 1
seam 0
HORSESHOE CANYON FORMATION
Thompson Coal Zone
Carbon Coal Zone
upper fine unit
lower fine unit
Drumheller Marine Tongue
HORSESHOE CANYON FORMATION
Carbon-Thompson Coal Zone
Upper Horseshoe Canyon
Weaver Coal Zone
Lower Horseshoe Canyon
HORSESHOE CANYON FORMATION
Whitemud Sandstone
Carbon tongue
Tolman tongue
D.M. tongue
Midland tongue
U. Bearpaw tongue
?
Hoodoo tongue
M. Bearpaw tongue
Strathmore tongue
L. Bearpaw tongue

Unit 1: Notable Features

- 3 discrete intervals different geometries
- volcanic ash horizon: Drumheller bentonite zone
- thick, abundant, coarser paleochannels at top of Unit 1

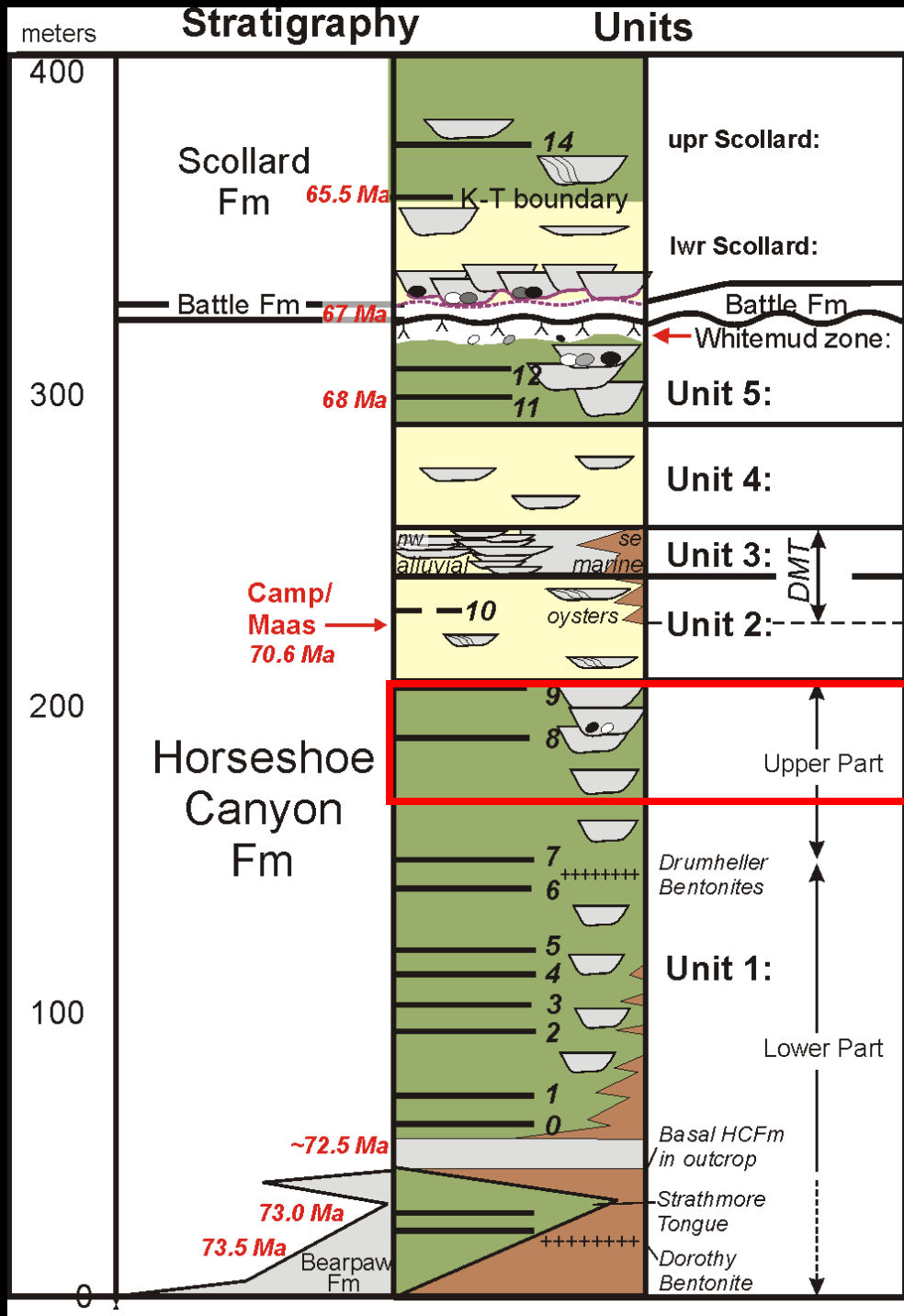


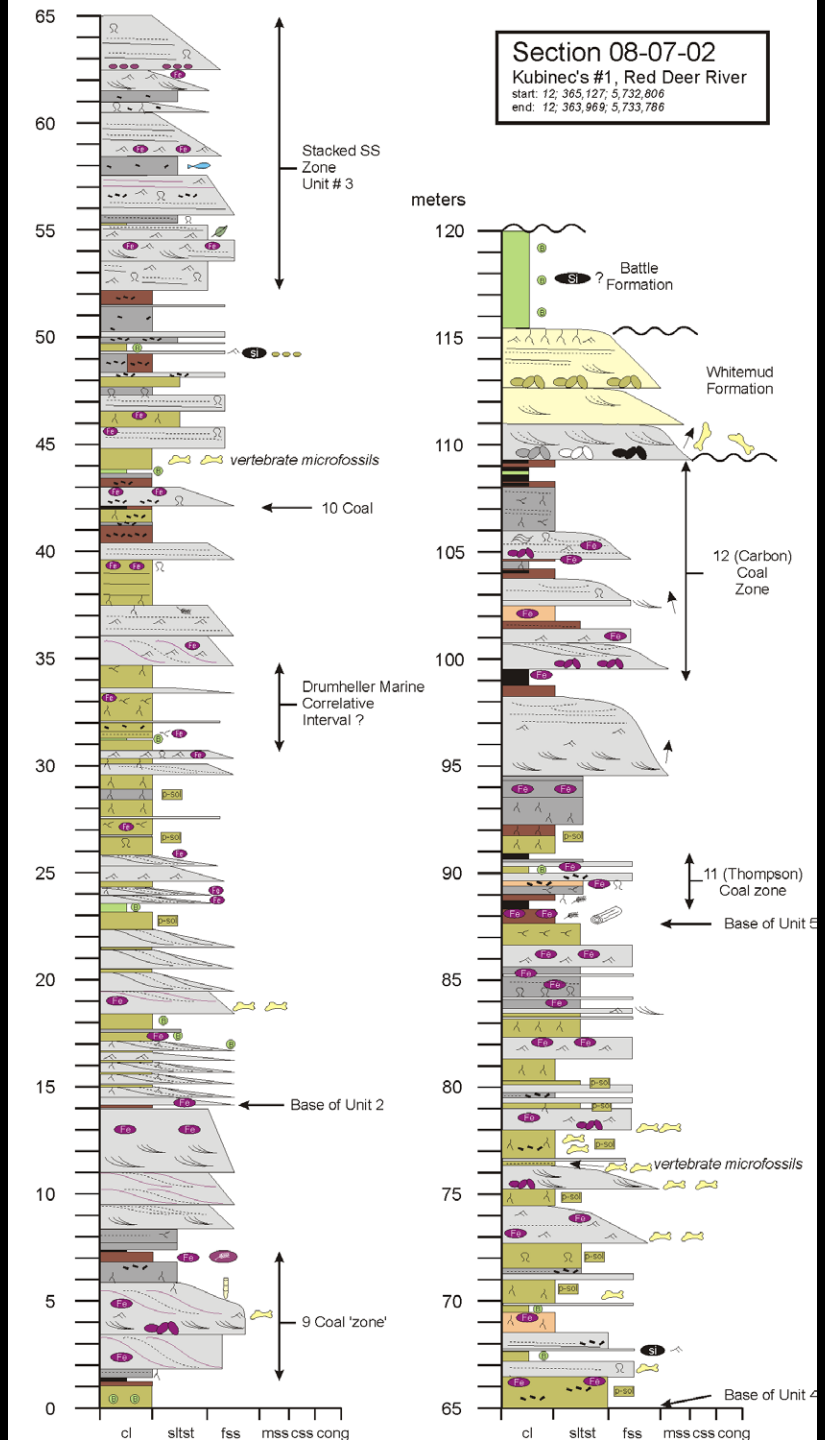

#7 coal
dbz


07-28-25-04W5
06-21-26-03W5
02/06-10-26-01W5
01-27-25-28W4
14-08-26-02W5
05-03-25-27W4
08-16-25-26W4
07-08-25-25W4
12-15-25-24W4
14-18-25-23W4
02-21-25-22W4
09-22-25-21W4*
16-33-25-20W4
16-02-26-19W4
10-21-26-18W4
Battle Fm
Horseshoe Canyon Formation
DPFm
OFm
FFm
Unit 5
Units 2 - 4
Unit 1
Carbon - Thompson Coal Zone (#11+12)
#10 Coal Swarm
Weaver Coal Zone (#8+9)
Garden Plain Coal Zone (#6+7)
Drumheller Coal Zone (#0-5)
Basal Coal Zone
Lethbridge Coal Zone
Strathmore Tongue
U5
U4
U3
U2
U1
Bearpaw Formation
Dorothy
Bentonit
Maximum flo
Drumheller M
200 m
25 km
R5W5
R1W5
R25W4
R20W4
Tp 28
Tp 24
Drumheller
Calgary

Unit 1: Notable Features

- 3 discrete intervals different geometries
- volcanic ash horizon: Drumheller bentonite zone
- thick, abundant, coarser paleochannels at top of Unit 1





Unit 3

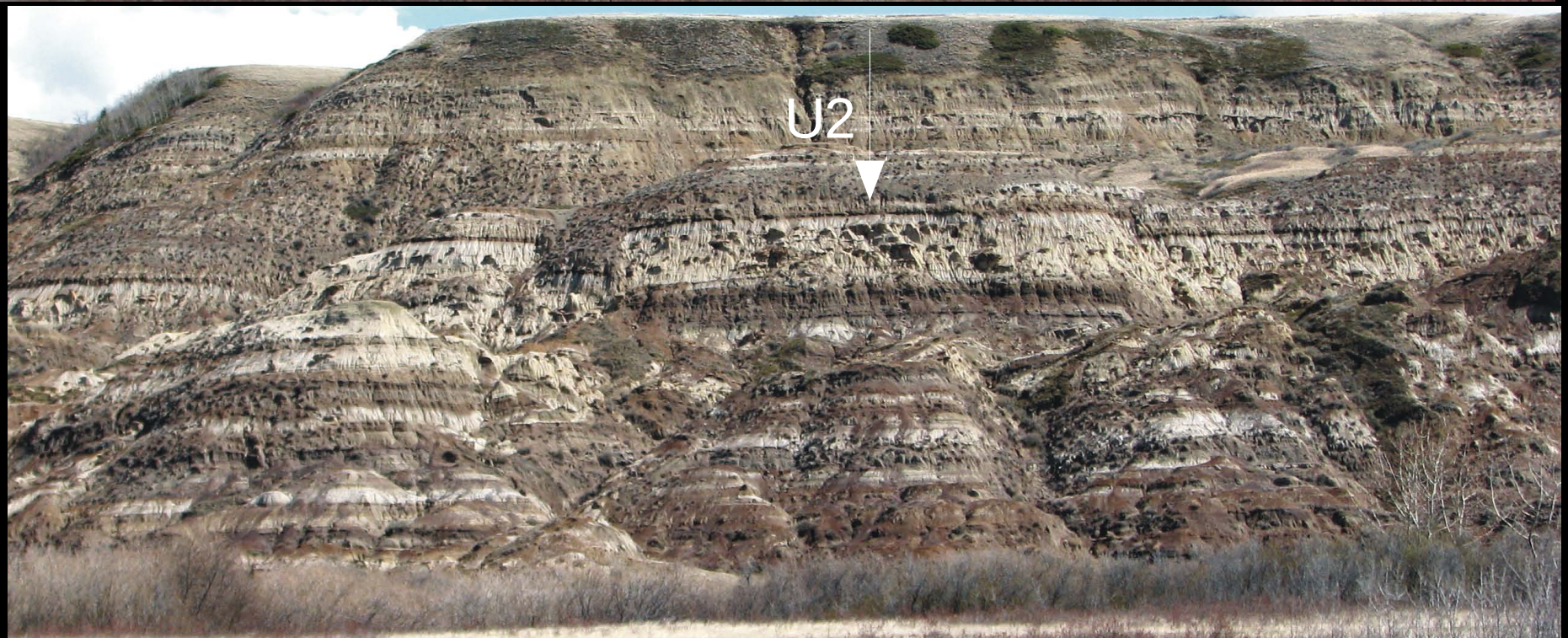
Unit 2

Unit 1 (top)

Unit 5

Unit 4

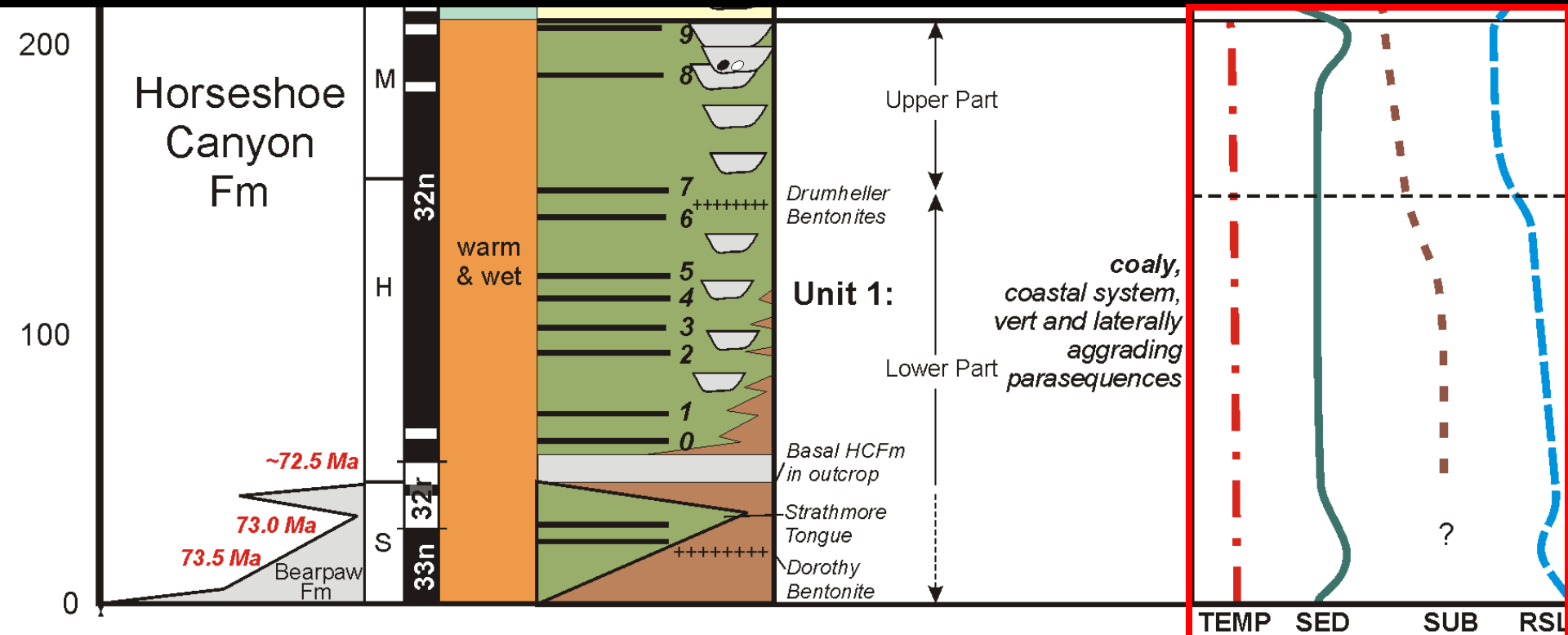

U2


U2

Unit 1 Interpretation

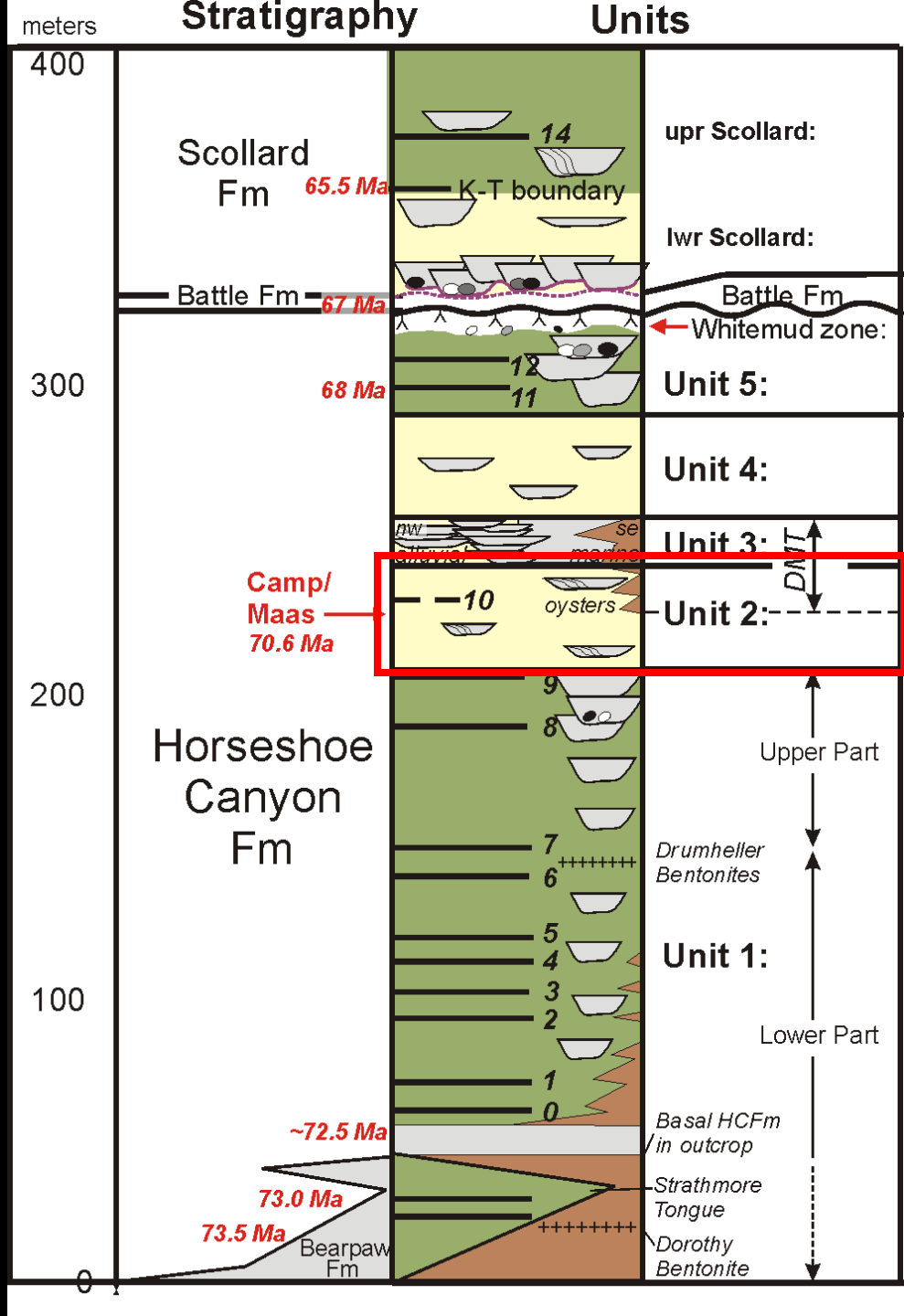
upstream & downstream controls

- possible drop in sea level above the # 4 coal
- and/or possible decrease in subsidence rate
- increased volcanic activity at #6-7 coal zone
- increase in sediment supply near top of Unit 1
- upsection decrease in accommodation



Unit 2: Notable Features

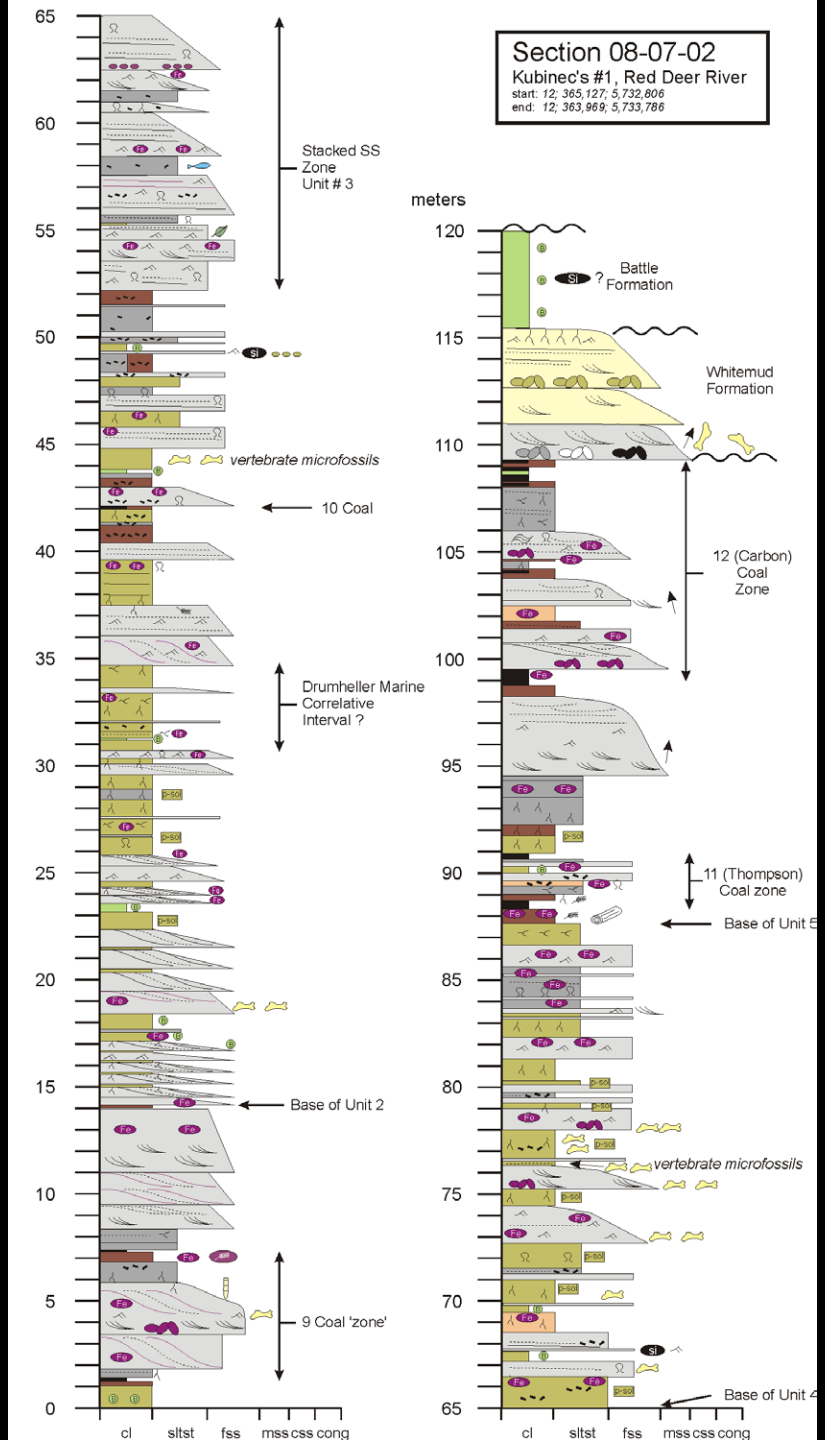
- paleochannels small
- fine grained ss
- subequal ss-mudstones
- base of DMT (transgression)
- shoreline coals rare-absent
- vertisols abundant
- decline in temp-sensitive taxa



Unit 3

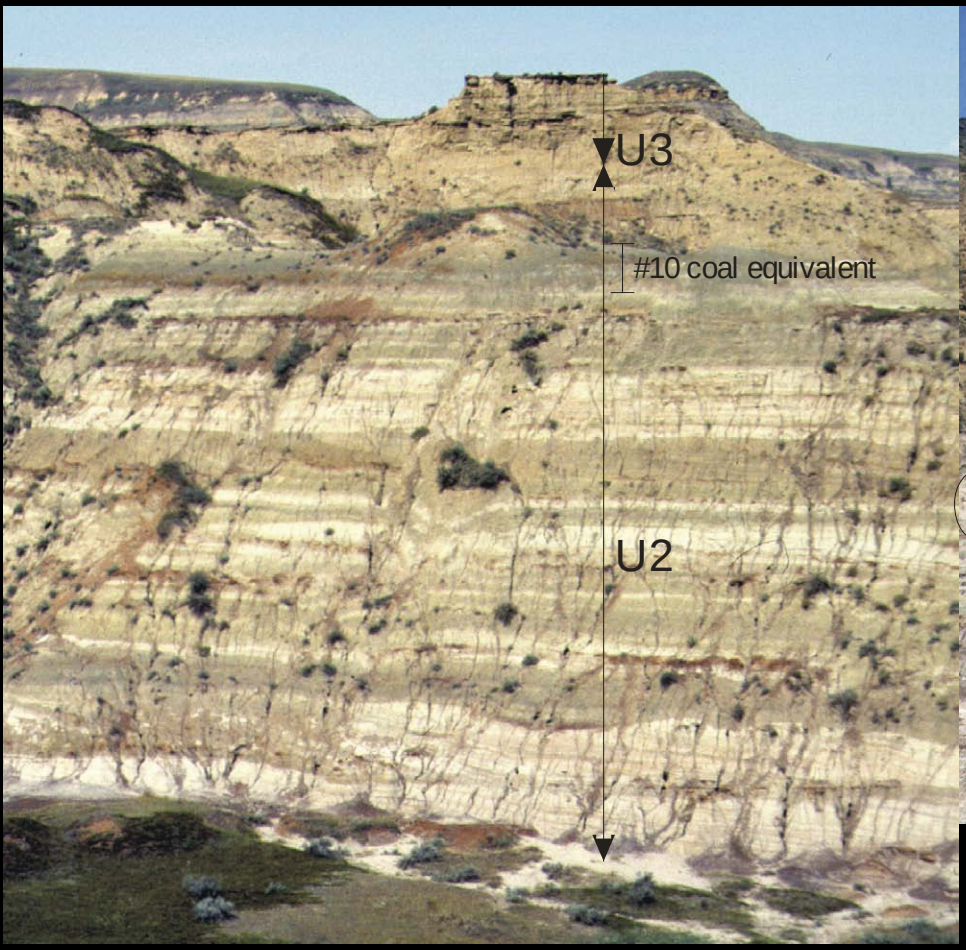
Unit 2

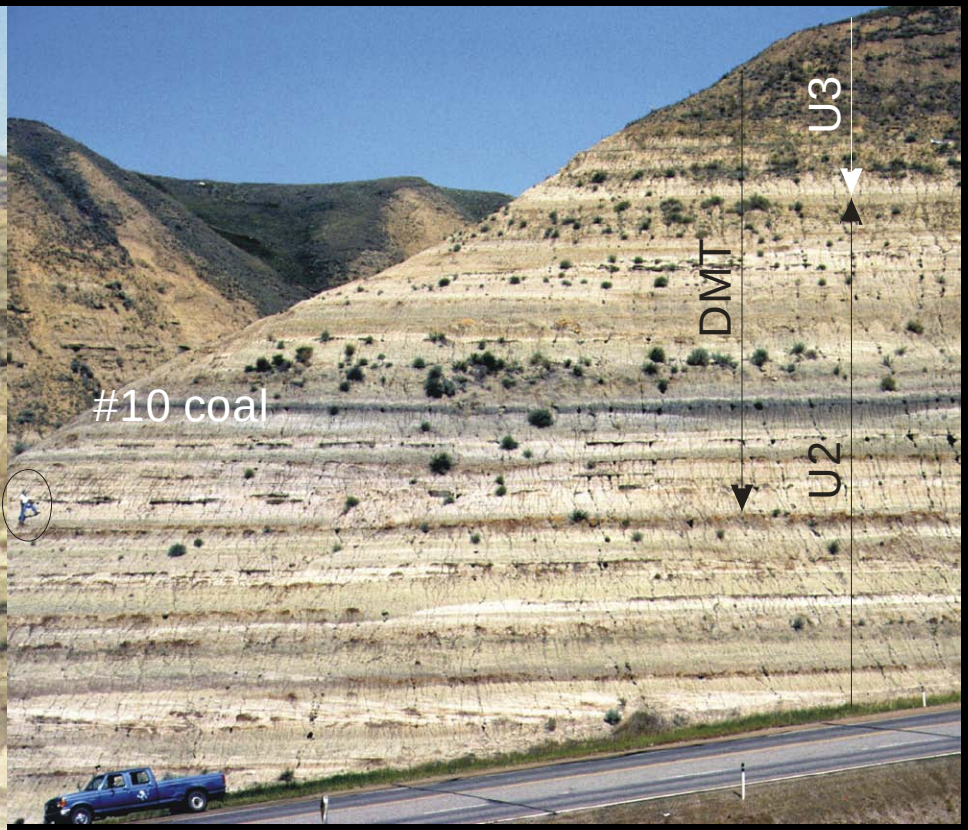
Unit 1
(top)



Unit 4

Unit 4

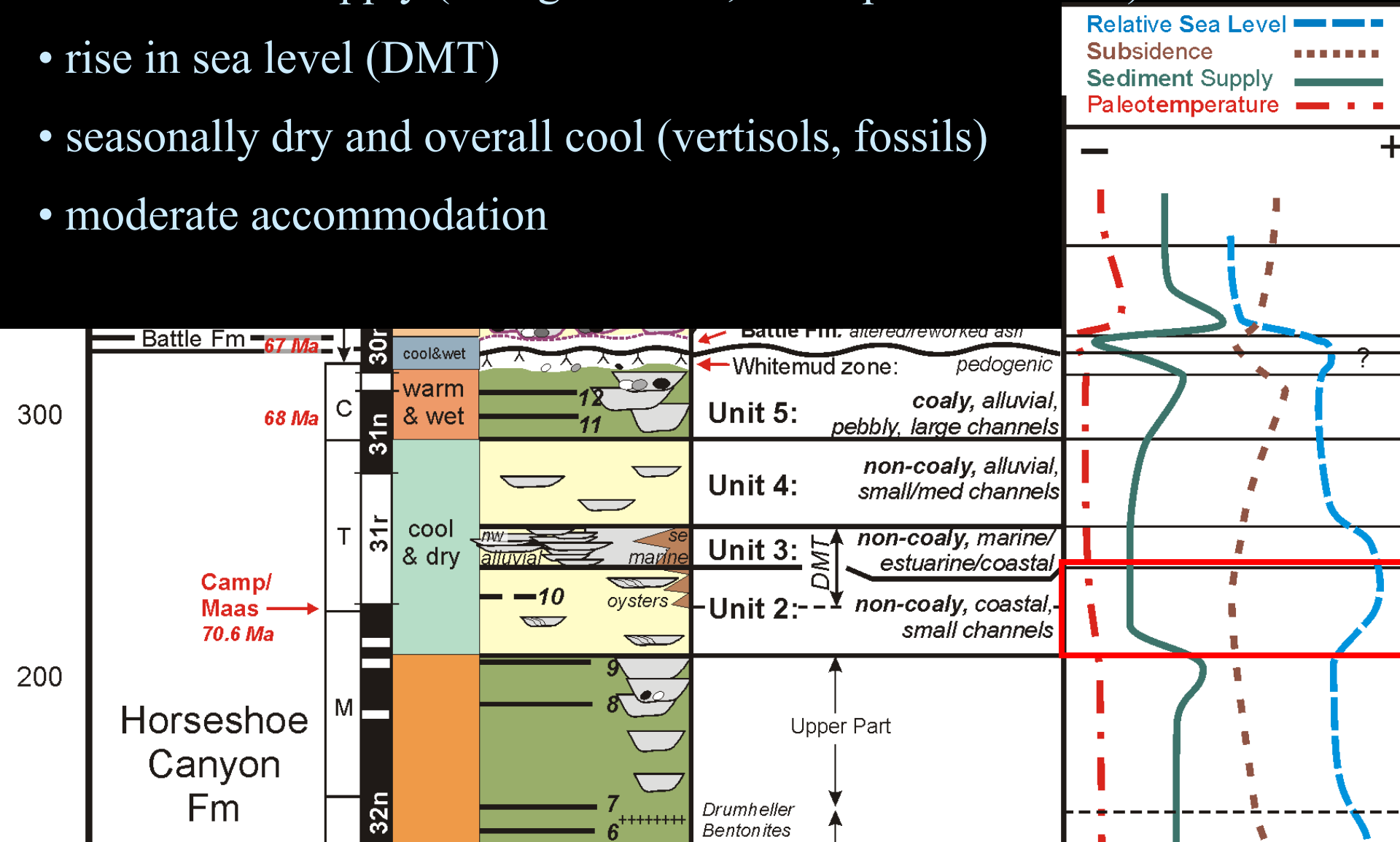

U3
#10 coal equivalent
U2


U3
DMT
#10 coal
U2

Unit 2: Interpretation

upstream & downstream controls

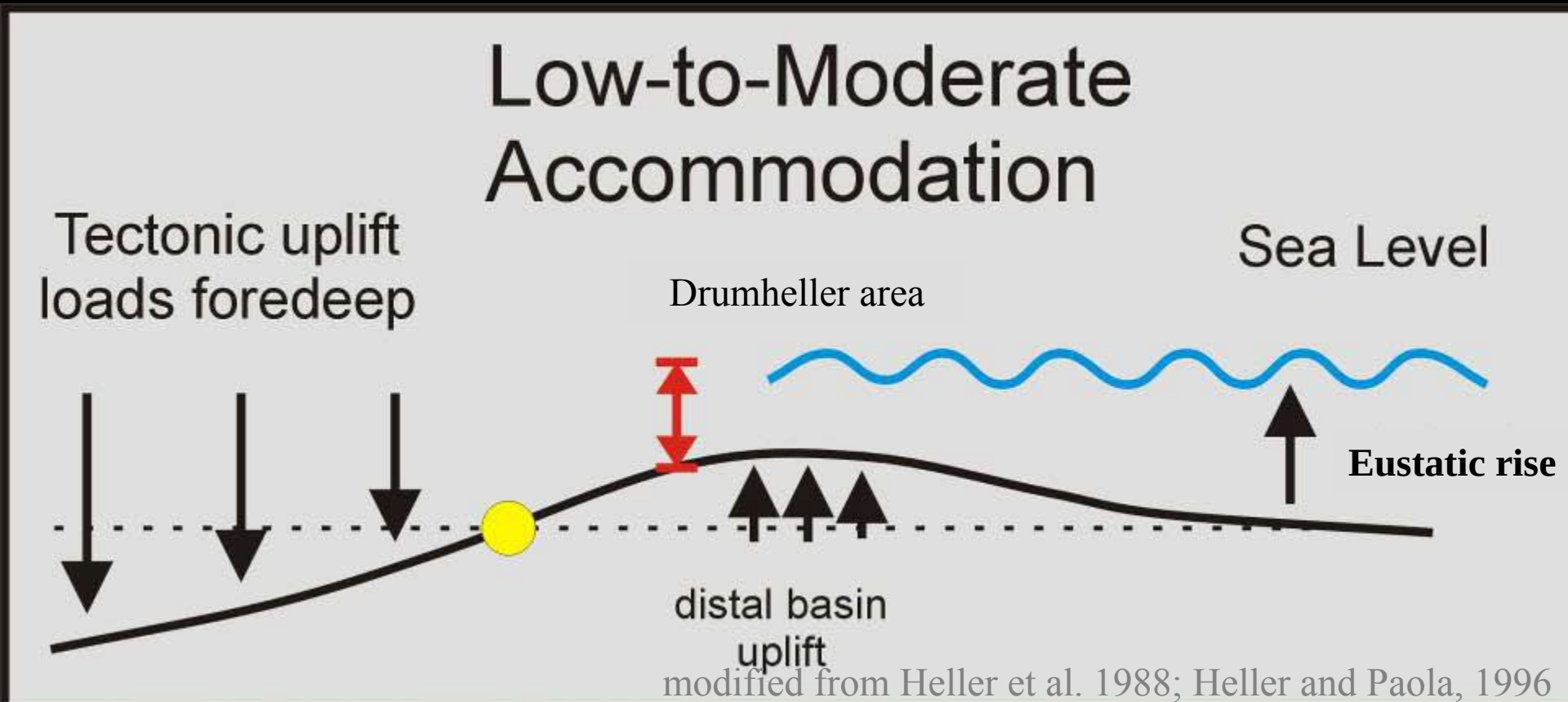
- reduced sed supply (fine-grained ss; small paleochannels)
- rise in sea level (DMT)
- seasonally dry and overall cool (vertisols, fossils)
- moderate accommodation



Unit 2: Interpretation

Unit 2 indicates uplift event (two-phase stratigraphic model):

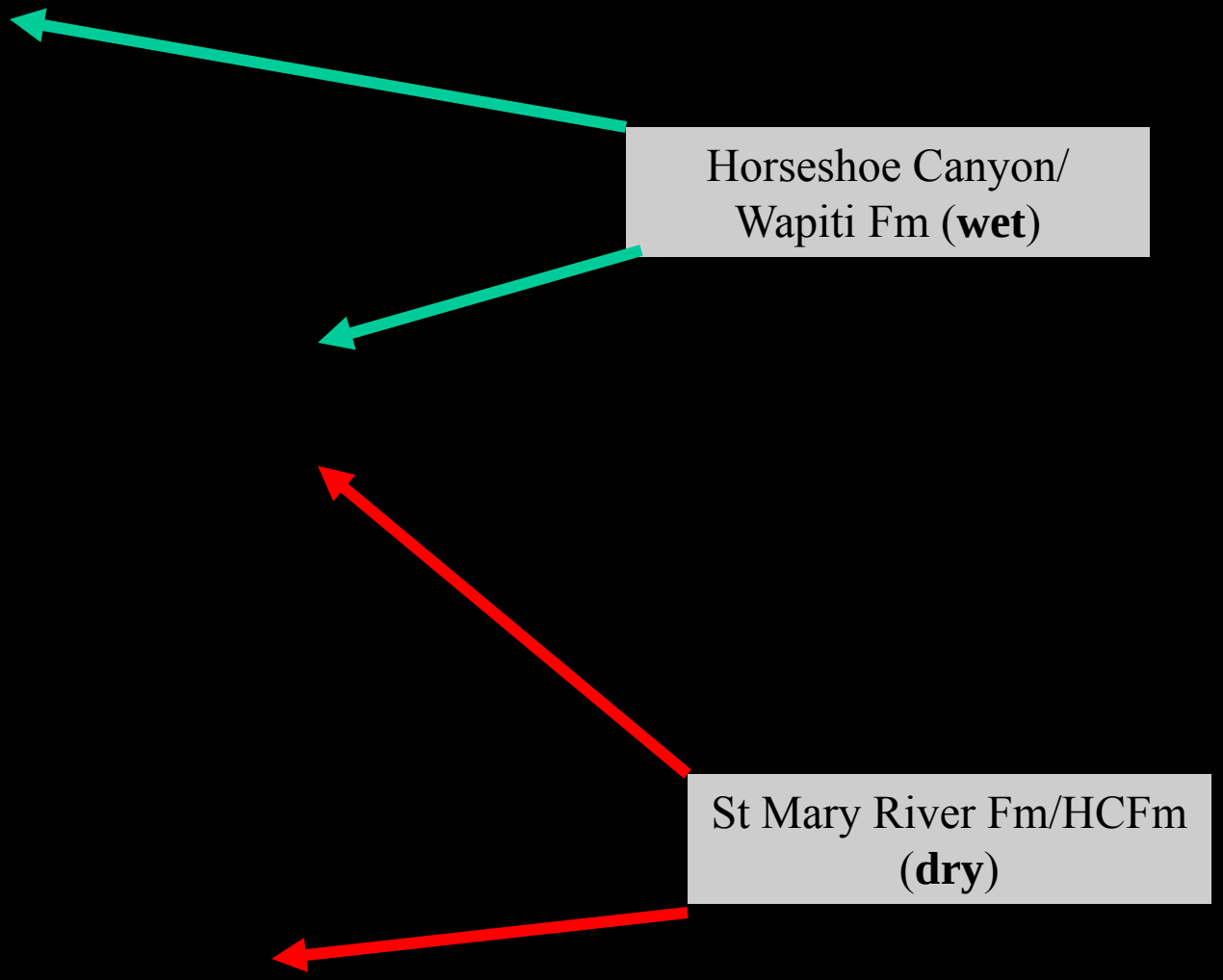
- sed is trapped in foredeep, starving the distal basin
- subsidence is reduced by forebulge uplift
- THUS...DMT reflects a eustatic sea level rise, unrelated to regional tectonics



modified from Heller et al. 1988; Heller and Paola, 1996

Unit 2: Interpretation

Uplift likely caused a northward shift in dry climate due to expanding rain-shadow effect



Jerzykiewicz & Sweet 1988;

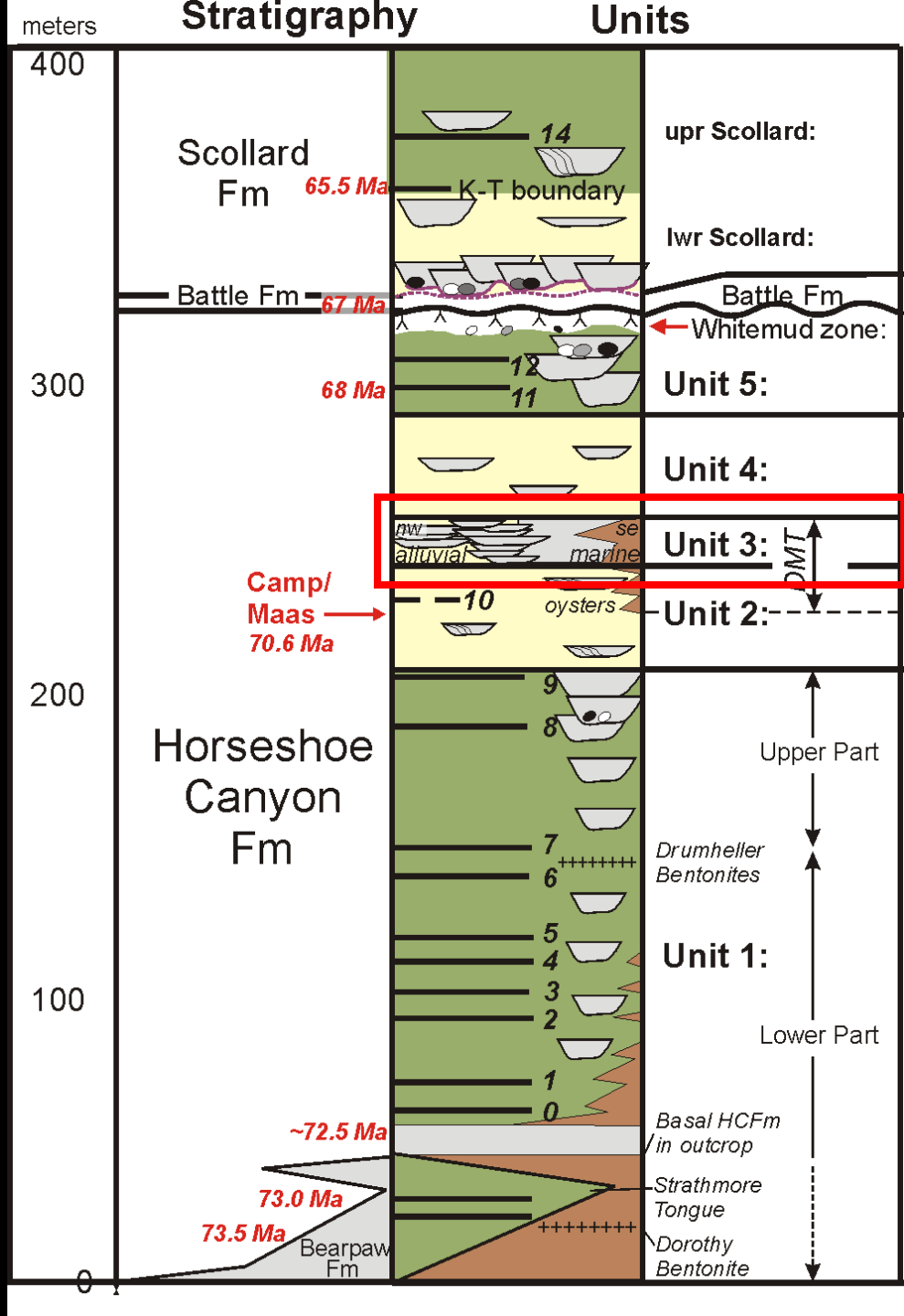
Nadon 1988;

Fanti & Catuneanu 2010

Unit 3: Notable Features

stacked ss (marine - alluvial)

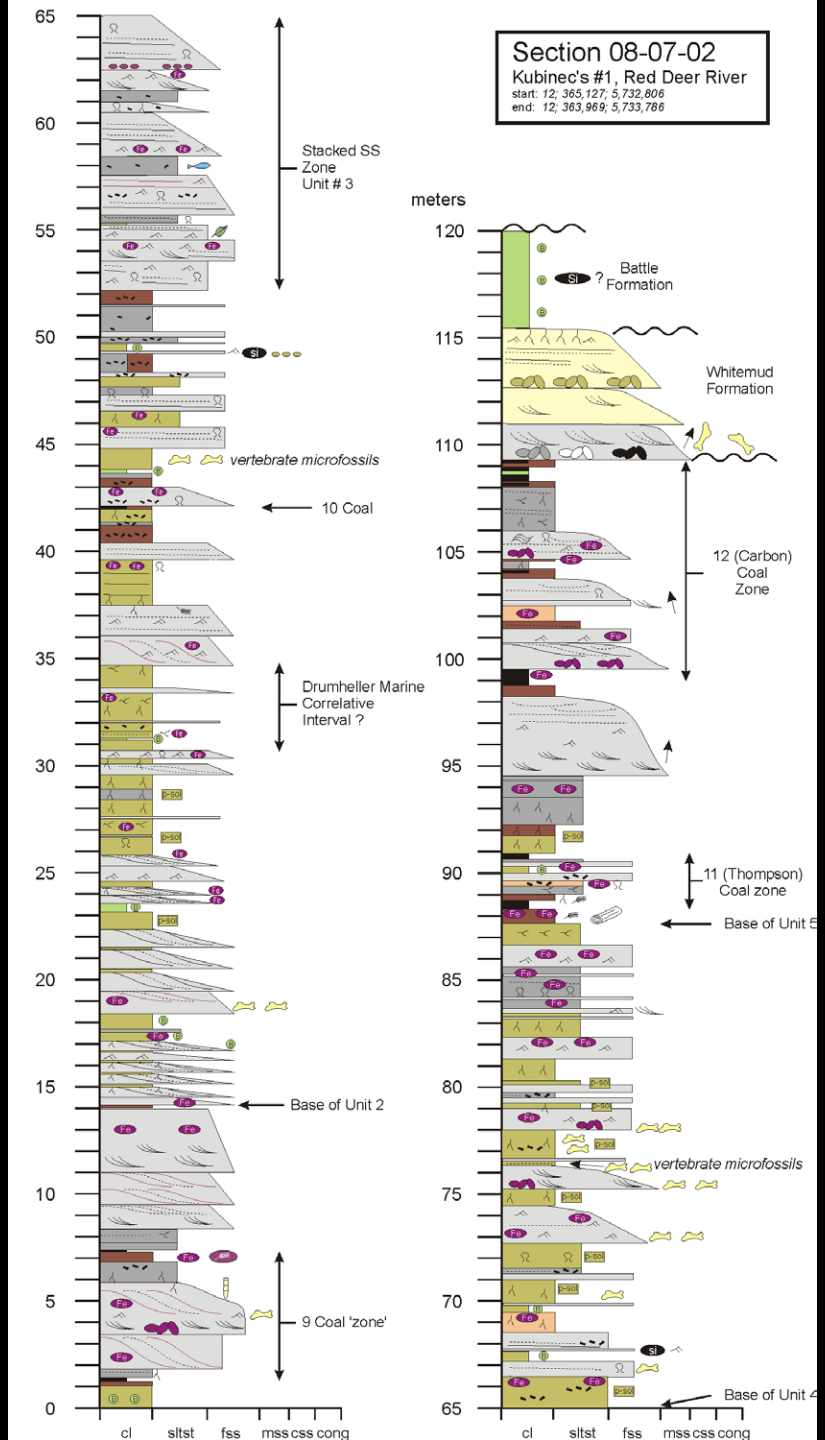
top of DMT



Unit 3

Unit 2

Unit 1
(top)



Unit 5

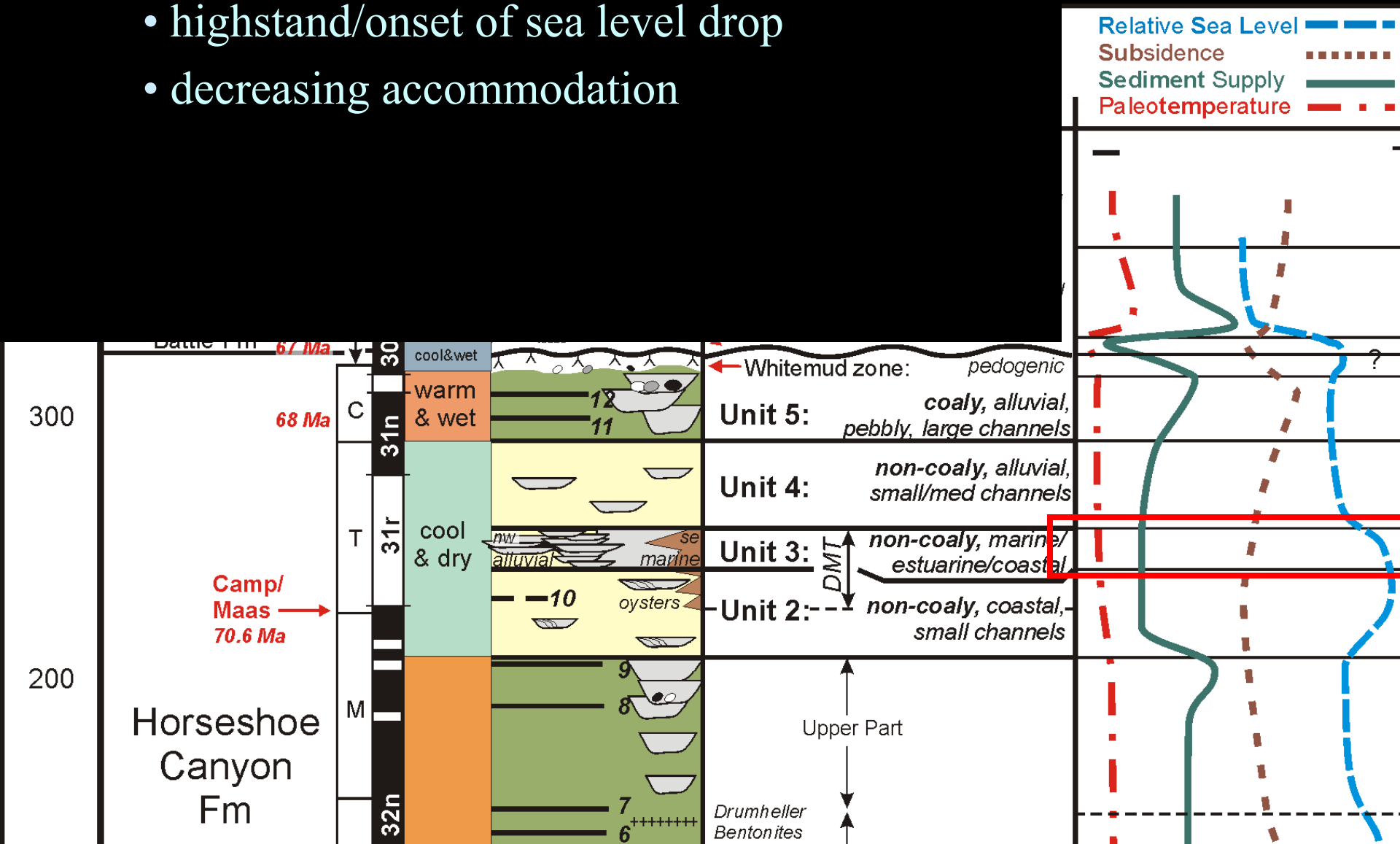
Unit 4


U3

Unit 3 Interpretation

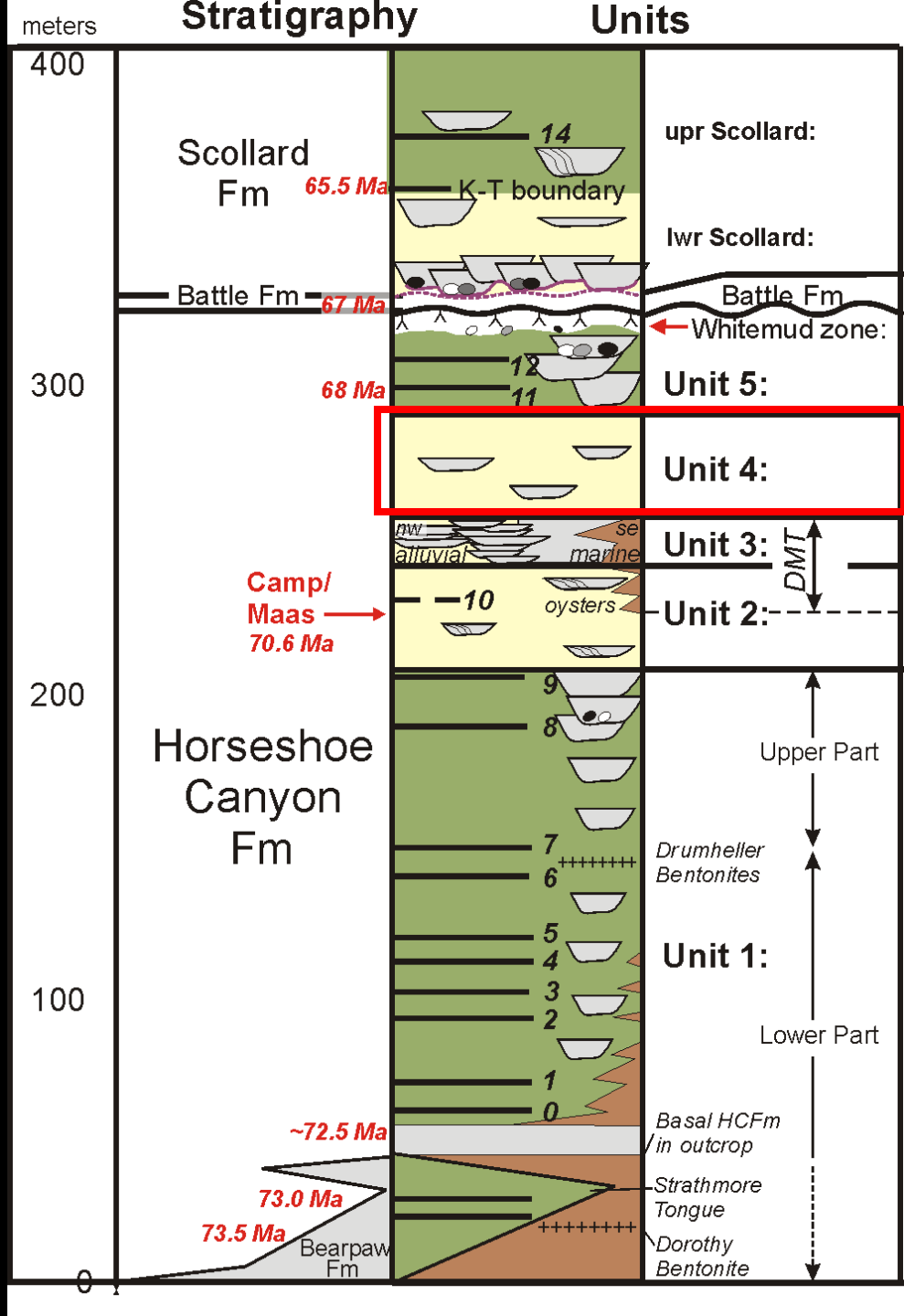
downstream controls

- highstand/onset of sea level drop
- decreasing accommodation



Unit 4: Notable Features

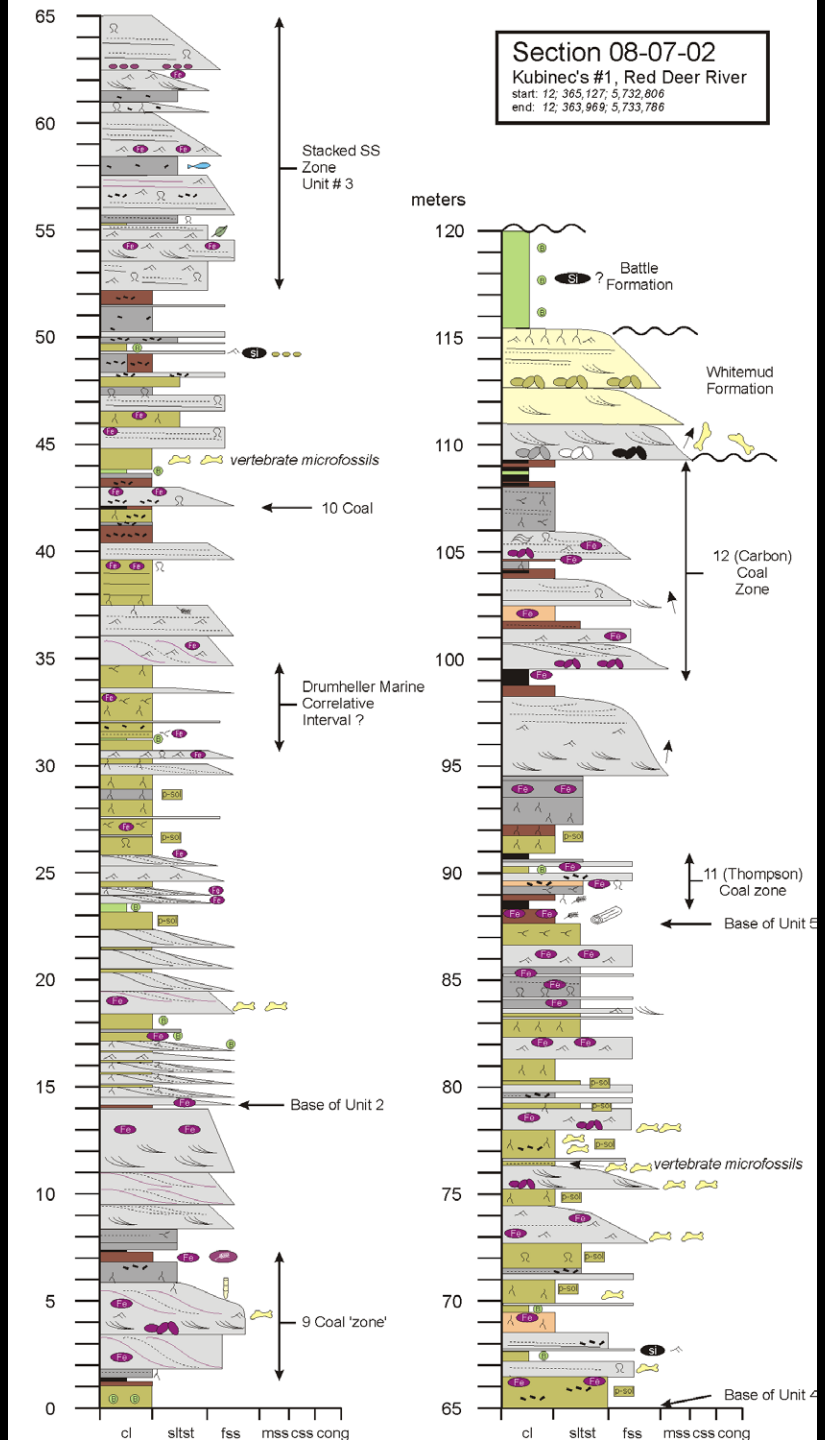
- subequal ss-mdst
- nonmarine
- vertisols
- small paleochannels (<2 m thick)
- fine-grained
- temp sensitive verts rare



Unit 3

Unit 2

Unit 1
(top)



Unit 5

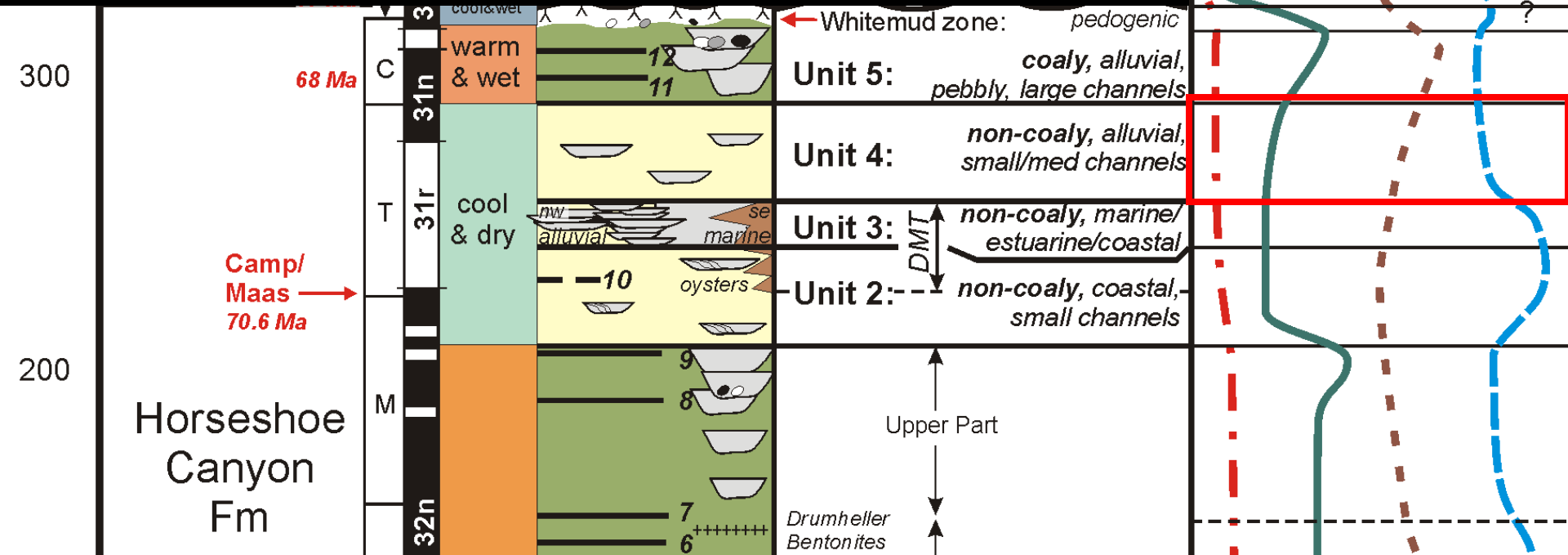
Unit 4


U5
U4
U3

Unit 4 Interpretation

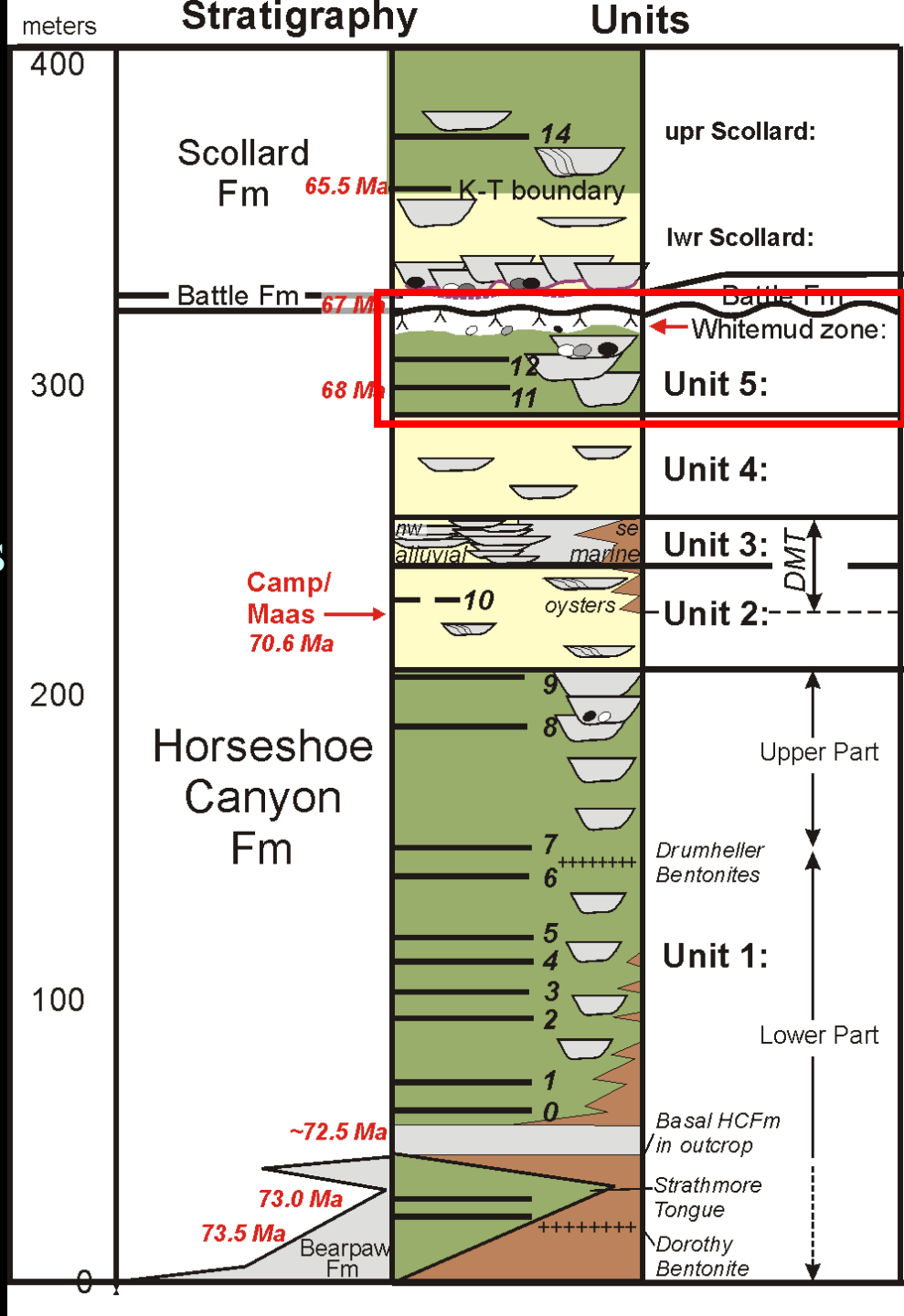
upstream & downstream controls

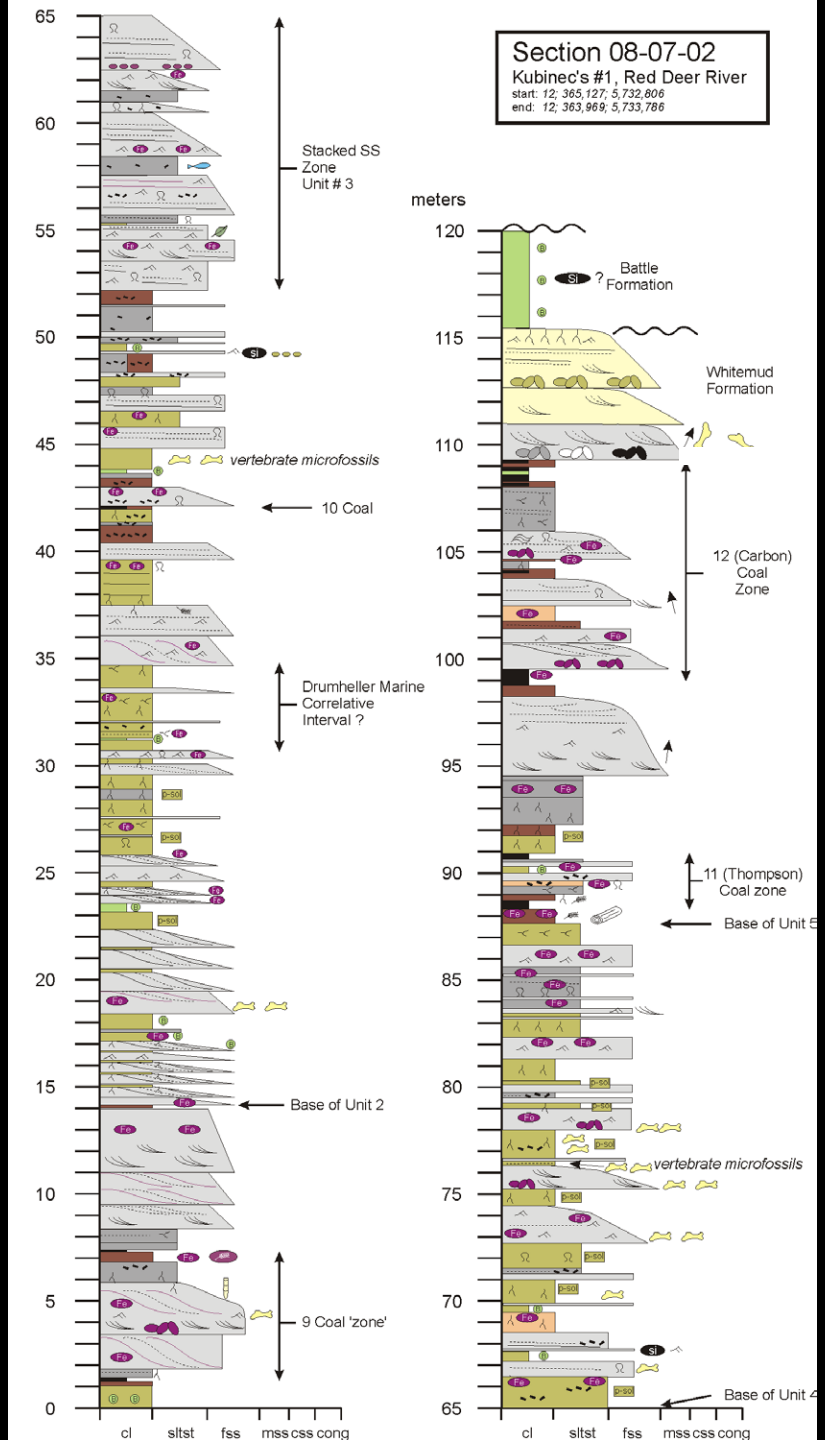
- continued cool and seasonally dry
- continued sea level drop (nonmarine)
- increased subsidence (subequal ss/mdst)
- moderate accommodation



Unit 5: Notable Features

- coaly
- fine- med-grained ss
- extrabasinal conglomerates!
- thick & abund paleochannel ss
- rare vertebrate fossils (?)
- leached-pedogenic zone (Whitemud kaolinte subunit) at top





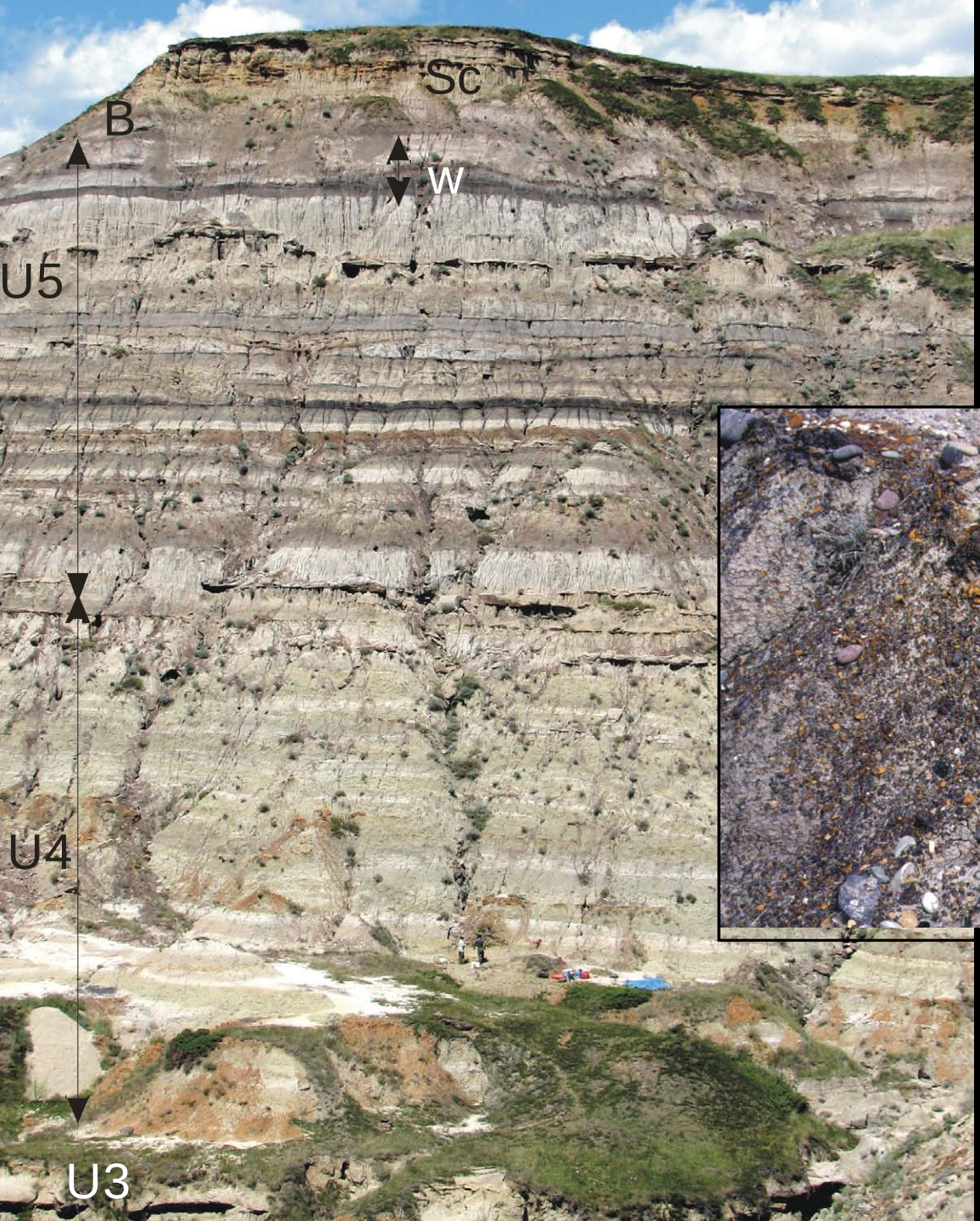
Unit 3

Unit 2

Unit 1 (top)

Unit 5

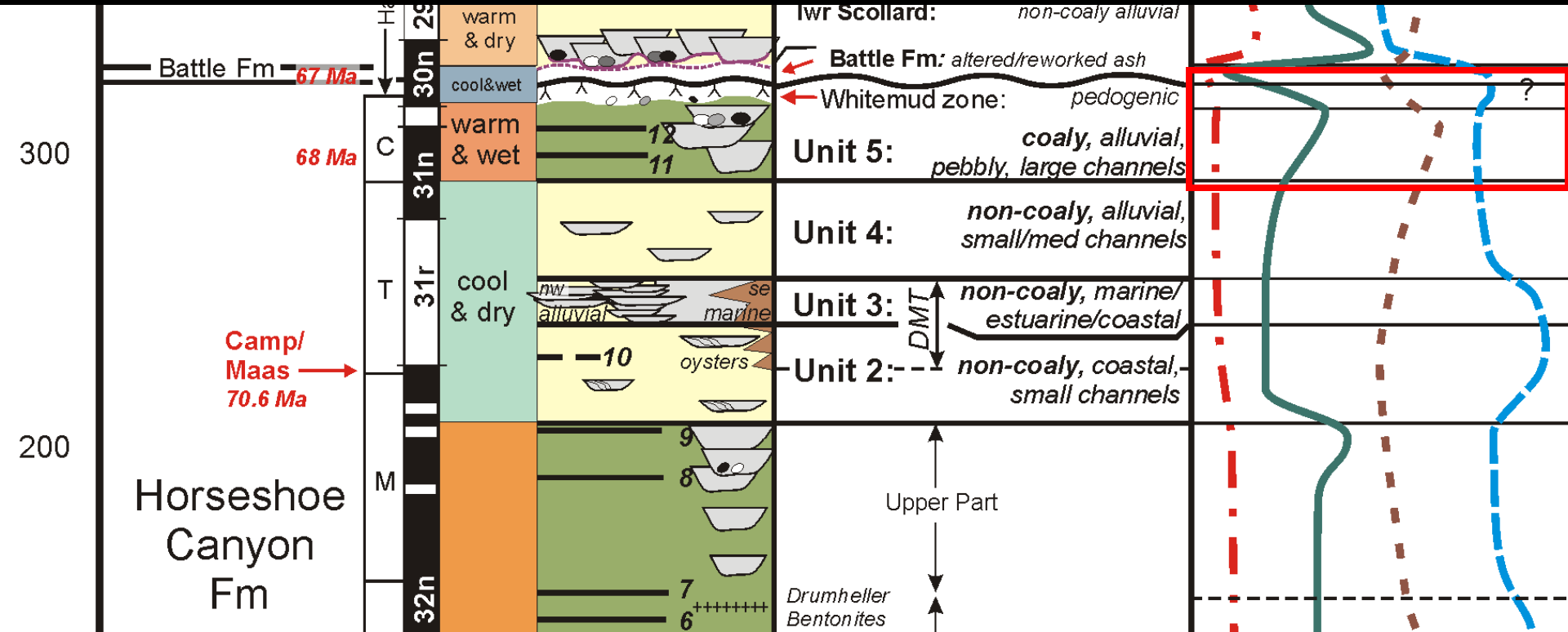
Unit 4


Sc
B
W
U5
U4
U3

Unit 5 Interpretation

upstream controls

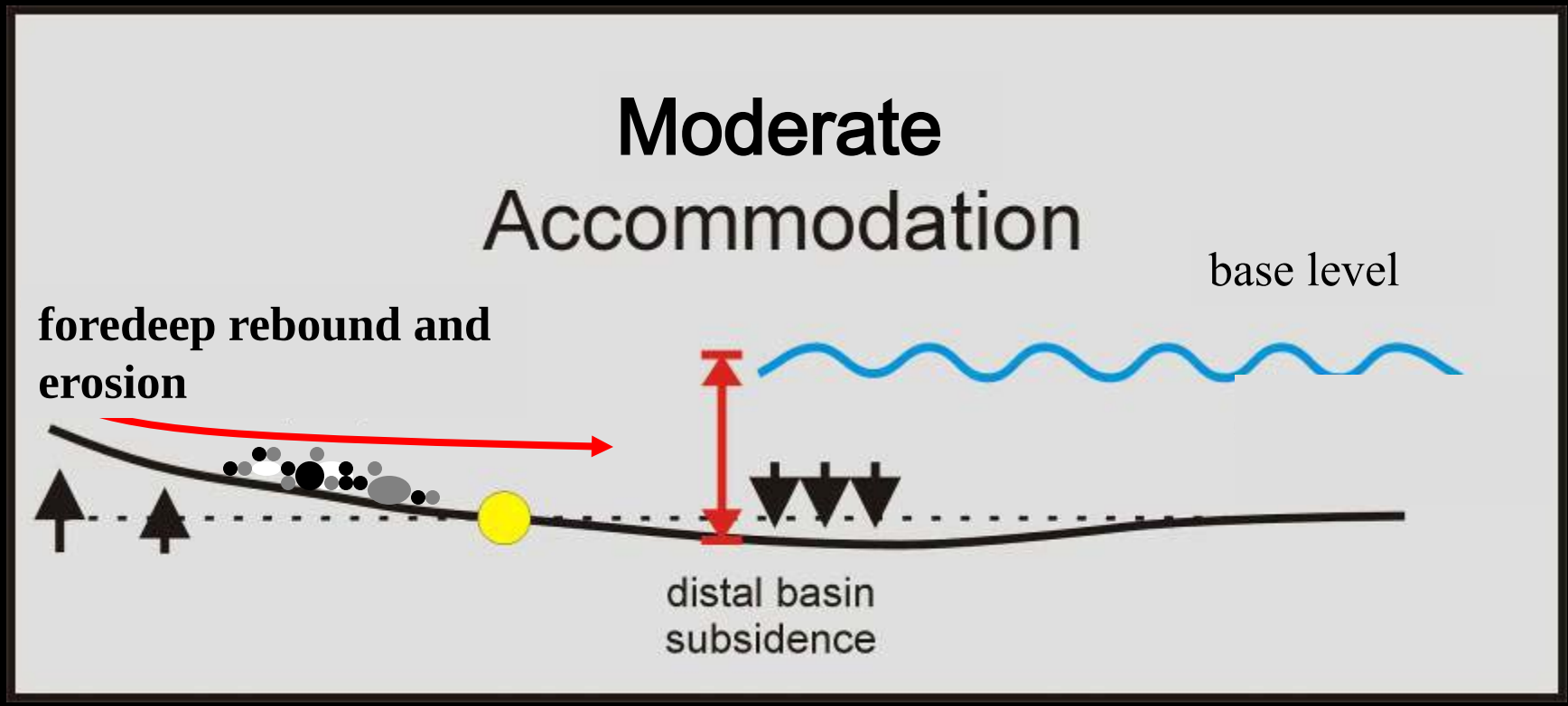
- increase and then decline in sediment supply (conglomerates/Whitemud
- increase and then decline in subsidence rate (coals/Whitemud)
- overall increased wetness (coals; kaolinites)
- upsection decrease in accommodation (stacked channels; Whitemud)



Unit 5 Interpretation

two-phase model context

- tectonic quiescence; foredeep rebound
- shift of wet climate north to south; regional increase in cool/wet climate
- eventual beveling and deep weathering of landscape (Whitemud)



Conclusions

- Revised stratigraphy/interpretations reflect combined upstream & downstream influences:

  sea level; sed supply; subsidence; climate; volcanism

- Two-phase strat model helps integrate sed supply, subsidence, sea-level change and climate data, creating a cohesive history.

- Resource potential should be evaluated in light of evidence for upstream controls

  e.g.: gas-hosted ss at top of Unit 1 and Unit 5, and Unit 3

Acknowledgements

Dennis Braman; Don Brinkman; RTMP Cooperating Society; J. Lerbekmo; A. Sweet; O Catuneanu; A. Hamblin; David Lloyd; Jim Barclay