

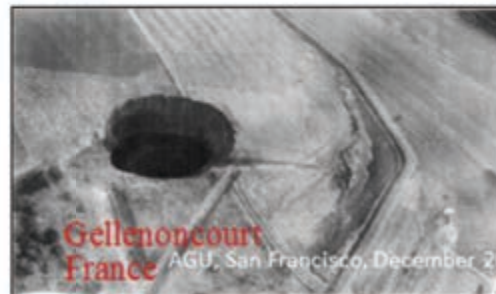
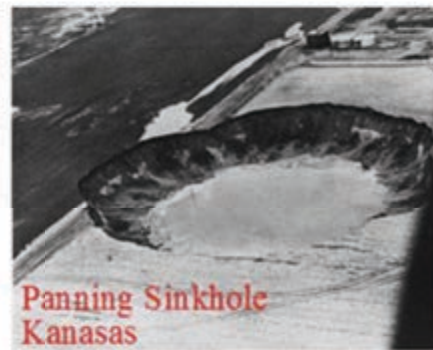


# CRATERS ABOVE SALT CAVERNS

Pierre Bérest, Ecole Polytechnique, France

# WORLD SALT SYMPOSIUM

June 19-21, 2018 Park City UT, USA





# 1

## Cratering above salt caverns: “Piston” versus “Hour-glass”



## “THE ORIGINAL SIN”

NO ROOF IS LEFT AT CAVERN TOP,  
ALLOWING DIRECT CONTACT BETWEEN  
CAVERN BRINE AND OVERBURDEN LAYERS



“STOPING”

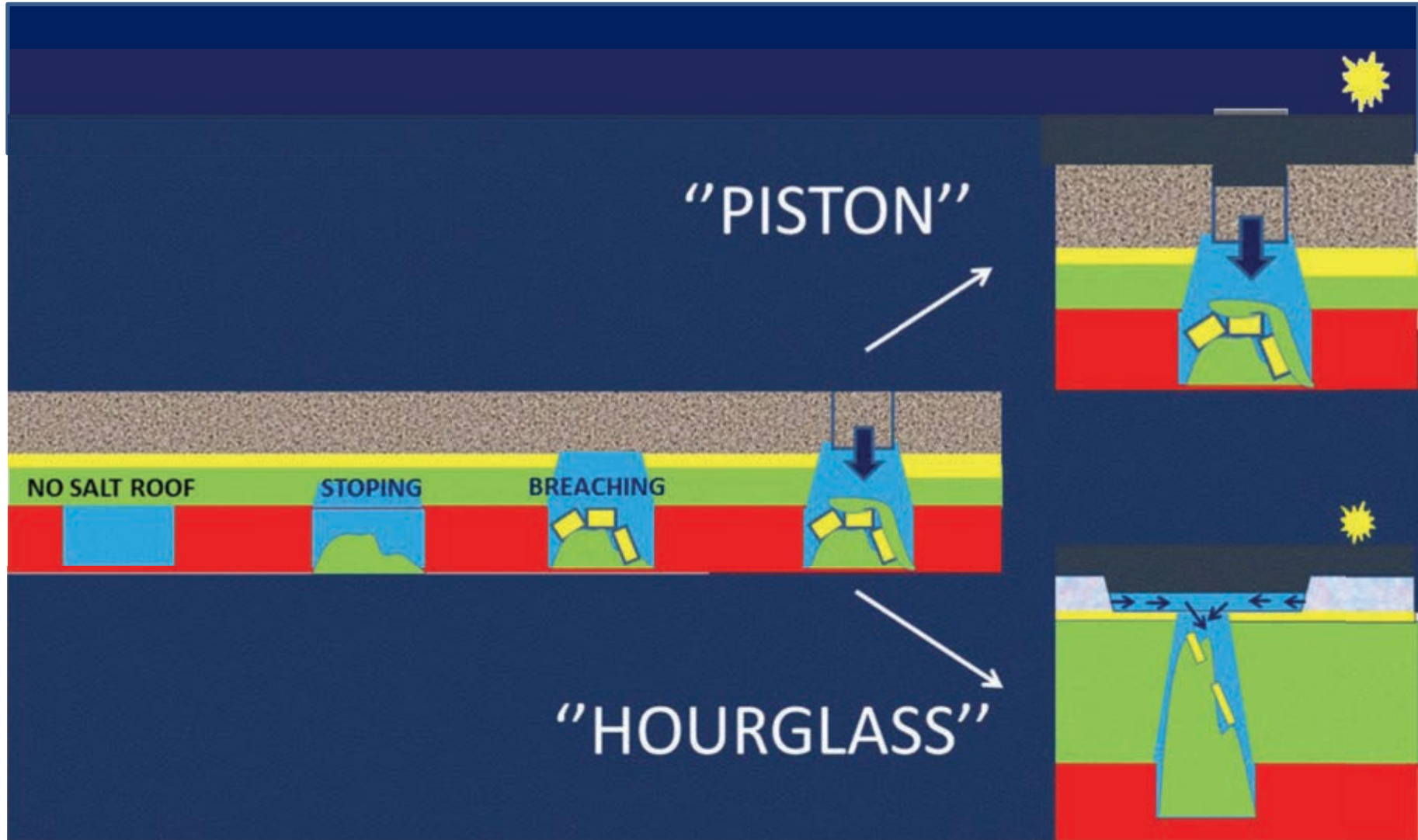
CLAYEY ROCKS IN THE OVERBURDEN  
ARE PRONE TO WEATHERING WHEN IN CONTACT WITH BRINE  
CAVERN ROOF RISES ,  
A CHEMICAL/MECHANICAL PROCESS WHICH CAN BE YEARS OR  
DOZENS OF YEARS LONG





“BREACHING”

CAVERN ROOF BREACHES A COMPETENT LAYER  
BELOW GROUND LEVEL



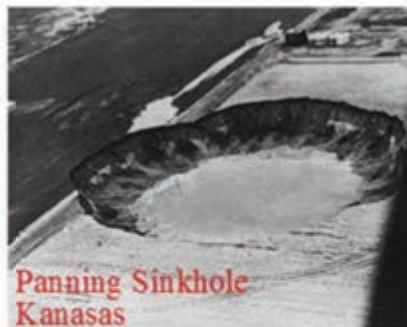
# WORLD SALT SYMPOSIUM

June 19-21, 2018

Park City UT, USA



Cargill Sinkhole  
Kansas



Panning Sinkhole  
Kansas



Bayou Corne  
Louisiana

HOUR  
GLASS



Cerville, France



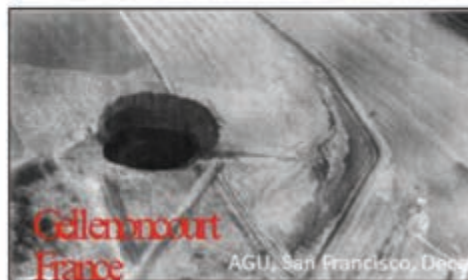
Haroud Berkaoui  
Algeria



Denver, Texas



Bucurali  
Russia



Cellermeurt  
France

AGU, San Francisco, Dec 2016



La Rape  
France

2016 March 2005

PISTON



# 2

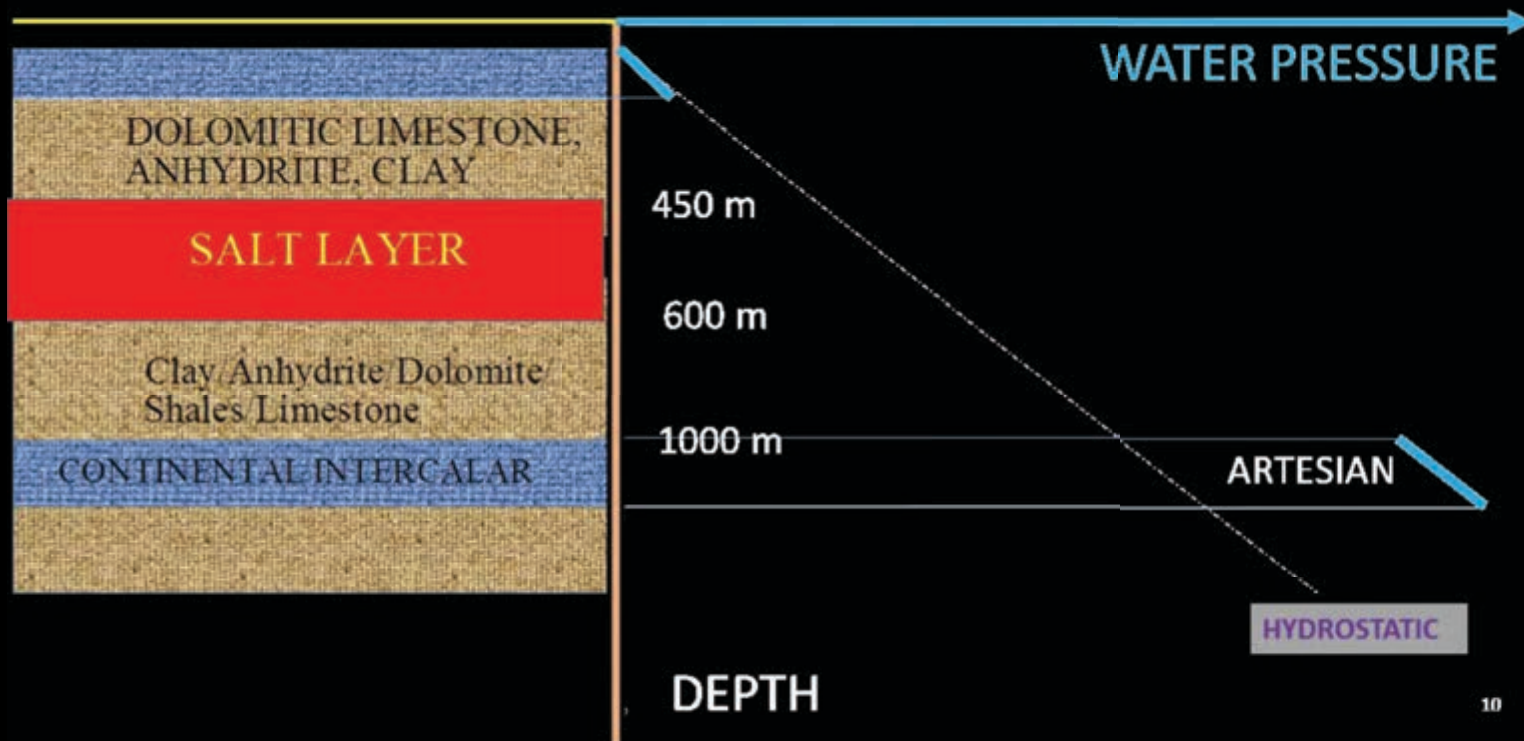
## **A « PISTON »**

Haoud Berkaoui (Algeria)

Morisseau JM. Uncontrolled leaching of salt layer in an oil field in Algeria. Proc. SMRI Technical Class and Technical Session, San Antonio; 15-16 Oct. 2000, 330-333.

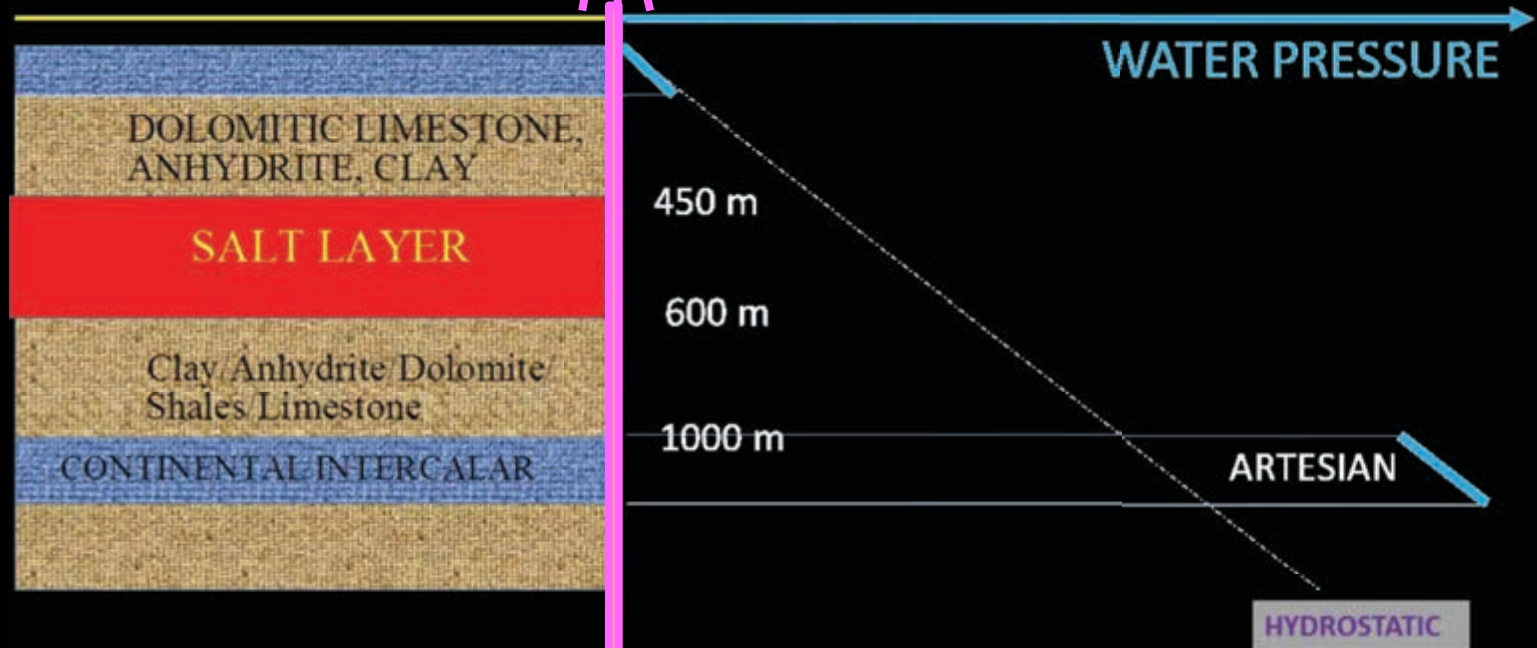


## Haoud Berkaoui (Algeria)





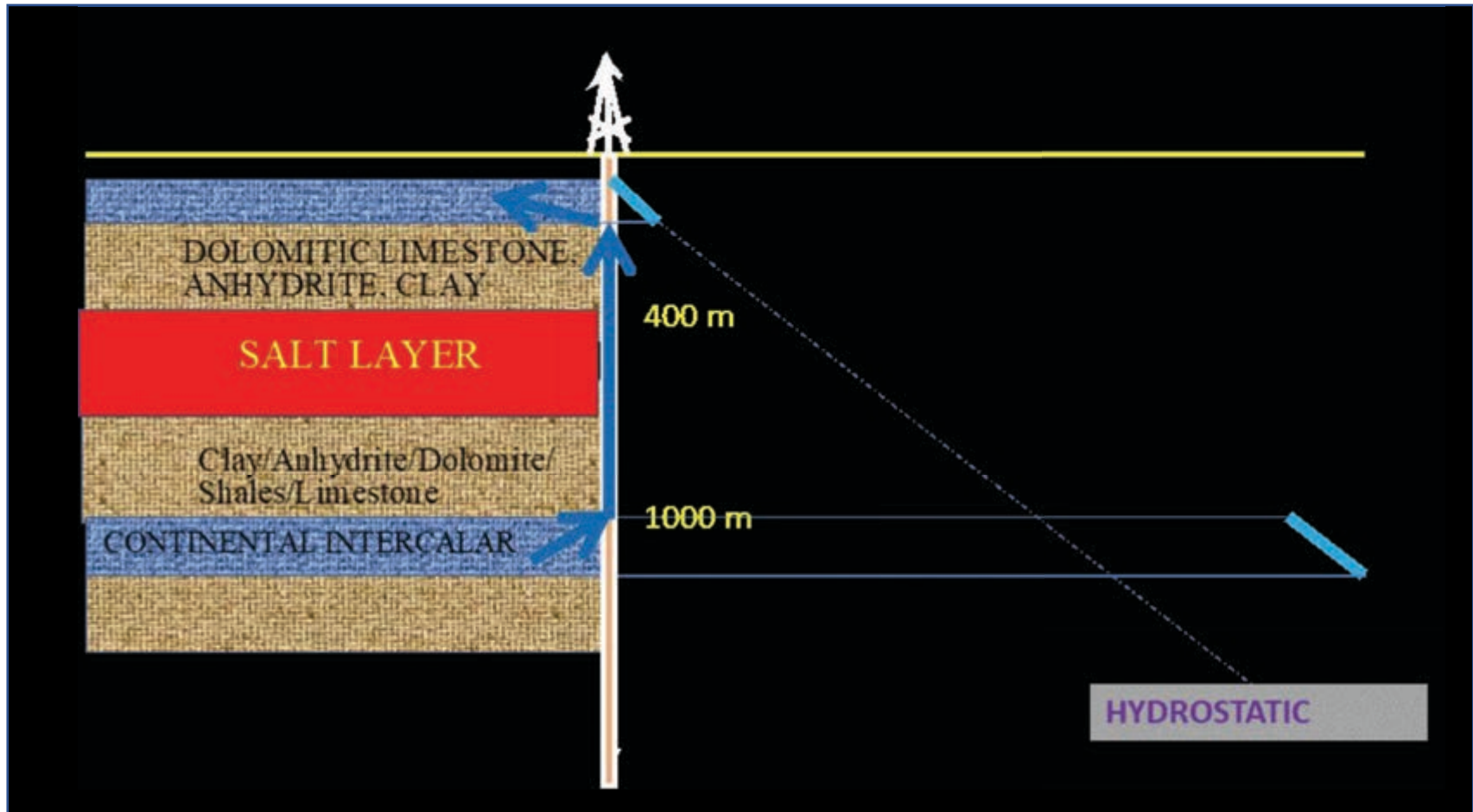
## Haoud Berkaoui (Algeria)



DEPTH

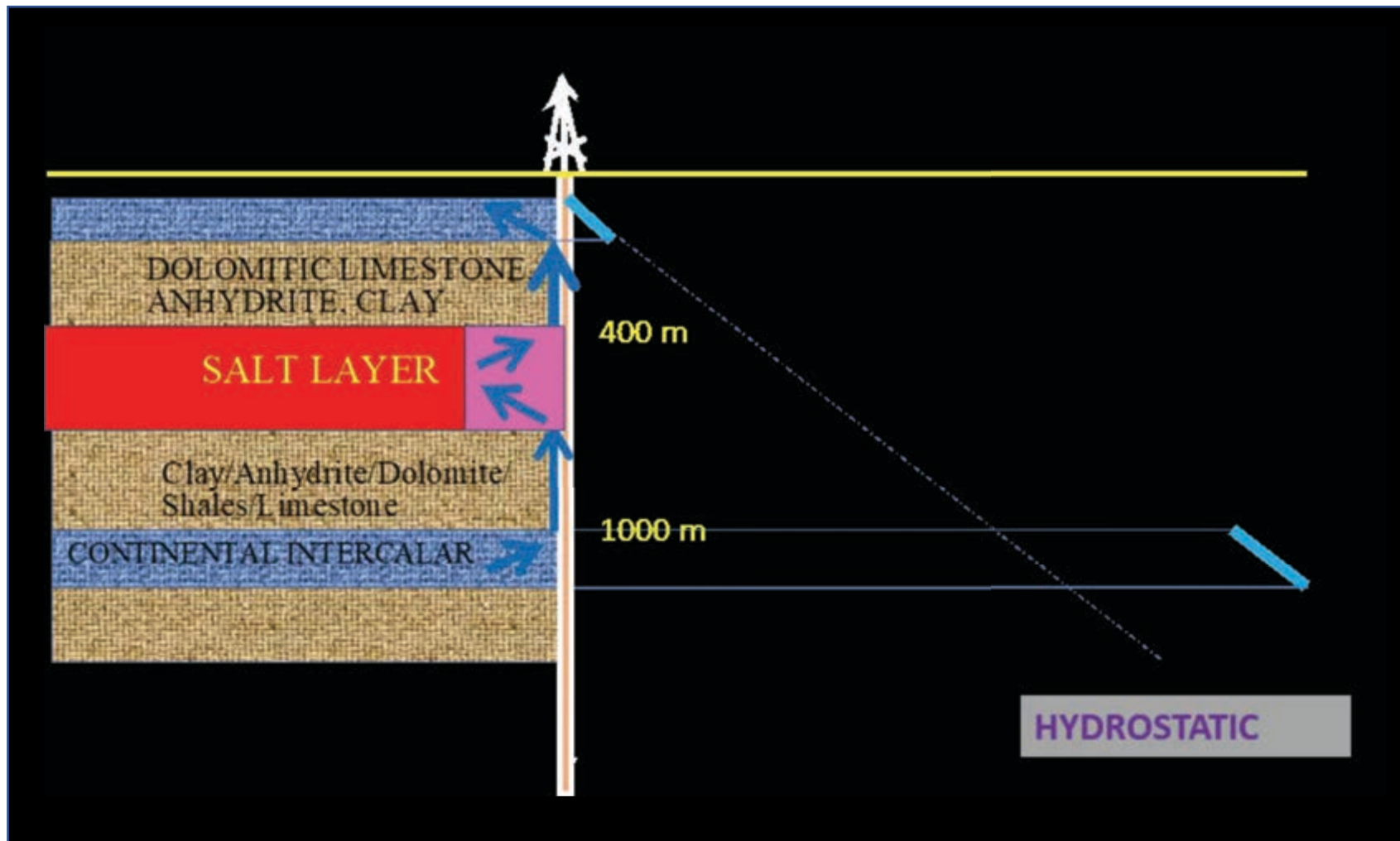
10

TO 3000 M



An oil well, 3000-m deep, was poorly abandoned, and water flowed from the artesian aquifer layer towards ground level





The salt layer was leached out by water flow, a cavern developed  
Its diameter reached 400 m.



Haoud Berkaoui:  
Sharp Vertical Edges

→ "PISTON"



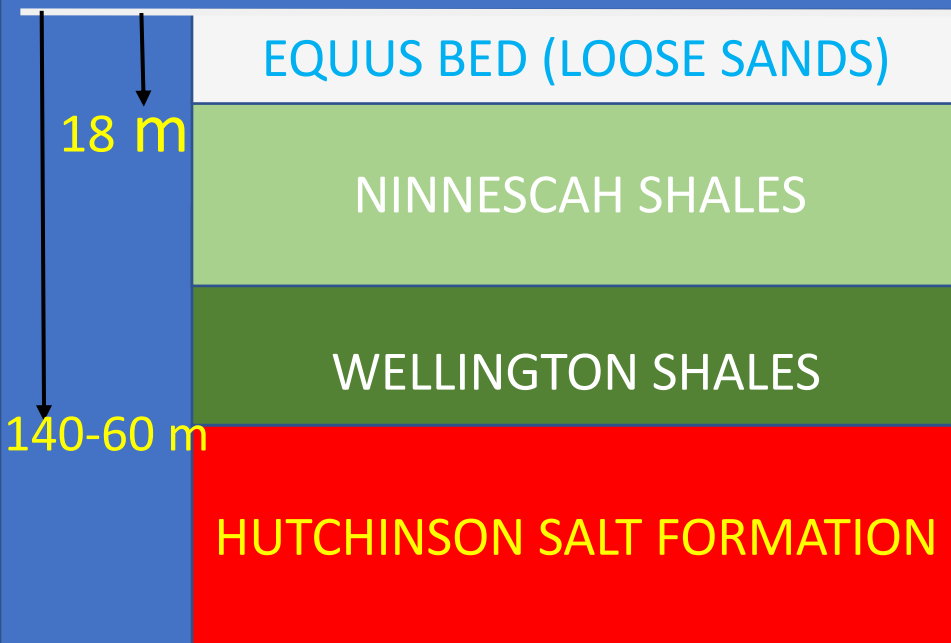
... until a rock cylinder, 200-m in diameter,  
dropped into the underlying cavern

# 3

## **AN « HOUR-GLASS »**

### Carey salt well #19 sinkhole, Kansas

Walters R.F. (1978) – Land subsidence in Central Kansas Related to Salt Dissolution. Kansas Geol. Survey Bull. 214, 1-82.



STRATIGRAPHY NEAR  
HUTCHINSON, KANSAS

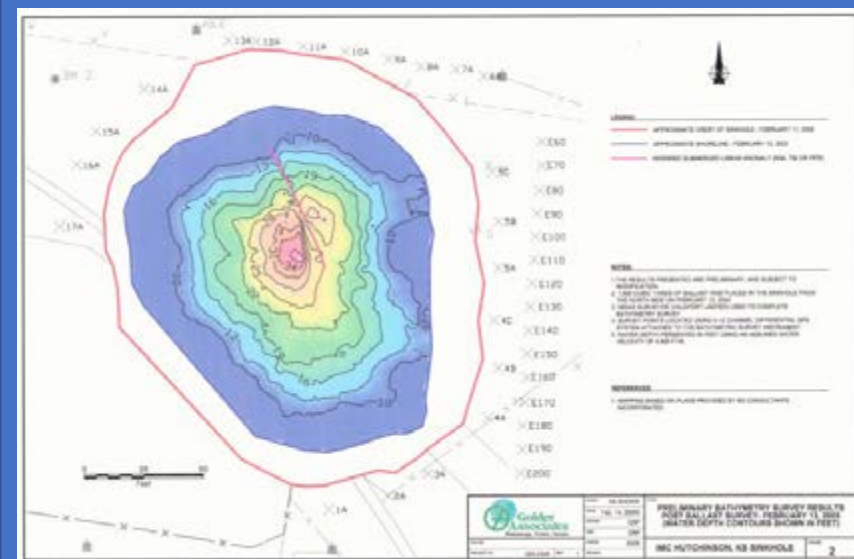
Brine wells have been operated in this salt formation since the late 1880s.

Before the 1979 regulations were enforced, no salt roof was left at the cavern top.

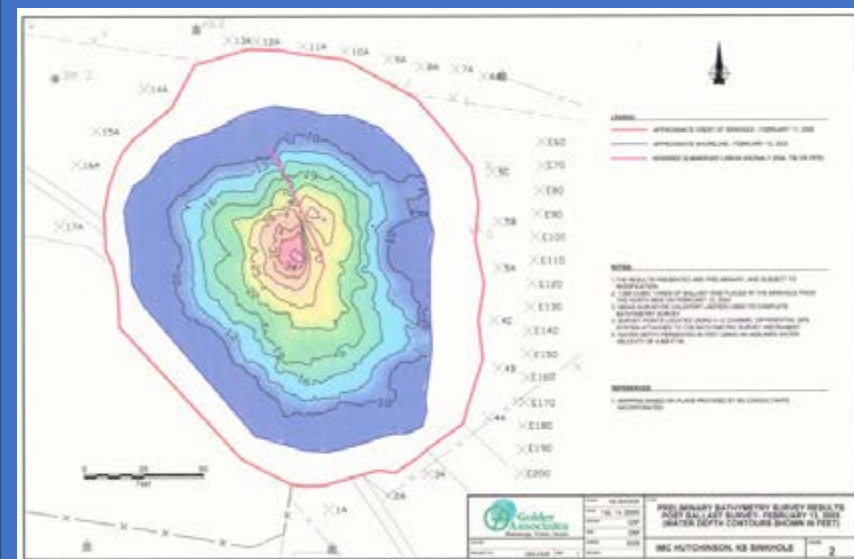
Stoping took place



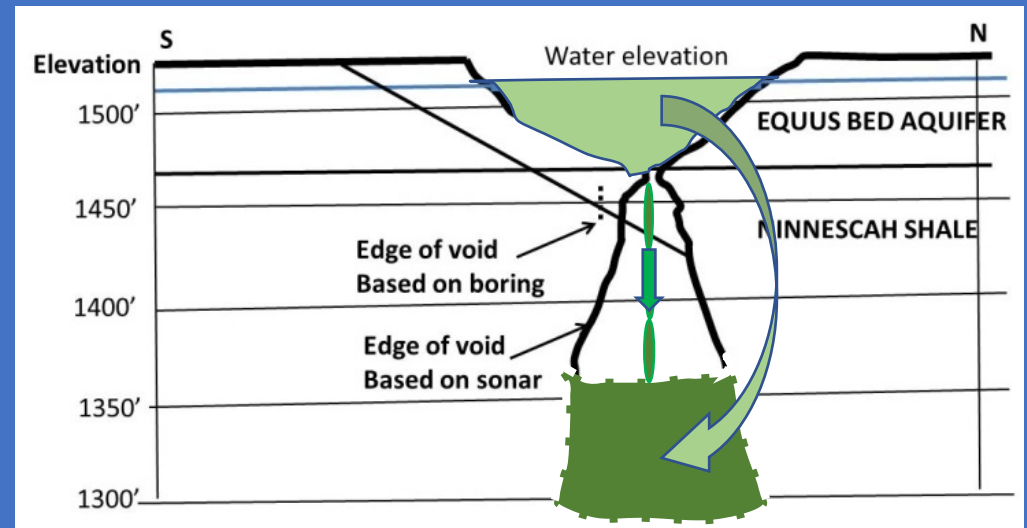




Carey salt well # 19 was abandoned in 1922. On the evening of January 3, 2005, a sinkhole developed rapidly around the wellhead (Cochran et al., 2005). Its depth was 45 ft (13 m), and its horizontal maximum diameter was 210 ft (63 m).



Well casing #19 is standing vertical in the N-W part of the sinkhole, clearly suggesting that no rigid cylinder had fallen. *The well casing should have dropped accordingly.*



A sonar survey revealed that the bedrock had been breached; loose sediments had flown to a (small) central hole, as in an hour-glass.



# 4

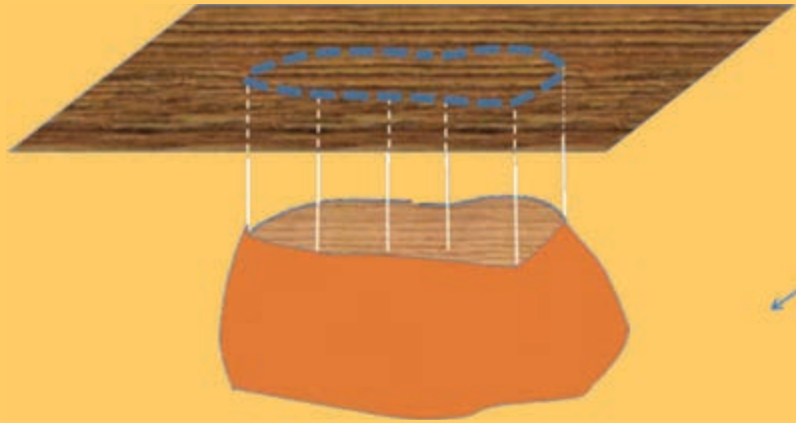
## Why sinkholes are circular?

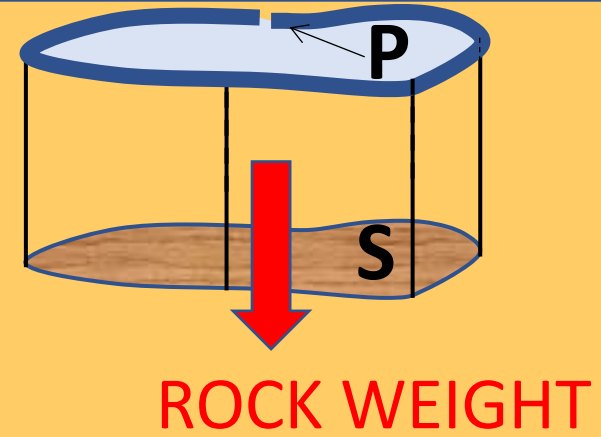
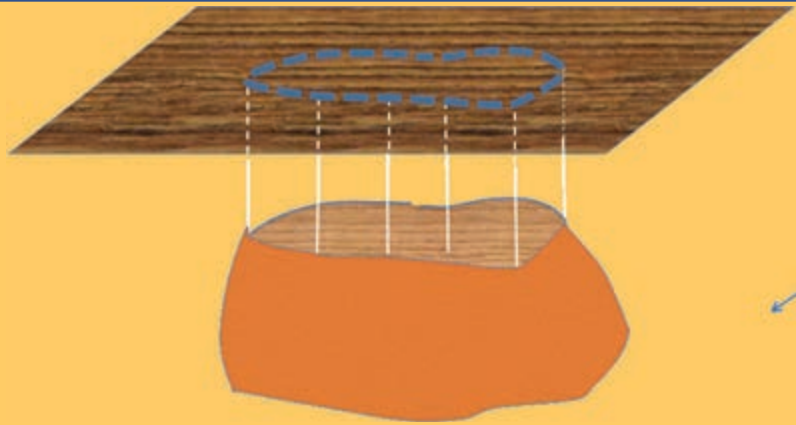


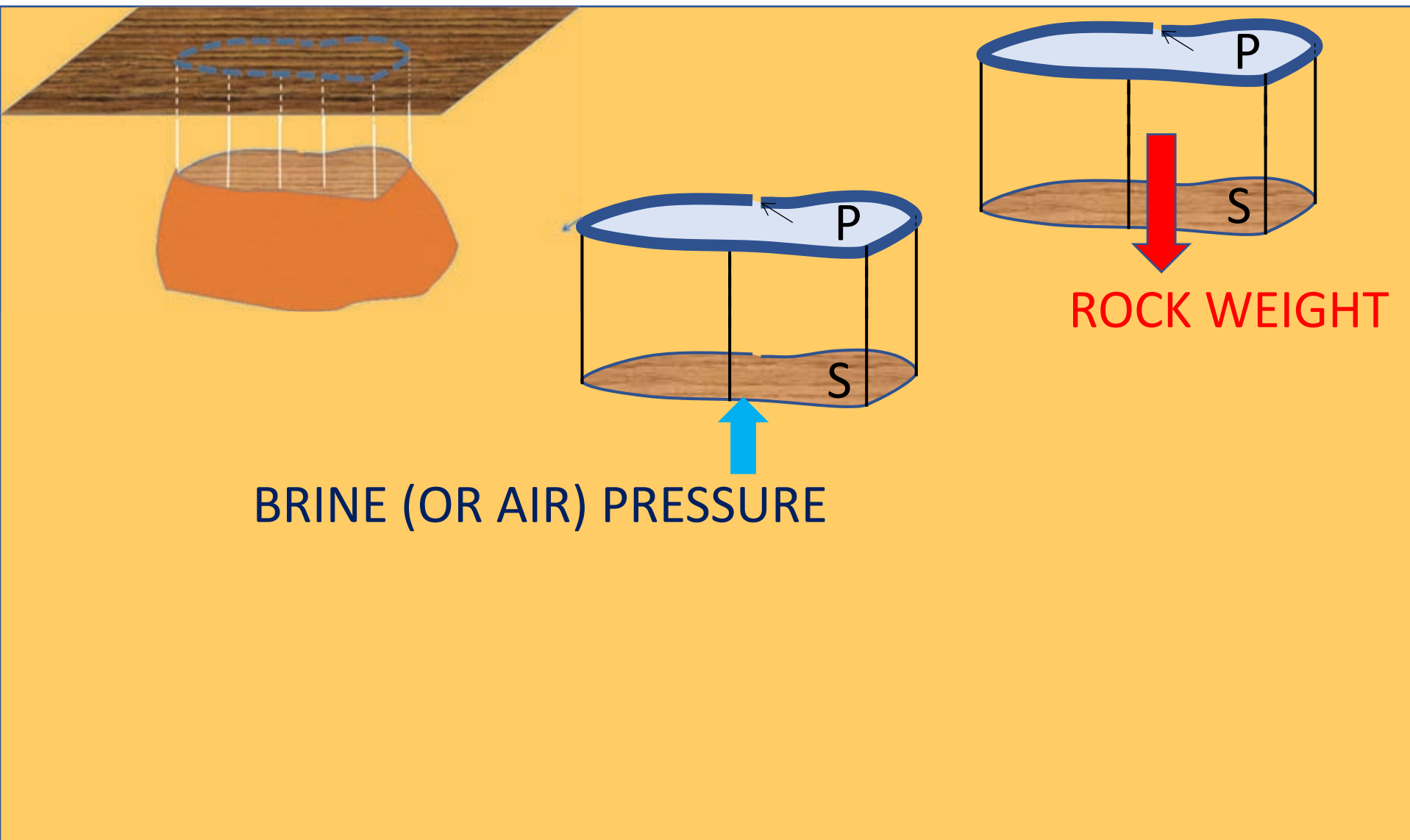


**A circular shape maximizes the weight/shear strength ratio, i.e., the area/perimeter ratio**

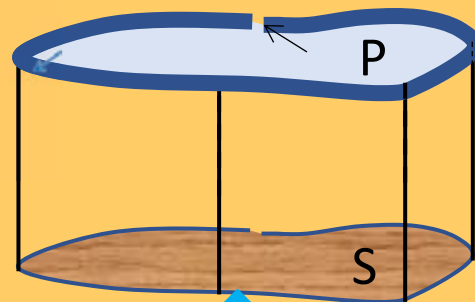
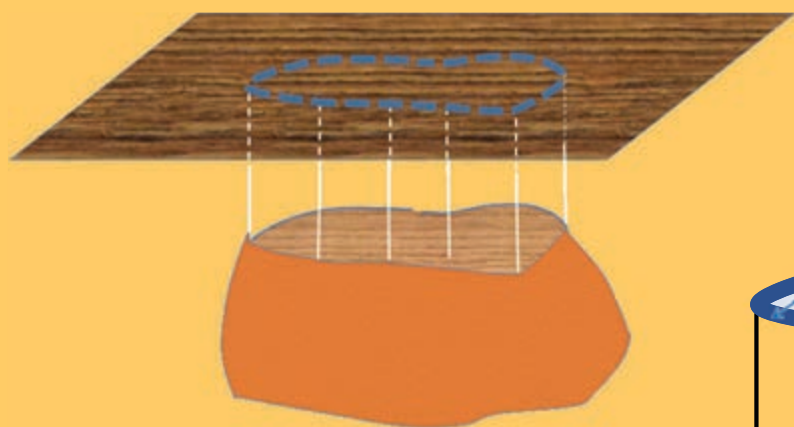




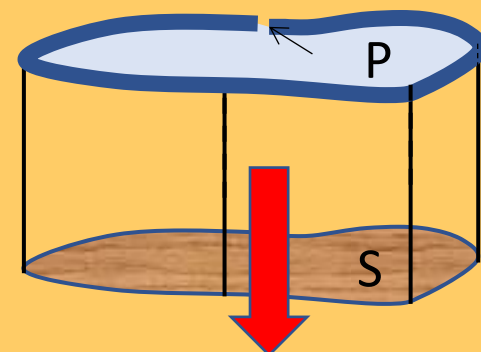




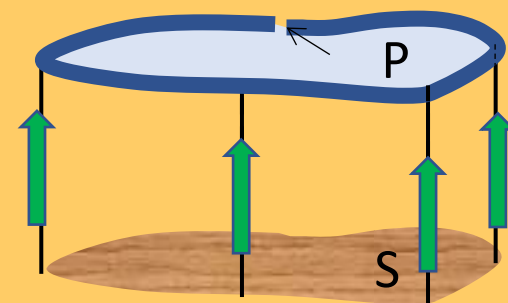




BRINE (OR AIR) PRESSURE



ROCK WEIGHT

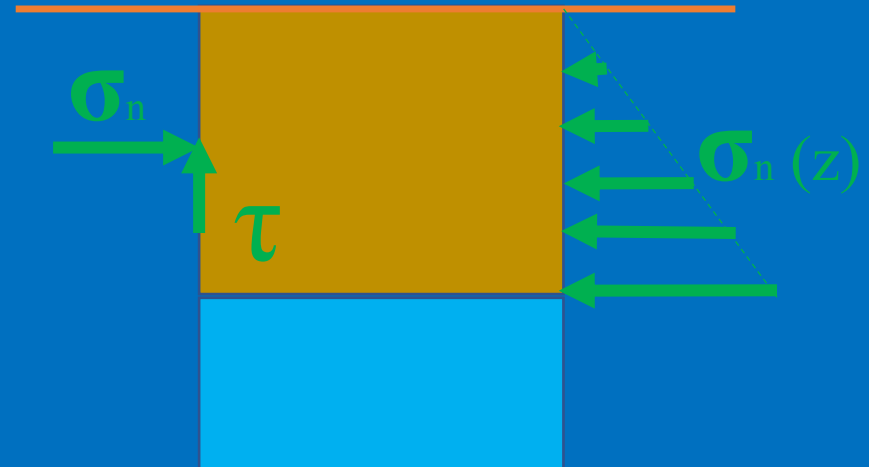


SHEAR STRESSES

$$SH\gamma_R = SH\gamma_B + P \int_0^H \tau(z) dz$$

$$SH\gamma_R = SH\gamma_B + P \int_0^H \tau(z) dz$$

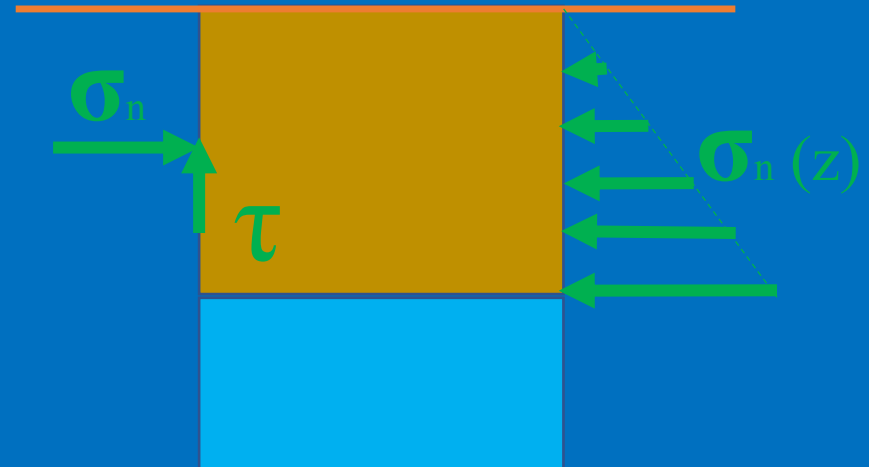
$$\sigma_n = \gamma_R z$$



$$SH\gamma_R = SH\gamma_B + P \int_0^H \tau(z) dz$$

$$|\tau| < C + f|\sigma_n|$$

$$\sigma_n = \gamma_R z$$



$$P \int_0^H \tau(z) dz = SH \gamma_R - SH \gamma_B$$

$$|\tau| < C + f |\sigma_n|$$

$$\sigma_n = \gamma_R z$$

EQUILIBRIUM IS IMPOSSIBLE WHEN:

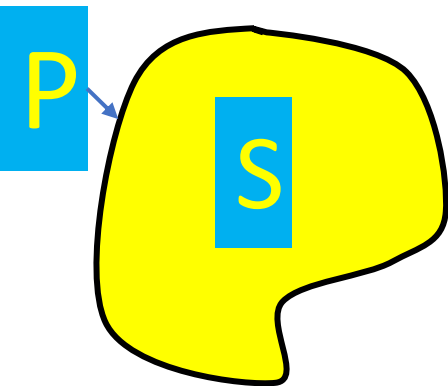
$$(\gamma_R - \gamma_b)S > P(C + f \gamma_R H / 2)$$

↑  
(WEIGHT)

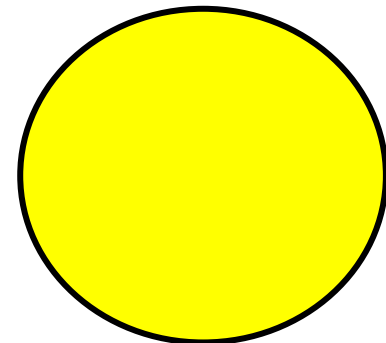
↑  
(MAX. SHEAR STRENGTH)

EQUILIBRIUM IS IMPOSSIBLE WHEN:

$$\frac{S}{P} > (C + f\gamma_R H / 2) / (\gamma_R - \gamma_b)$$



THE MOST UNFAVOURABLE CONTOUR  
IS A CIRCLE, RADIUS  $R$  (*Dido's problem*)



$$(\gamma_R - \gamma_b)R > (2C + f\gamma_R H)$$

THERE EXISTS A CRITICAL RADIUS SUCH THAT EQUILIBRIUM IS IMPOSSIBLE





**A circular shape maximizes the weight/shear strength ratio, i.e., the area/perimeter ratio**



# QUESTIONS?



The author benefited from contributions from many colleagues who kindly provide him with information, pictures and comments, among whom Brad Barré, Terje Brandshaug, Mark Cartwright, Xavier Daupley, Kenneth Johnson, Kevin Hill, Emmanuel Ledoux, David Mitchell (*The Advocate*, Baton Rouge), Harriet Neal, Eulogio Pardo Iguzquiza, Mario Parise, Lélia Picabia, Will Pettitt, Joe Ratigan, Julie Shemeta, Leo Van Sambeek, John Voigt, Joel Warneke.