Depositional and Geomorphic Characteristics of Ocean Basins at Different Stages of Their Evolution – The Wilson Cycle Revisited*

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Abstract

The evolution of major ocean basins of the world is associated with the development of characteristic assemblages of seafloor geomorphic and depositional features. We carried out a multivariate classification of ocean basins, based on an existing digital global map of seafloor features that are related to major phases of evolution according to the Wilson Cycle, namely young, mature, declining and terminal evolutionary stages. "Young" ocean basins are characterized by the absence of ocean trenches, young ocean crust (<8 MA), comparatively large areas of continental slope, thick marginal sediment accumulations, and a relatively large percent area of mid-ocean ridge rift valley (above 1.7%). "Mature" ocean basins are characterized by relatively thick marginal sediment deposits (mean thickness of 940 m), large percentage areas of continental rise (mean of 19.8%) and large areas of submarine fans (mean of 4.3%). The area of ocean trench is relatively small in all "mature" ocean basins compared with "declining" and "terminal" basins, ranging from 0 to 0.3%. A defining geomorphic feature of the "declining" category is that around 1% of their area is trench, which is more than twice the area of trenches contained in the other categories. "Declining" ocean basins contain the highest concentration of seamounts (3.5 to 5 seamounts per 100,000 km^2), which is more than double the mean value (1.4 seamounts per 100,000 km^2) that occurs for the "mature" category with the next highest concentration; this difference is attributed to seamount burial in Mature ocean basins. The "terminal" category of ocean basins is characterized by the greatest mean sediment thickness (4,311 m) and greatest percentage area of submarine fans (7.2%) of any ocean basin.

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Wilson, J.T., 1966, Did the Atlantic close and then re-open?: Nature, v. 211, p. 676-681.

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ACE 101: Bridging Fundamentals and Innovation

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Did the Atlantic close and then re-open?
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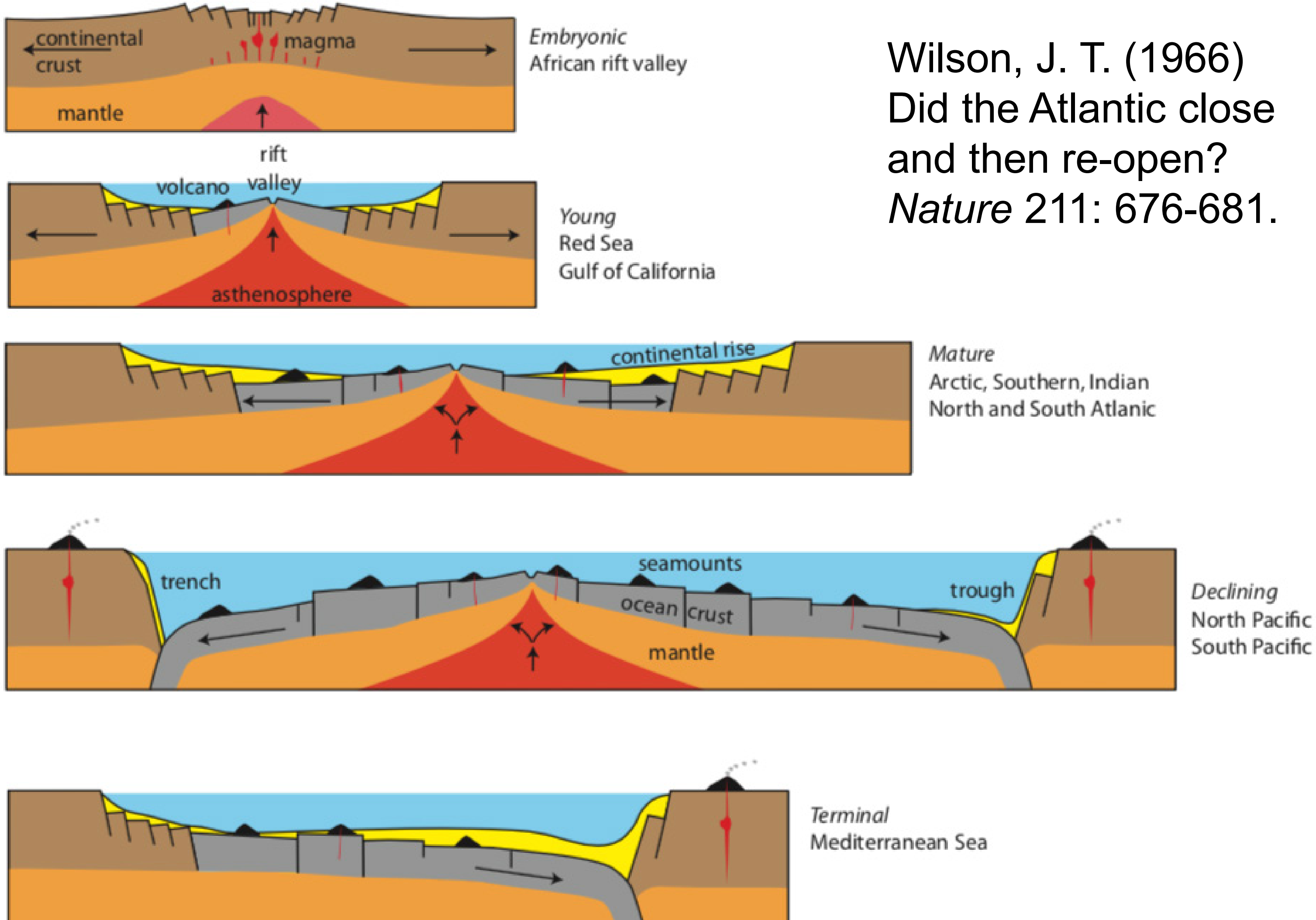
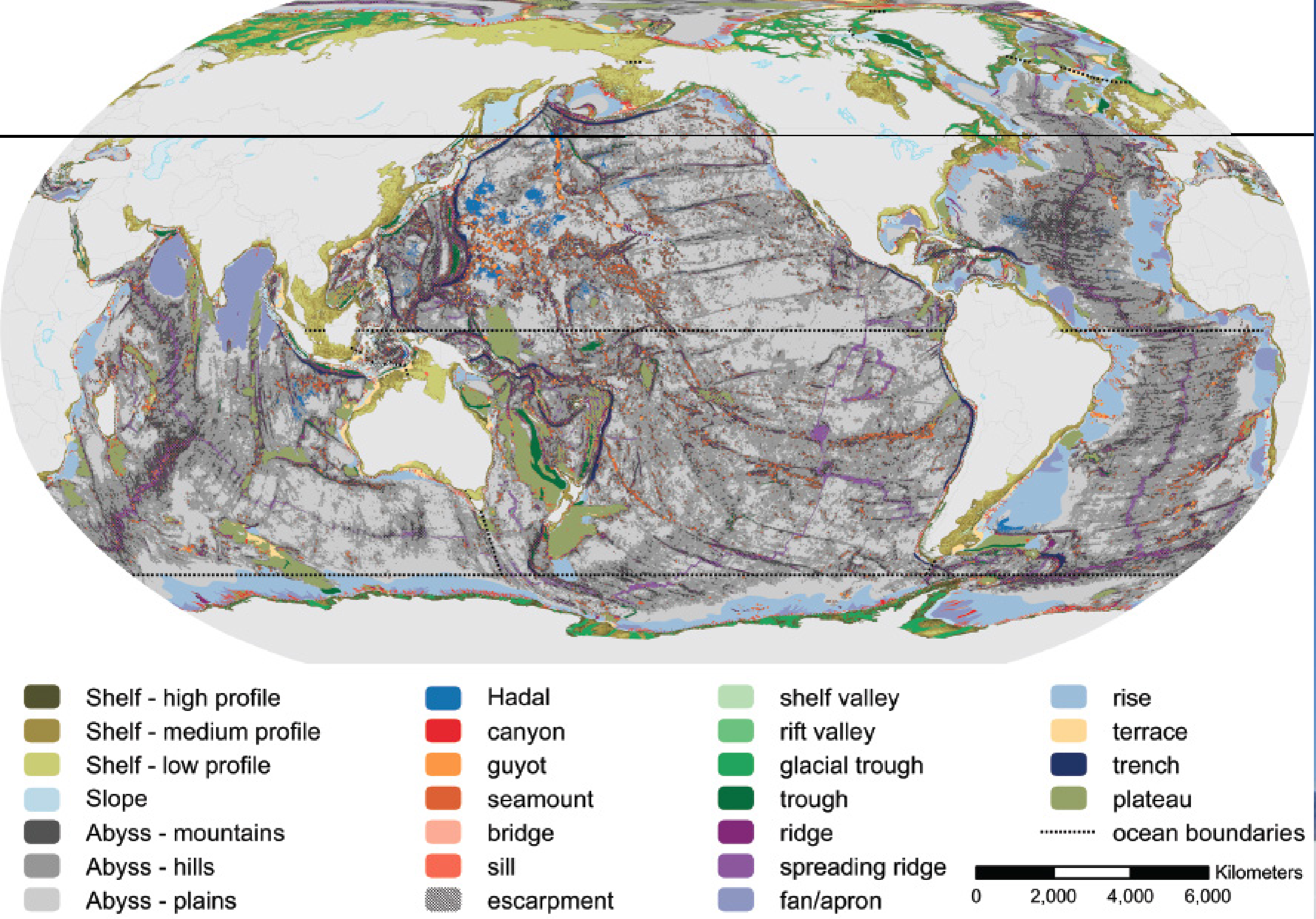


Aims:

Quantitative statistical analysis of ocean basin geomorphology to identify and document changes in the geomorphic composition of ocean basins as they evolve from embryonic to terminal stages of evolution according to the Wilson Cycle

Identify ocean basin evolutionary phases most influenced by depositional processes in terms of area of submarine canyons, fans and continental rise



Harris et al. (2014) Geomorphology of the oceans, *Marine Geology* 352: 4-24.

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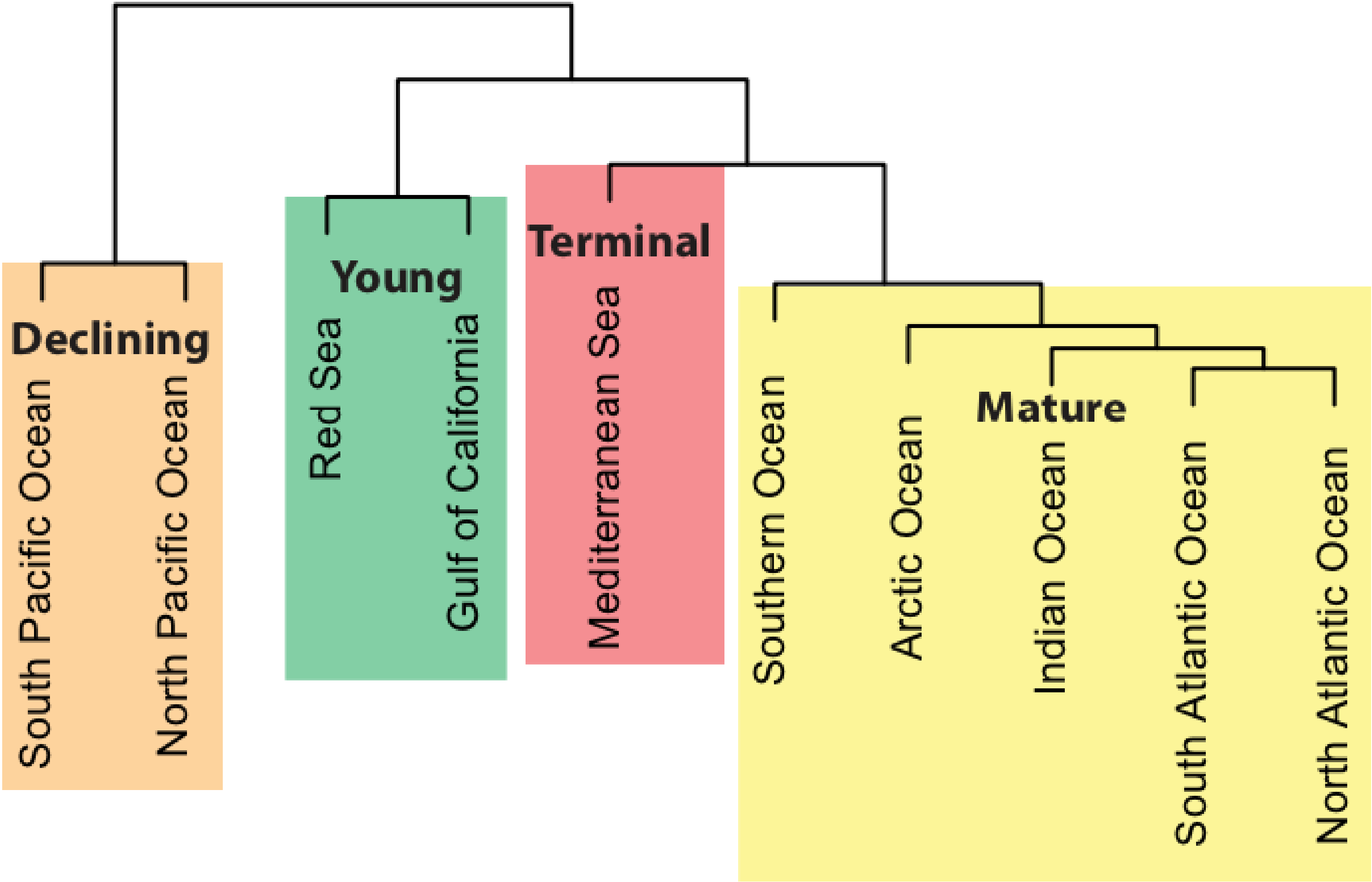
Methods

- Classification of ocean basins using hierarchical clustering in the R statistical package
- Based on 15 (out of 24 possible) spatial variables including geomorphic features, sediment thickness (Divins 2003), ocean crust age and spreading rate (Muller et al., 1997).
- Mean values for major ocean basins: Red Sea; Gulf of California; Arctic Ocean; Southern Ocean; Indian Ocean; South Atlantic Ocean; North Atlantic Ocean; South Pacific Ocean; North Pacific Ocean; and the Mediterranean Sea

Harris, P. T. and M. MacMillan-Lawler (2017). Origin and characteristics of ocean basins. In: *Submarine Geomorphology*, A. Micallef, S. Krastel and A. Savini (Eds), Springer Geology. pp 111-134.

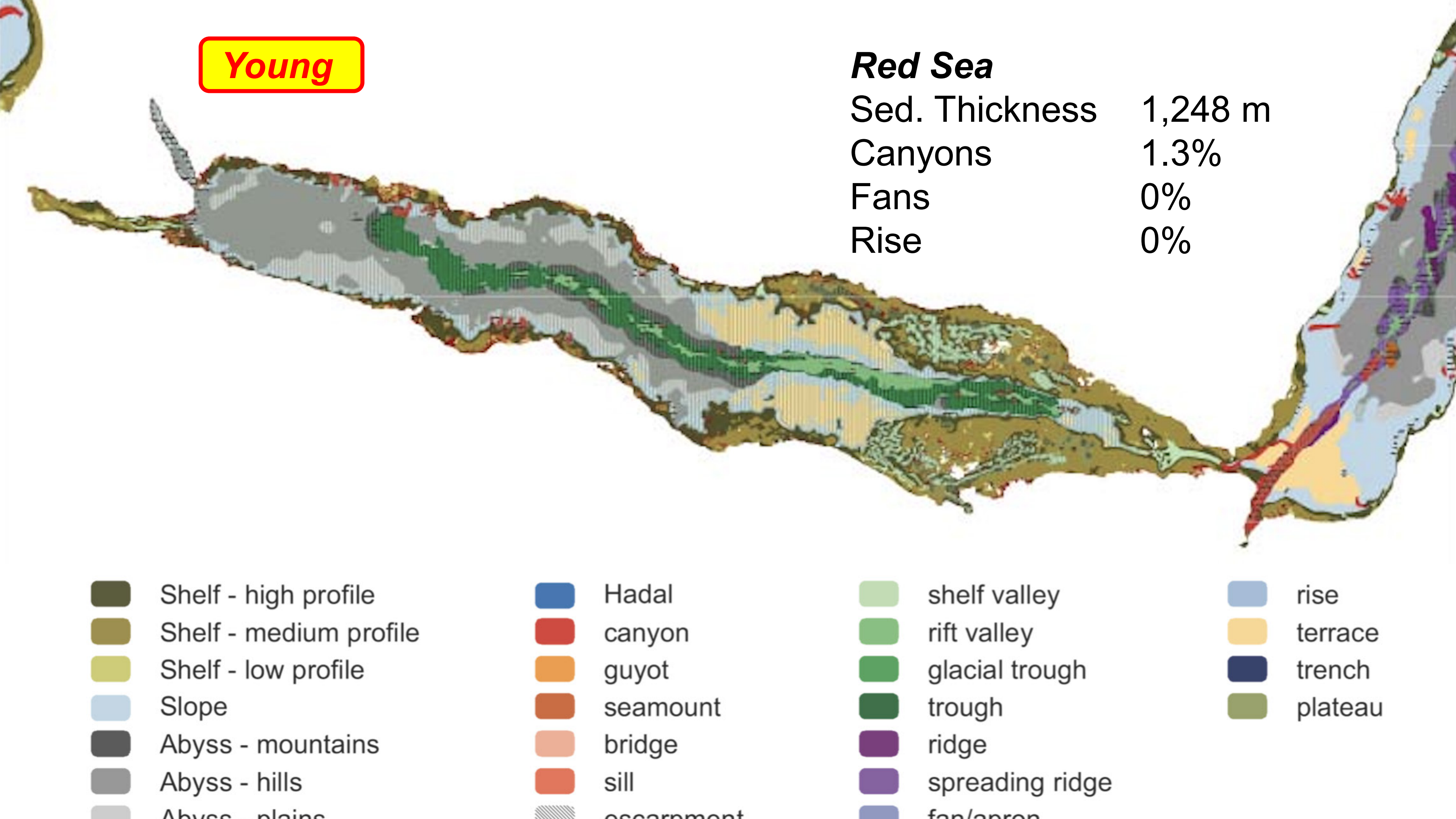
Stage	Ocean basin name	% Trench	Age mean (Ma)	Age max (Ma)	Sediment thickness (m)	Spreading rate mm/yr	% Slope	% Abyssal plains	% Canyons	% Bathymetric Basin	% Fan	% Seamount	Seamounts per 10^5 km^2	% Ridge	% Rift Valley	% Rise	% Spreading Ridge
Young	Red Sea	0	0	0	1248	10	33.3	11.5	1.30	96.5	0	0	0	0	4.5	0	0
	Gulf of California	0	1	8	357	43	74.9	3.6	8.80	16.7	0.9	0.5	0.9	0	1.7	0	0.5
Mature	Arctic Ocean	0	69	159	854	31	14.6	33	5.70	46.4	2.4	0.1	0.123	1.9	0.5	14.5	4
	Southern Ocean	0.04	70	160	984	27	3.5	48.6	3.10	54.2	6.6	0.9	1.24	1.8	0.1	38.1	1.9
	Indian Ocean	0.2	55	159	703	40	6.1	32.5	1.10	48.7	6.5	1.4	1.56	2.5	0.2	9.3	2.3
	South Atlantic Ocean	0.2	57	139	722	26	4.1	26.1	0.80	46.7	2.3	2.1	2.46	2.8	0.3	16.2	3
	North Atlantic Ocean	0.3	74	180	1442	19	9.2	27.4	2.00	45.1	3.5	1.4	1.74	2.6	0.3	20.9	1.8
Declining	South Pacific Ocean	0.9	47	152	229	58	3.8	26.8	1.10	46.5	0.03	2.8	3.49	3	0.2	0.7	2.2
	North Pacific Ocean	1.1	79	175	386	57	6.2	32.9	0.80	44.6	0.3	4.1	4.95	3.7	0.1	1.3	1.1
Terminal	Med. Sea	0.6	186	278	4311	29	39.2	26.5	7.00	69.7	7.2	0.3	0.827	1.1	0	16.6	0


Declining
South Pacific Ocean
North Pacific Ocean
Young
Red Sea
Gulf of California
Terminal
Mediterranean Sea
Mature
Southern Ocean
Arctic Ocean
Indian Ocean
South Atlantic Ocean
North Atlantic Ocean

Young

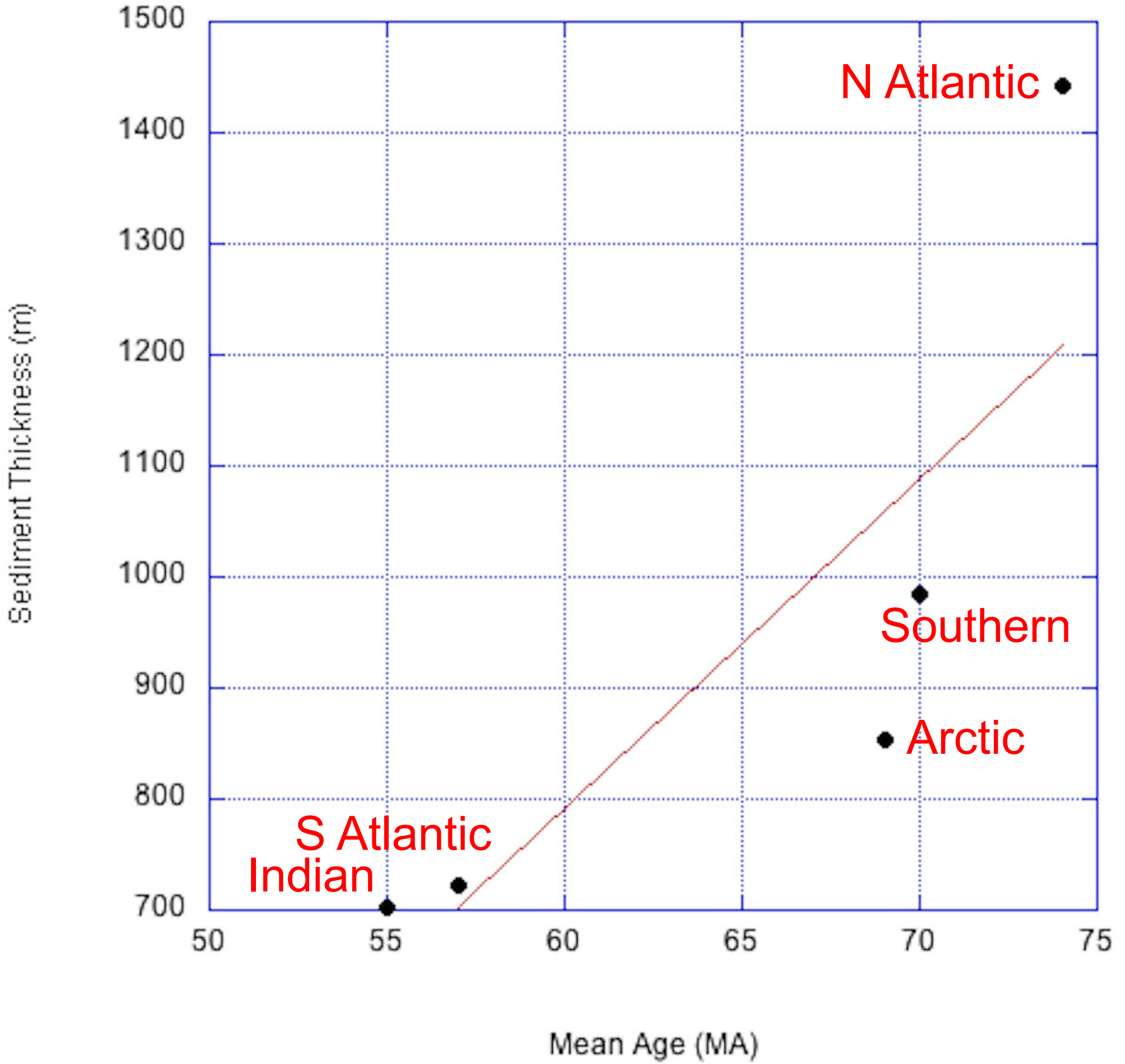
Red Sea

Sed. Thickness	1,248 m
Canyons	1.3%
Fans	0%
Rise	0%



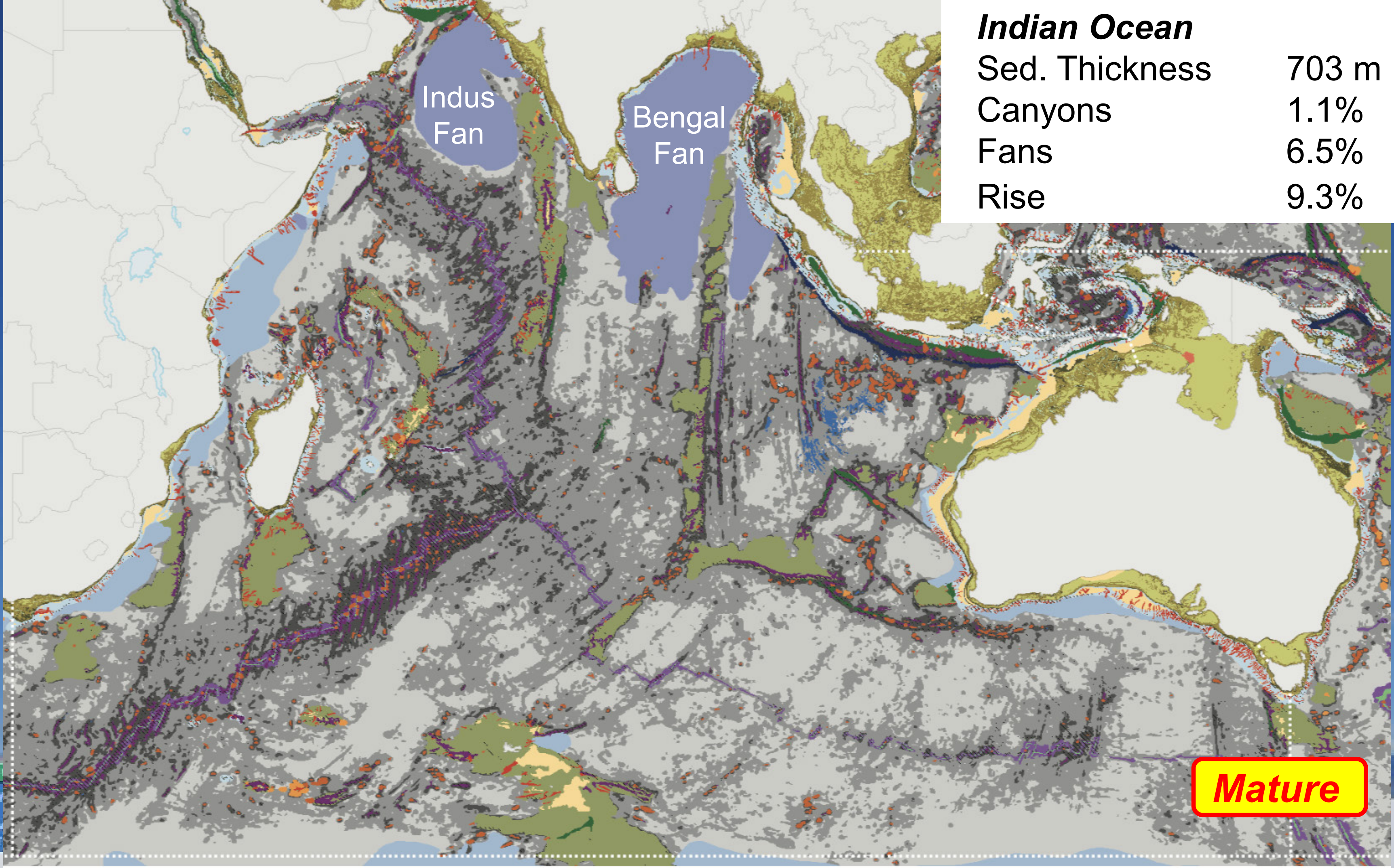
r = 0.83

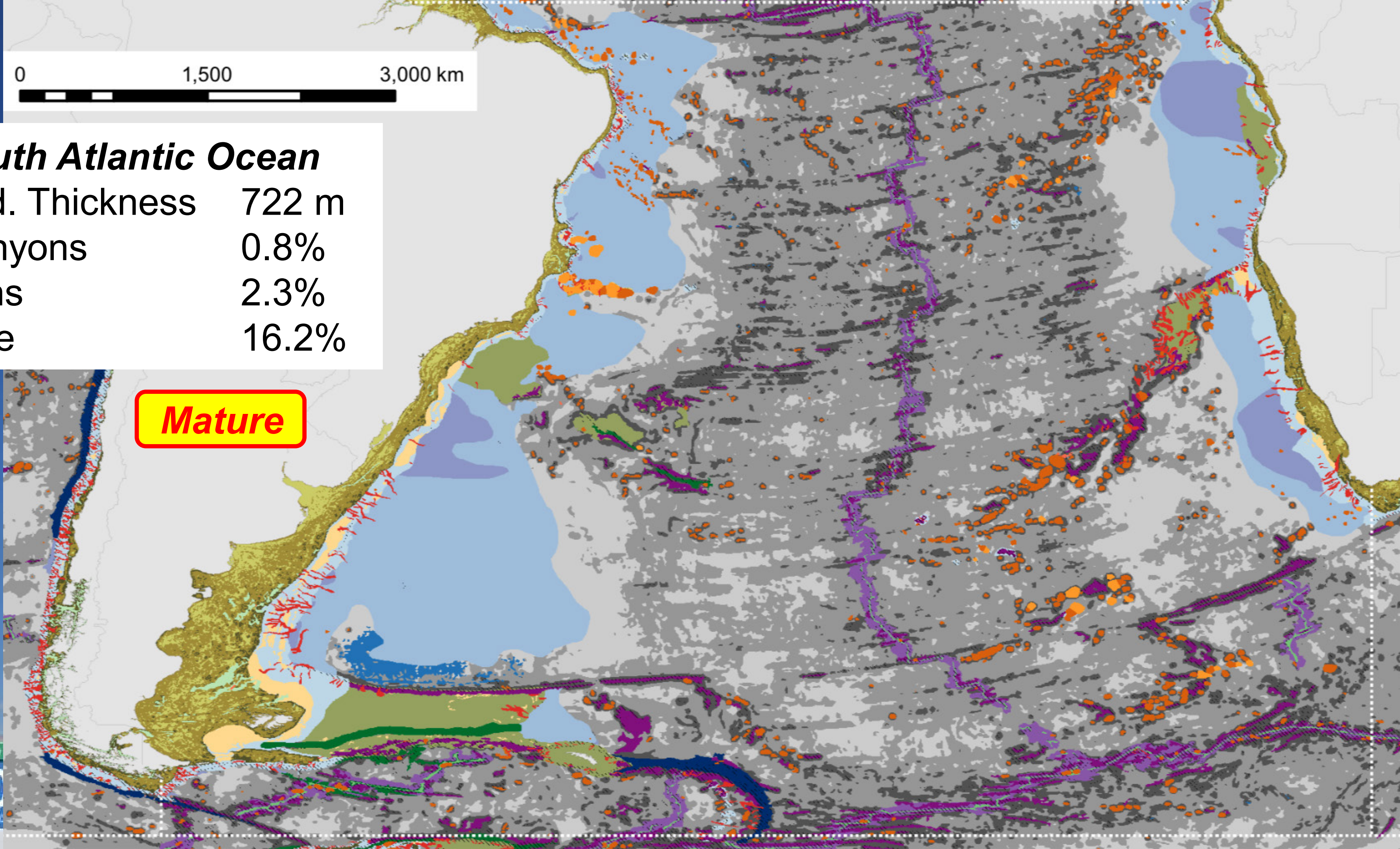
Sediment thickness increases with age of basin



Indian Ocean

Sed. Thickness	703 m
Canyons	1.1%
Fans	6.5%
Rise	9.3%





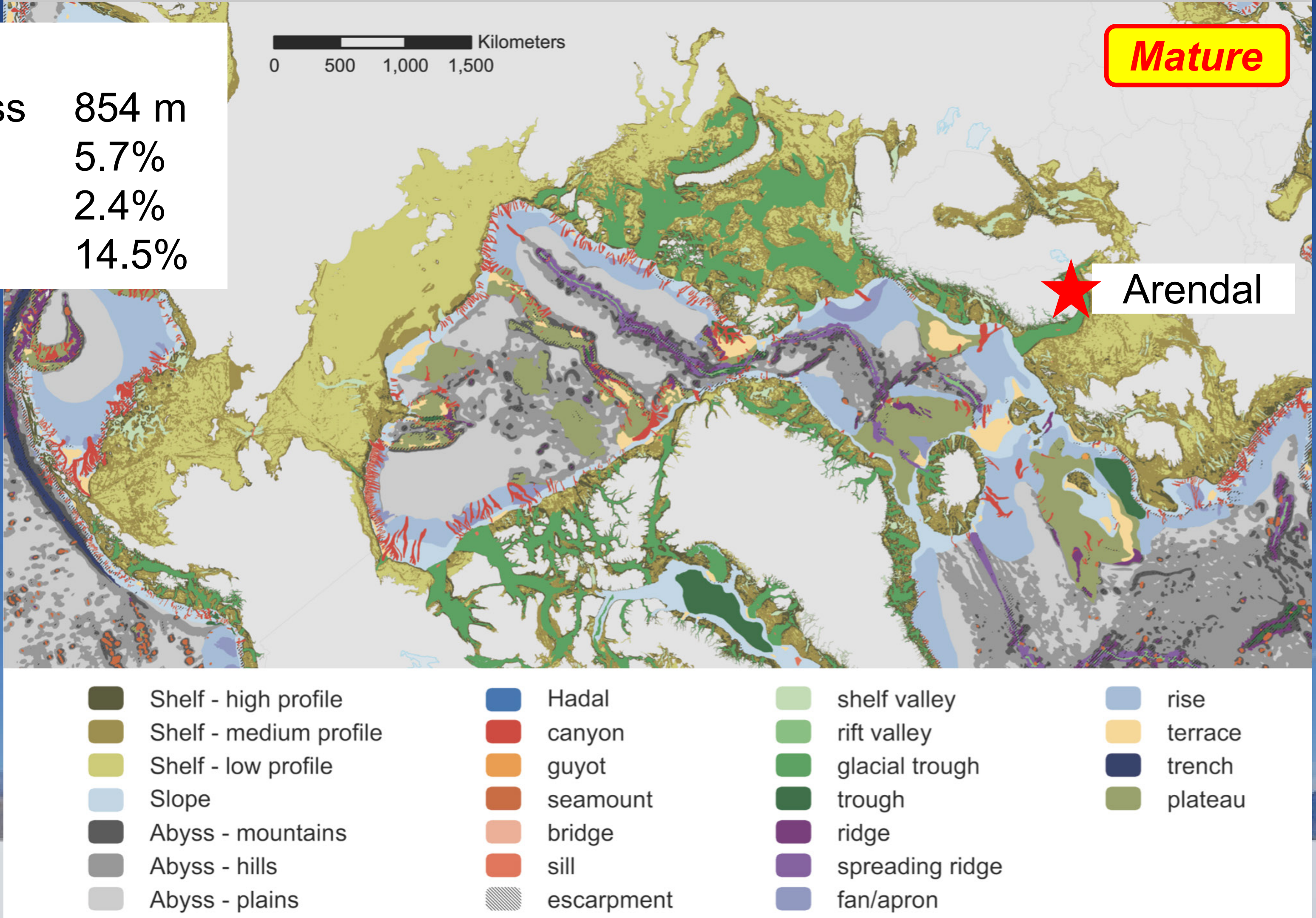
South Atlantic Ocean

Sed. Thickness	722 m
Canyons	0.8%
Fans	2.3%
Rise	16.2%

Arctic Ocean

Sed. Thickness	854 m
Canyons	5.7%
Fans	2.4%
Rise	14.5%

Glacial troughs correspond with broad continental rise



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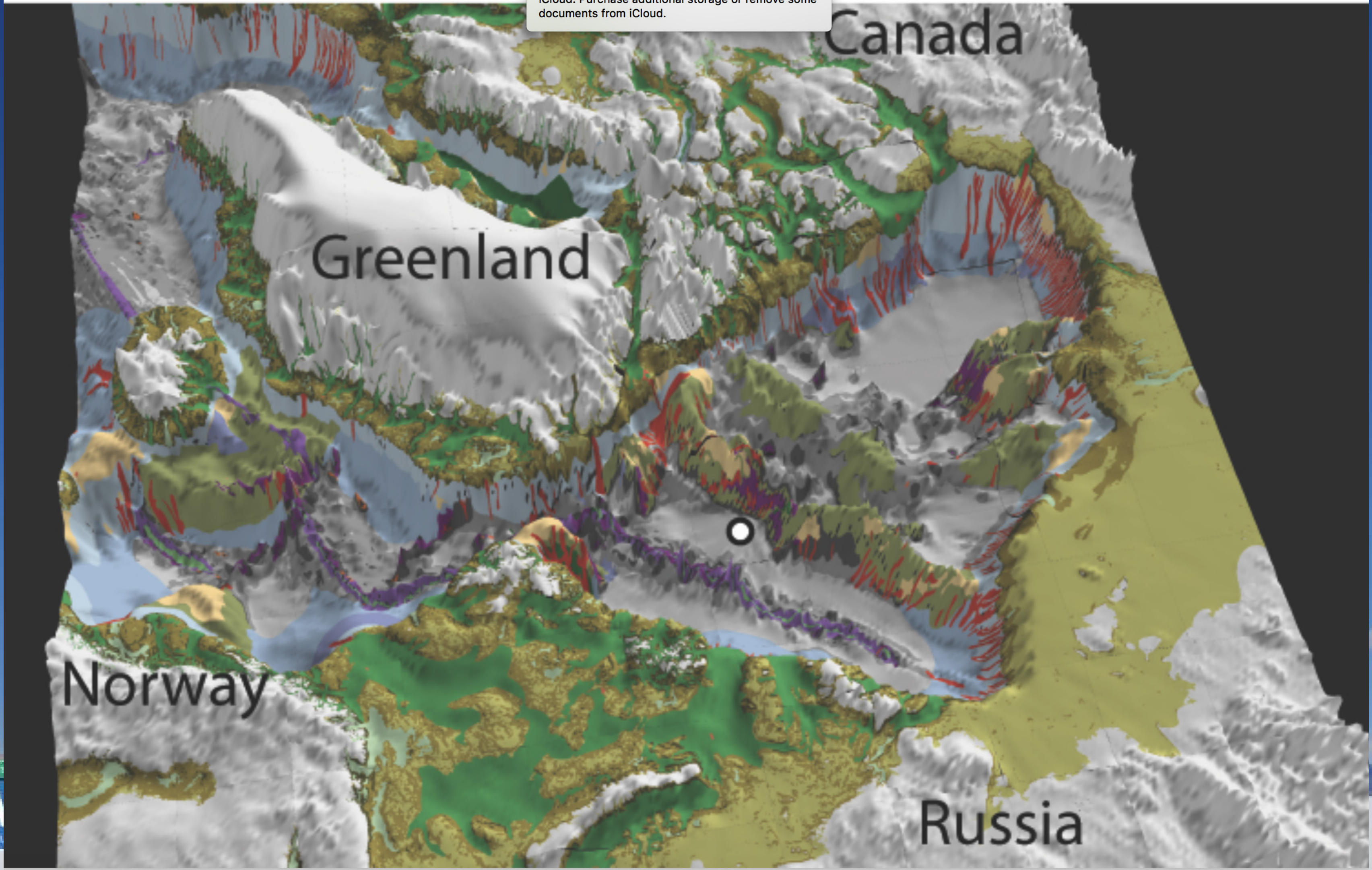
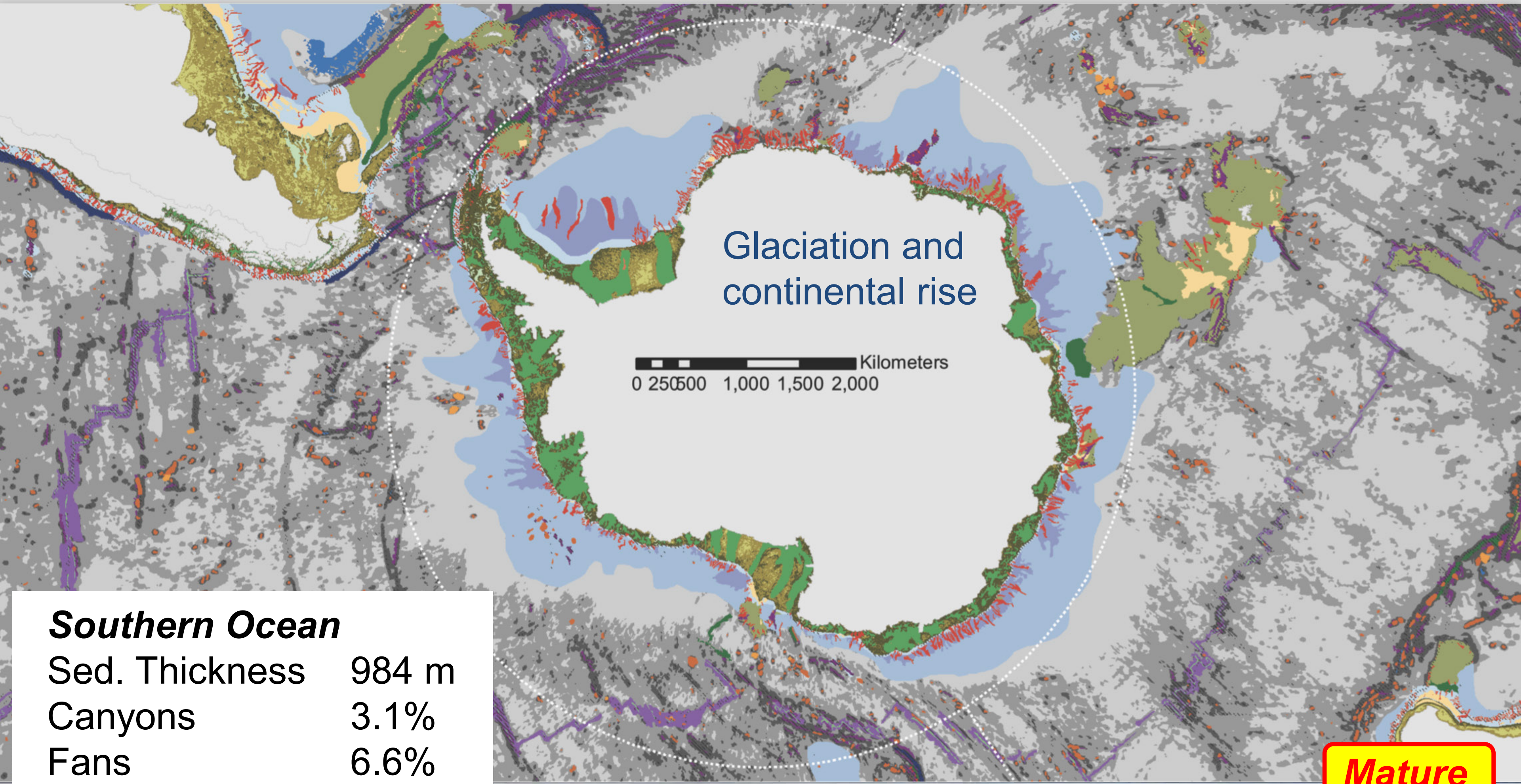




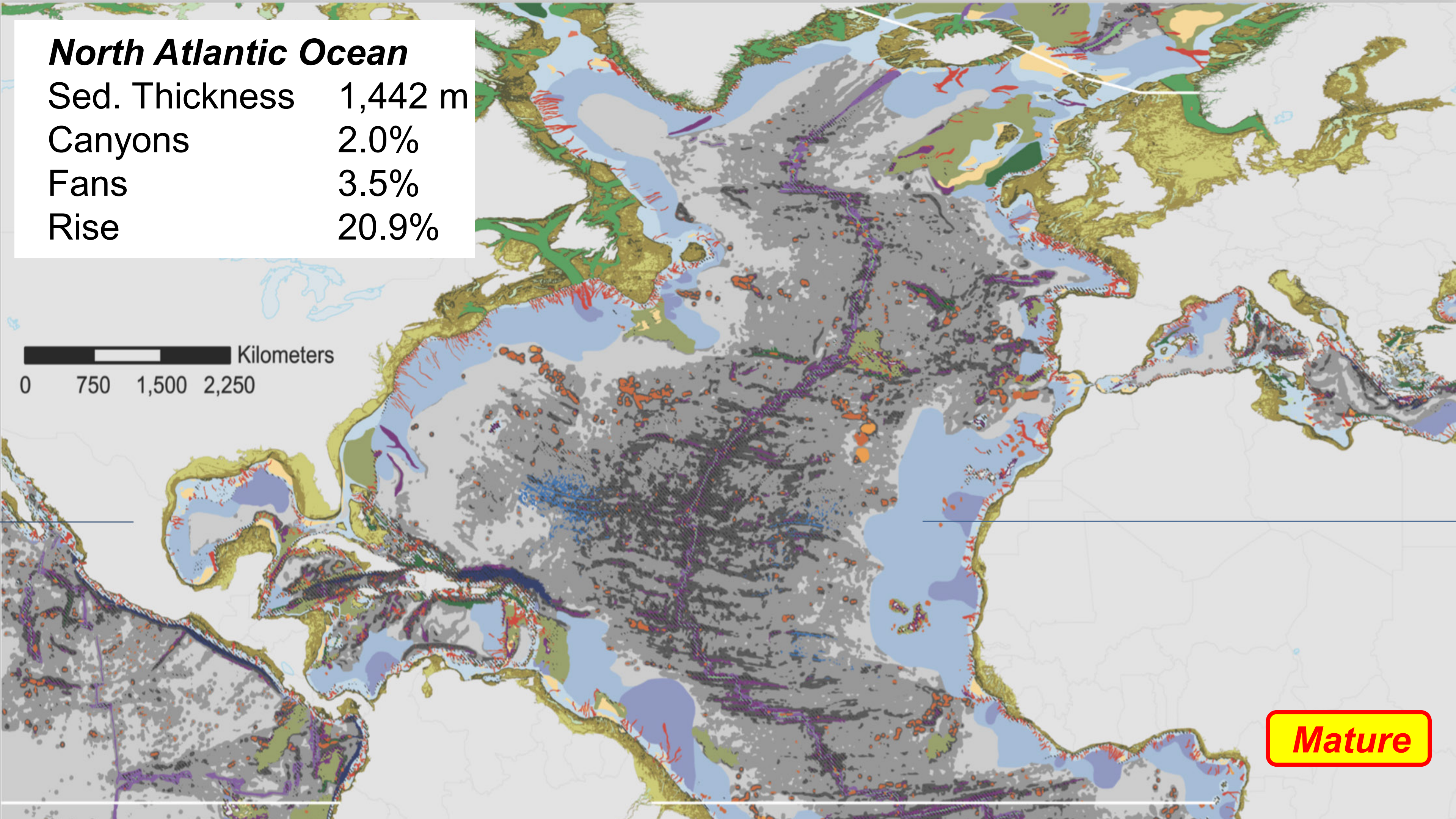
Southern Ocean

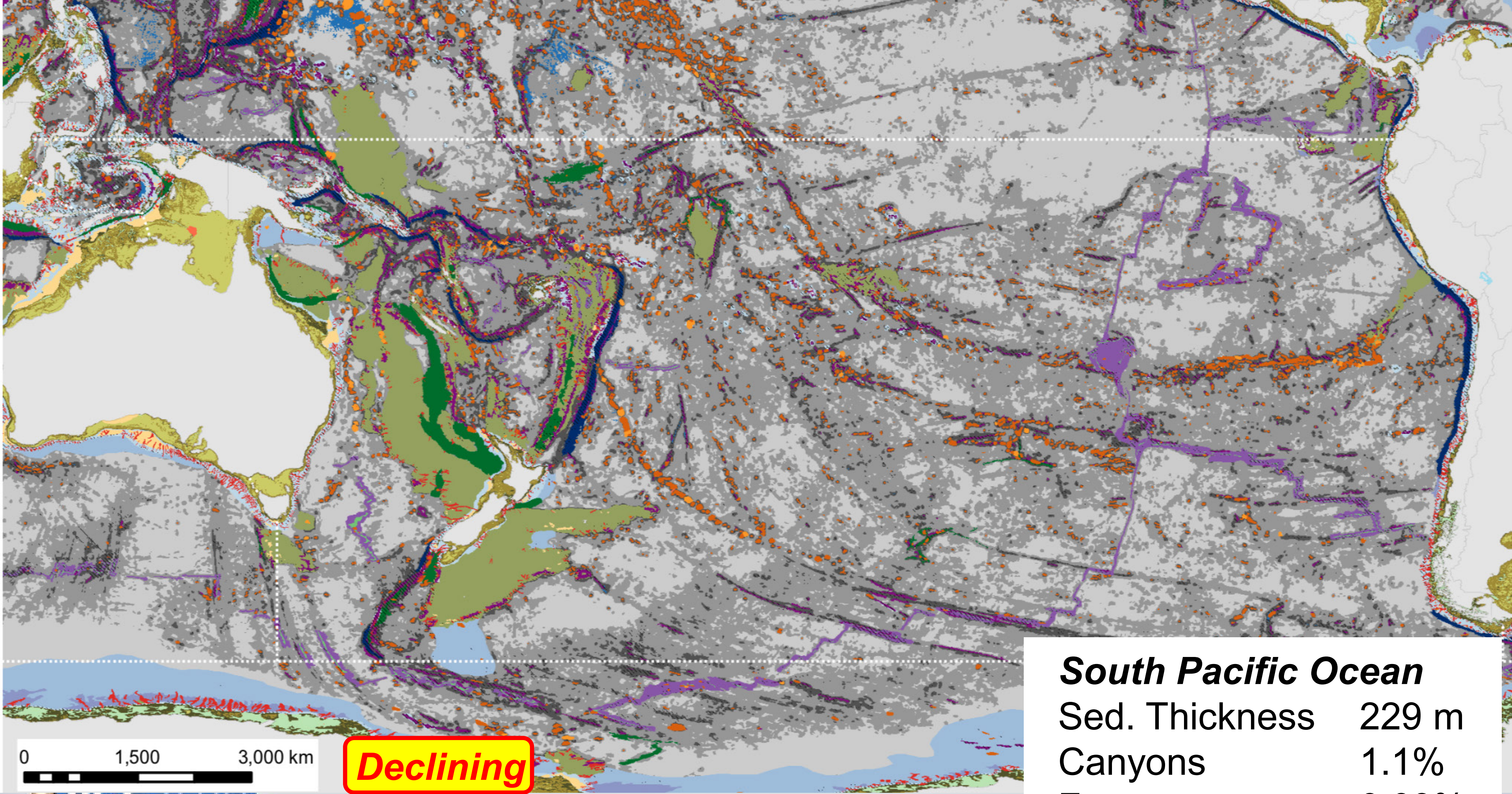
Sed. Thickness	984 m
Canyons	3.1%
Fans	6.6%
Rise	38.1%

Mature

North Atlantic Ocean

Sed. Thickness	1,442 m
Canyons	2.0%
Fans	3.5%
Rise	20.9%

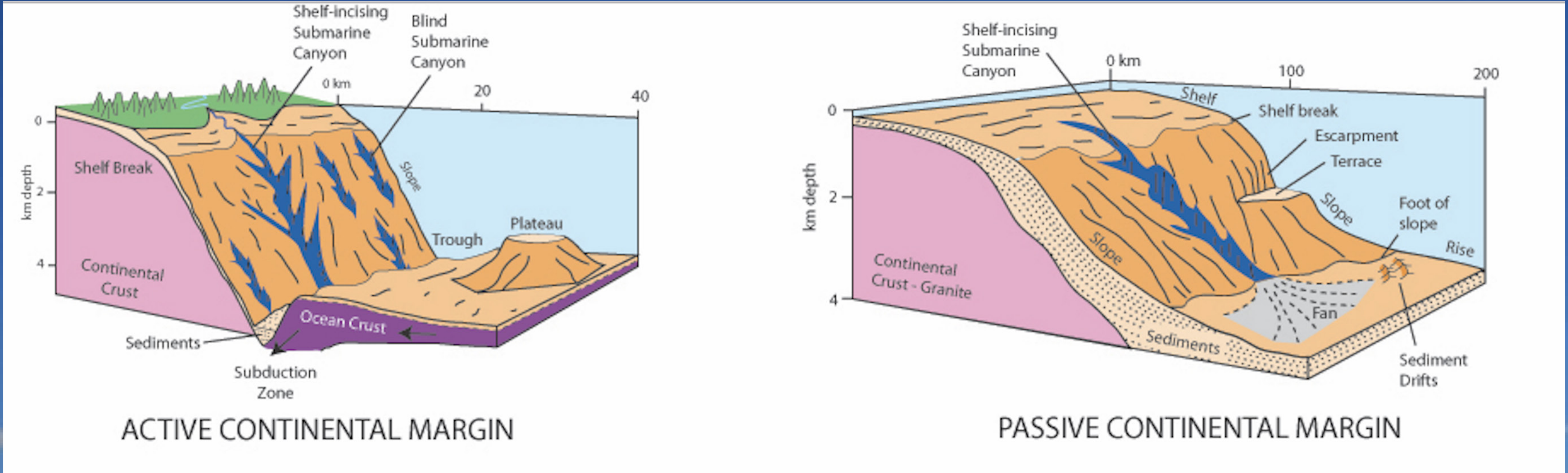




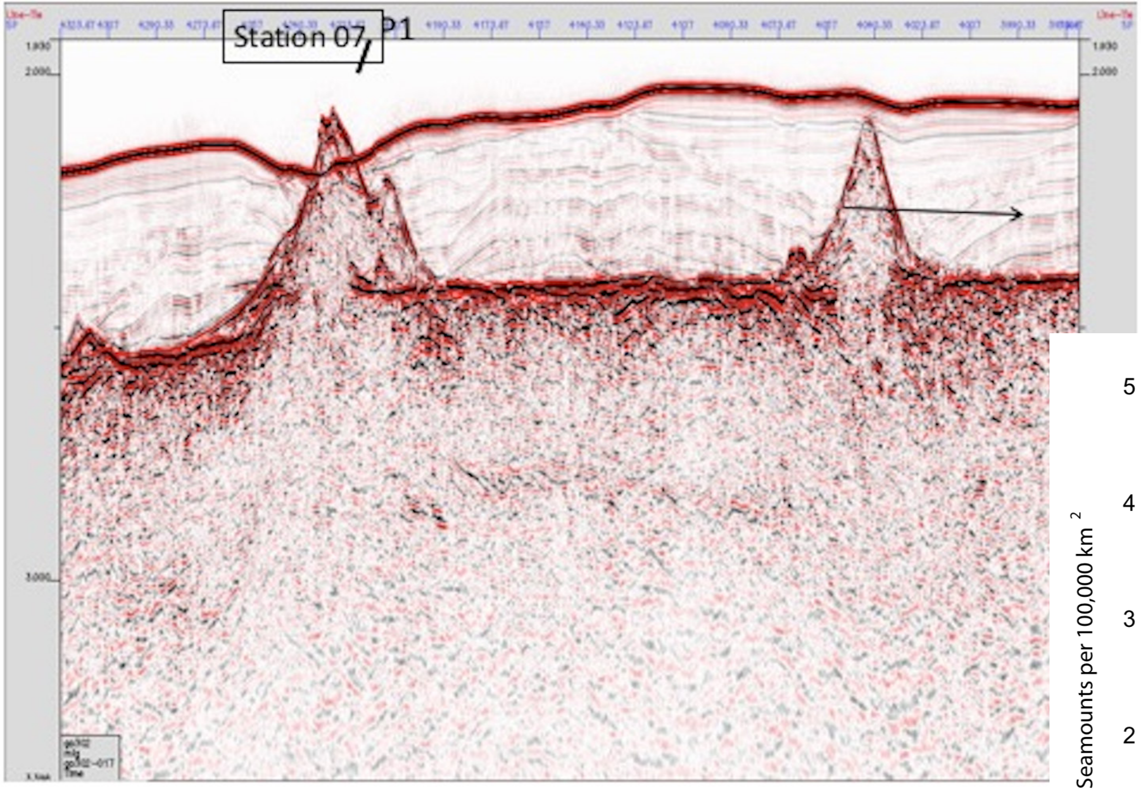
South Pacific Ocean

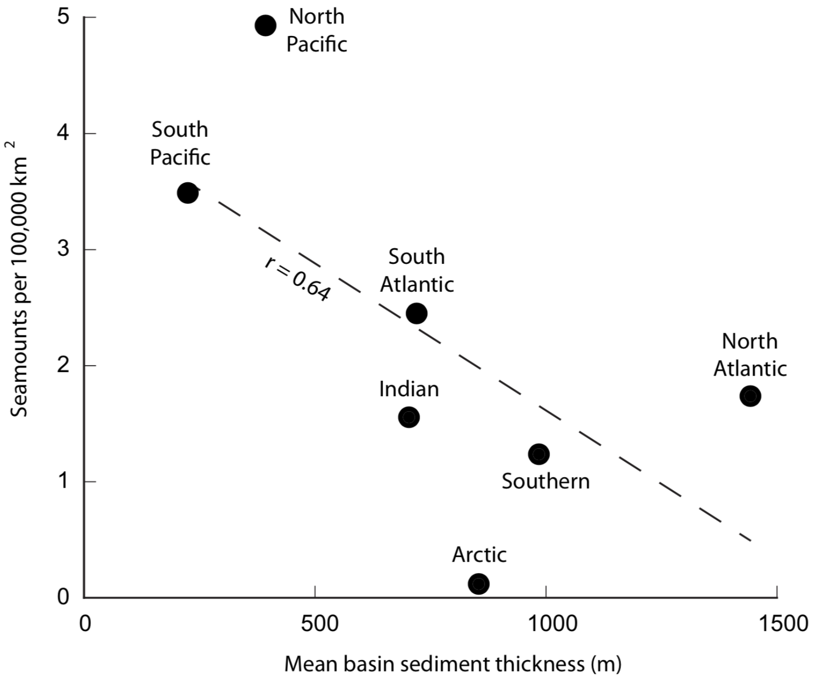
Sed. Thickness	229 m
Canyons	1.1%
Fans	0.03%
Rise	0.7%

Contrast in depositional patterns between active and passive margins



Seamounts appear to be less common in Mature basins due to burial





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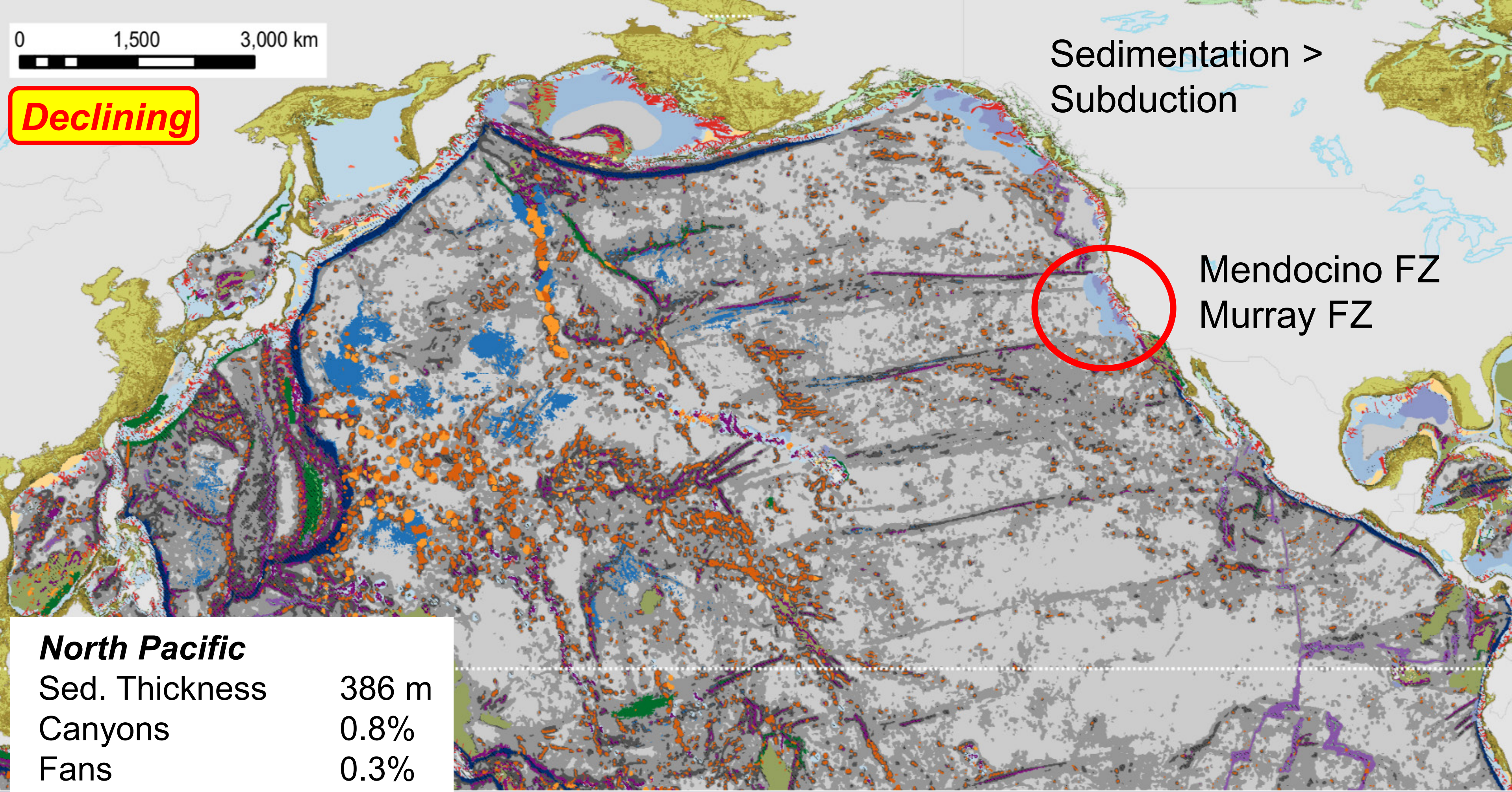
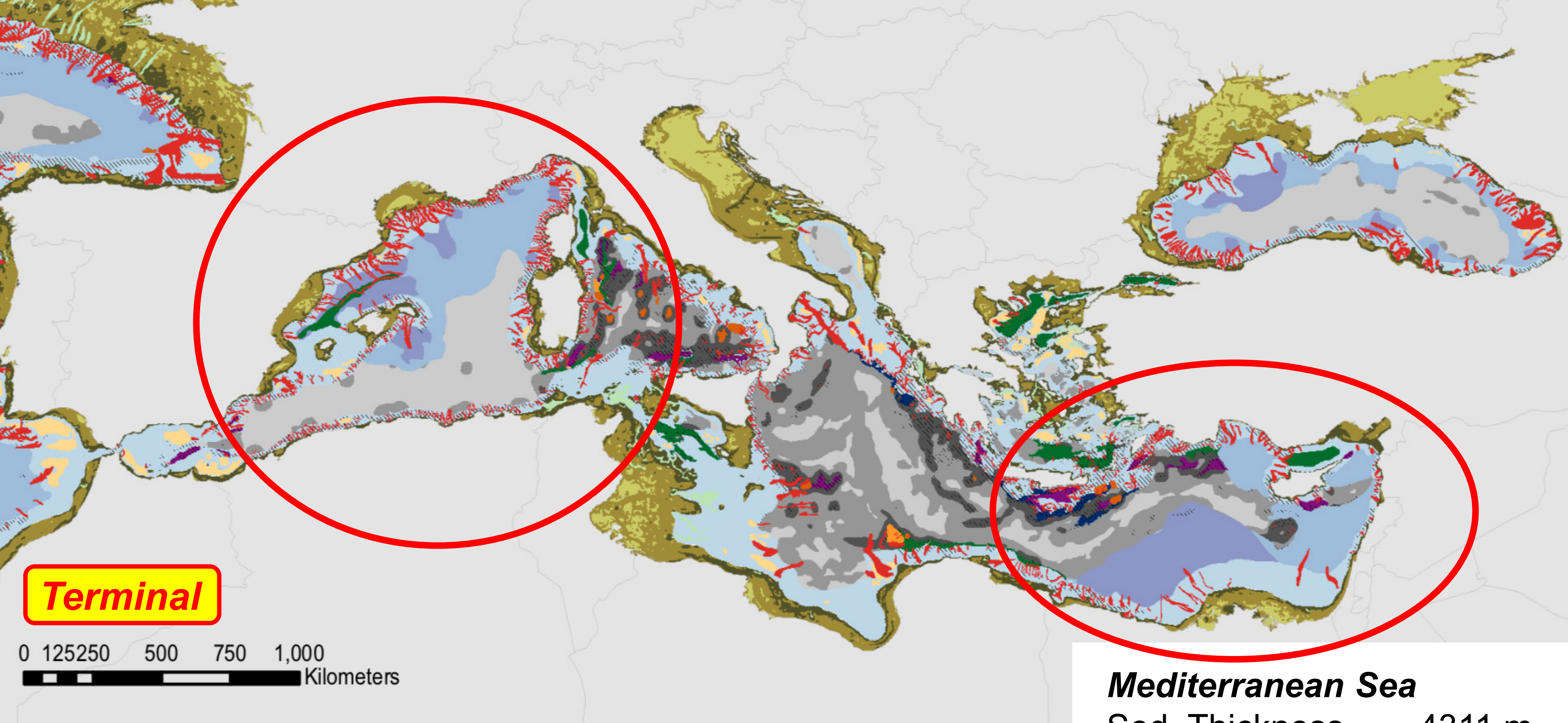
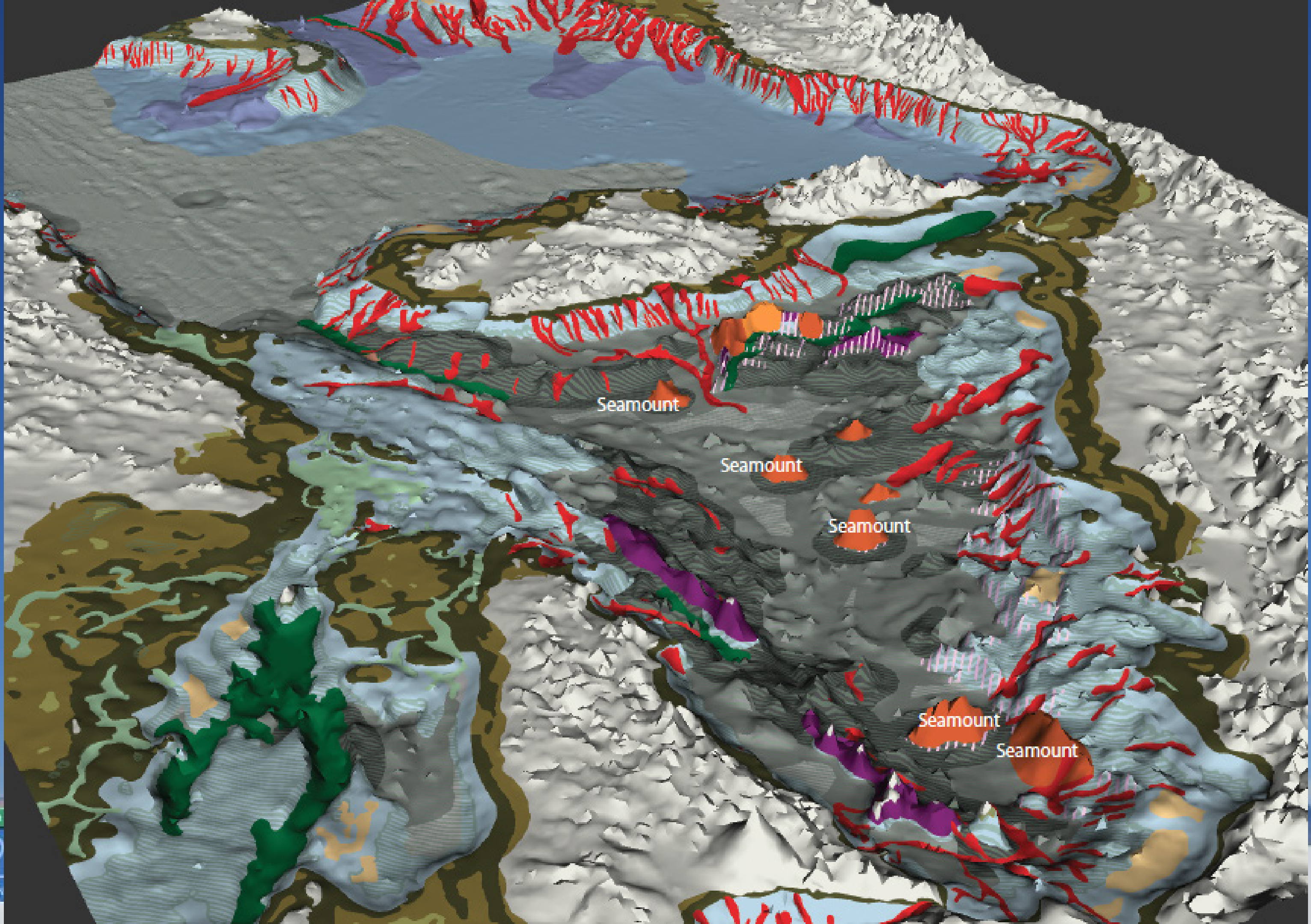


North Pacific	
Sed. Thickness	386 m
Canyons	0.8%
Fans	0.3%
Rise	1.3%



Mediterranean Sea	
Sed. Thickness	4311 m
Canyons	7.0%
Fans	7.2%
Rise	16.6%


Seamount
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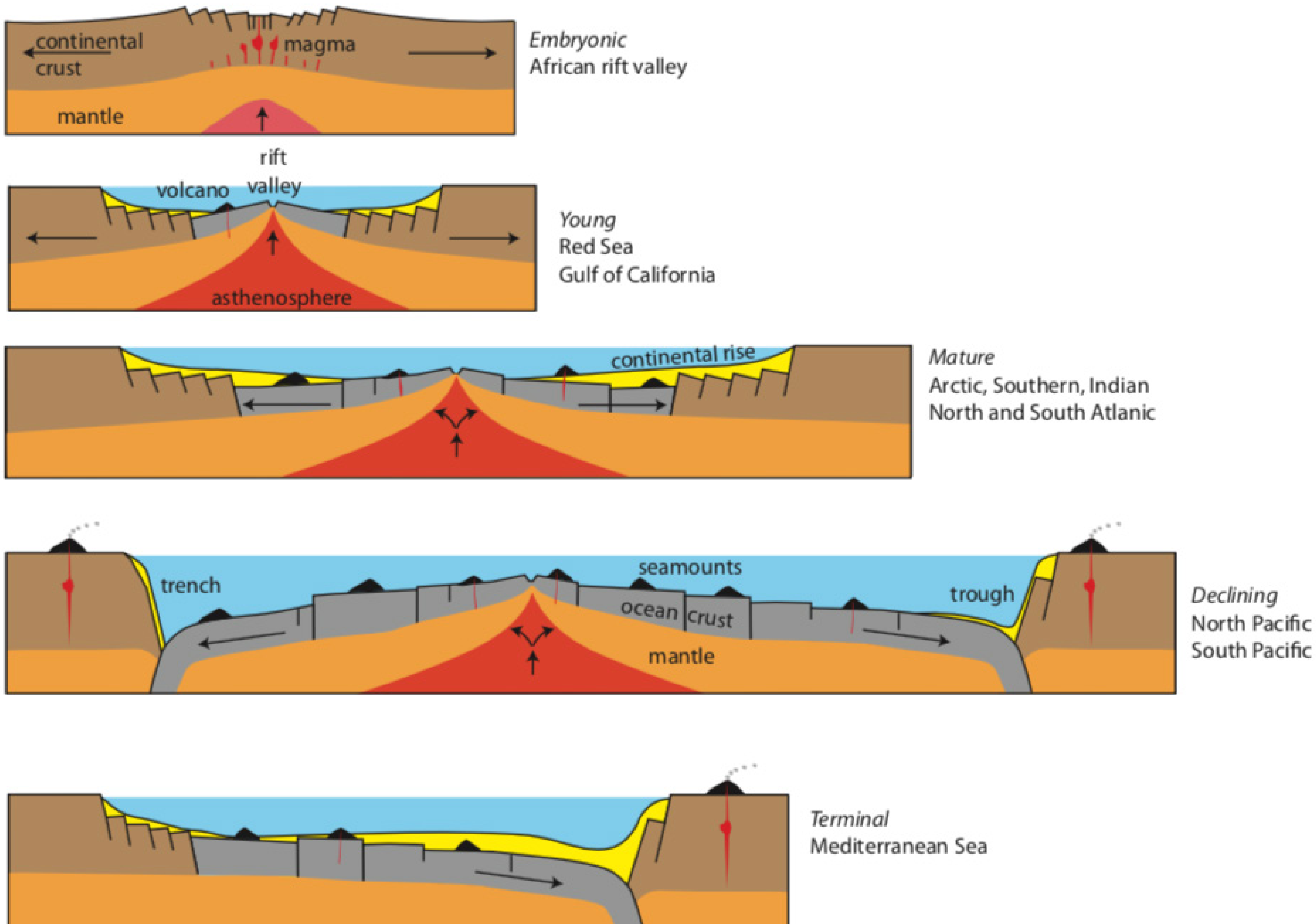

continental
crust
magma
mantle
Embryonic
African rift valley
rift
valley
volcano
asthenosphere
Young
Red Sea
Gulf of California
continental rise
Mature
Arctic, Southern, Indian
North and South Atlantic
trench
seamounts
trough
ocean crust
mantle
Declining
North Pacific
South Pacific
Terminal
Mediterranean Sea

Conclusions:

1. Geomorphic analysis provides quantitative boundaries for ocean basin depositional systems in relation to Wilson Cycle
2. Terminal ocean basins (Mediterranean Sea) have thickest sediments, greatest percent area of canyons and fans
3. Mature ocean basins: mean sediment thickness increases with mean basin age
4. Declining ocean basins contain the least area of depositional features (NB deposition along transform plate boundaries)