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In this chapter we will look at the process taken to define the start of the Pleistocene epoch

A review: Milankovitch measured the sun’s radiation, which was measured at the top of the atmosphere. Its radiation is measured with 1-2% differences because of the earth's eccentricity which can have a tremendous affect on the atmosphere, land, and water depending on season, latitude, earth’s place in orbit, tilt, and wobble. (eccentricity, obliquity, precession)

- Solar radiation impacts glacial melting, vapor, and sublimation (ice → vapor),
- Solar radiation impacts atmospheric gases such as, CO$_2$, Methane, and Nitrogen,
- Solar radiation impacts ground and water temperatures, terrestrial/water biomasses,
- And, where the Northern/Southern hemispheres are pointing during aphelion (farthest) and perihelion (nearest point to sun).
There is a rough ratio of 1:2:4 between eccentricity, obliquity, and precession. To the right, the dotted lines encompassing 120K years, takes you through one complete eccentricity cycle (the longest cycle) and shows the apparent ratio.

Chart provided by NASA
How did the *Pleistocene* (epoch) of the Quaternary (system) get its *start time* established. The time divisions are part of the requirement for consistent use of stratigraphic nomenclature time divisions of geologic time. (USGS Fact Sheet 2007-3015, Mar 2007 was used until Aug 2018 – see the Note at bottom of page for current divisions of Geologic Time)

The *early definition* of the Pleistocene was the presence of organisms living in cold conditions and 90-95% had to be living today

In 1948 a type location was added:

> “was marked by the first appearance of cold-water species in well exposed sedimentary successions in southern Italy” (Imbrie, p 152)

That wasn’t something that could be used worldwide - how do you correlate other formations or other places.

Note: USGS Fact Sheet 2018-3054 dtd Aug 2018 moved the Quaternary/Pleistocene boundary between the Tertiary/Pliocene back to 2.58 mya from its 1.8 mya date.
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Back in 1906 in a French brick yard, B. Brunhnes noticed baked bricks became magnetized.
   He checked out local lava fields and they showed magnetization from north.

Along about 20 years later M. Matuyama noticed that lava fields retained the existing magnetic orientation when they cooled. And he found several reversals.

By the 1950-1960 several geophysicists concluded that magnetic reversal did in fact exist.

And, yes, the author has seen the old Navy P-3’s flying low over the Crescent Formation west of Port Ludlow (it’s been a couple of years since last sighting).
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Pleistocene could then be identified as the Olduvai normal in the Matuyama reversal:

“the first appearance of the cold-water marine ostracod Cytheropteron testudo.” (Lowe, p.3)

Later evidence put the date of the Olduvai normal at 1.81 mya. Evidence, such as, Lake records, loess, and deep-sea cores substantiated the date.

There was a debate as to whether it should be pushed back to around 2.5 mya (Lowe, p.3). (And USGS Fact Sheet 2018-3054 dtd Aug 2018 did just “that”.)

The Hays, Imbrie, and Shackleton article (Science, 1976) confirmed the start of the Pleistocene epoch. See next page.

That date defined the beginning point that Pleistocene stratigraphy could be applied worldwide; however, it has subsequently been moved to 2.58 mya.
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Williams calls this a “famous paper”: “which reveals the presence of eccentricity, obliquity, and the two main precession frequencies within this record.” (Williams, p 90-91)

- 100K eccentricity
- 41K obliquity
- 23K and 19K precession

Their paper was based on $\delta^{18}O$ collaborating evidence found in two marine cores from the S. Indian Ocean that substantiated marine sediment core V28-238 stratigraphy.

Did they do this alone? Oh, they did not.
Their success was the culmination of work done by many people and institutions: (just a few)

a. C. Emiliani as early as 1955 discovers at least seven glacial and interglacial periods in deep sea cores (14 stages)
   In 1966, using core P6304-9 which extended the isotope stages back to Stage 17

b. N. Shackleton spent 10 years modifying “a mass-spectrograph for isotopic studies of Pleistocene fossils.” (Imbrie, p. 164) He recognized that the mass-spectrograph must be able to count fewer specimens in the core. I.e., he “therefore resolved to modify the instrument so that accurate readings could be obtained from a small number of specimens.”
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Their success was the culmination of work done by many people and institutions: (con’t)

c. T. Saito located Core V28-238 which spanned the Brunhes-Matuyama boundary (confirmed) at Lamont. This was a complete record that allowed age dating of the Pleistocene. (see Slide 5 for update). The below cores helped substantiate V28-238.

   1. Core RC11-120 raised in 1967 from the S. Indian Ocean (E79° 52’, S43° 31’),

   2. In 1971 Core E49-18 was raised from the Southern Indian Ocean (E90° 09’, S46° 03’) (Imbrie, p. 198-201, Hays, et. al., Science, Vol 194, p1121-1132)

D. Subsequently, Lisiecki and Yaymo developed a globally distributed benthic δ¹⁸O record (algorithm) that took the results of 57 cores back to 5.2Mya (see Slide 10 for reference)

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Core V28-238 (Below is a normalized curve from deep sea core V28-238)
This curve allowed geologic stratigraphy to be applied world-wide.

Being lighter, isotope $^{16}O$ evaporates first from the water and forms the ice sheets. $^{18}O$ is left and this is what organisms use in their shells.

Imbrie, J. et al, 1990, SPECMAP Archive #1. IGBP PAGES/World Data Center-A for Paleoclimatology Data Contribution Series # 90-001. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA (file 17)
With this stratigraphy developed, it would be applied worldwide. See the lists in the lower left-hand corner (below) of the applicable marine sediment cores from the Atlantic and Pacific Oceans.

The below chart reflects 20 combined Atlantic (red) and 14 combined Pacific records (blue). They are similar.

Atlantic records are from ODP sites 980, 982, 983, 984, 552, 607, 664, 502, 658, 659, 925, 926, 927, 928, 929, and 1090, and sites RC13-229, GeoB1041, and GeoB1214.

Pacific records are from ODP sites 677, 846, 849, 1012, 1020, 806, 1123, 1143, and 1146, and sites V19-28, V21-146, PC72, and PC18

Original reference:
Lisiecki, L.E. and Raymo, M.E. 2009
Diachronous benthic δ¹⁸O responses during late Pleistocene terminations
Paleoceanography, 24, PA 3110, doi:10.1029/2009PA001732
ETP (red) with $^{18}O$ (blue) isotope superimposed upon graph.

- Time is normalized
- Graph lines are smoothed

ETP set up conditions for ice sheets, it takes 6K years for those conditions to be expressed on earth as ice sheets.
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In Chapter 4, the newsreel will continue to explore:

a. Exclusions or ground rules for our presentation. (keeping it focused)

b. Feedback and associated mechanisms

c. Setting the stage for glacial activities during the Pleistocene