Jerusalem Earthquake of 33 A.D.

Evidence within Laminated Mud of the Dead Sea, Israel

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Abstract: Jerusalem Earthquake of 33 A.D.

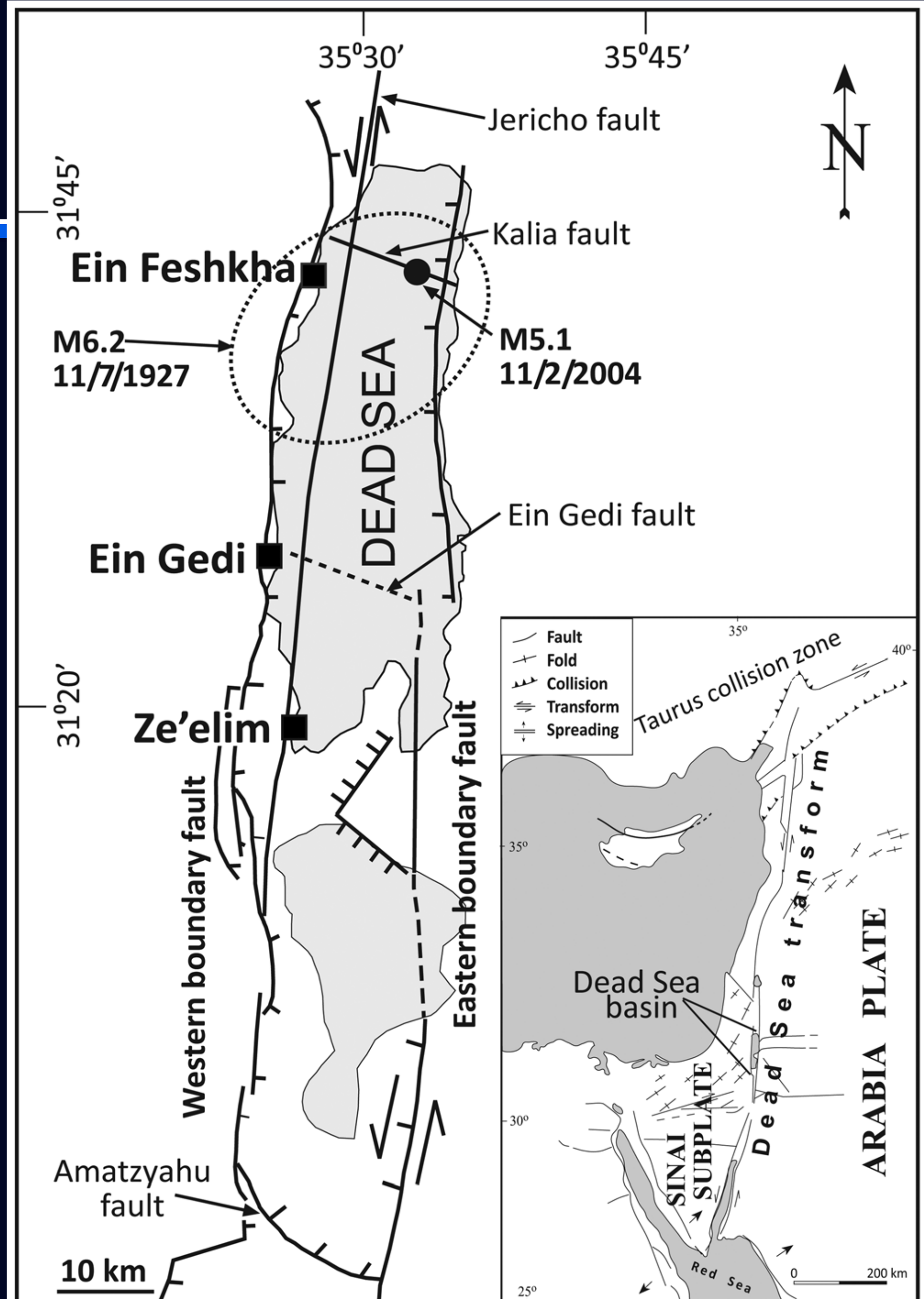
- Two thousand years ago the Dead Sea Basin was shaken by two earthquakes that left two widespread seismites within laminated Dead Sea sediment. The first earthquake (spring 31 B.C., Jericho fault, M~7.2) transformed adjacent Dead Sea laminated mud and aragonite into a persistent and distinctive intraclast breccia seismite in places greater than 1 m thick. The 1st-century Jewish historian Josephus described the 31 B.C. earthquake as a significant social and economic event during King Herod's reign. A second seismite occurs within laminated mud and aragonite at 10 to 85 cm above the 31 B.C. seismite. Varve counting above the 31 B.C. datum indicates the second seismite can be assigned to 31 A.D. (+/- 5 years), but history specifies as 33 A.D. Superb mud laminae exposures are provided in two gullies at the southwest corner of the Dead Sea at Wadi Ze'elim fan delta where the 33 A.D. seismite outcrops 55 to 85 cm above the 31 B.C. intraclast breccia. The 33 A.D. seismite at Ze'elim is intraformationally folded, 8-cm-thick, sometimes brecciated, silicate mud and aragonite/gypsum laminae. Seismite facies progress from "linear waves" to "asymmetric billows" to "breccia" expressing transition to Kelvin-Helmholtz turbulence within the uppermost shearing laminae during shaking. Recumbent folds and imbricate faults are consistent with gravity collapse upon a broad arch structure during shaking. Folded seismite transitions northward within fan deltas to thicker intraclast breccia, suggesting an epicenter nearer Jerusalem. Matthew, the 1st-century synoptic Gospel author, reported two earthquakes in Jerusalem in 33 A.D. These are the Jerusalem earthquakes of April 3 at the crucifixion of Christ (Matt. 27:51), and April 5 at the resurrection of Christ (Matt. 28:2). Luke, a first century physician and historian, reported a smaller earthquake in the summer at the gathered assembly (Acts 4:31). The persistent 33 A.D. seismite indicates the biggest 33 A.D. earthquake was M~6.0. This biggest earthquake was likely April 3, 33 A.D. that startled city residents and caused moderate damage, especially to the western side of Temple Mount. Pivots of two, 20-m-high, metal doors of the Temple appear to have been damaged, and the 20-m-high curtain in front of the doors was torn, likely by displacement of the lintel of the Temple during the earthquake.

Overview

- Tectonic setting of the Dead Sea fault
- Seismite record within Dead Sea mud
- Earthquake and seismite of 31 B.C.
- Earthquakes and seismite of 33 A.D.
- Analysis of seismite deformation
- How these earthquakes impacted history

Location map depicting the tectonic setting for this field study. Normal faults are shown as solid lines with hachures on the downthrown side. Left-lateral strike-slip faults are shown as solid lines with arrows. The Dead Sea Basin was formed by pull apart along the non-parallel junction between two, en echelon, left-lateral strike-slip faults (a “releasing bend” along the transform fault system between the Sinai Subplate and the Arabian Plate). Notice the left-lateral displacement of the Jericho Fault through the field study area at Ze’elim.

(from Kagan et al., 2011, with detail of the Ze’elim structure after Bartov and Sagy, 2004).



Wadi Ze’elim Fan Delta with local incised gullies

Shore of the Dead Sea at Wadi Ze’elim is now 422 meters below sea level. It is the deepest depression on earth’s surface. Ancient fan delta sediments are exposed because of the lake’s low level.

Wadi Ze’elim laminated aragonite & silicate mud

Mud layering at Wadi Ze'elim fan delta

Laminated mud

Laminated aragonite

Laminated mud

Silt & fine sand

Laminated aragonite

Fine sand and mud

Clay mud & silt

Sand w. climbing ripples

Seismite – a distinctive sedimentary bed or group of laminae which has been disturbed by the wave action of an earthquake through the addition of shear acceleration usually just beneath the sediment-water interface.

Principles of earthquake deformation beneath the sediment-water interface: Fine-grained mud just beneath the sediment-water interface typically displays a 10% decrease in porosity downward through a distance of a few centimeters. That downward decrease in mud porosity is associated with a ten-fold increase in the bulk mud viscosity. Because of the downward ten-fold increase in the viscosity of mud just beneath the sediment-water interface, deformation style within this thin zone varies significantly. During an earthquake, the Reynolds number at the sediment-water interface is about ten times higher than Reynolds number within the more-compact mud just several centimeters below. This significantly higher Reynolds number just below the sediment-water interface causes a transition to turbulence at peak ground accelerations of 0.2 to 0.6 g, and fully turbulent shear of mud at peak ground accelerations above 0.6 g. P-waves are high frequency and vibrate individual mud particles, separating particle-particle contacts and tending to induce sediment liquefaction. S-waves of an earthquake are slower moving and lower frequency. S-waves cannot transmit energy to the clear water above the sediment-water interface, because clear water has no shear strength. So, S-wave energy is translated into shear disturbance of mud at the sediment-water interface if the threshold peak ground acceleration exceeds about 0.2 g.

Transition to turbulence along a boundary during shear

Cigarette smoke shows styles of deformation

5. "Turbulent mixing"

4. "Coherent vortices"

3. "Asymmetric billows"

2. "Linear waves"

1. "Laminar flow" at boundary

Technical term for boundary transition is "Kelvin-Helmholtz instability"

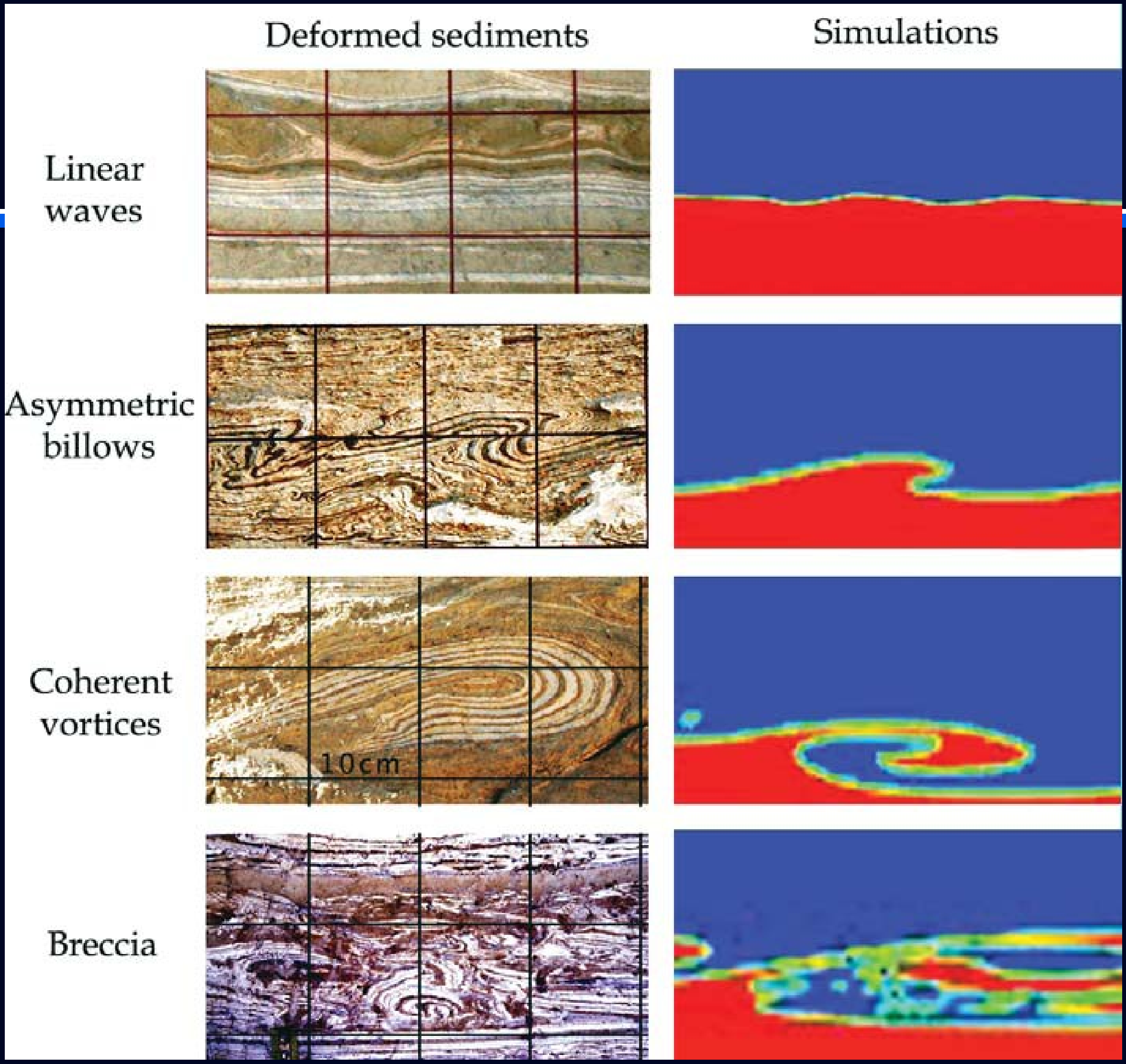
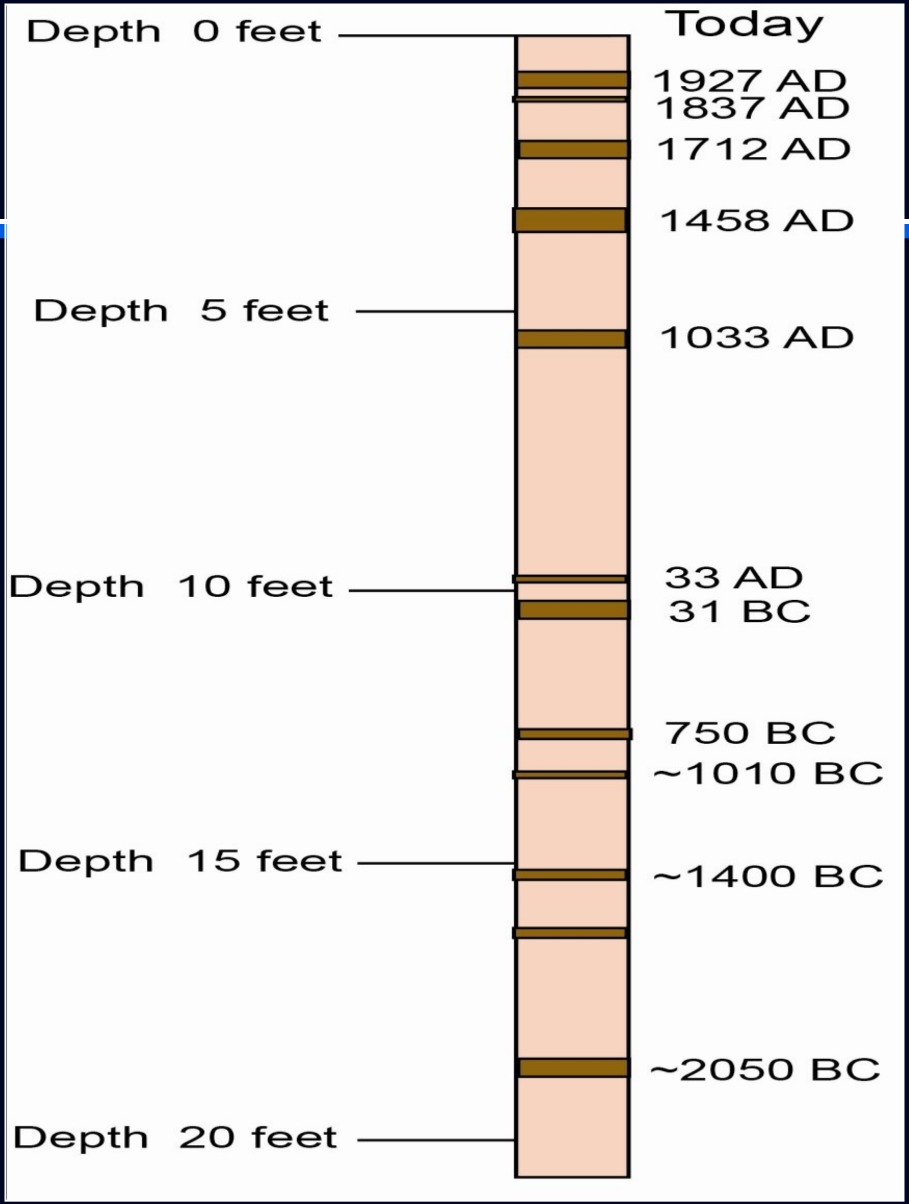


Diagram from Wetzler et al., 2010.

Deformation styles of seismites in the Pleistocene Lisan Formation appear to be simulated by the transition to shear-induced turbulence at the sediment-water interface. A 10 cm grid overlays Lisan seismites.



Sketch of the uppermost 7 meters of the Dead Sea core at En Gedi showing the position of prominent seismites and dates of probable earthquakes.

Earthquake of 31 B.C.

- Described by Josephus and Herod
  - *Wars of the Jews*, Book 1, Chapter 19, Paragraphs 3 & 4
- Rupture length 110 km on Jericho fault
  - Reches and Hoexter, 1981
- Up to 3.5 m of dip-slip movement
  - Reches and Hoexter, 1981
- Thickest Dead Sea seismite
  - Ze'elim fan delta, > 2 m thickness in this study
- Magnitude ~ 7.2
  - Kagan et al., 2011

Earthquakes of 33 A.D.

- At the Cross

  (Friday, April 3, 33 A.D.)

  – Matt. 27:51
- At the Empty Tomb

  (Sunday, April 5, 33 A.D.)

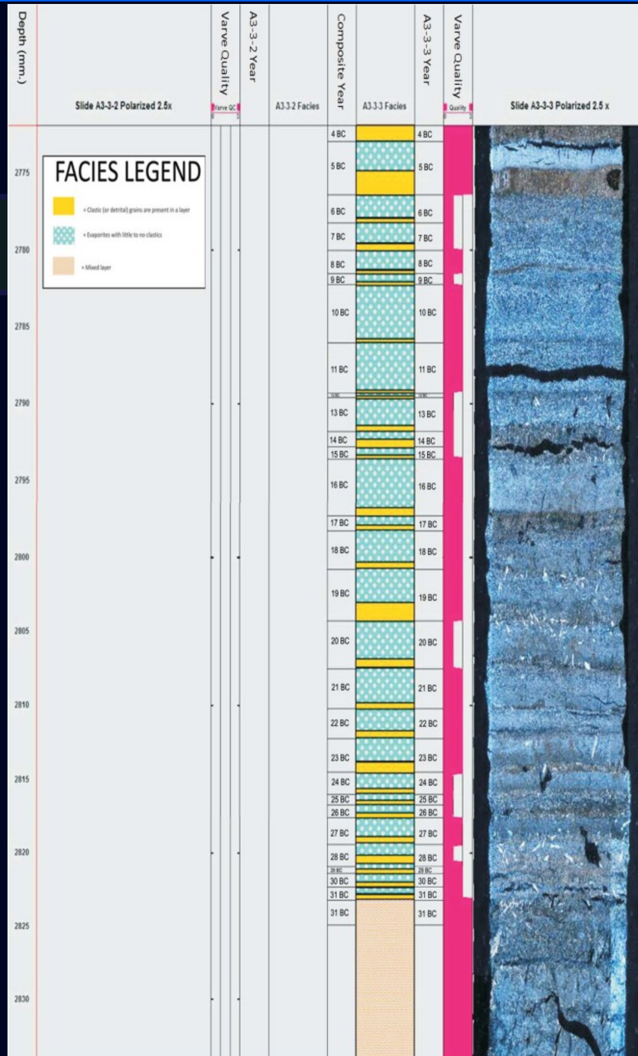
  – Matt. 28:2
- At the gathered assembly

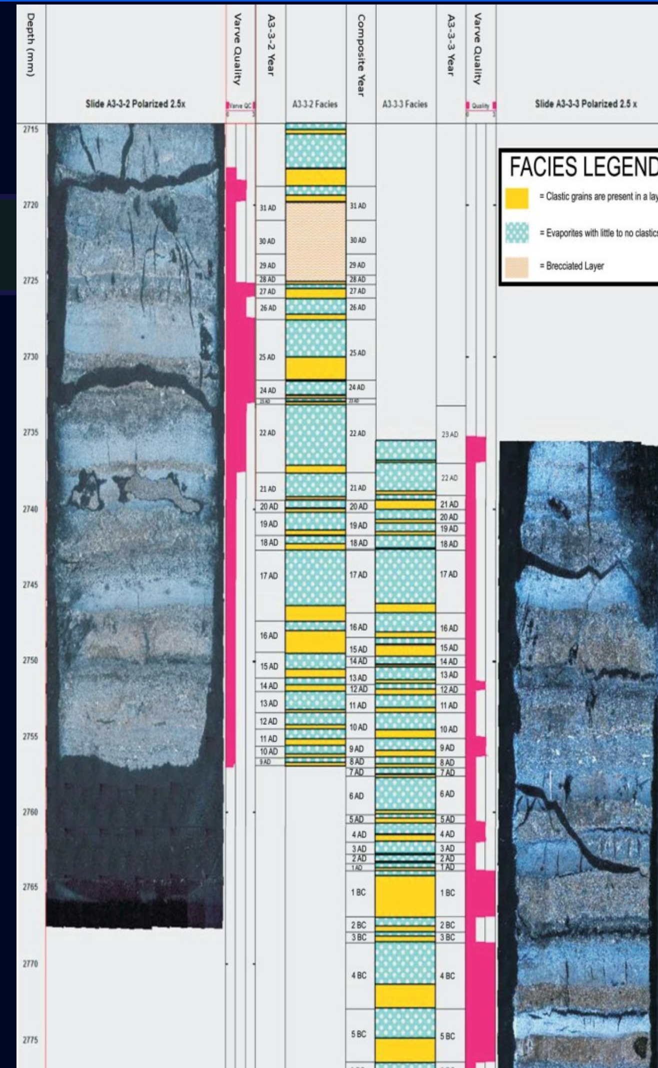
  (Summer, 33 A.D.)

  – Acts 4:31

Village of Qumran was where the Dead Sea Scrolls were buried. The village is along the Jericho fault. The site appears to have been abandoned after the 31 B.C. earthquake.

Faulting cuts architecture at Qumran. 31 B.C. displacement is mostly dip-slip.





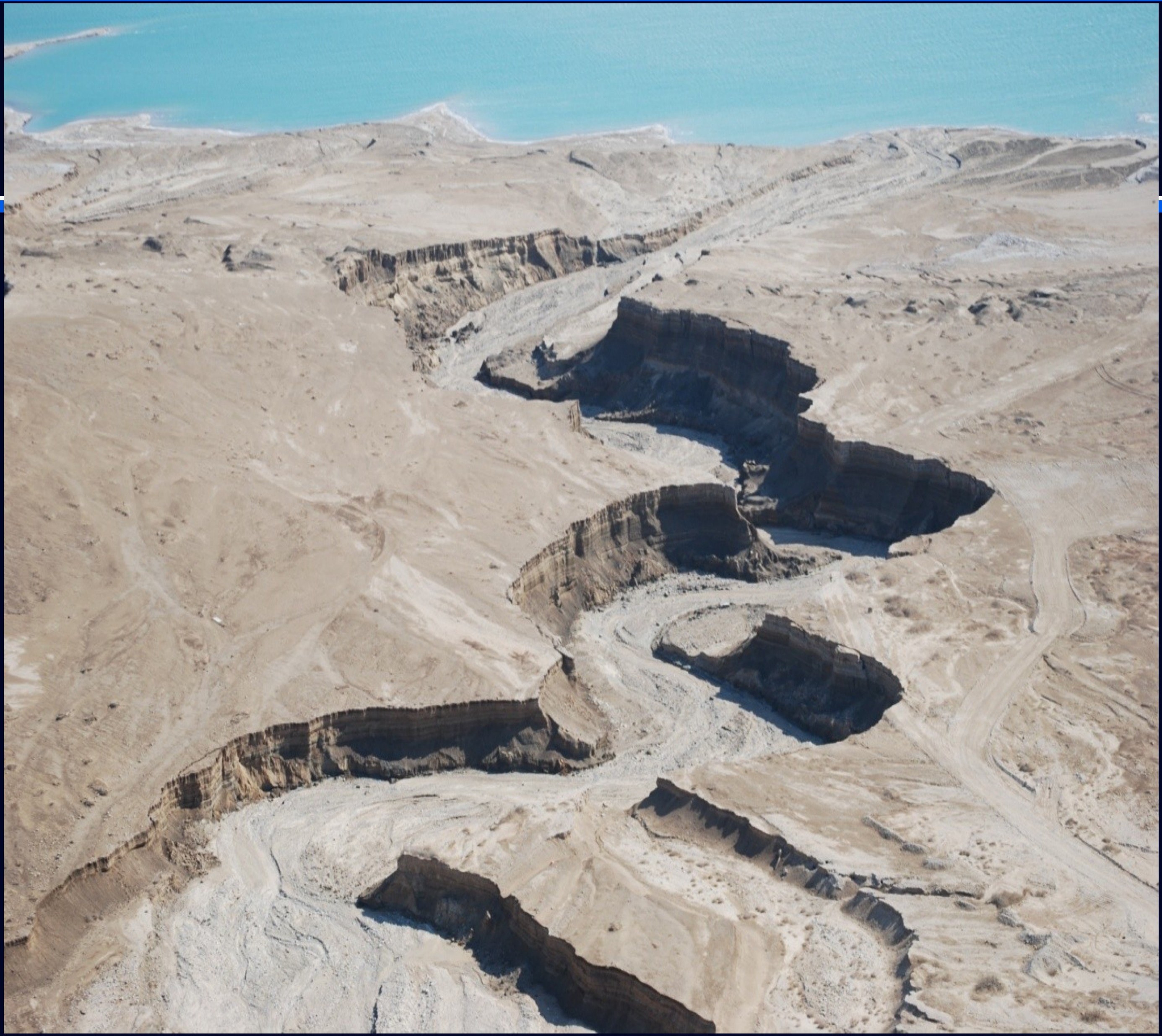
Used by permission of Jeffrey Williams

Laminae counting within the En Gedi core calibrates the year of the Jerusalem Earthquake relative to the Jericho Earthquake of 31 B.C. Jericho Earthquake (lower left) and Jerusalem Earthquake (upper right). Jerusalem Earthquake calibrates to 31 A.D. +/- 5 years (Williams et al., 2012). Historical records specify three earthquakes in 33 A.D.

Overview of Ze’elim fan delta looking west into the upper drainage basin in the Judean Mountains. Note the intake pipes at the lake shore on the lower left. Seven gullies on the fan-delta surface can be numbered from south to north (left to right) beginning at the intake pipes.

Ze'elim distal fan delta showing the locations of the four measurement sites. Note that the measurement sites are about 1 kilometer north of the intake pipes for the southern evaporation basin. Also notice the 400-m-long scale bar in lower left. Satellite photo is dated 4/2/2011, only two months after field investigations and the oblique aerial photography. Shore line of lake was 422 meters below sea level.

Detail of the four measurement and sample locations showing their relationship to the trend line of the axis of the "Ze'elim Arch" (blue line). The "Ze'elim Arch" is a broad anticline apparent in the elevation of the 31 B.C. seismite on the distal eastern edge of the Ze'elim fan delta. Gullies are numbered going northward from the intake pipes. Gully 2 is lower part of this photo. Seismites were studied in Gully 2 and Gully 3. The observed thickness of the 31 B.C. seismite decreases with distance away from "Ze'elim Arch." The amount of deformation within the 33 A.D. seismite decreases with distance (and perhaps old lake's water depth increases) away from "Ze'elim Arch." Note scale bar in lower left has length of 100 m.



Oblique aerial photo of Gully 2 looking eastward over the measurement sites.

Detail of Gully 2 looking southeast. The very thick 31 B.C. seismite is a lighter band within the shadowed cliff in the upper left. The 31 B.C. seismite ramps upward to the left onto the “Ze’elim Arch” that runs parallel to the upper border of the photo. Apparent dip of the 31 B.C. seismite may be 5 degrees westward.

Oblique aerial photo looking northwestward at the north side of Gully 2 where the “Ze’elim Arch” crosses Gully 2. Notice the very thick 31 B.C. seismite midway up the north wall of Gully 2. Also, notice the pervasive imbricate extensional fractures within the 31 B.C. seismite. These extension fractures dip in two directions away from the axis of the arch. Strike of the extensional fractures parallels the axis of the arch. At this location at the top of the “Ze’elim Arch” there is apparent dip downward on both the left and right sides of this photo at the structural high of the 31 B.C. seismite.

Gully 2 looking eastward (downstream) toward the Dead Sea. Notice the very thick 31 B.C. seismite about halfway up the cliff on both sides of the gully.

Gully 2 south side showing the 1.6 meter thick 31 B.C. breccia seismite with pervasive extensional fractures dipping westward (toward the right, away from the "Ze'elim Arch"). As the seismite formed, it had enough cohesiveness uniformly distributed to allow gravity to form pervasive but small extensional fractures.

Gully 2 south side showing seismite of 33 A.D. at thickness of 7 centimeters at position 87 centimeters above 31 B.C. seismite. Mud patina was removed with shovel to expose seismite.

Gully 2 south side showing detail of 33 A.D. seismite. Recumbently folded seismite has fold axes that dip eastward toward the “Ze’elim Arch.” Deformation involves “push to the right” that is consistent with gravity-induced shear during the earthquake. These deformed laminations display the characteristics of “asymmetric billows” associated with the onset of Kelvin-Helmholtz turbulence, here the input was not strong enough to brecciate the seismite with turbulent flow. Peak ground acceleration is here approximately 0.5 g (Wetzler et al., 2010),

Gully 3 oblique aerial view looking eastward over the measurement sites.

33 A.D.

31 B.C.

Gully 3 (north side) with 33 A.D. seismite above a thinner 31 B.C. seismite.

Detail of 33 A.D. seismite shown previously. “Linear waves” give way to an “asymmetric billow” (center) having the appearance of showing the onset of Kelvin-Helmholtz turbulence near the sediment-water interface as the earthquake was deforming the layer.

Probable seismite of 33 A.D. showing development of “linear waves,” the lowest order deformation feature that can be attributed to the onset of Kelvin-Helmholtz instability. Instability shown here is well before fully turbulent brecciation. Wave amplitude ~ 6 cm.

Seismite of 33 A.D. in Gully 3, north side. The outcrop is covered by mud patina that was removed here with shovel. Recumbent folds within the seismite have axial planes that dip eastward toward the "Ze'elim Arch." Deformation is consistent with "push from the right." Liquefaction and tearing of laminae is evident at the right. "Asymmetric billow" (left and center) transition to the first indication of brecciation (right) showing the appearance of Kelvin-Helmholtz turbulence near the sediment-water interface as the earthquake was deforming the layer.

Matthew’s description of the crucifixion:

“Now from the sixth hour there was darkness over all the land unto the ninth hour…. And, behold, the veil of the temple was rent in twain from the top to the bottom; and the earth did quake, and the rocks rent; And the graves were opened; and many bodies of the saints which slept arose,… Now when the centurion, and they that were with him, watching Jesus, saw the earthquake, and those things that were done, they feared greatly, saying, Truly this was the Son of God.”

(Matthew 27:45, 51, 52 and 54)

The Temple in Jerusalem during King Herod's day had a huge, east-facing curtain (veil) that was suspended on the eastern lintel in front of the metal doors marking the entry to the Holy Place. The 33 A.D. earthquake evidently displaced the Temple's lintel, tore the curtain, and shifted the pivots for the metal doors. Other damage appears to have occurred to the western side of Temple Mount.

Peter's Speech in Jerusalem on Pentecost

Explaining to an unruly crowd what has just happened,
Sunday, May 24, 33 A.D.

"This is what was spoken of through the prophet Joel:
'And I will show wonders in heaven above,
and signs in the earth beneath;
blood, and fire, and vapour of smoke:
the sun shall be turned into darkness,
and the moon into blood,
before that great and notable day of the Lord come.'
… To which we are all witnesses."

Acts 2:19, 20, 32; Peter is quoting Joel 2:30, 31

Lunar Eclipse -- ~3:20 pm local time 4/3/33

Javascript Lunar Eclipse Explorer

http://eclipse.gsfc.nasa.gov/JLEX/JLEX-index.html

Events of April 3, 33 A.D.?

At ~3:30 pm Jerusalem time on Friday April 3, 33 A.D., As Passover lambs are being sacrificed in the Temple, five extraordinary events occur….

- The extinguished sun begins to shine
- The Temple Veil is torn
- The Earth shakes as rocks crack
- The Moon enters the Earth’s shadow
- Jesus dies on the Cross

Conclusion

- A distinctive and widespread seismite exists within Dead Sea sediment documenting a moderate earthquake in ~33 A.D.
- Shear-induced structures within the seismite of 33 A.D. at Ze’elim are distributed upon the flank of an arch structure on the old floor of the lake.
- Shear-induced structures within the seismite at Ze’elim mark the distinctive transition to turbulence at the sediment-water interface.
- Historical reports describe moderate damage to well-built structures in Jerusalem.
- Brecciated seismite northward of Ze’elim also suggests an epicenter near Jerusalem with the largest 33 A.D. earthquake being M ~ 6.

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