Geochemical and Mineralogical Dispersion Models in Till: Physical Process Constraints and Impacts on Geochemical Exploration Interpretation

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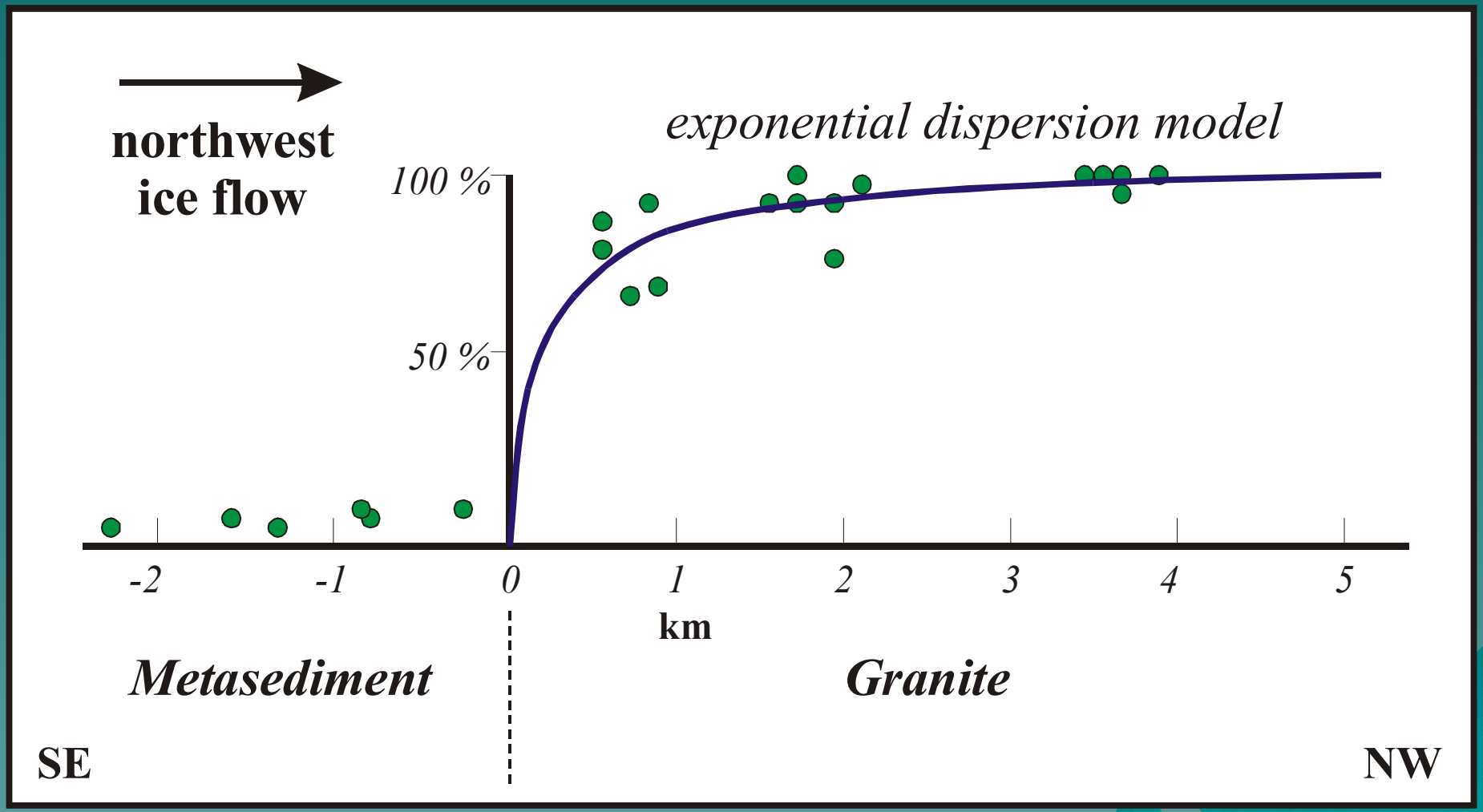
Glacial Dispersion Models

- Dilution (or enrichment) of geochemical or mineralogical till concentrations at a geological contact have historically been described using two types of quantitative dispersion models:
  - ***Exponential Dispersion***
    basal (lodgement) till
  - ***Linear Dispersion***
    overlying (ablation/melt-out) till

Glacial Dispersion Models

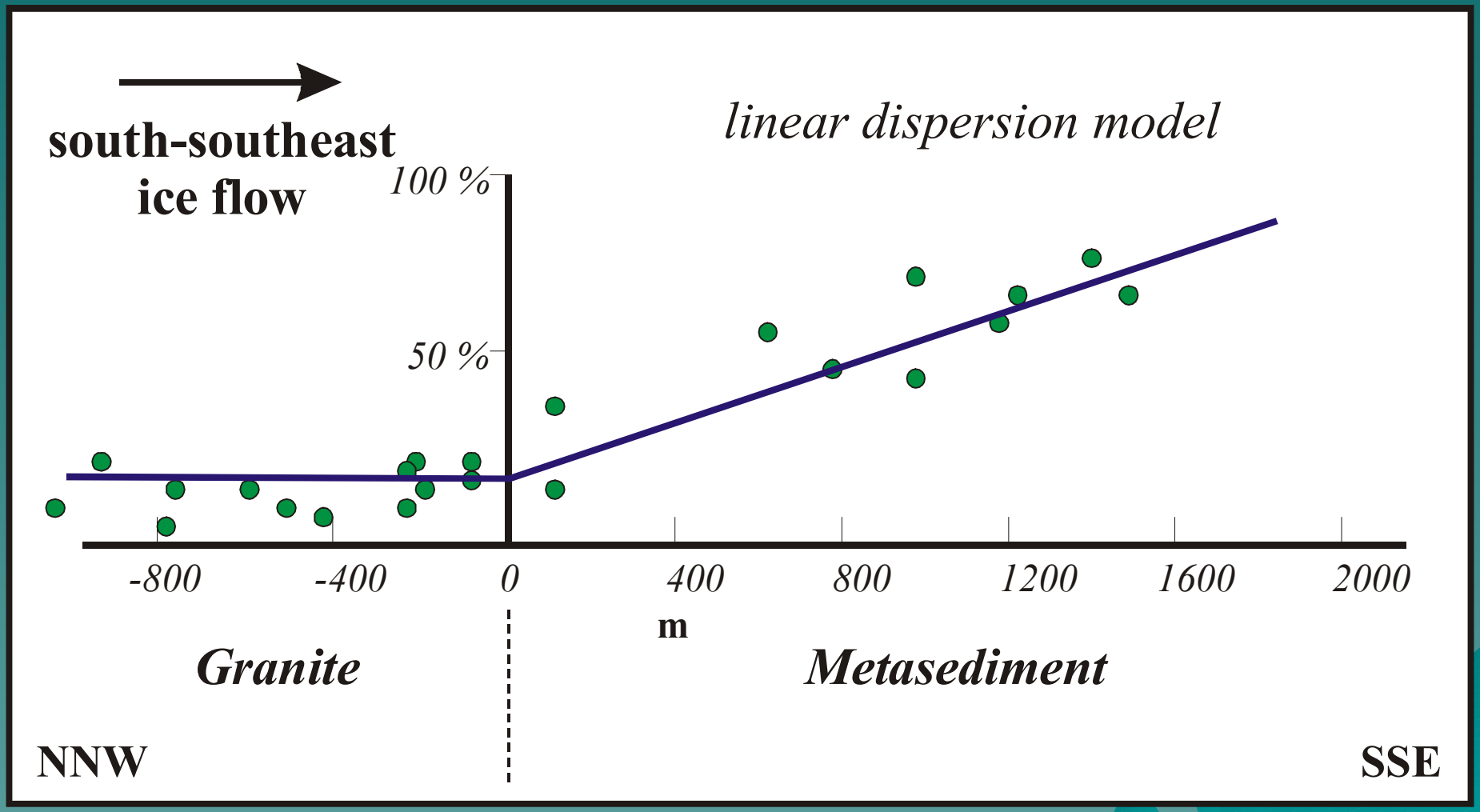
% Granite Clasts in Lodgement Till



Data courtesy of Ralph Stea, NS-DNR

Glacial Dispersion Models

% Metasediment Clasts in Ablation Till

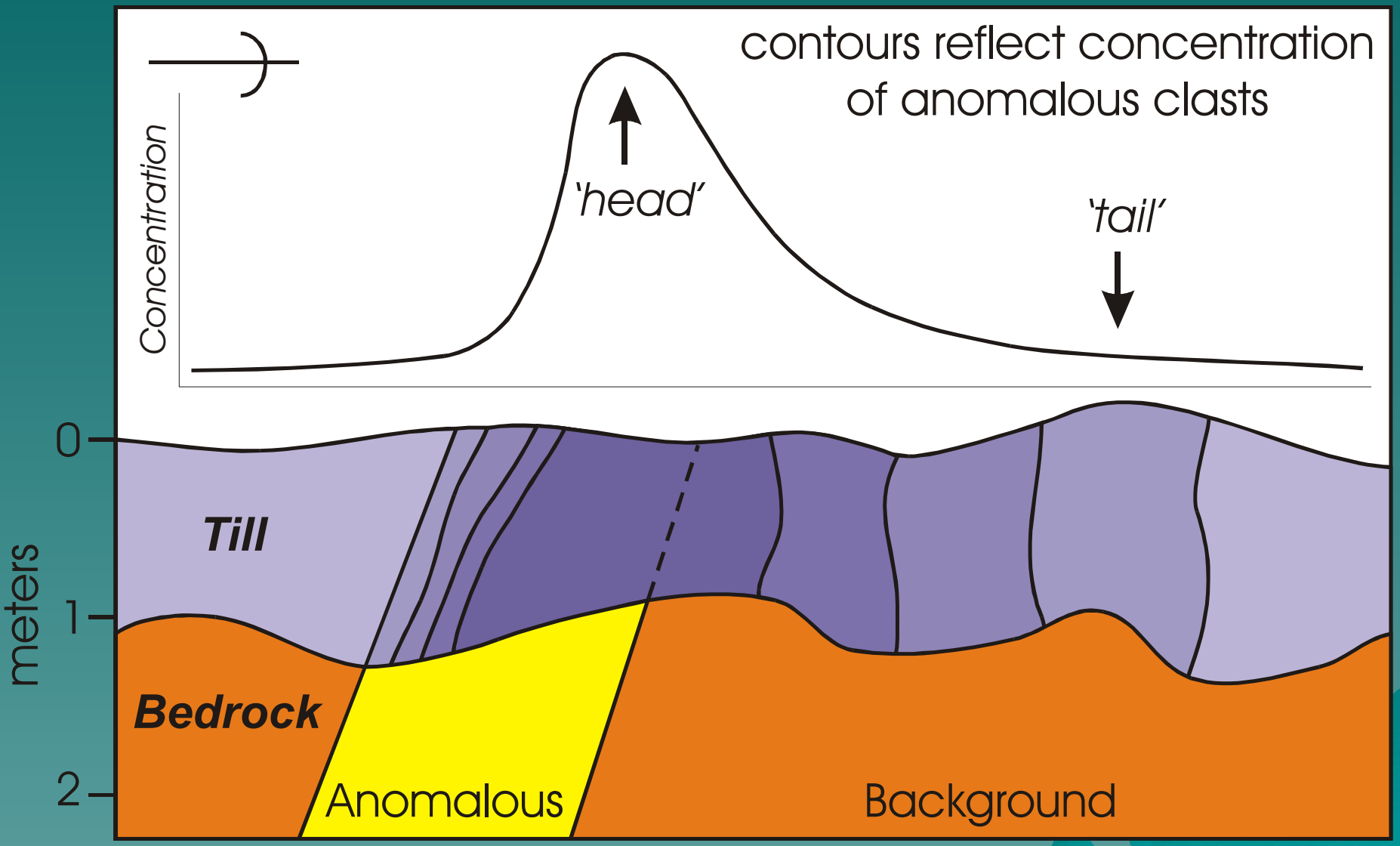


Data from Finck & Stea (1995)

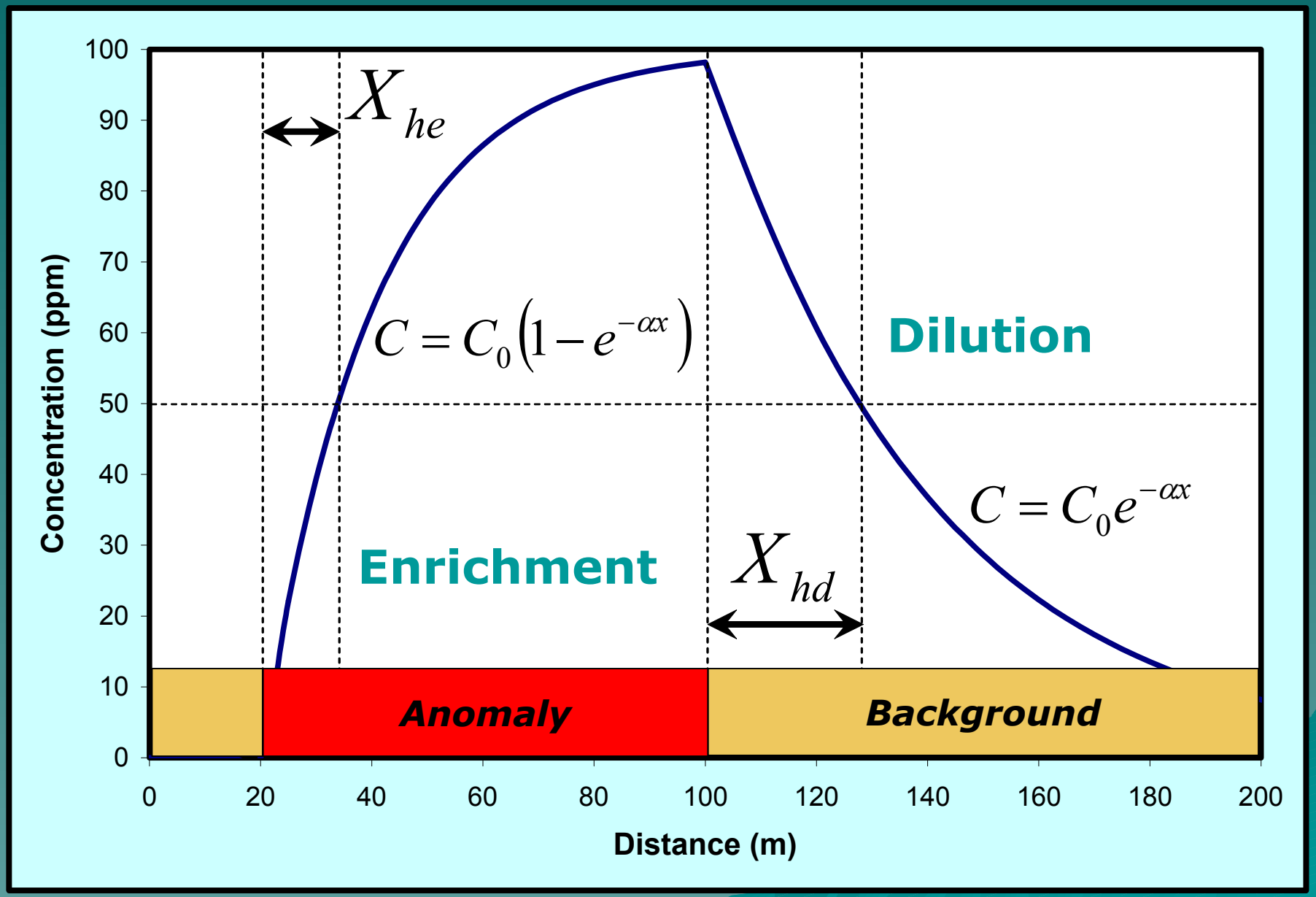
Glacial Dispersion Models

- Are these quantitative numerical models consistent with the physical processes that erode, transport and deposit till?
- If not, are there alternative numerical models that are consistent with these processes?
- Do any of these models provide insight into glacial entrainment, transport and depositional processes?

Exponential Dispersion Model

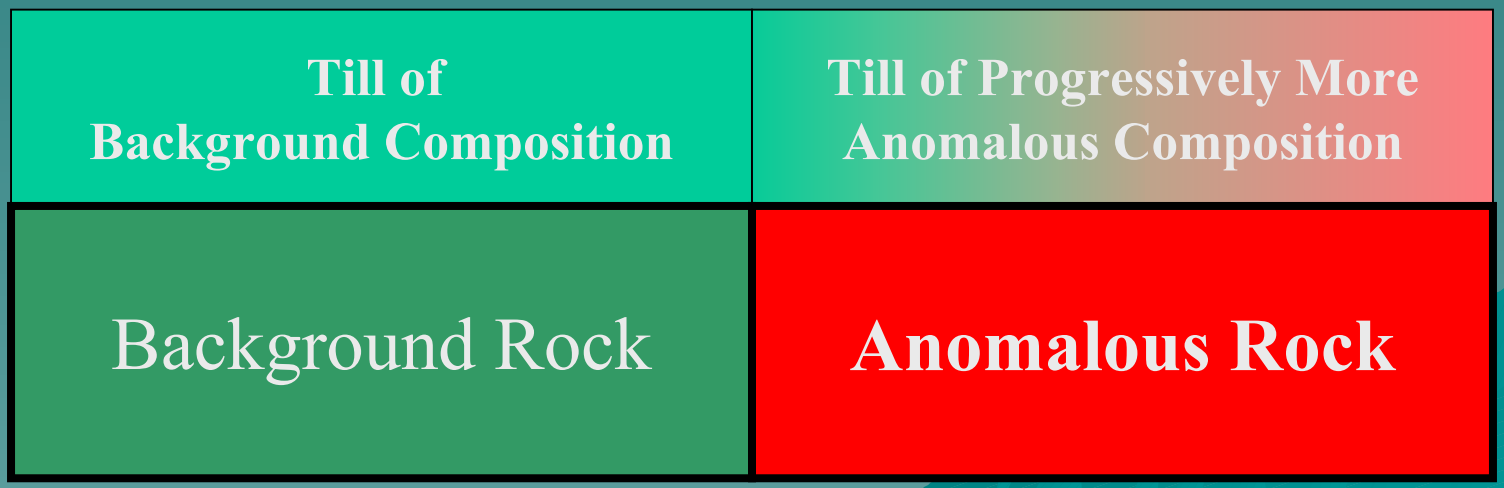


Exponential Dispersion Model – Equations

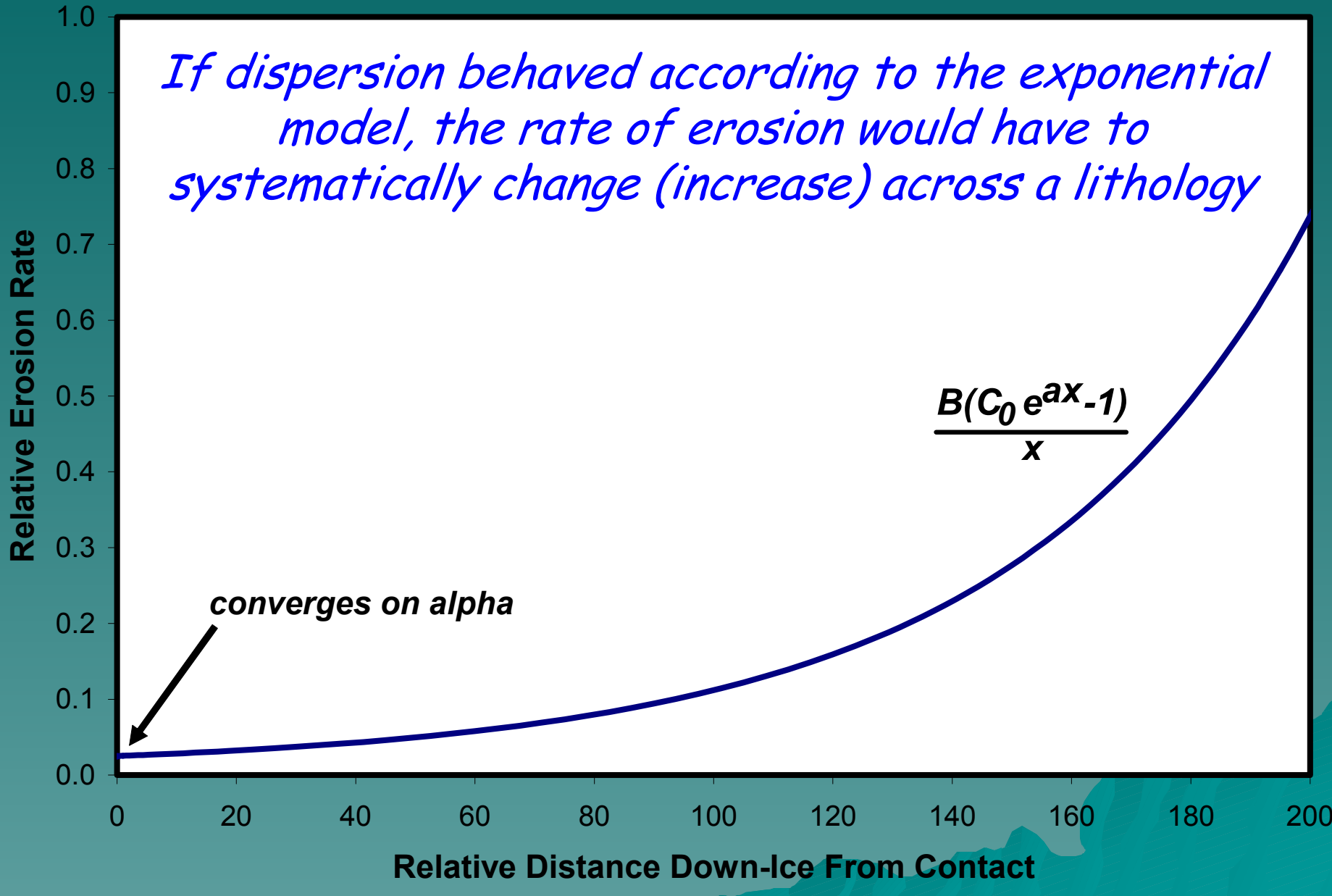


Exponential Dispersion Physical Meaning

- Dispersion Model:
  - glacier flows from background to anomalous rocks, both of which are homogeneous
  - en-glacial load first contains a certain amount of background material; anomalous material is added
  - The rate of addition of the anomalous material necessary to create an exponential pattern can be determined



Exponential Dispersion Physical Meaning



Exponential Dispersion Physical Meaning

- Dispersion Model:
  - erosion rates are constant over each rock (*although they may be different & locally variable*)
  - therefore, amount of anomalous material increases linearly with distance
  - over anomalous rock, the background concentration is diluted by the addition of anomalous material (***a*** = amount added)
  - ***b*** = amount of background material in glacial load before anomalous rock entrainment
  - ***a/(a+b)*** = anomalous material concentration
  - ***b/(a+b)*** = background material concentration

Exponential Dispersion Physical Meaning

Rock	0	1	2	3	4	5	*meters*
A	0	1	2	3	4	5	*amounts*
B	5	5	5	5	5	5	*amounts*
Total	5	6	7	8	9	10	
% A	*0*	*17*	*28*	*37*	*45*	*50*	***a/(a+b)***
% B	*100*	*83*	*72*	*63*	*55*	*50*	***b/(a+b)***

- Thus, this simple physical model defines an ***Inverse Dispersion Model:***

a/(a+b) & b/(a+b)

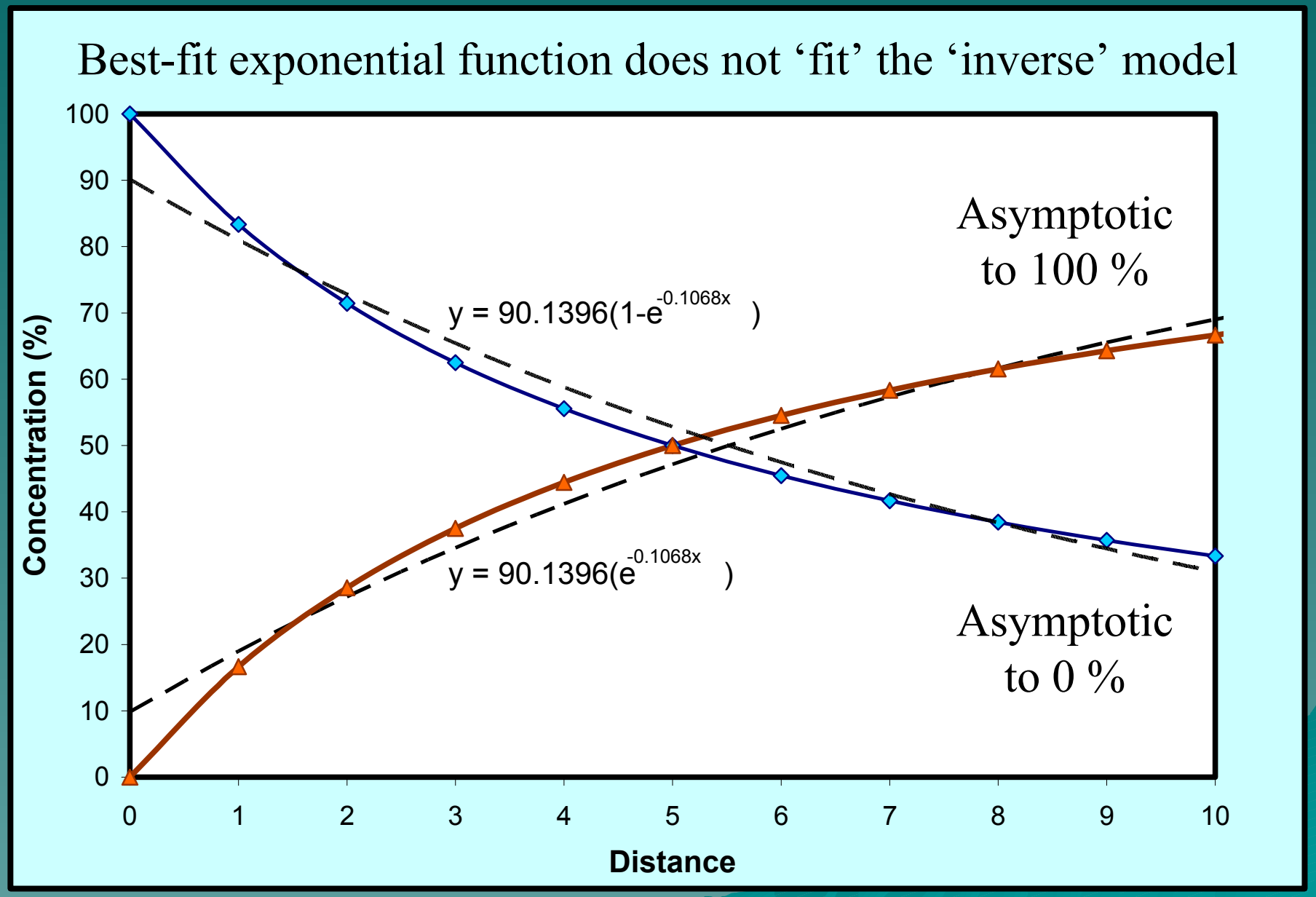
Inverse Dispersion Model

- ***This model is different from an exponential model!***

$$e^{-x} = \sum_{n=0}^{\infty} \frac{(-x)^n}{n!} = 1 - x + \frac{x^2}{2} - \frac{x^3}{6} \cdots \neq \frac{c}{c+x}$$

- ***The Exponential Function:***
  - initially decreases slower than the inverse function
  - converges to 0 faster than the inverse function

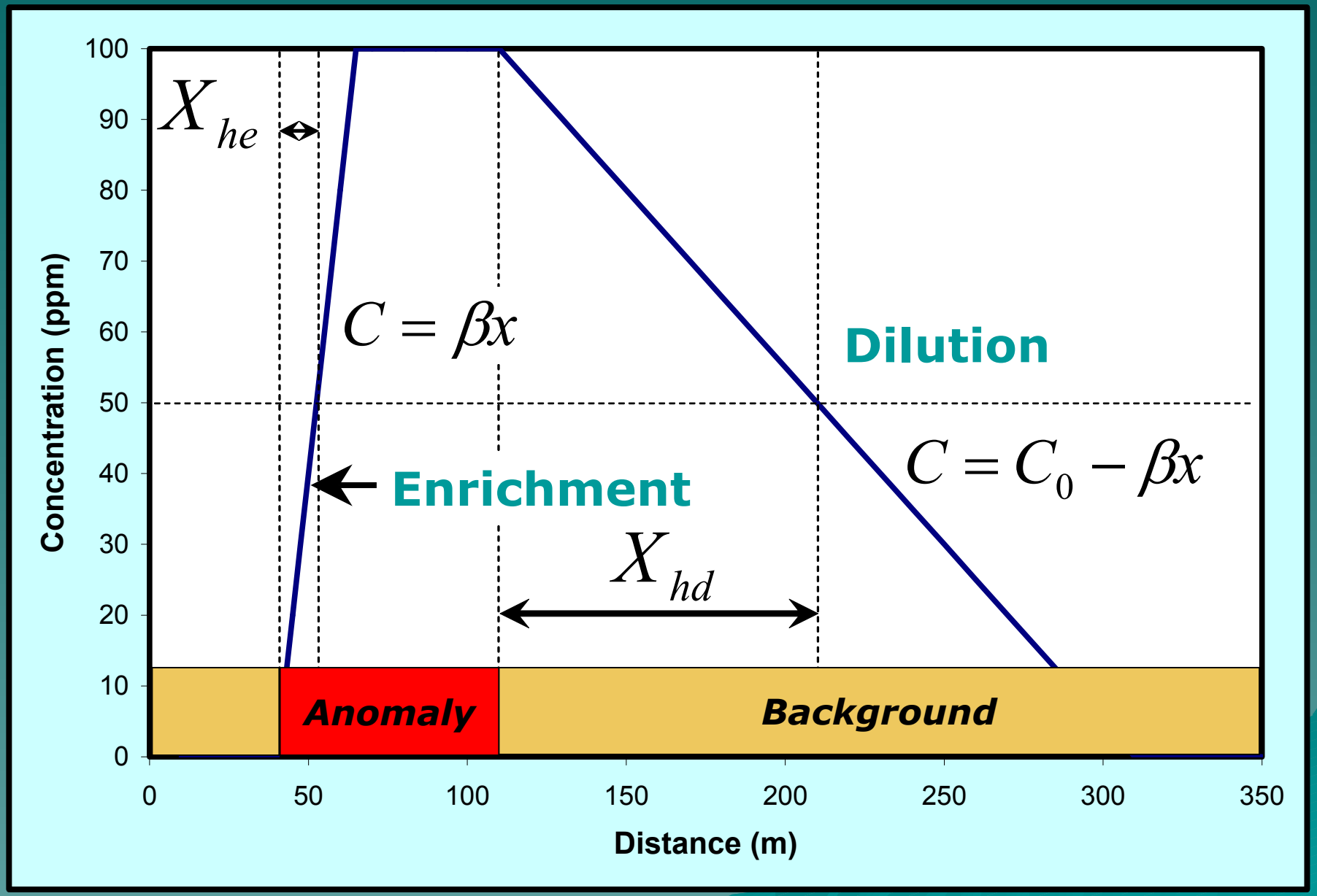
Dispersion Physical Meaning



Linear Dispersion Model

- What about the linear dispersion model?

Linear Dispersion Model – Equations



Linear Dispersion Physical Meaning

- if glacial erosion is constant, anomalous material is added to the en-glacial load ***linearly*** (***da*** = c > 0)
- thus, the only way to produce linear dilution or enrichment patterns is to ensure the amount of material in the en-glacial load is constant (***a + b = k***)
- so, for each increment of anomalous material added, an equal amount of background material must be lost from the en-glacial load (possibly due to shearing) to locations higher in the glacier; ***da = -db***)
- This must happen in spite of the fact that the composition of the en-glacial load becomes progressively more enriched in anomalous material

Linear Dispersion Physical Meaning

Rock	0	1	2	3	4	5	*meters*
A	0	1	2	3	4	5	*amounts*
B	5	4	3	2	1	0	*amounts*
Total	5	5	5	5	5	5	
% A	*0*	*20*	*40*	*60*	*80*	*100*	***a/k***
% B	*100*	*80*	*60*	*40*	*20*	*0*	***b/k***

- ***a/k*** & ***b/k*** are linear decay sequences
- To create a linear decay, only background material can be removed from the en-glacial load; unfortunately, this load becomes progressively more enriched in anomalous material

Improbable!

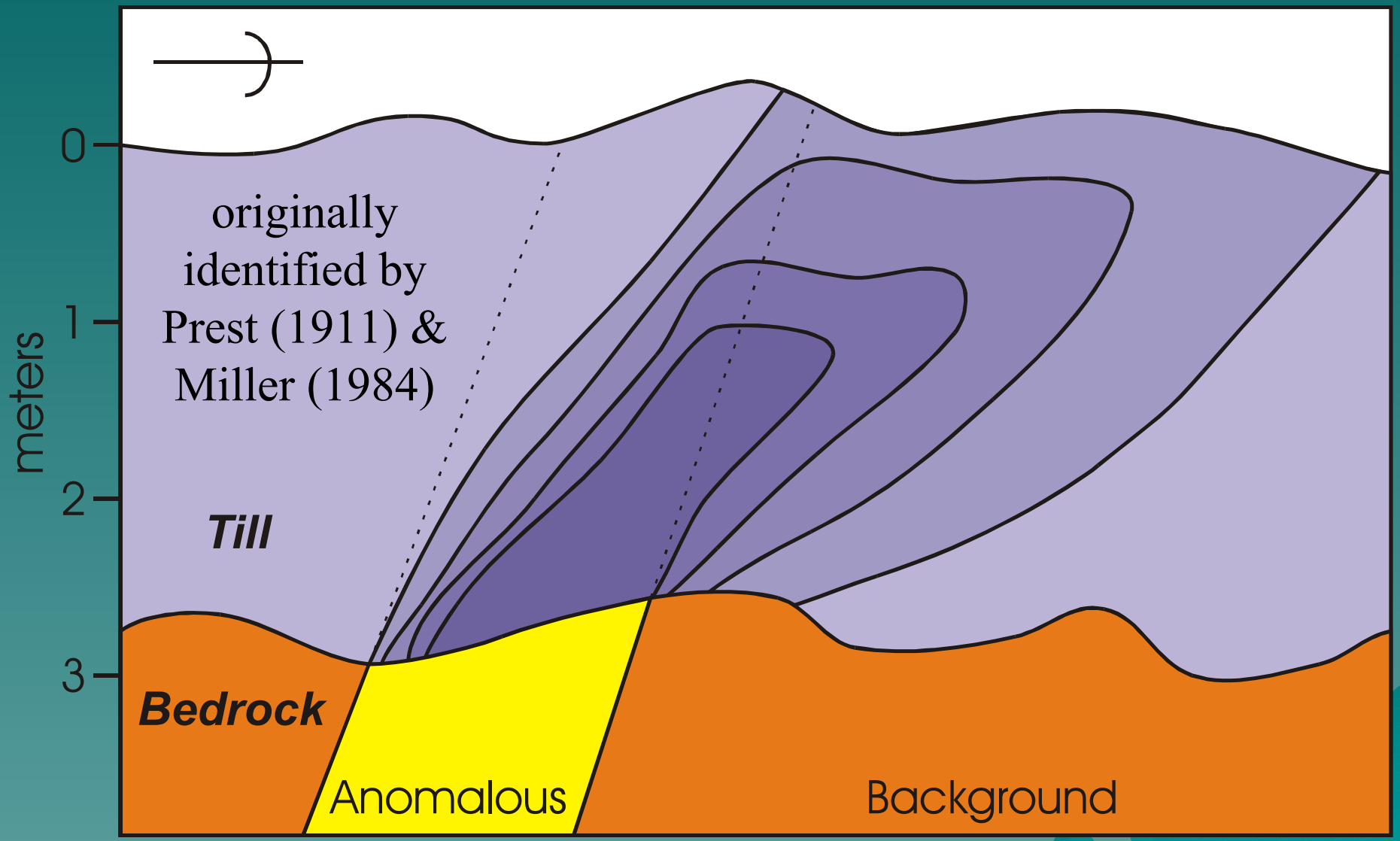
Dispersion Models

Both dispersion models are ***physically inconsistent with sub-glacial processes!***

- Does an alternative dispersion model exist that explains the observed dilution / enrichment patterns in glacial till?

YES !

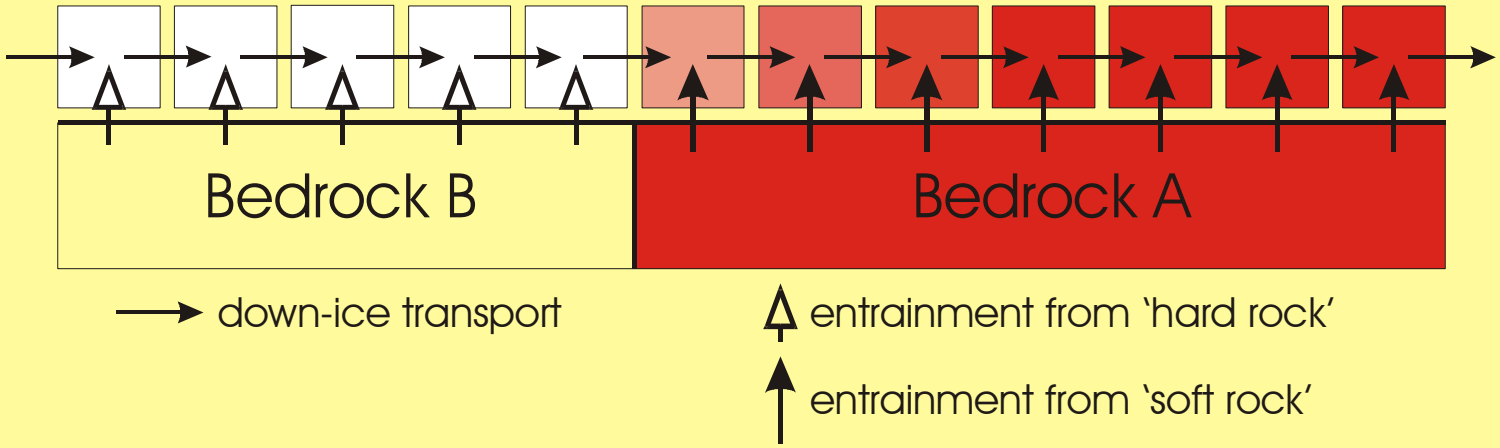
Aggradational Dispersion Model



Aggradational Dispersion Model

Glacial Flow Direction →

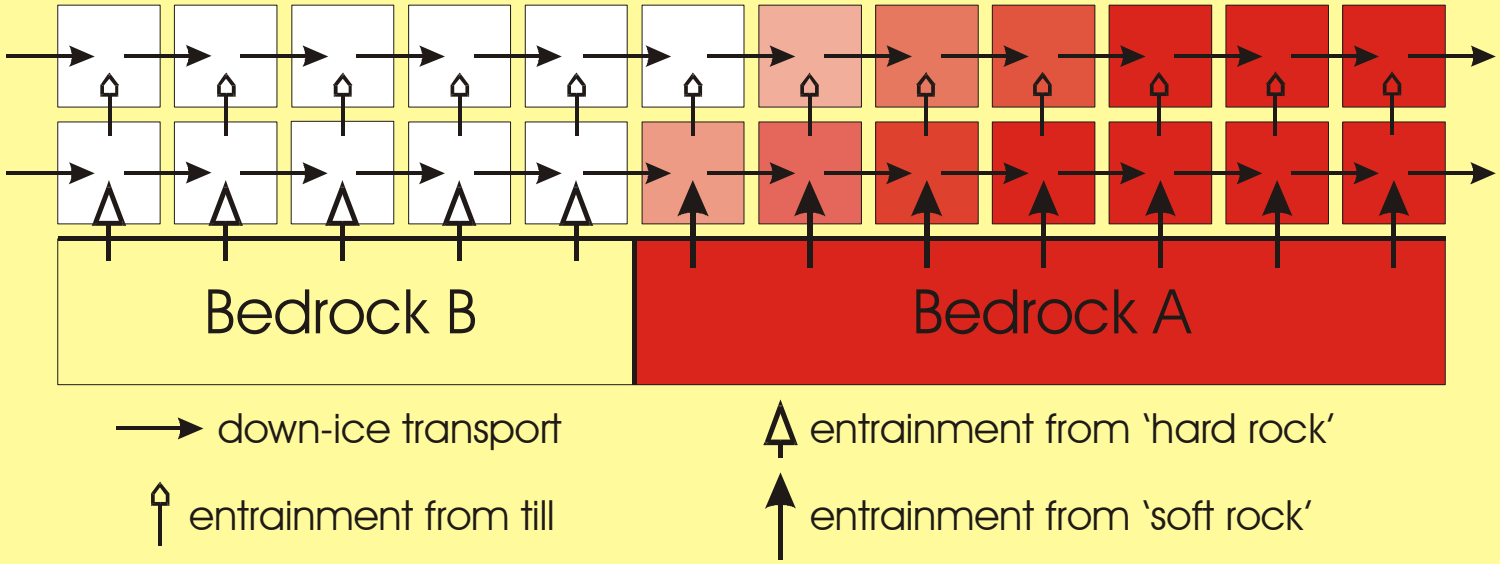
- in the basal layer, the bedrock compositional contact is sharp, so the till immediately above it exhibits an inverse decay / enrichment pattern



Aggradational Dispersion Model

Glacial Flow Direction →

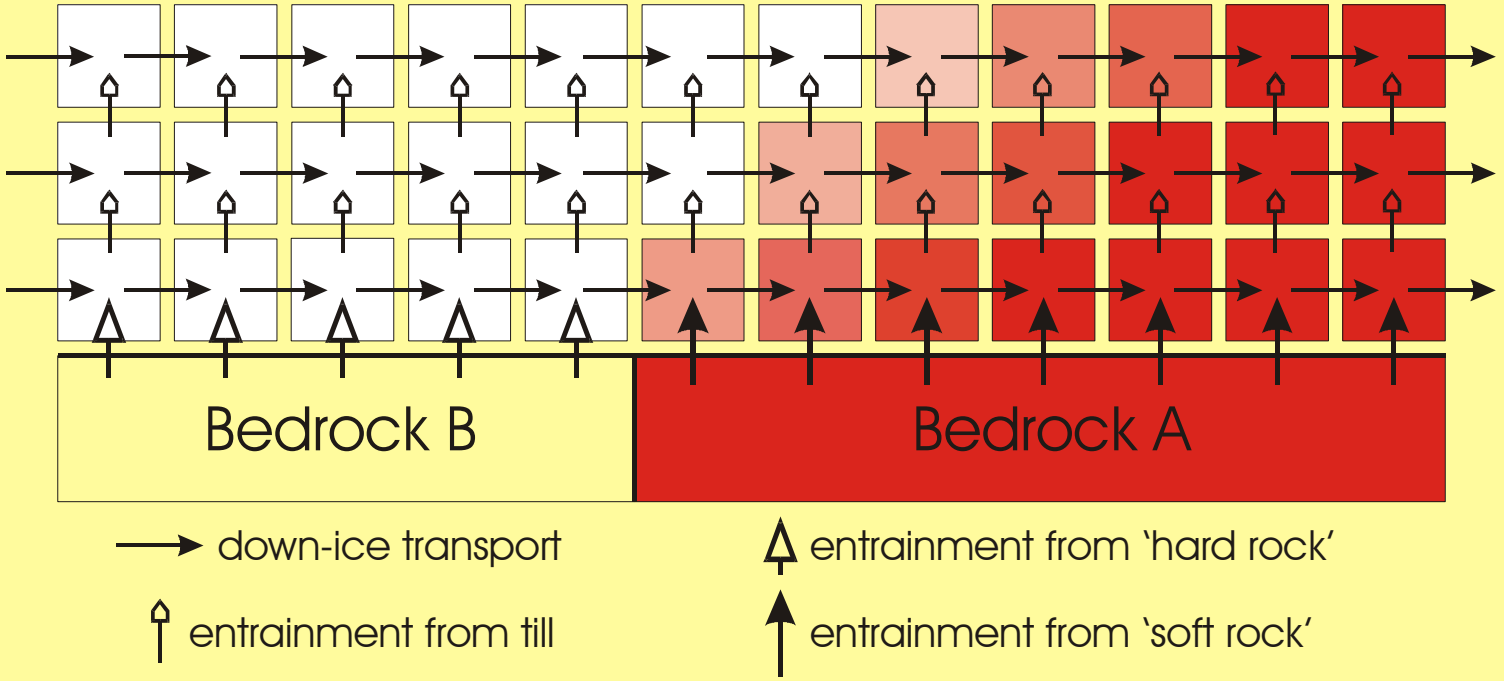
- the anomalous material in the first layer of ice is mixed with background material, then transported up- and down-ice
- the compositional contact in the second till layer is thus more gradational



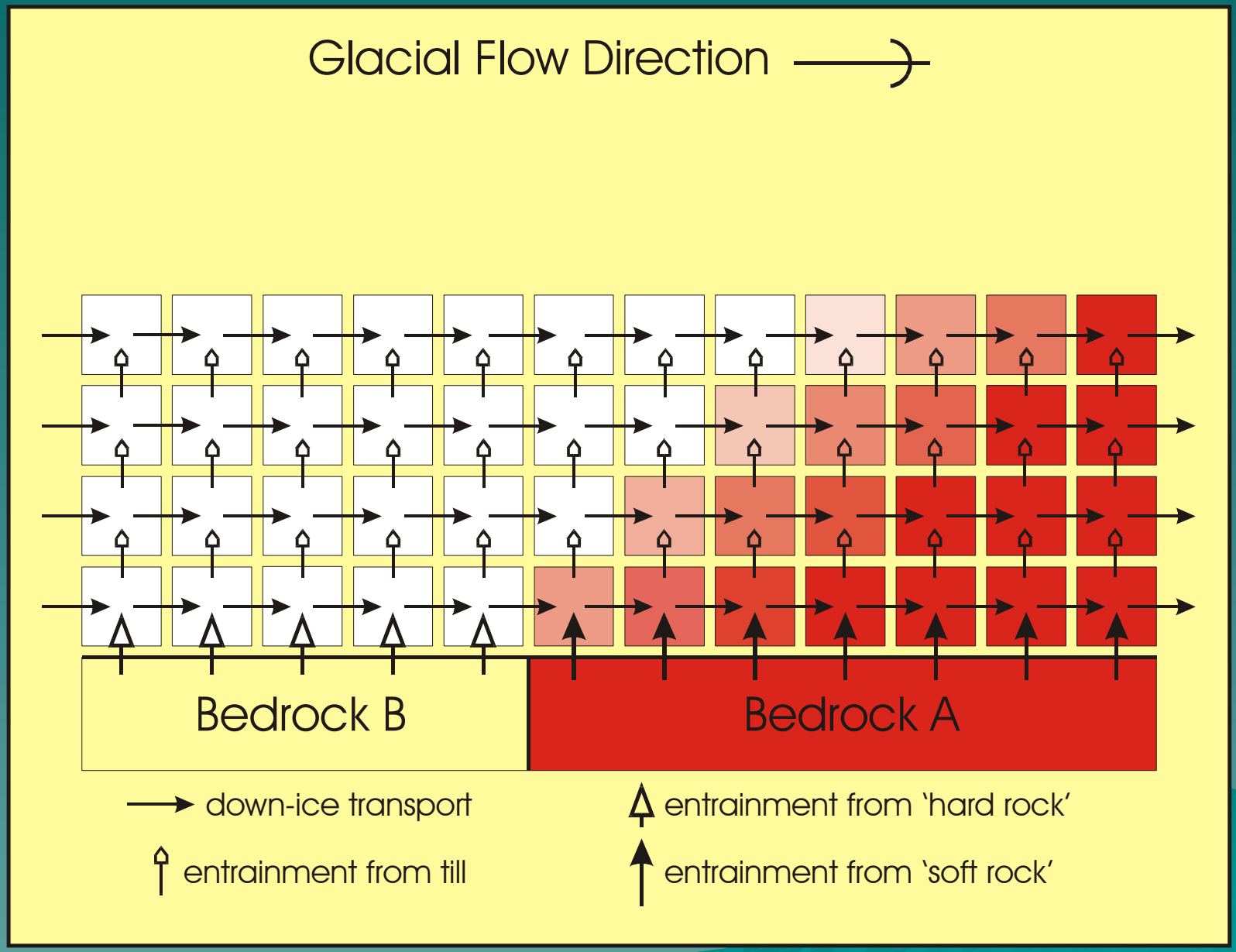
Aggradational Dispersion Model

Glacial Flow Direction →

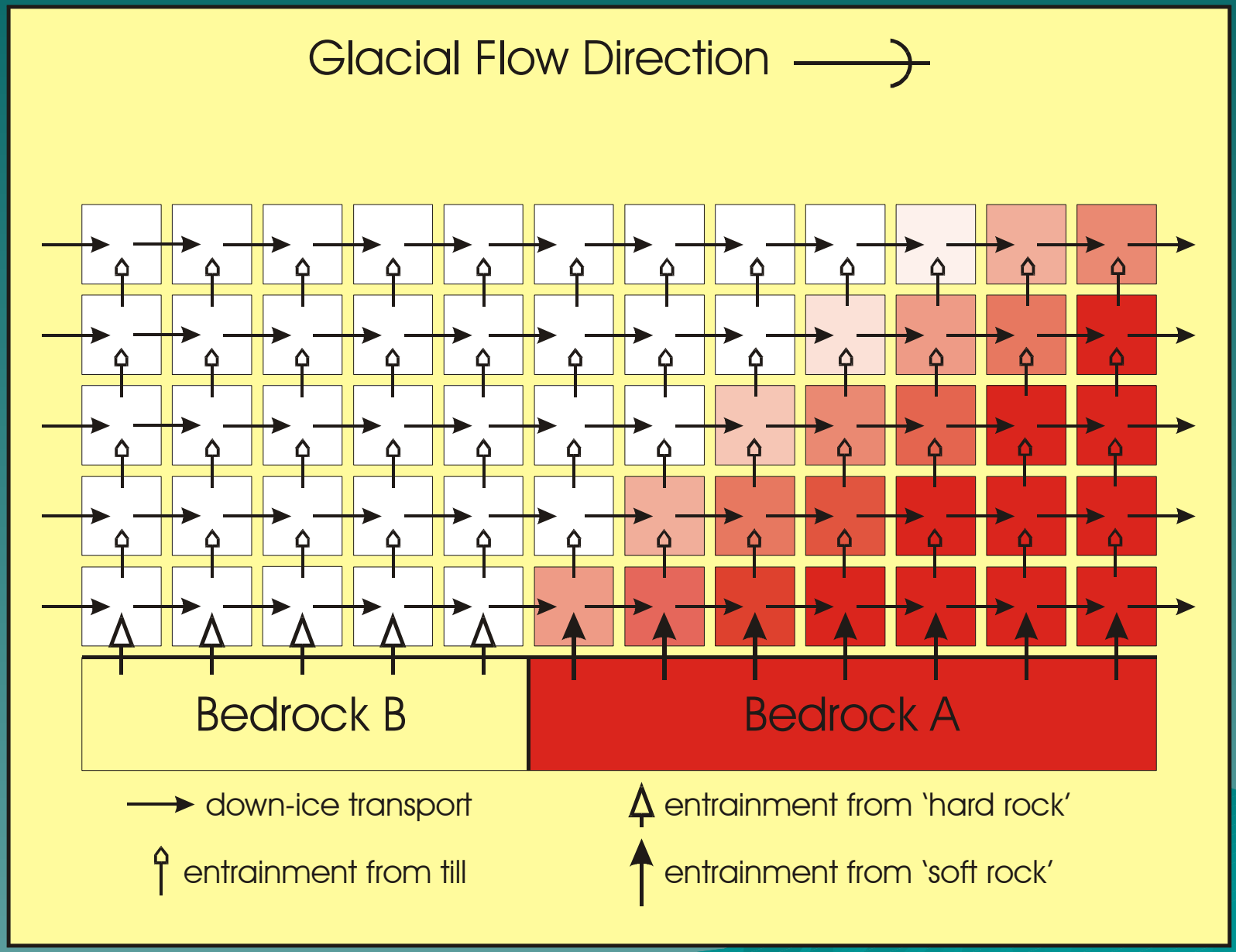
- the third till layer exhibits even more of a gradational compositional 'contact' (*non-inverse dispersion model*)



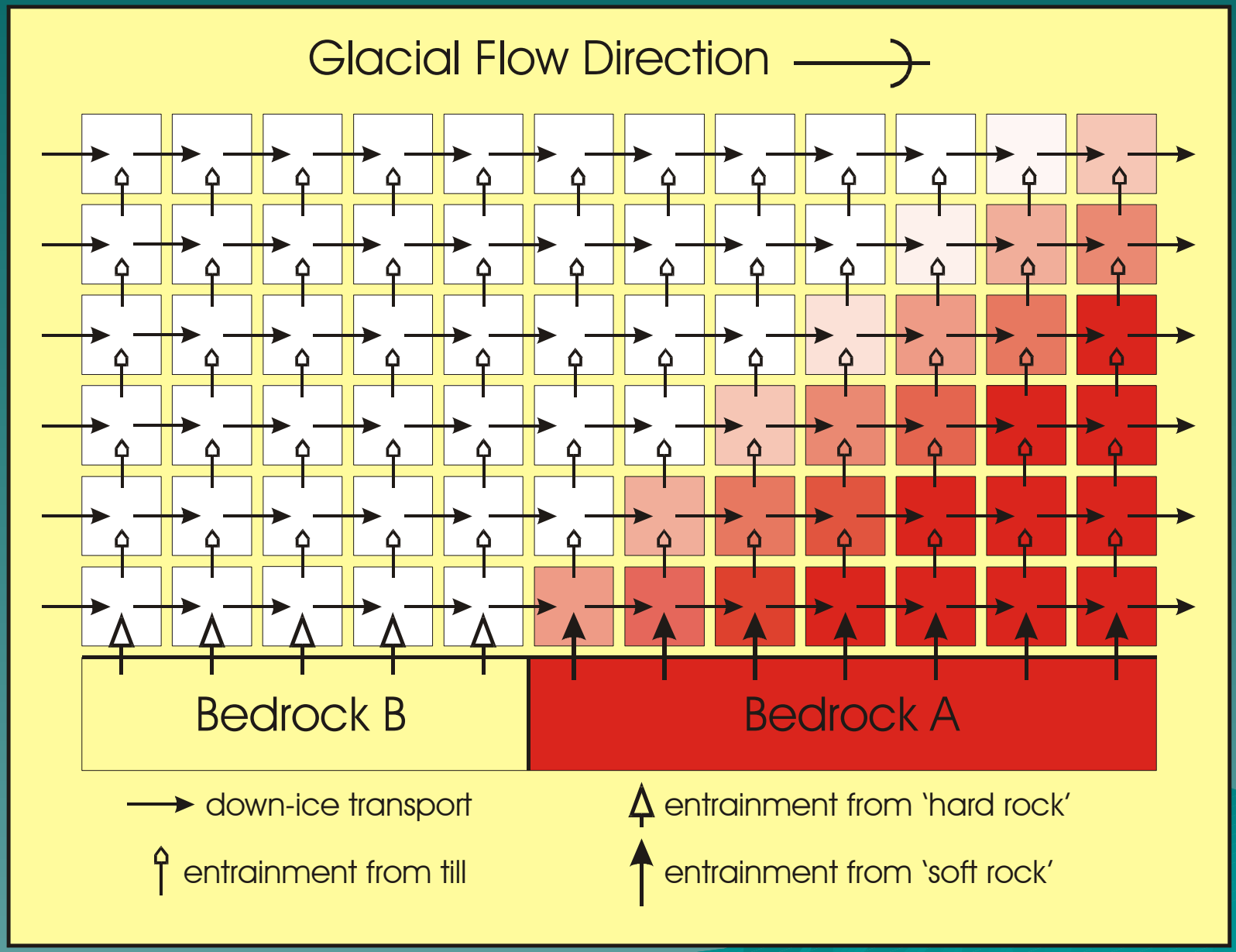
Aggradational Dispersion Model



Aggradational Dispersion Model



Aggradational Dispersion Model

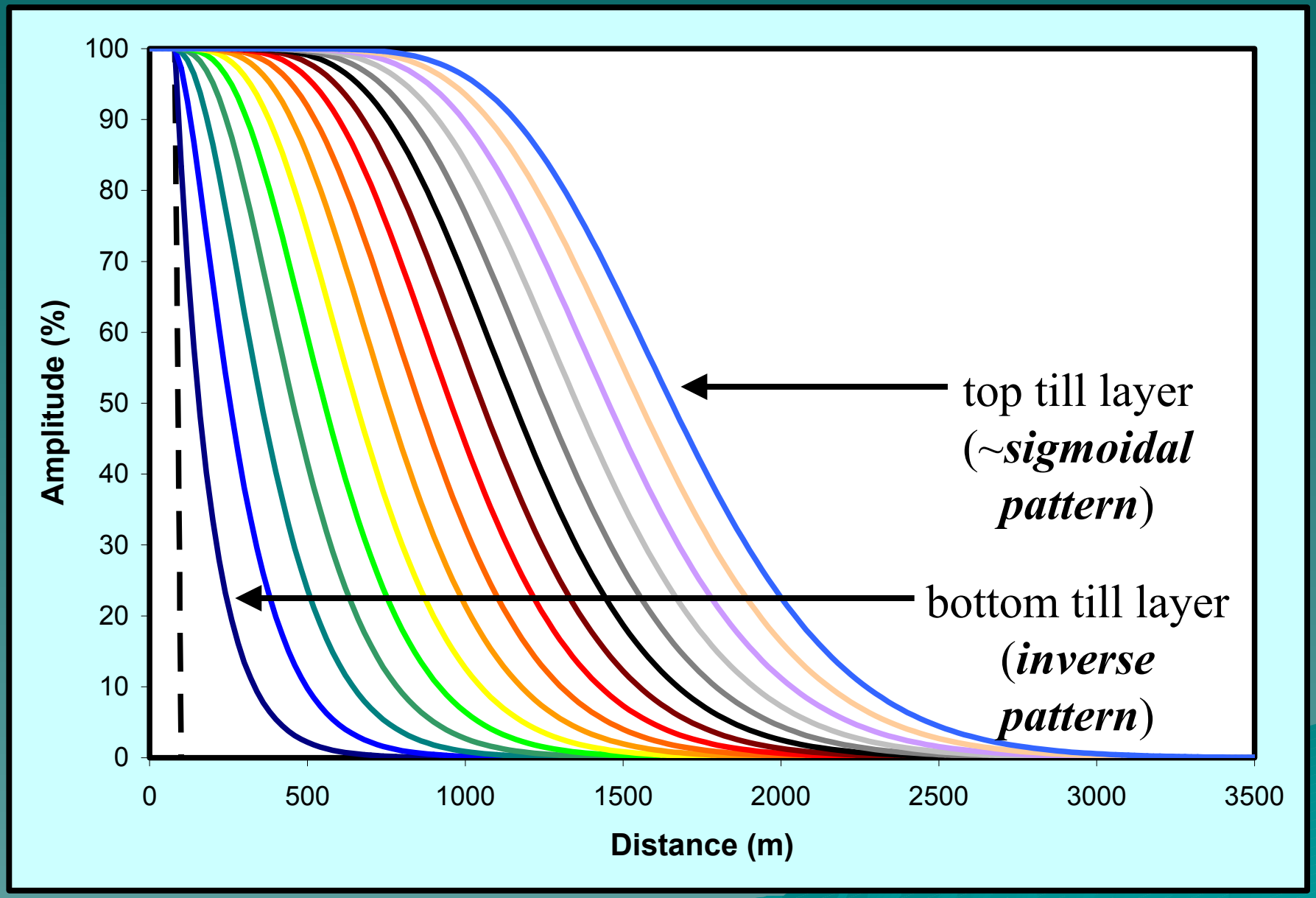


Aggradational Dispersion Model

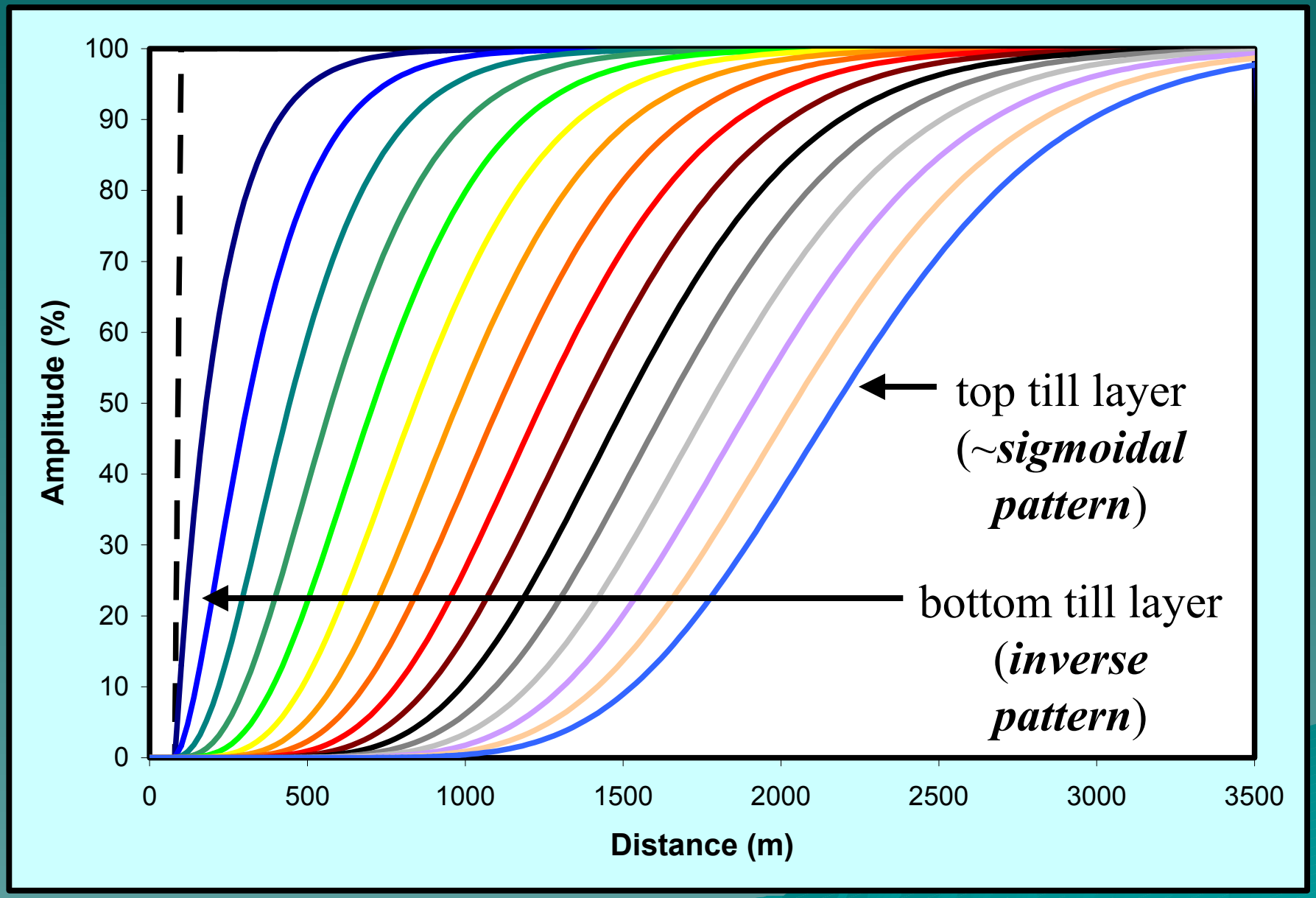
Distance		0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
Till Layers	10	0	0	0	0	0	0	0	0	2	3	6	8	10	11	11	10
	9	0	0	0	0	0	0	0	1	3	5	8	10	11	11	11	9
	8	0	0	0	0	0	0	0	2	5	8	10	12	12	11	10	8
	7	0	0	0	0	0	0	1	4	8	11	13	13	12	10	8	6
	6	0	0	0	0	0	0	3	7	11	14	14	13	11	8	6	4
	5	0	0	0	0	0	1	6	12	16	16	14	11	8	6	4	3
	4	0	0	0	1	1	2	12	18	18	16	12	8	6	4	2	1
	3	0	0	1	3	6	9	21	22	18	13	8	5	3	2	1	0
	2	0	2	7	13	19	26	30	21	13	7	4	2	1	1	0	0
	1	0	17	32	44	53	61	27	12	5	2	1	0	0	0	0	0
Bedrock		0	100	100	100	100	100	0	0	0	0	0	0	0	0	0	0
		Background		Anomaly				Background									

- anomalous material is smeared down-ice
- width of the anomaly increases down-ice
- concentrations of most anomalous material decrease down-ice (diluted by mixing)
- concentration patterns differ in each layer of the till

Background Material Dispersion Patterns

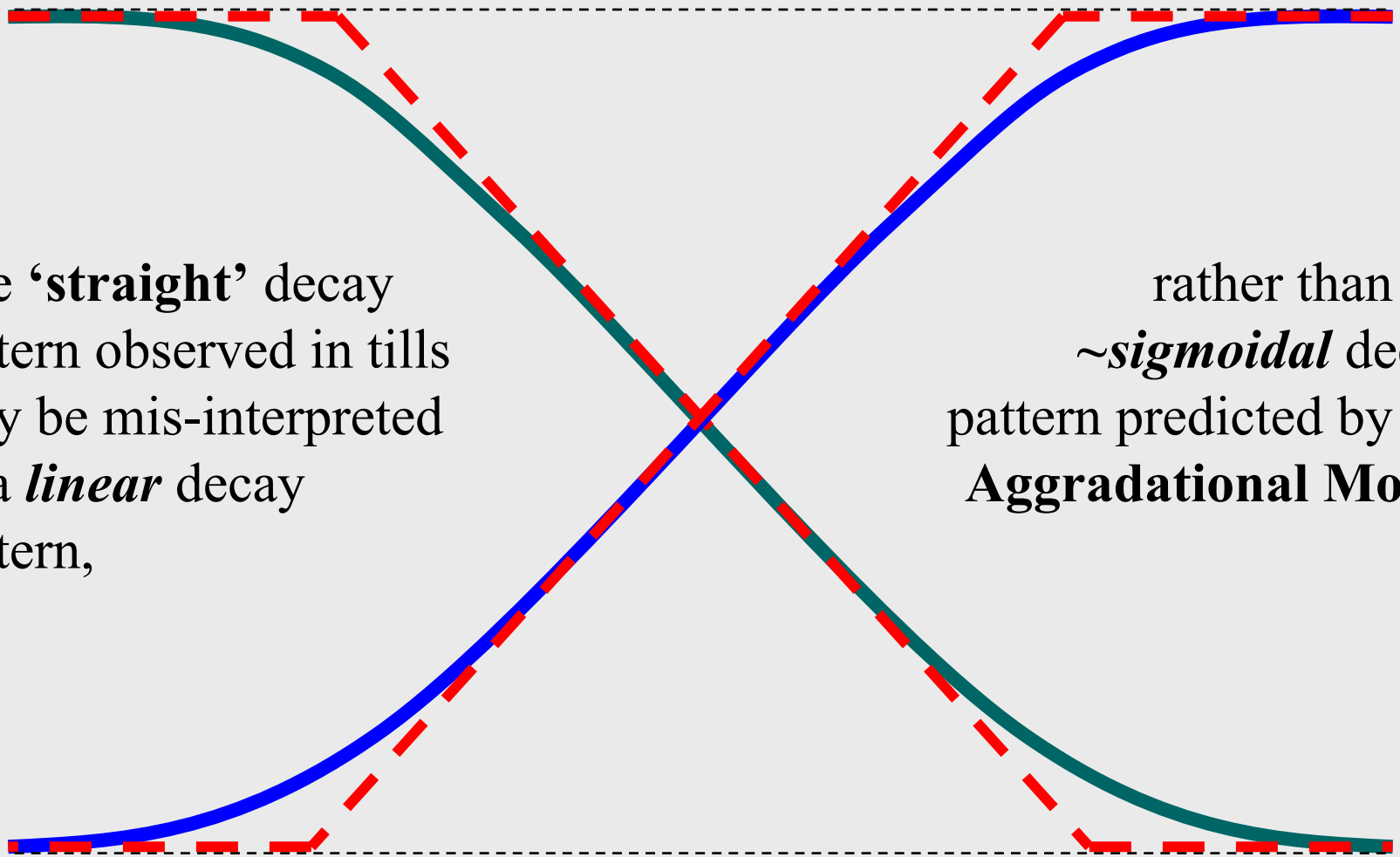


Anomalous Material Dispersion Patterns



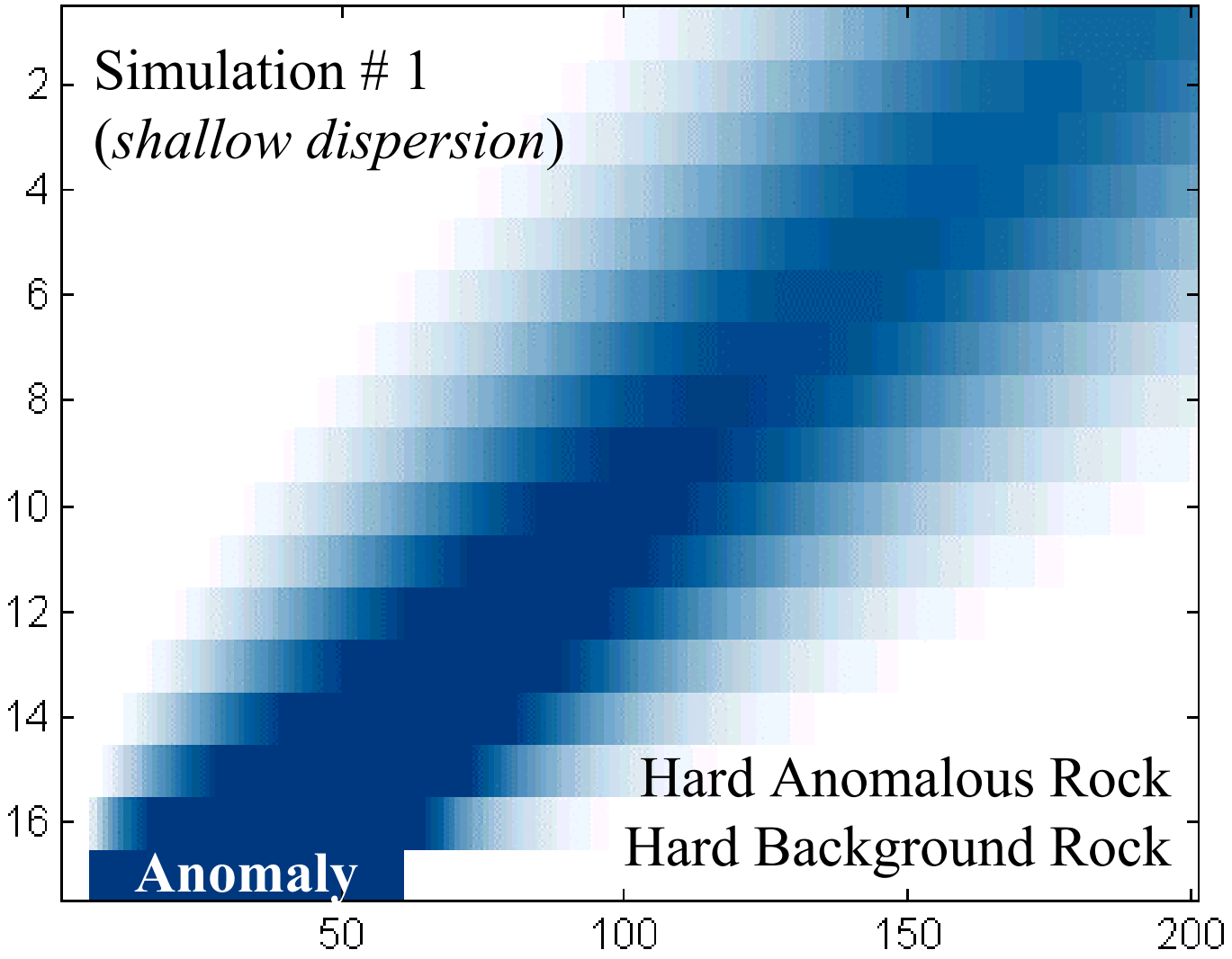
Aggradational Dispersion Model

The **'straight'** decay pattern observed in tills may be mis-interpreted as a ***linear*** decay pattern,



rather than the ***~sigmoidal*** decay pattern predicted by the **Aggradational Model**

Aggradational Dispersion Model



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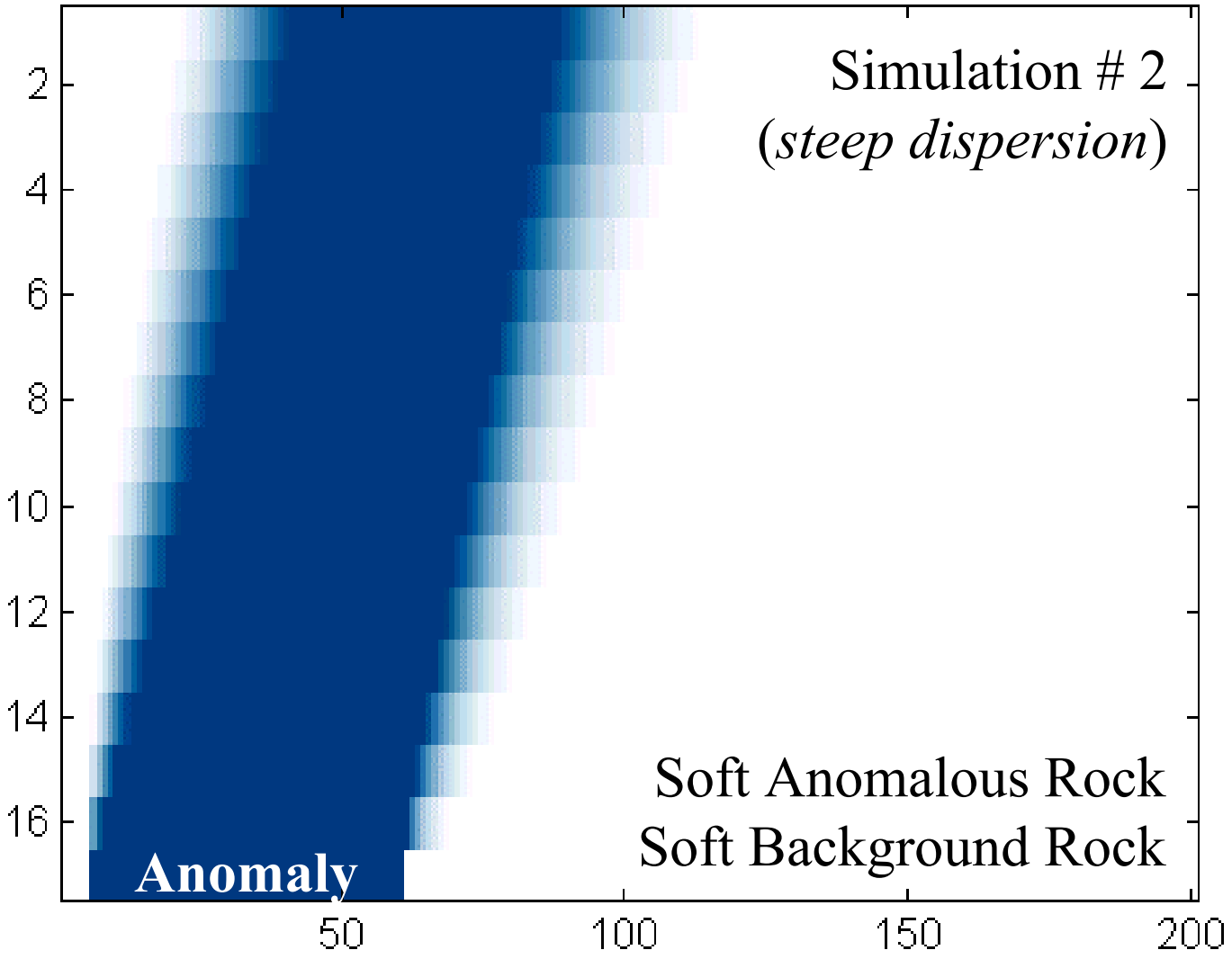
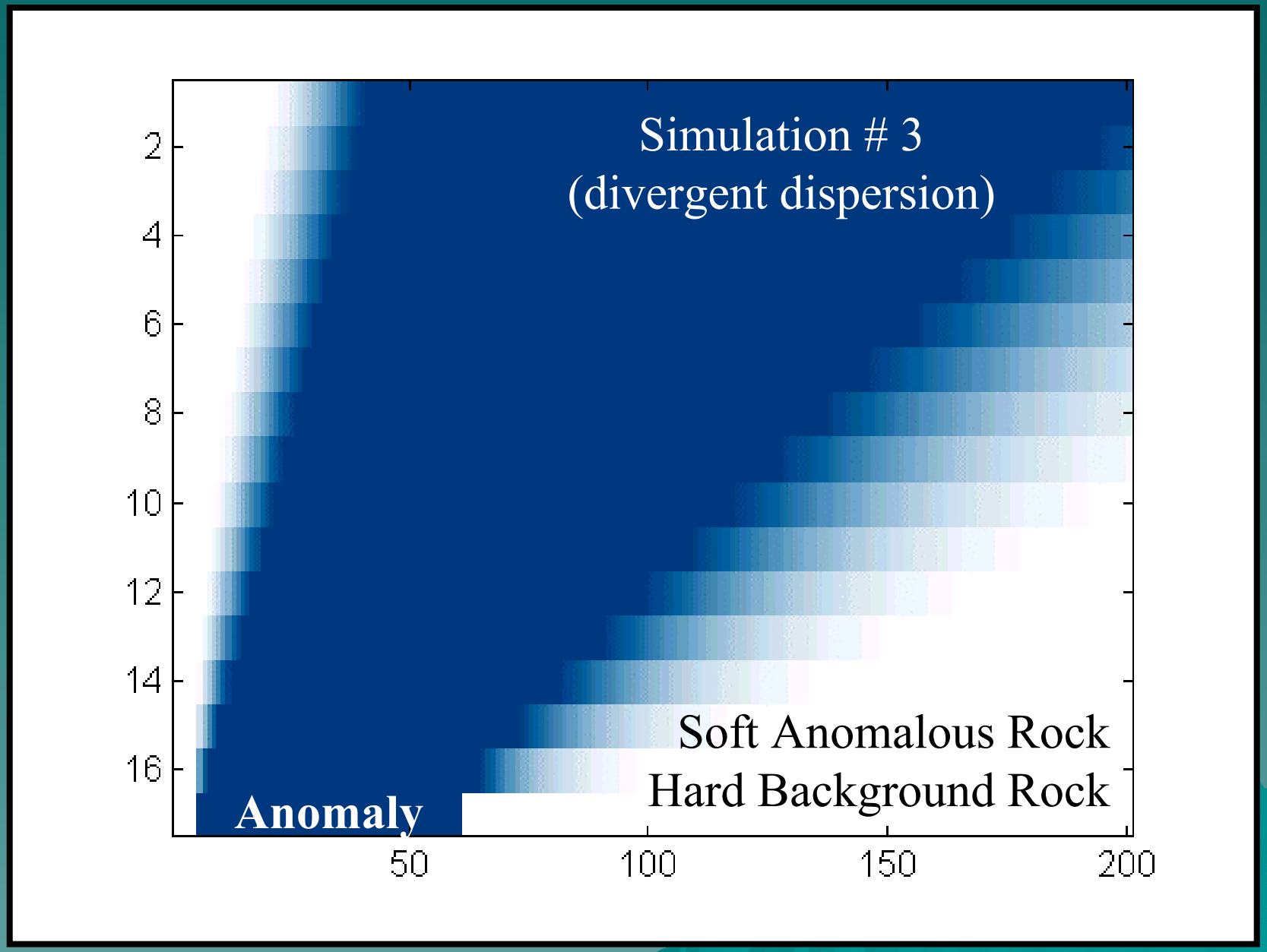
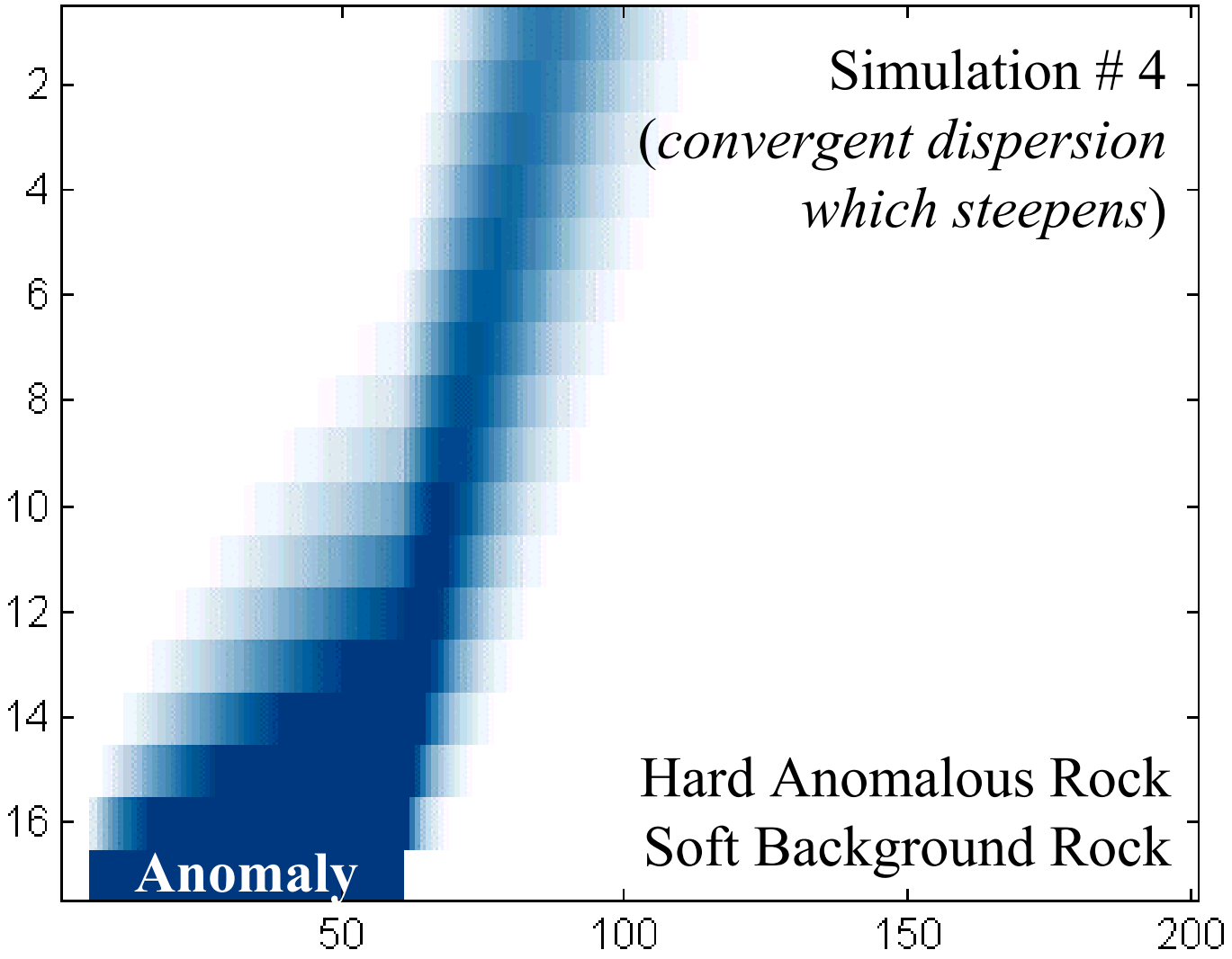


Aggradational Dispersion Model



Aggradational Dispersion Model



Conclusions

- The ***Exponential and Linear Dispersion Models*** are numerically inconsistent with the physical model for which they are ascribed
- An alternative ***Aggradational Dispersion Model*** is proposed that has both physical justification and explains both observed dispersion patterns (*'pseudo-exponential' and 'pseudo-linear'*)

Conclusions

- The type of dispersion pattern created by the ***Aggradational Dispersion Model*** depends on the level that one looks in the till
- Mineralogical and geochemical sampling:
  - at deep levels in thicker till sections, or in thin tills (*lodgement tills*) will produce 'inverse' dispersion patterns
  - at shallow levels in thicker till sections (*ablation tills*) will produce '~sigmoidal' dispersion patterns

Conclusions

- The ***Aggradational Dispersion Model*** provides insight into how glacial dispersion patterns can be controlled by the '*erodability*' of the bedrock
  - hard rock => shallower dispersion
  - soft rock => steeper dispersion
  - soft anomaly => divergent dispersion
  - hard anomaly => convergent dispersion steepens

Future Work

- To date, the ***Aggradational Dispersion Model*** has been represented by a finite difference/material transfer model
- Need to develop a quantitative representation of the ***Aggradational Dispersion Model*** by solving this partial differential equation

$$\left(\frac{\partial a}{\partial x}\right)+\left(\frac{\tau}{T}\right)\left(\frac{\partial a}{\partial z}\right)=k\nabla^2(a)=k\left(\frac{\partial^2 a}{\partial x^2}+\frac{\partial^2 a}{\partial z^2}\right)$$

- This will produce an equation describing the family of curves which can be regressed to estimate the location of an up-ice contact

Thank You!

Questions?

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http://www.gov.ns.ca/natr/meb/canqua/till.htm

photo courtesy of Ralph Stea, NS-DNR