Milankovitch ice sheet and Cretaceous sea level models face the same sedimentary problem Part 2.

Same equilibrium and instability

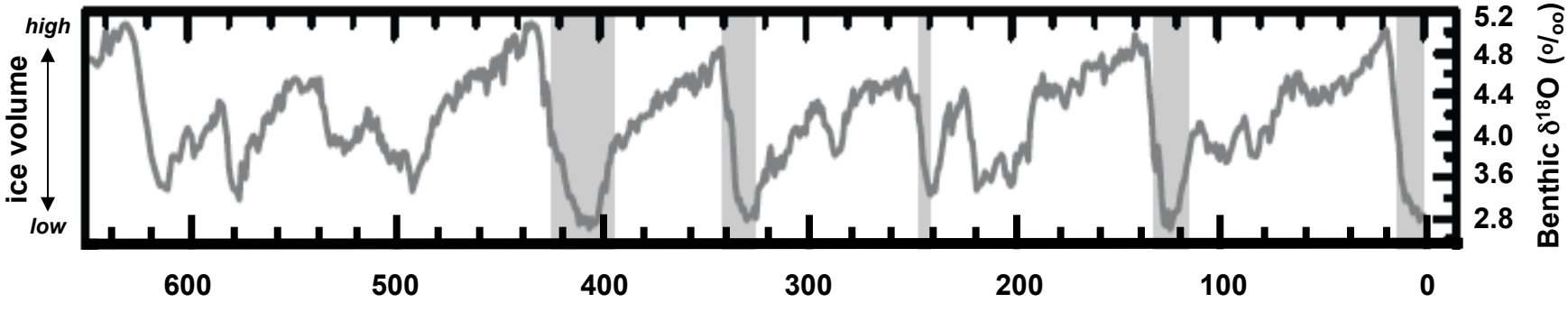
Stuart R. Gaffin
Center for Climate Systems Research

GISS Luncheon Seminar Series

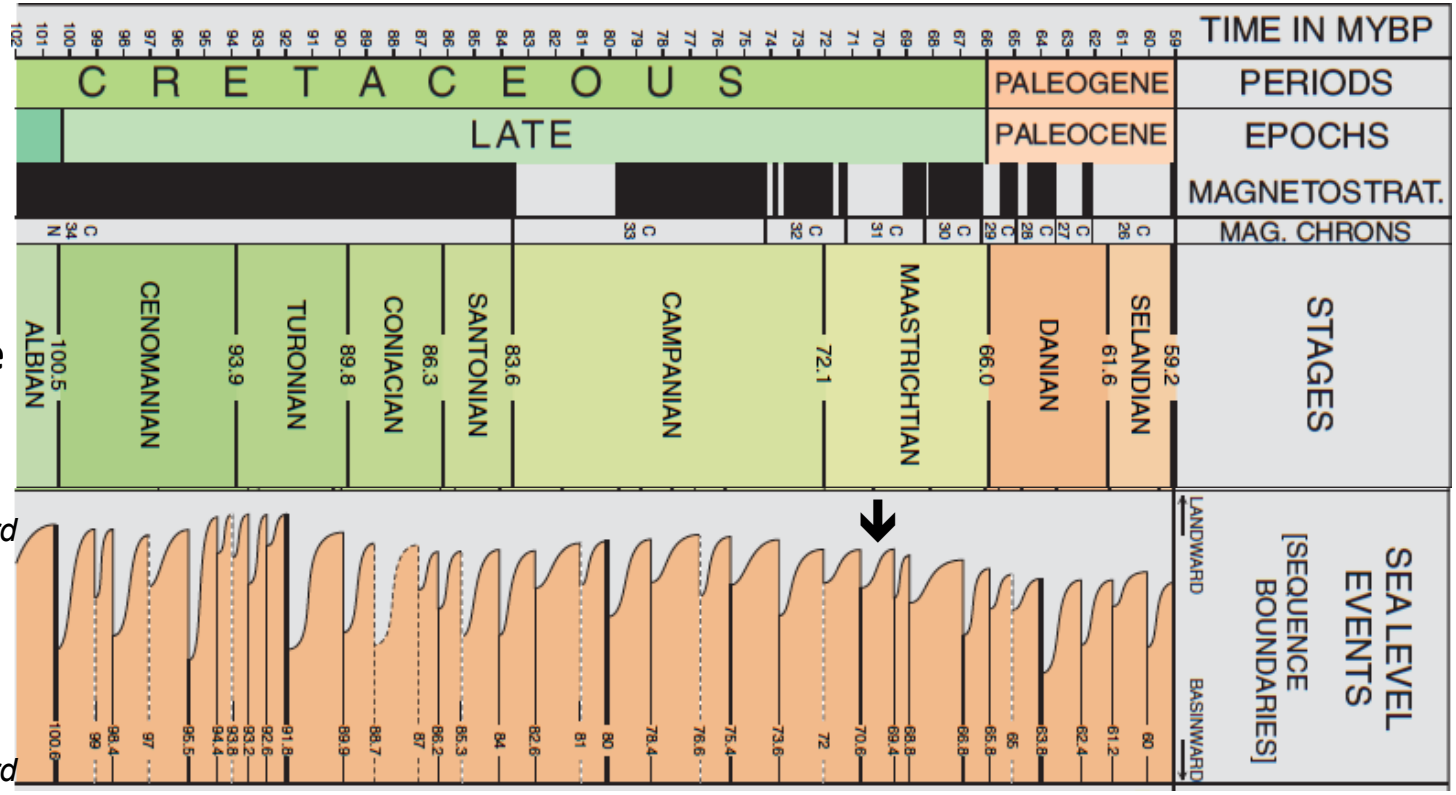
January 11, 2017

Pleistocene 100 Kyr Ice Sheet Cycles ↓

Lisiecki and Raymo, 2005



Cretaceous 1-3 Myr <u>Relative</u> Sea Level Cycles ↓



relative ↓

landward

Relative sea level

basinward

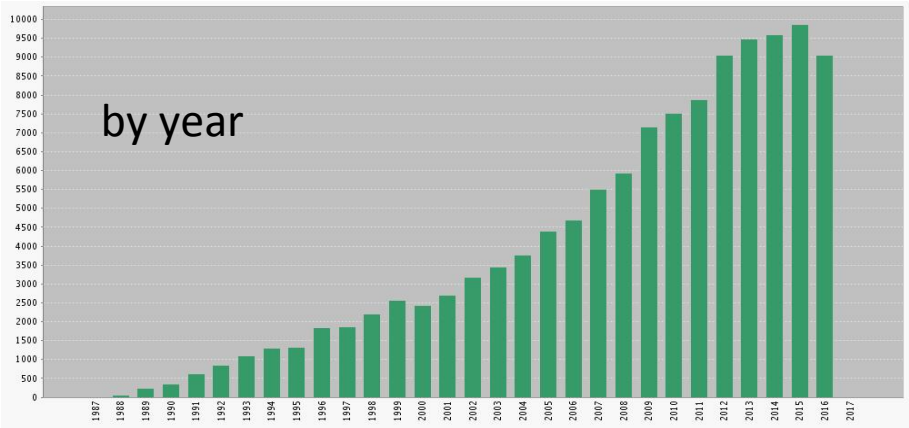
Haq 2014

CHRONOLOGY OF FLUCTUATING SEA LEVELS SINCE THE TRIASSIC

By: HAQ, BU; HARDENBOL, J; VAIL, PR

SCIENCE Volume: 235 Issue: 4793 Pages: 1156-1167 Published: MAR 6 1987

Times Cited: 4,233

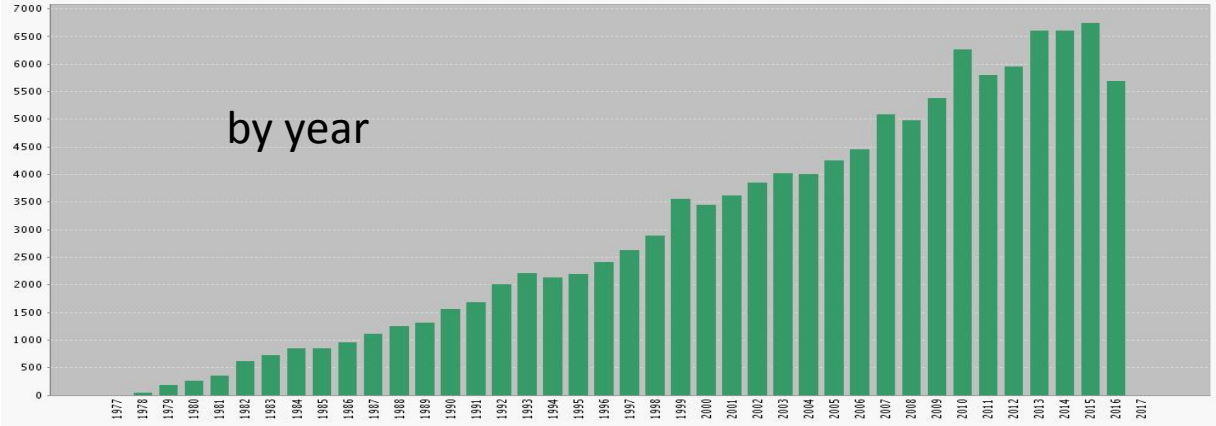


VARIATIONS IN EARTHS ORBIT - PACEMAKER OF ICE AGES

By: HAYS, JD; IMBRIE, J; SHACKLETON, NJ

SCIENCE Volume: 194 Issue: 4270 Pages: 1121-1132 Published: 1976

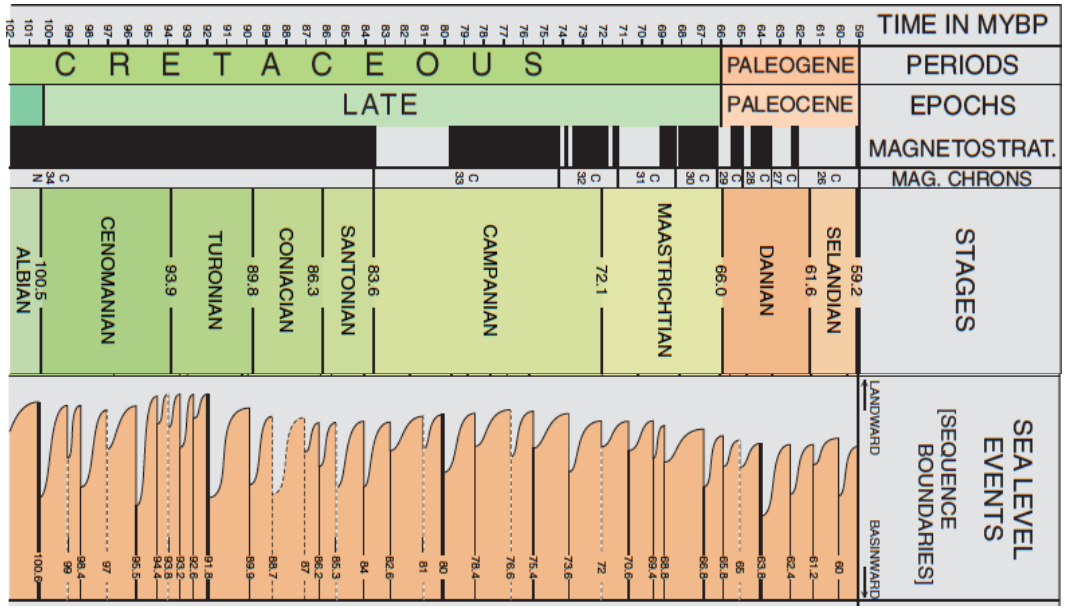
Times Cited: 1,938



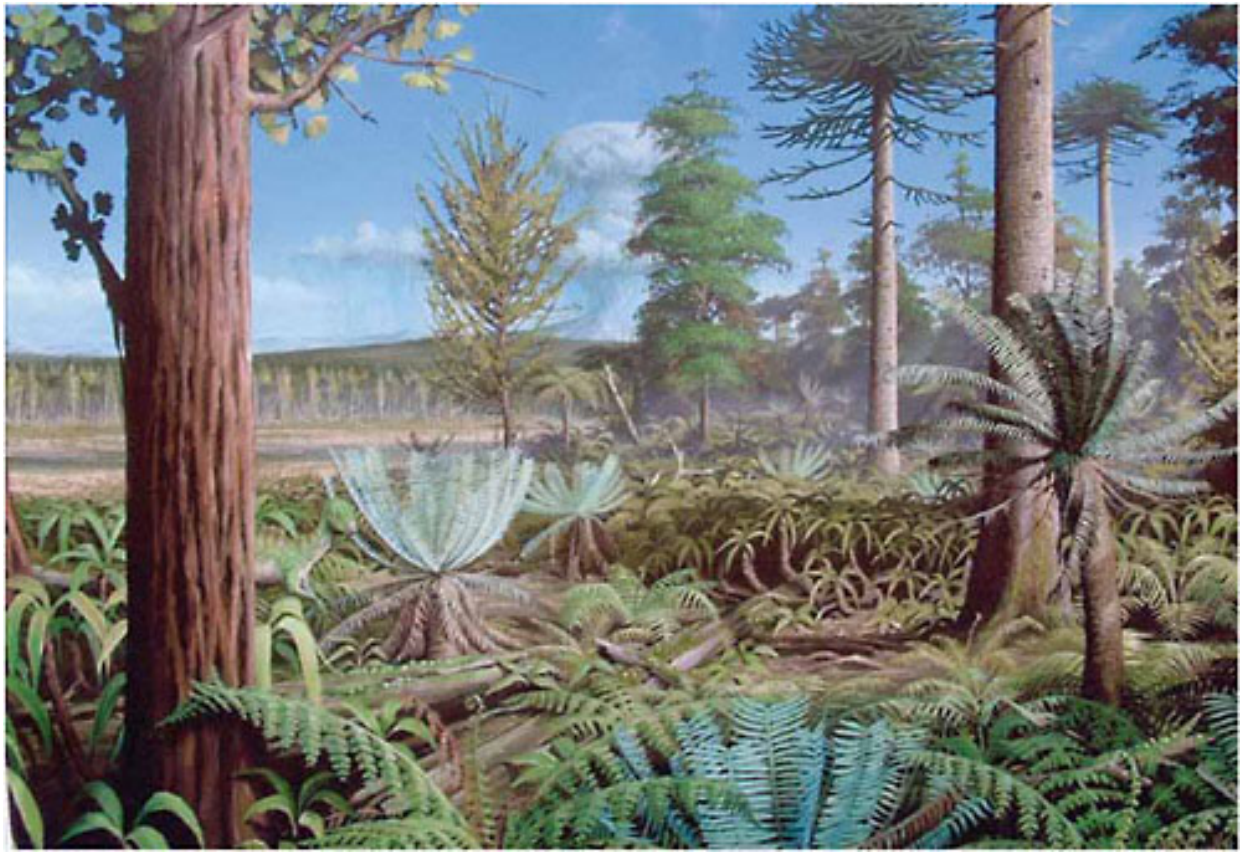
"… causes for third-order cyclicity … on ~ 0.5 to 3 Myr timescales in the Cretaceous world, where we lack direct evidence for major ice caps, **remain cloaked in mystery** …"

B. Haq, 2014,

Global and Planetary Change 113 (2014) 44–58



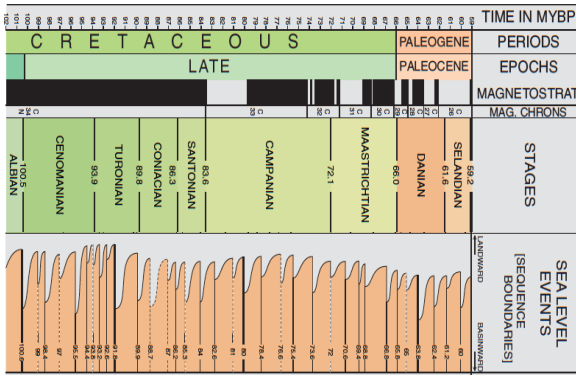
Antarctic Peninsula Plant Reconstruction Coniacian Santonian ~87 Myr BP

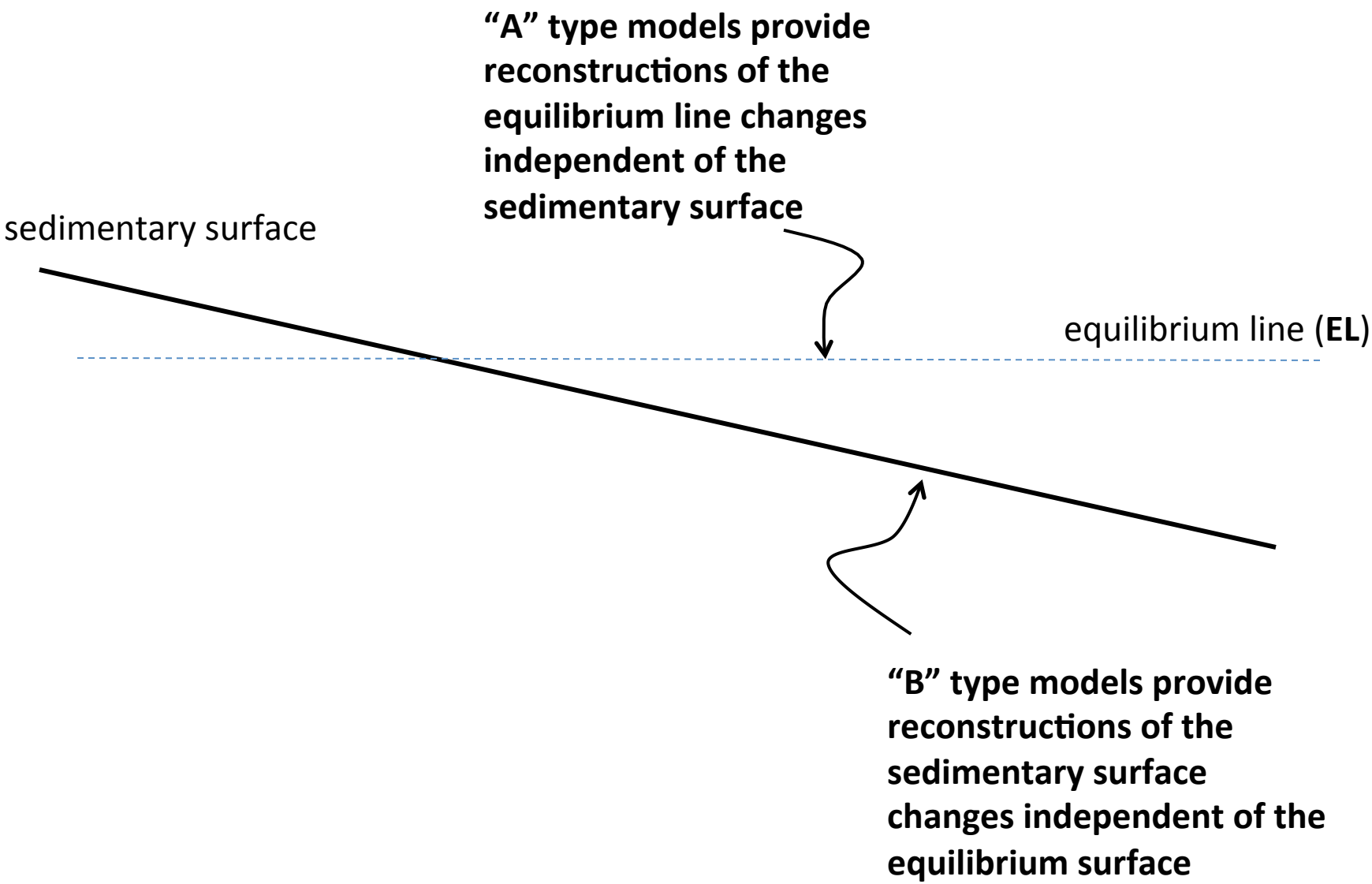


Howe (2003)

"….the climate was generally warm and humid to allow the growth of large conifers, with mosses and ferns in the undergrowth."

Mean Annual Temperature: 17-19 °C
70° South Latitude




"A" type models provide reconstructions of the equilibrium line changes independent of the sedimentary surface
sedimentary surface
equilibrium line (**EL**)
"B" type models provide reconstructions of the sedimentary surface changes independent of the equilibrium surface

CRETACEOUS "GREENHOUSE"

Ocean basin volume & water volume models

Palaeo-eustatic sea-level models "backstripping" models

Cretaceous "greenhouse" record for relative sea level changes

$$A + B = C$$

Milankovitch theory & ice sheet models

Direct reconstructions of ice sheet elevation changes thru time from field data.

Late Pleistocene $\delta^{18}O$ record for ice volume

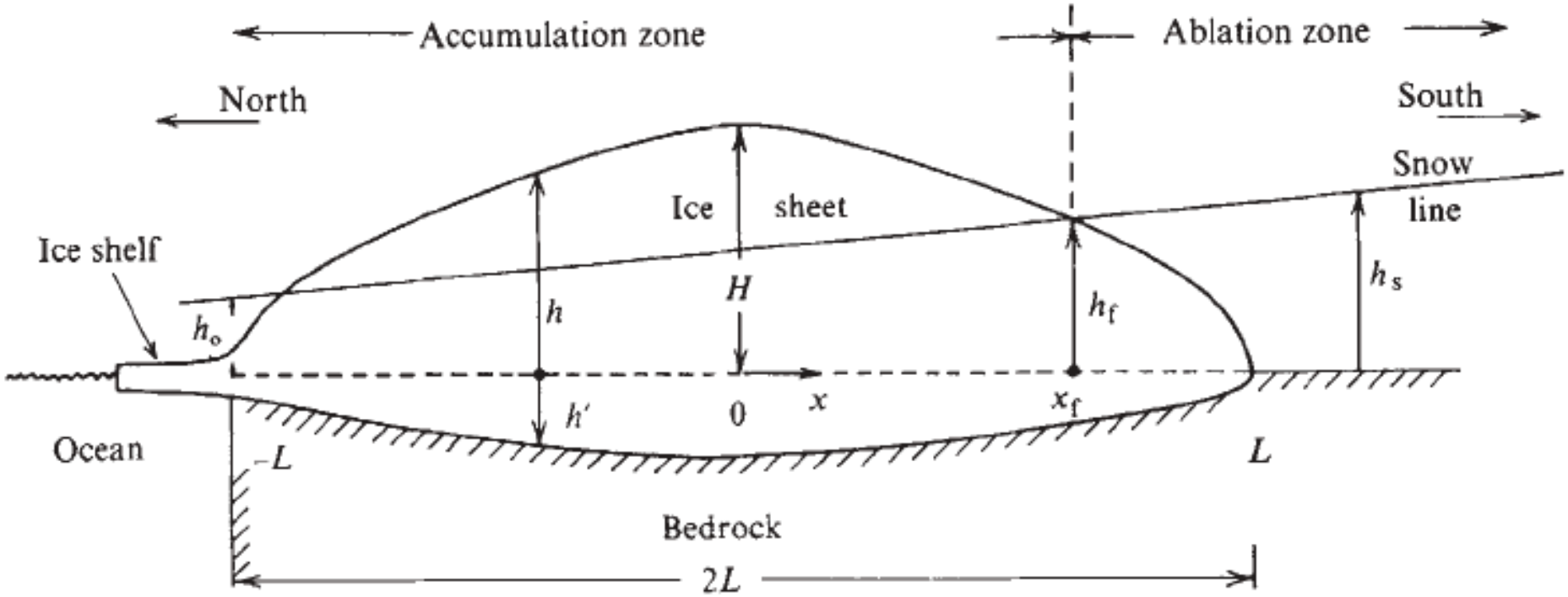
PLEISTOCENE "ICE HOUSE"

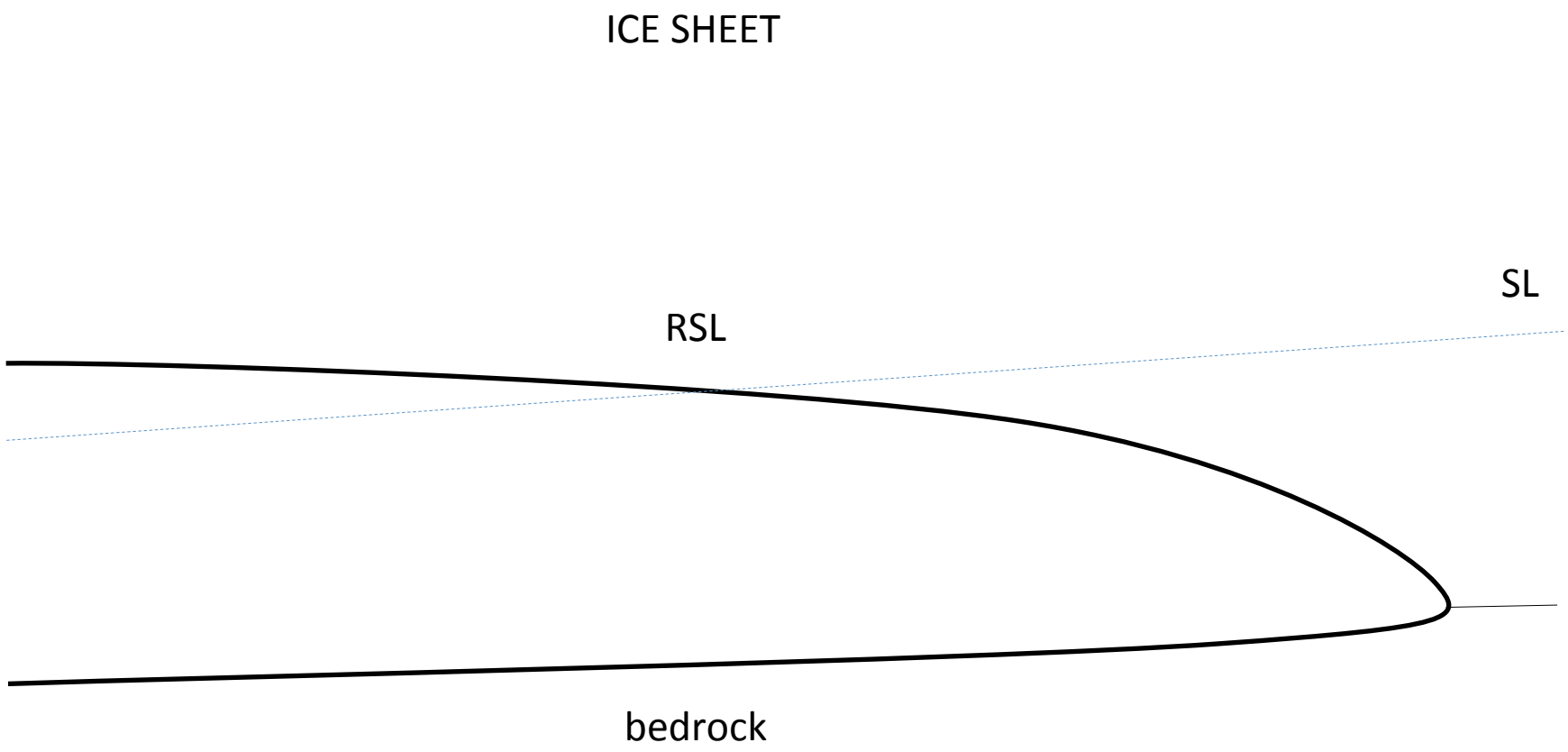
Milankovitch solar radiation variations and ice age ice sheet sizes

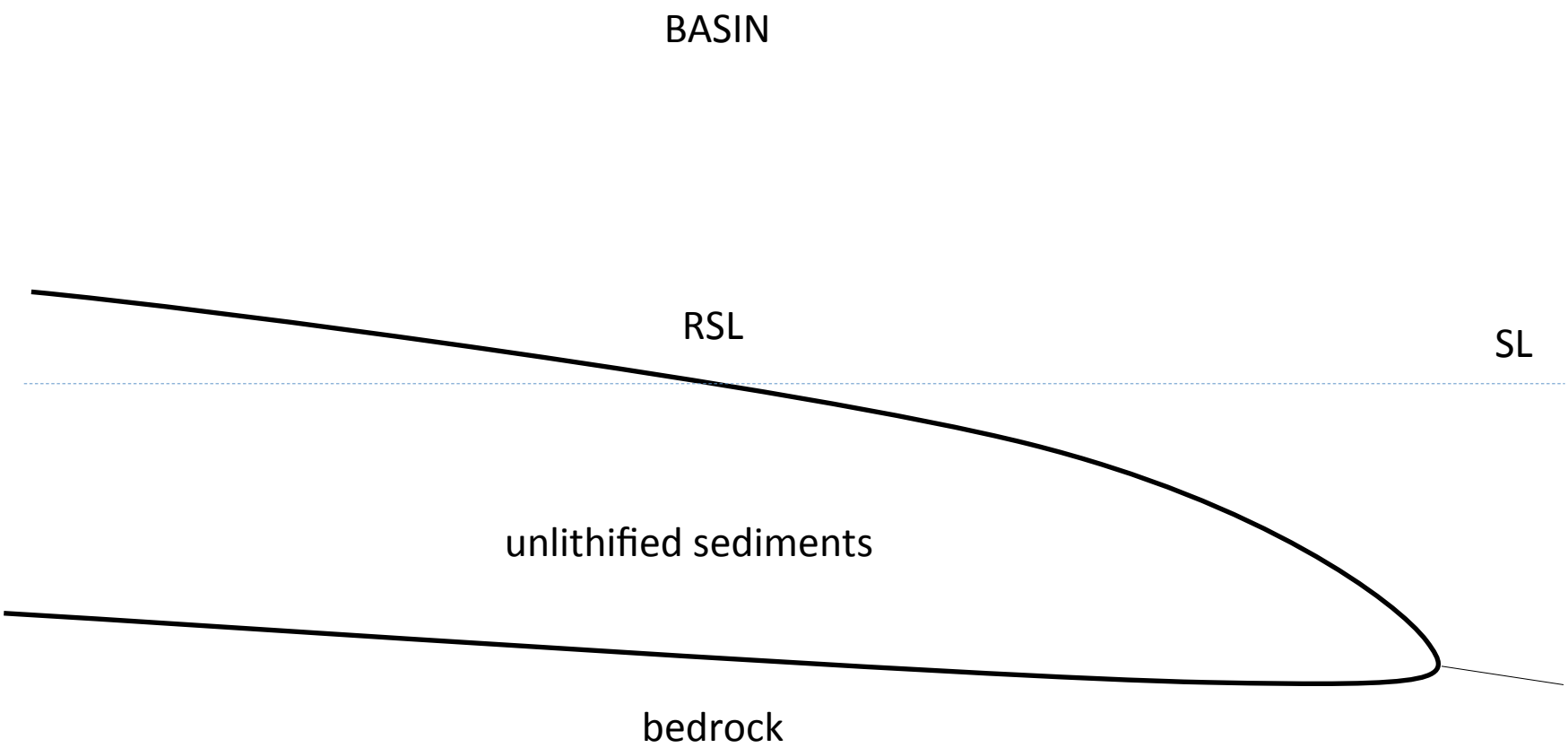
Nature Vol. 261 May 6 1976

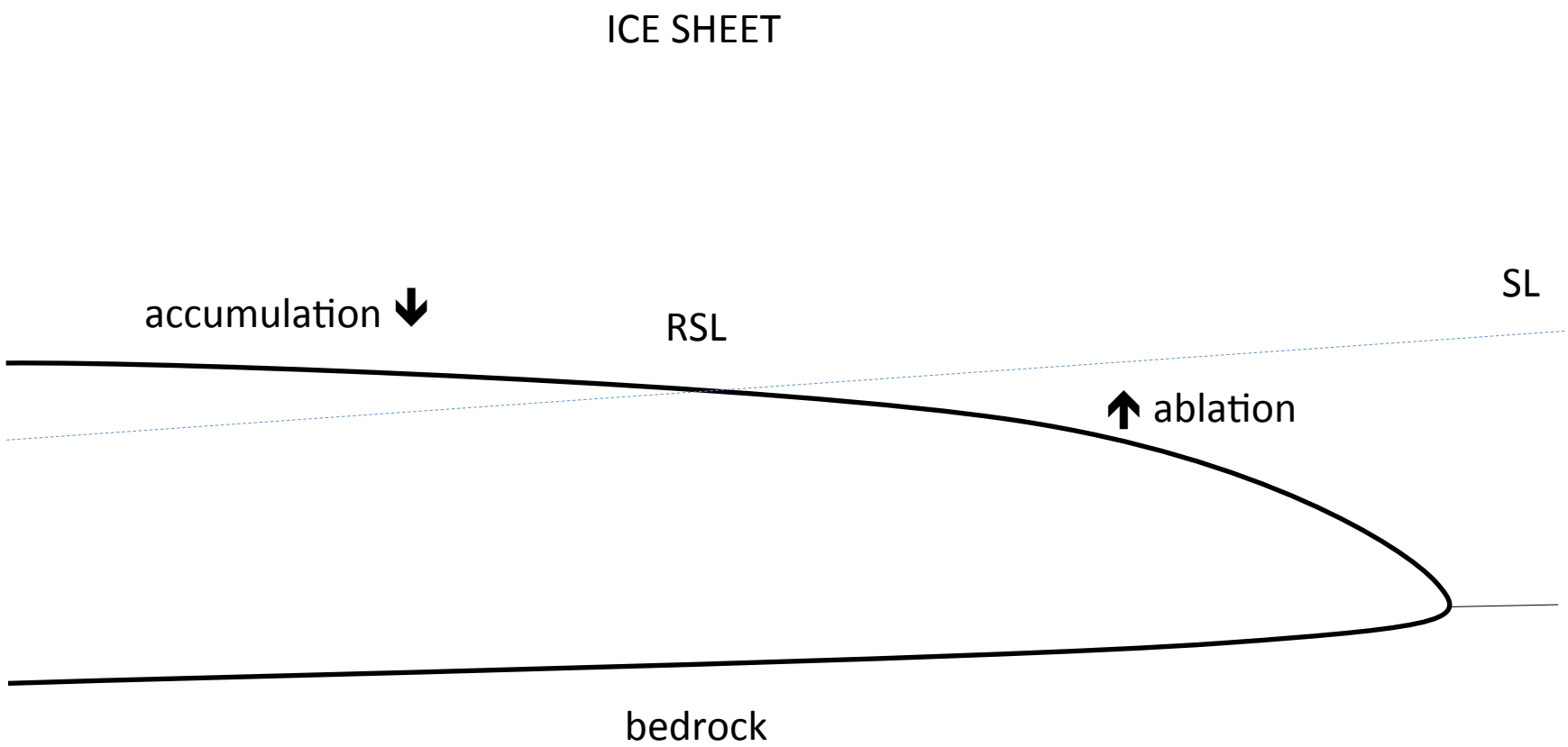
Johannes Weertman

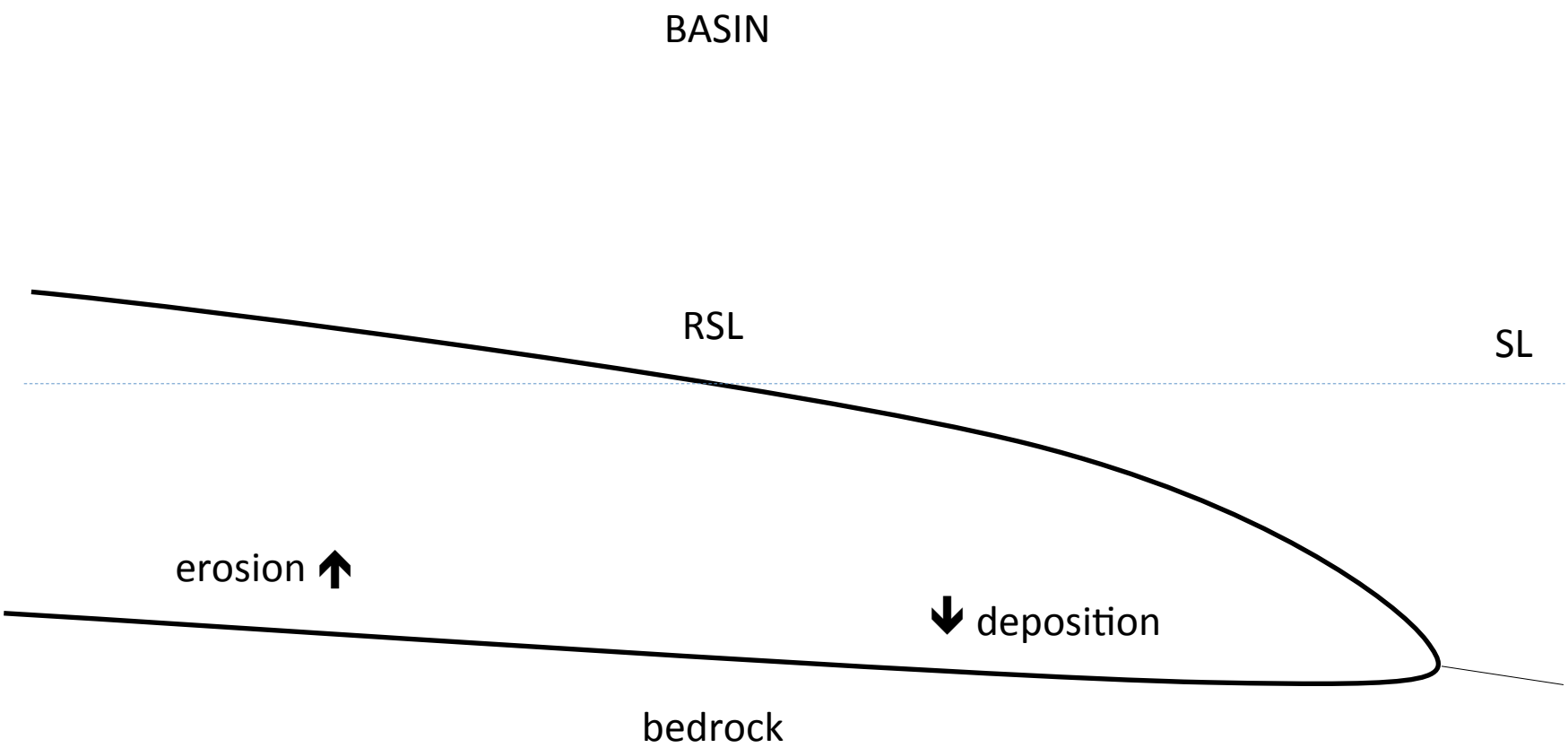
Department of Materials Science & Engineering, and Department of Geological Sciences, Northwestern University, Evanston, Illinois 60201

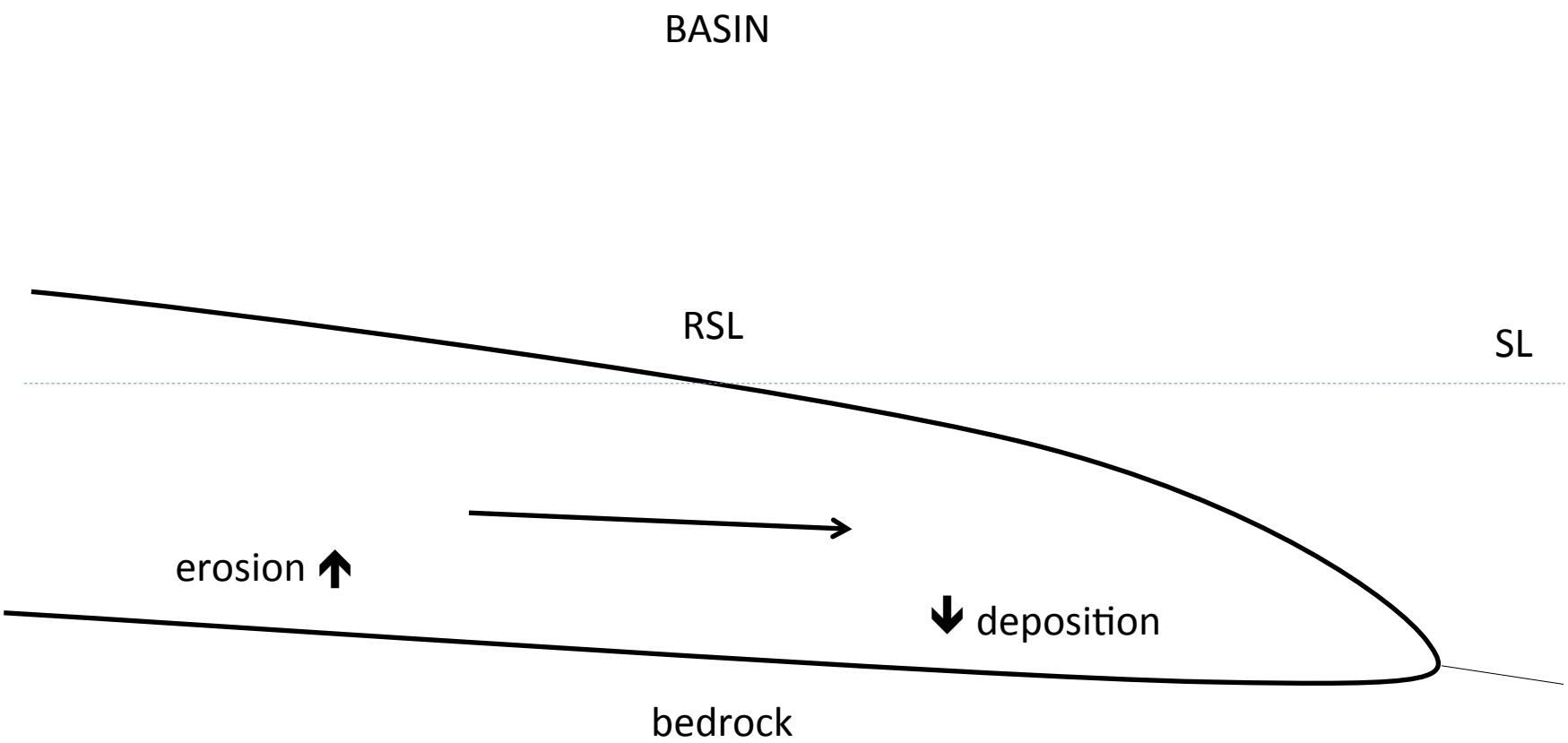


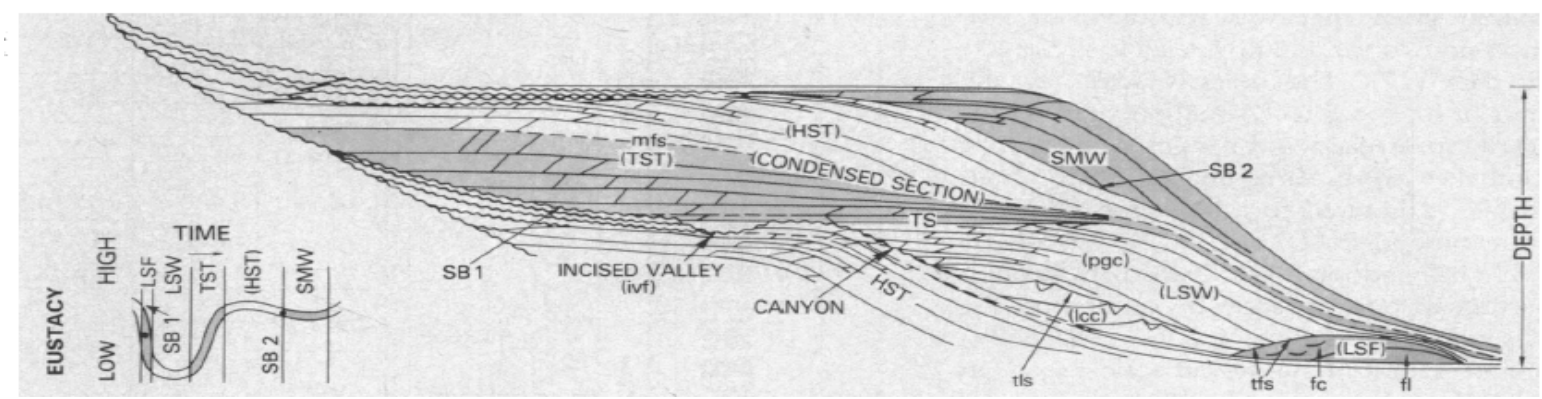

ICE SHEET
SL
RSL
bedrock


BASIN
RSL
SL
unlithified sediments
bedrock

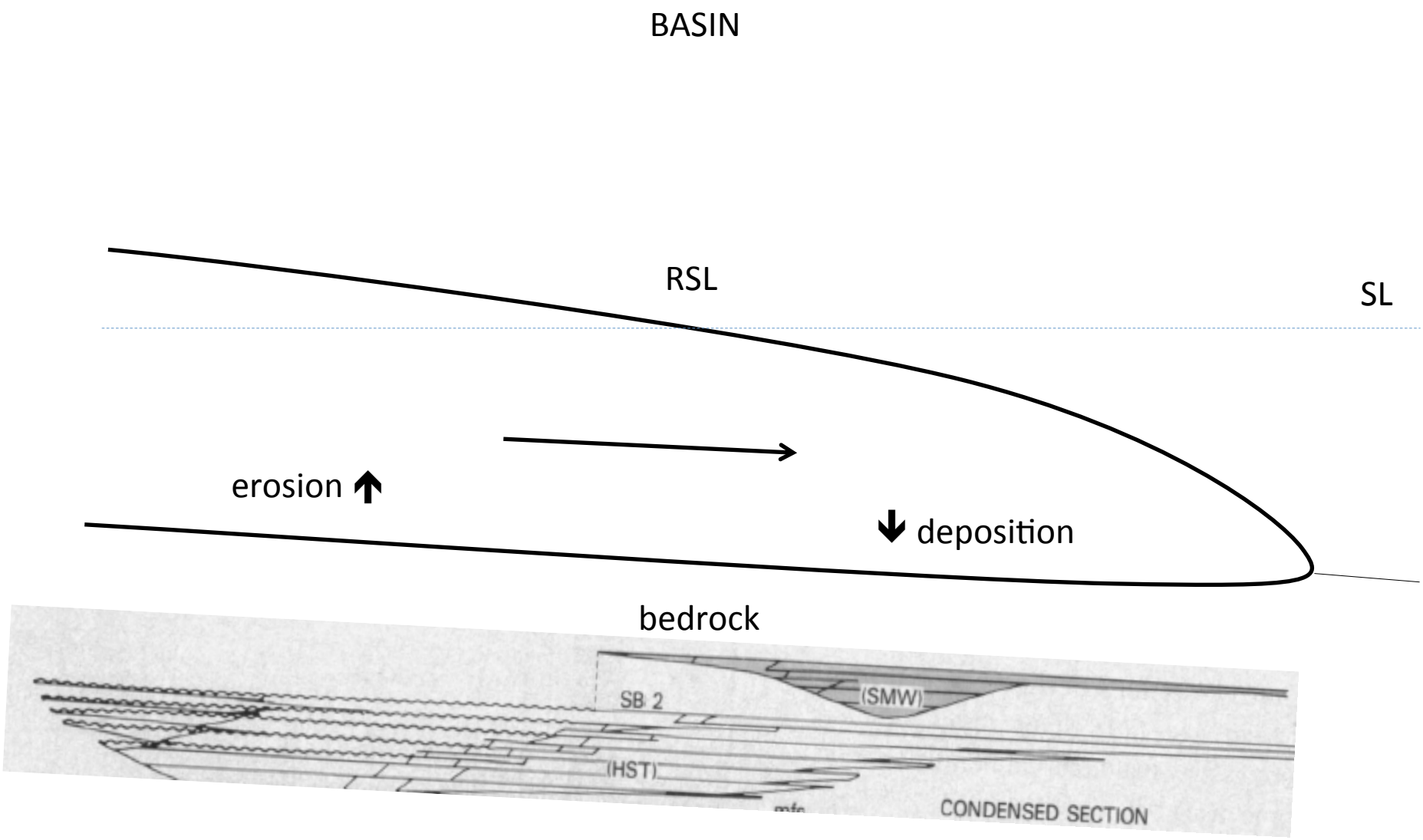

ICE SHEET
accumulation
RSL
SL
ablation
bedrock


BASIN
RSL
SL
erosion
deposition
bedrock



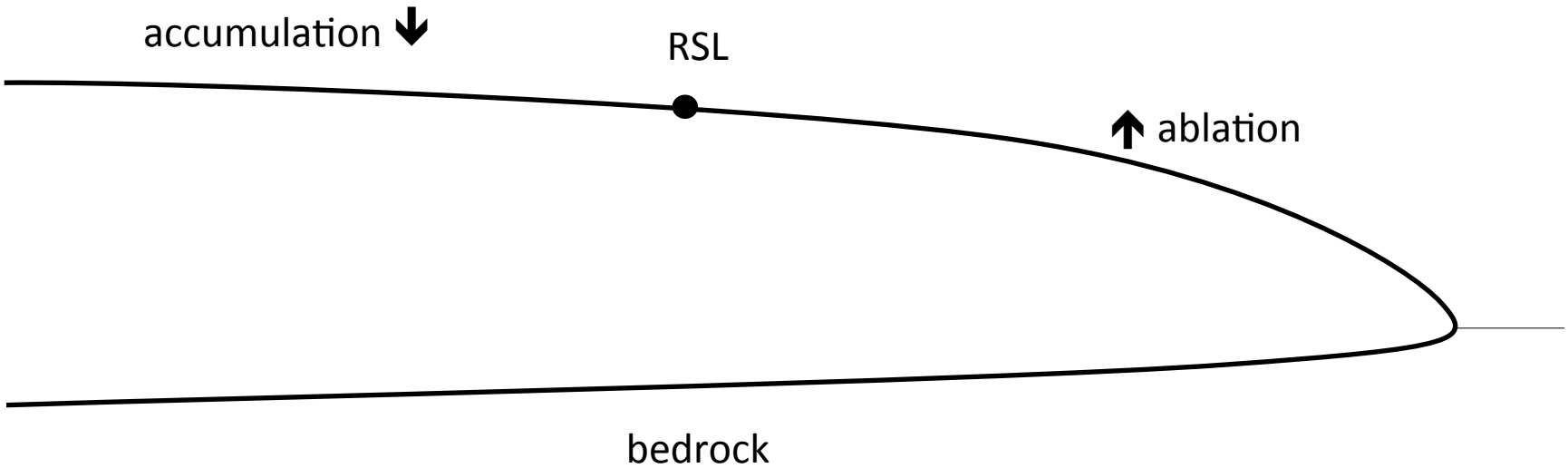


Haq et al, 1987



Haq et al, 1987

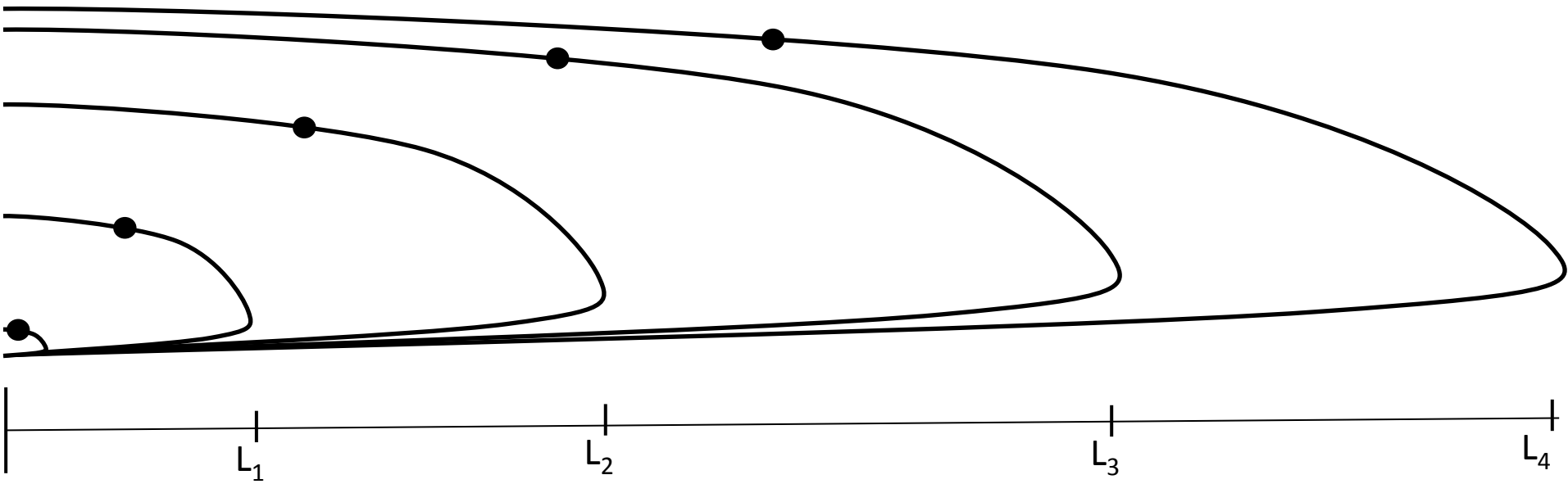
EQUILIBRIUM ICE SHEET



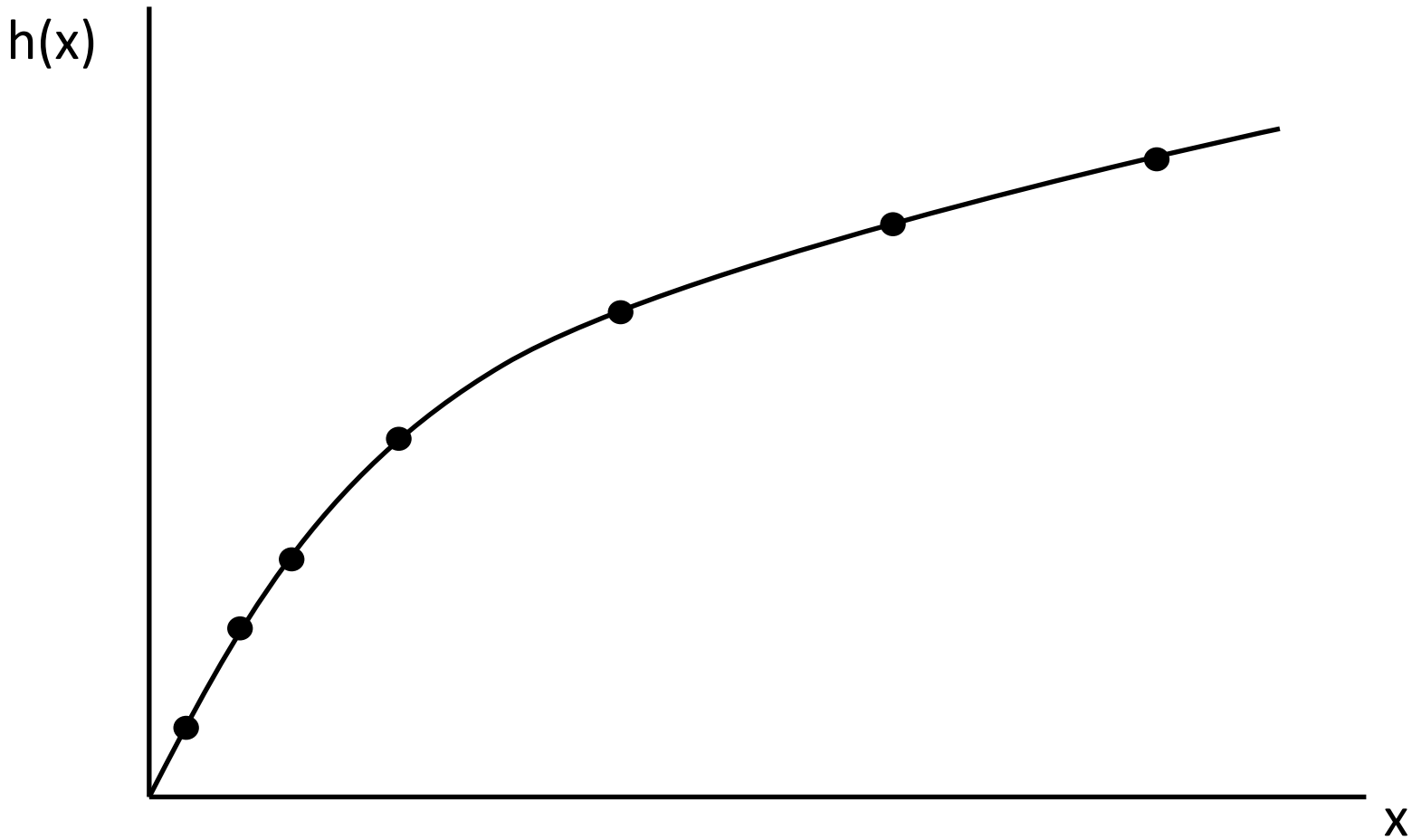
Let the black dot above ● be the position of the relative snow line for an equilibrium ice sheet, where total accumulation behind = total ablation in front.

Here is how that black dot moves in space for progressively bigger equilibrium ice sheets, as the length L increases,

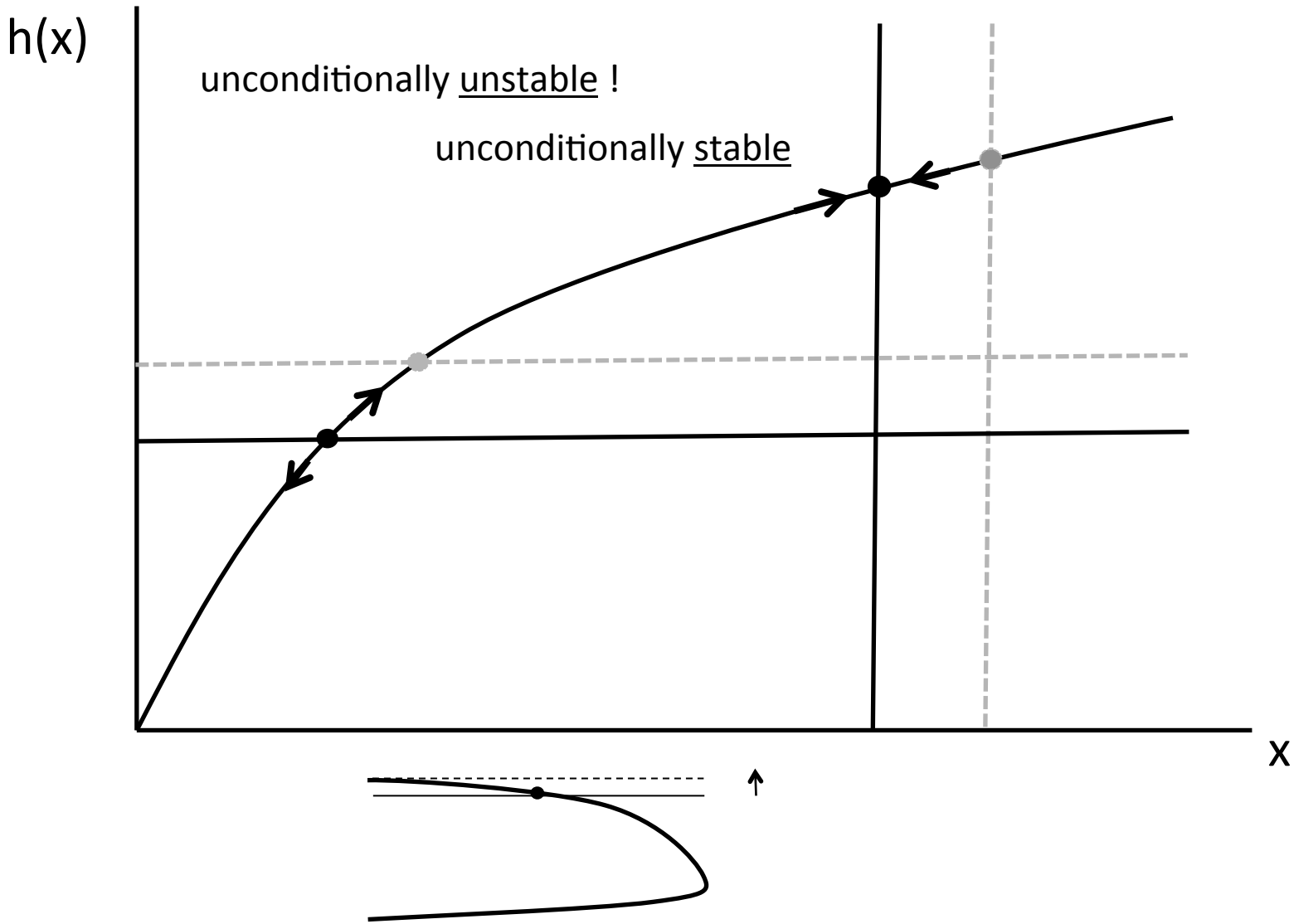
for a surface shape, $f(x, L) = (L - x)^{1/2}$, for example.



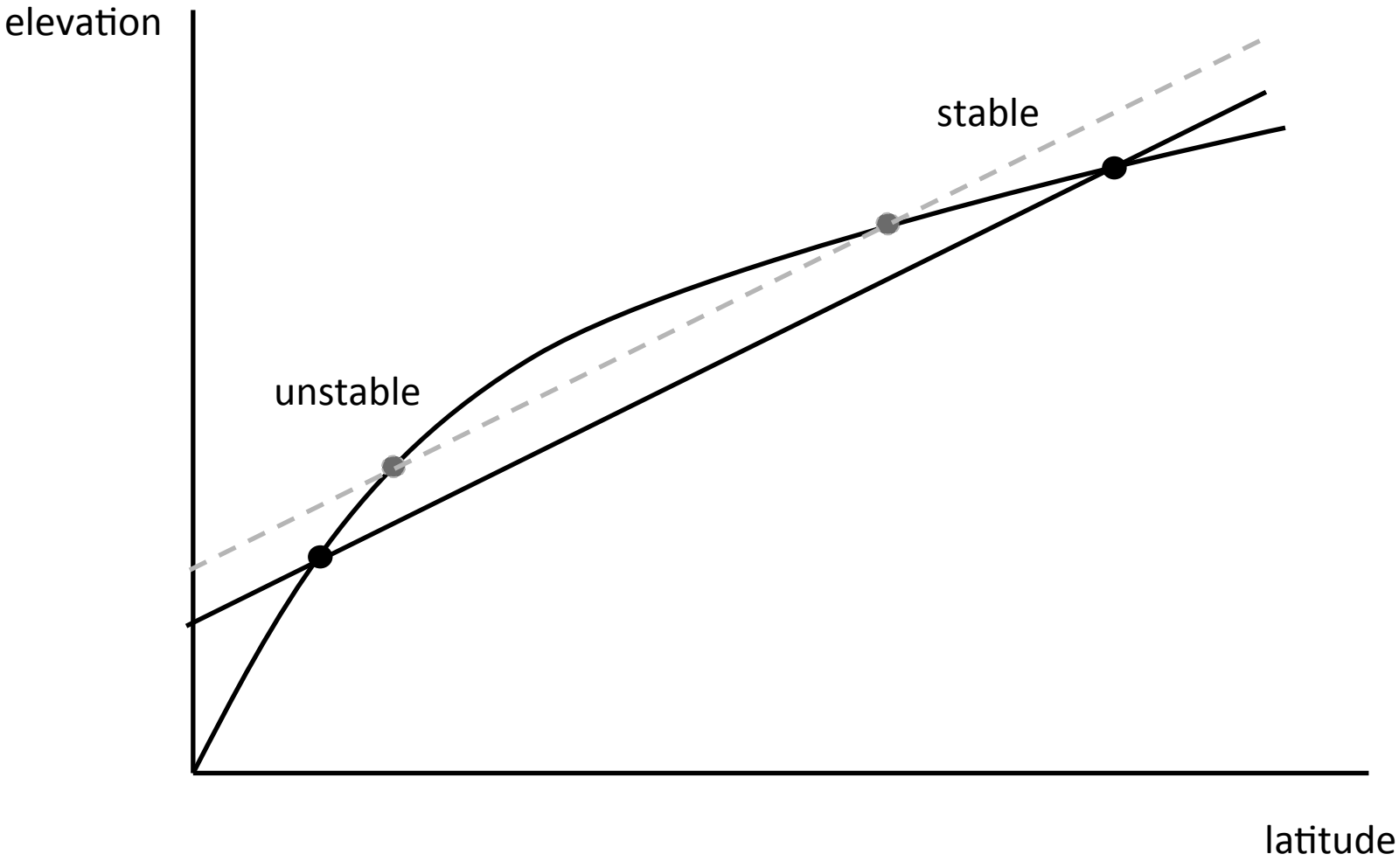
The mathematically “perfect” equilibrium snow line in the atmosphere



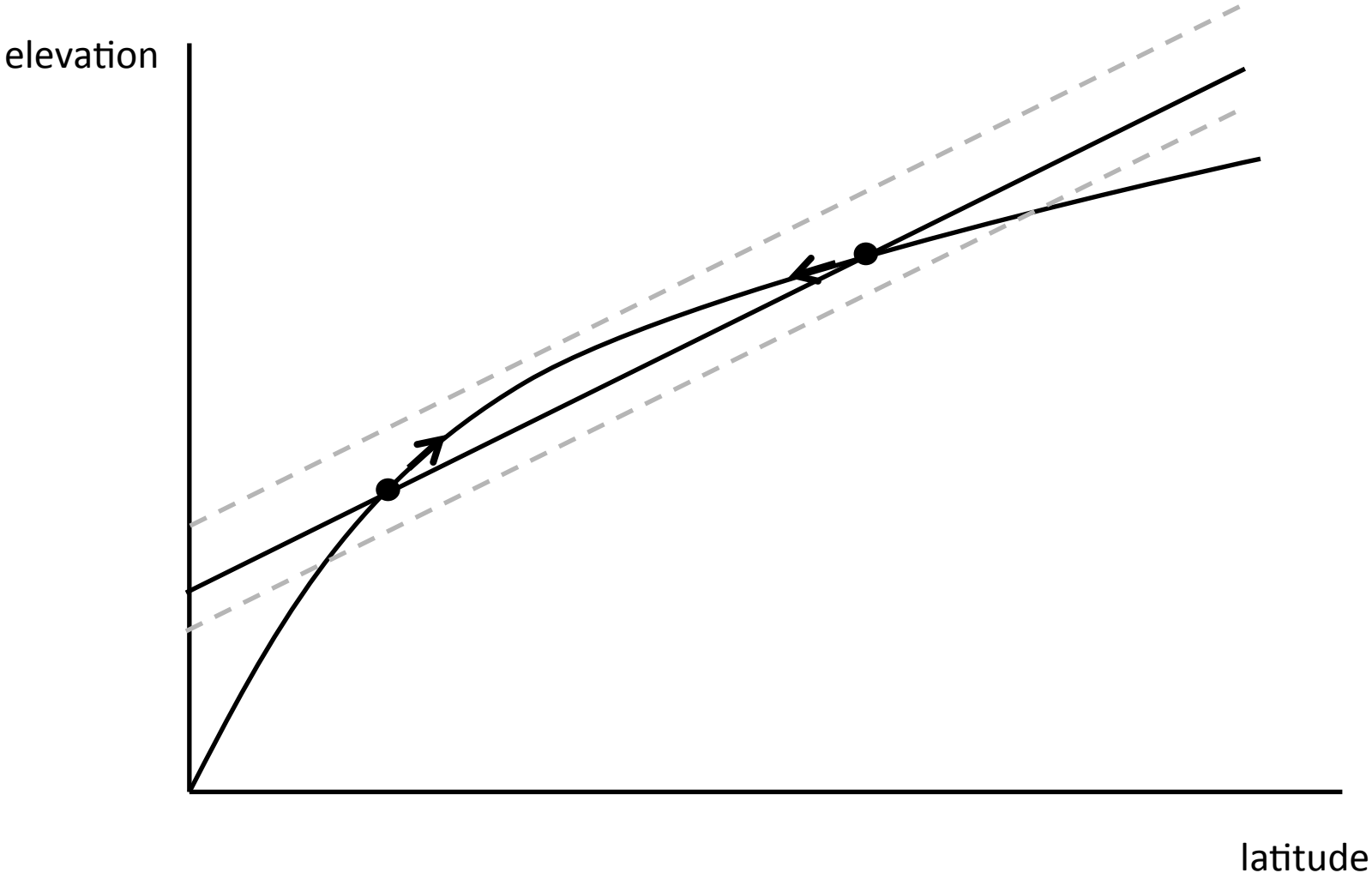
The mathematically “perfect” equilibrium snow line in the atmosphere



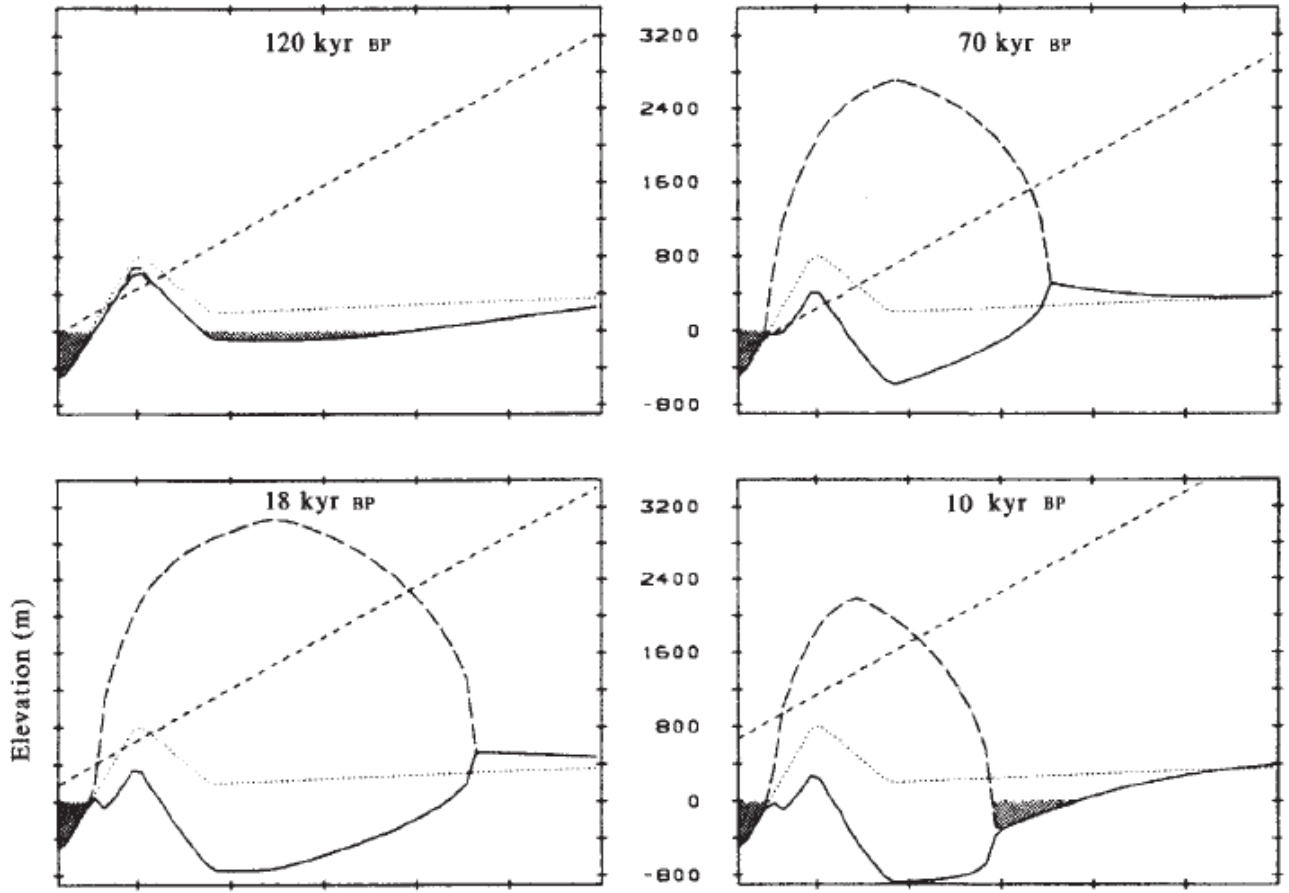
Arguably, the most realistic snowline model for continental scale ice sheets



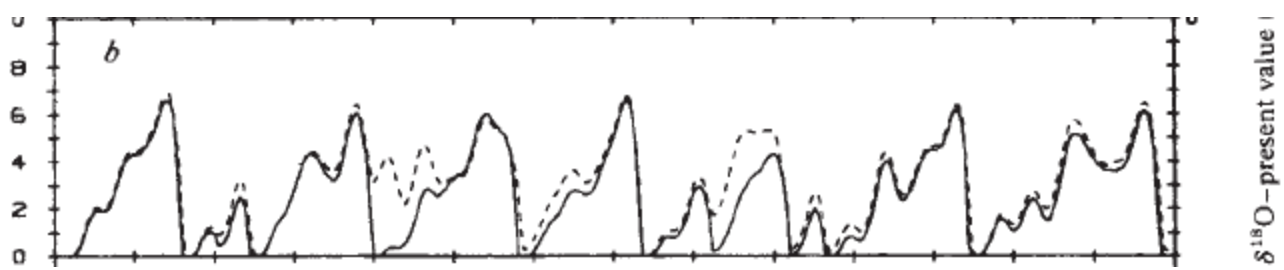
Large mass oscillations are possible from small movements of the snowline

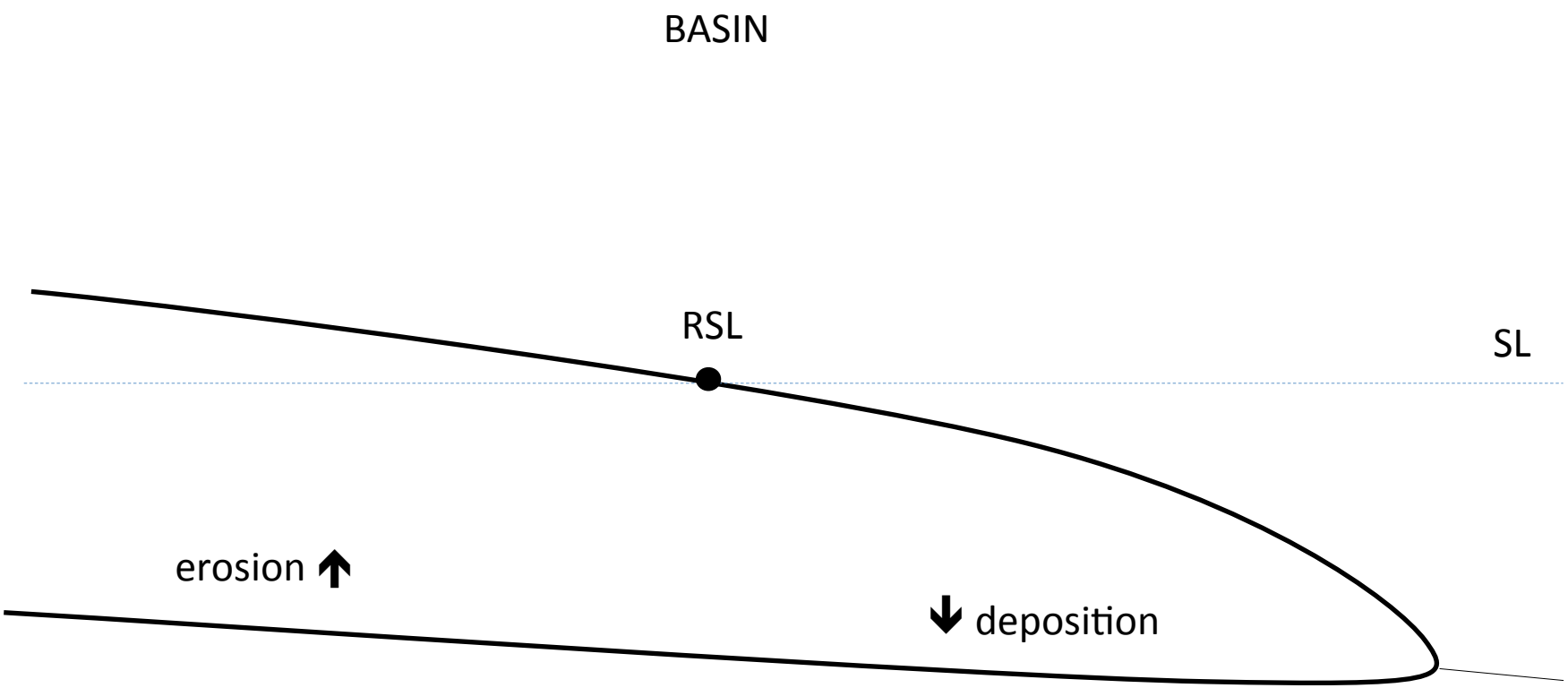


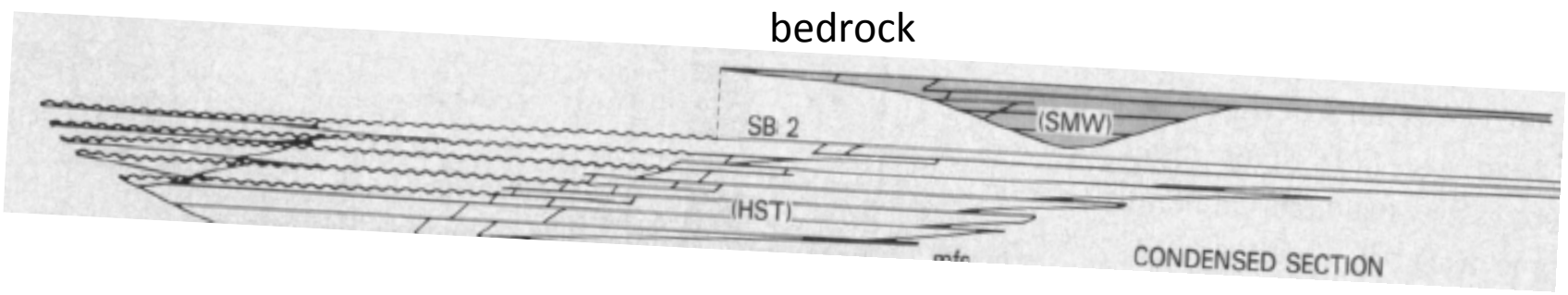
e.g. Pollard, 1982



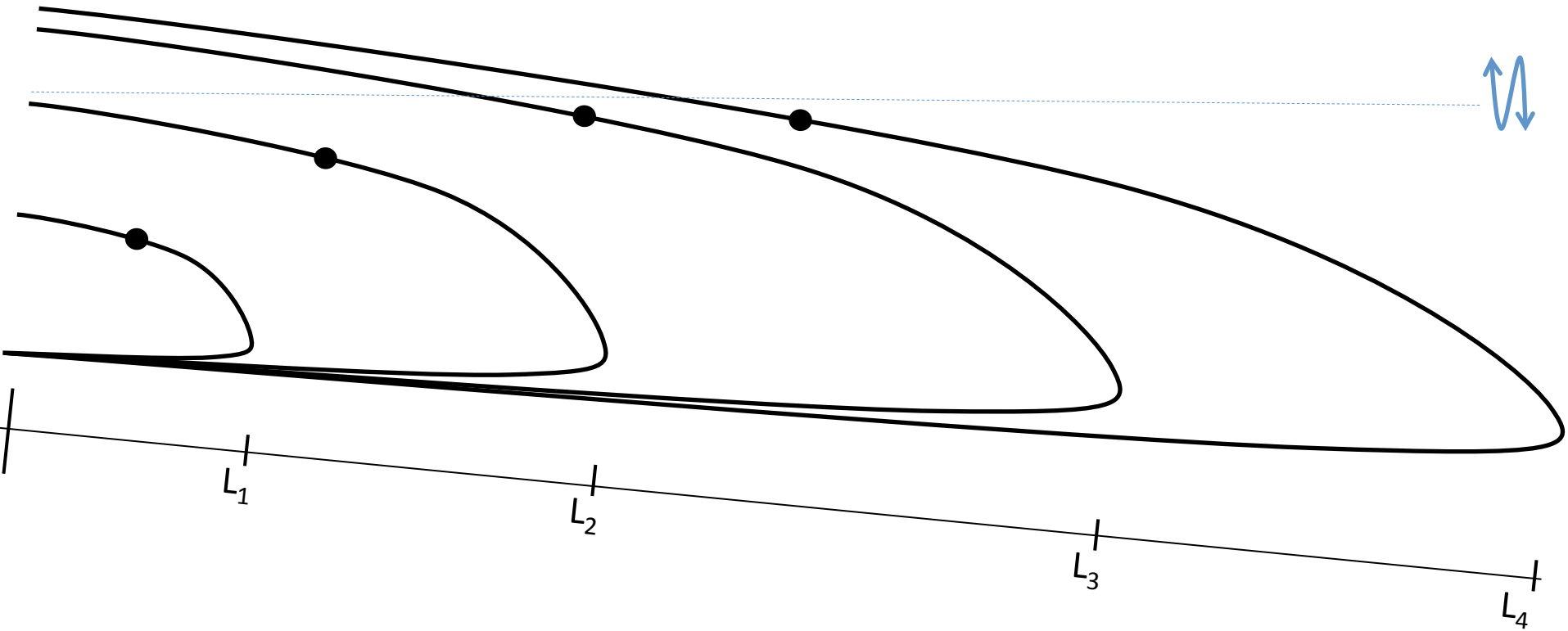
Simulated
Ice volume
$\delta^{18}O$




BASIN
RSL
SL
erosion
deposition
bedrock

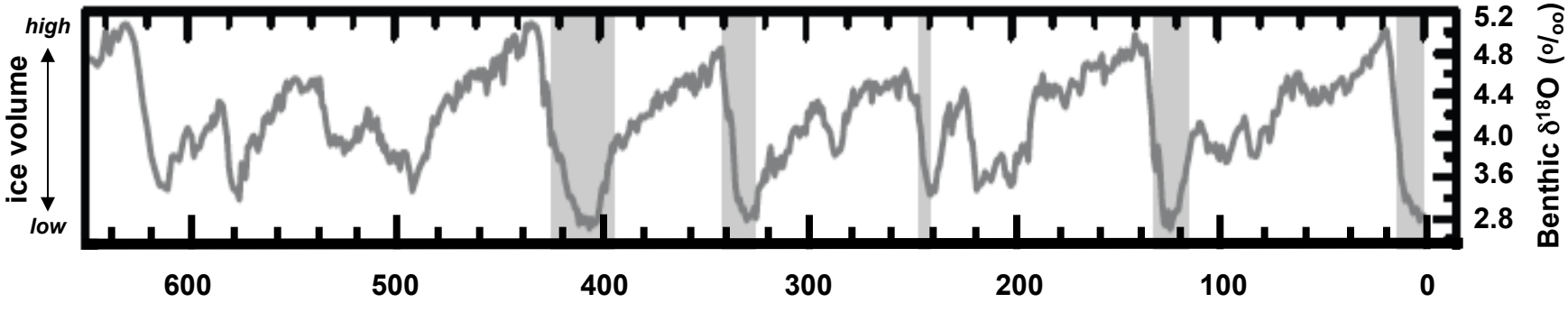

SB 2
(SMW)
(HST)
CONDENSED SECTION

SUCCESSIVE EQUILIBRIUM BASIN SURFICIAL SEDIMENTS

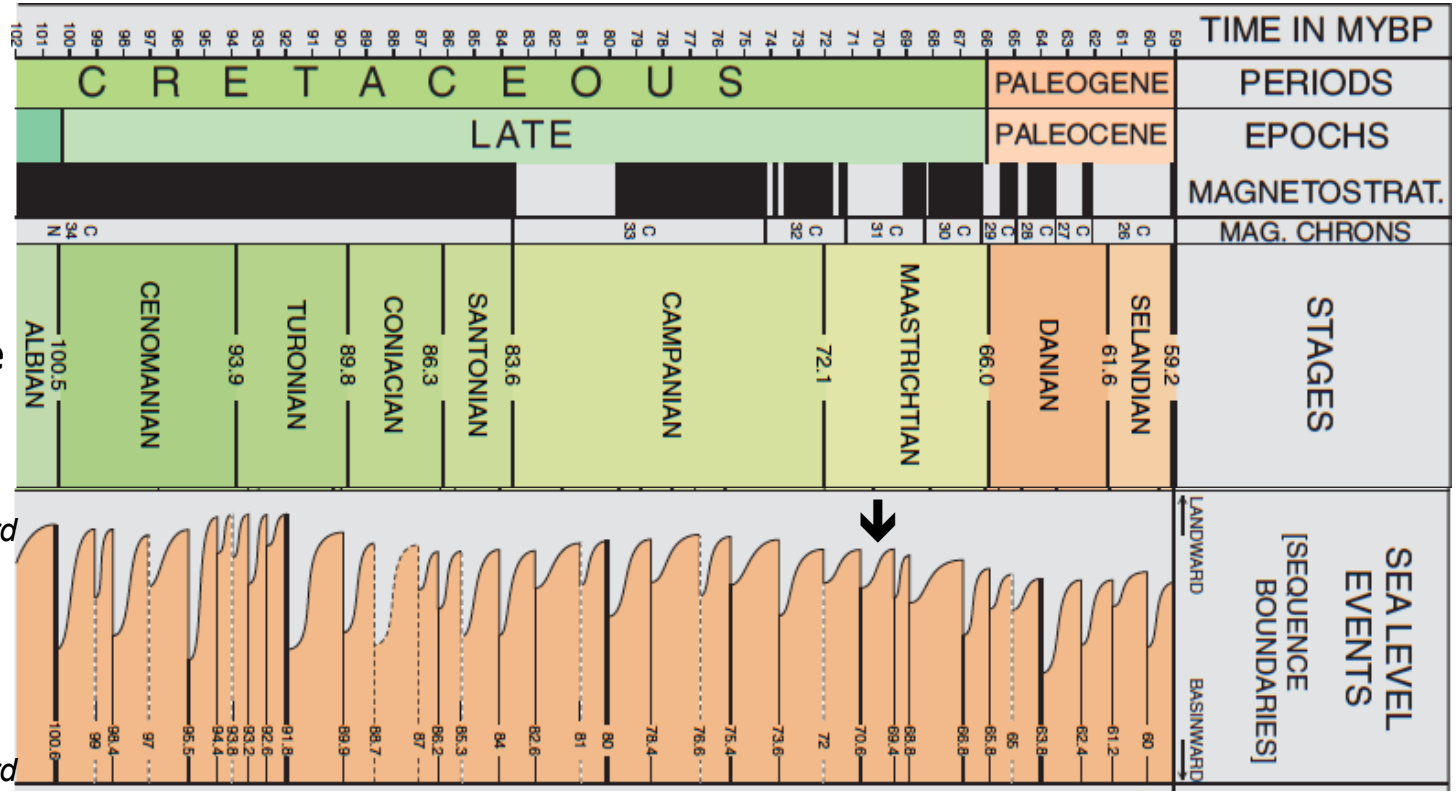


Pleistocene 100 Kyr Ice Sheet Cycles ↓

Lisiecki and Raymo, 2005



Cretaceous 1-3 Myr <u>Relative</u> Sea Level Cycles ↓



relative ↓

landward

Relative sea level

basinward

Haq 2014

- 3 general elements define Milankovitch ice sheet models: (1) non-linear surface, (2) two areal zones of mass supply and sink, (3) a nearly horizontal (but still sloping) mass controlling horizon.

- The bedrock record of Cretaceous (and the entire Phanerozoic) 3rd order relative sea level cycles demands one postulate a surficial mass of nonlithified sediments which mediates observed bedrock erosion and deposition.

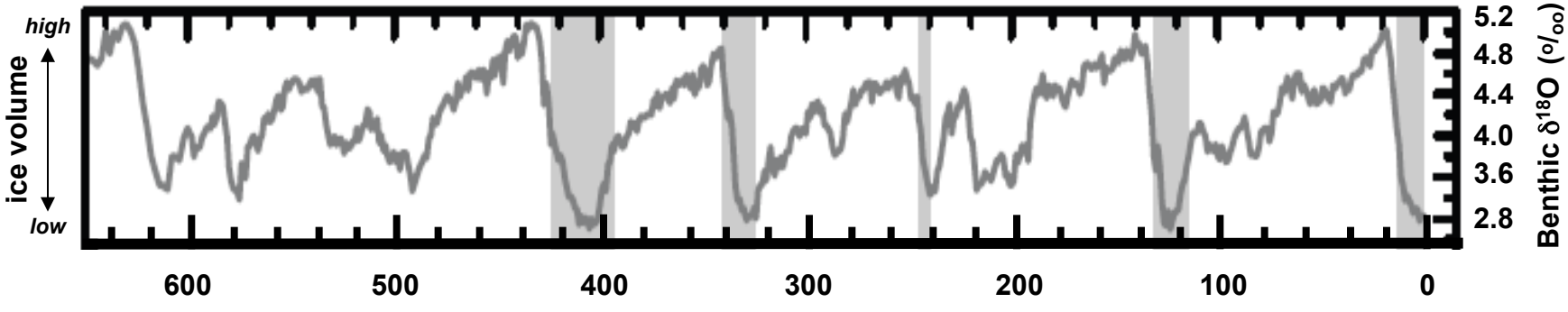
- This surficial mass of nonlithified sediments possesses the same 3 general elements defined in Milankovitch ice sheet models and which are capable of large mass volume changes from very small snowline changes.

- Erosional unconformities provide local mass to surficial sediment volume that causes instability and pushes relative sea level basinward.

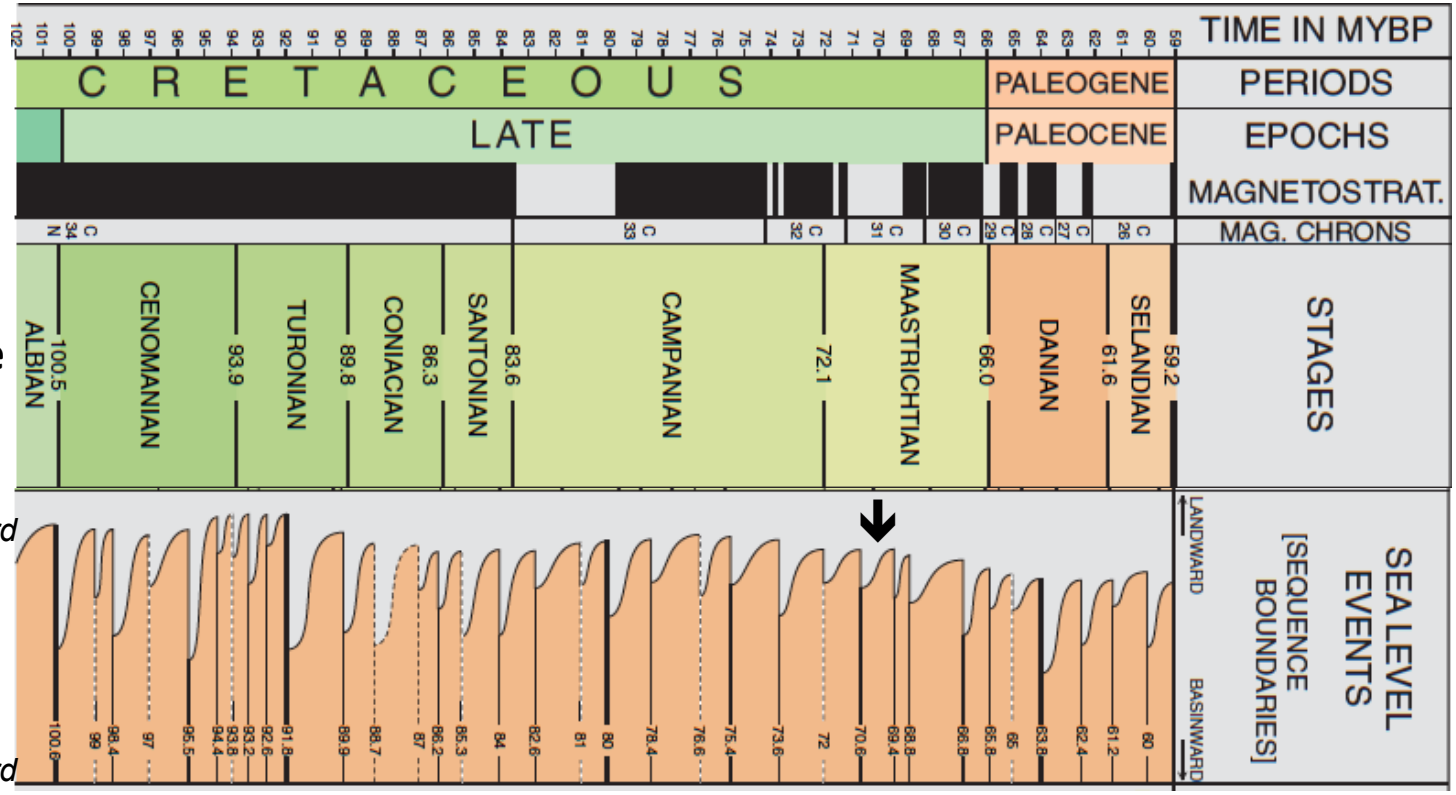
- Modeling this instability like Milankovitch ice models will require more generalizable data on surface profiles and dimensions in the sequence stratigraphy bedrock record.

Pleistocene 100 Kyr Ice Sheet Cycles ↓

Lisiecki and Raymo, 2005



Cretaceous 1-3 Myr <u>Relative</u> Sea Level Cycles ↓



relative ↓

landward

Relative sea level

basinward

Haq 2014