



Why Glass Sometimes Breaks

PV Module Reliability Workshop

NREL, Golden, CO 2010/02/19

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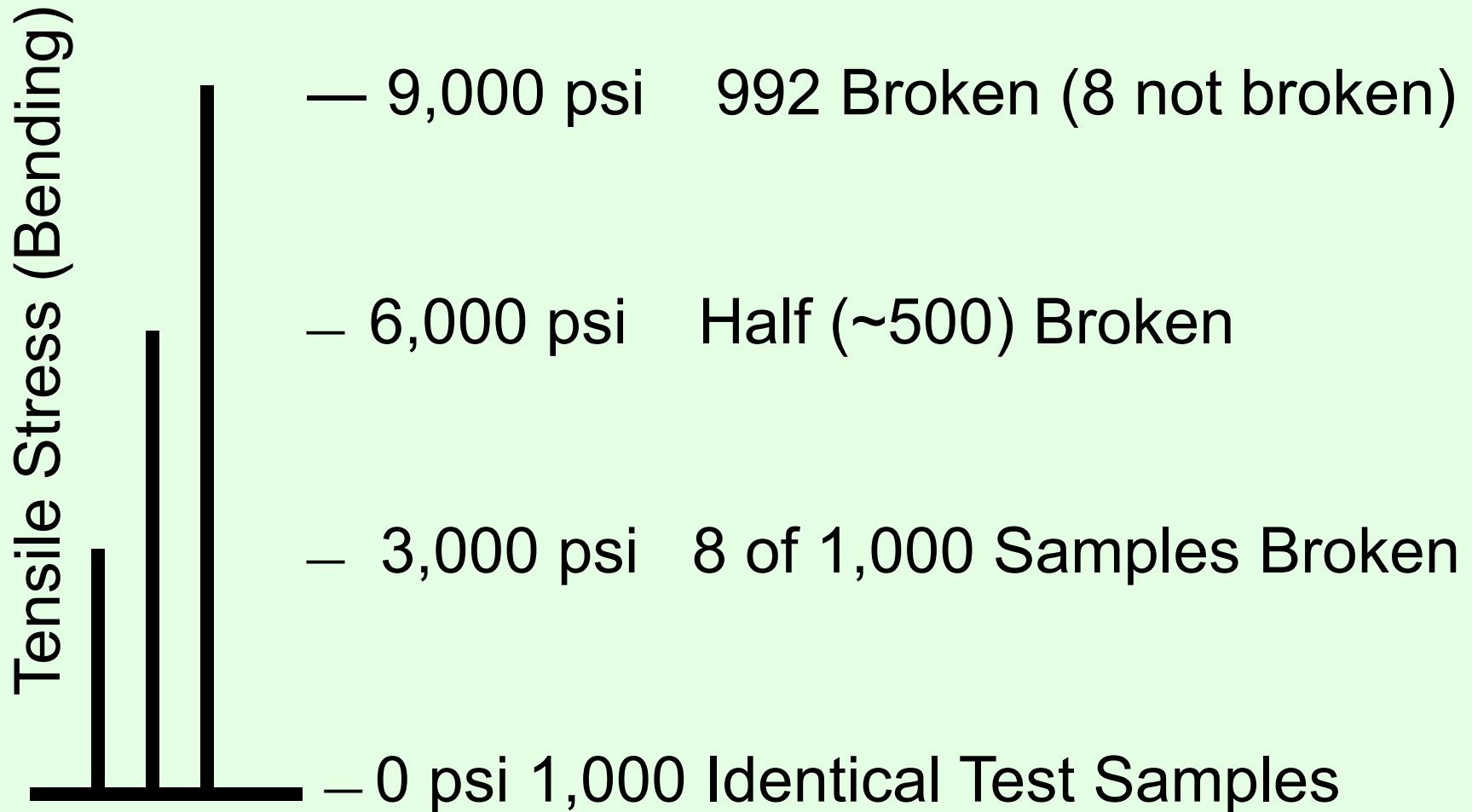
Breakage Causes

Glass breaks when an applied load exceeds the strength of the glass

The big question is:

Was the load too great, or
was the glass too weak?

How Strong is Annealed Glass?



Conclusion: Don't use glass for Rupture Disks

Glass Strength

- 1. Heat-Strengthened Glass is ~ 2 times Stronger than Annealed**
- 2. Tempered Glass is ~ 4 times Stronger than Annealed Glass**
- 3. Chemically Strengthened Glass can be > 4 times Stronger than Annealed**

How does Coating Glass Affect its Strength?

- Coating Types:

- “Soft” Vacuum Sputtered –

 - Applied post glass manufacture

 - No change to glass strength – damage already done

 - Moisture & Temperature Sensitive

- “Hard” CVD (Chemical Vapor Deposition)-

 - Applied during glass manufacture

 - Small improvement ~20% by protecting top side only

 - High temperature (650+C) resistance

 - Durable - weatherproof

 - Temperable, Bendable

Breakage Causes

1. **Tensile Stress:** 1.a. Bending
1.b. Thermal
1.c. NiS inclusion expansion in FT or HS
2. **Impact:** 2a. Hard Body – Hail Stones
2b. Soft Body – Snow Slide
3. **Crushing**
4. **Acts of God?** *God doesn't break glass – we do*
5. **Mother Nature?** *'Hurricanes Happen'*
– don't blame your mother

Finding Breakage Causes

FRACTOGRAPHICS can find the cause.

It only takes: enough time; enough money;
and having all the broken pieces near the
fracture origin

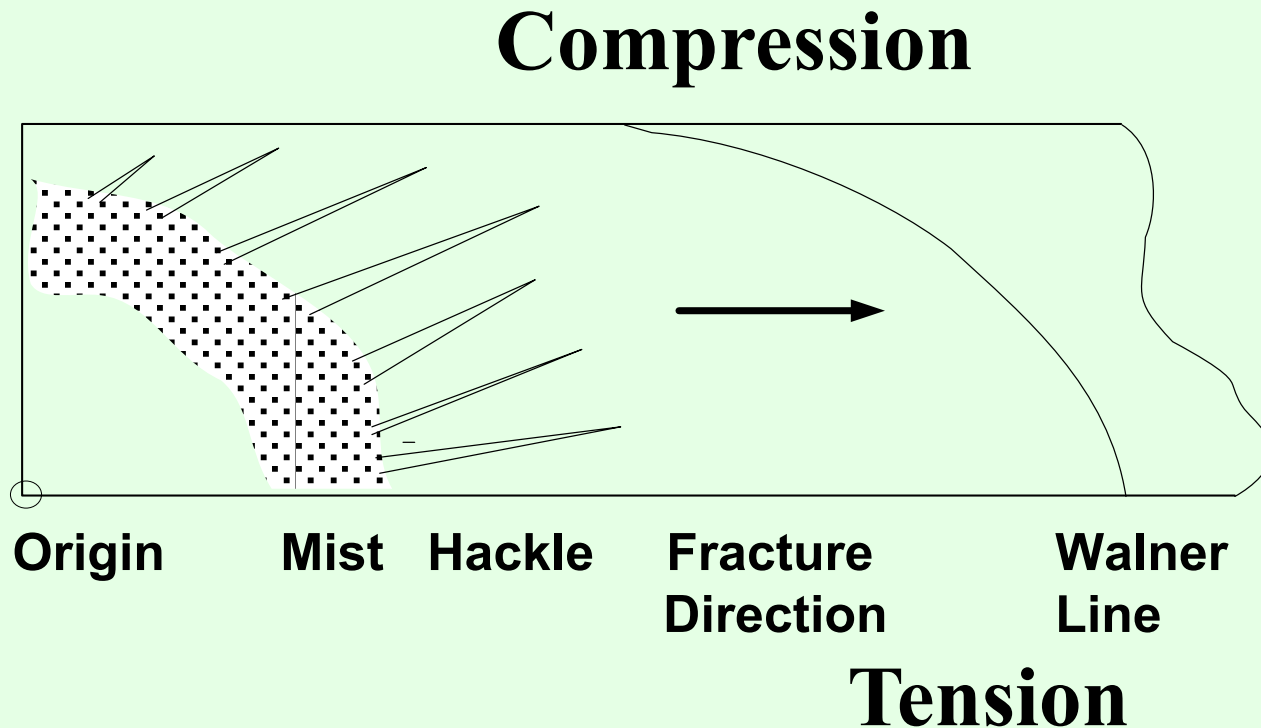
See: ASTM C1256-93 "Interpreting Glass Fracture Surface Features"

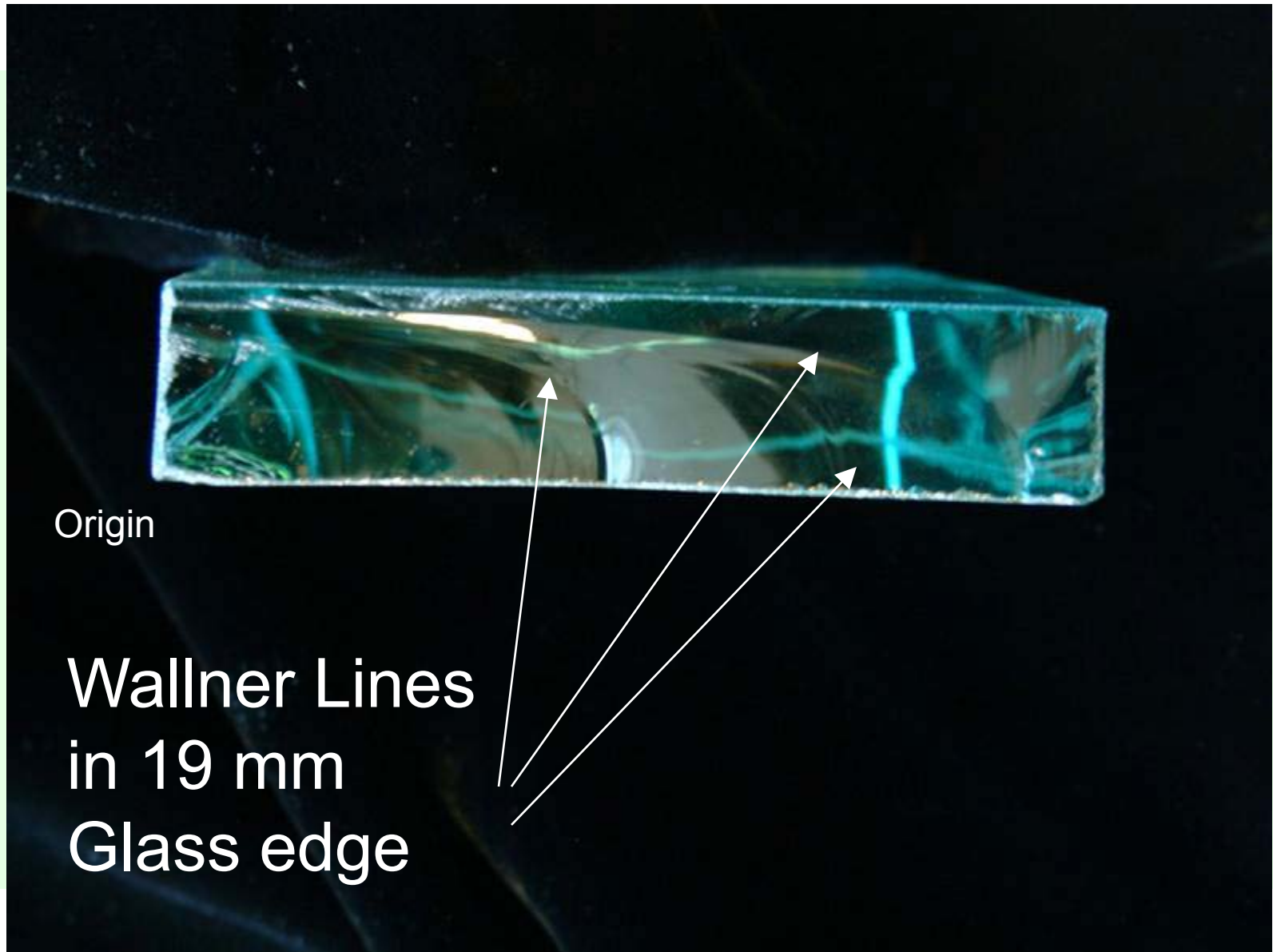
ASTM C1678-07 "Standard Practice for Fractographic Analysis"

“White Boat Rock”

Bending or Thermal Cause

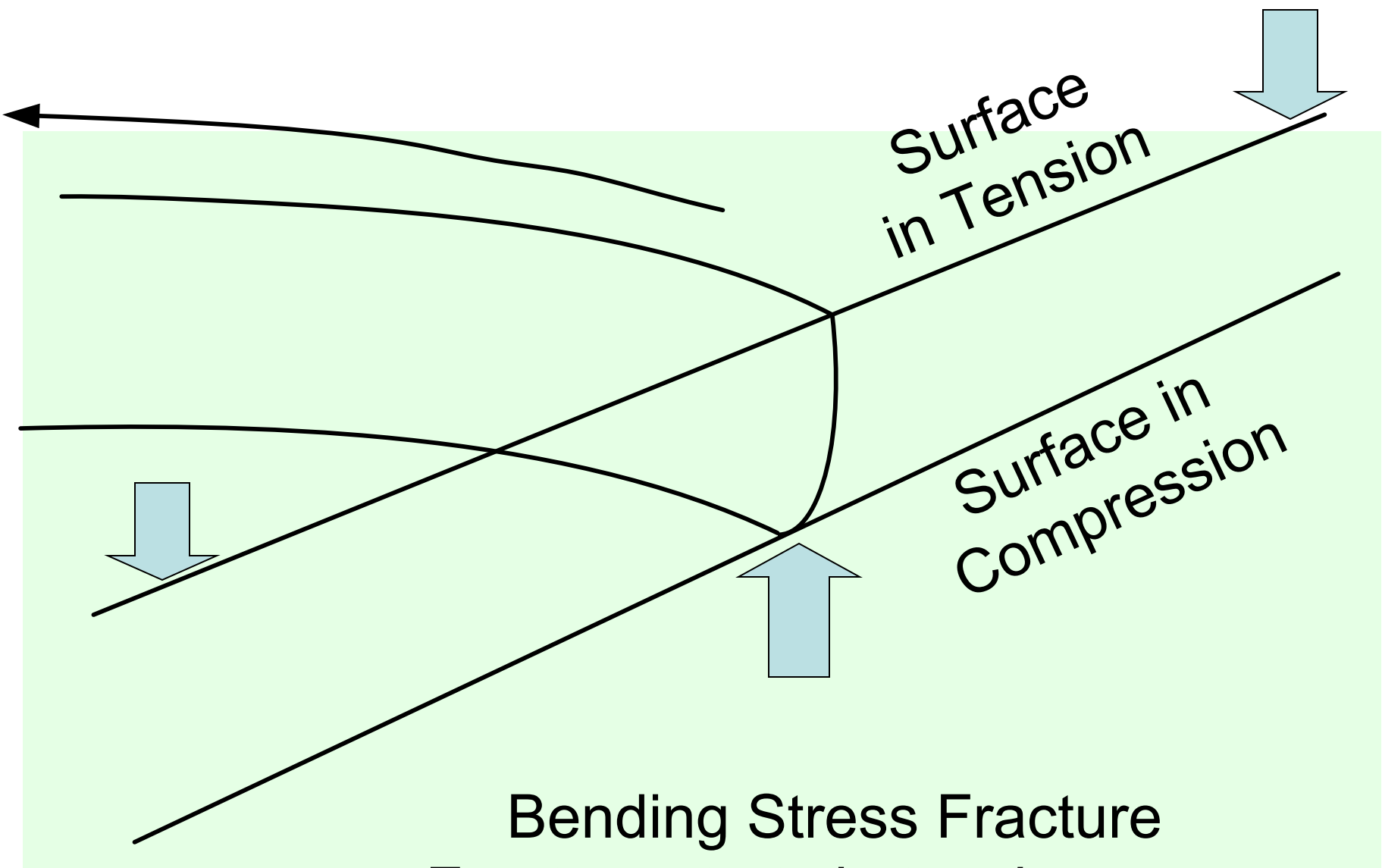
First, find the fracture origin



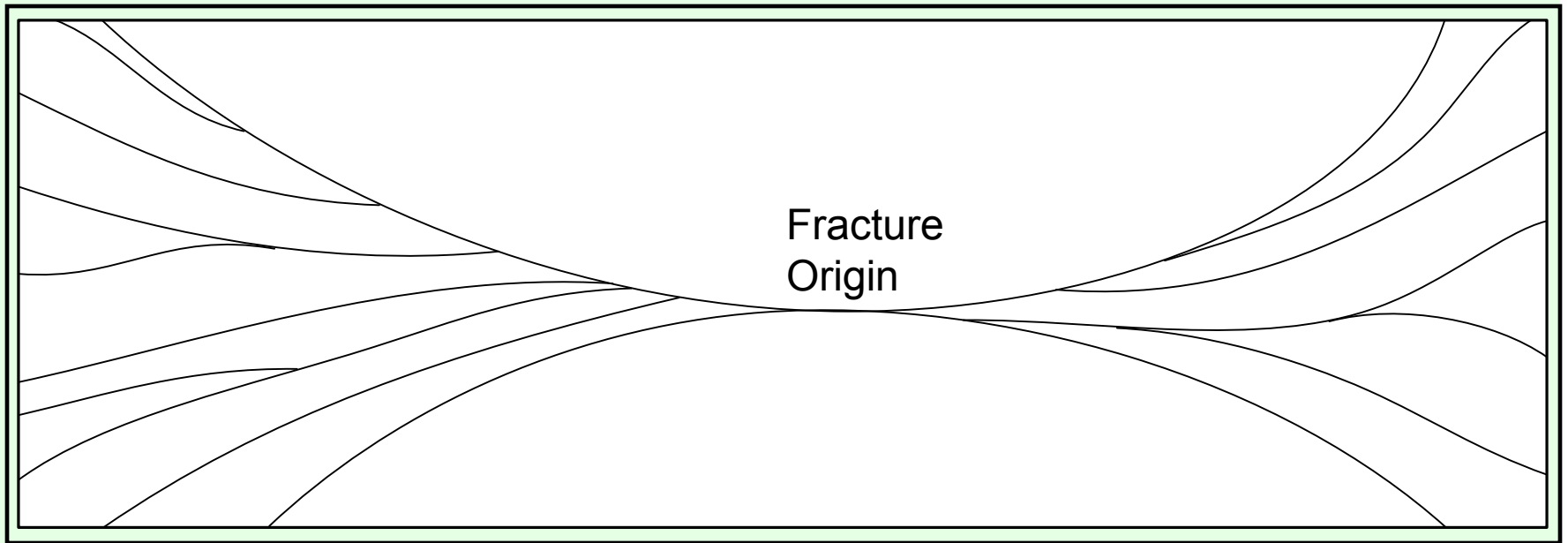


Origin

Wallner Lines
in 19 mm
Glass edge

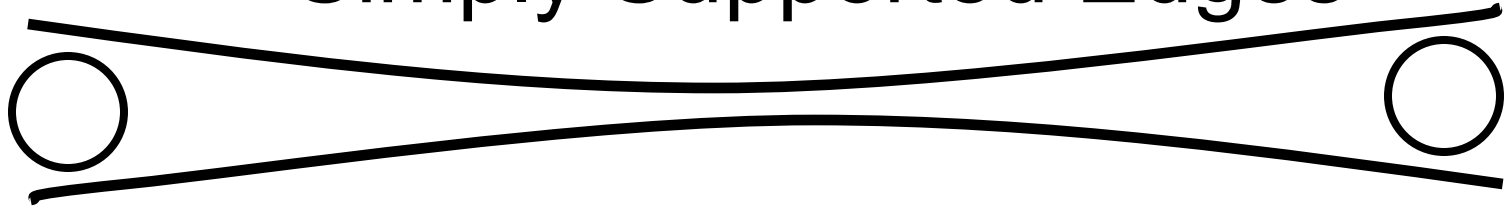


Bending Stress Fracture
Fracture starts in tension zone

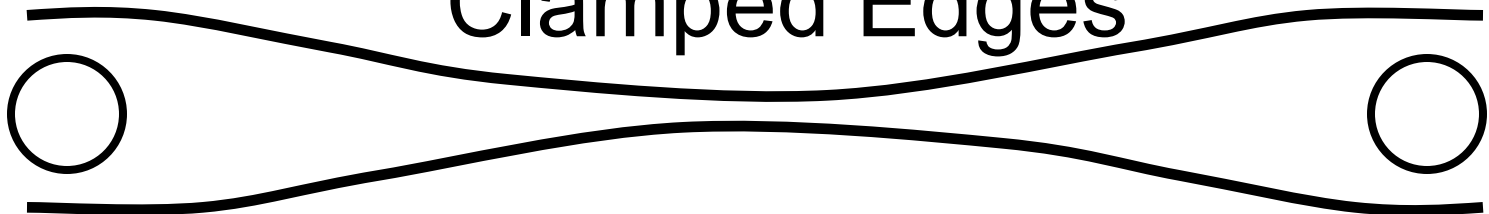


Properly glazed High Aspect Ratio Sealed Insulating Glass.
Breakage from too High or too Low air space pressure

'Saucer' shape Simply Supported Edges



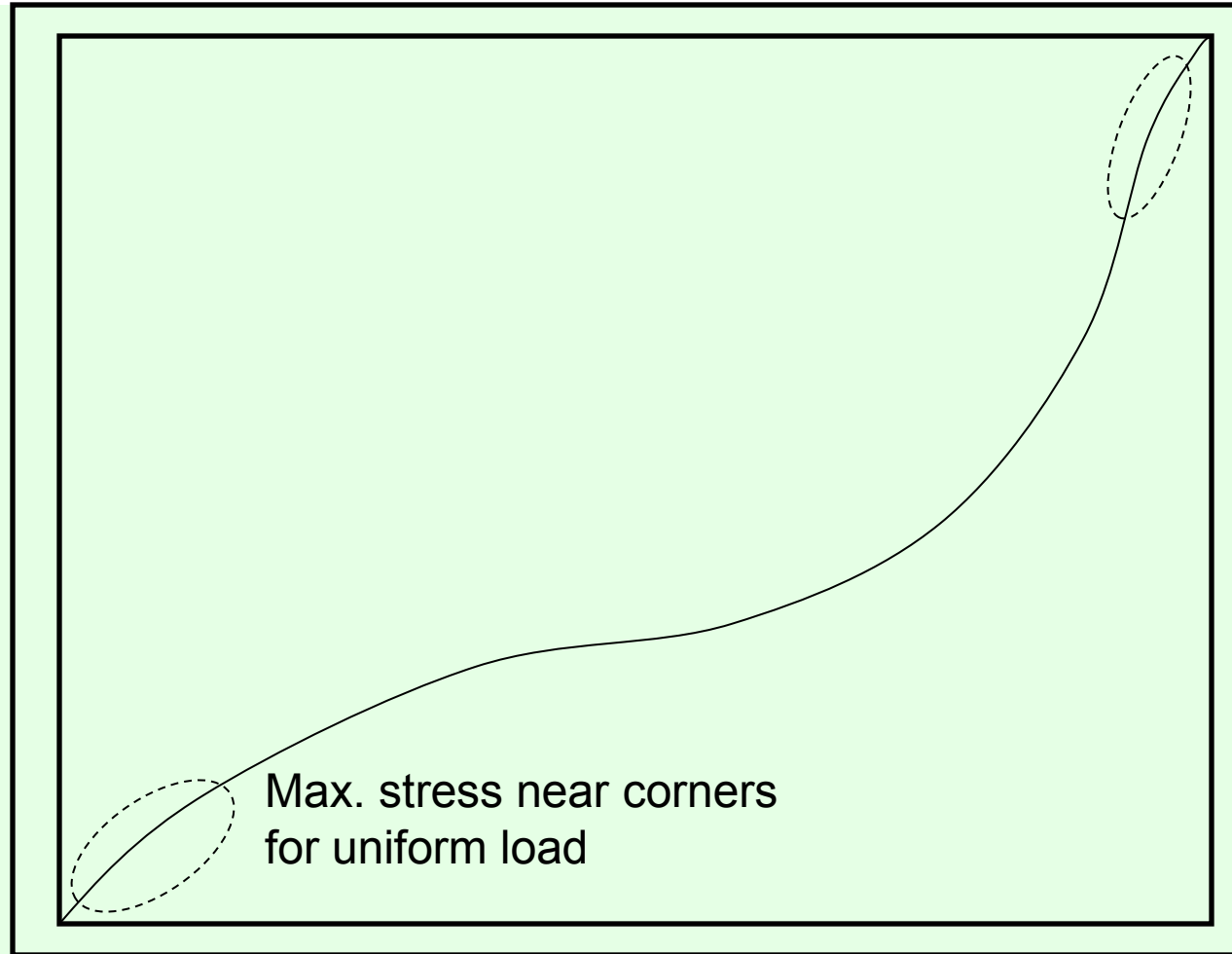
'Soup Plate' shape Clamped Edges

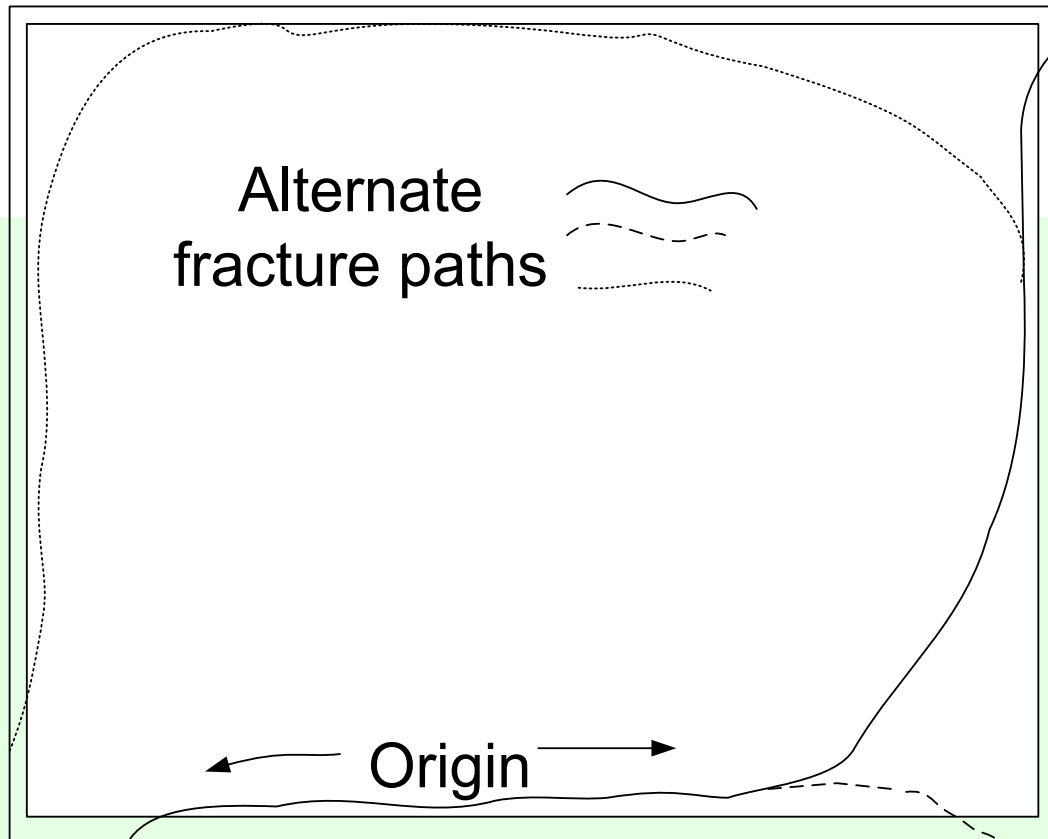


4 x stress under IG air space
 $\pm$ pressure load

Sealed Insulating Glass
Simply Supported Edges.

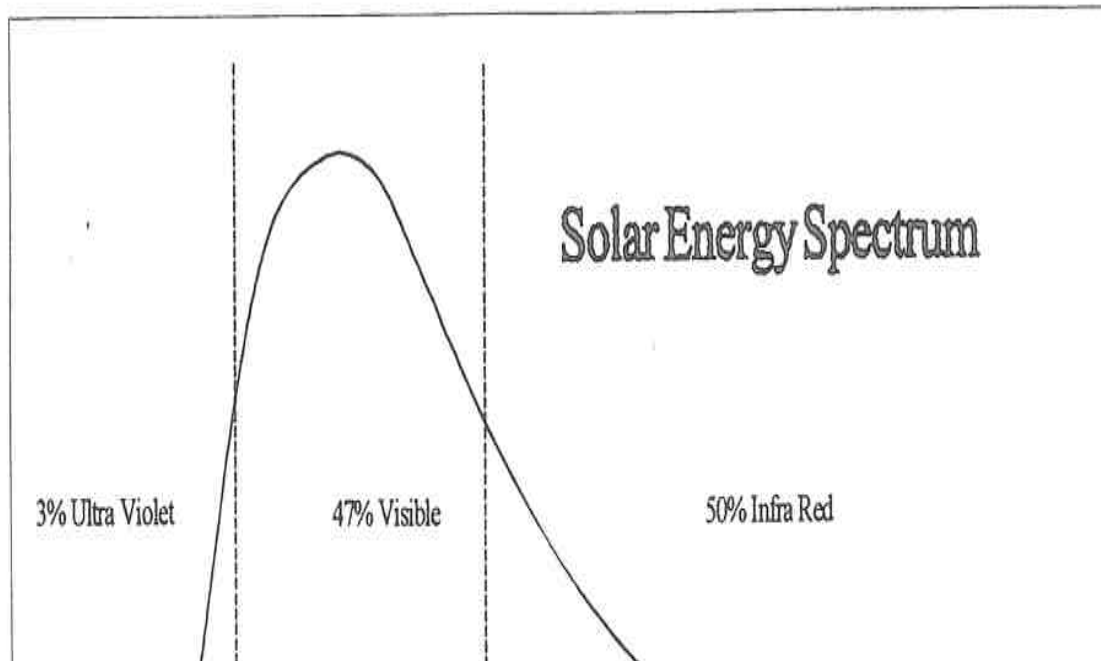
Break caused by excessive $\pm\Delta$ Pressure in sealed air space.





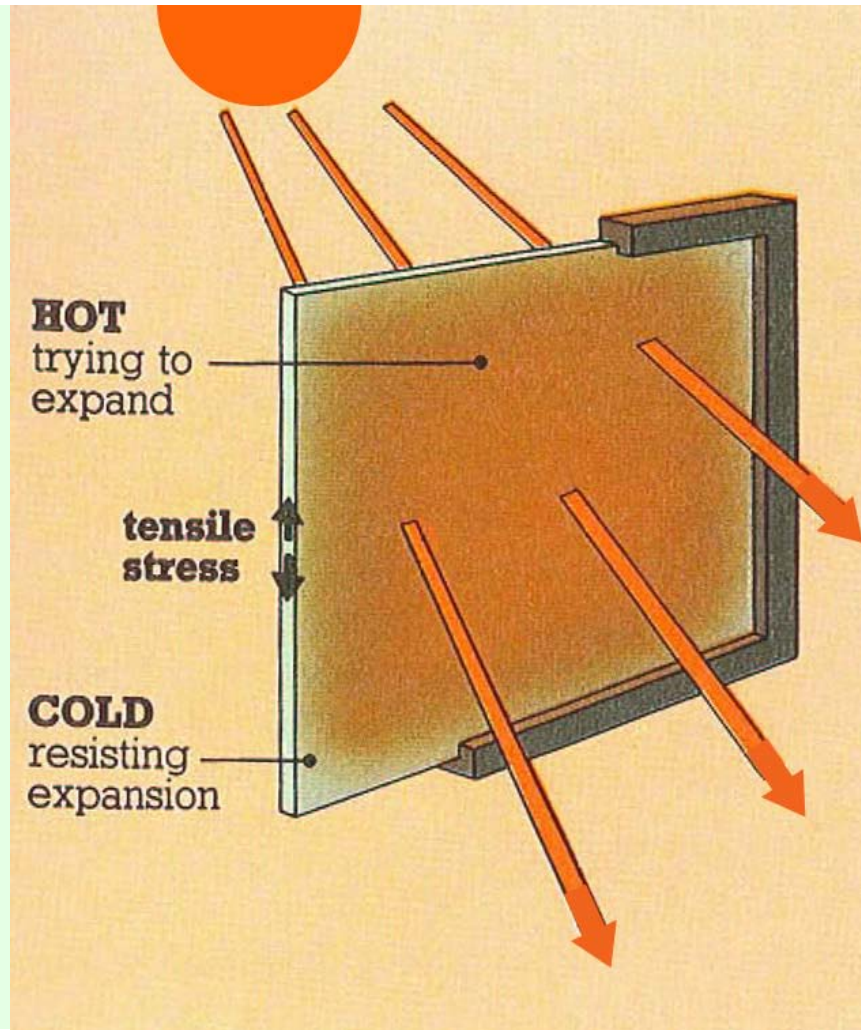
Incorrect 'Clamped Edges' create very high bending stresses at low temperatures in Insulating Glass. Fracture origin at a scratch.

Thermal Loads



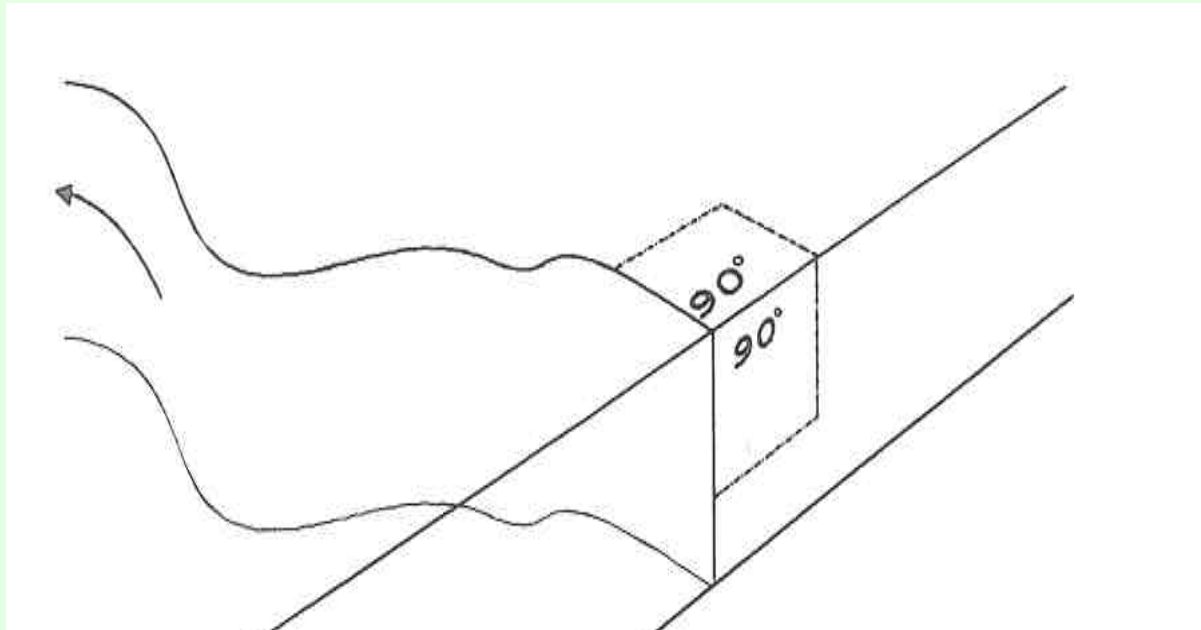
A glass or coating can appear clear yet absorb a large amount of invisible Solar IR energy and so incur significant stress

Thermal Stress Generation



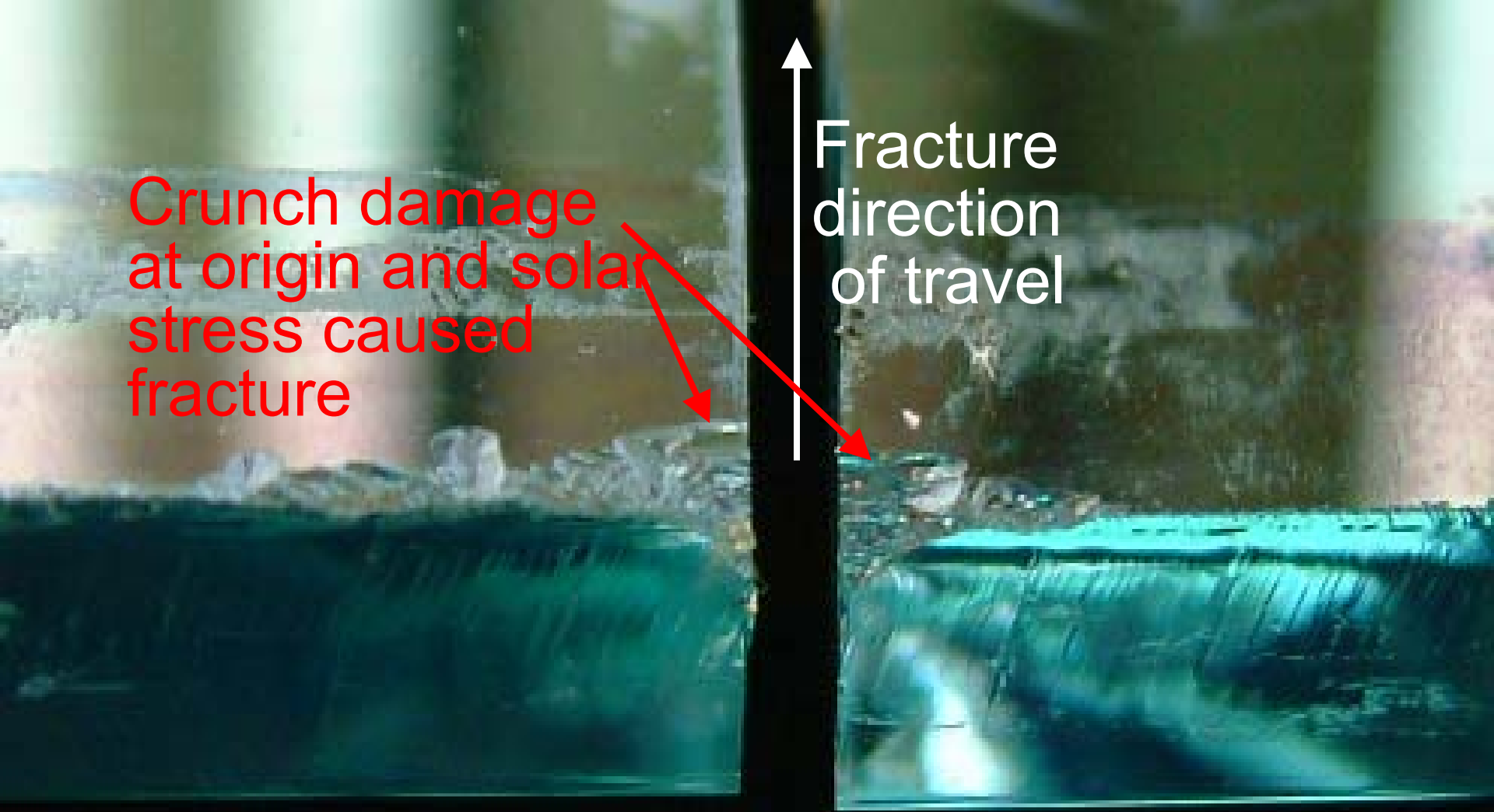


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Classic Thermal Stress fracture origin.

Break typically starts in the central $\frac{3}{4}$ of the edge length and not at a corner.

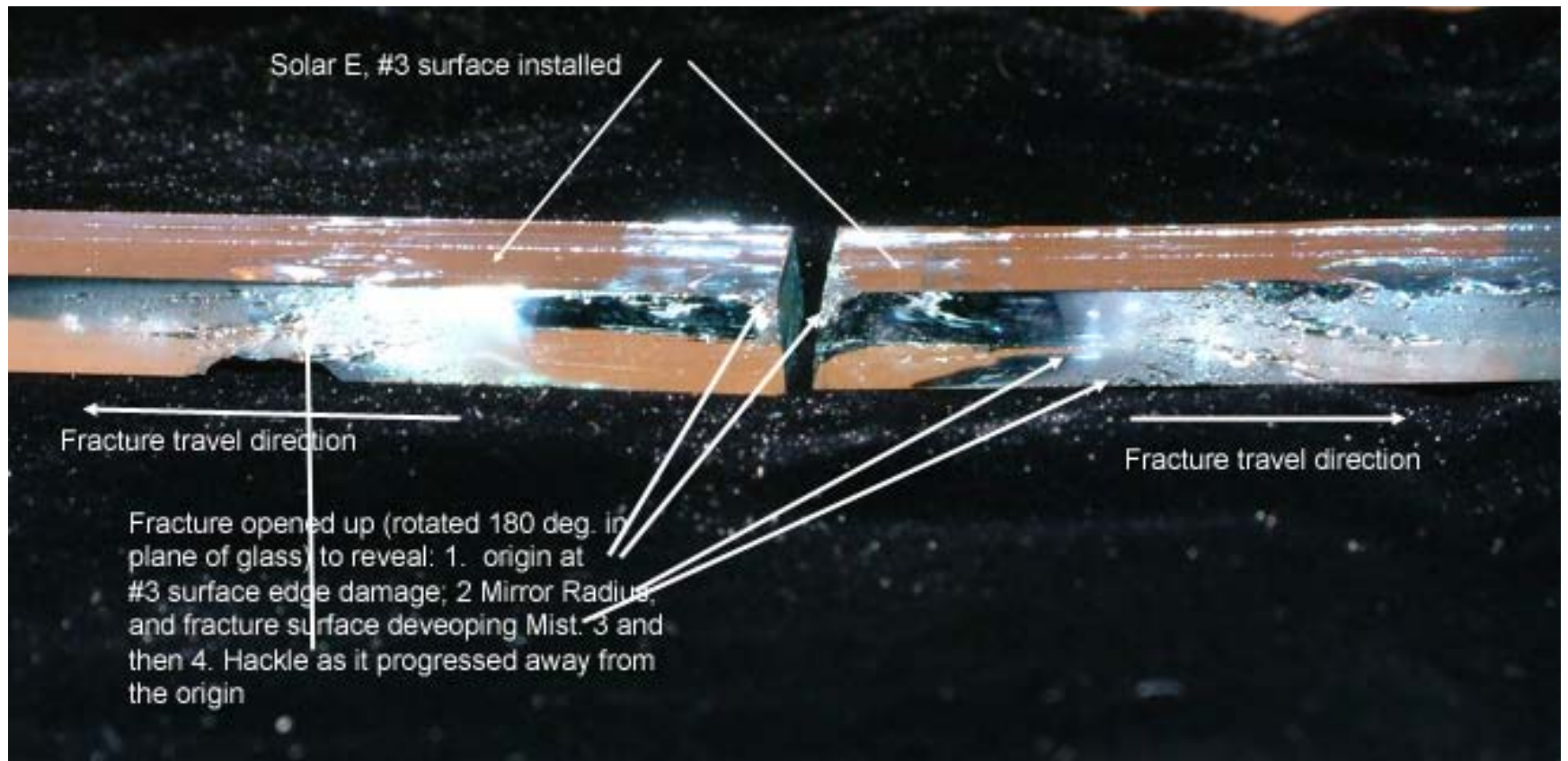


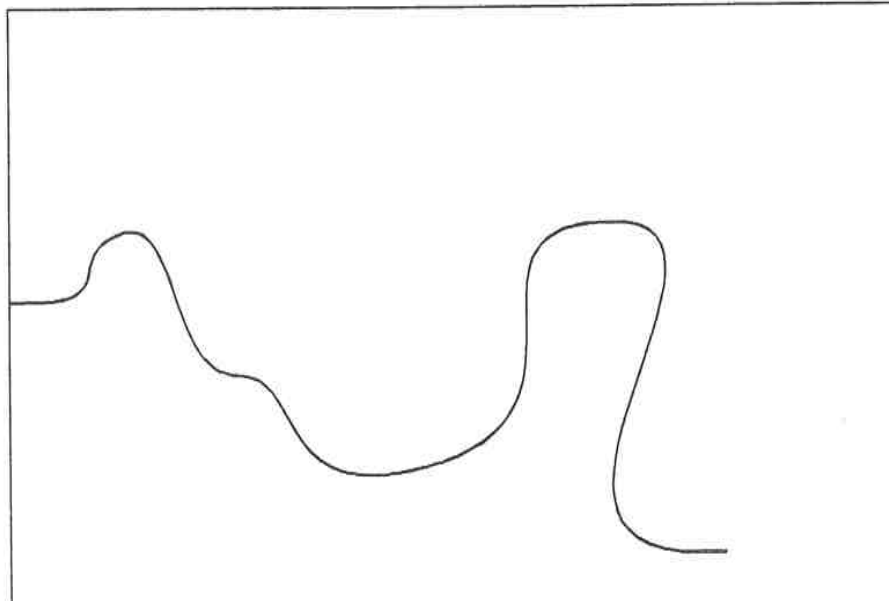
Crunch damage
at origin and solar
stress caused
fracture

Fracture
direction
of travel

Cut edge – poor quality

Solar E (solar absorbing Low E coating) incorrectly used on #3 Surface (should be #2).
Energy Advantage Low E can be correctly used on either #2 or #3 Surface

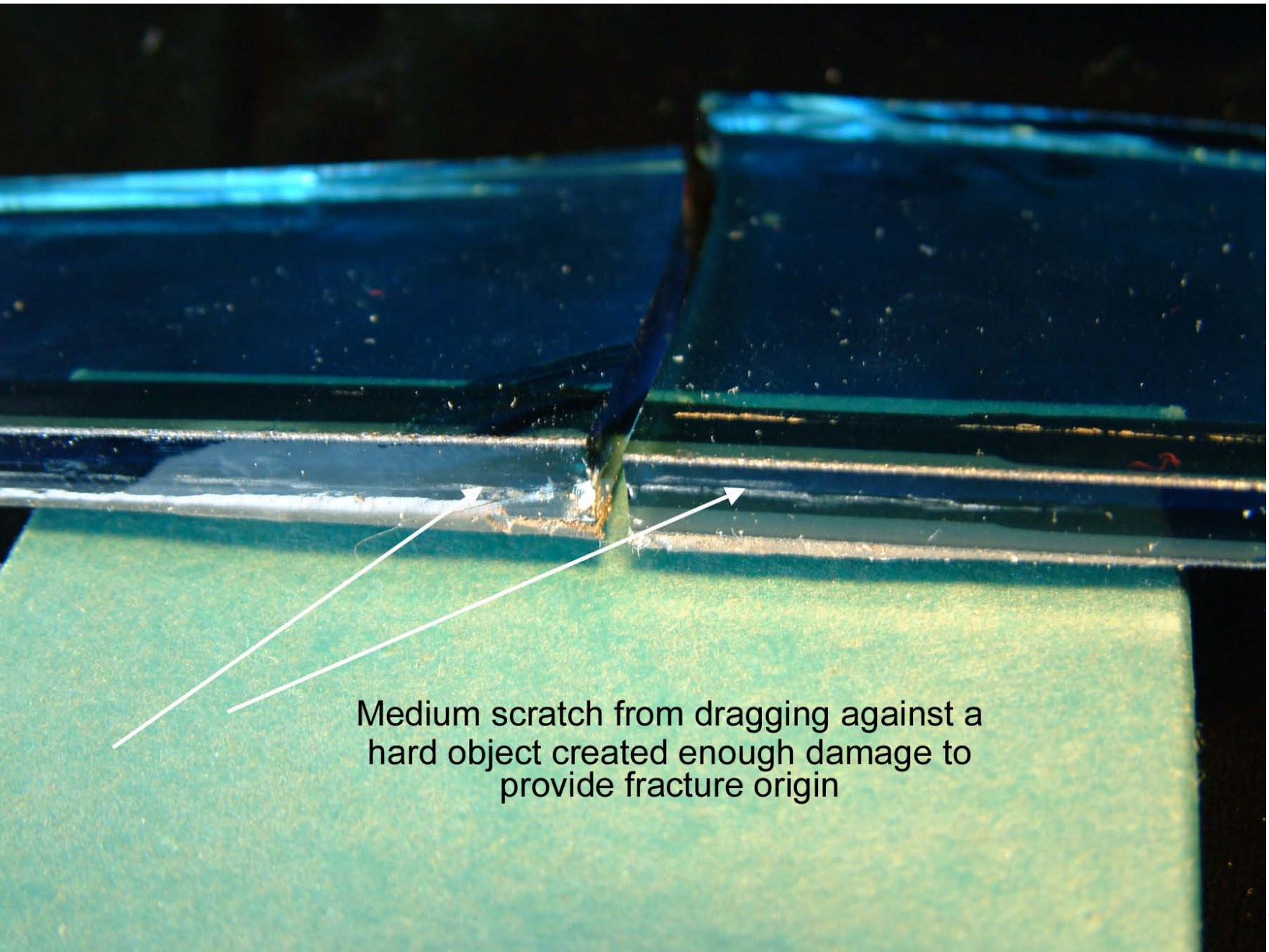




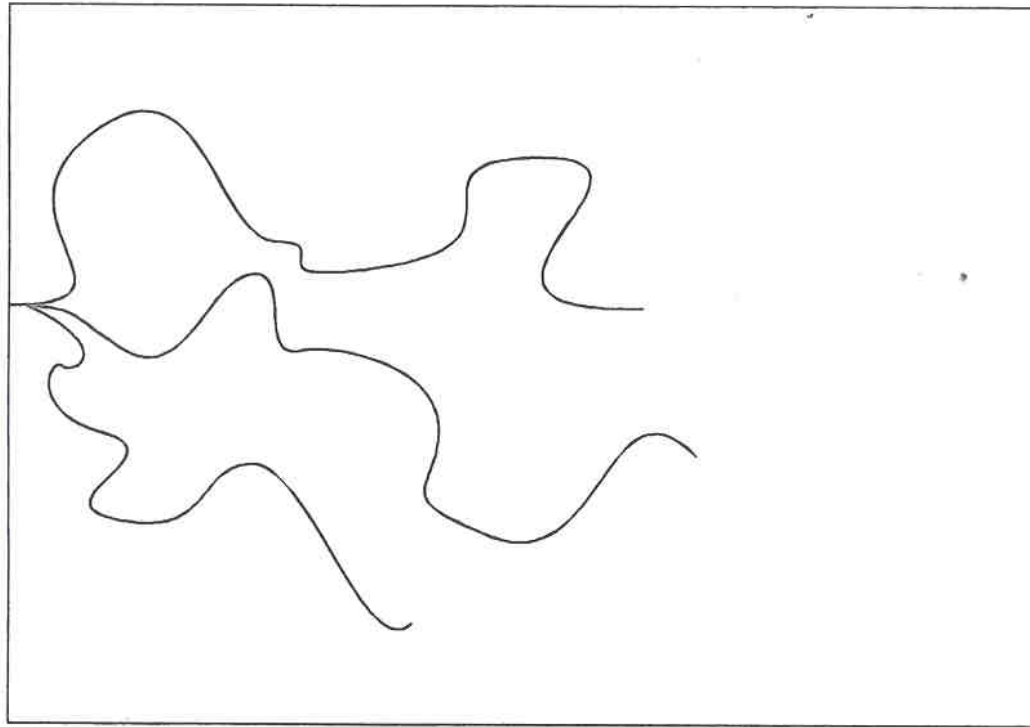
Low Stress: Single crack suggests a weaker glass edge. Less energy was needed to propagate the crack







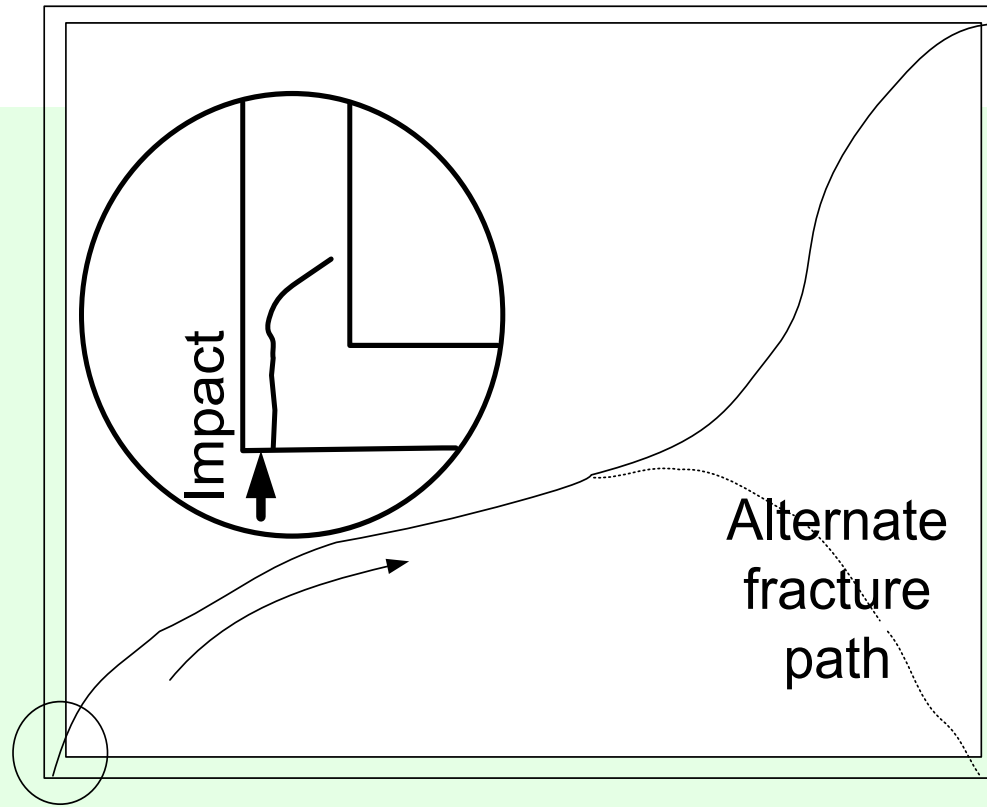
Medium scratch from dragging against a hard object created enough damage to provide fracture origin



High Stress: Multiple crack surfaces were needed to absorb excessive energy.

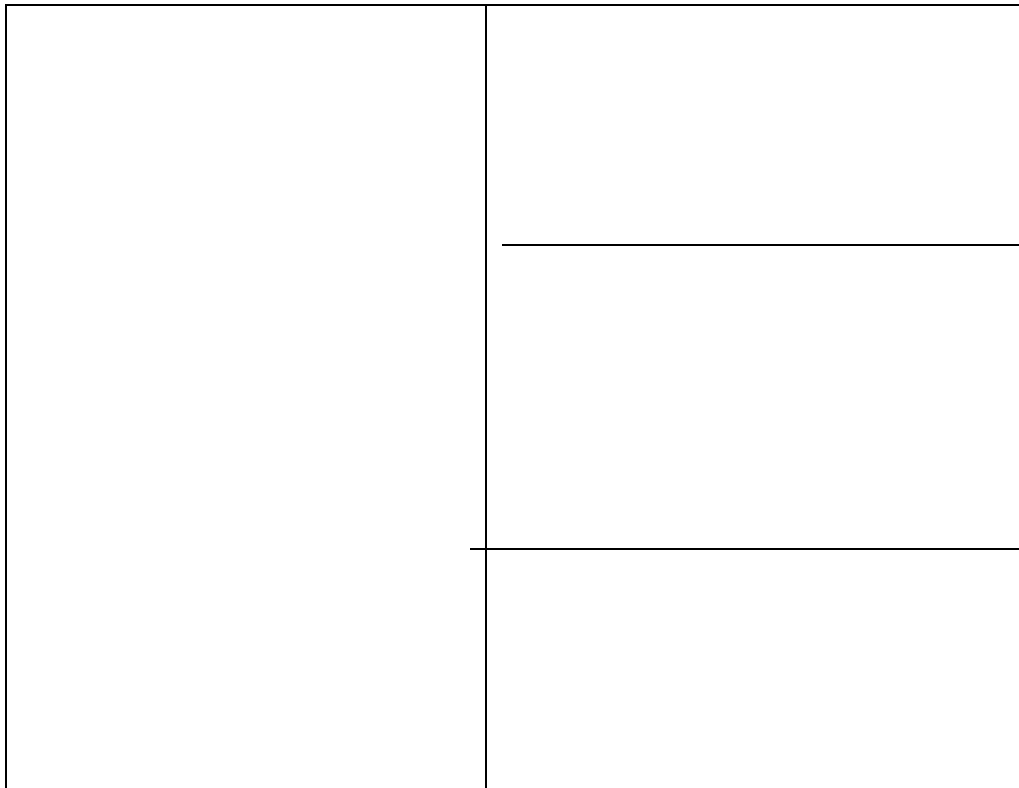






A corner impact easily creates a 10 or 20 mm long crack which waits for a high stress situation to make it run. Here low winter temperature contracts the sealed air space and creates a large bending stress.

Over-running Interrupted Cut Score Line



Weld Splatter Damage



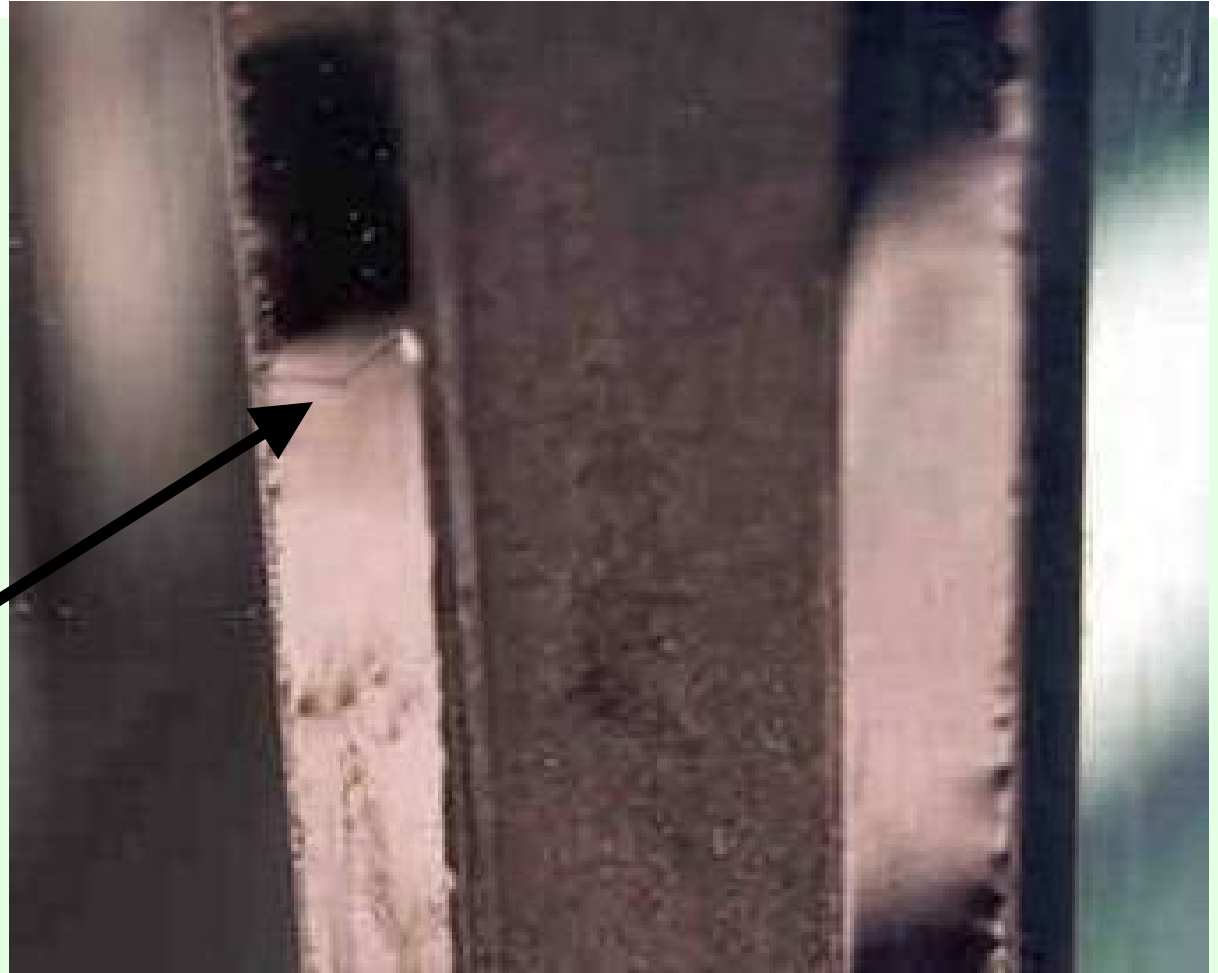
Insufficient sealant
in IG gun head
made rub marks
causing many
vents of sub-
millimeter size in
glass cut edge



6 mm

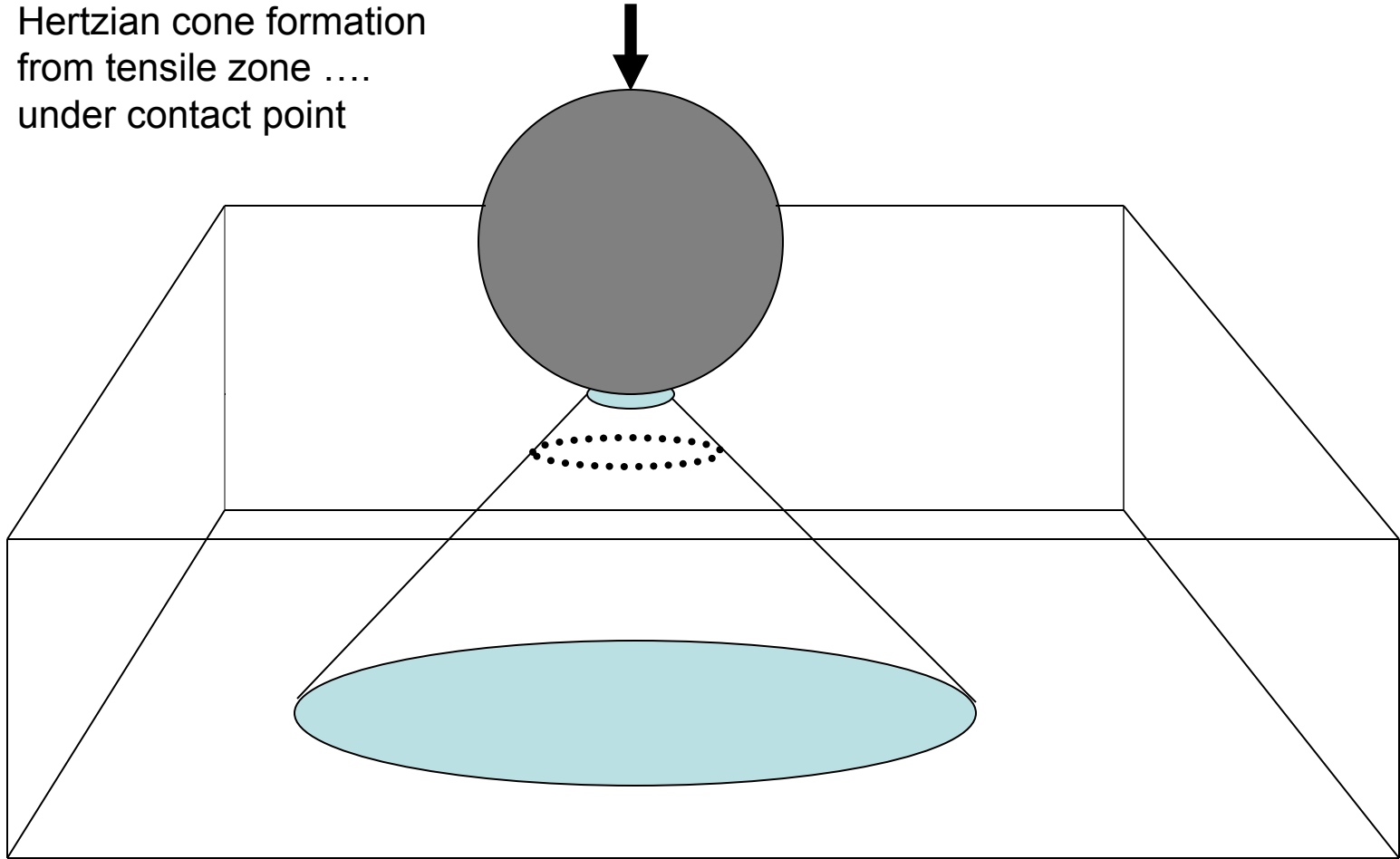
Fracture

Origin at rub mark on IG cut edge. Thermal stress caused the small vent to run



Impact Cause

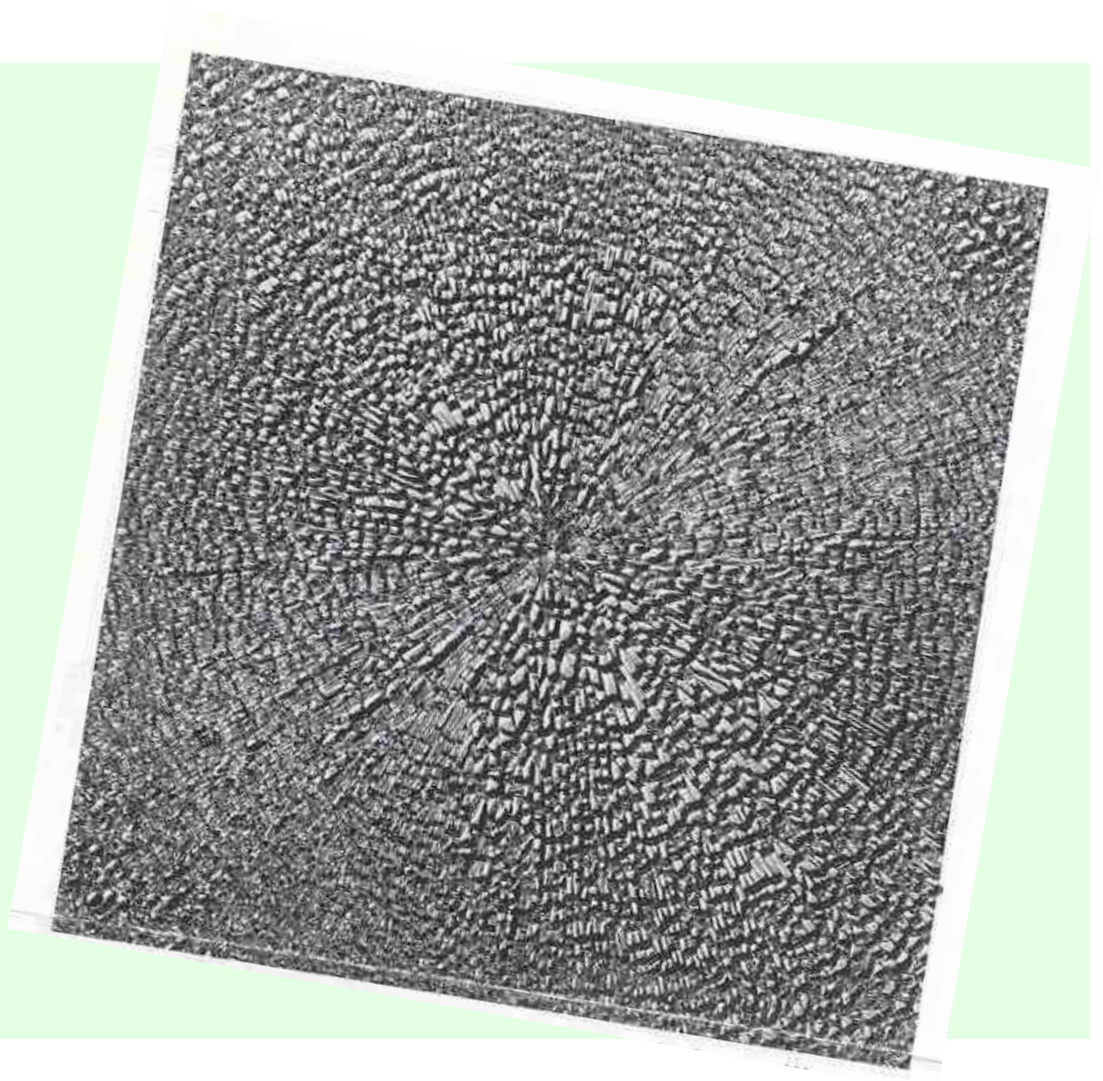
Hertzian cone formation
from tensile zone
under contact point



Tempered Glass

Fracture origin at
plate center

Look for surface
damage or very
small inclusion in
glass at origin









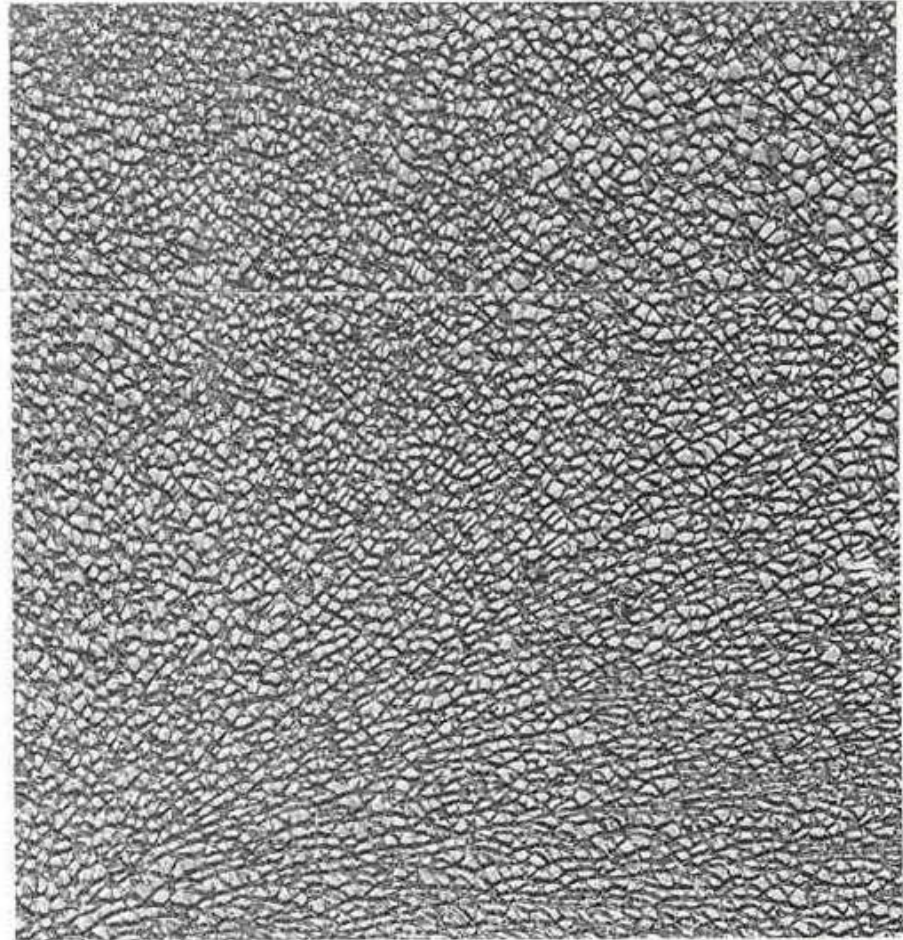
TEMPERED GLASS

– On rare occasions, heat-treated (tempered and sometimes even heat-strengthened) glass can break spontaneously, without any applied load, due to small inclusions that may be present in all float glasses.

Tempered Glass

Corner origin of fracture.

Look for corner-crunch damage



Wind Loads

Wind Loads used to be 60 second duration gusts.

Now the building codes use 3 second duration gusts.

3 second gusts are greater than those of 60 sec.

But Glass is stronger when the load duration is shorter so there was little change when the codes changed.

Other Considerations

1. Condensation Damage

Soda-Lime window glass can be corroded by alkalis. Small amounts of water (dew?) leach sodium making an alkali solution which attacks the silicate structure. See drinking glasses washed too often in domestic dish washers.

Other Considerations

2. Solarization

Some glass compositions show slight yellowing when exposed to strong UV light for extended periods of time.

Summary

Will my glass break?

Nobody knows for sure. You can't tell how strong it is, until it was.

Design glass not to break (low probability), but if it does, the consequences must be acceptable.

What to Do

Was the load too great?

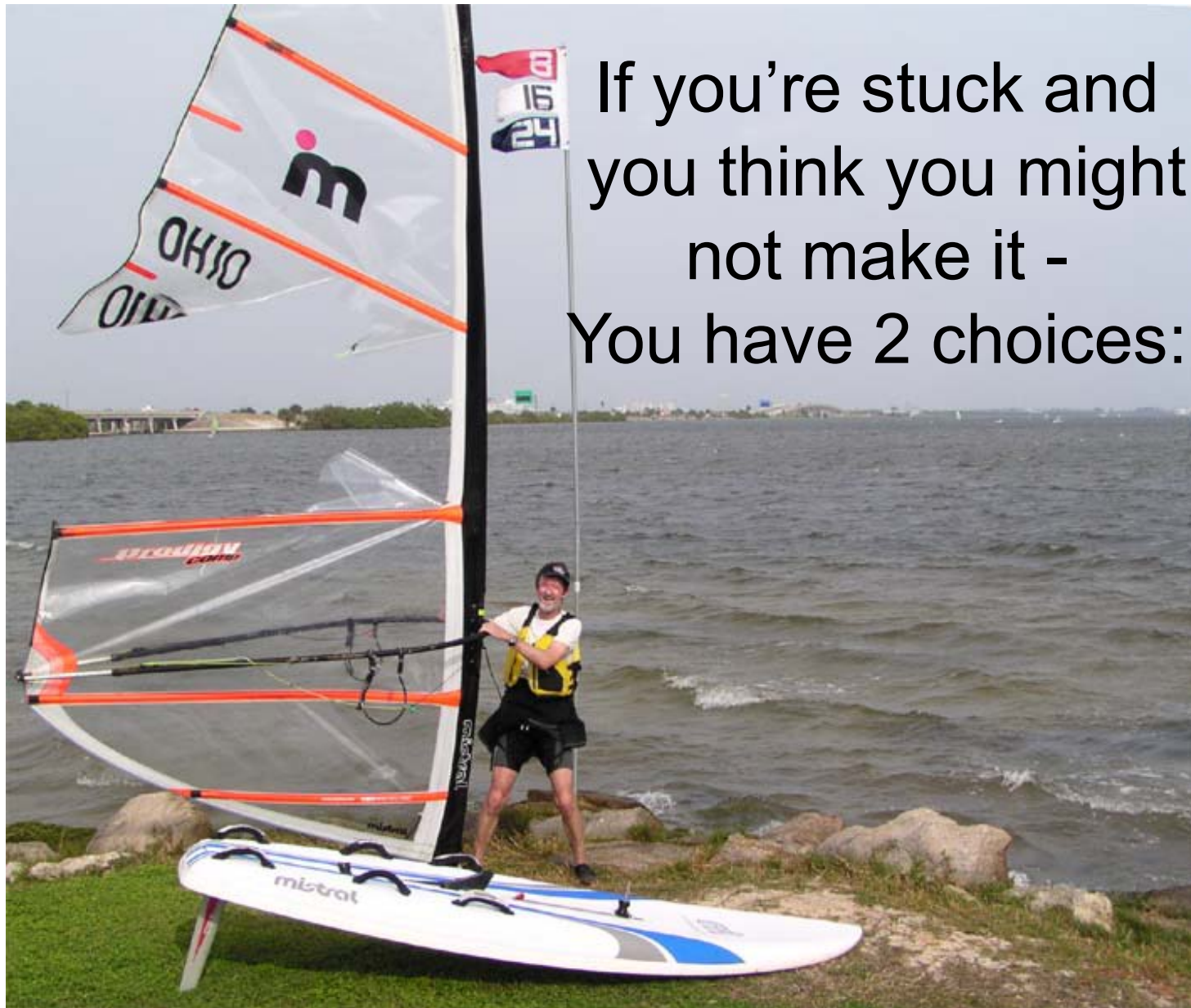
Reduce the load or stress

or

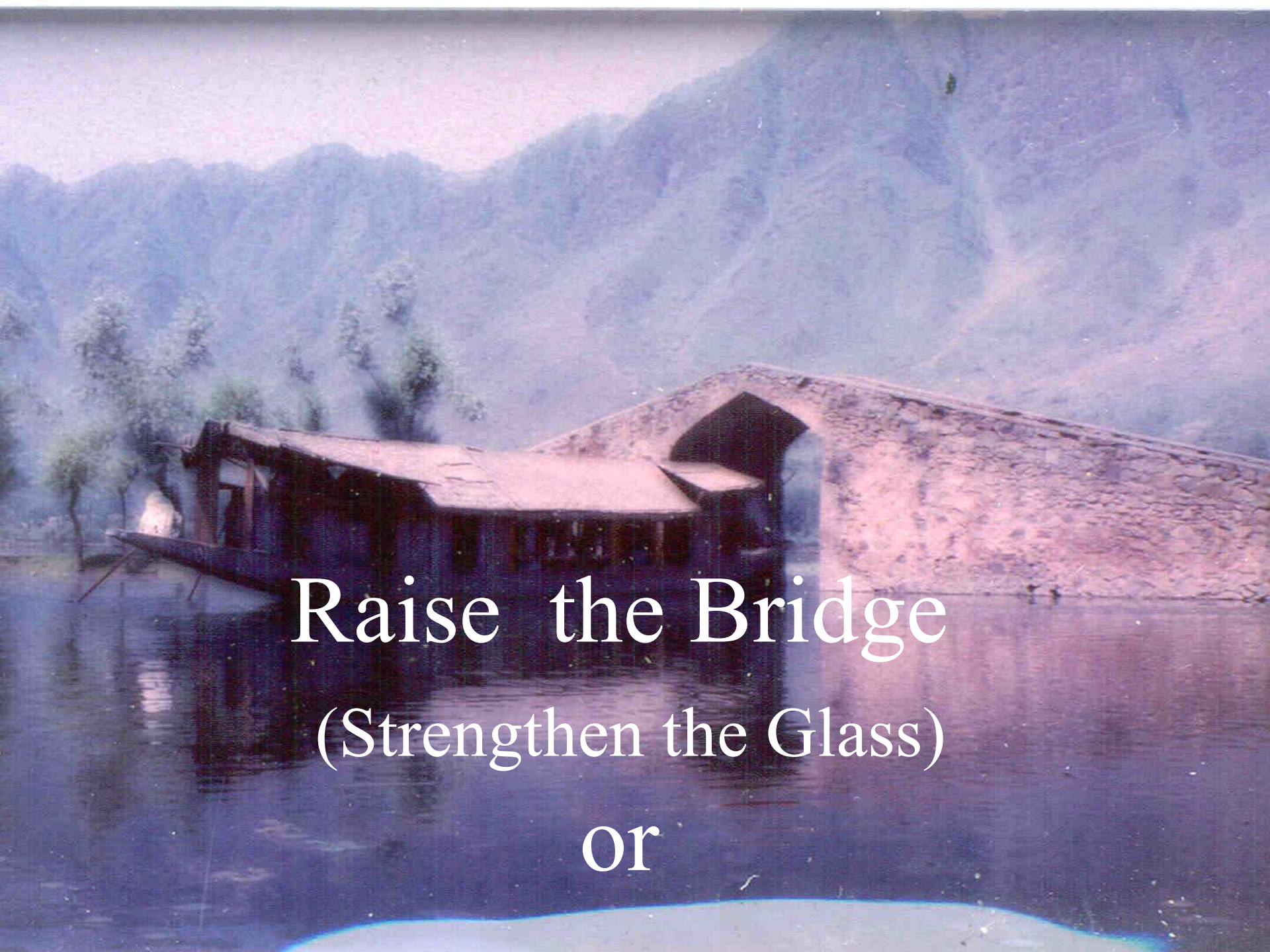
Was the glass too weak?

Strengthen the glass





If you're stuck and
you think you might
not make it -
You have 2 choices:

A painting of a stone bridge over a river. The bridge has a large archway and a smaller structure on the left. The background shows mountains and trees. The text is overlaid on the painting.

Raise the Bridge
(Strengthen the Glass)
or

Lower the River (Reduce the Load)

