

Early Permian Proximally- to Distally-Steepened Cool-Water Shelf-to-Basin Transition, Sverdrup Basin, Arctic Canada*

Benoit Beauchamp¹

Search and Discovery Article #50632 (2012)**

Posted July 2, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

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Abstract

Artinskian (Lower Permian) and Wordian (Middle Permian) cool-water heterozoan carbonates formed extensive shelves in the Sverdrup Basin, Arctic Canada, where they pass laterally into substantially deeper water sediments that accumulated in a slope to basinal setting. The cool-water sedimentary regime followed a Pennsylvanian-Early Permian interval of warm water sedimentation that led to extensive shelf and shelf margin reef development. The shallow-shelf to deep-basin transition in the less productive carbonate cool-water setting contrasts with the far more prolific warm-water carbonate factories and their transition to Deepwater settings that existed earlier in the basin. In addition to a major drop in sediment production, cool water shelves or shelf-margins are devoid of reefs (only isolated mud mounds in the Artinskian, none in the Wordian) and microbial fabrics that play an important role in stabilizing slopes in their warm-water counterpart. Furthermore, heterozoan carbonate sediments composed of echinoderms, bryozoans, and brachiopods, ranging from whole fossils to bioclasts, remained uncemented on the sea floor and at shallow burial depth due to the cooler water setting. The sediments were thus much freer to be moved around than in their warm water counterparts. Cool-water carbonate shelves of the Sverdrup Basin thus bear much resemblance to later clastic shelves as the sedimentary accumulations expanded from a relatively narrow nearshore area following the large second-order transgressions to prograde in a basinward direction via a series of gently-inclined clinoforms. The recurrent pattern of progradation evolved from proximally-steepened shelf to distally-steepened shelf with relatively coarse heterozoan sediments avalanching in a basinal direction with time. Once the sediment was formed on the sea floor following the death of various organisms, the principal agent for the redistribution were storms that were free to sweep wide areas of the shelf as they were unimpeded by shelf margin or mid-shelf reef constructions as in the earlier warm water setting. Ultimately, sloping carbonates pass into spiculitic chert which represents sedimentation in a distal shelf, ramp, and slope setting. Coarse-grained turbidities are relatively well developed in these cool-water settings owing to the availability of a rich supply of loose coarse grained material on the shelf, which is not the case in the older warmer setting.

References

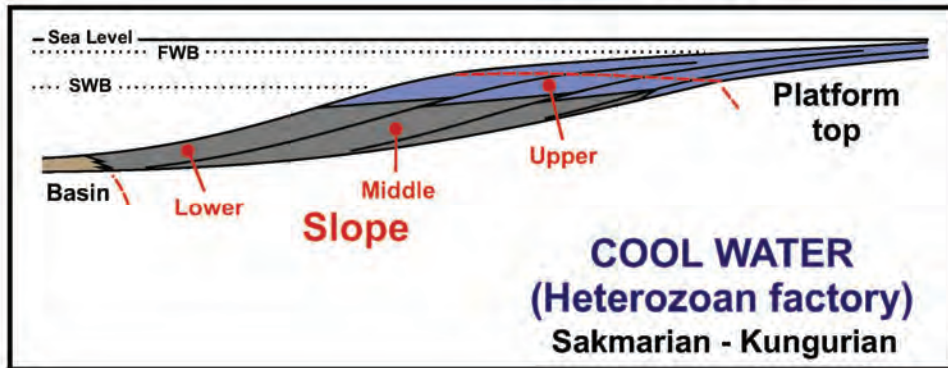
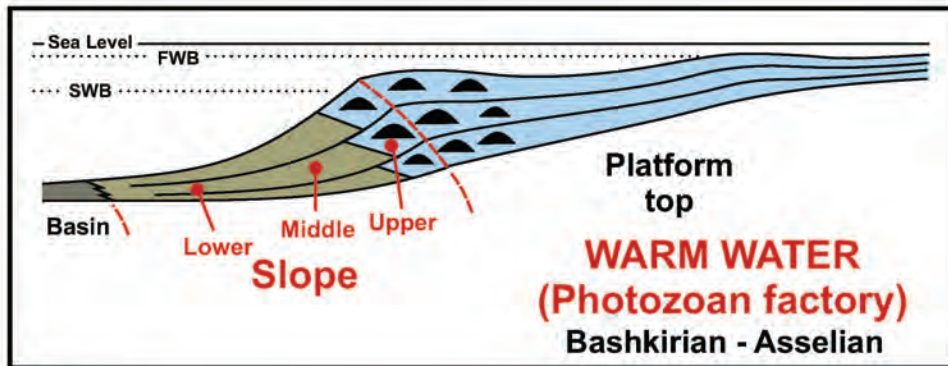
- Davies, G.R., 1977, Turbidites, Debris Sheets, and Truncation Structures in Upper Paleozoic Deep-Water Carbonates of the Sverdrup Basin, Arctic Canada: SEPM Special Publication No. 25, p. 221-247.
- Throsteinsson, R., 1974, Carboniferous and Permian stratigraphy of Axel Heiberg Island and western Ellesmere Island, Canadian Arctic Archipelago: Geological Survey of Canada Bulletin #224.
- Ziegler, P.A., and F. Horvath, (eds.), 1996, Structure and prospects of Alpine Basins and Forelands: Peri-Thethys Memoir 2, Museum of Natural History, Paris, France, 547 p.

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University of Calgary





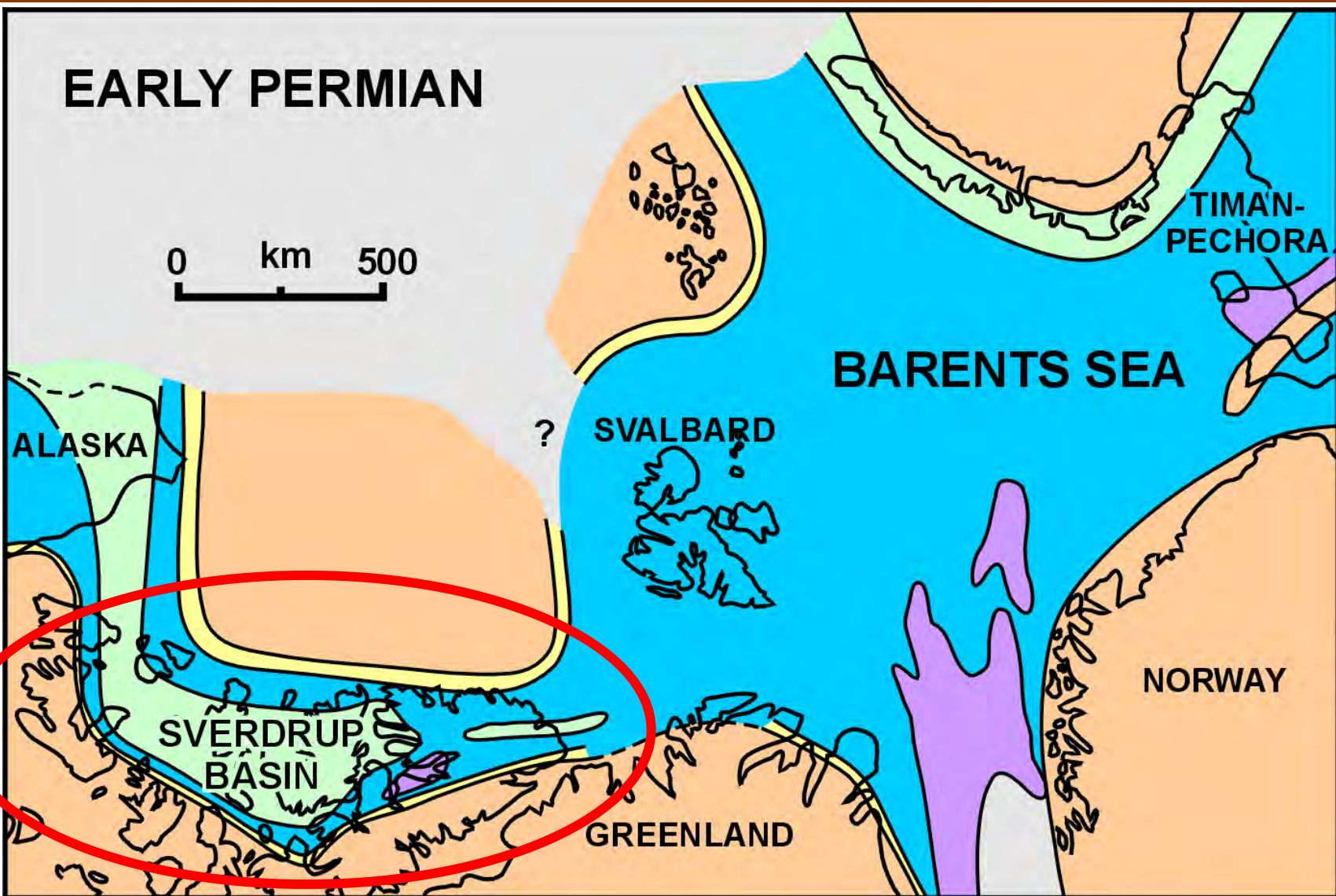
Presenter's notes:

- Six fundamental conditions have to be met for biogenic siliceous deposits to precipitate, accumulate and be preserved as bedded chert in the rock record :
 - Adequate supply of silica and nutrients
 - Transport mechanism for silica and nutrients
 - Opportunistic biota (sponge, radiolarian, diatom)
 - Suitable marine environment for biota
 - Minimal carbonate and/or clastic dilution
 - Favourable post-mortem setting above and below sea floor

Let's examine how these conditions fared before, during and after the PCE

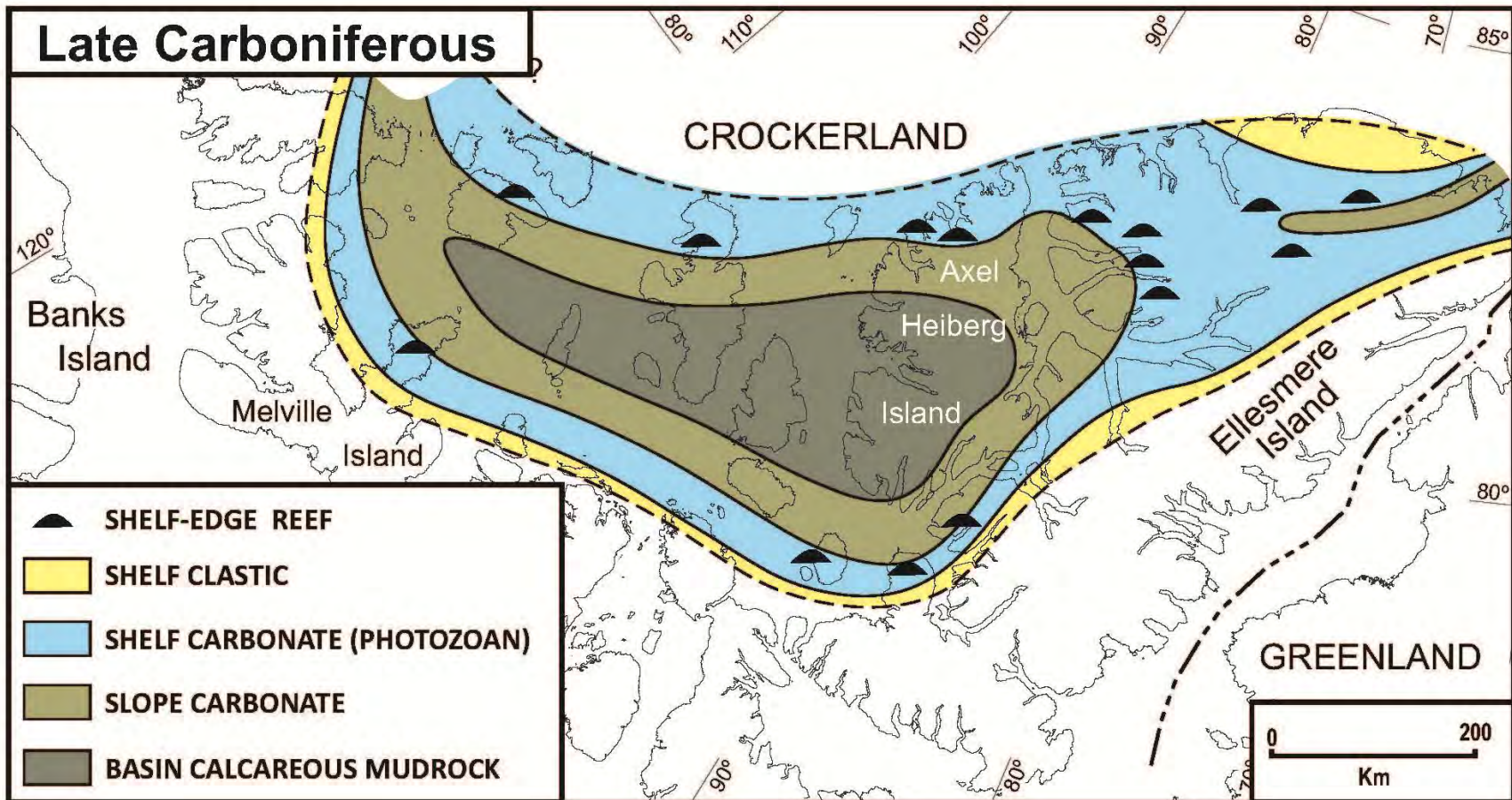
EARLY PERMIAN

0 km 500

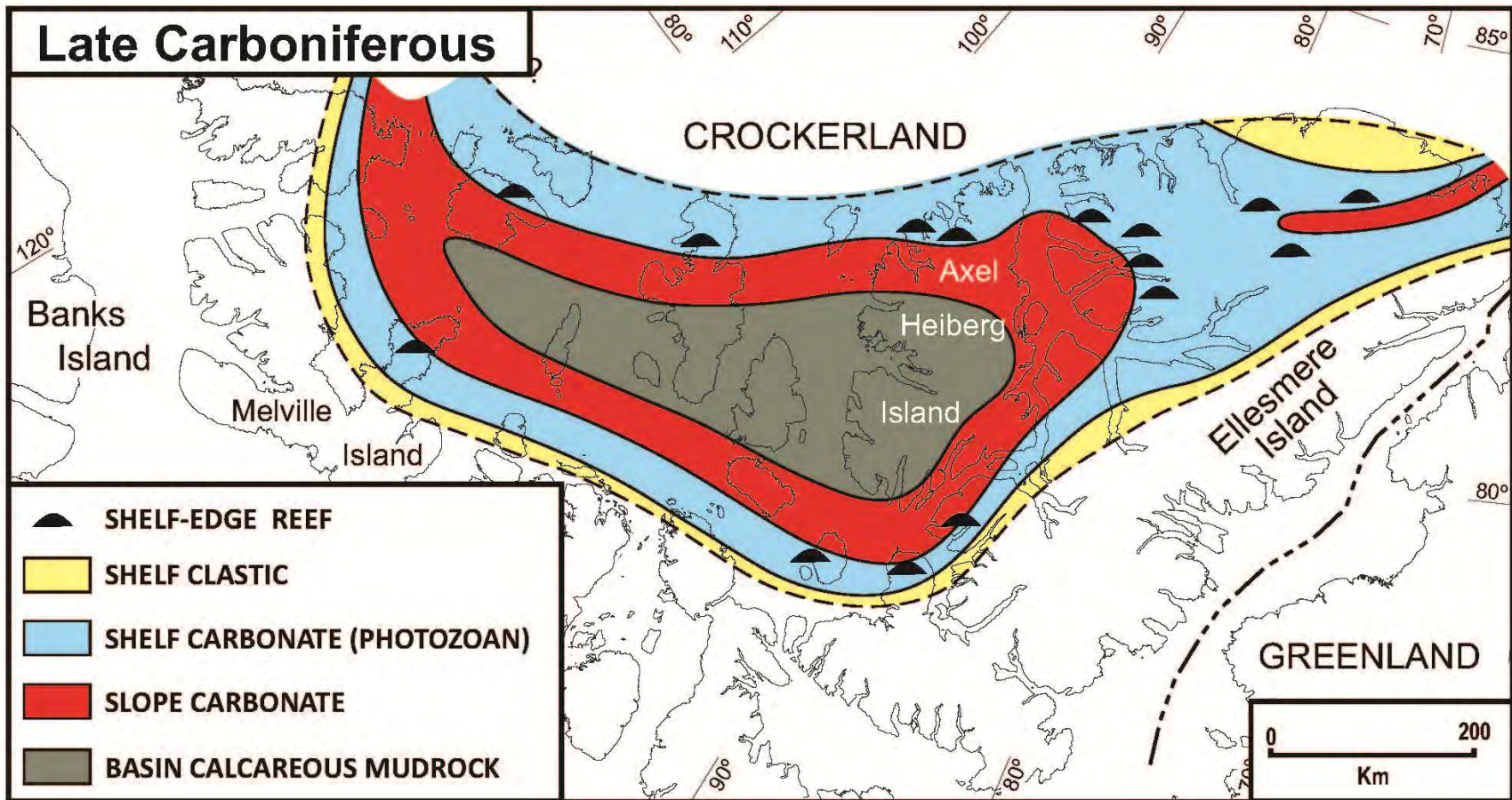


Land	Fluvial-shelf siliciclastics	Shelf carbonates	Marine evaporites	Shelf chert	Trough mudrocks
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Late Carboniferous



Late Carboniferous



Davies, G.R., 1977

Turbidites, Debris Sheets, and Truncation Structures in Upper Paleozoic Deep-Water Carbonates of the Sverdrup Basin, Arctic Canada.

SEPM Special Publication No. 25, p. 221-247.



Thorsteinsson, 1974

				Basin Margin	Basin Centre
LOWER TRIASSIC				BJ	BF
PERMIAN	UPPER	LOPINGIAN	CHANGHSINGIAN		
			WUCHIAPINGIAN		
	MIDDLE	GUADALUPIAN	CAPITANIAN		
			WORDIAN	TF DE	
			ROADIAN	AS	VH
			KUNGURIAN	SB	
CARBONIFEROUS	LOWER	CISURALIAN	ARTINSKIAN		
			SAKMARIAN		
			ASSELIAN		
	UPPER		GZHELIAN	CF BC TQ MB NA	HF
			KASIMOVIAN	CF AN	
			MOSCOVIAN	CF CF	
			BASHKIRIAN		OF
	LOWER		SERPUKHOVIAN		BF BF
			VISÉAN	EF	
			TOURNAISIAN		

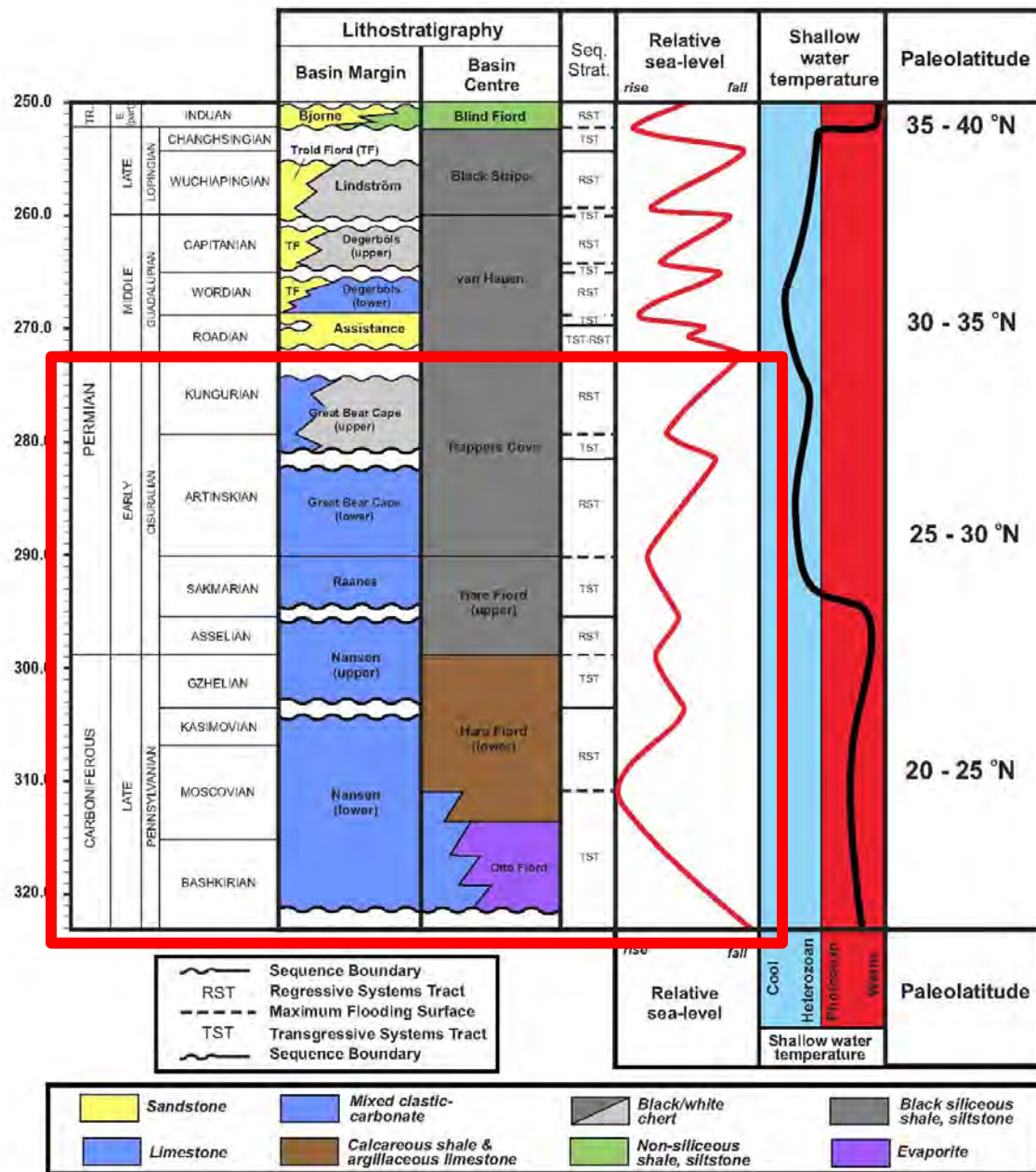
-  Limestone
-  Evaporite
-  Sandstone, minor conglomerate
-  Dark-coloured chert, shale, siltstone
-  Green non-siliceous shale, siltstone
-  Shale, siltstone, argillaceous limestone

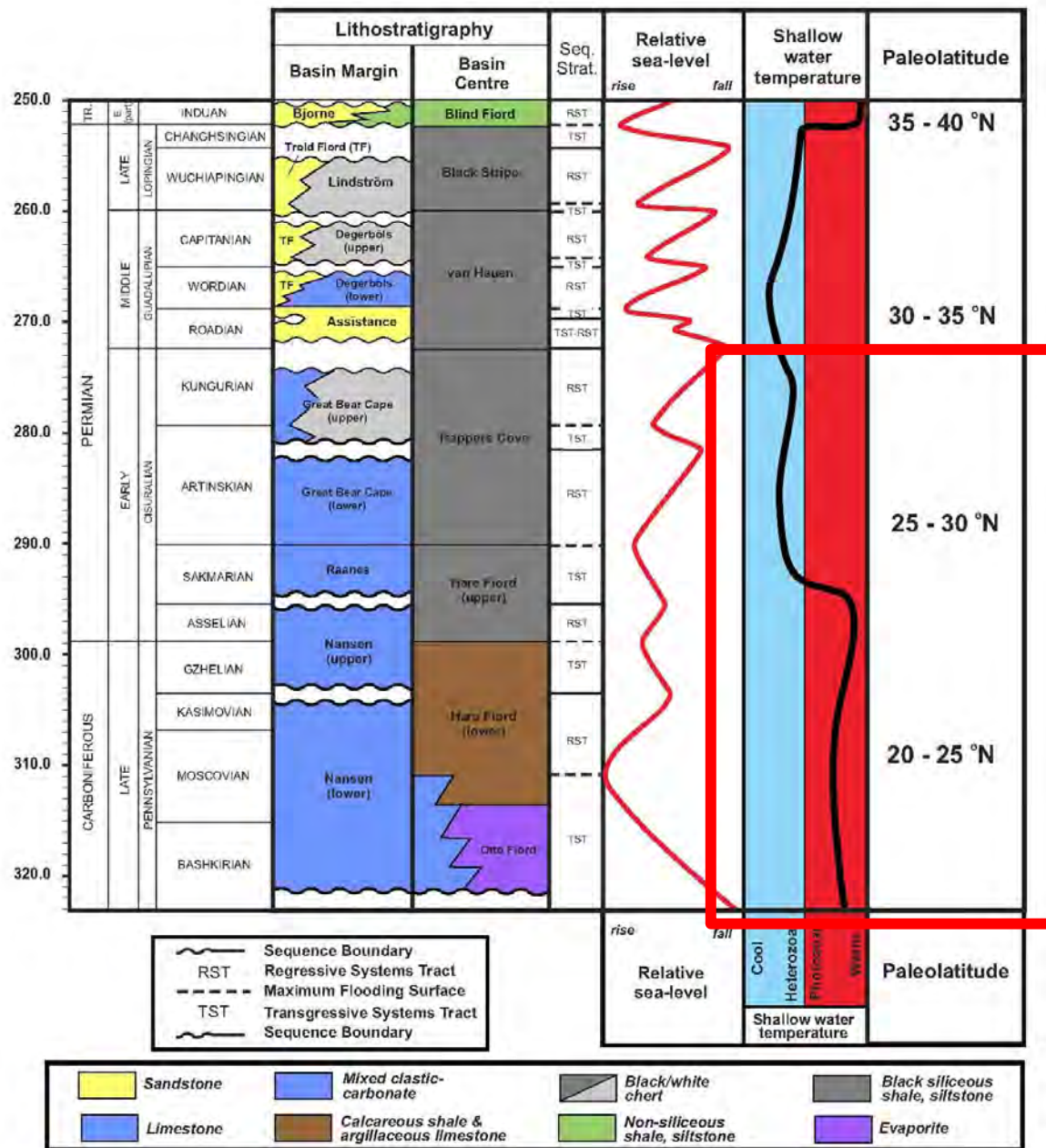
EF EMMA FIORD FM
 BF BORUP FIORD FM
 AN ANTOINETTE FM
 NA NANSEN FM

SB SABINE BAY FM
 AS ASSISTANCE FM
 TF TROLD FIORD FM
 DE DEGERBØLS FM

CF CANYON FIORD FM
 BC BELCHER CHANNEL FM
 TQ TANQUARY FM
 MB MOUNT BAYLEY FM

OF OTTO FIORD FM
 HF HARE FIORD FM
 VH VAN HAUEN FM
 BF BLIND FIORD FM
 BJ BJORNE FM

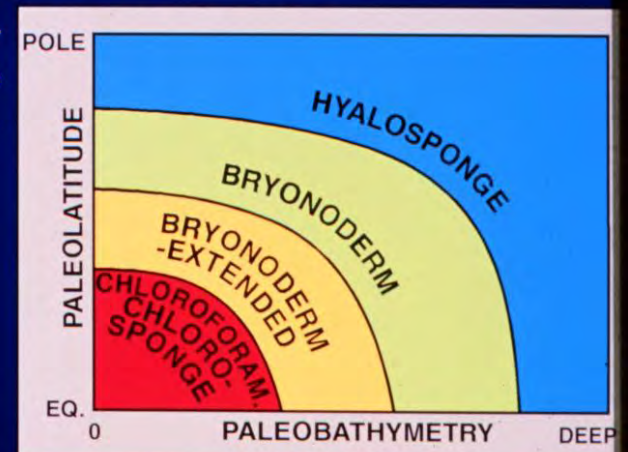




PHOTOZOAN (WARM)

HETEROZOAN (COOL)

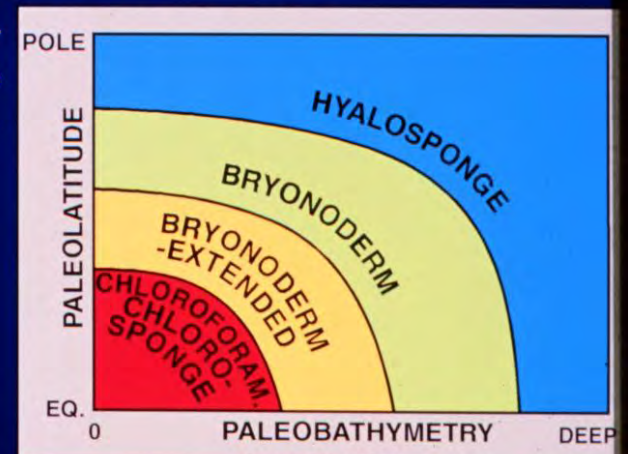
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SPONGE SPICULE				
BRYOZOAN				
ECHINODERM				
BRACHIOPOD				
MOLLUSC				
SMALL FORAMINIFER				
SOLITARY RUGOSE CORAL				
TUBIPHYTES				
FUSULINID				
COLONIAL RUGOSE CORAL				
RED ALGAE				
ENCrustING FORAM.				
PHYLLOID ALGAE				
DASYCLADACEAN				
PALAEOAPLYSINA				
INOZOAN-SPHINCTOZOAN				
ARCHAEOLITHOPORELLA				
ONCROID				
OOID				



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(WARM)**

**HETEROZOAN
(COOL)**

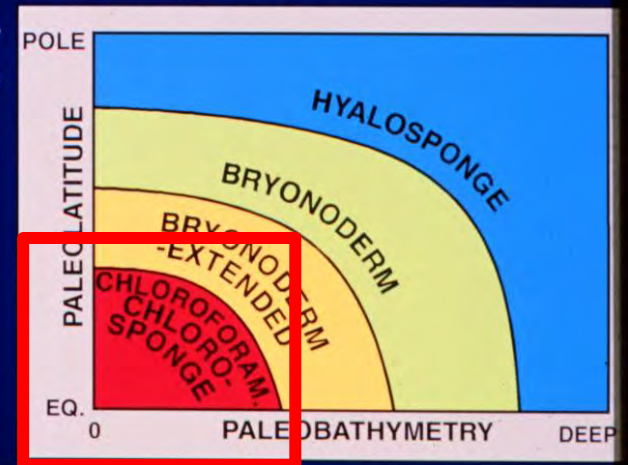
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HETEROZOAN (COOL)

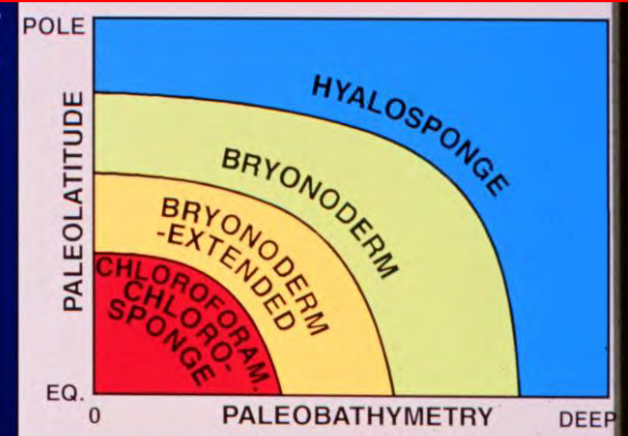
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HETEROZOAN (COOL)

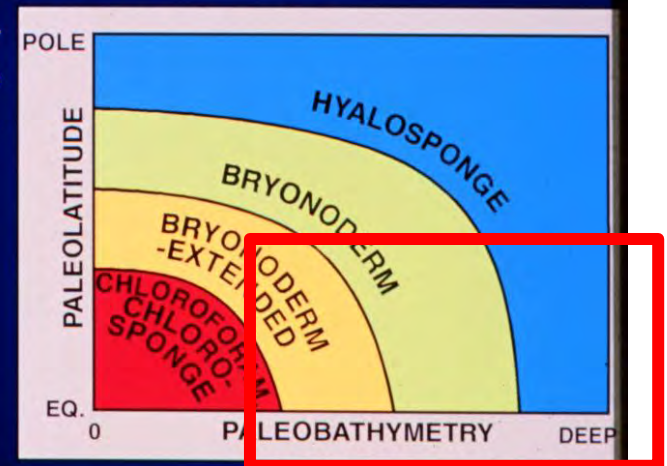
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SPONGE SPICULE	-----	-----	-----	-----
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BRACHIOPOD	-----	-----	-----	-----
MOLLUSC	-----	-----	-----	-----
SMALL FORAMINIFER	-----	-----	-----	-----
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ONCROID	-----	-----	-----	-----
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HETEROZOAN (COOL)

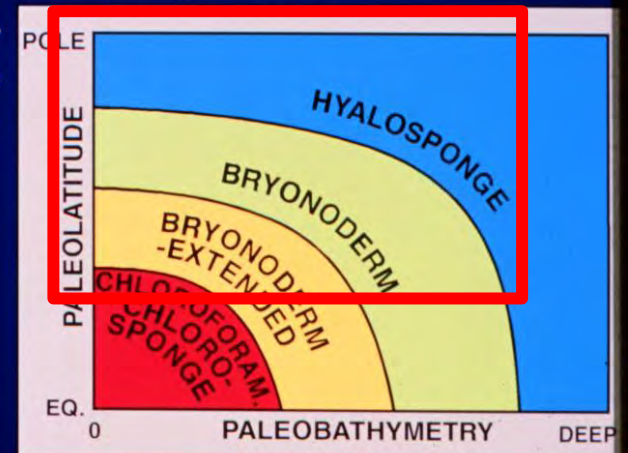
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ASSELIAN

Shallow-water biota

- *Bryomol*
- *Chlorofoam*
- ▼ *Chlorosponge*

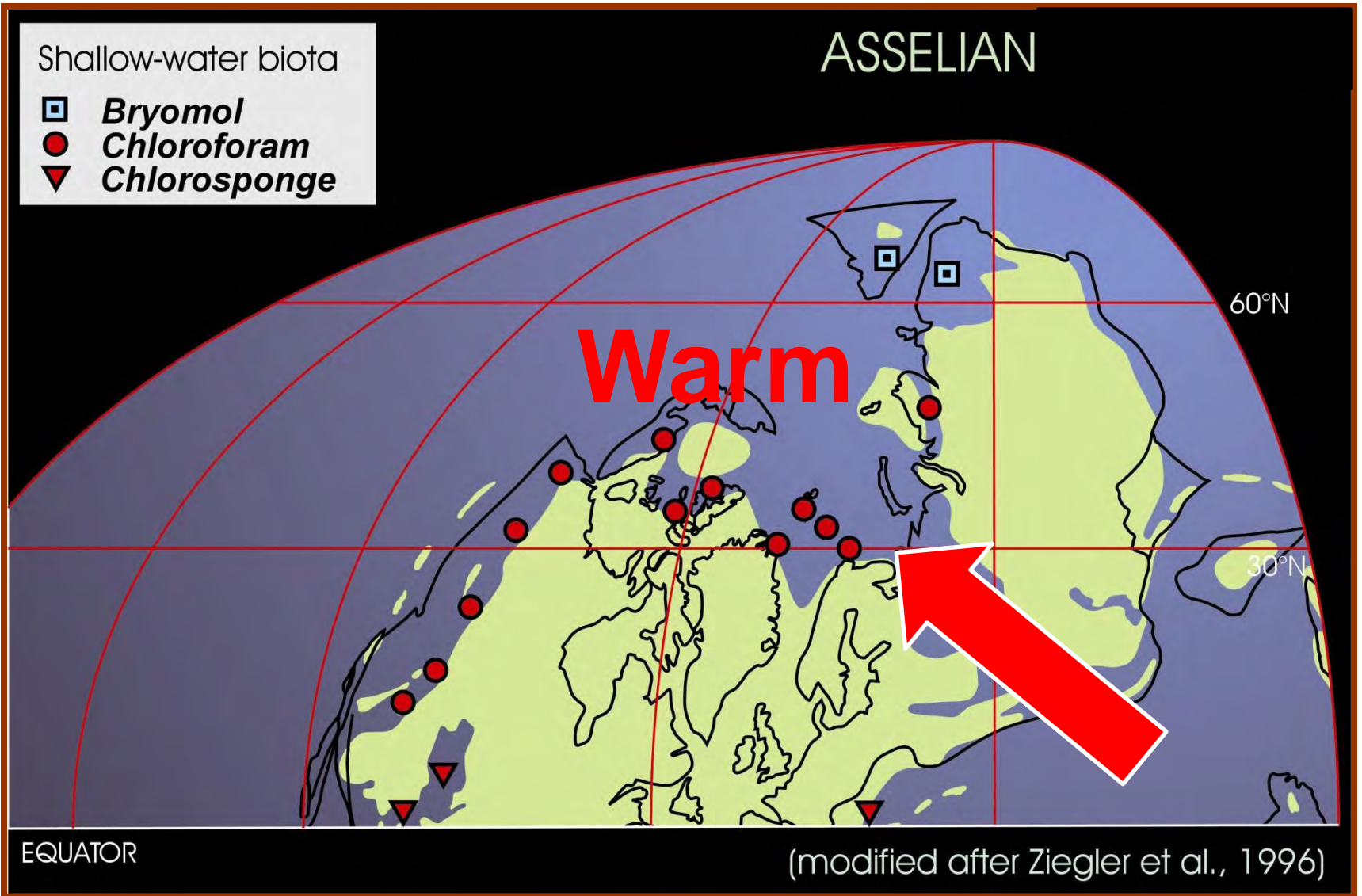
Warm

60°N

30°N

EQUATOR

(modified after Ziegler et al., 1996)



ASSELIAN

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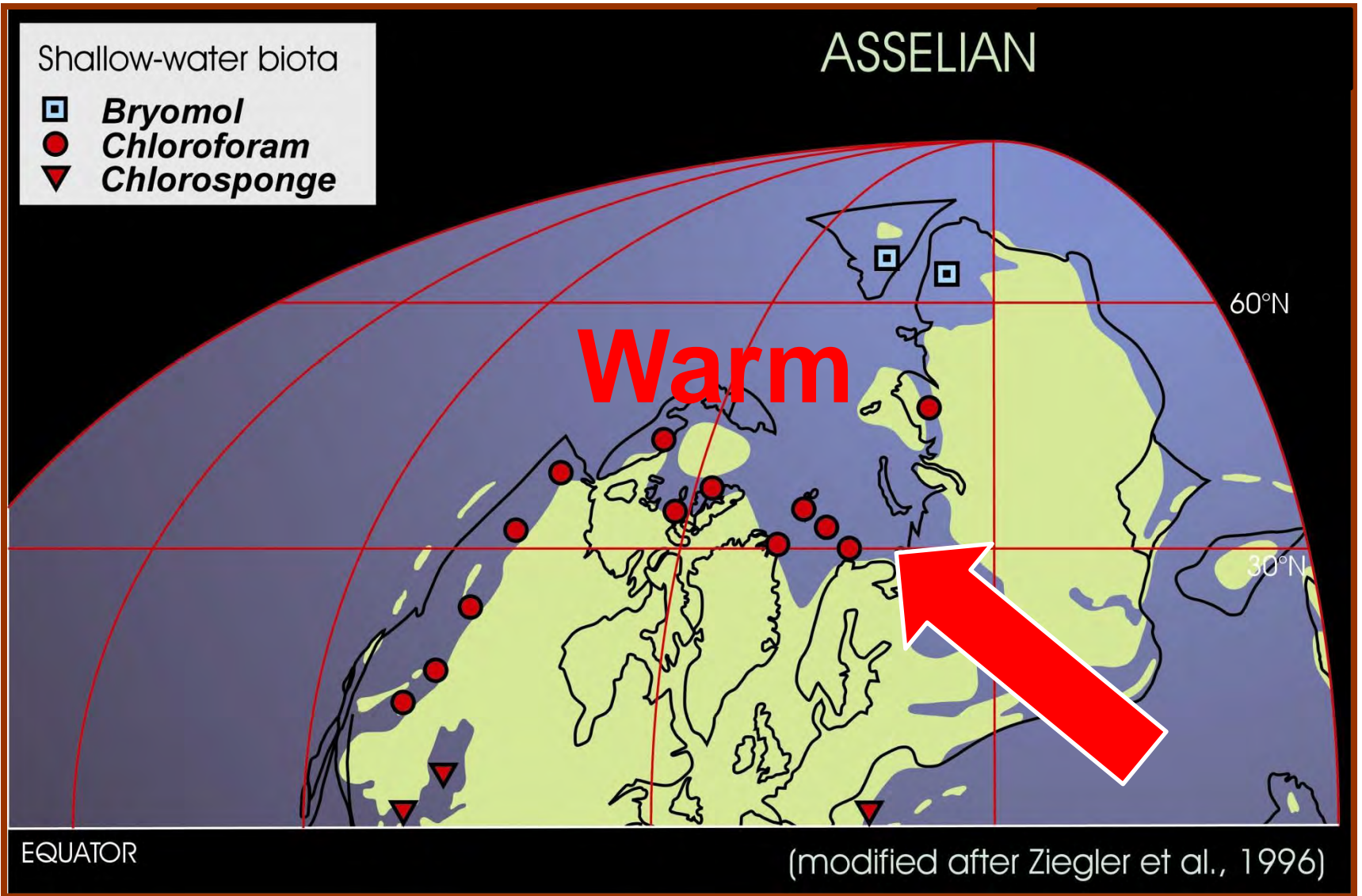
Warm

60°N

30°N

EQUATOR

(modified after Ziegler et al., 1996)



ARTINSKIAN

Shallow-water biota

- ▣ *Bryomol*
- ◐ *Bryonoderm-ext.*
- ◑ *Bryonoderm*
- *Chlorofoam*
- ▼ *Chlorosponge*

Chert

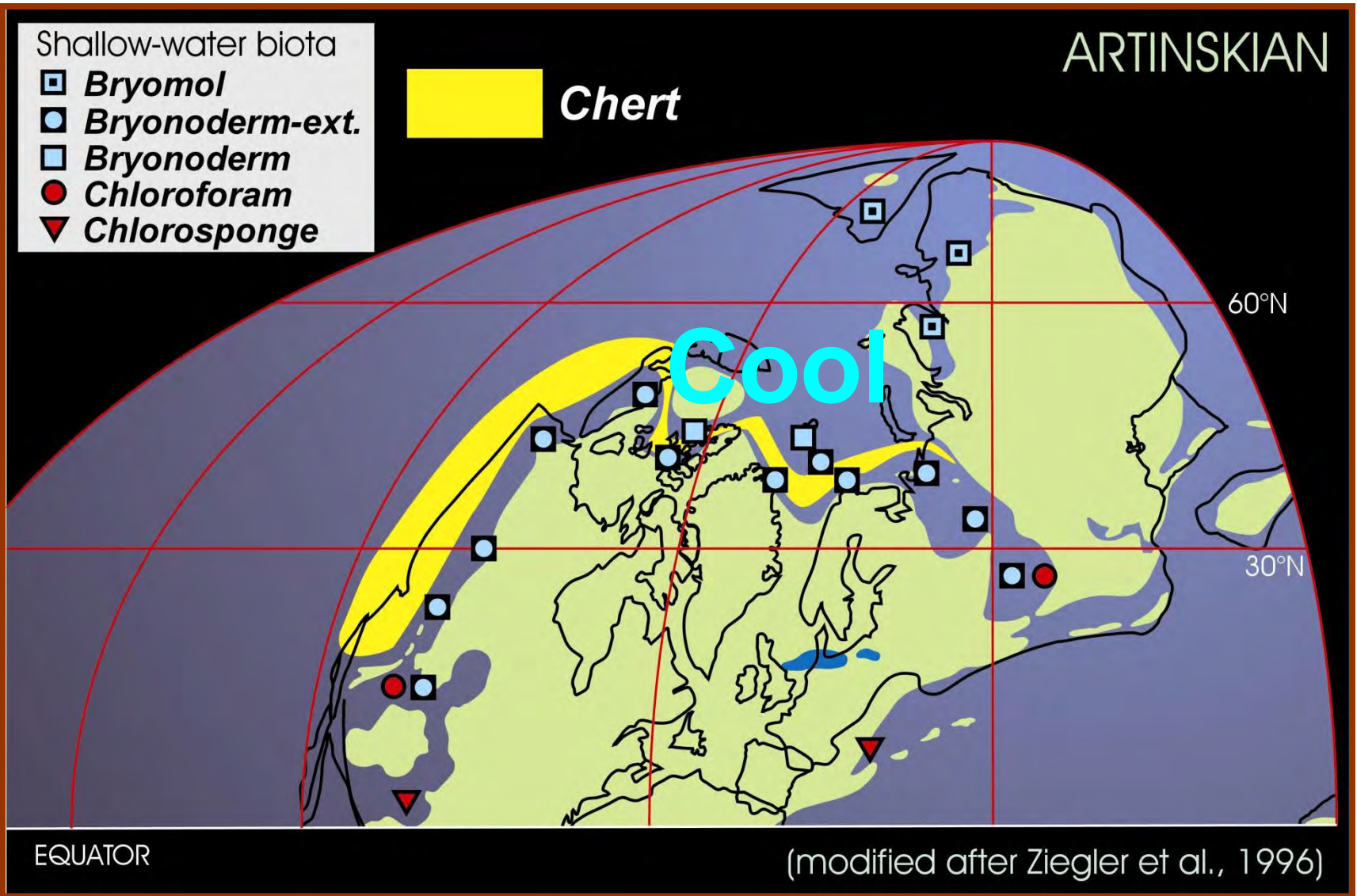
Cool

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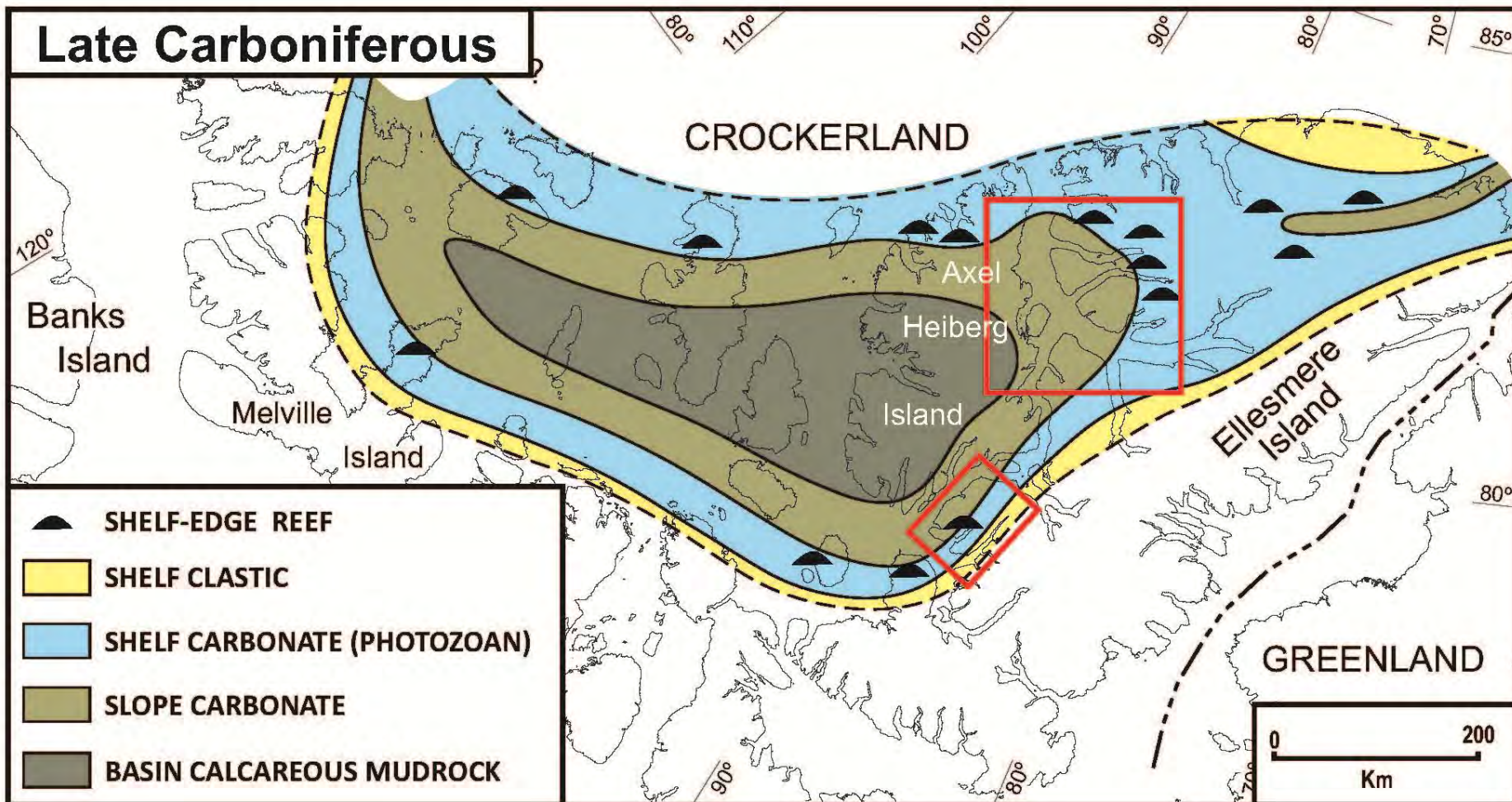
30°N

EQUATOR

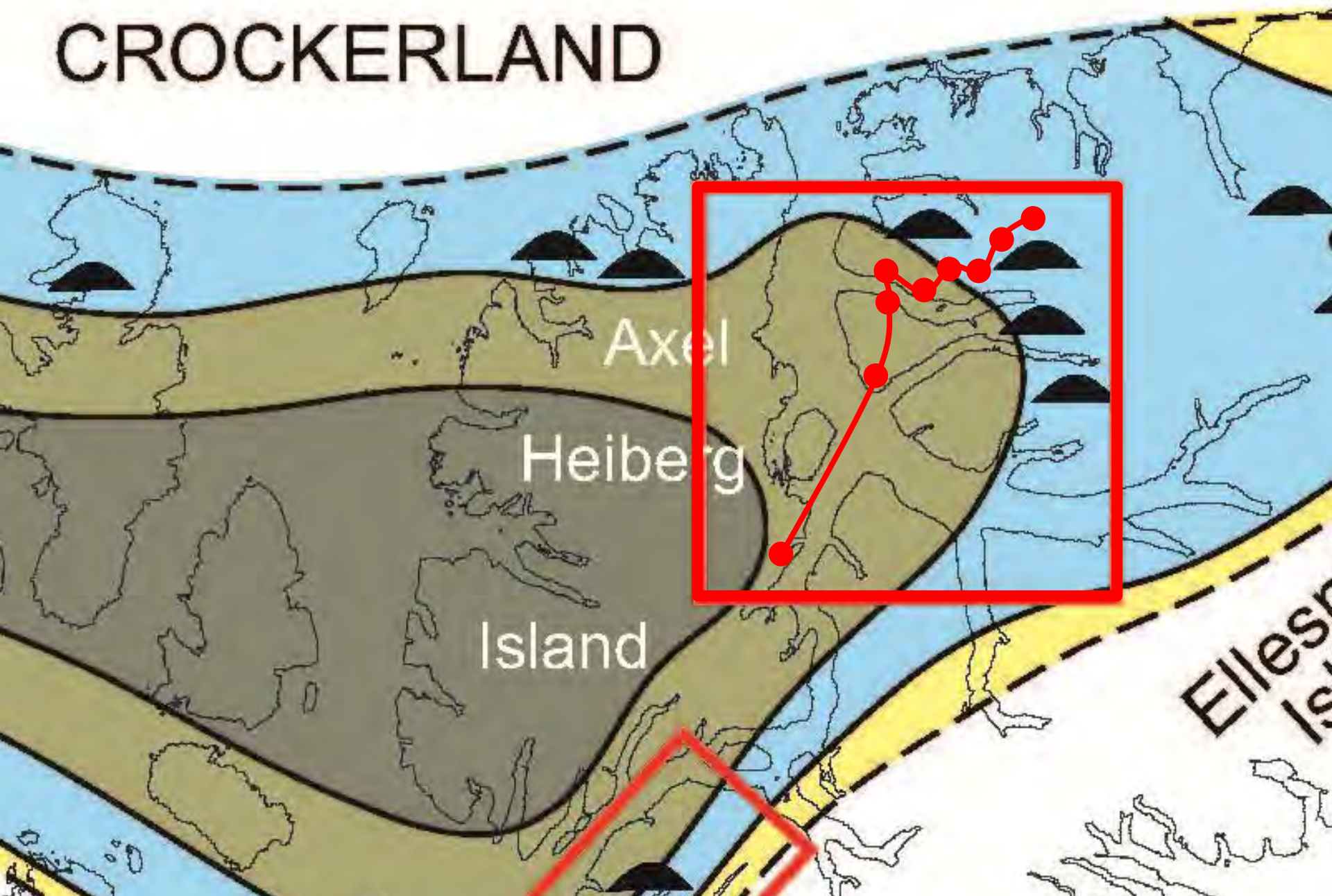
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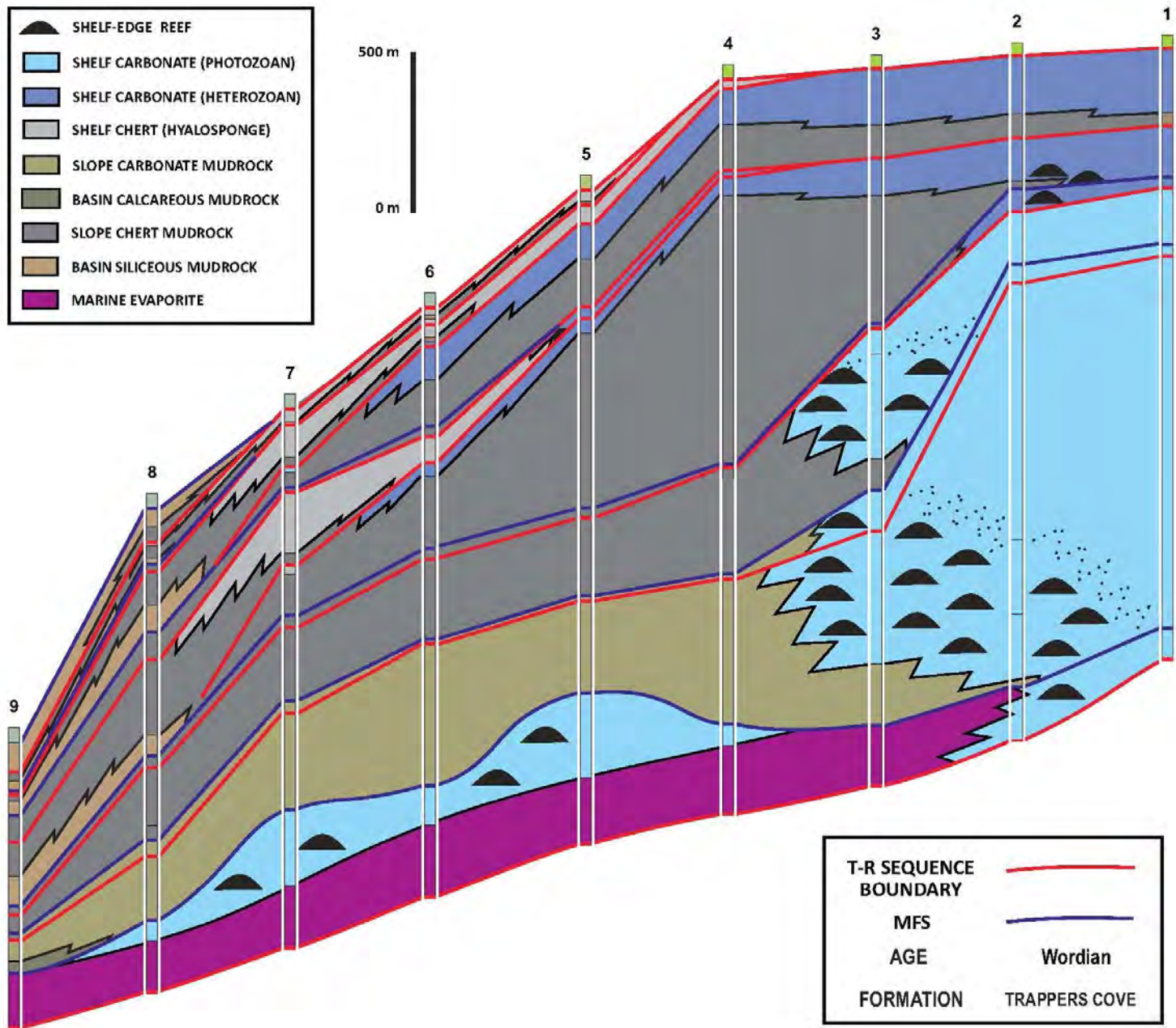


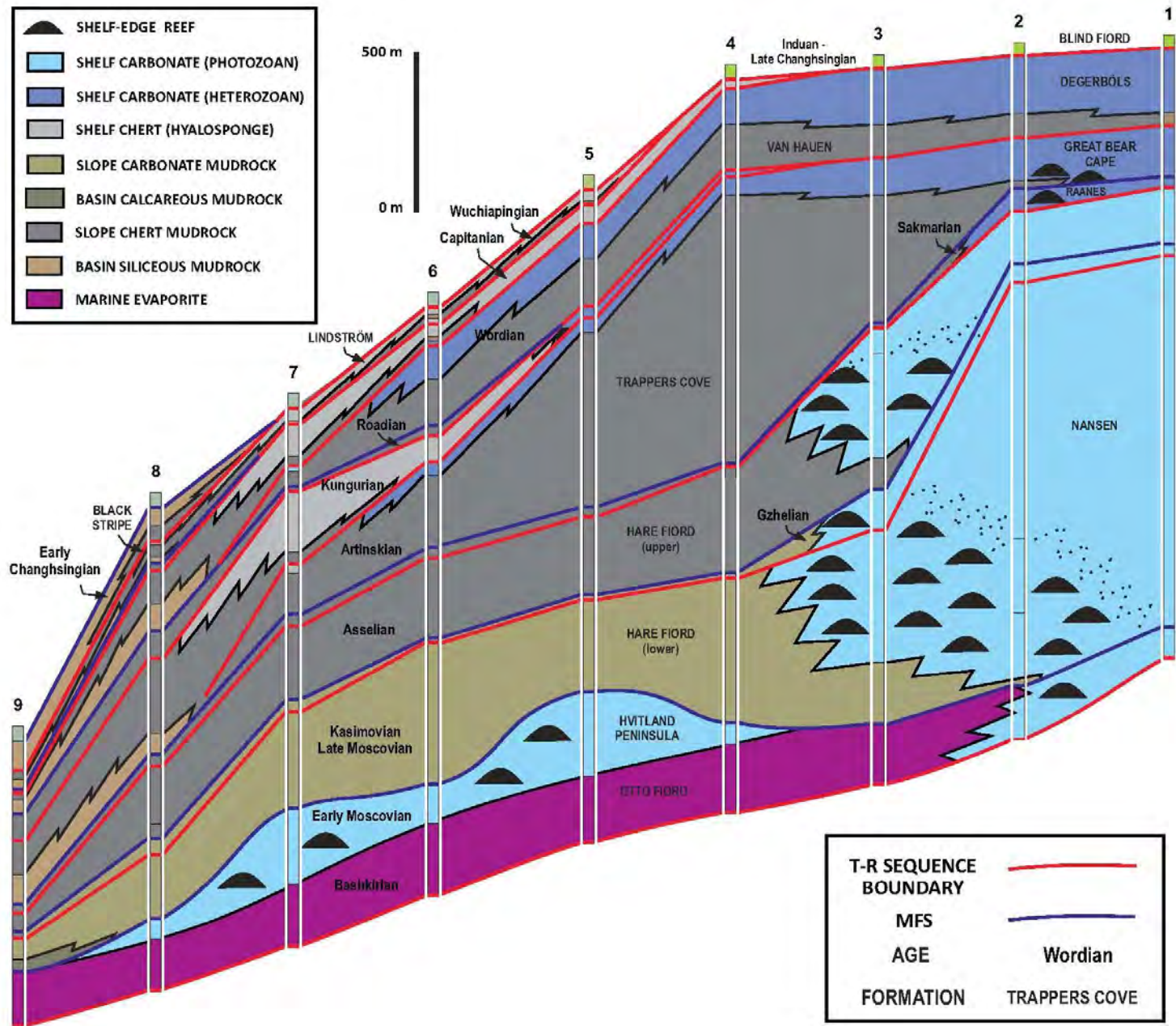
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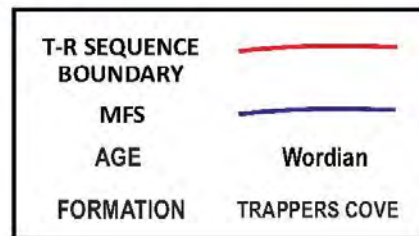
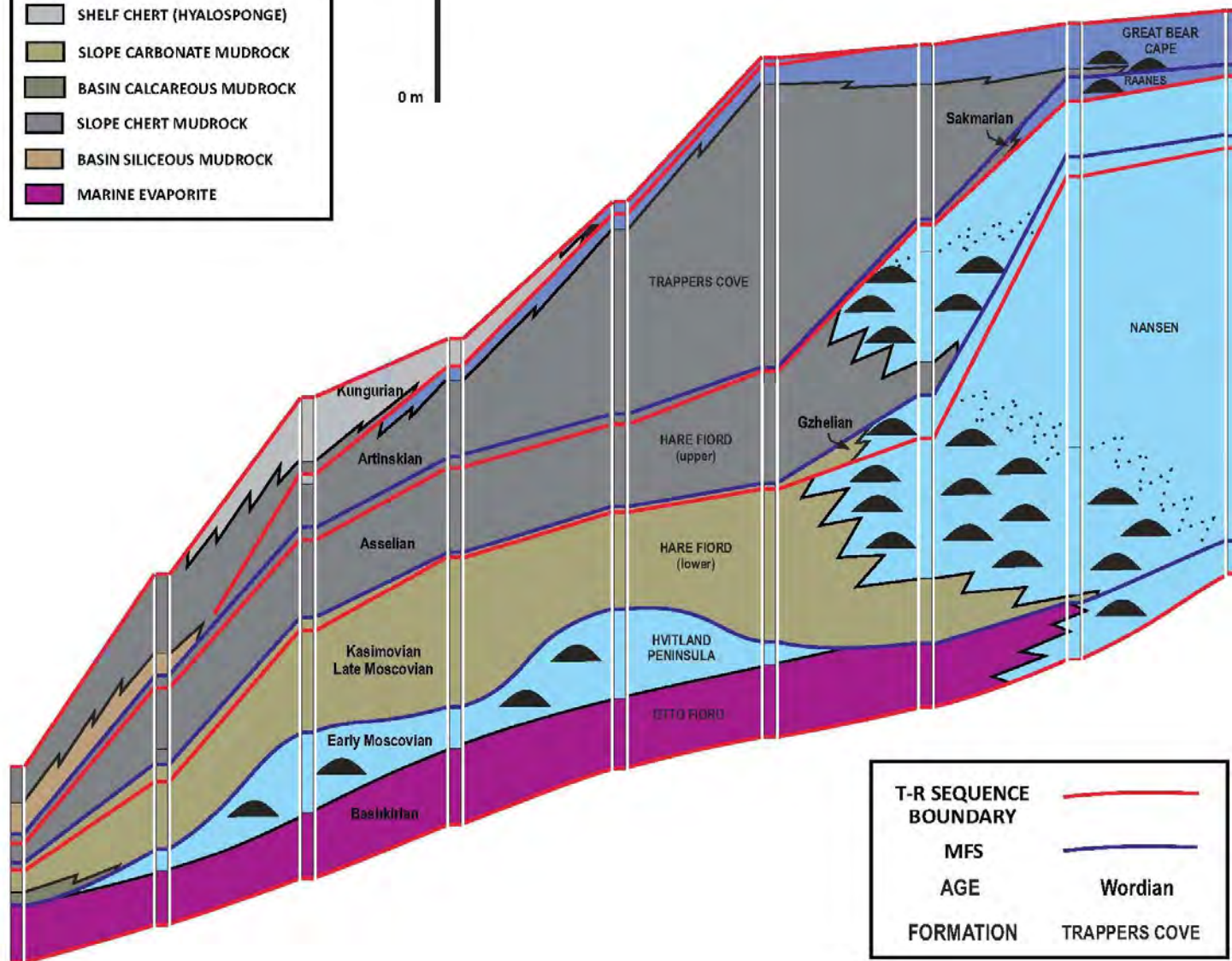


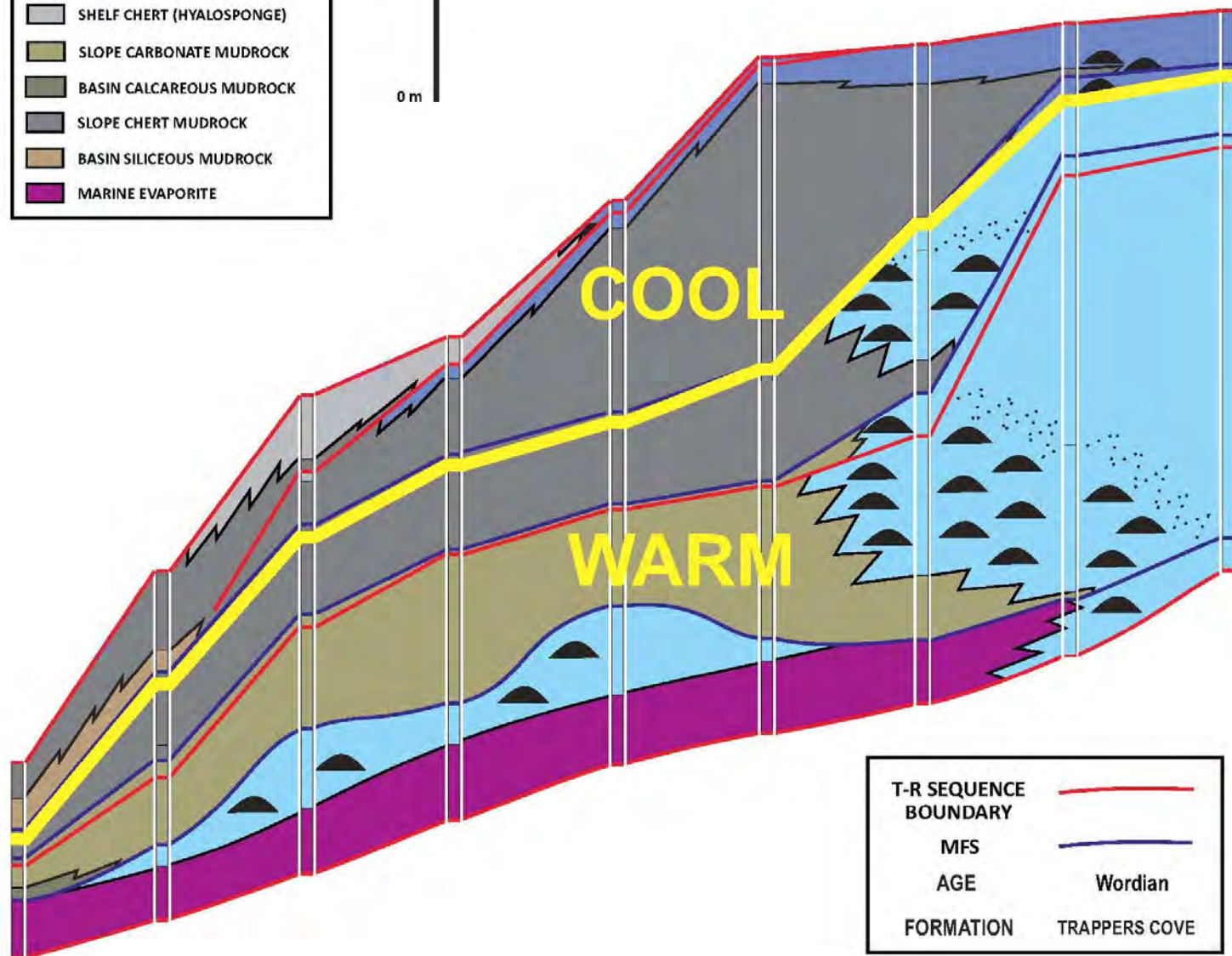
CROCKERLAND

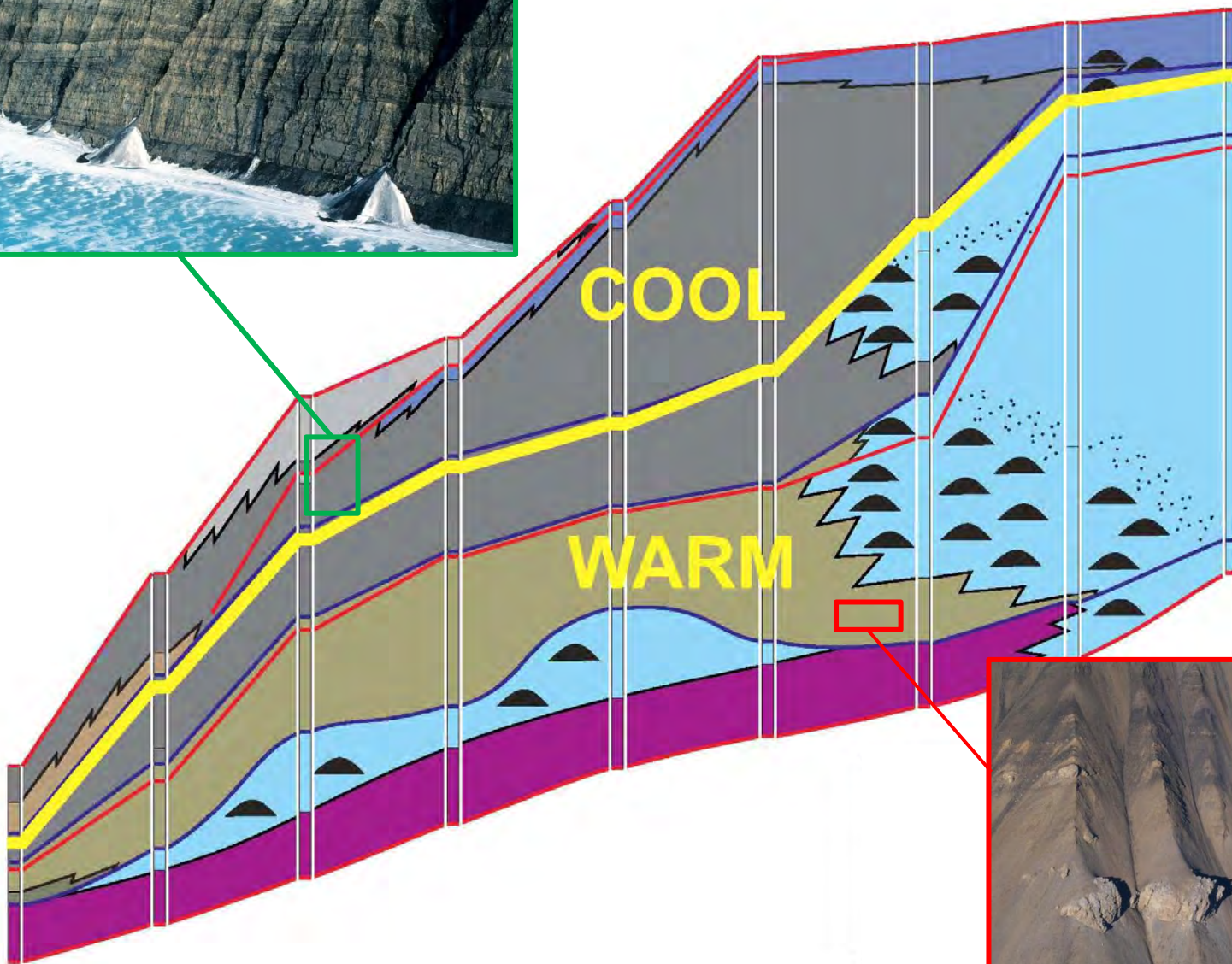












	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
SLOPE (RESEDIMENTED)	Cemented reef flanks	Upper slope		
	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
	Debris flow	Upper to middle slope		
	Grain flow	Middle slope		
	Turbidites	Middle to lower slope		
SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinofolds	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		

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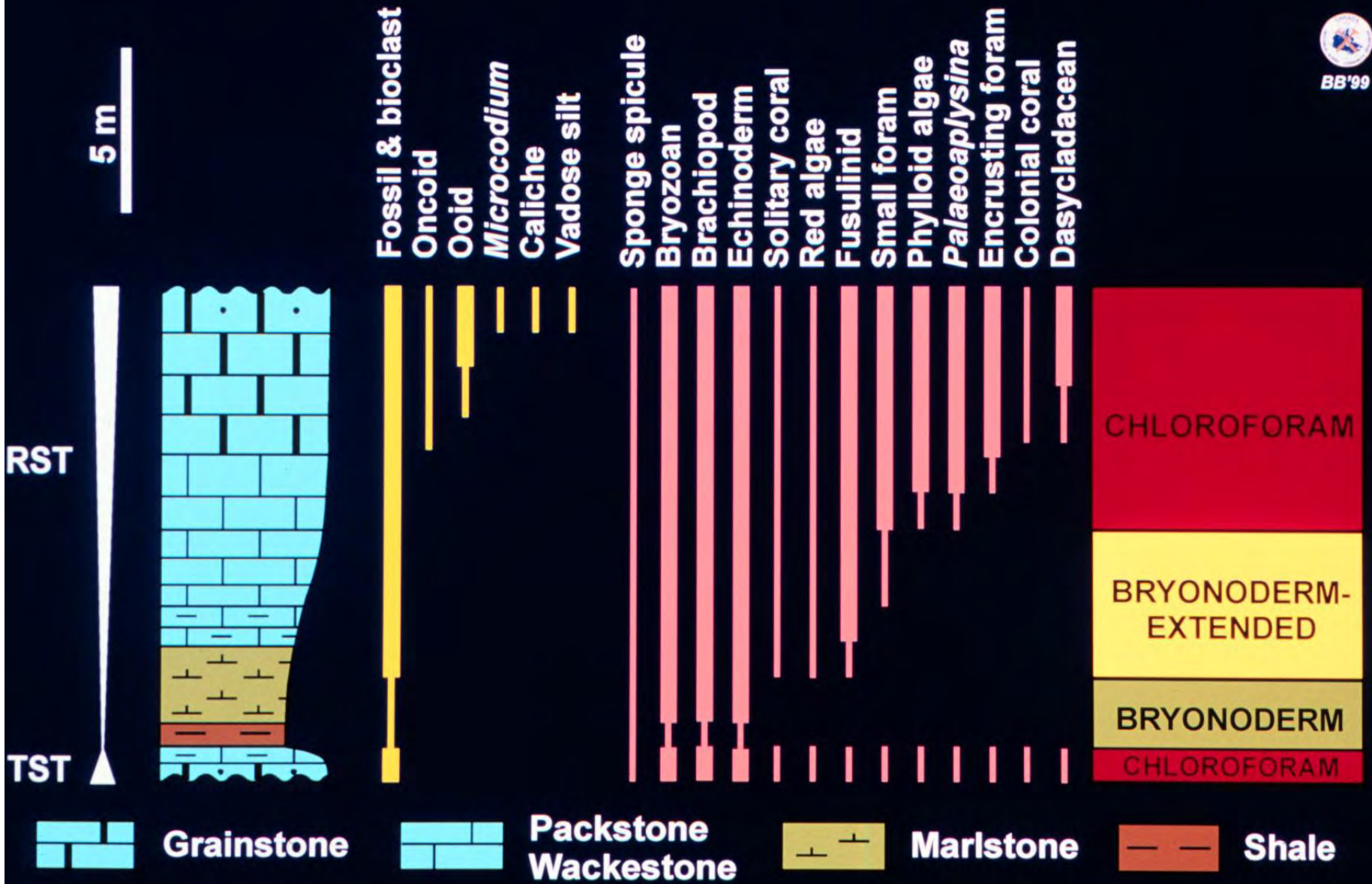
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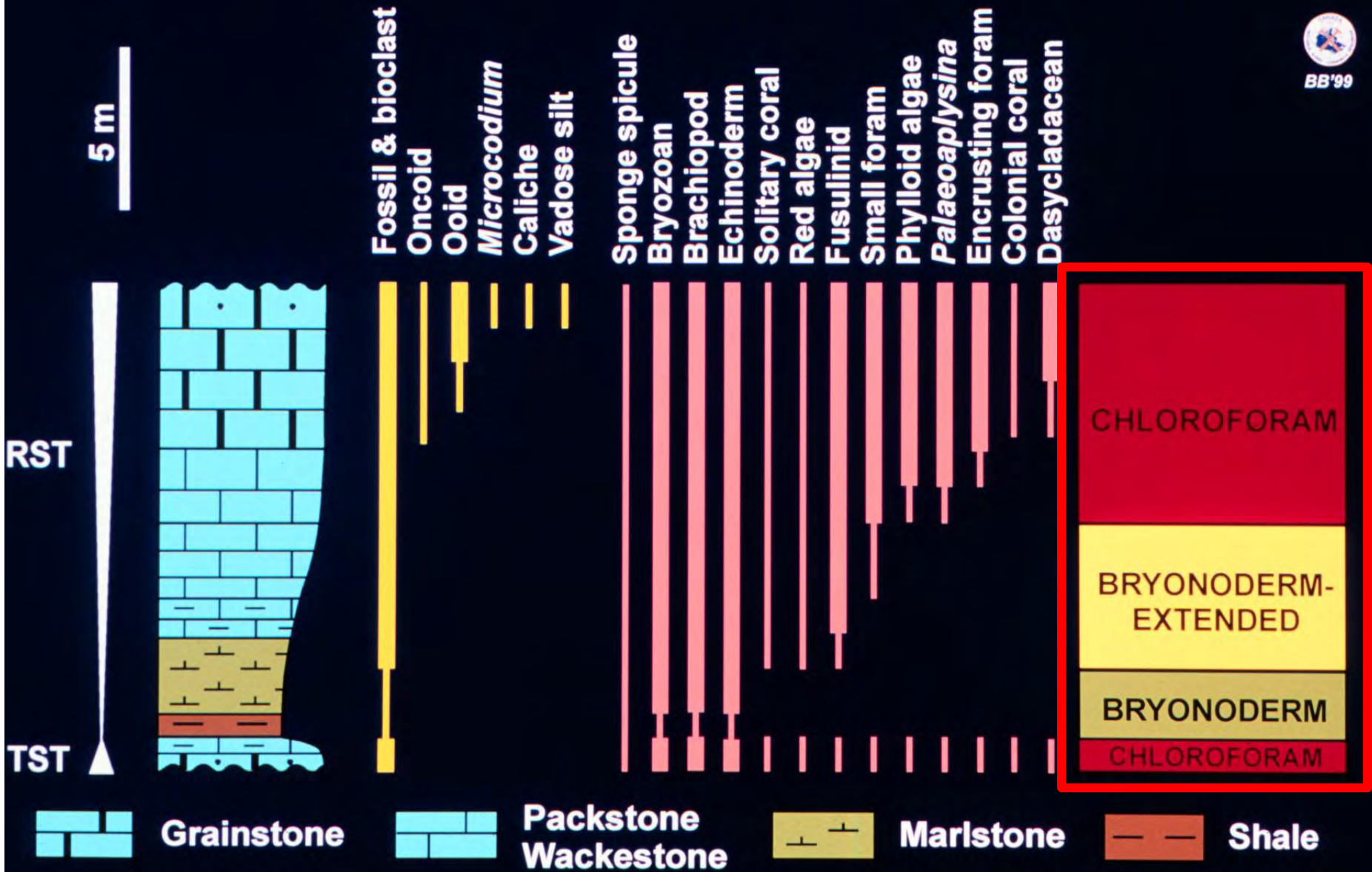
Bashkirian - Asselian



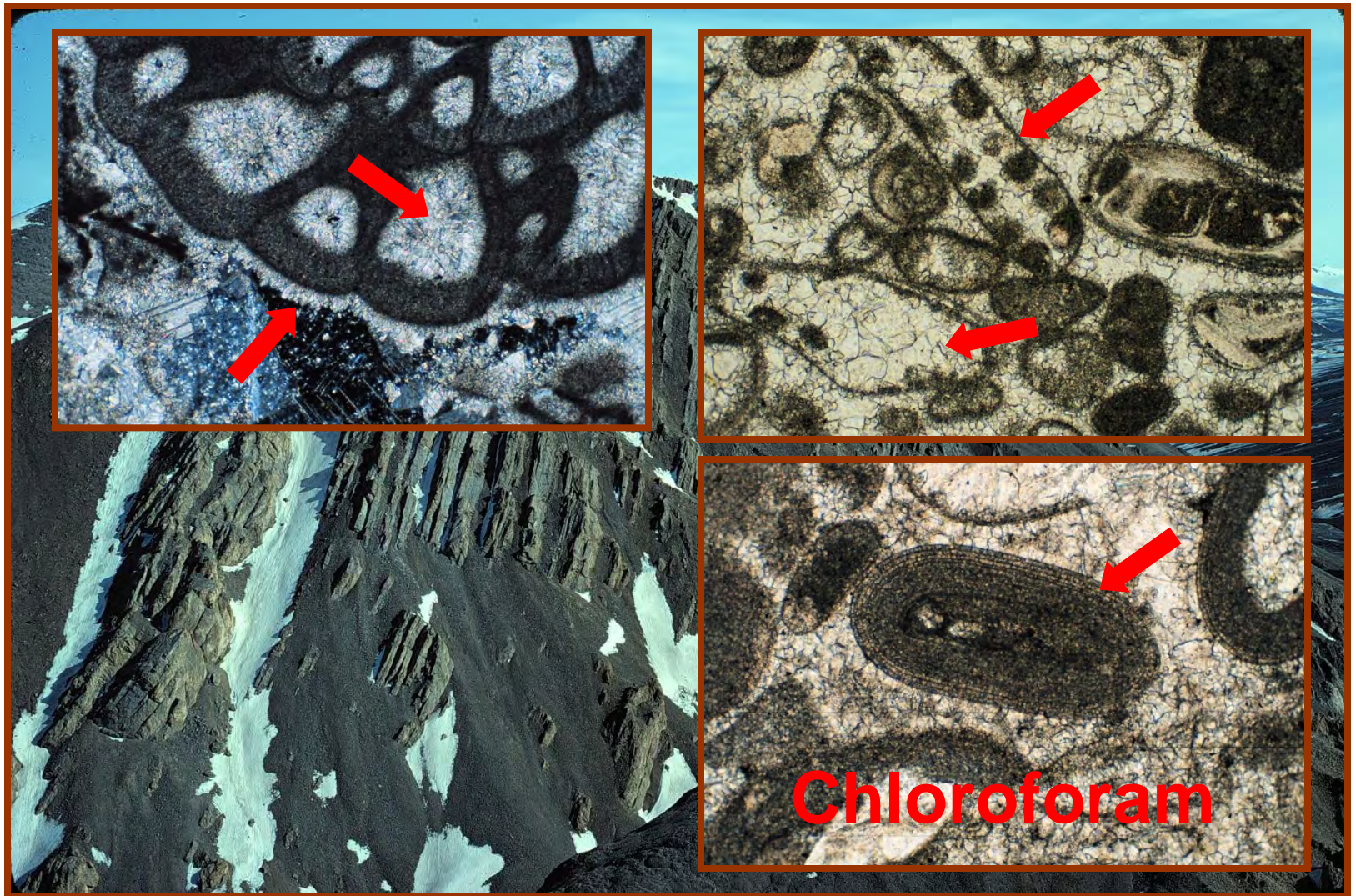
Bashkirian - Asselian







Photozoan carbonate factory

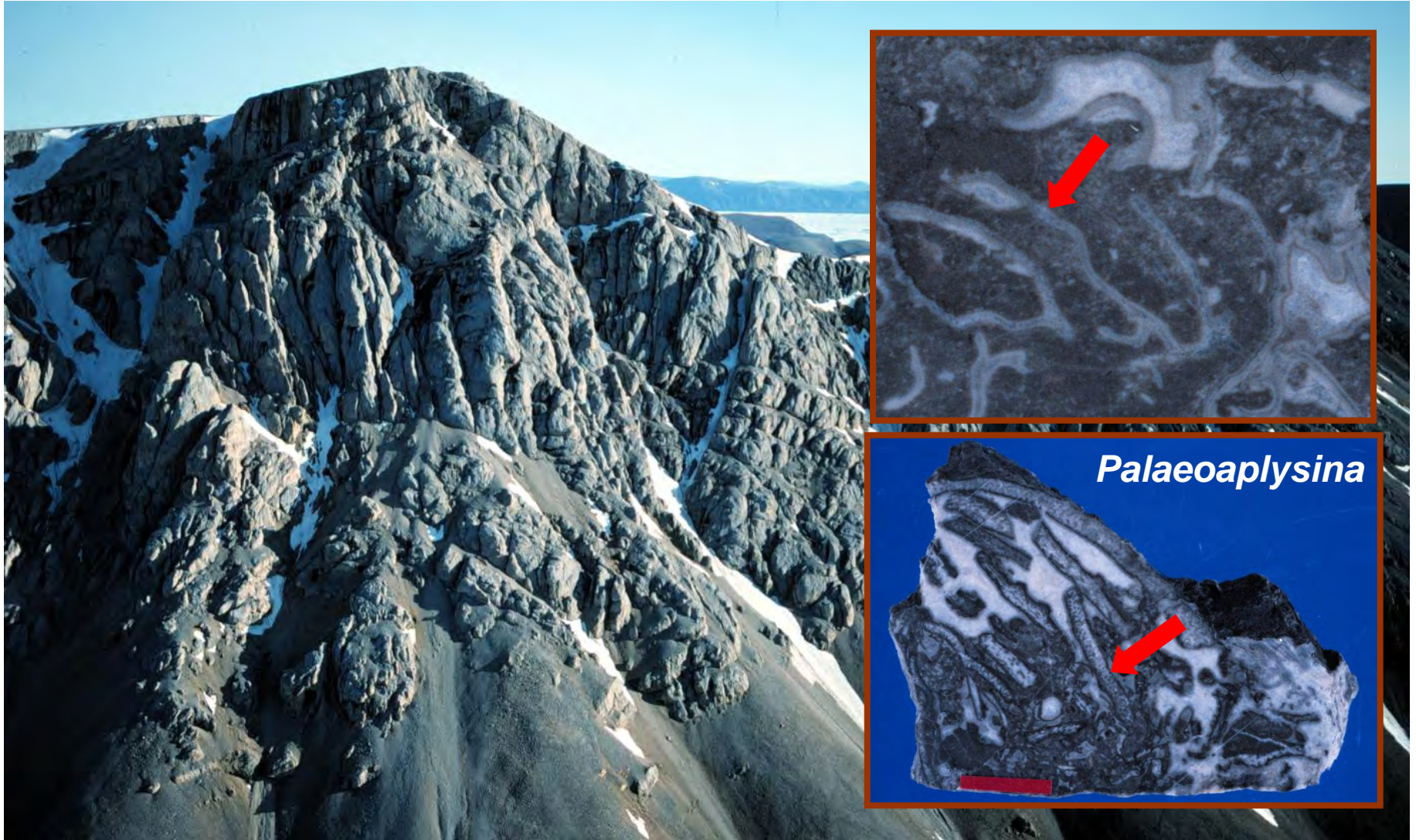


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	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
SLOPE (RESEDIMENTED)	Cemented reef flanks	Upper slope		
	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
	Debris flow	Upper to middle slope		
	Grain flow	Middle slope		
	Turbidites	Middle to lower slope		
SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinofolds	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		

Bashkirian - Asselian



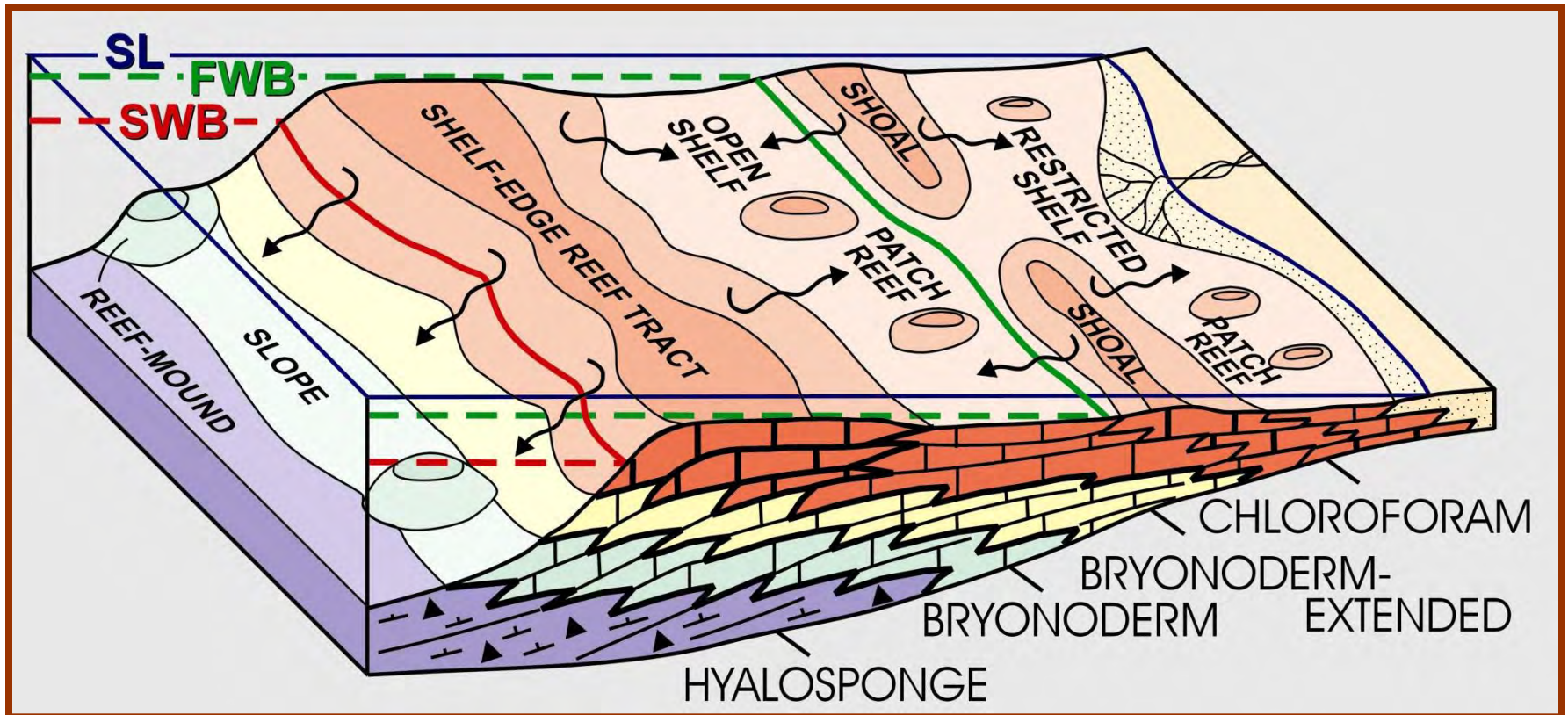
Bashkirian - Asselian



Warm (Bashkirian to Asselian)

Silica factory

Carbonate factory

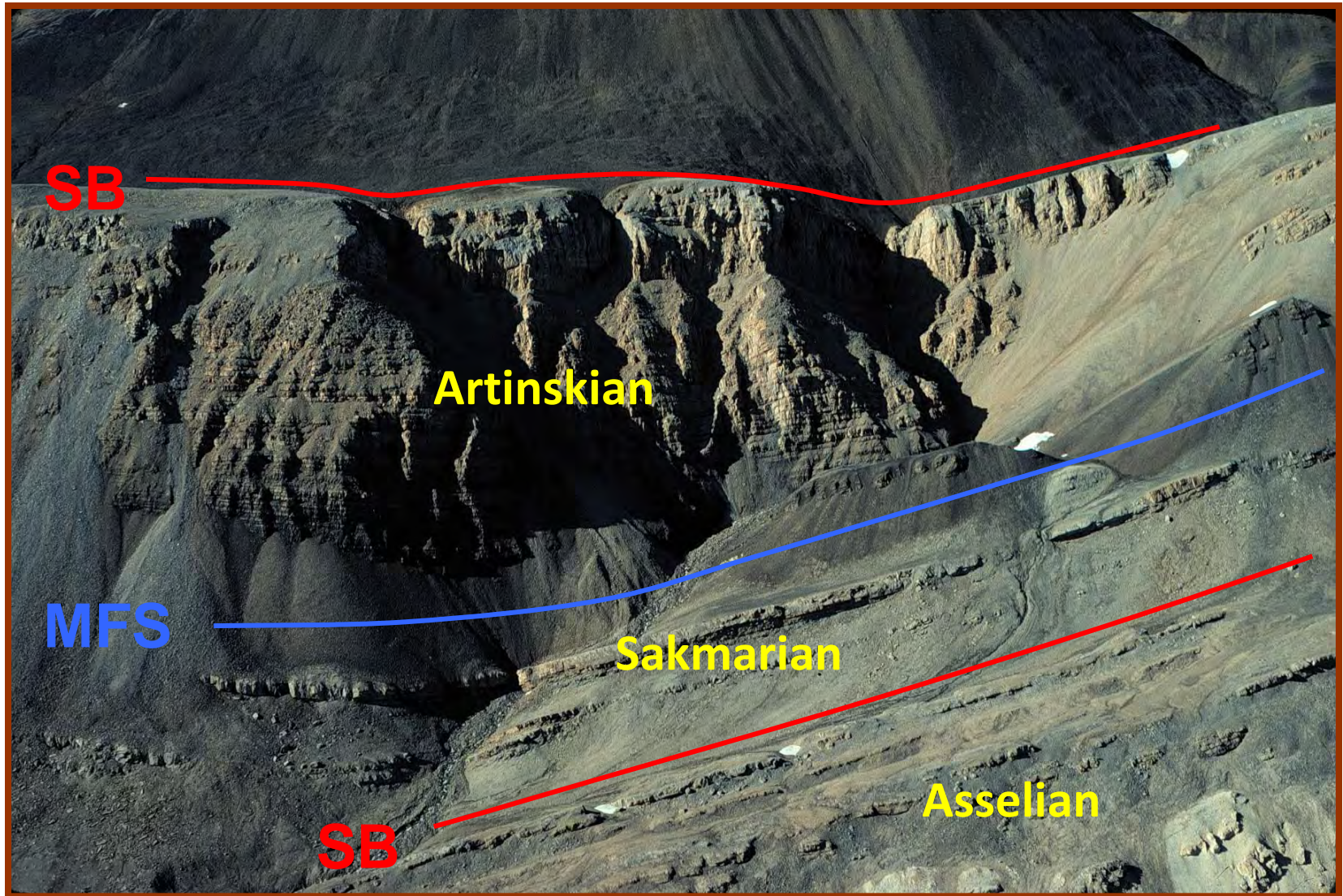


	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
SLOPE (RESEDIMENTED)	Cemented reef flanks	Upper slope		
	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
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	Grain flow	Middle slope		
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	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinoforms	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		

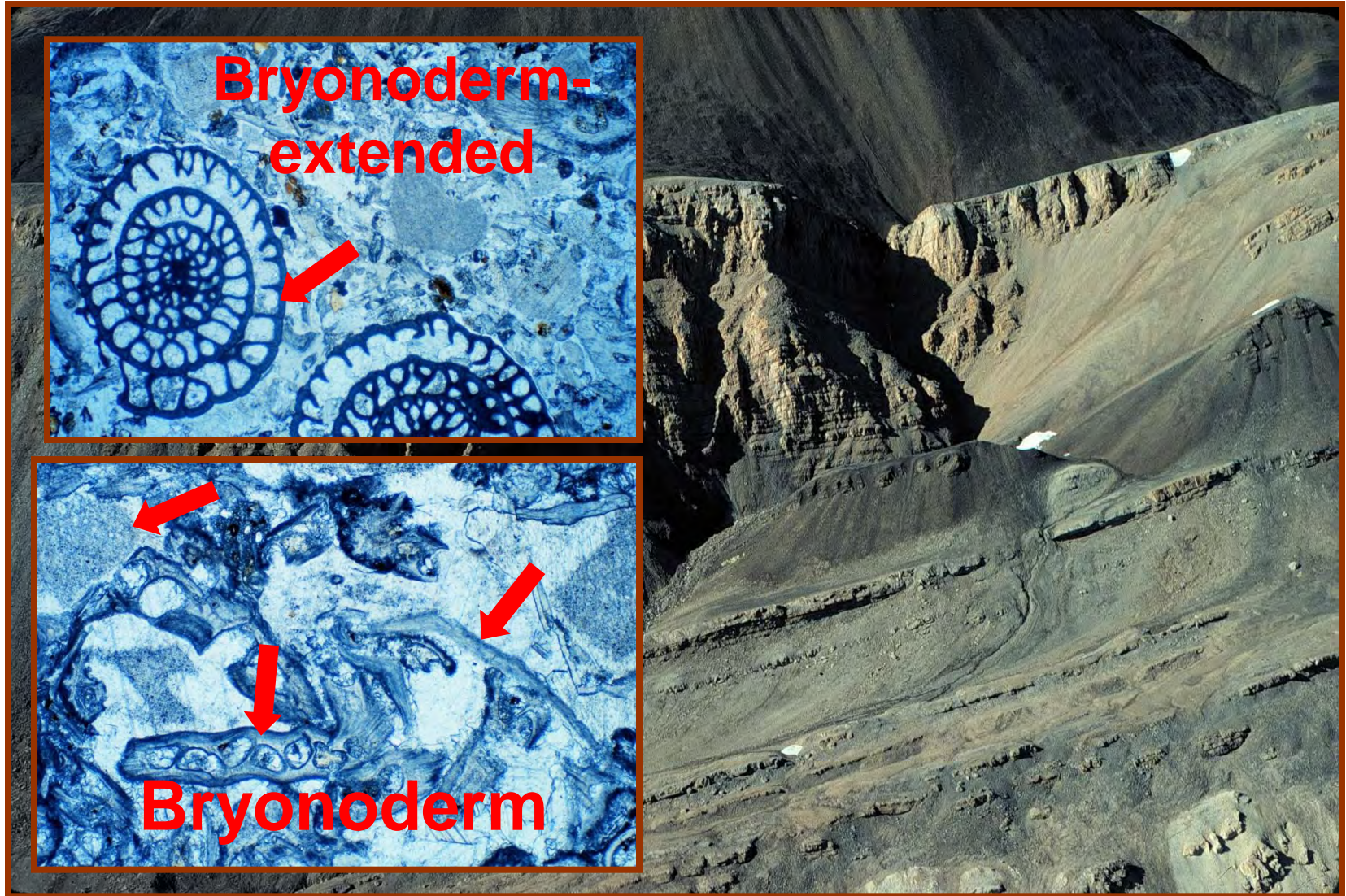
Sakmarian - Kungurian



Sakmarian - Kungurian



Heterozoan carbonate factory

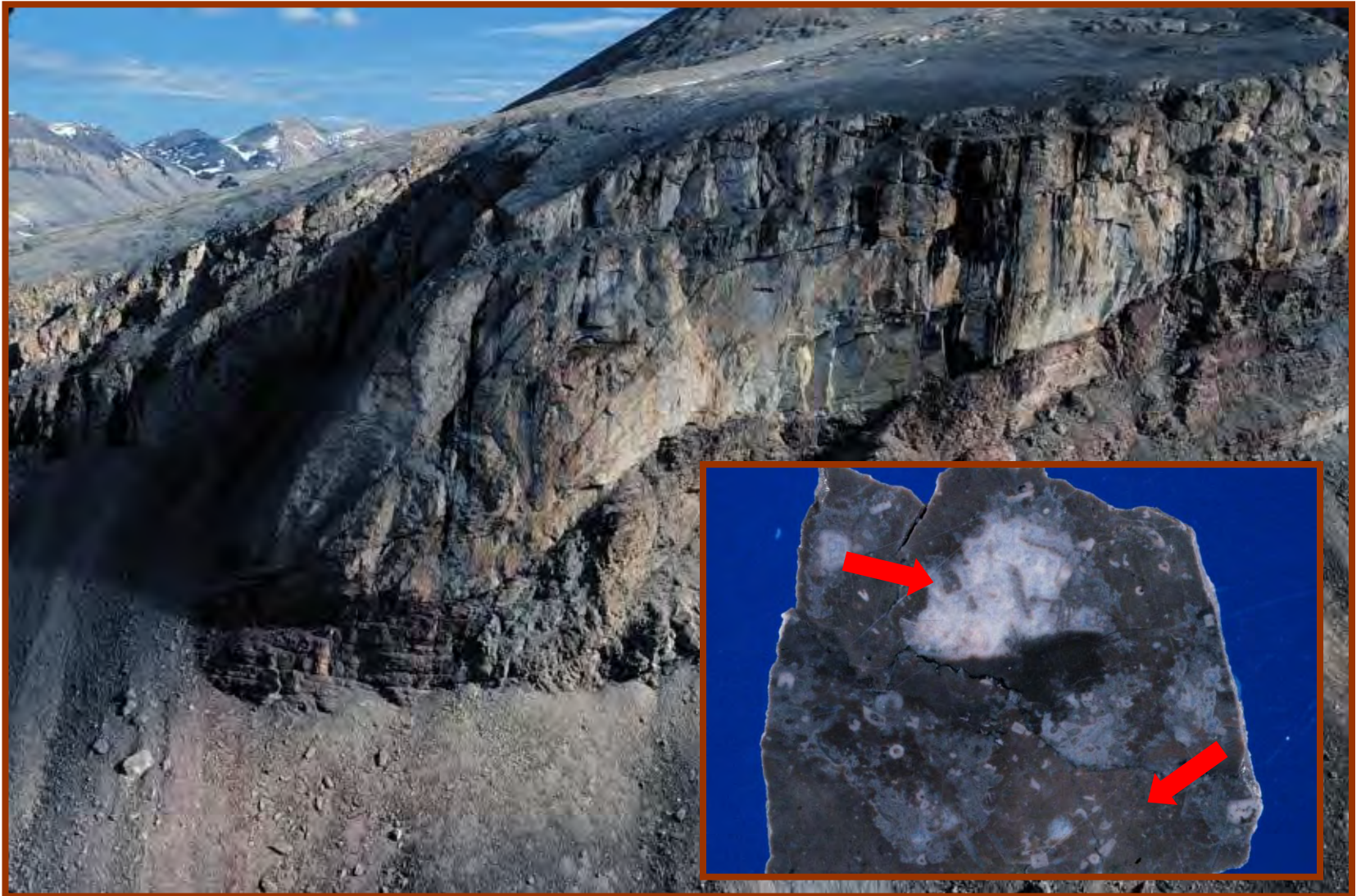


	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
SLOPE (RESEDIMENTED)	Cemented reef flanks	Upper slope		
	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
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SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
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	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinoforms	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		

Sakmarian - Kungurian



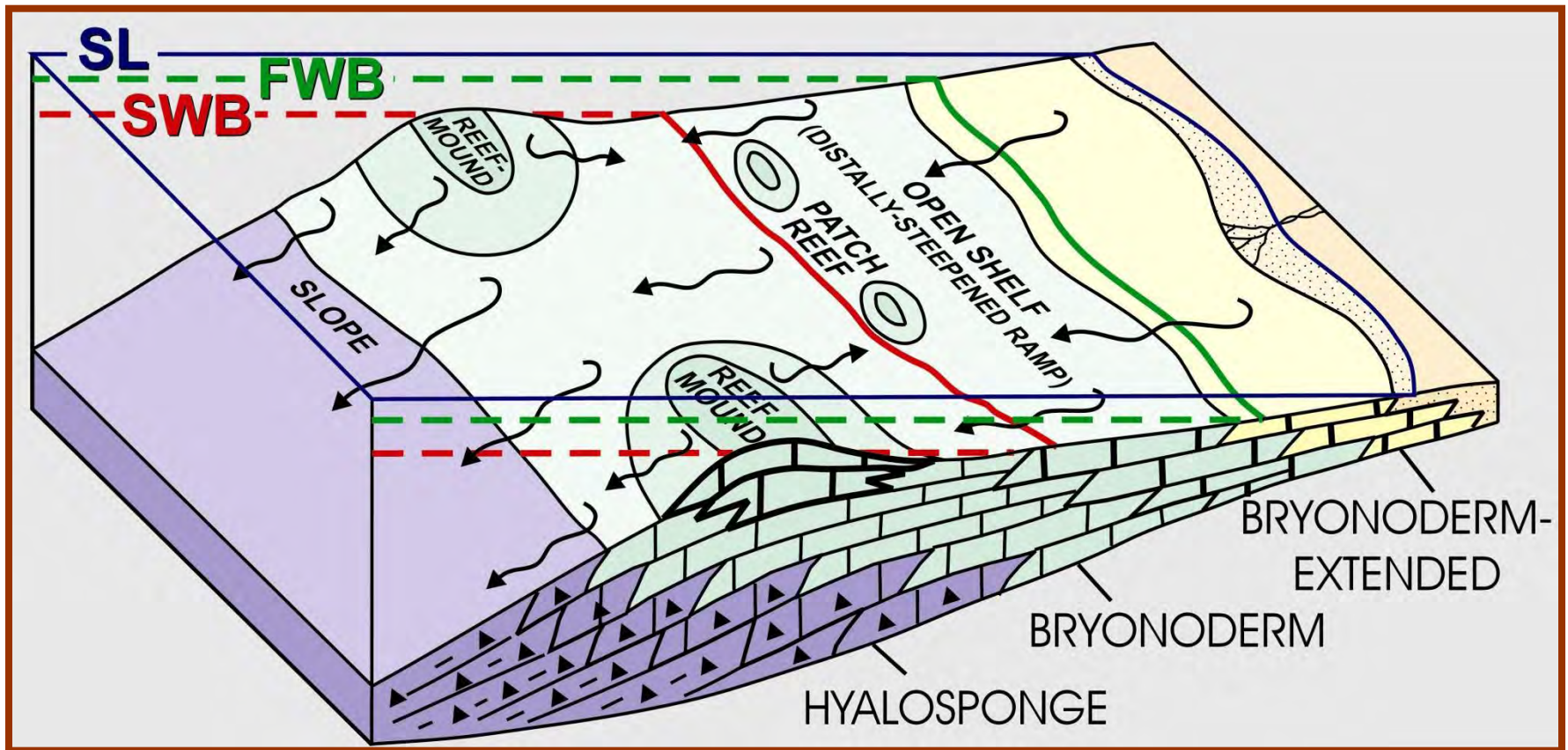
Sakmarian - Kungurian



Cool (Sakmarian - Kungurian)

Silica factory

Carbonate factory



Bashkirian-Asselian Shelf

- **Warm**
 - High productivity photozoan carbonate factory
 - Cyclic shelf sedimentation
 - Early cemented reefal margin & shelf sediments

Sakmarian-Artinskian Shelf

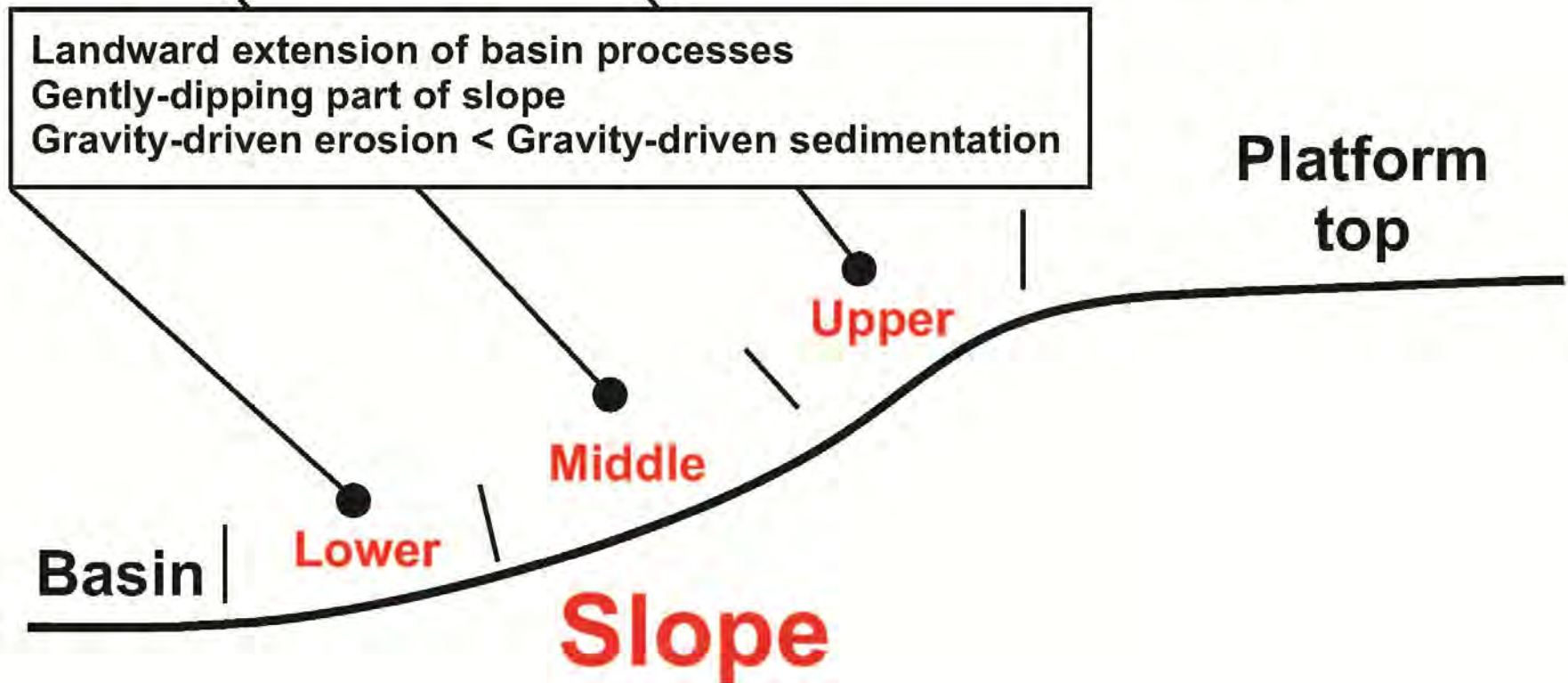
- **Cool**
 - Low productivity heterozoan carbonate factory
 - Non-cyclic shelf sedimentation
 - Non-cemented / non-reefal margin & shelf sediments

	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
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Basinward extension of shelf processes
Steepest part of slope
Gravity-driven erosion > Gravity-driven sedimentation

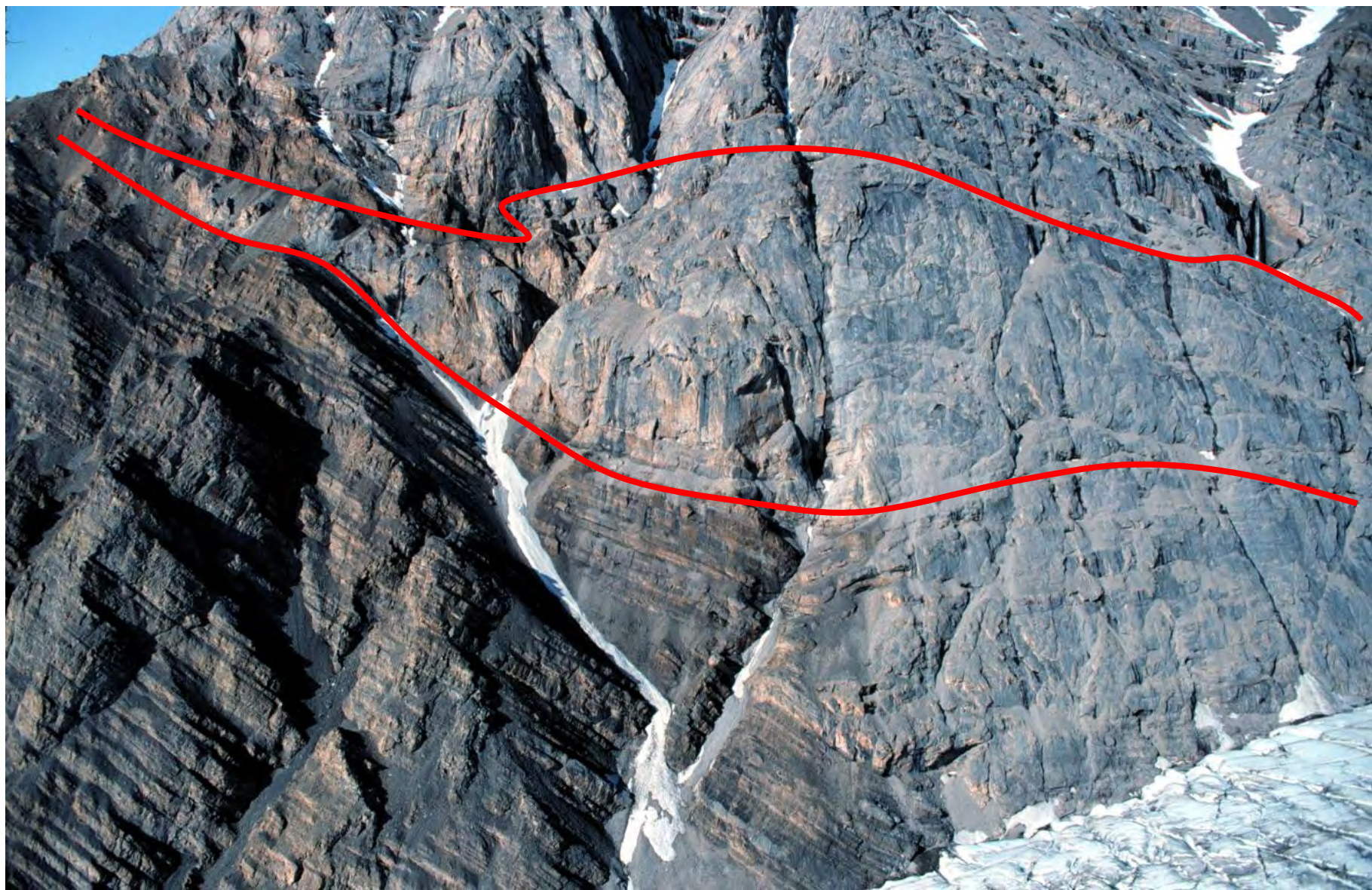
Beyond extension of shelf processes
Concave-up part of slope
Gravity-driven erosion = Gravity-driven sedimentation

Landward extension of basin processes
Gently-dipping part of slope
Gravity-driven erosion < Gravity-driven sedimentation



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	Cemented reef flanks	Upper slope		
SLOPE (RESEDIMENTED)	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
	Debris flow	Upper to middle slope		
	Grain flow	Middle slope		
	Turbidites	Middle to lower slope		
SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinoforms	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		



Cyclic Shelf

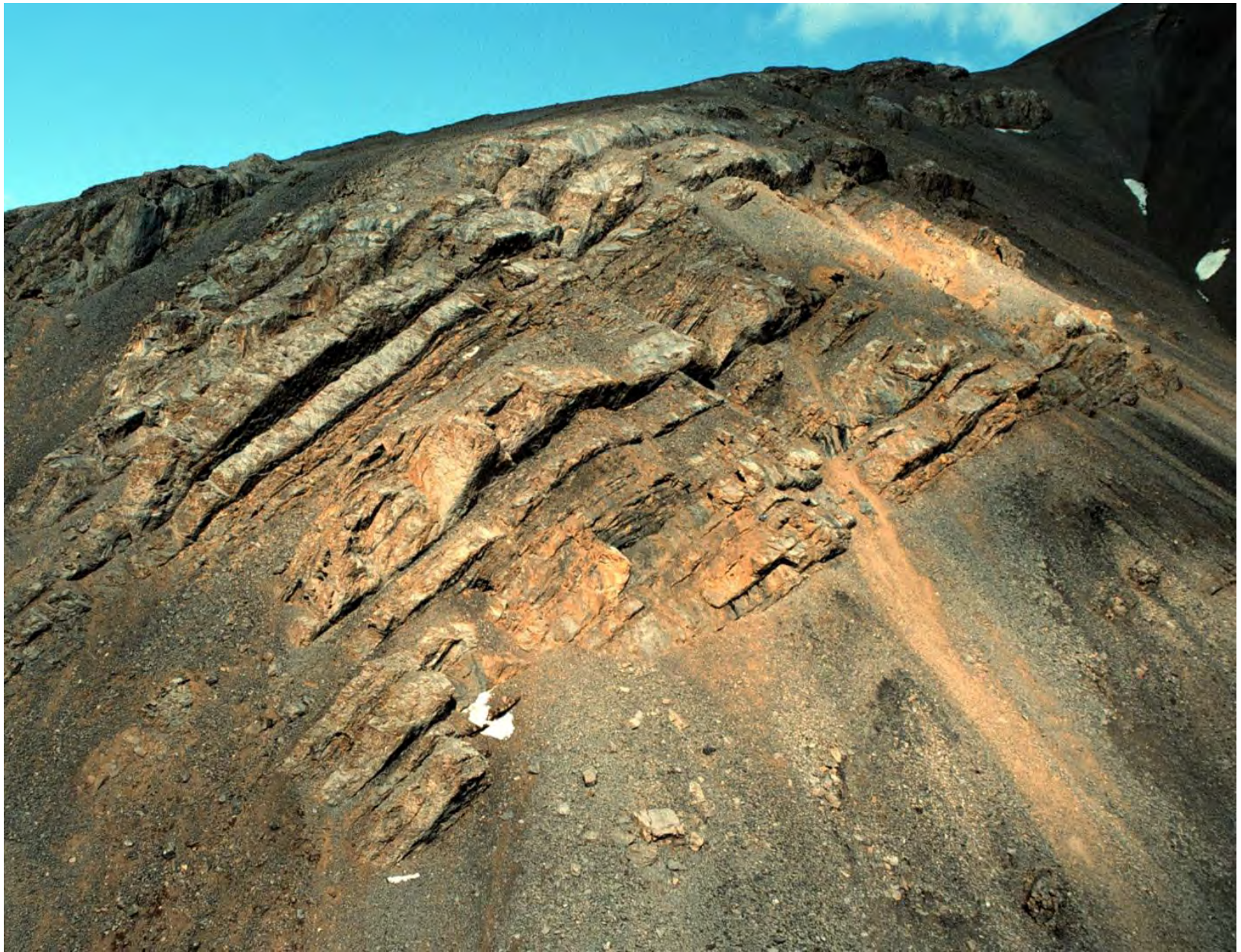


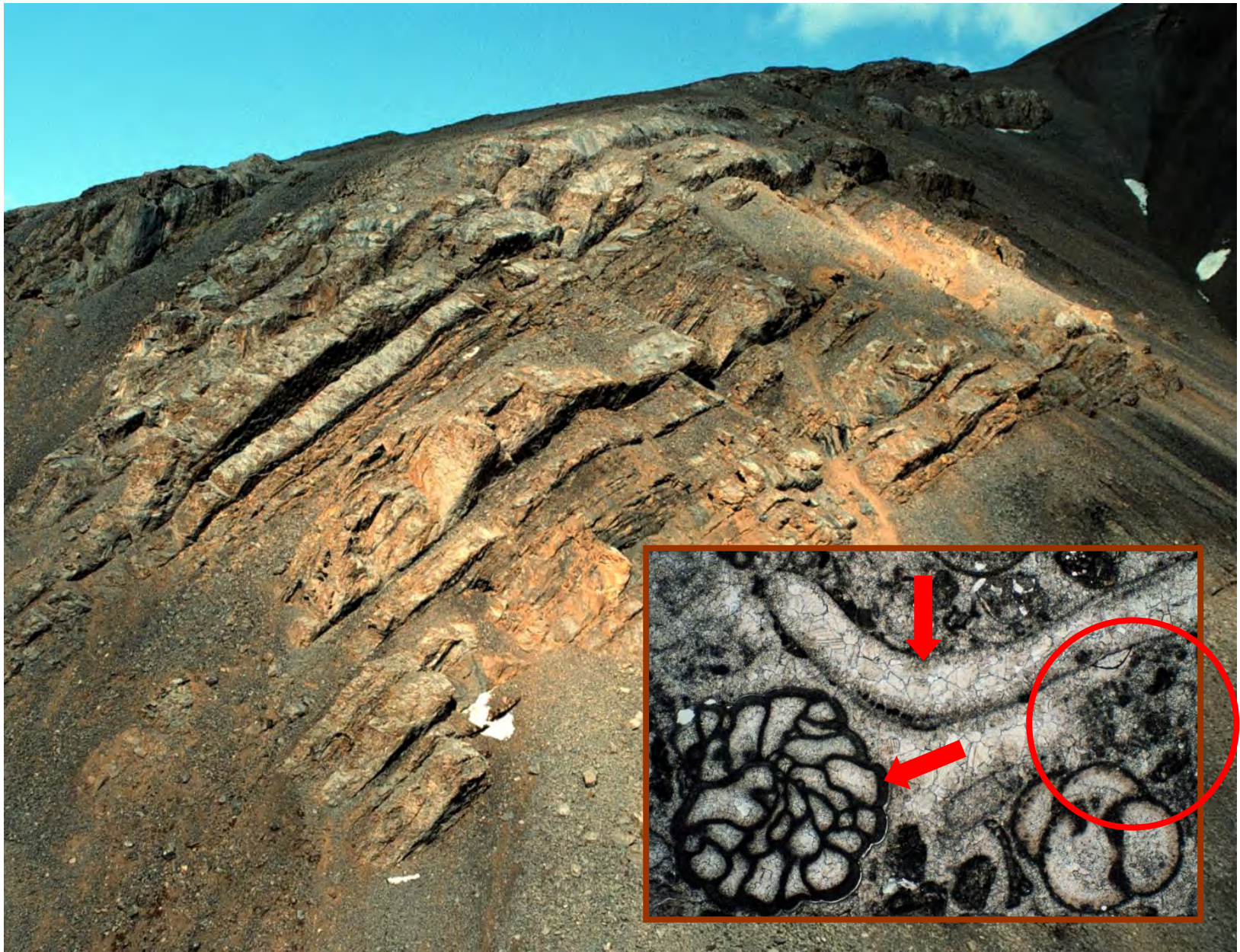




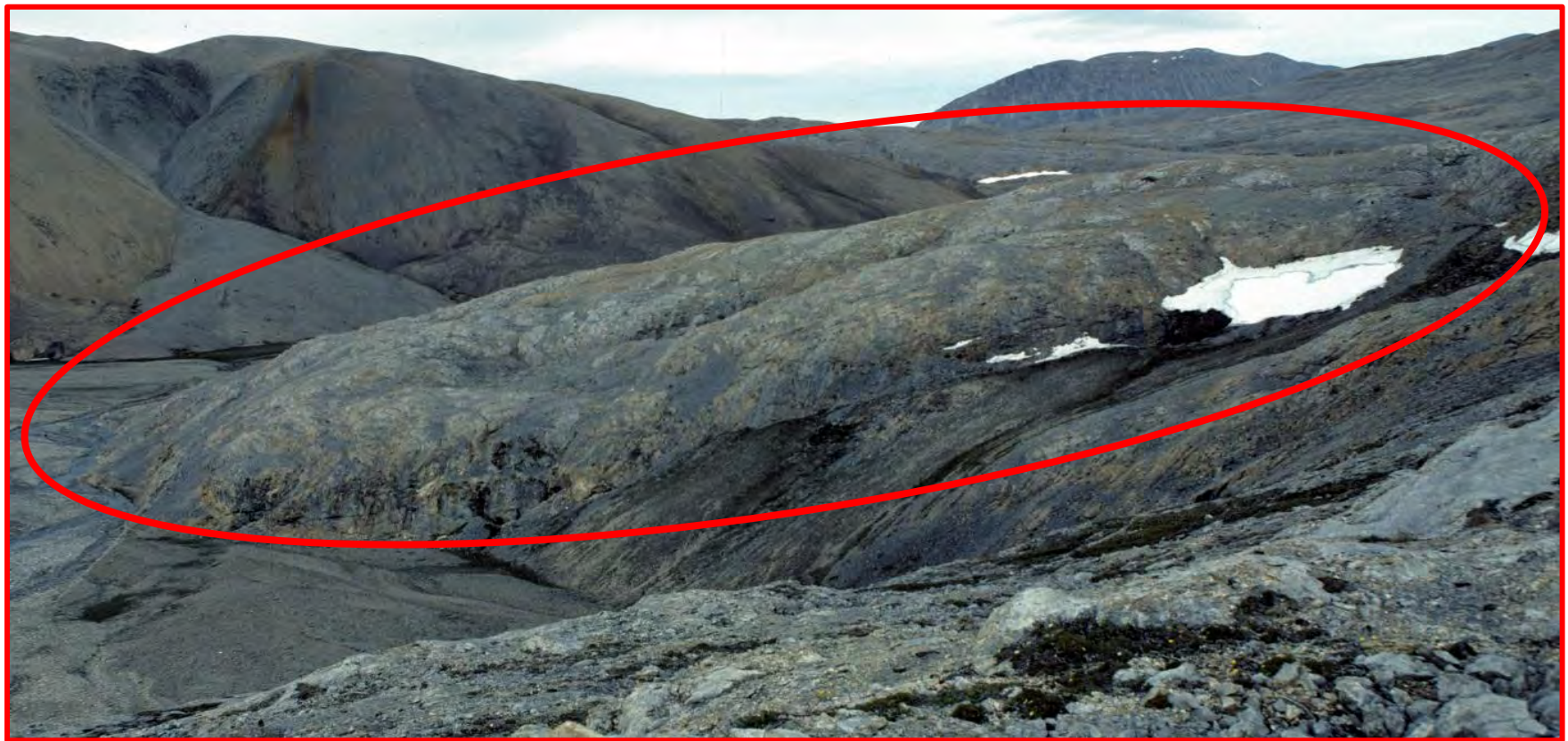
**Middle slope
carbonates**







	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
	Cemented reef flanks	Upper slope		
SLOPE (RESEDIMENTED)	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
	Debris flow	Upper to middle slope		
	Grain flow	Middle slope		
	Turbidites	Middle to lower slope		
SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinoforms	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		





	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
	Cemented reef flanks	Upper slope		
	Submarine rock fall	Upper to middle slope		
SLOPE (RESEMENTED)	Breccia and meqabreccia	Upper to middle slope		
	Debris flow	Upper to middle slope		
	Grain flow	Middle slope		
	Turbidites	Middle to lower slope		
SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinoforms	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		

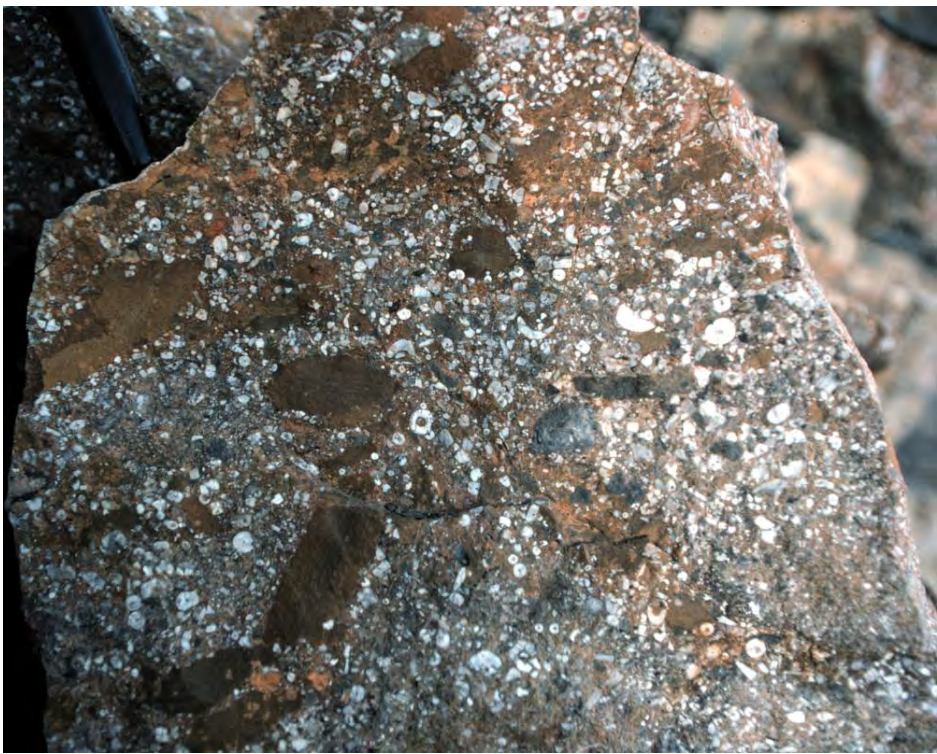




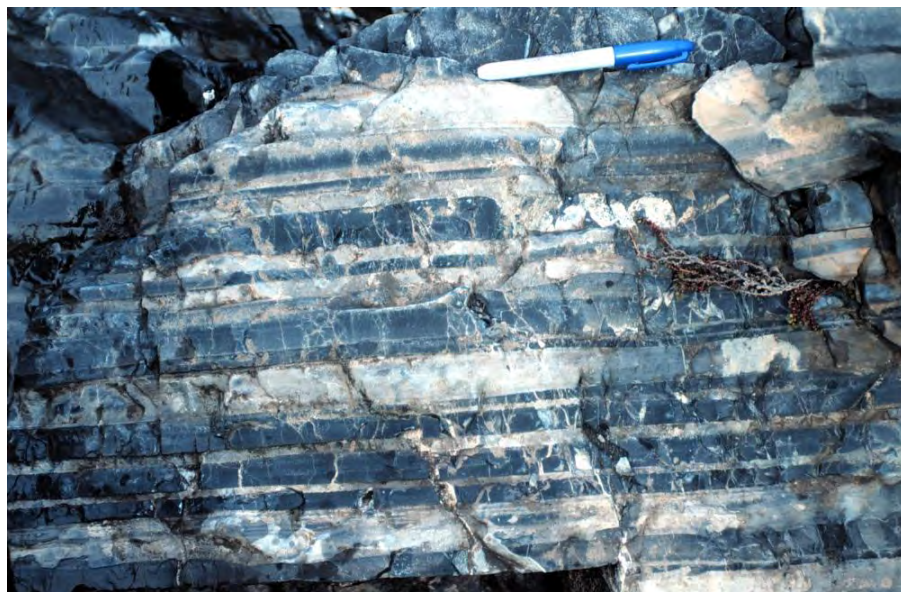
	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
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	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
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	Grain flow	Middle slope		
SLOPE (HEMIPELAGIC)	Turbidites	Middle to lower slope		
	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
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SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
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			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
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	Debris flow	Upper to middle slope		
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SLOPE (HEMIPELAGIC)	Turbidites	Middle to lower slope		
	Hemipelagic (carbonate)	Middle to lower slope		
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SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
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BASIN	Condensed deposits	Basin		



	FEATURE	ENVIRONMENT	SETTING	
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SHELF	Shelf carbonates	Open to protected cyclic shelf		
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SHELF	Shelf carbonates	Open to protected cyclic shelf		
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SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
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BASIN	Condensed deposits	Basin		







Lower slope
distal turbidites
& hemipelagic

The photograph shows a dark, layered rock face, likely a sedimentary deposit. A red line is drawn diagonally across the face, separating the 'Lower slope' area from the 'Basin' area. A blue line is drawn diagonally across the face, separating the 'Basin' area from the 'MFS' area. The 'MFS' label is written in blue, italicized text along the blue line. The foreground shows a body of water with ice floes.

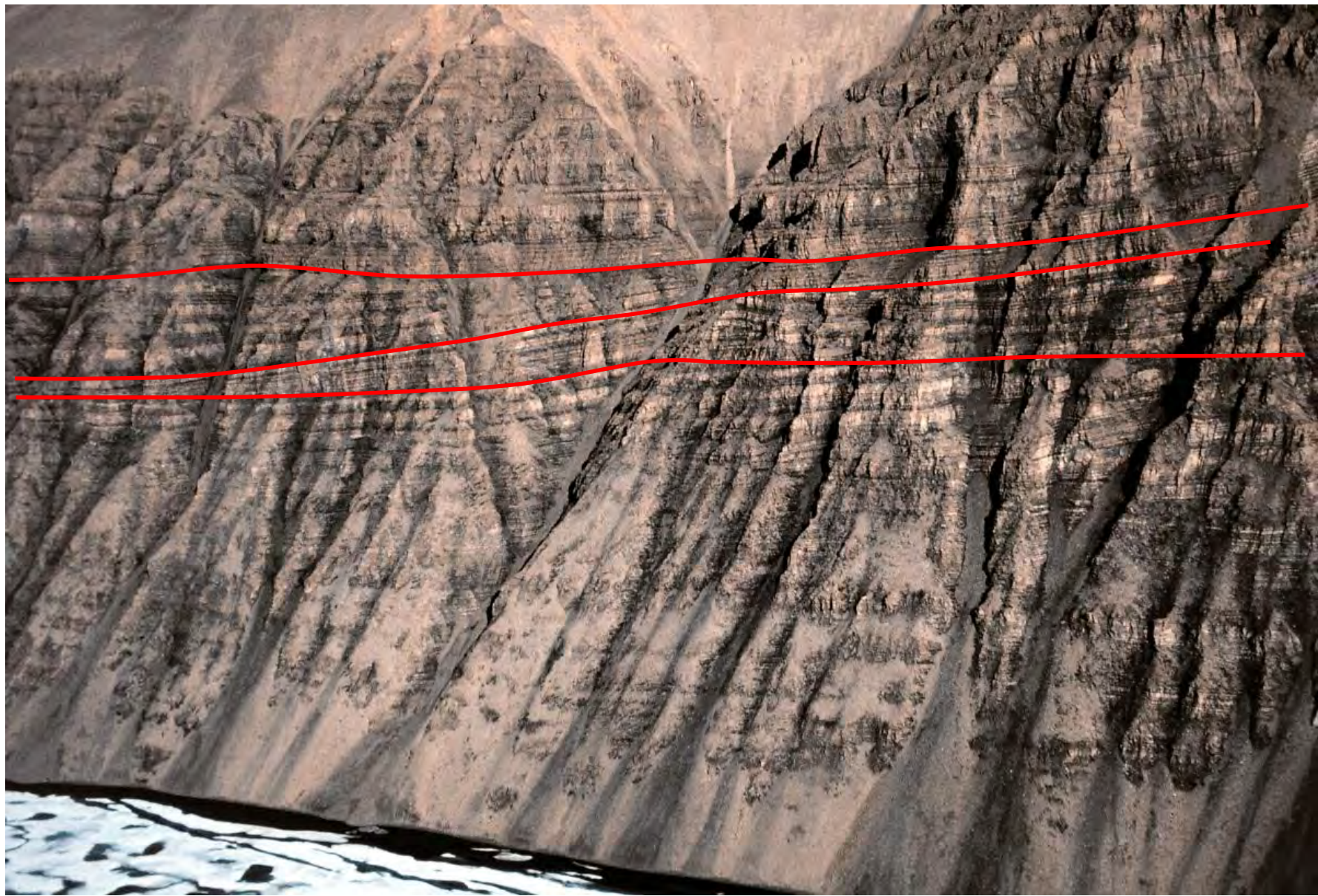
Basin
Condensed
hemipelagic

MFS

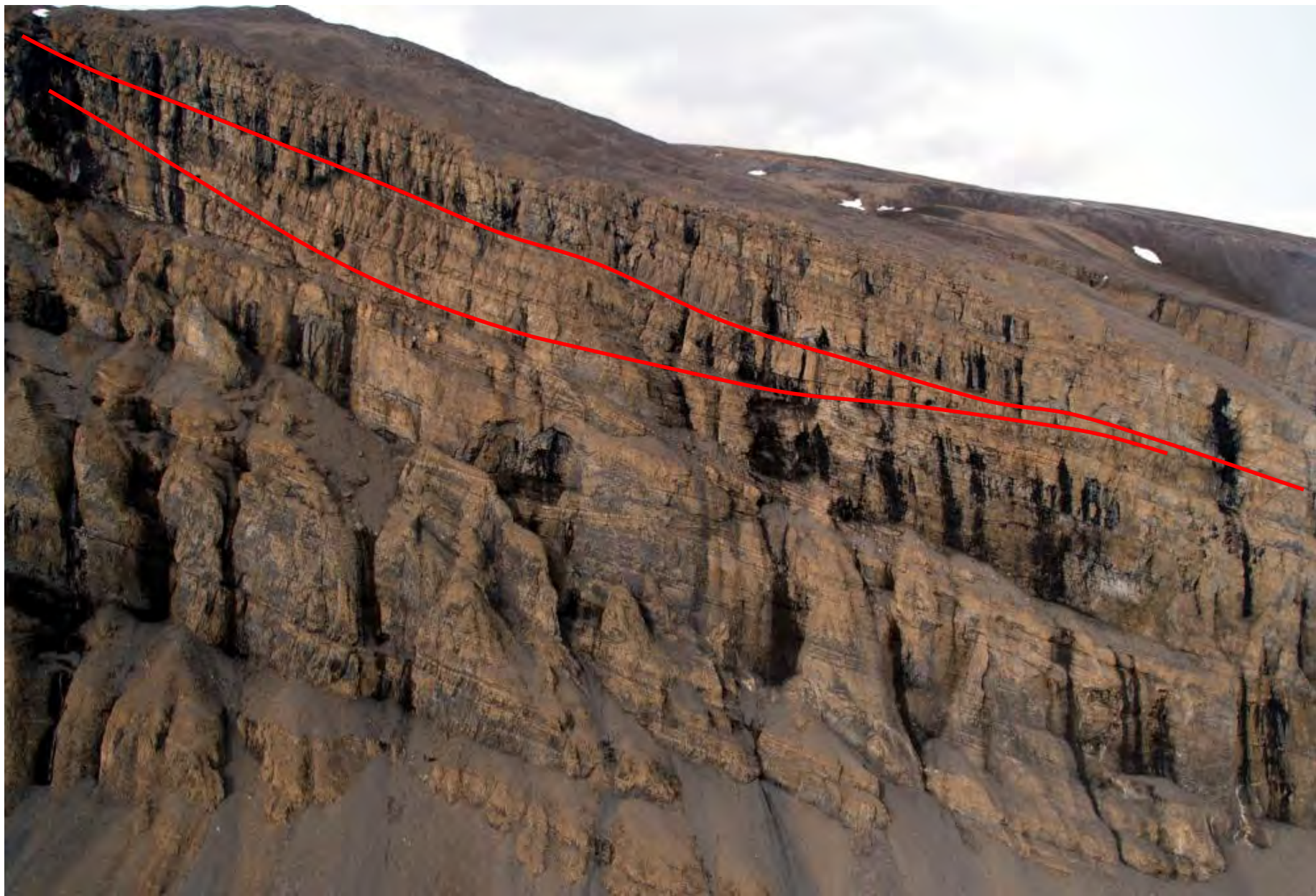
	FEATURE	ENVIRONMENT	SETTING	
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SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (bioclastic)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinofolds	Upper, middle and lower slope		
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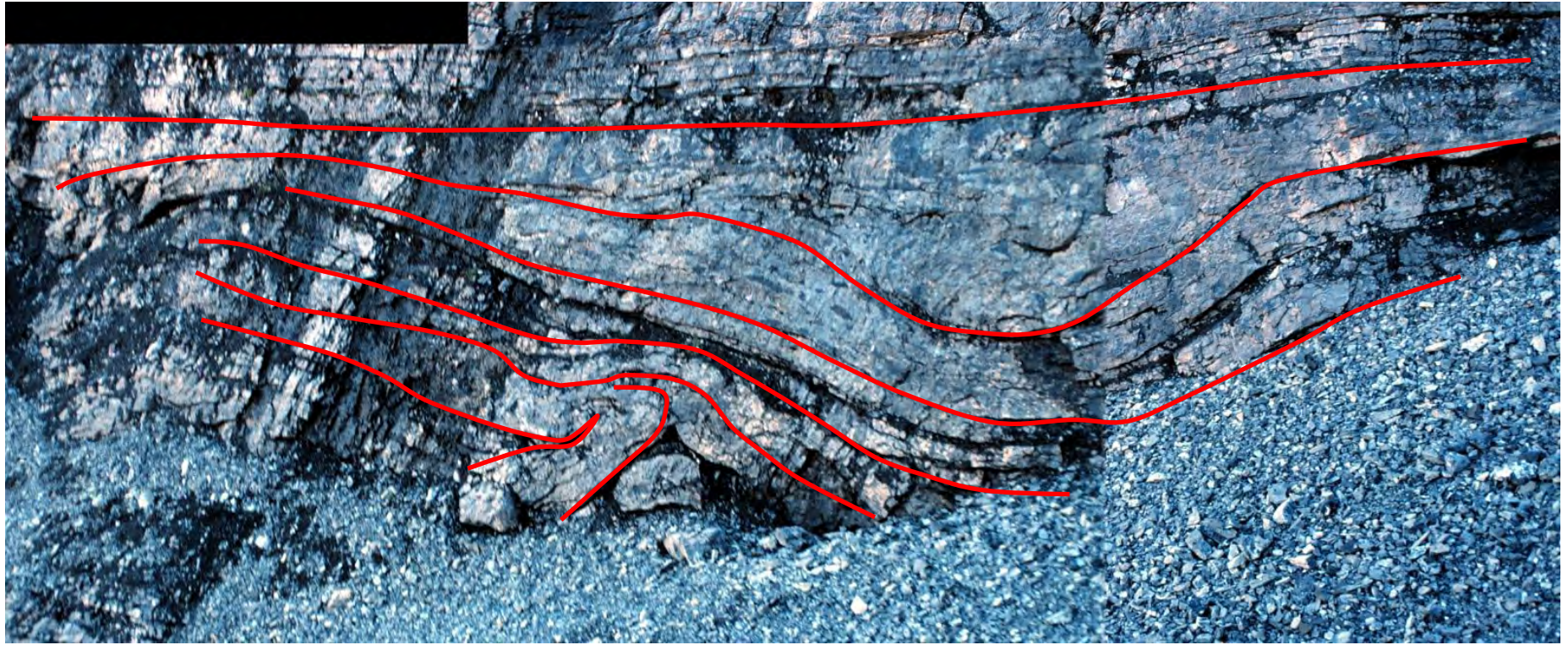






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SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (FEATURES)	Truncation surfaces	Upper to middle slope		
	Clinoforms	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		





	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
	Shelf-edge reefs (photozoan)	Outer shelf to shelf-edge reef tract		
	Shelf-edge reefs (heterozoan)	Outer shelf to shelf-edge mud mound		
SLOPE (IN SITU)	Mud mounds (heterozoan)	Upper slope		
	Benthic carbonate	Upper to middle slope		
	Benthic chert	Upper to middle slope		
SLOPE (RESEDIMENTED)	Cemented reef flanks	Upper slope		
	Submarine rock fall	Upper to middle slope		
	Breccia and megabreccia	Upper to middle slope		
	Debris flow	Upper to middle slope		
	Grain flow	Middle slope		
	Turbidites	Middle to lower slope		
SLOPE (HEMIPELAGIC)	Hemipelagic (carbonate)	Middle to lower slope		
	Hemipelagic (clastic)	Middle to lower slope		
	Hemipelagic (biosiliceous)	Middle to lower slope		
SLOPE (S)	Truncation surfaces	Upper to middle slope		
SLOPE (CLINOFORMS)	Clinofolds	Upper, middle and lower slope		
SLOPE (SLUMP)	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		

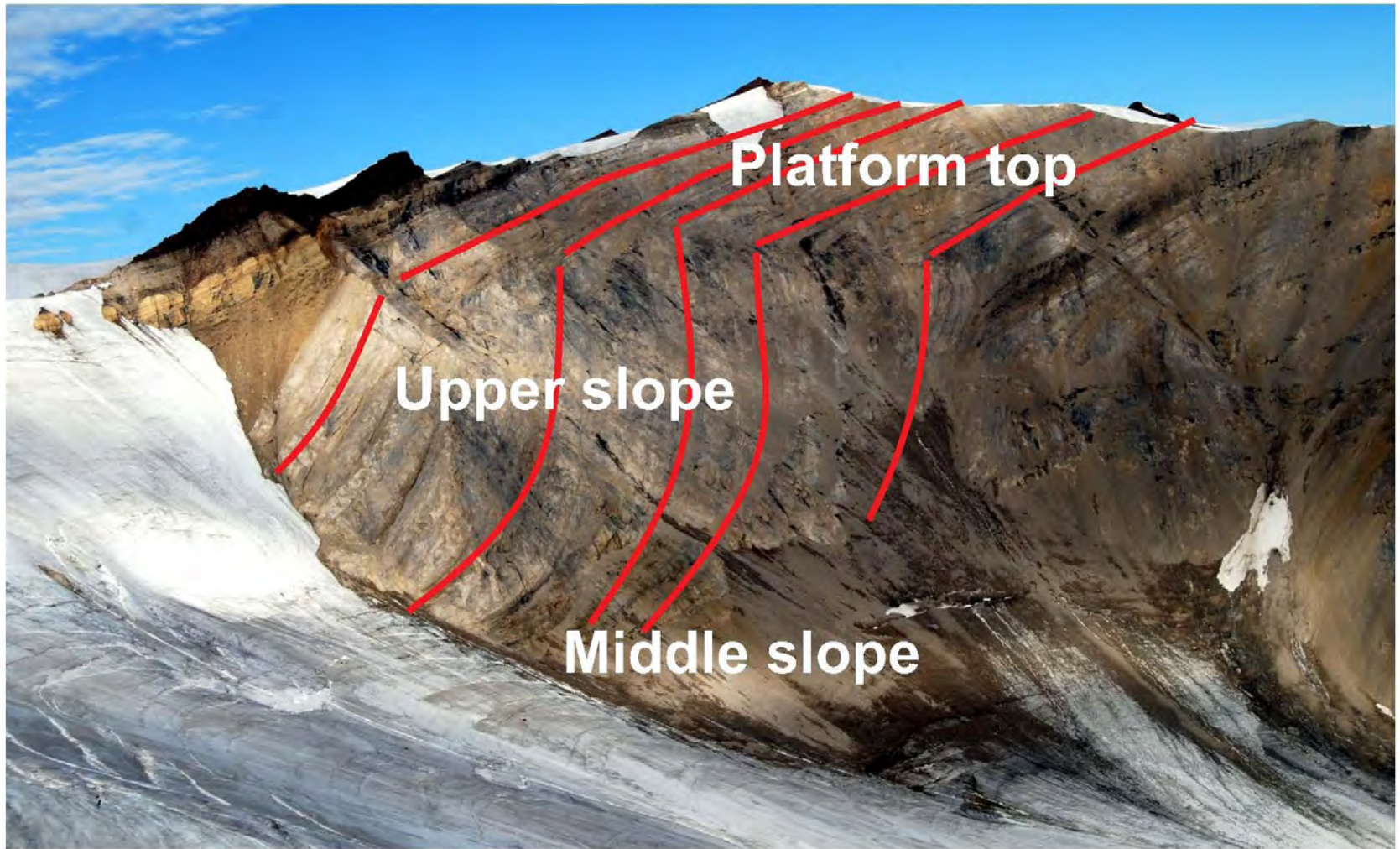
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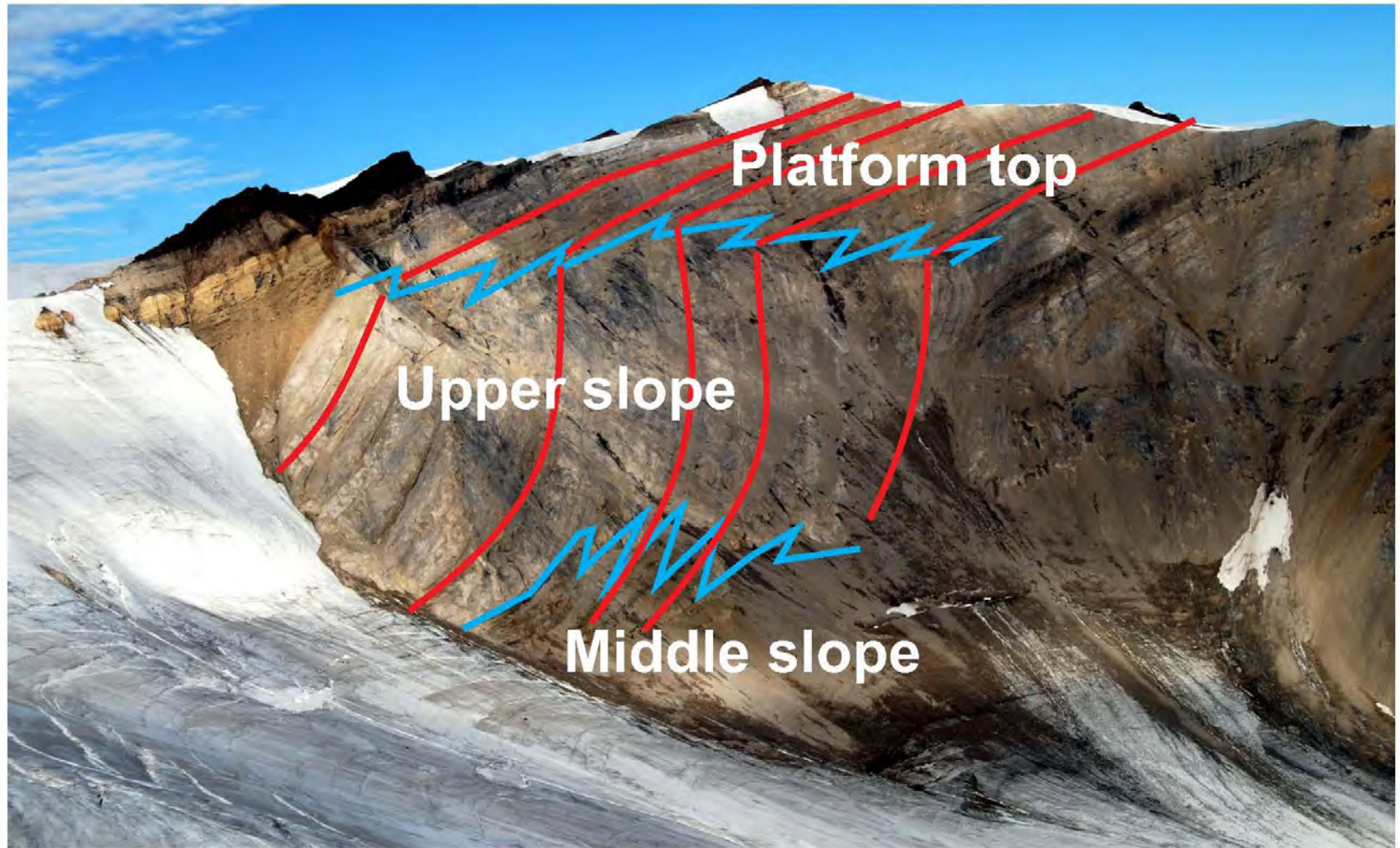
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WARM PHOTOZOAN FACTORY



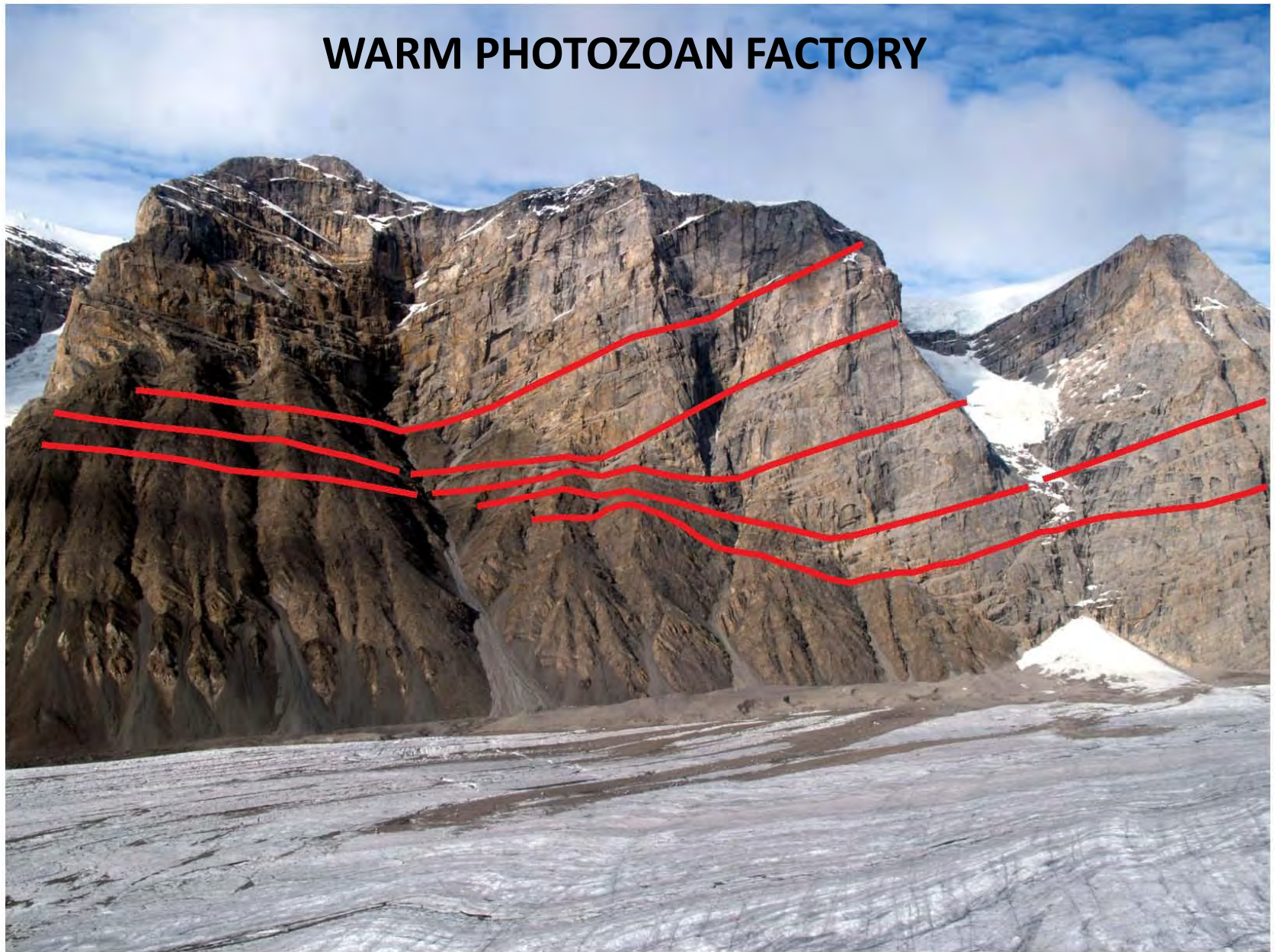
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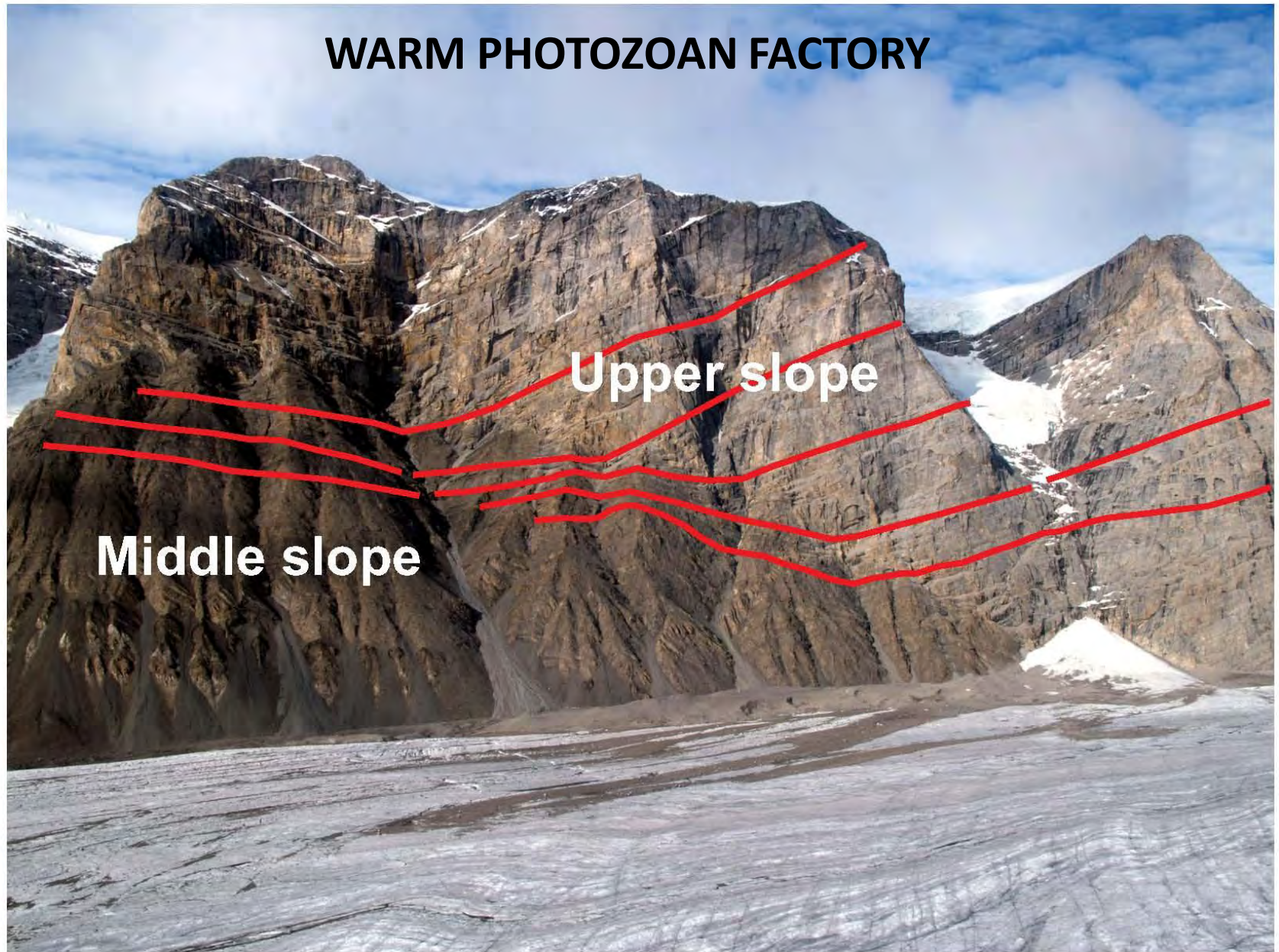
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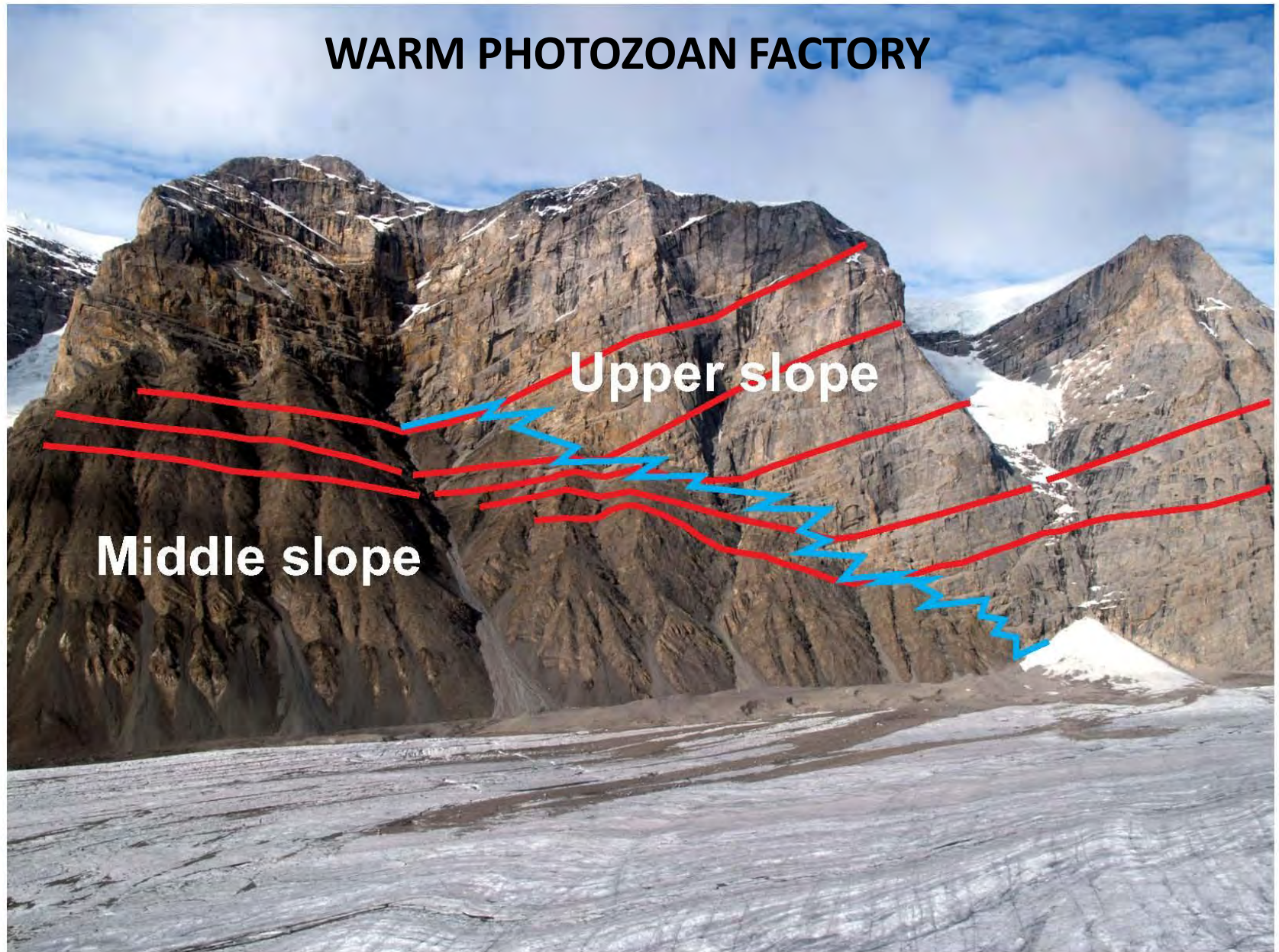
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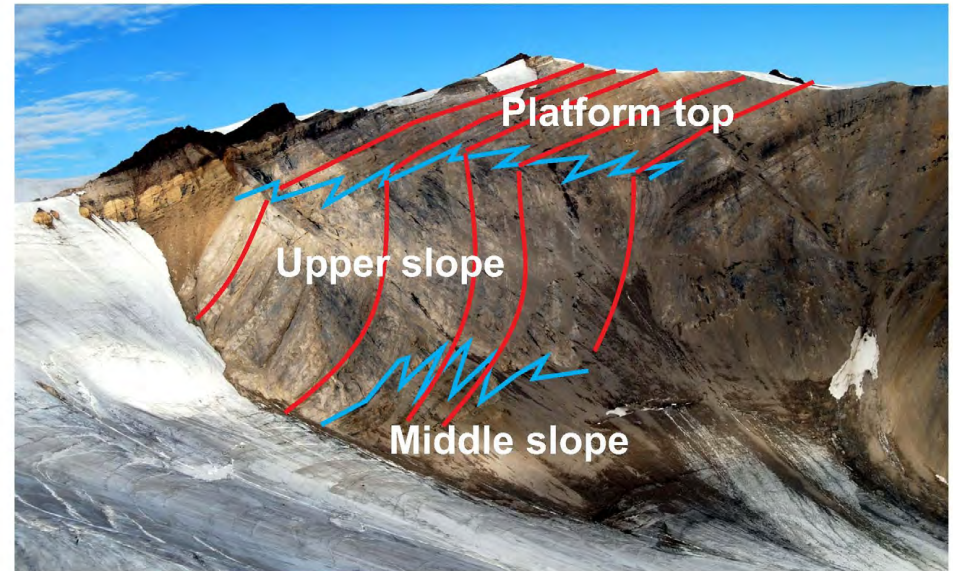
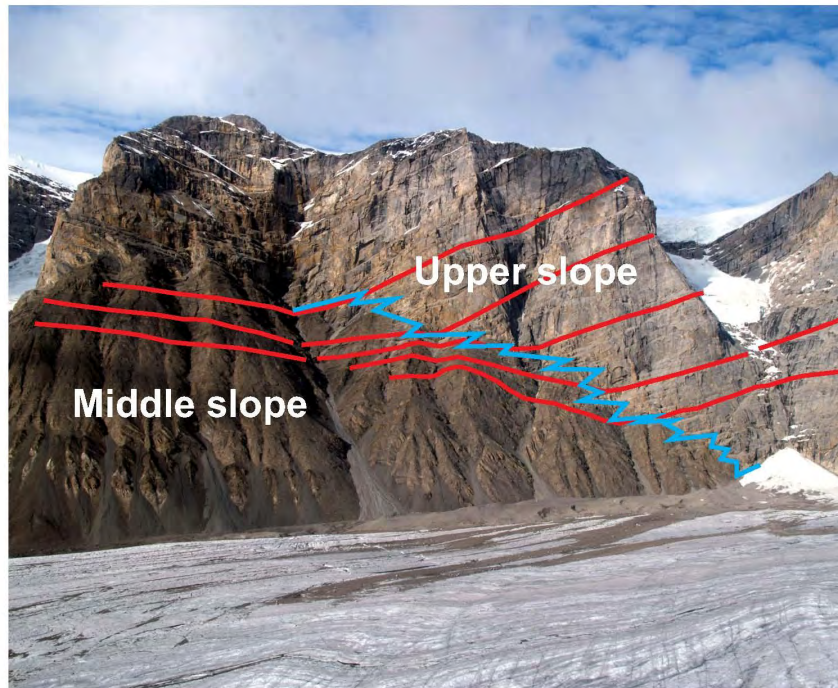
WARM PHOTOZOAN FACTORY



WARM PHOTOZOAN FACTORY



WARM SHELF-TO-BASIN TRANSITION



COOL HETEROZOAN FACTORY



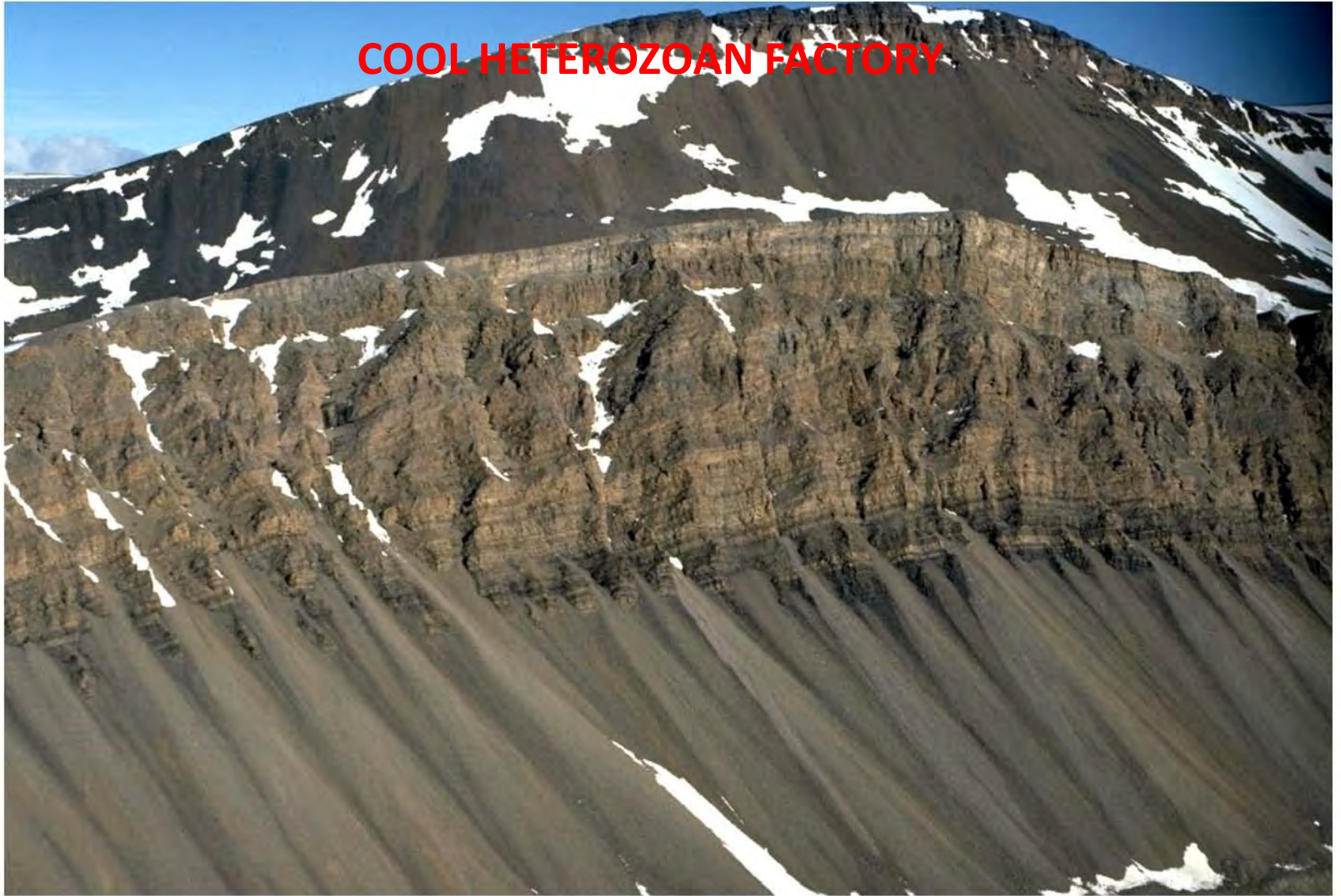
COOL HETEROZOAN FACTORY



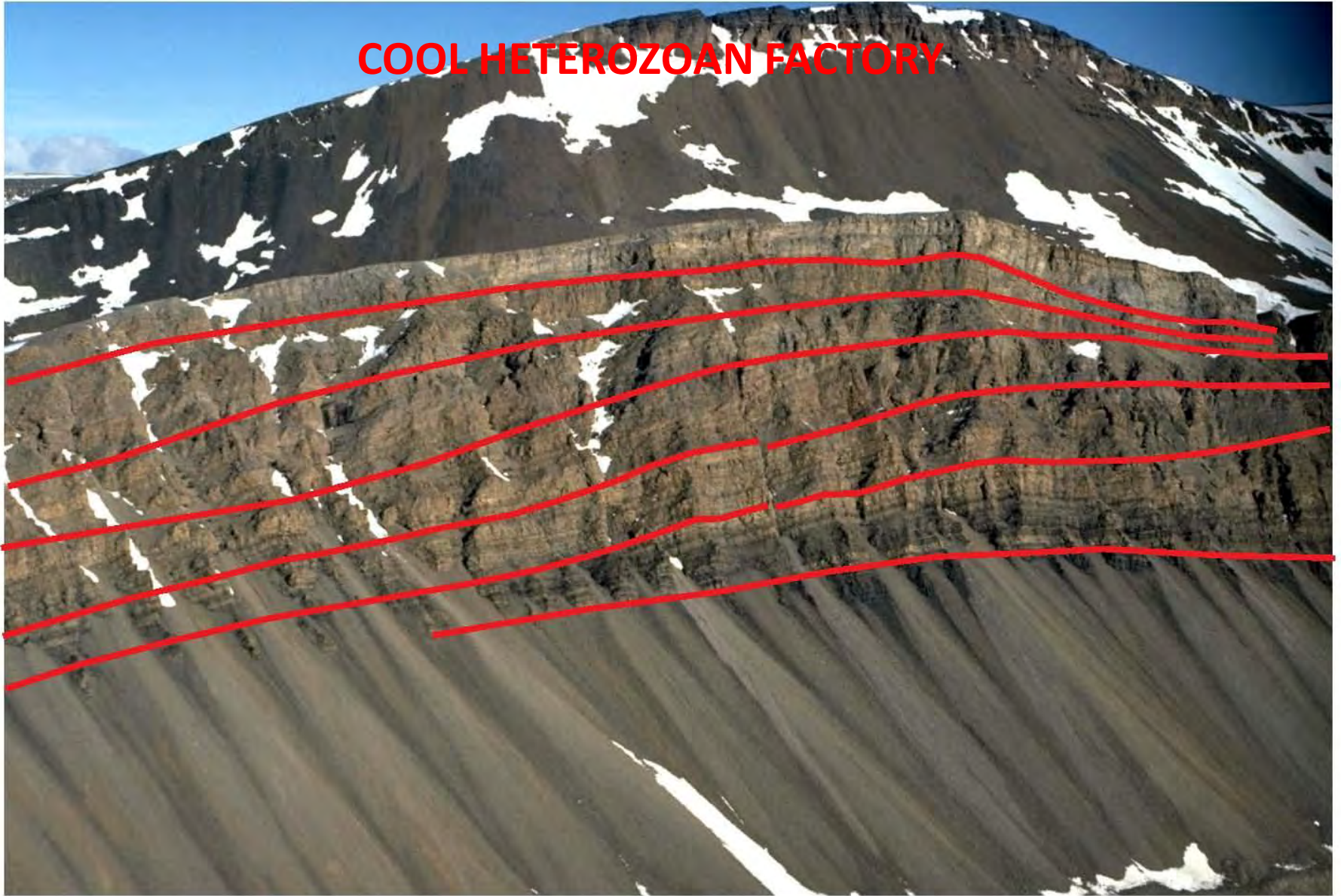
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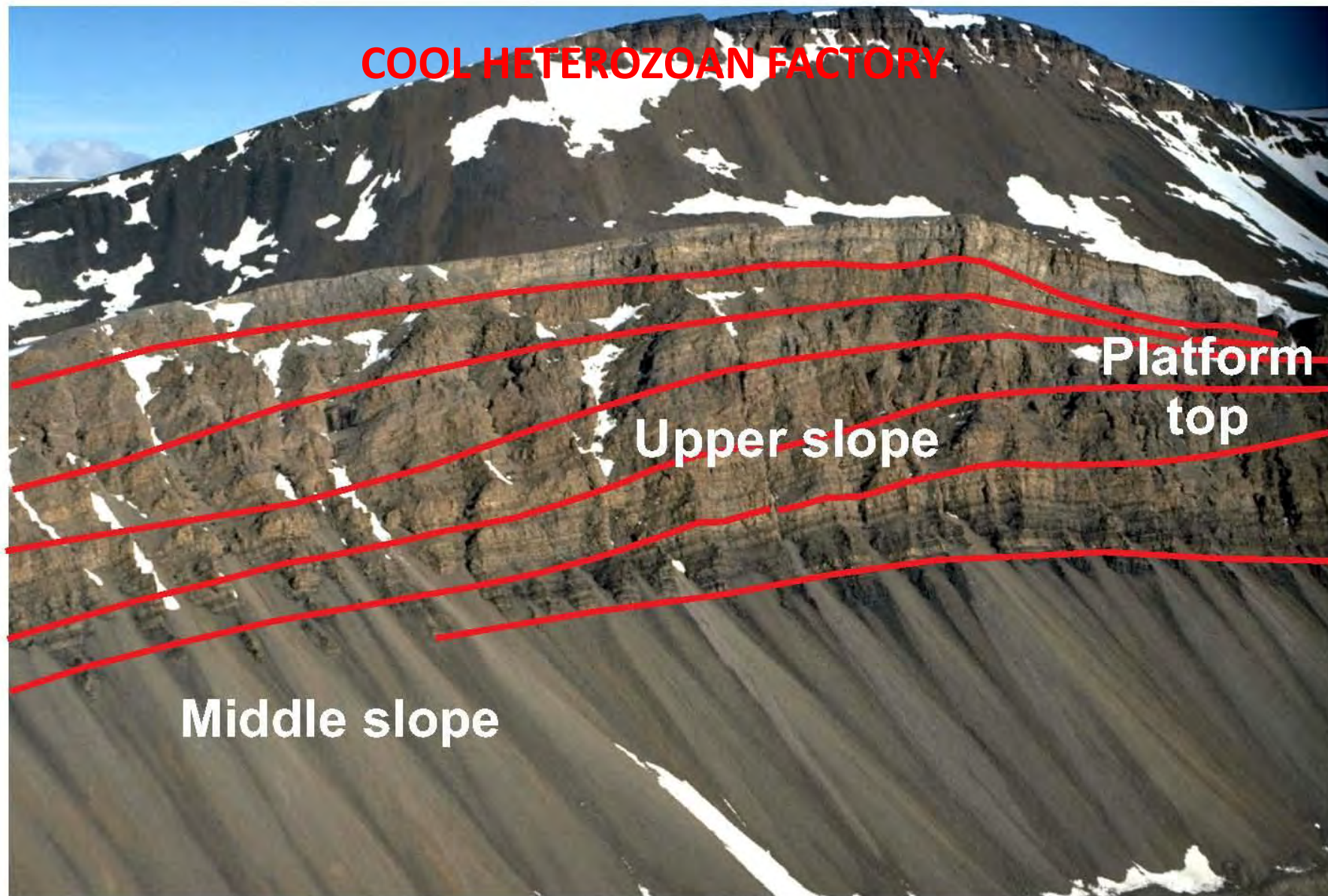
COOL HETEROZOAN FACTORY



COOL HETEROZOAN FACTORY



COOL HETEROZOAN FACTORY

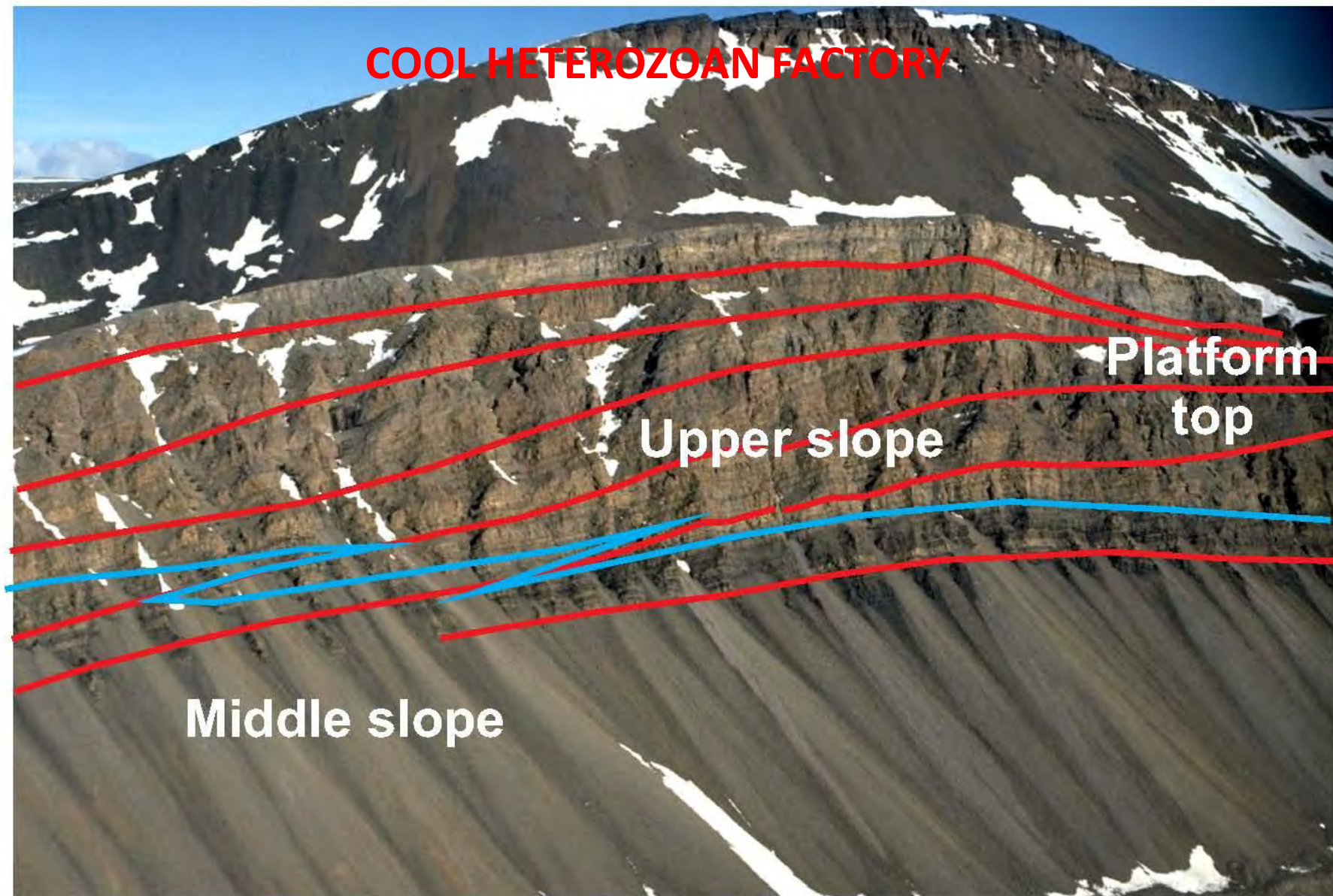


Platform
top

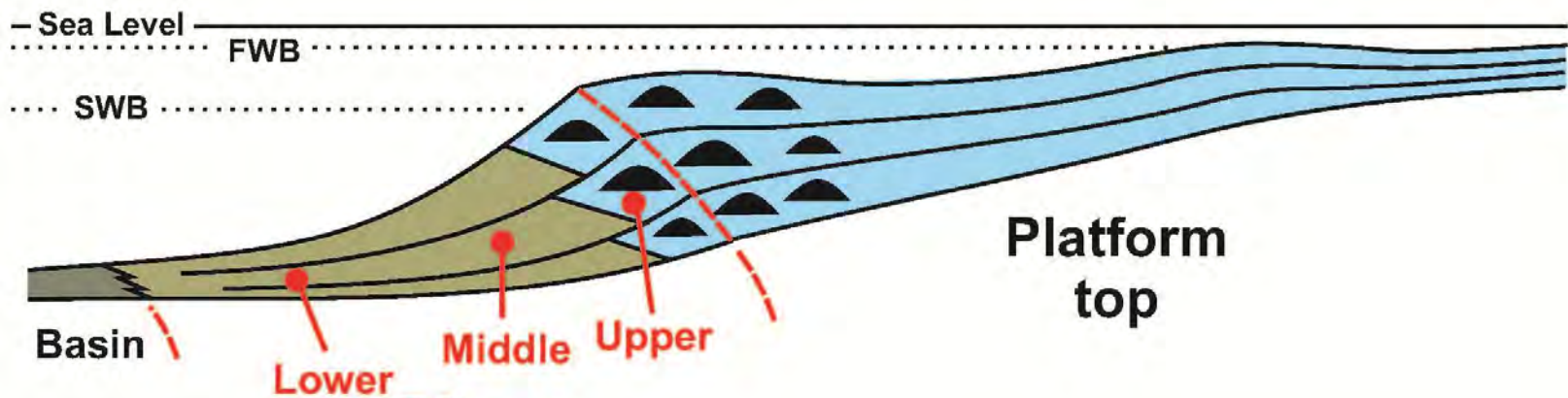
Upper slope





Middle slope

COOL HETEROZOAN FACTORY

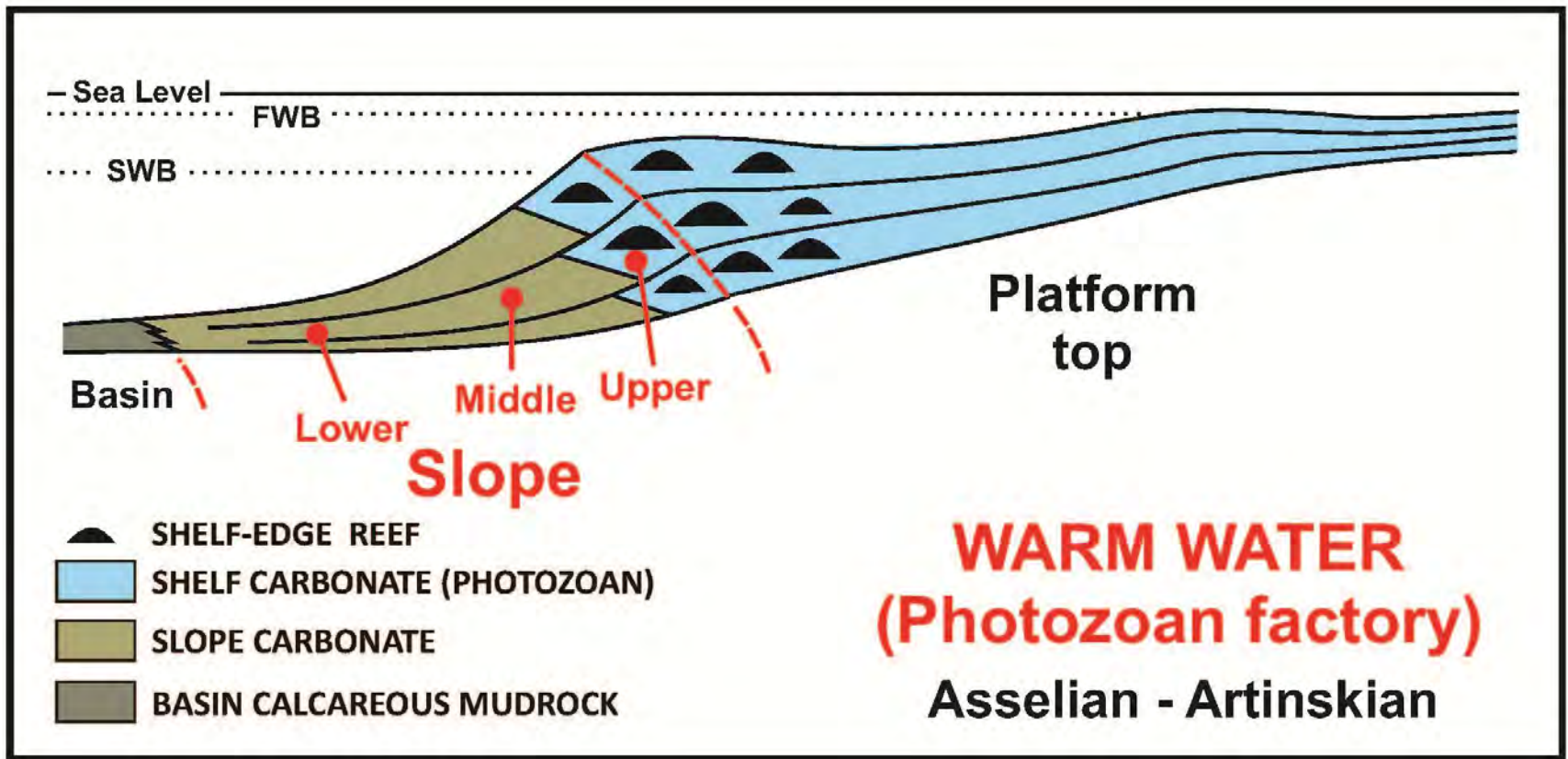


	FEATURE	ENVIRONMENT	SETTING	
			WARM	COOL
SHELF	Shelf carbonates	Open to protected cyclic shelf		
	Ramp carbonates	Open non-cyclic ramp		
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	Clinofolds	Upper, middle and lower slope		
	Slump folds	Middle to lower slope		
BASIN	Condensed deposits	Basin		



-  SHELF-EDGE REEF
-  SHELF CARBONATE (PHOTOZOAN)
-  SLOPE CARBONATE
-  BASIN CALCAREOUS MUDROCK

WARM WATER
(Photozoan factory)
Asselian - Artinskian

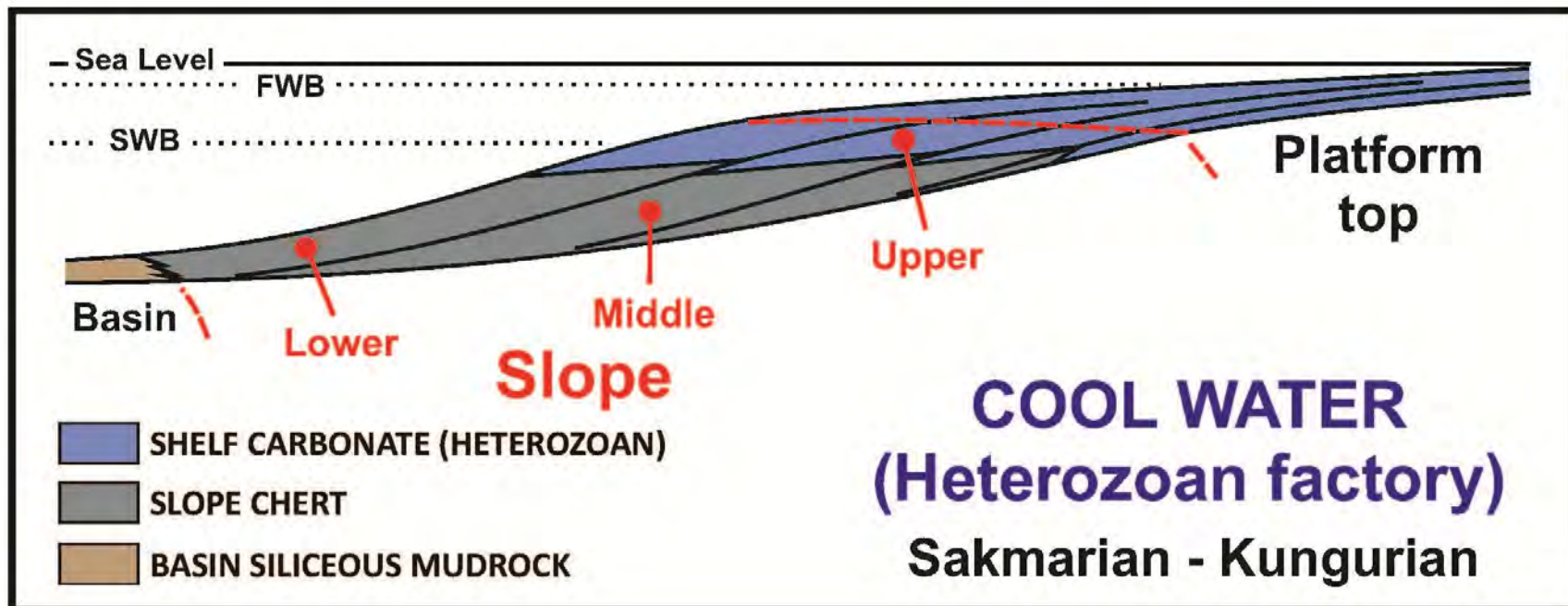


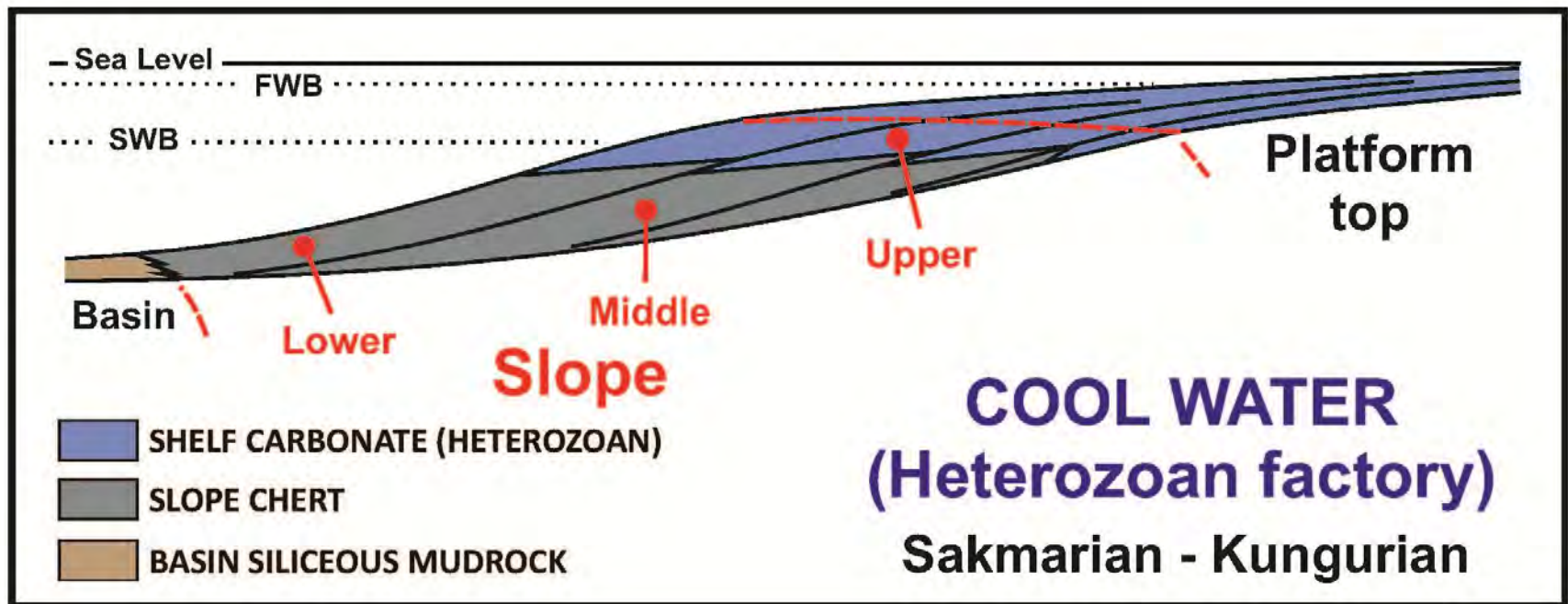
Key processes

- Highly productive warm-water photozoan carbonate factory
- Reefal shelf-margin (storm barrier)
- Early marine cemented (marine cement & microbial fabric)

Key slope products

- Well defined platform-slope margin
- Steep upper slopes
- Lithified shelf debris & slump folds
- **Distally-steepened shelf-edge**





Key processes

- Poorly productive cool-water heterozoan carbonate factory
- Non-reefal shelf-margin (no storm barrier)
- Not early marine cemented

Key slope products

- Poorly defined platform-slope margin
- Gentle upper slopes
- Non lithified sediments (no debris, no slump folds)
- **Proximally- to distally-steepened ramp**

