UNIVERSITY OF MICHIGAN

MichiganEngineering

Emergence of tidewater and ice shelf calving dynamics using a granular model of ice

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QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Supported by NSF and NASA

Observations show

Floating termini (ice shelves and ice tongues):

1) Normal mode of calving is large tabular bergs that detach from rifts

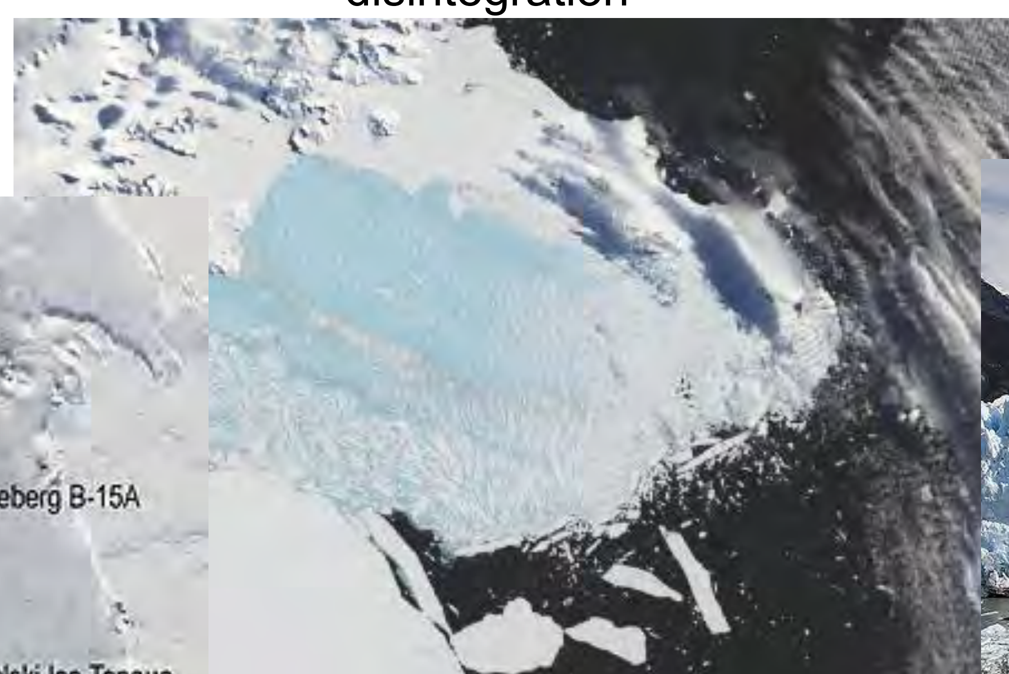
2) Explosive disintegration is possible if the ice is sufficiently fractured

Grounded termini (ice shelves and ice tongues):

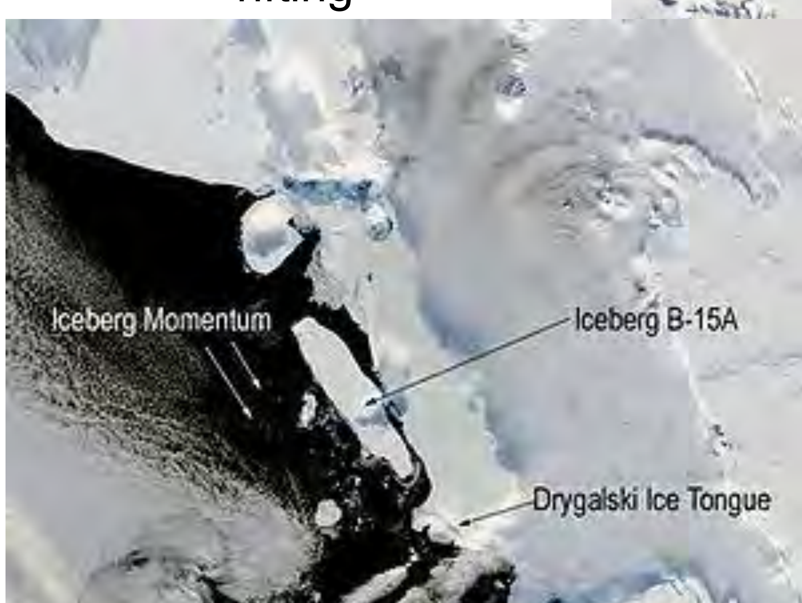
1) Normal mode of calving is ice-thickness sized bergs

2) Calving rate is (often) correlated with water depth

disintegration



rifting



tidewater water depth calving law

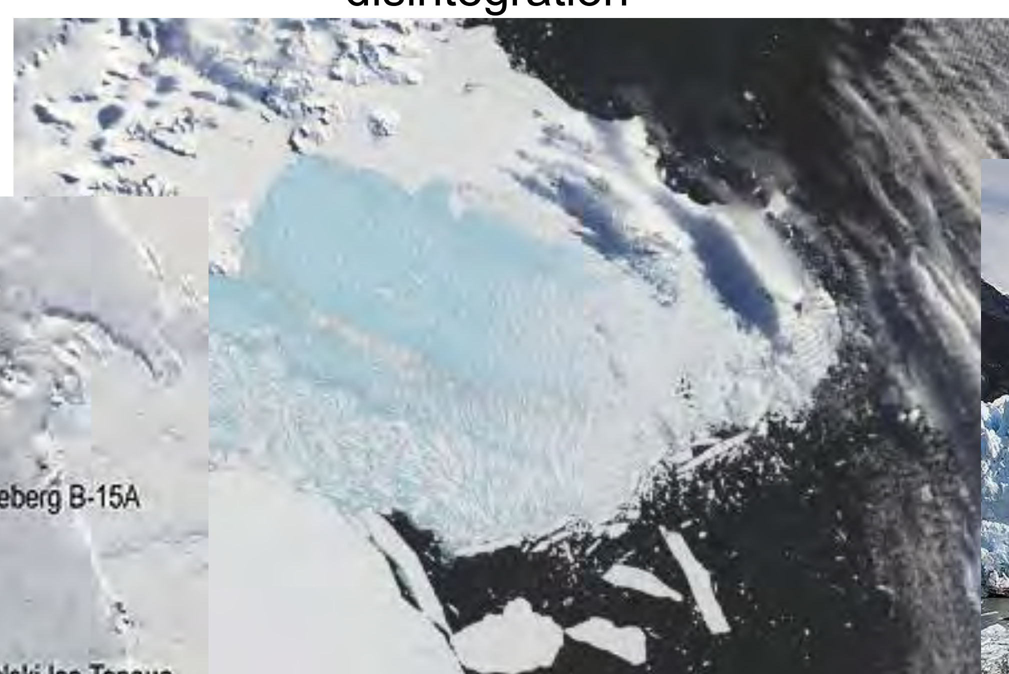
Can calving style be explained by a simple model?

1) Geometry:
Ice thickness (H) & water depth (D) determines the stress field

2) Yield strength of ice:
Normal and shear yield strength determines when the ice breaks

3) Density of pre-existing fractures
Stress history of ice, surface melt pond assisted fracturing, englacial fracture networks determines how fractured the ice near the terminus is

disintegration



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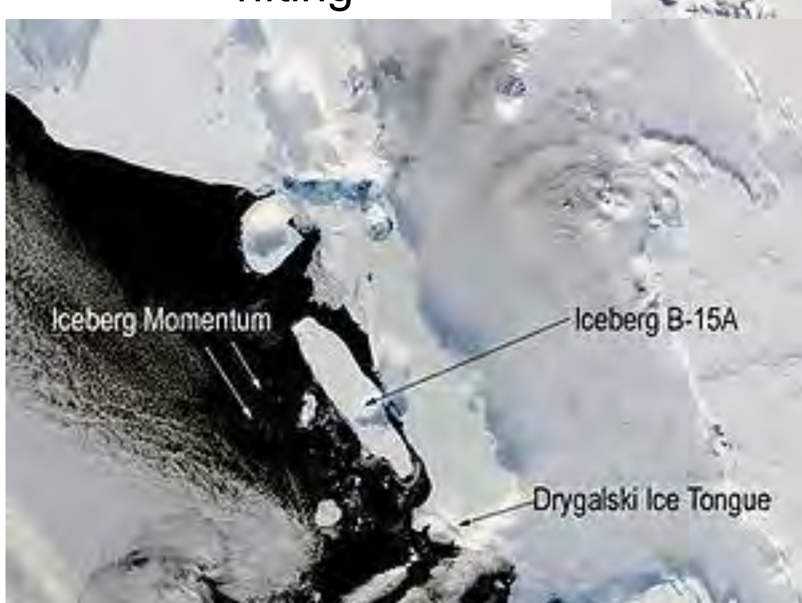


tidewater water depth calving law

Conceptual Model of Ice: Molecular Dynamics

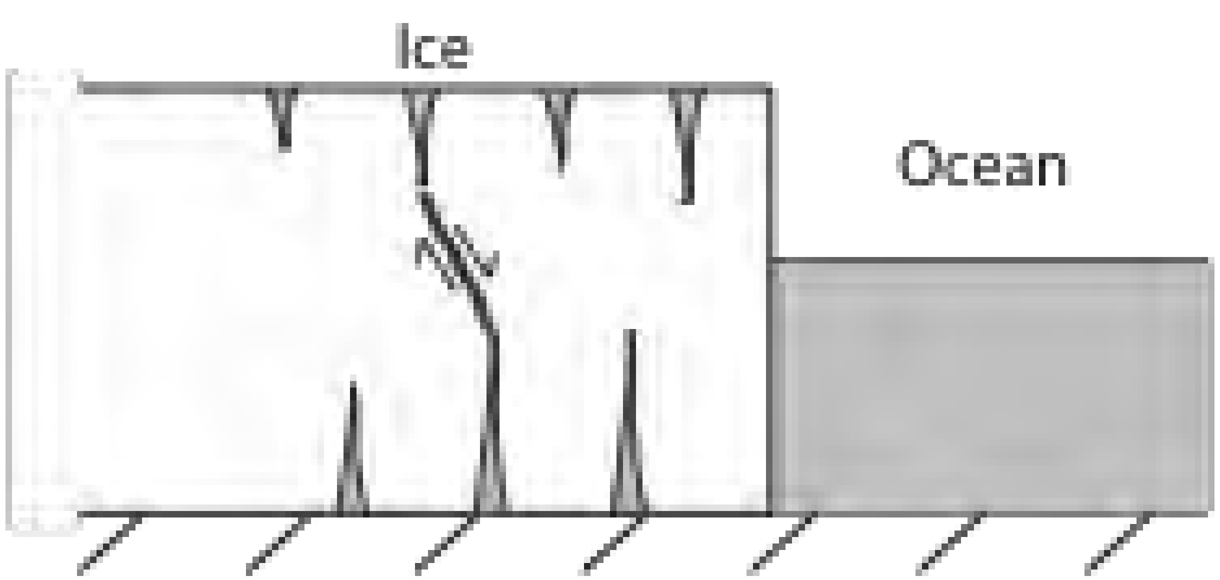
Atom: *from Greek meaning uncuttable or indivisible*

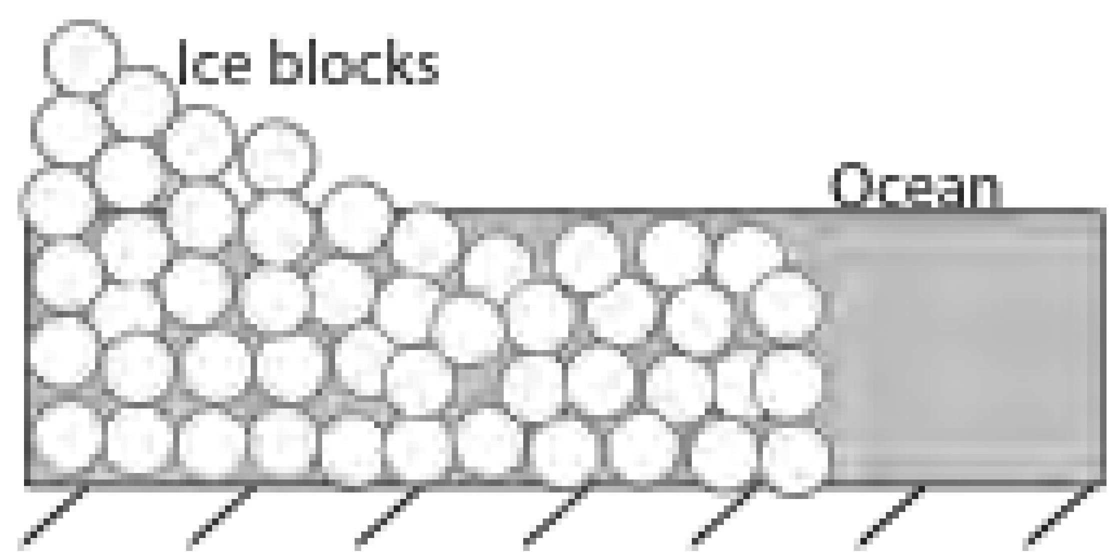
Molecule: *Atoms held together by bonds*

> "Atoms" of ice are spherical boulders of ice 50 m in radius
> "Molecules" are boulders of ice glued together by bonds with finite strength

continuous ← spectrum of behavior → discrete

bonds have *normal* and *shear* strength





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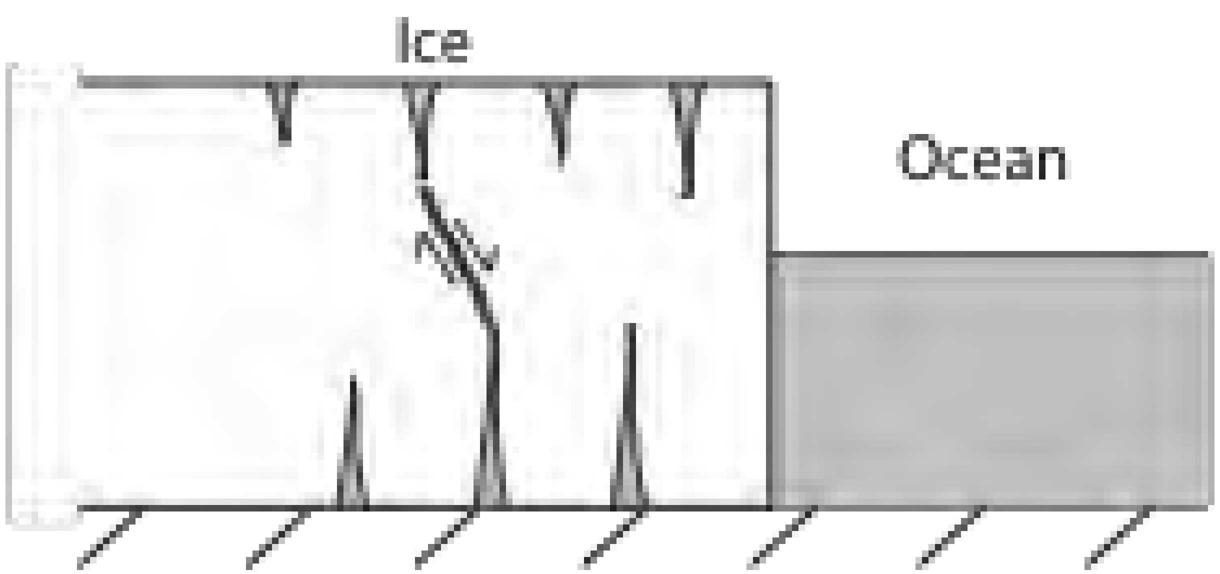
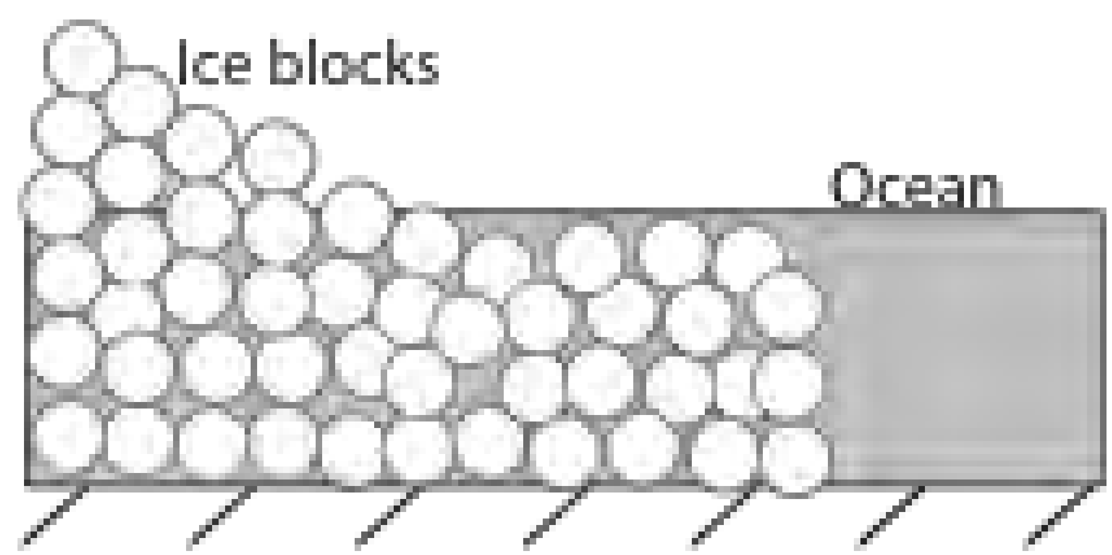
Spheres of ice interact through: (1) elasticity, (2) friction, (3) bond forces

continuous (all bonds intact) ←— spectrum of behavior —→ discrete (all bonds broken)

bonds have *normal* and *shear* strength





music of the spheres?

Shear failure is important for thick, land terminating glaciers

Bond strength : 150 kPa (normal), **1** GPa (shear)

H ~ 660 m

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

(note the large crevasse ~ one ice thickness from the front)

Bond strength : 150 kPa (normal), **10** GPa (shear)

H ~ 660 m

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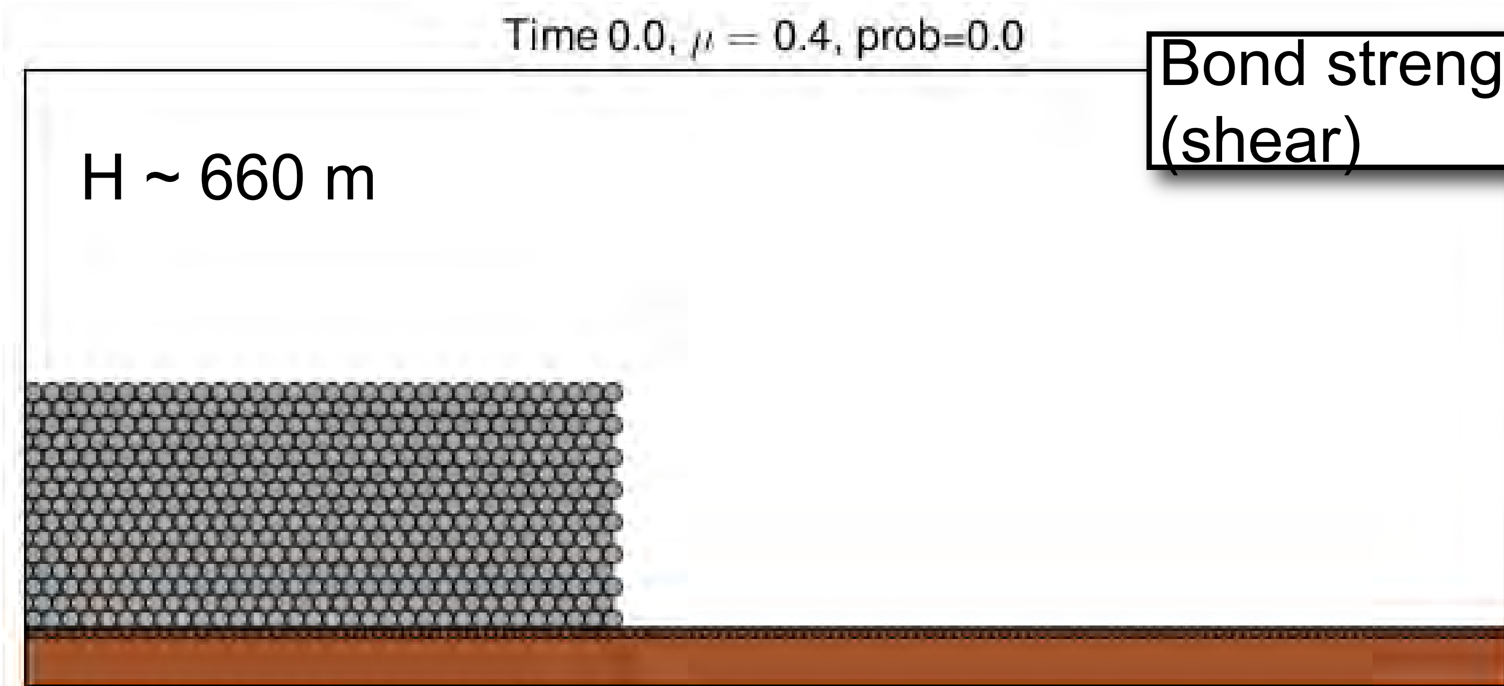
Shear failure is important for thick, land terminating glaciers



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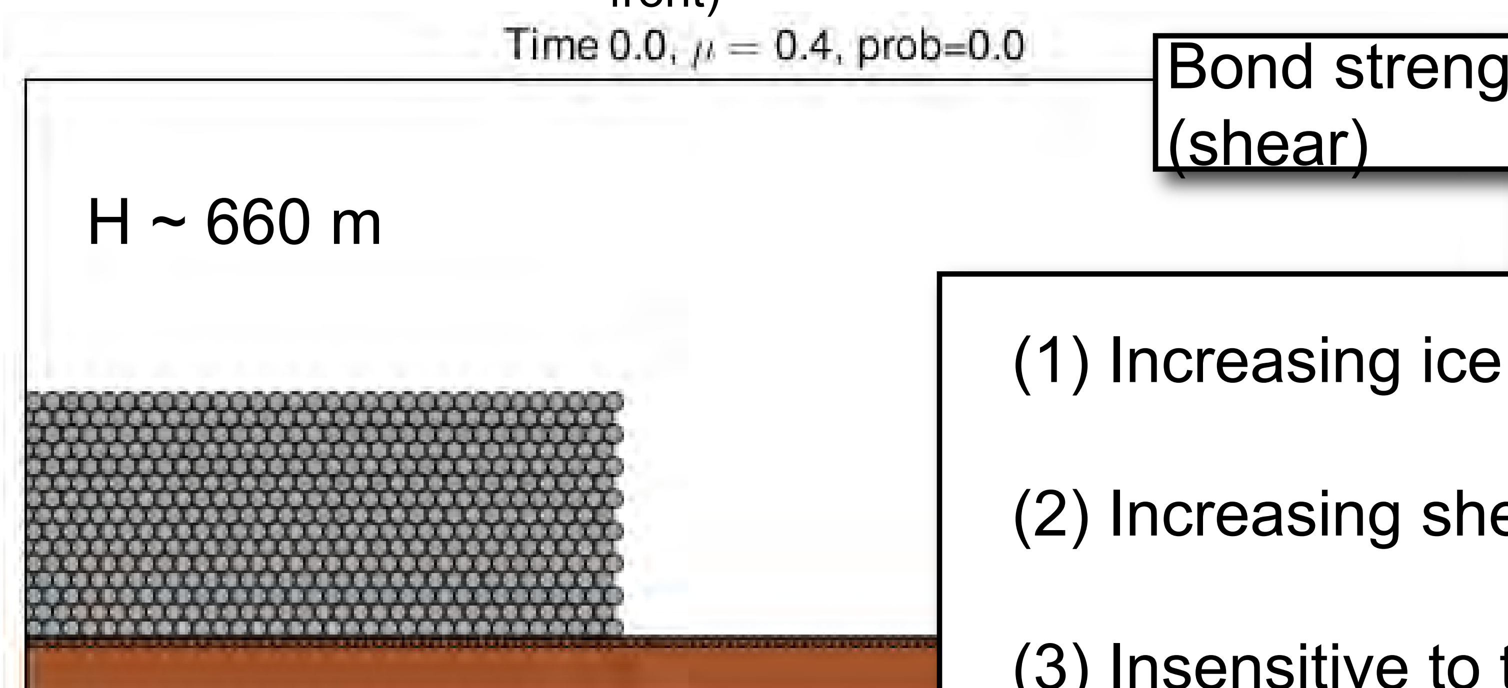

Bond strength : 150 kPa (normal), **10** GPa (shear)

(1) Increasing ice thickness **decreases** stability

(2) Increasing shear strength **increases** stability

(3) Insensitive to tensile yield strength

Just add water . . .

D ~ 100 m

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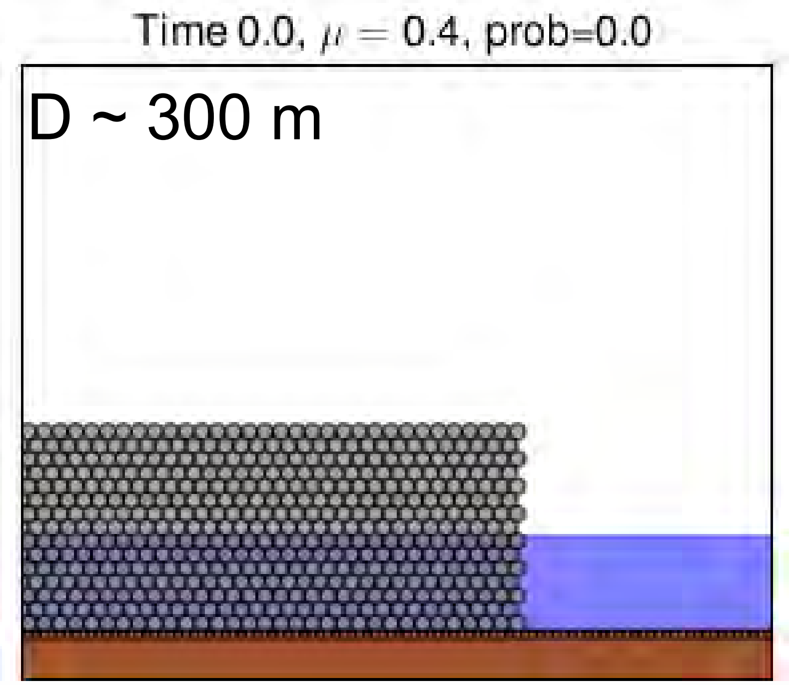
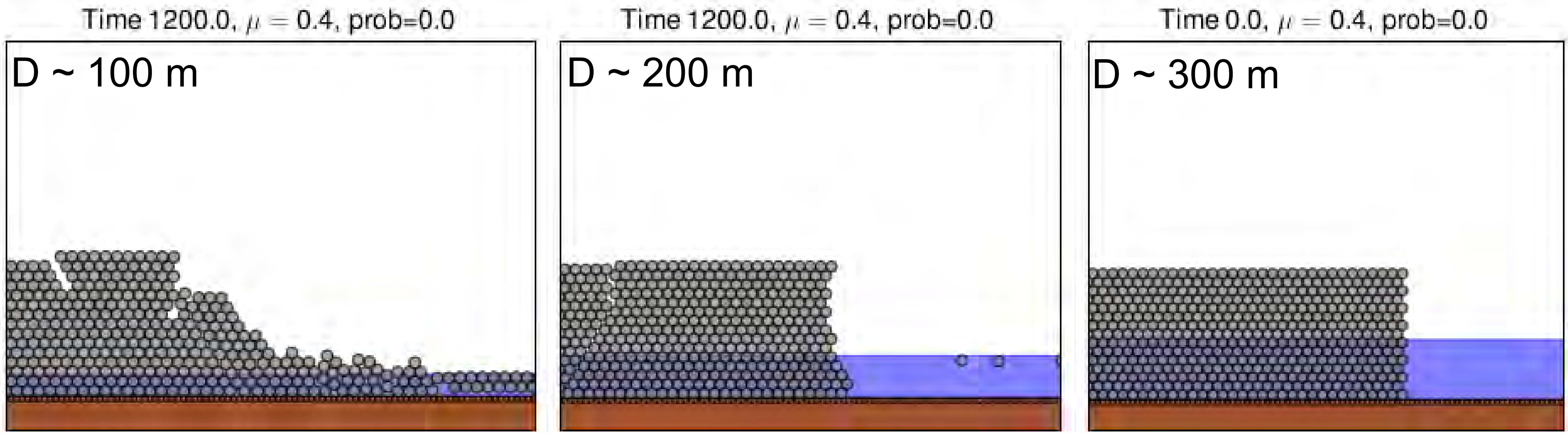
D ~ 200 m

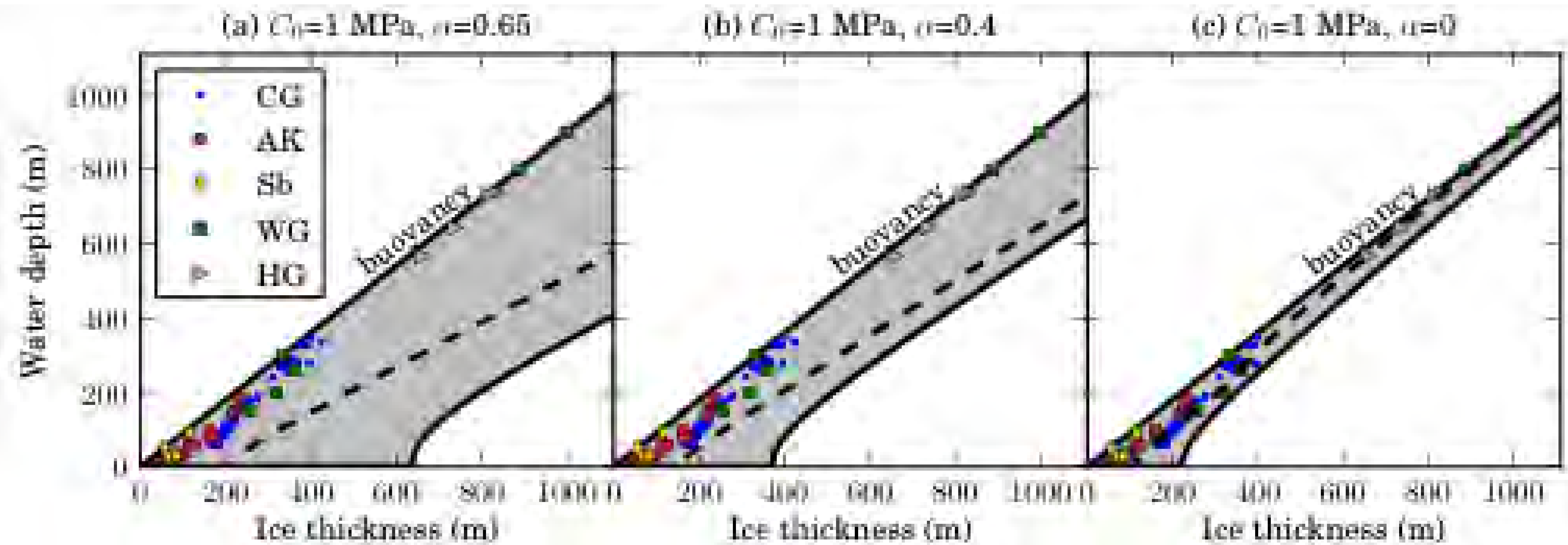
QuickTime™ and a
H.264 decompressor
are needed to see this picture.

D ~ 300 m



Just add water . . .





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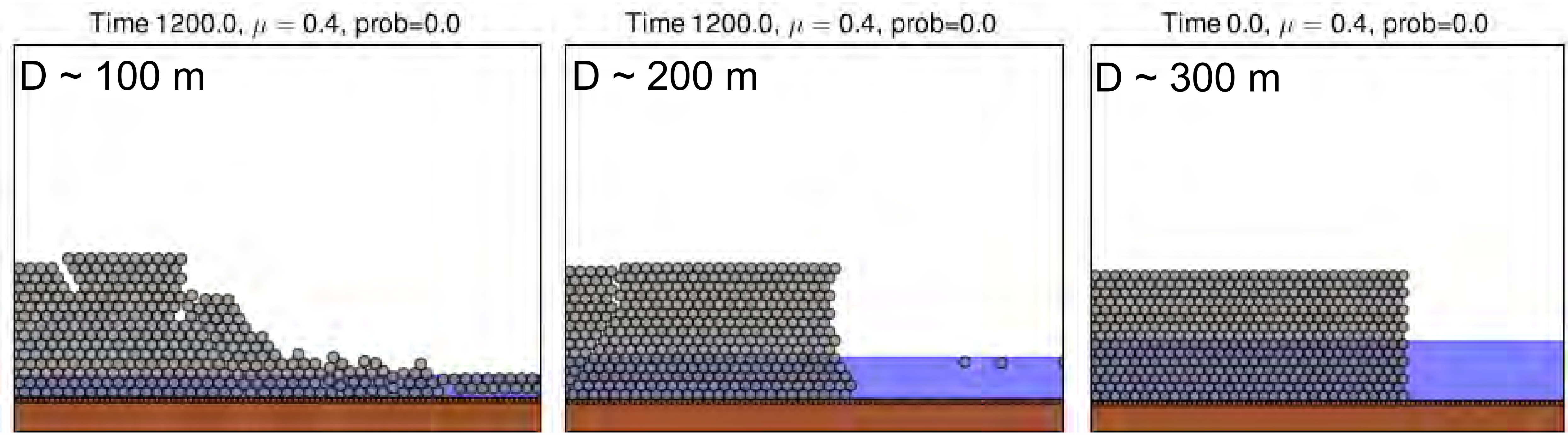

But when the ice is already fractured . . .

30% of bonds broken

D ~ 500 m

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H.264 decompressor
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Height-above-buoyancy calving is related to the transport of broken ice away from the terminus

Stable ice shelves are possible if the ice is intact

H ~ 350 m
Bond strength : 150 kPa (normal), 1 GPa (shear)

Percent of bonds broken: 0%

QuickTime™ and a
H.264 decompressor
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Transition from intact to rifting as fracture density increases

H ~ 350 m

Bond strength : 150 kPa (normal), 1 GPa (shear)

Percent of bonds broken: 0%

QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Percent of bonds broken: 40%

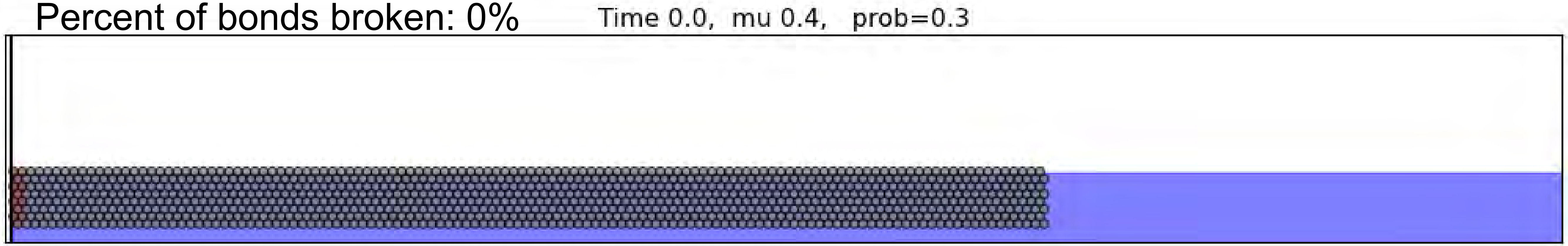
QuickTime™ and a
H.264 decompressor
are needed to see this picture.

Eventually ice shelf becomes unstable and disintegrates

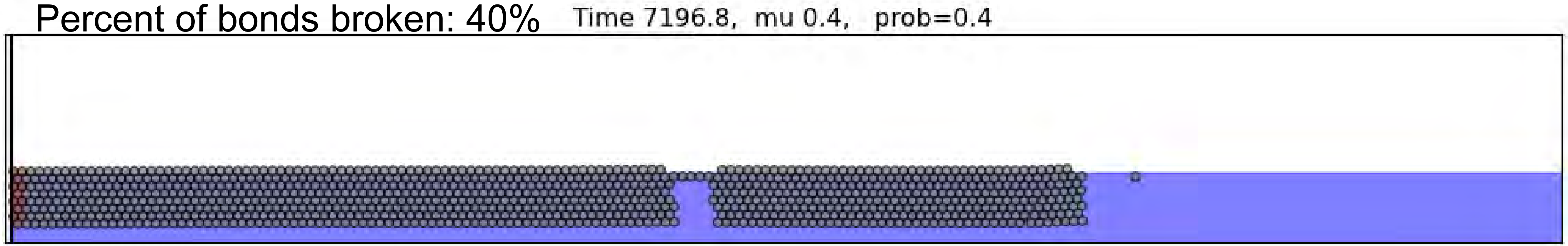
H ~ 350 m

Bond strength : 150 kPa (normal), 1 GPa (shear)

Percent of bonds broken: 0%



Percent of bonds broken: 40%



Percent of bonds broken: 60%

QuickTime™ and a
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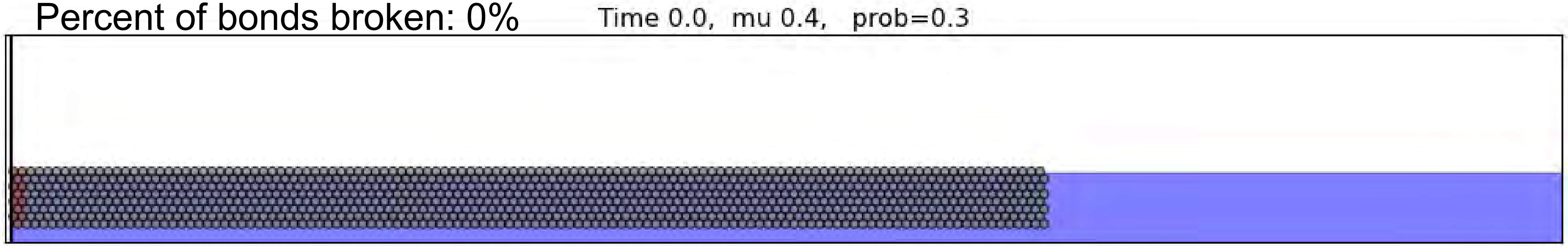
Eventually ice shelf becomes unstable and disintegrates

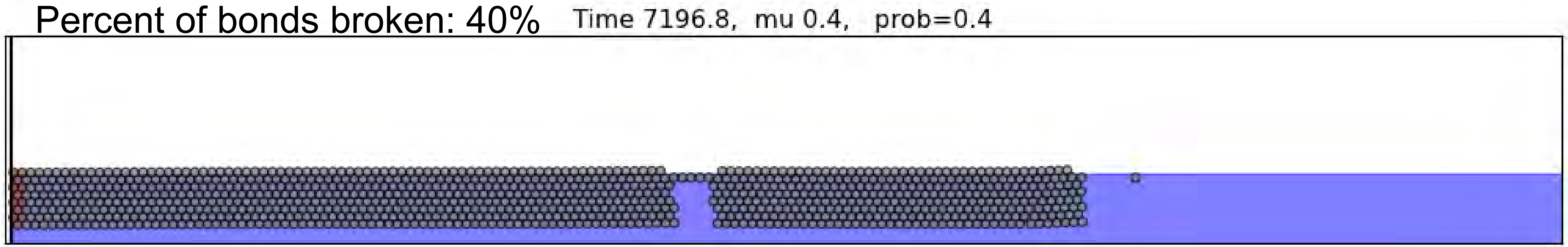
H ~ 350 m

Bond strength : 150 kPa (normal), 1 GPa (shear)

Percent of bonds broken: 0%



Percent of bonds broken: 40%



Percent of bonds broken: **80**%

QuickTime™ and a
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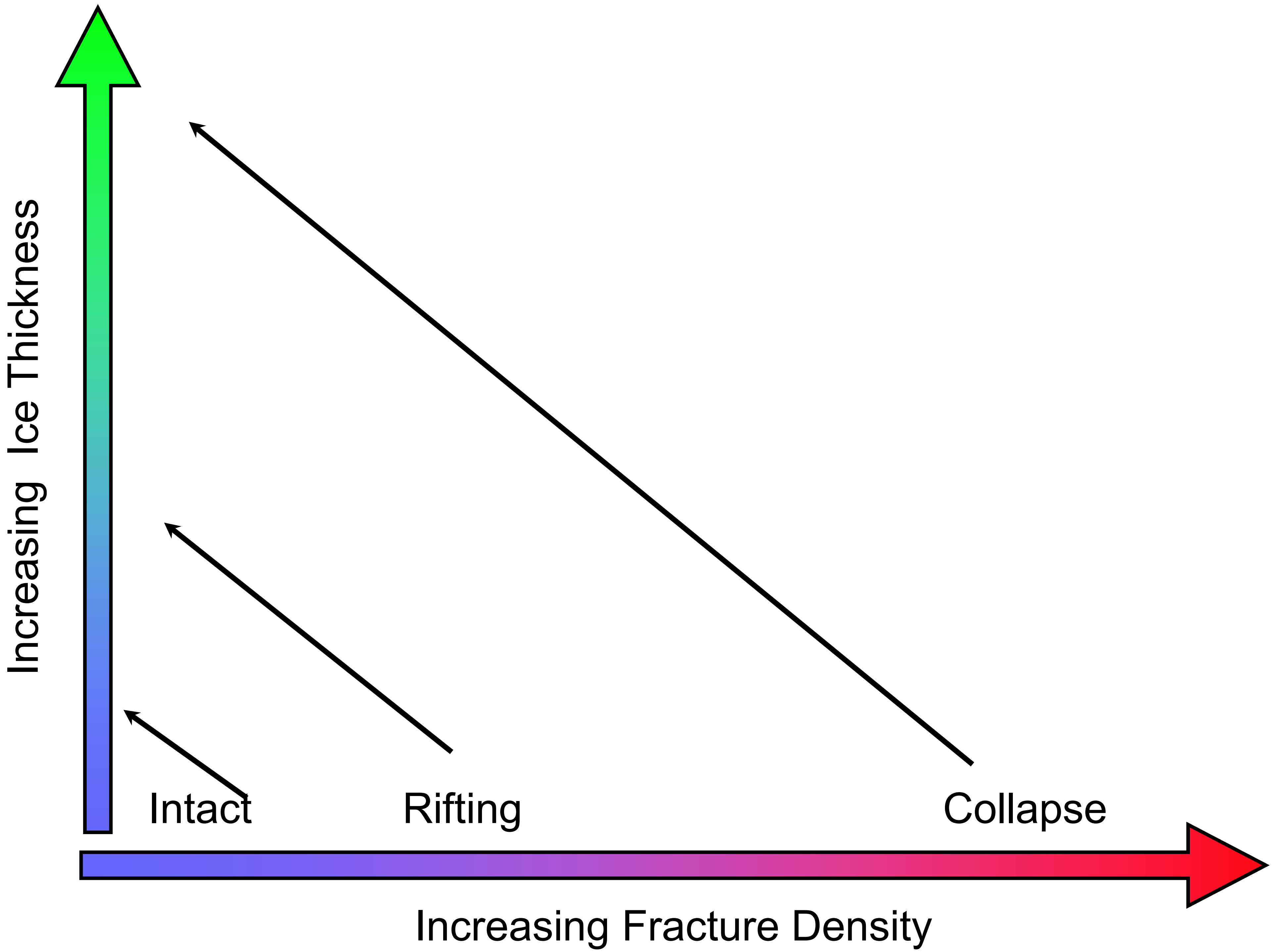
Transition to Disintegration



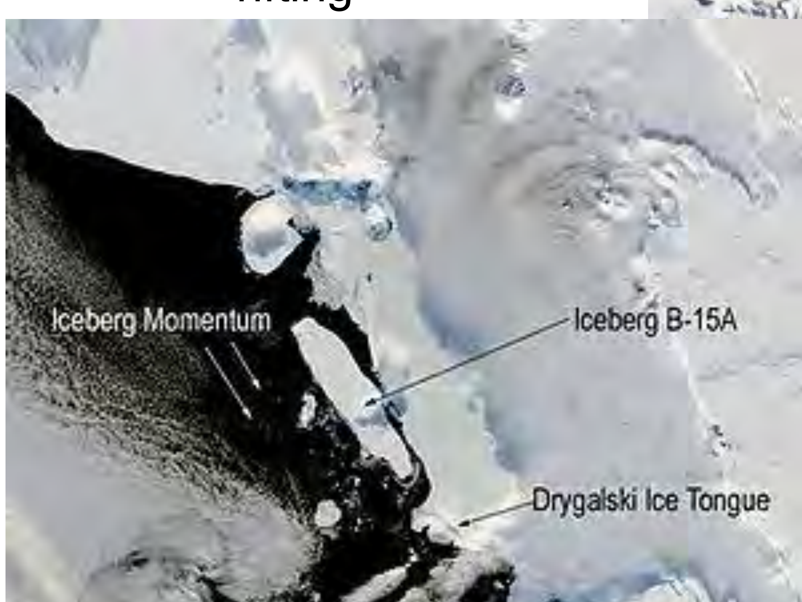
Mode of calving determined by interplay between 3 variables

1) Geometry: → *specified for a given glacier*
Ice thickness & water depth determines the stress field

2) Yield strength of ice: → *determined from laboratory measurements*
Normal and shear yield strength determines when the ice breaks

3) Density of pre-existing fractures → *provides upper and lower bounds on advance/retreat mag*
Stress history of ice, surface melt pond assisted fracturing, englacial fracture networks determines how fractured the ice near the terminus is

rifting



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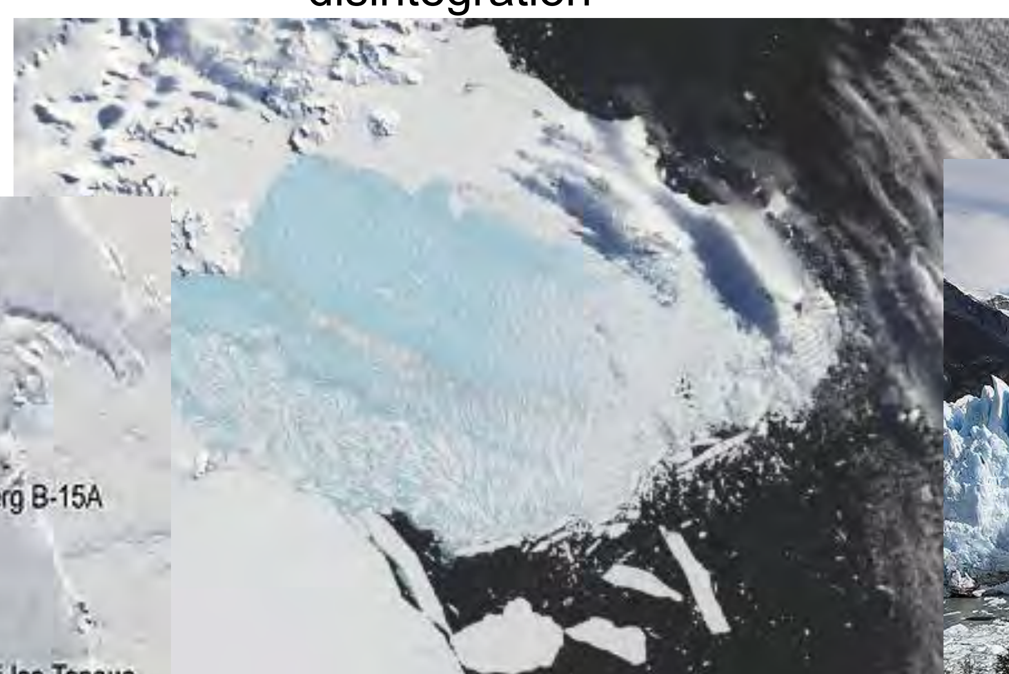

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