Is there a Western Indian Ocean “Coral Triangle”?

David Obura

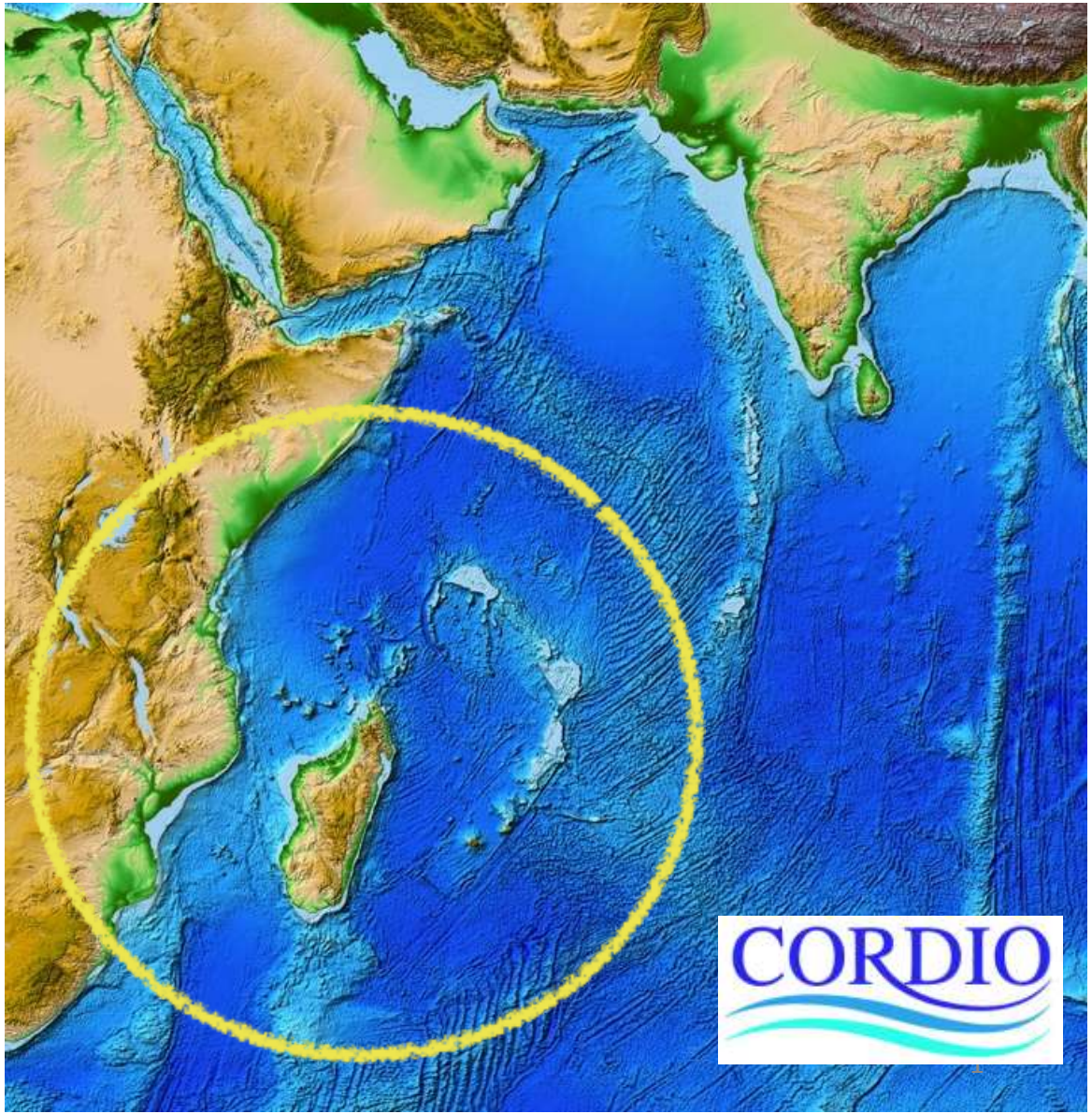
with Melita A. Samoilys, Johann R.E. Lutjeharms*, Juliet Hermes, Chris Reason, Raymond Roman, Charine Collins, Lorenzo Alvarez-Filip, Denis Macharia

** Professor Johann Reinder Erlers Lutjeharms, the world's pre-eminent expert on the oceanography of the Agulhas Current, sadly passed away on 8 June 2011. This talk is dedicated to him.*

Marine Science for Management programme, WIOMSA. 2008-11

26 ICRI General Meeting
Indian Ocean Day.
13 December 2011, La Reunion

www.cordioea.org



What do I mean by a “coral triangle”?

Geo-physical integrity (geology, oceanography)

Ecological integrity (connectivity, productivity, diversity)

Historical integrity (evolutionary dynamics)

Human affairs (politics, culture, history)

Outline

1) TODAY

Biodiversity patterns - corals

The South Equatorial Current and the Mozambique channel

2) EVOLUTIONARY HISTORY

Geology

- Plate tectonics
- Mascarene-Reunion hotspot

Marine climate and habitats

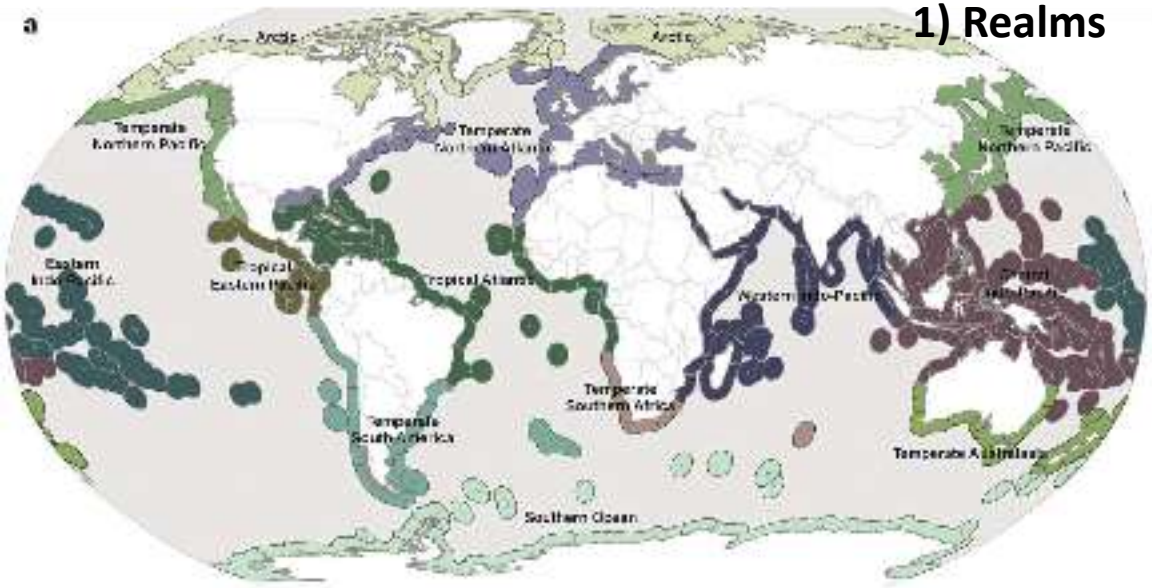
- Paleoclimate and marine carbonatesContinental shelf area and shallow seas
- Connectivity

Coral phylogeny

3) SO WHAT?

Conclusions

Relevance



Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas (MEOW)

Spalding et al. 2008. Bioscience 57:373-383

2) Provinces

Scleractinian corals - Global Marine Species Assessment (GMSA)
IUCN Red List of Threatened Species

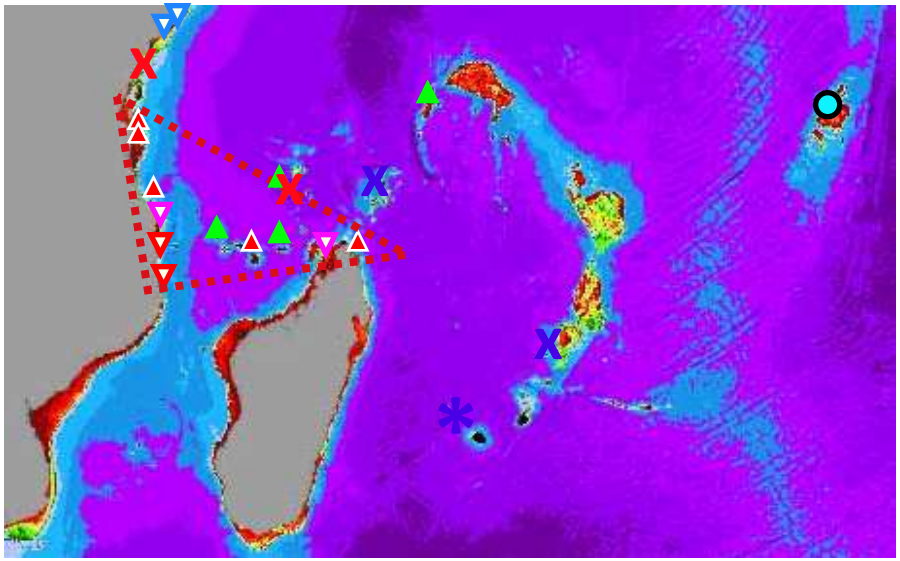
3) Ecoregions

Results

1.All West Indo-Pacific provinces group together, except the Andaman Seas, which group with the Central Indo-Pacific provinces.
2.Within the West Indo-Pacific, the Western Indian Ocean Province (#20) ecoregions are the core/central cluster
3.Within the Western Indian Ocean Province (#20) the East African Coast (95) and West & North Madagascar (#100) are the most closely related ecoregions.

Survey data, coral species assemblages at 24 sites in the WIO

- 413 coral species

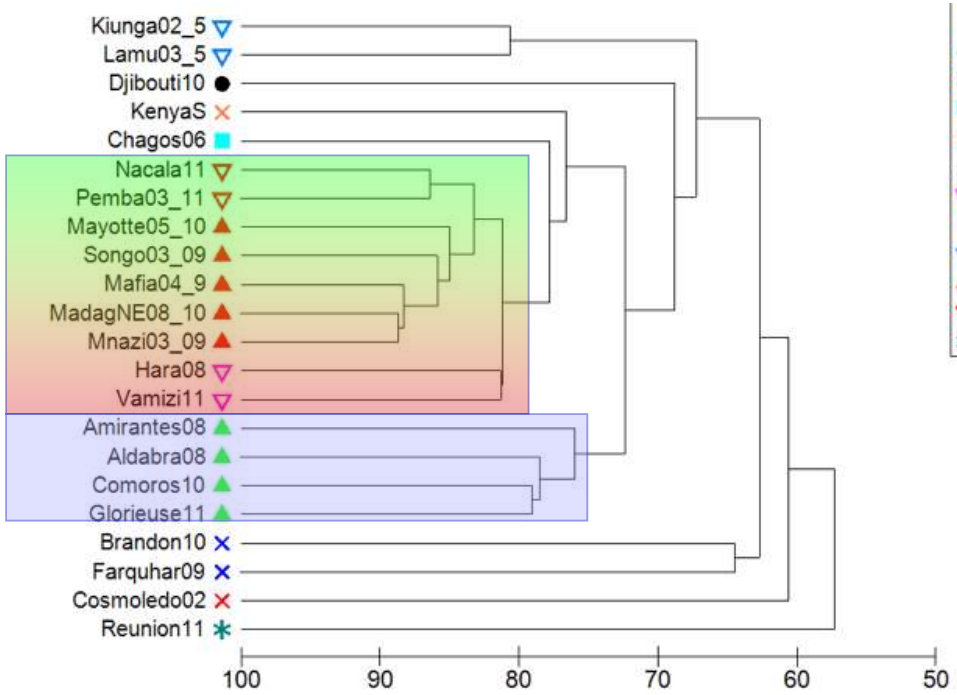


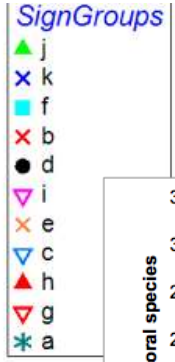
- Central cluster of sites - mixed EA coral coast and W&N Madagascar sites. Highest diversity in the region,
- Comorian and Seychelles islands

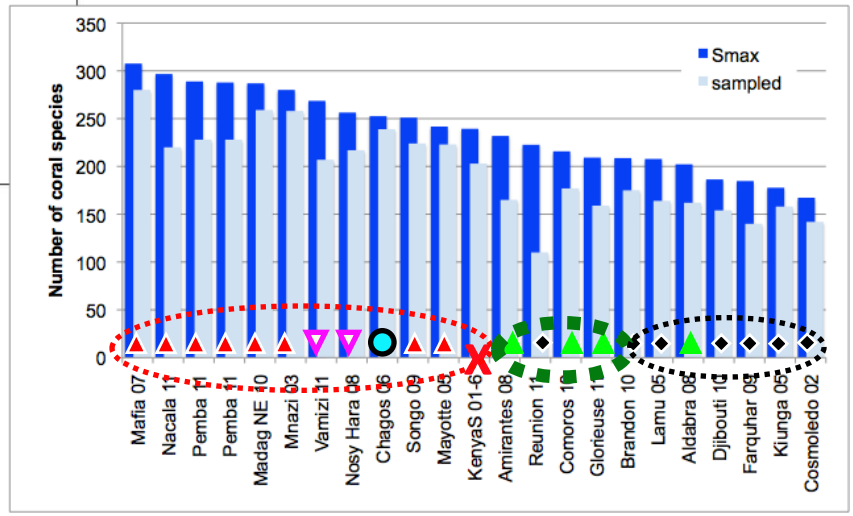
There is no biological boundary between the mainland and islands!!!

Core high biodiversity region in the northern Mozambique channel

Concentric/radial pattern around the northern Mozambique channel

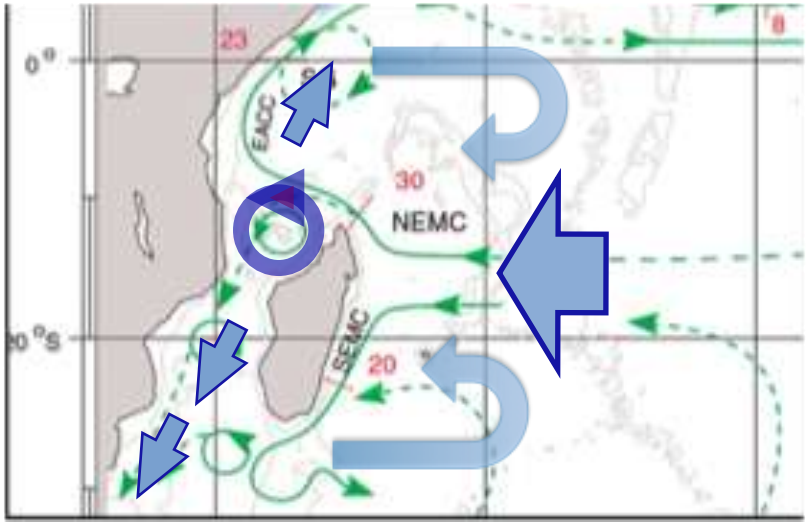






Oceanographic features that support these patterns

1) South Equatorial Current - East-west transport of corals across the Indian Ocean from the Indonesian region.



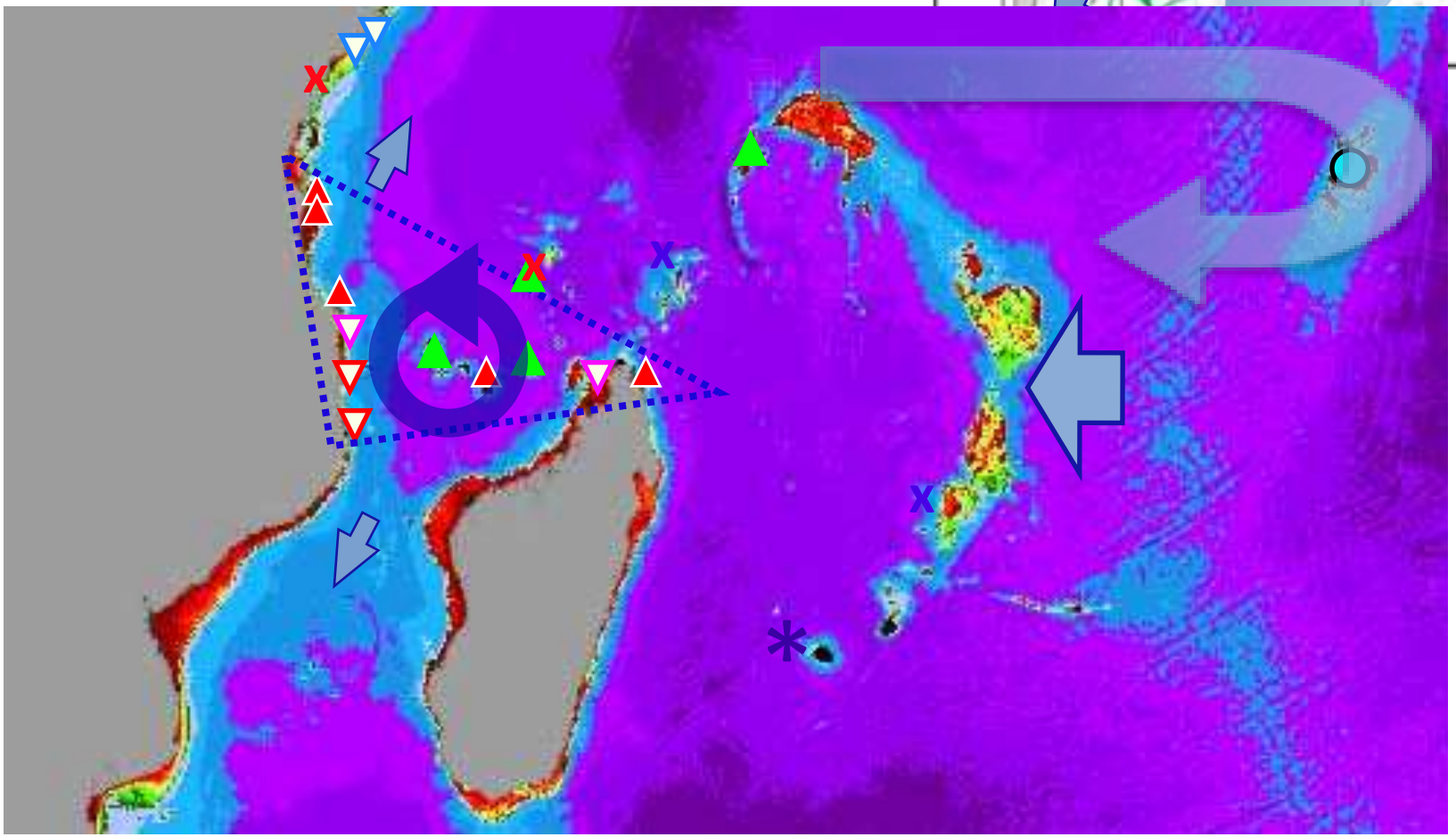
2) Mozambique channel gyres & eddies result in high connectivity across the northern Mozambique Channel and potential for accumulation of genetic and larval material

3) Currents flow north and south from the northern Mozambique Channel, with some eddies and return flow in the north (Seychelles/Chagos) and south (Mauritius/Reunion)

QuickTime™ and a
JVT/AVC Coding decompressor
are needed to see this picture.

Anti-cyclonic eddies – counter-clockwise rotation, positive sea level anomalies, warm core eddies.

Cyclonic eddies – clockwise rotation, negative sea level anomalies, cold core eddies.


EACC
NEMC
SEMC
0°
20°S
23
30
20

Outline

1) TODAY

Distinct regional faunal identity, encompassing the WIO, northwest Indian Ocean and Red Sea/Gulfs regions

High diversity core region centred on the NMC (corroborated by other studies)

Currents that distinguish the NMC as an accumulation center, and source for other regions within the WIO

J. Biogeography - MS submission

2) EVOLUTIONARY HISTORY

Geology

- Plate tectonics
- Mascarene-Reunion hotspot

Marine climate and habitats

- Paleoclimate and marine carbonatesContinental shelf area and shallow seas
- Connectivity

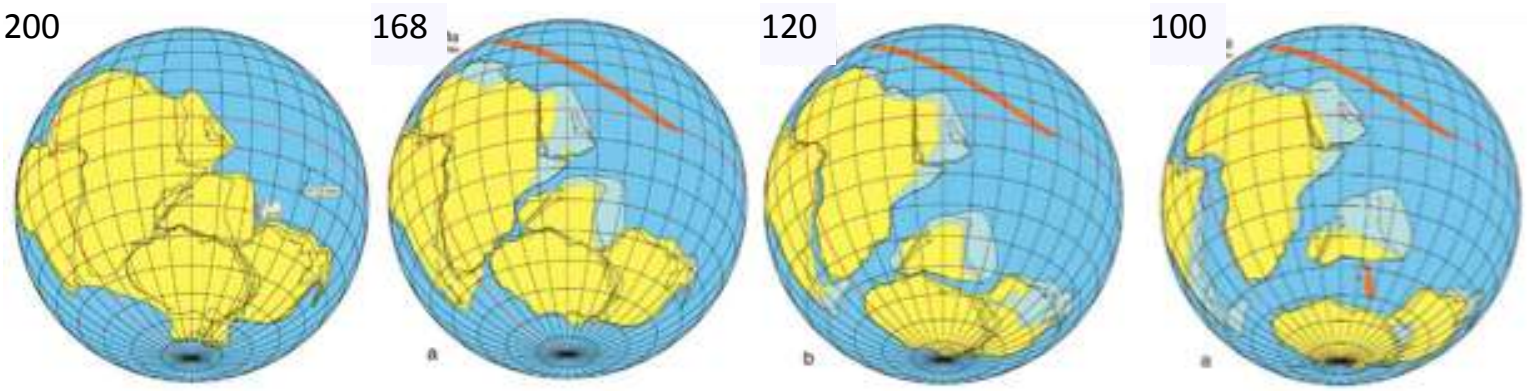
Coral phylogeny

3) SO WHAT?

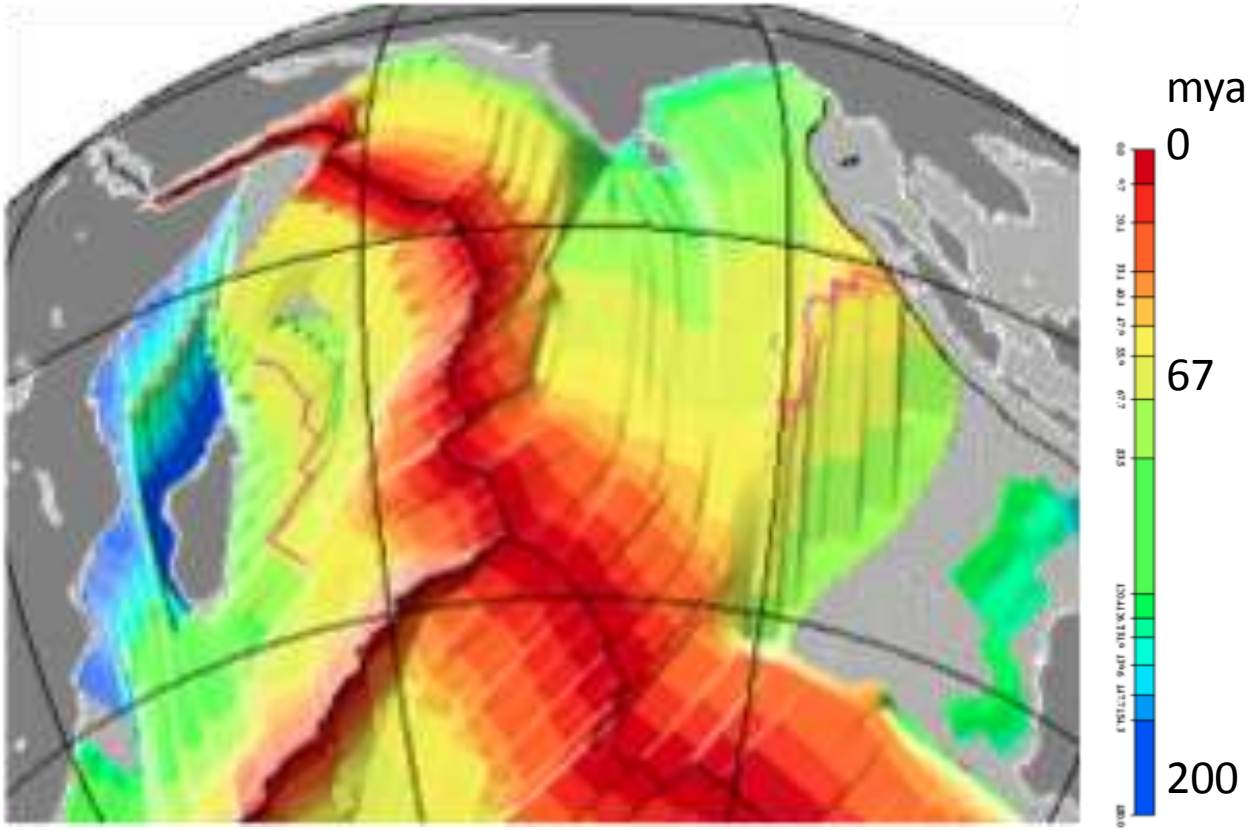
Conclusions

Relevance

Plate tectonics



Age of the ocean floor



The Mozambique channel has the oldest coastlines in the Indian Ocean

The Tethys Sea

mya

250 opening of Tethys Sea, eastern shore of Pangea

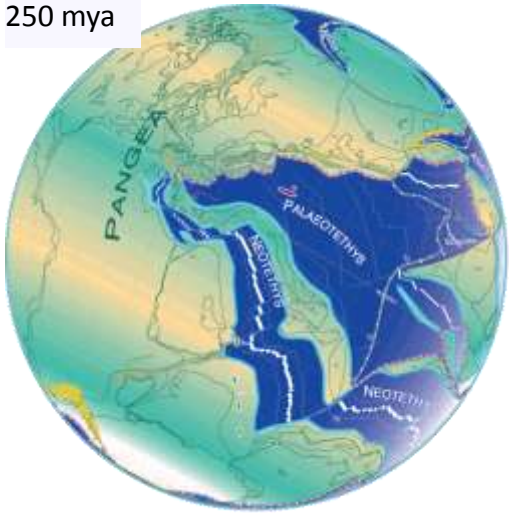
175 equatorial opening as breakup of Pangaea into Gondwana and Laurasia

150 greatest influence of Tethys - shallow seas between Laurasia and Gondwana -> shallow carbonates and main coral province globally

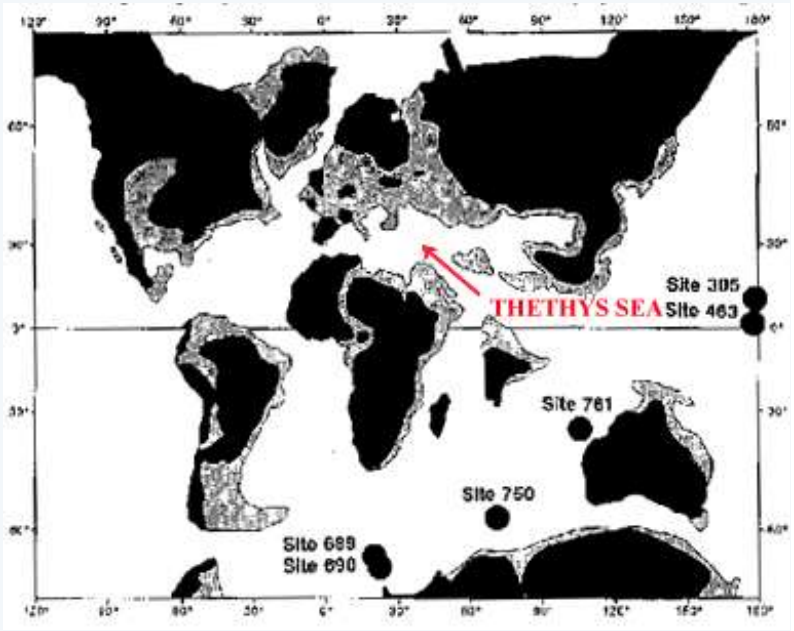
60-45 (Eocene) progressive obstruction by India, and by Africa/Middle East moving northwards

15 (Miocene) effective closure of Tethys

250 mya



70 mya. Shaded areas are shallow seas - drowned continental margins



70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Paleogene 66-23 my

Neogene 23-2.6 my

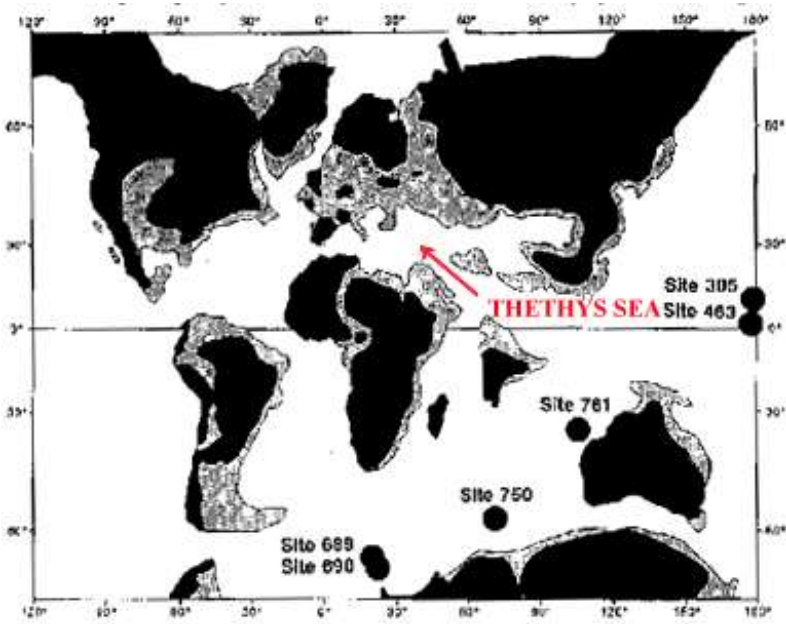
Quarterly 2.6-0

Cretaceous-Tertiary mass extinction

Eocene 55-35 mya

Miocene 24-5 mya

Tethys Sea decline



From 70 - 35 mya, the Tethys Sea was the most extensive province of reef growth on the planet, with the largest reefs and most diverse coral fauna

From 24 mya, the Indo-Malayan region started to form as Australia bumped into SE Asia, forming the high diversity Coral Triangle region

70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

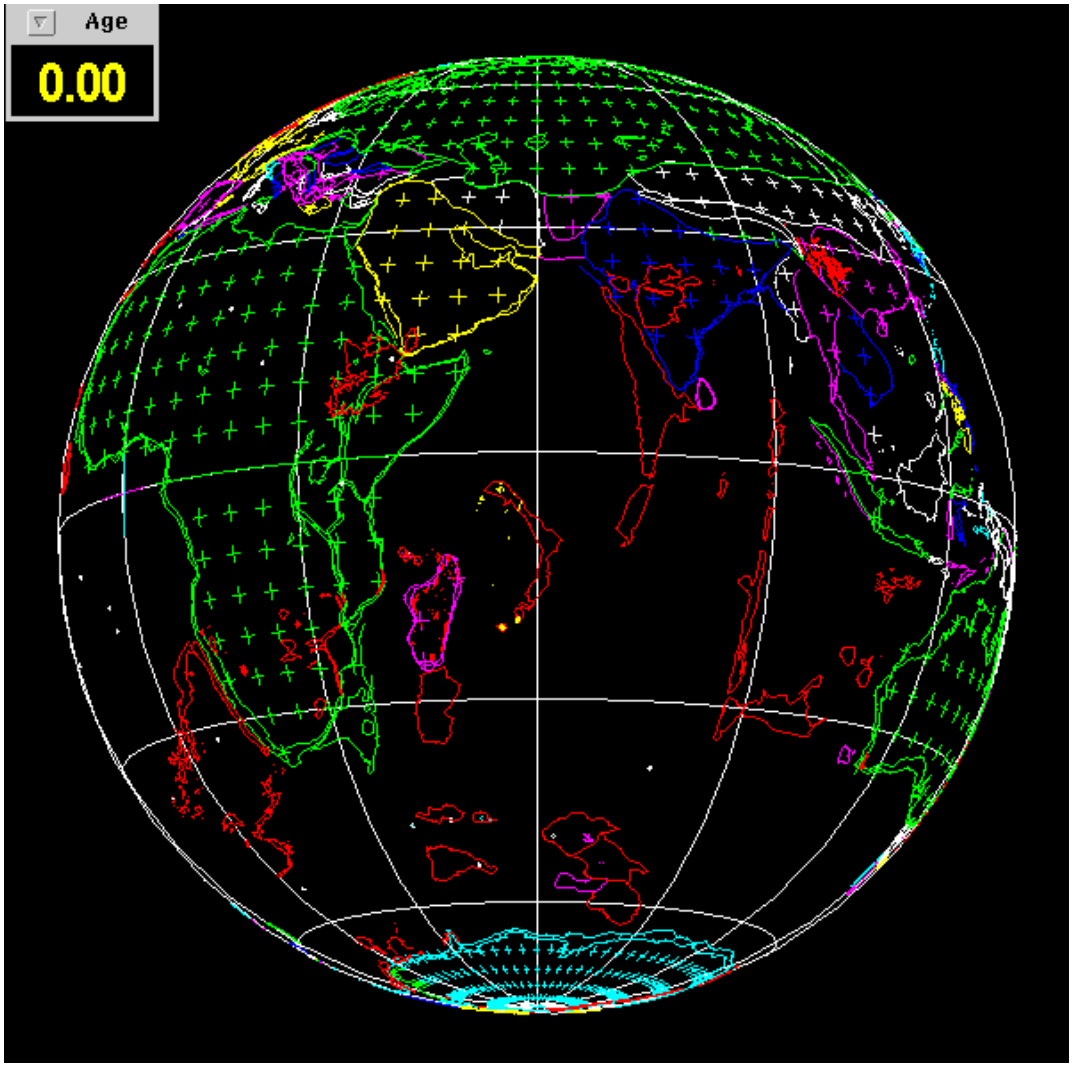
Paleogene 66-23 my

Neogene 23-2.6 my

Quarternary 2.6-0

Plate tectonics animation,

67 mya to present



Legend

TECTONIC PLATES

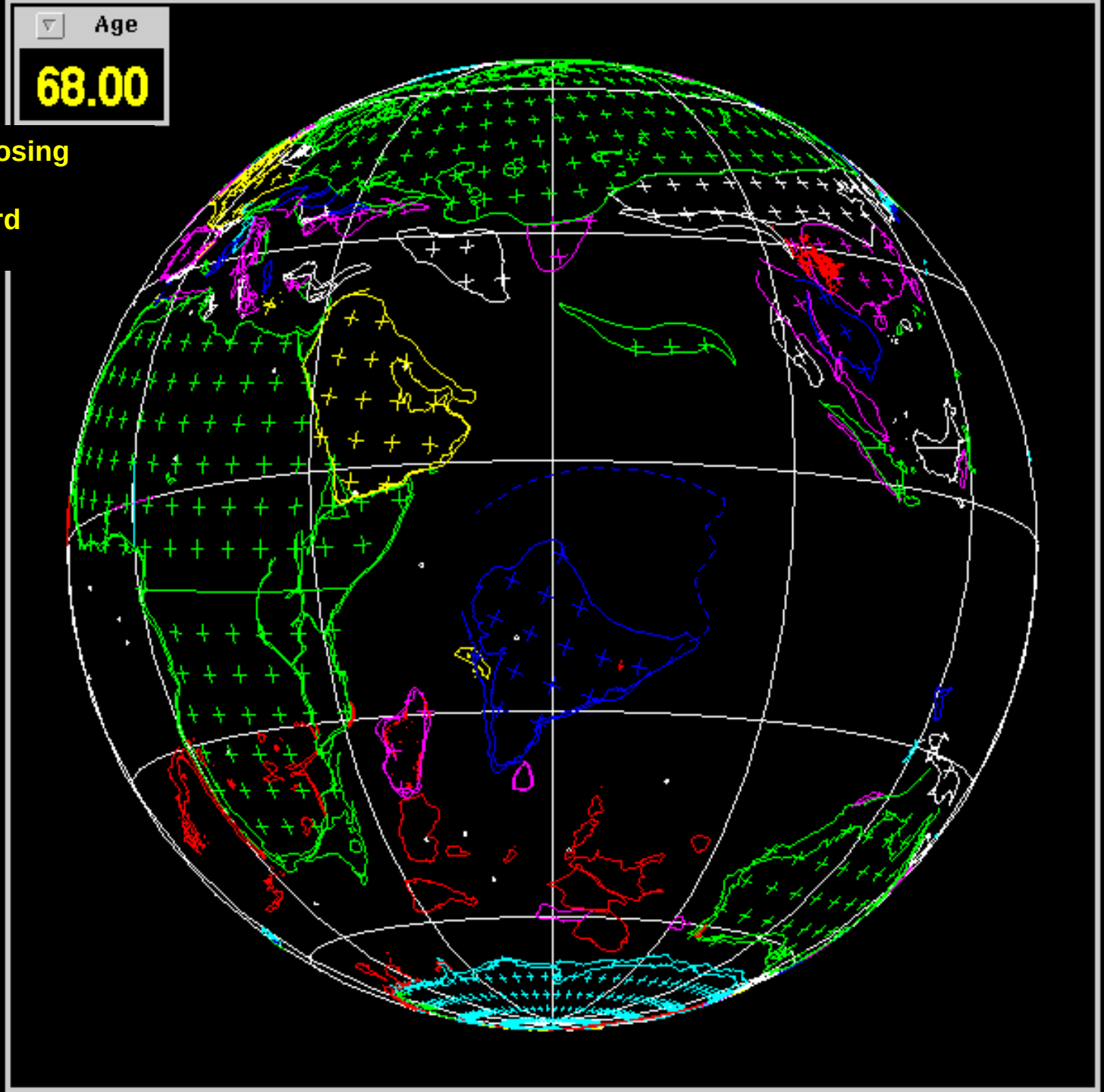
Varied colour - craton/continental crust outlines

HOTSPOTS

Red - Large Igneous Provinces (hotspot activity)

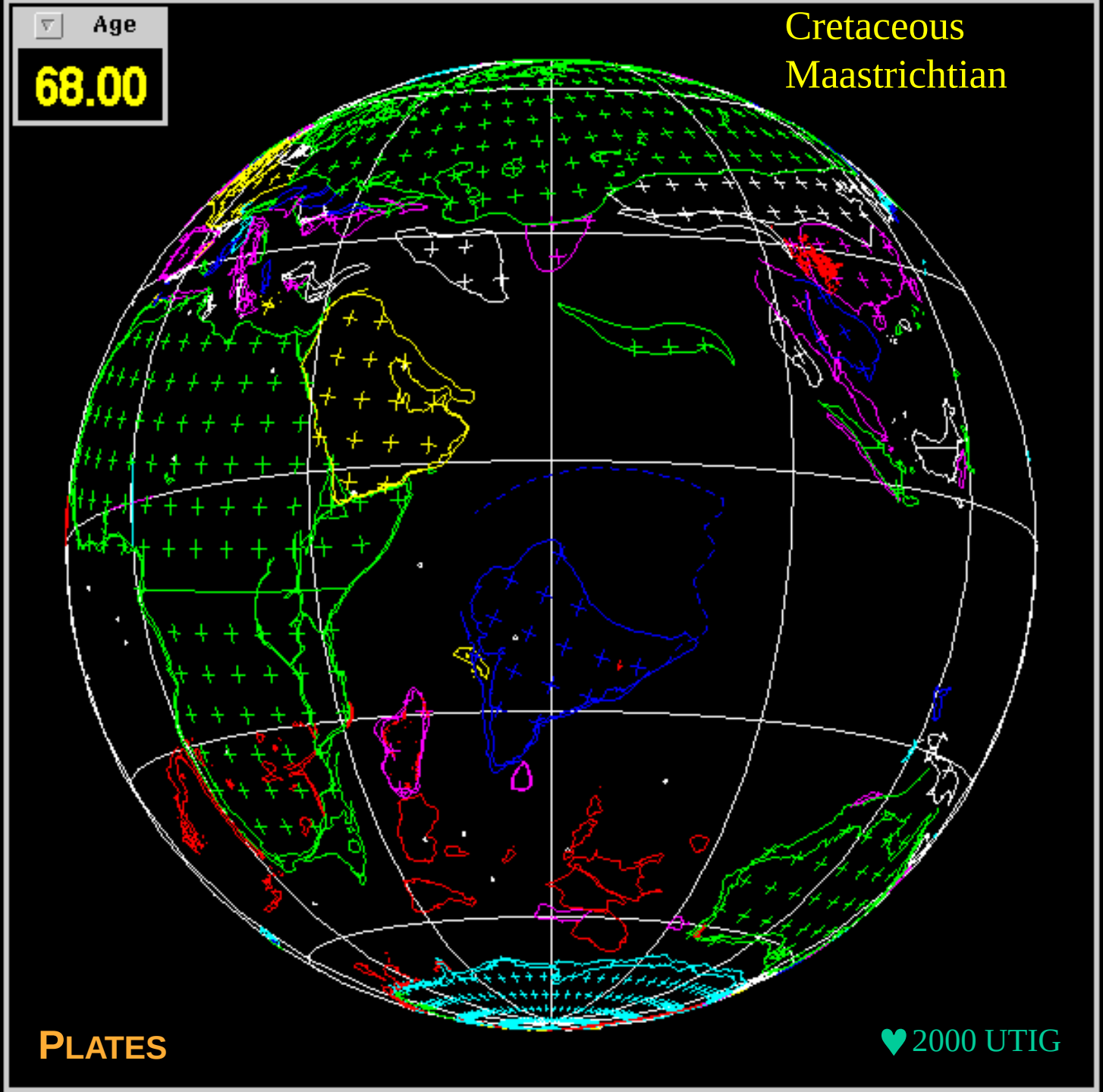
By
L.A. Lawver, M.F. Coffin, L.M. Gahagan, D.A. Campbell, and J.-Y. Royer

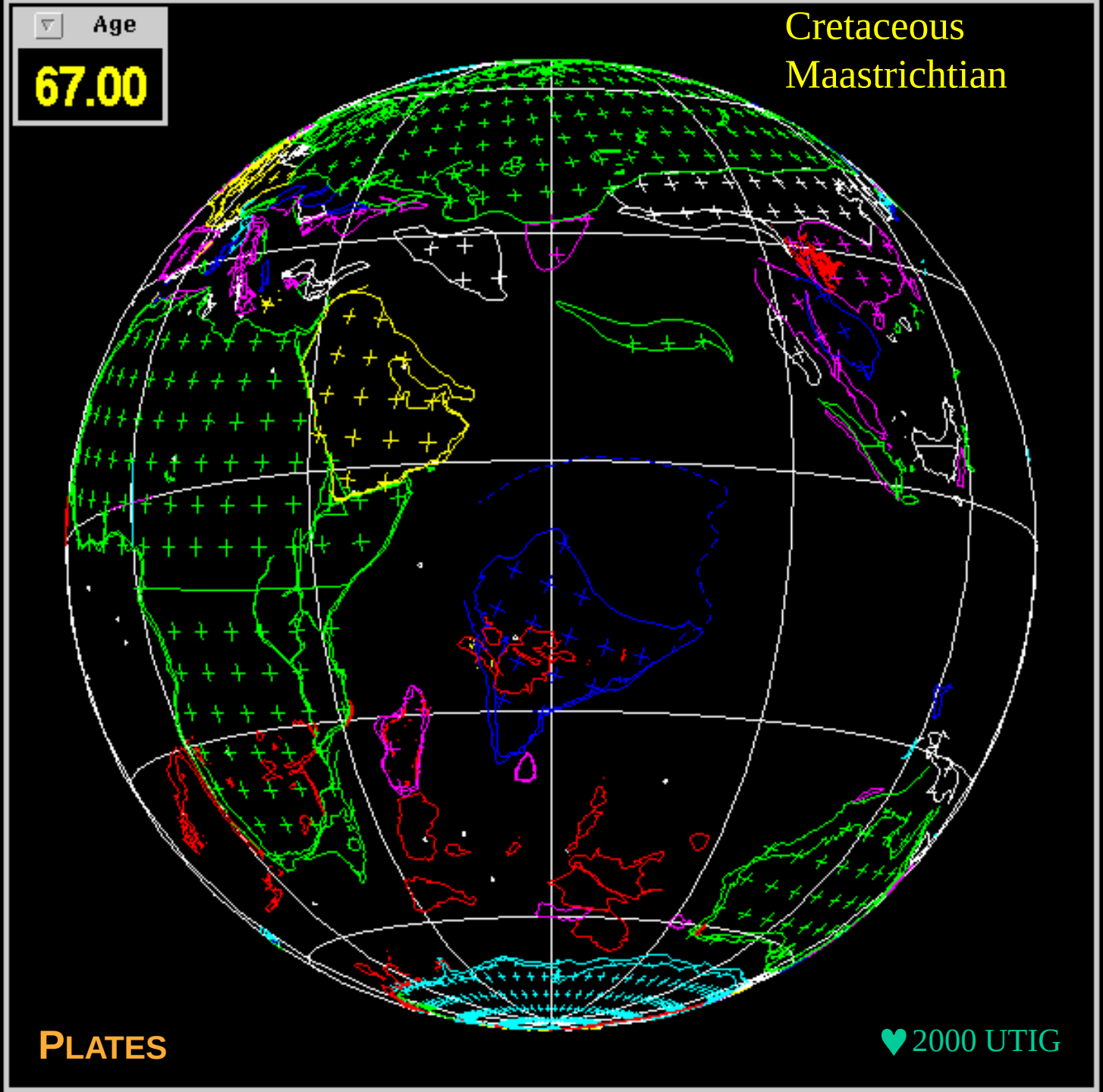
Sponsors: Conoco, Elf, Exxon-Mobil, Norsk Hydro, and Statoil.

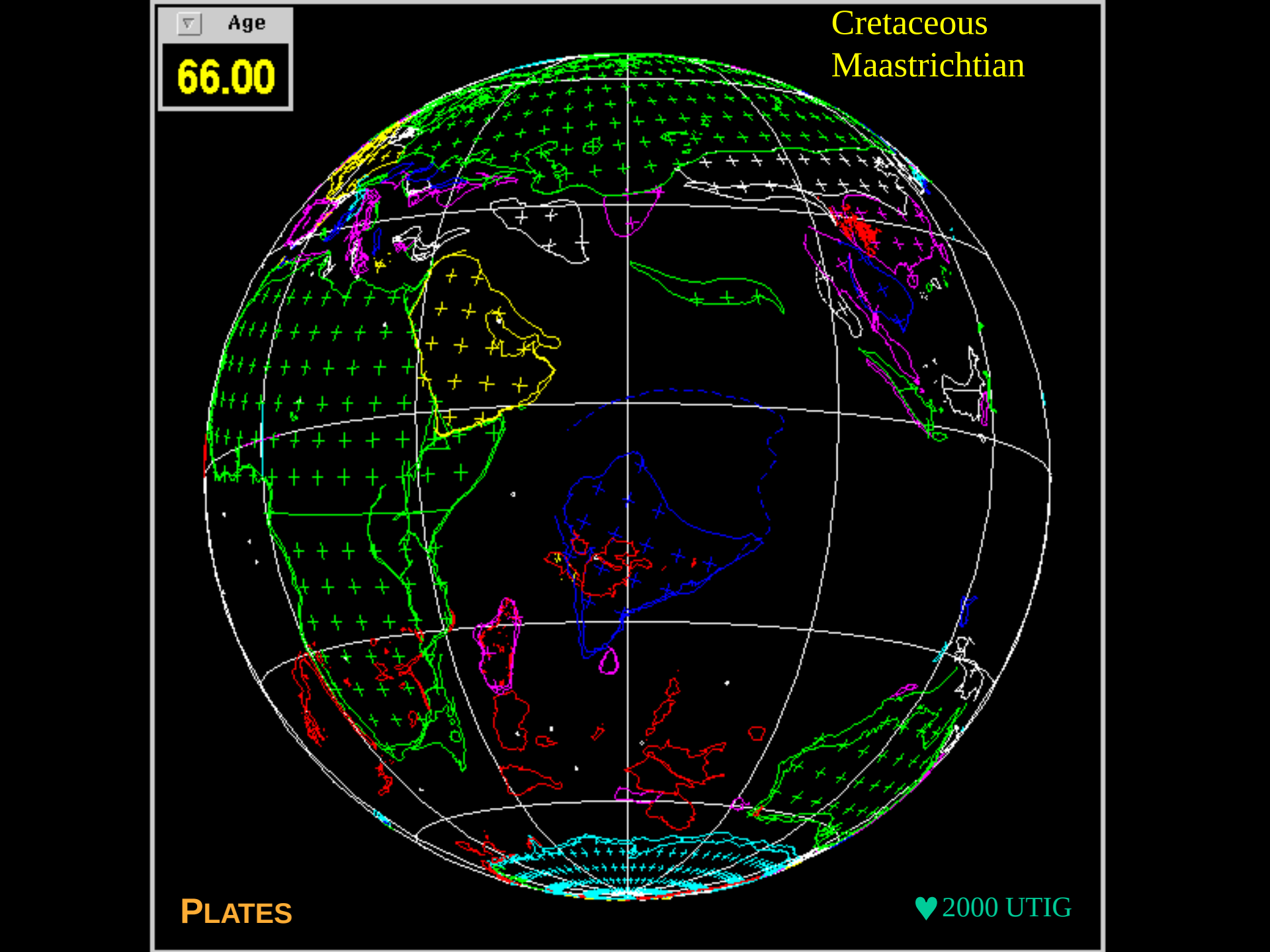


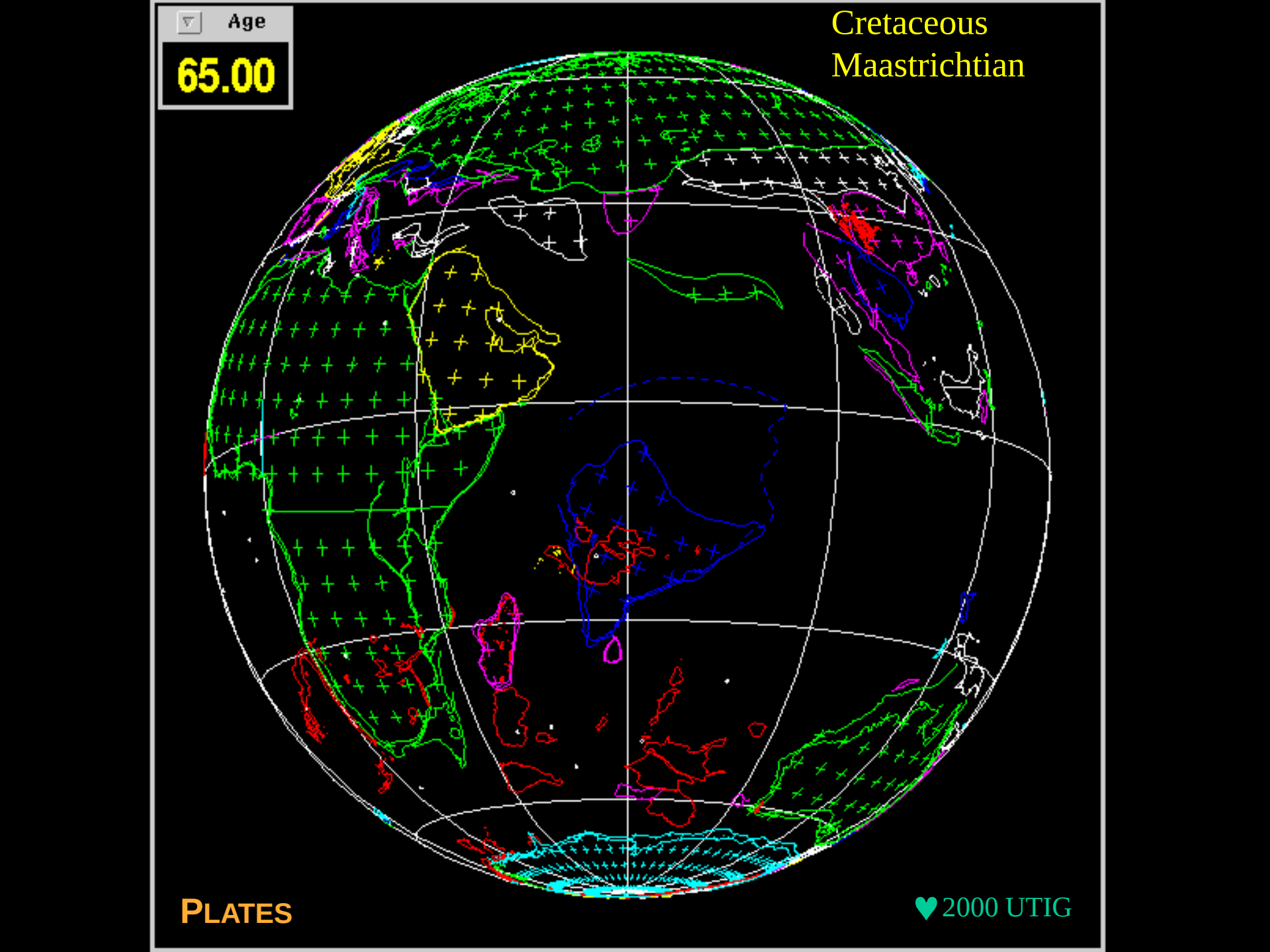
i - Tethys closing

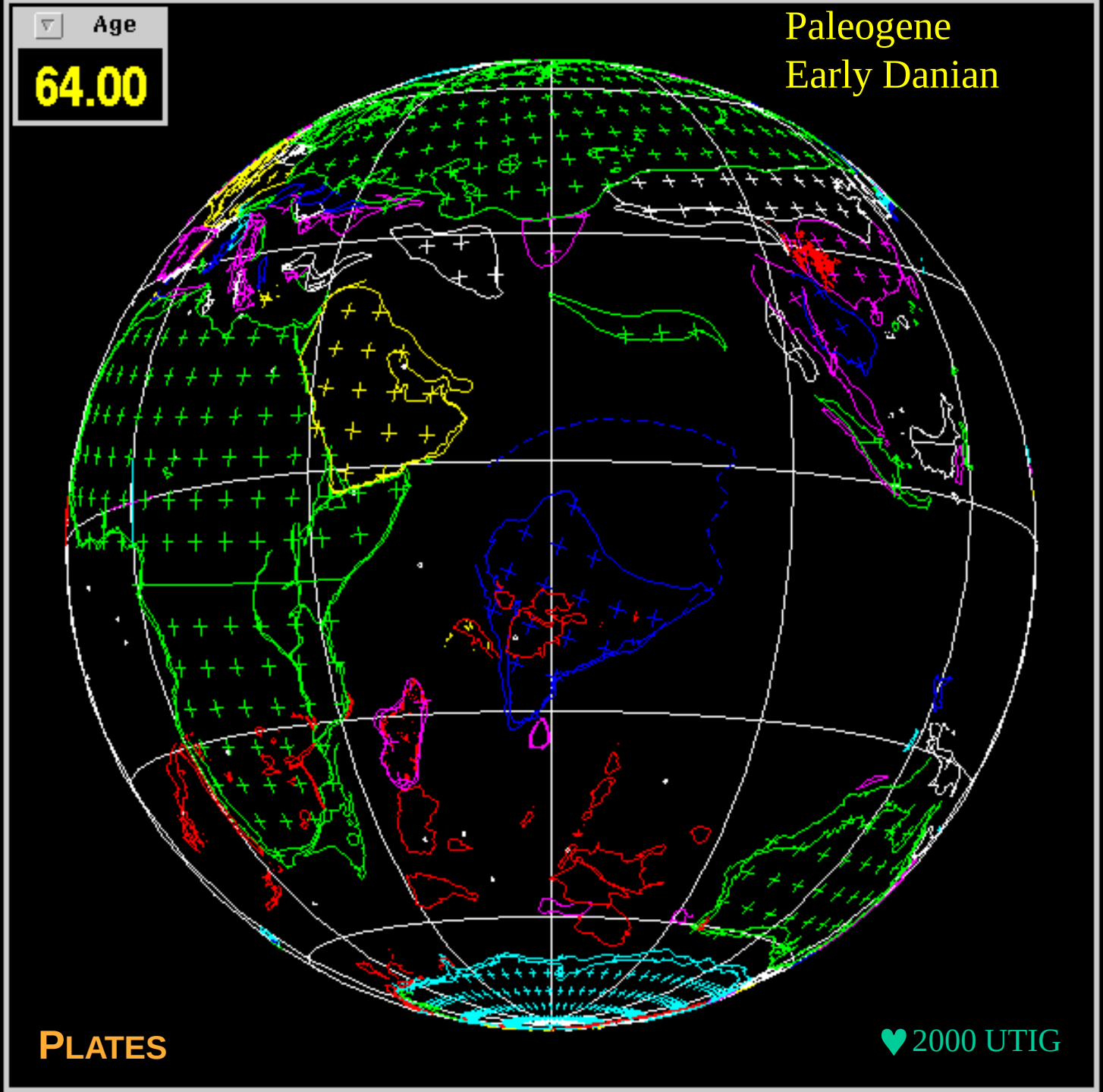
ii - northward movement

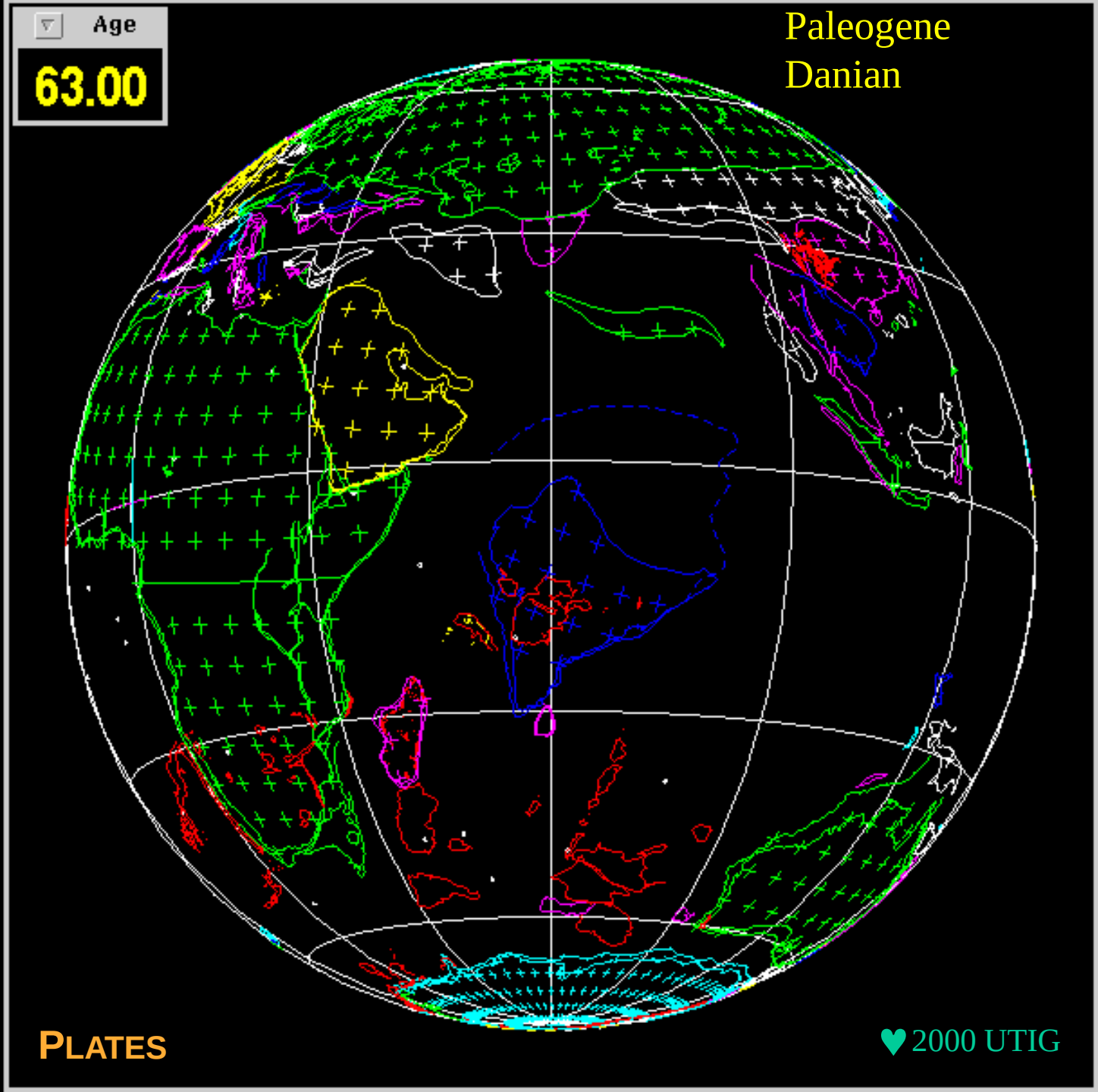

Age
68.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

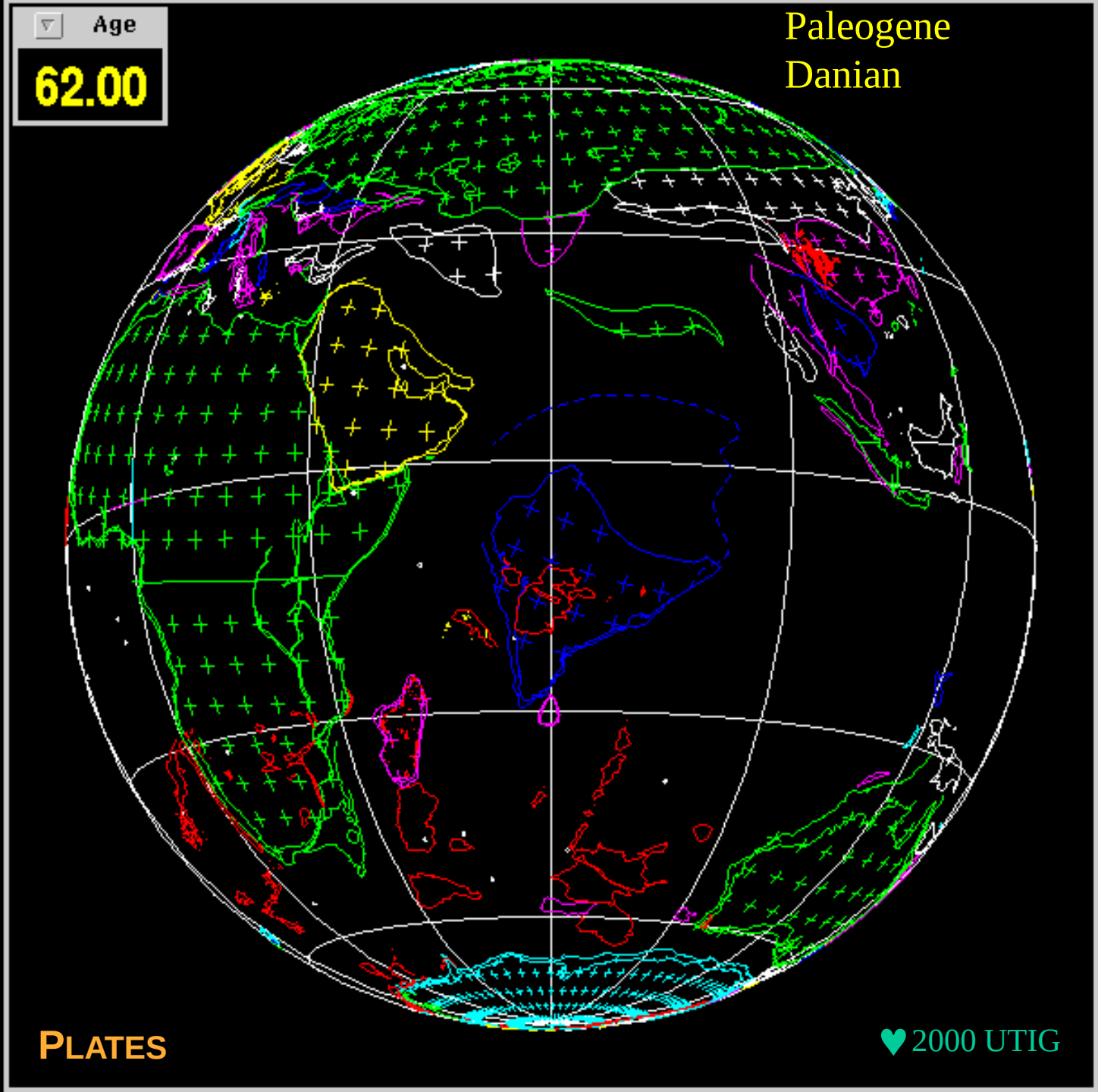

Age
67.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

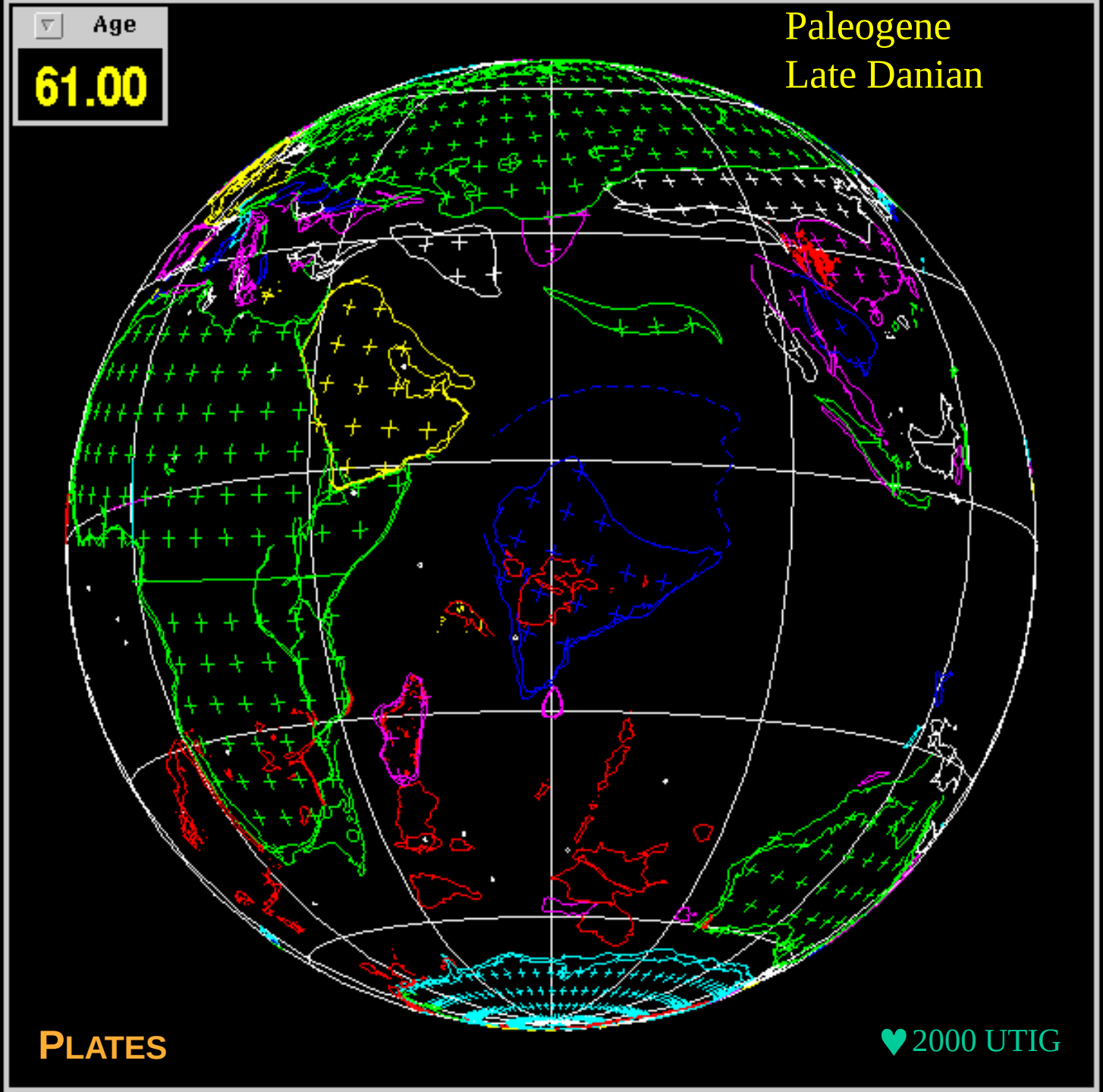

Age
66.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

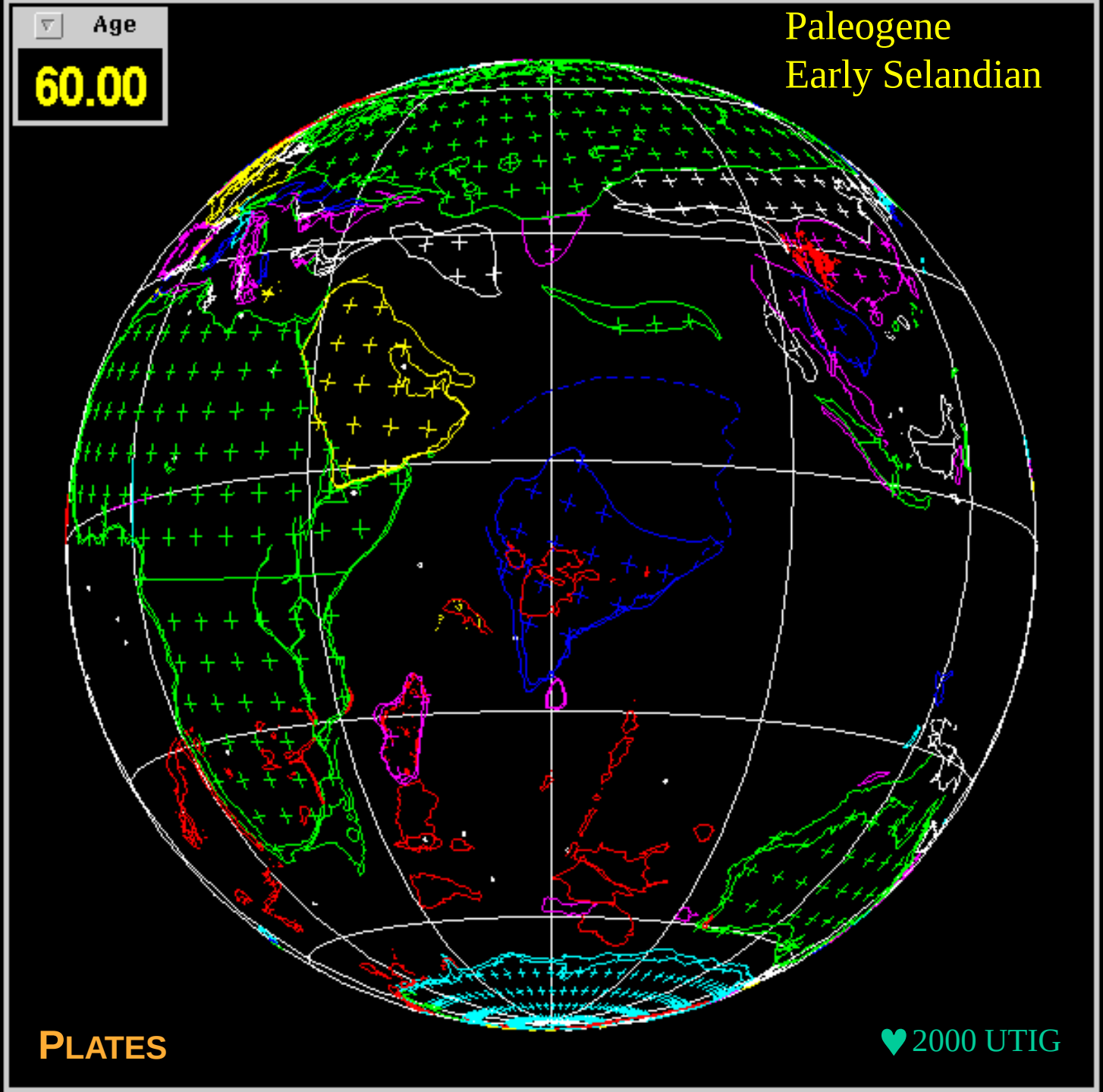

Age
65.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

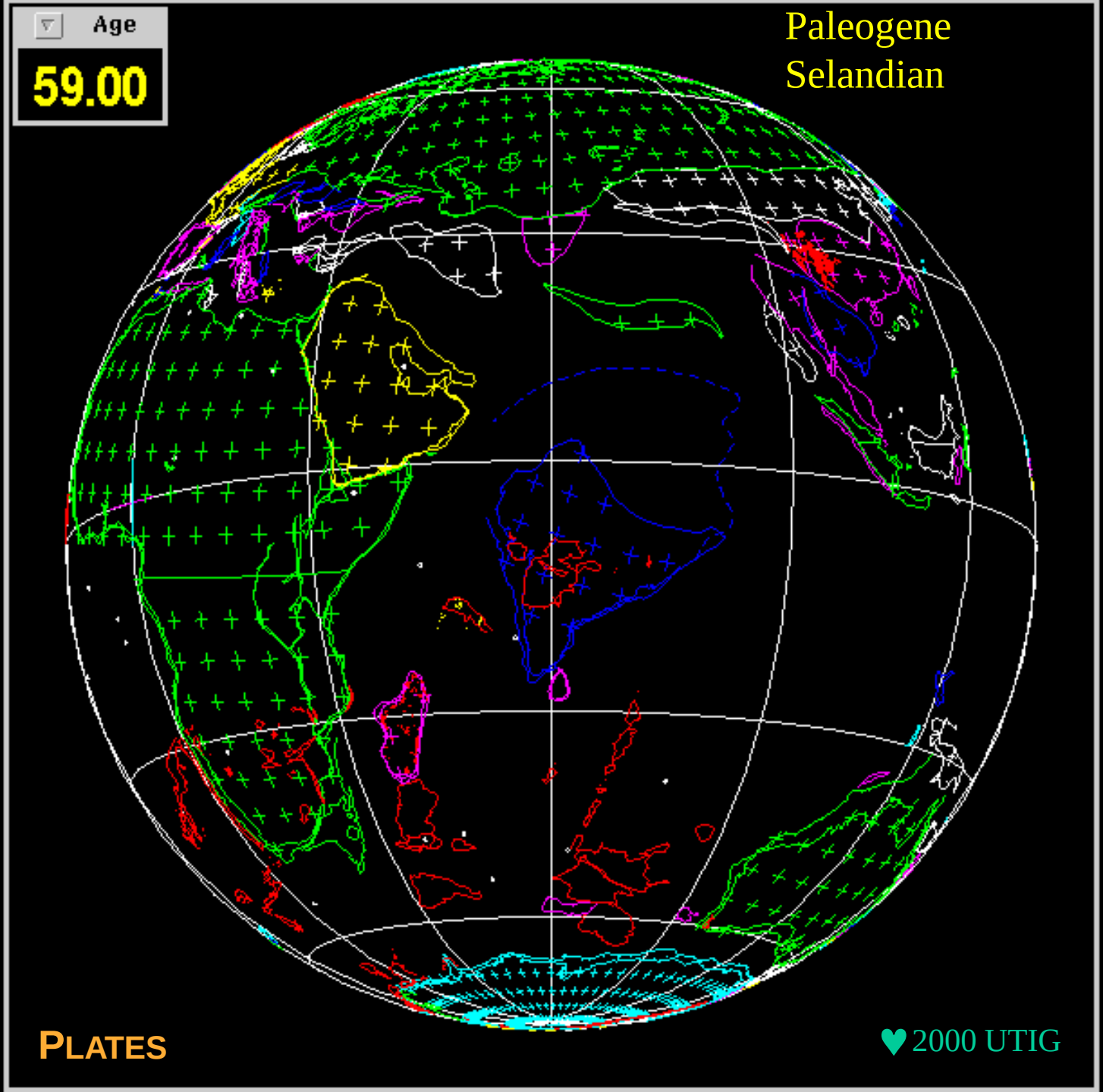

Age
64.00
Paleogene
Early Danian
PLATES
♥2000 UTIG

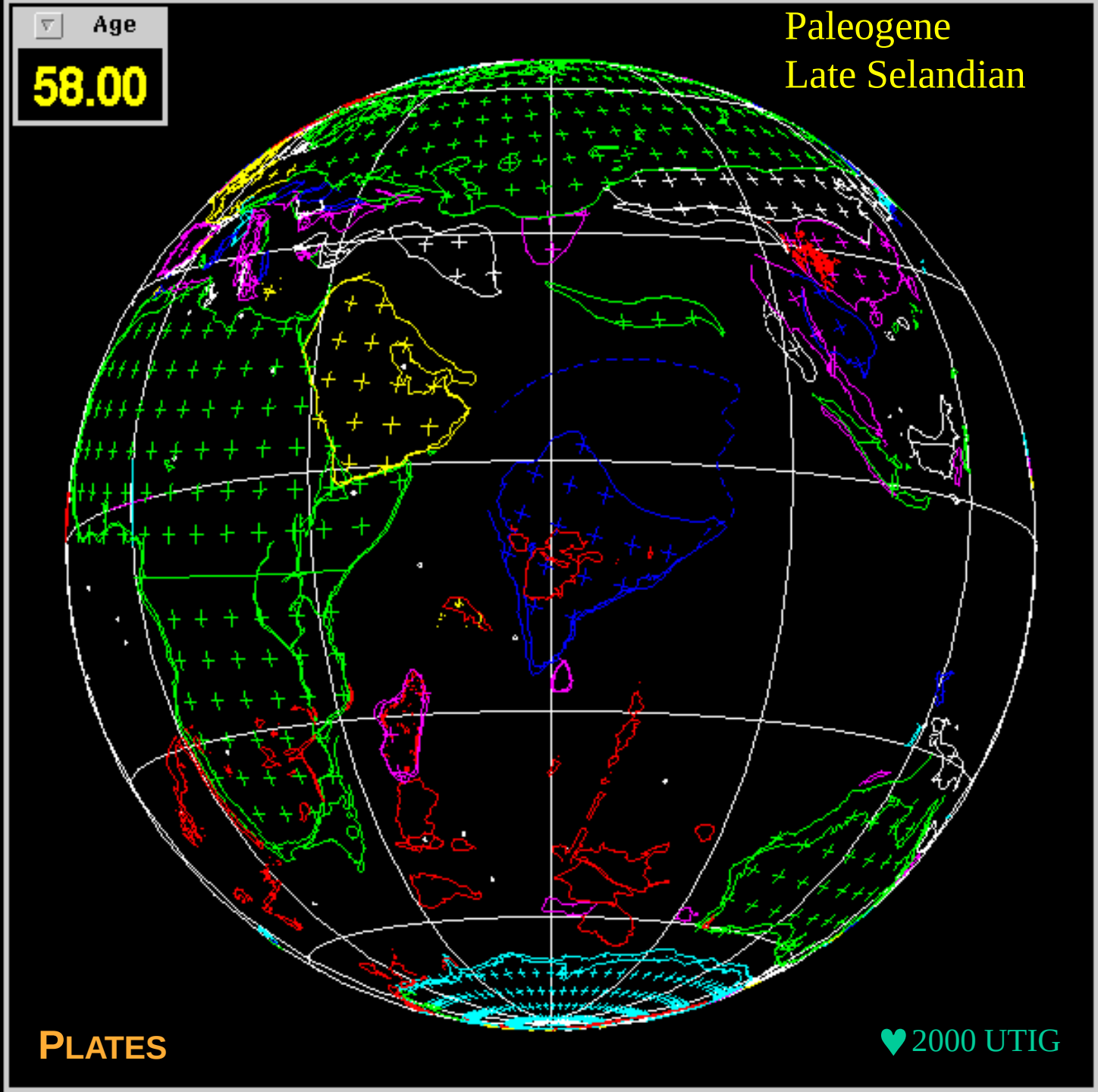

Age
63.00
Paleogene
Danian
PLATES
♥2000 UTIG

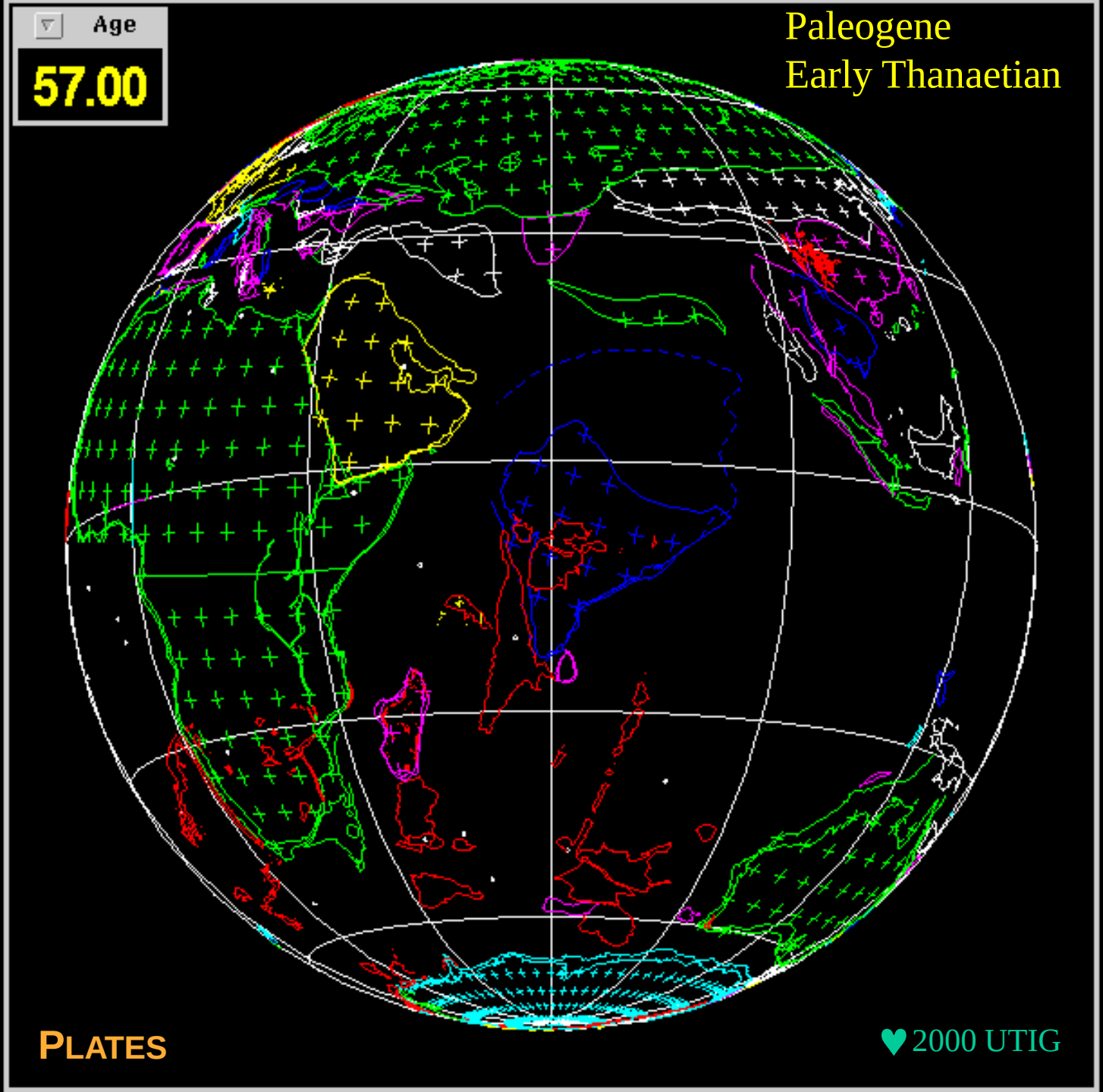

Age
62.00
Paleogene
Danian
PLATES
♥2000 UTIG

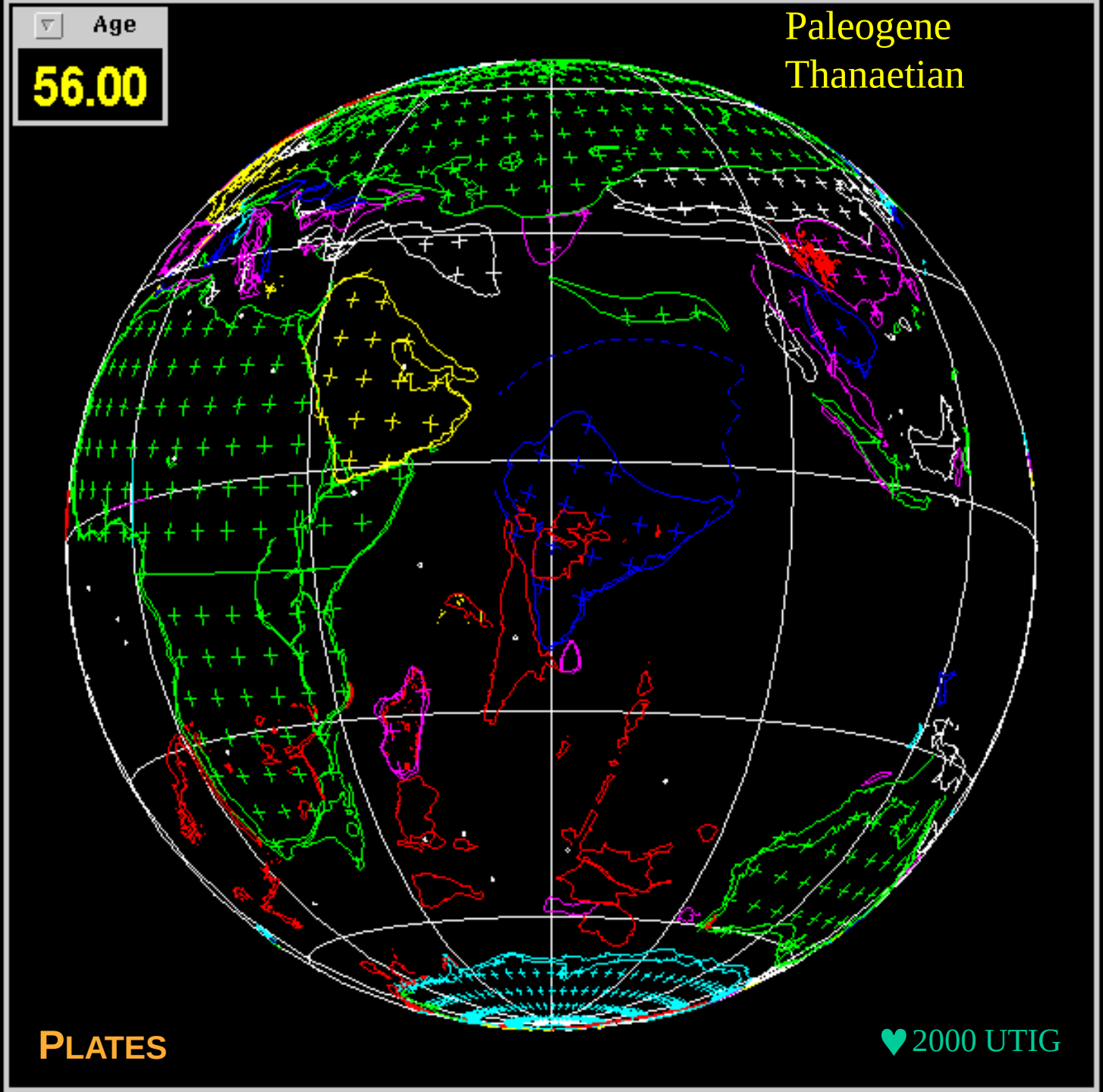

Age
61.00
Paleogene
Late Danian
PLATES
♥2000 UTIG

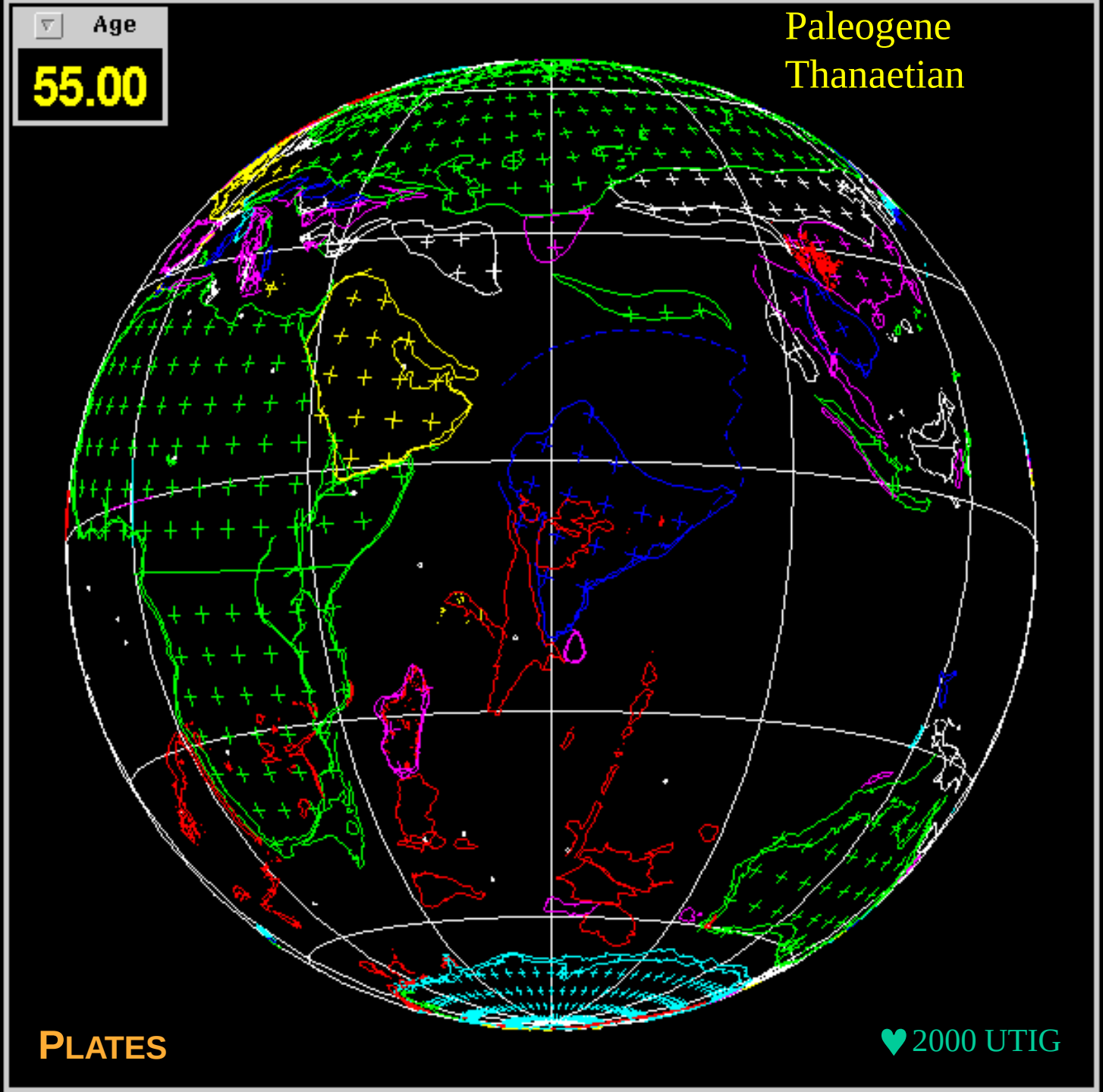

Age
60.00
Paleogene
Early Selandian
PLATES
♥2000 UTIG

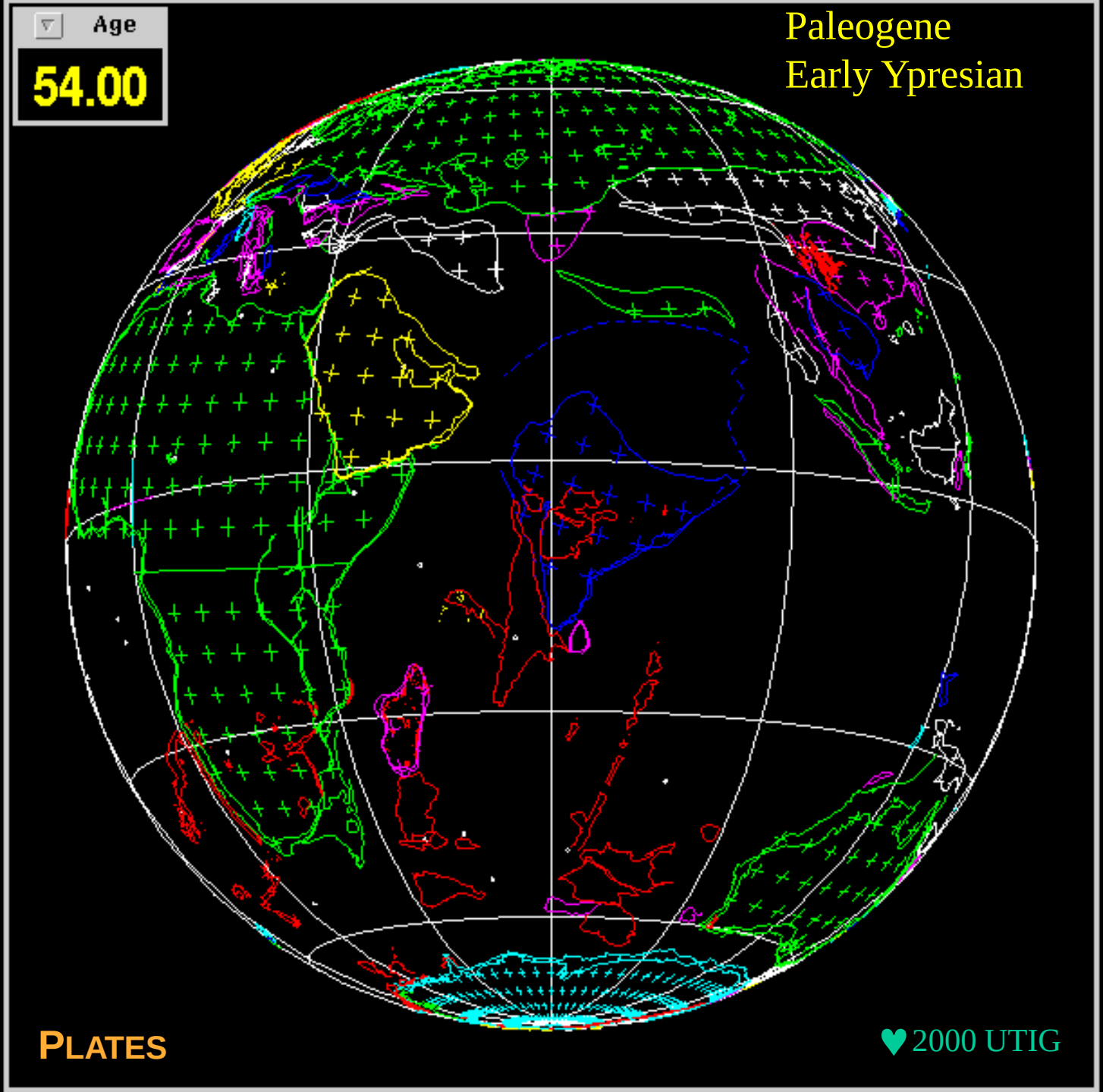

Age
59.00
Paleogene
Selandian
PLATES
♥2000 UTIG

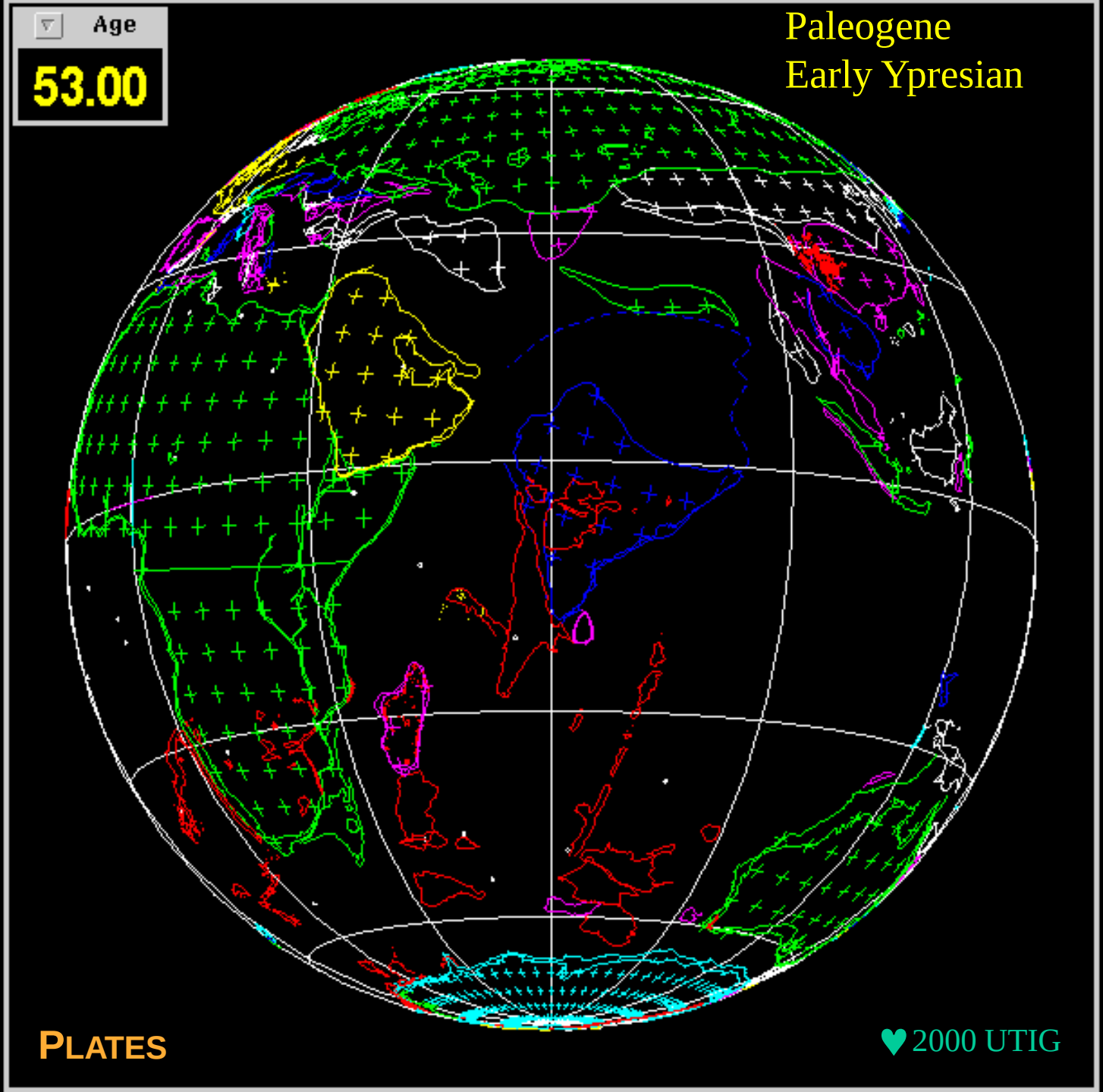

Age
58.00
Paleogene
Late Selandian
PLATES
♥2000 UTIG

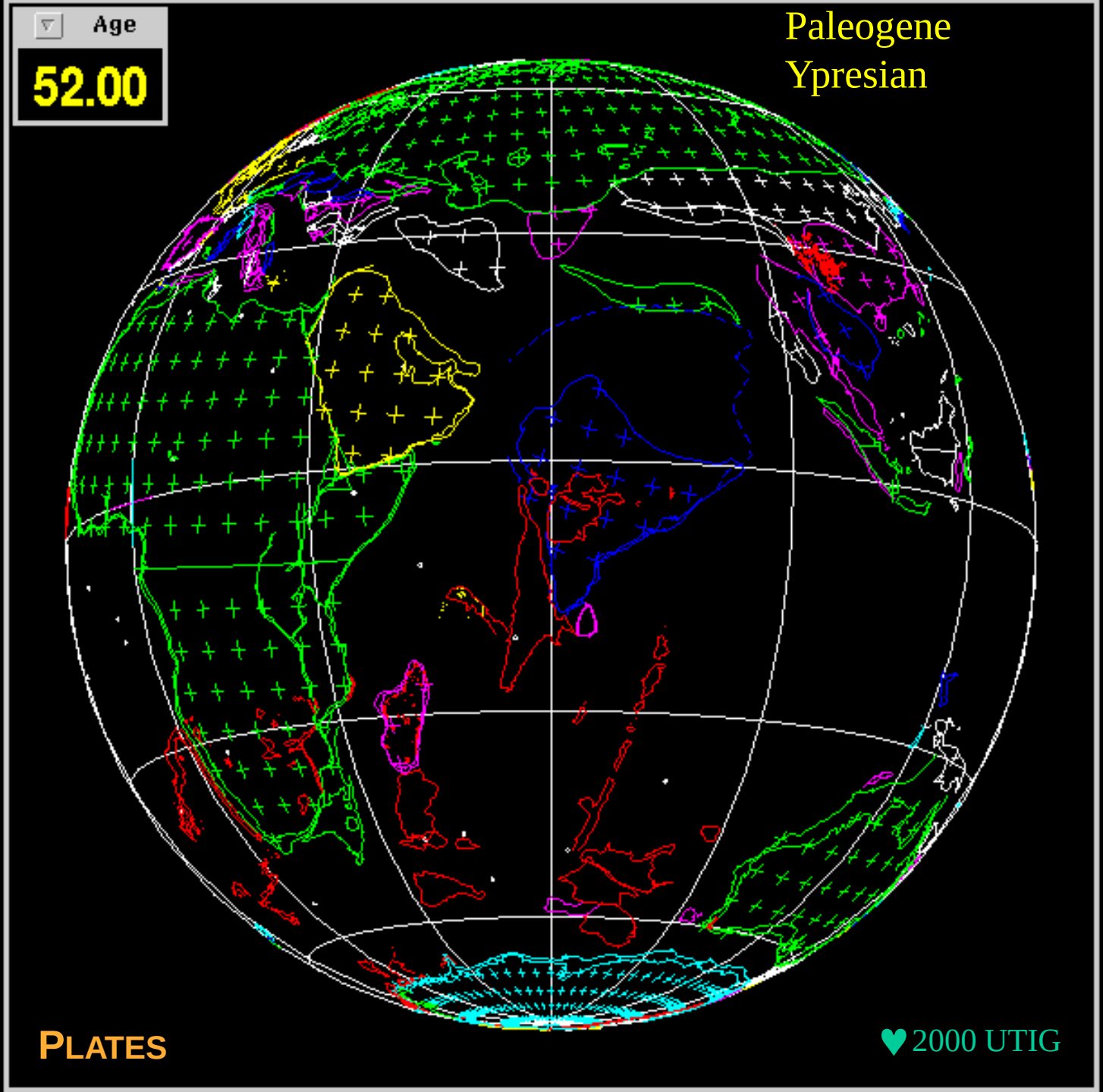

Age
57.00
Paleogene
Early Thanaetian
PLATES
♥2000 UTIG

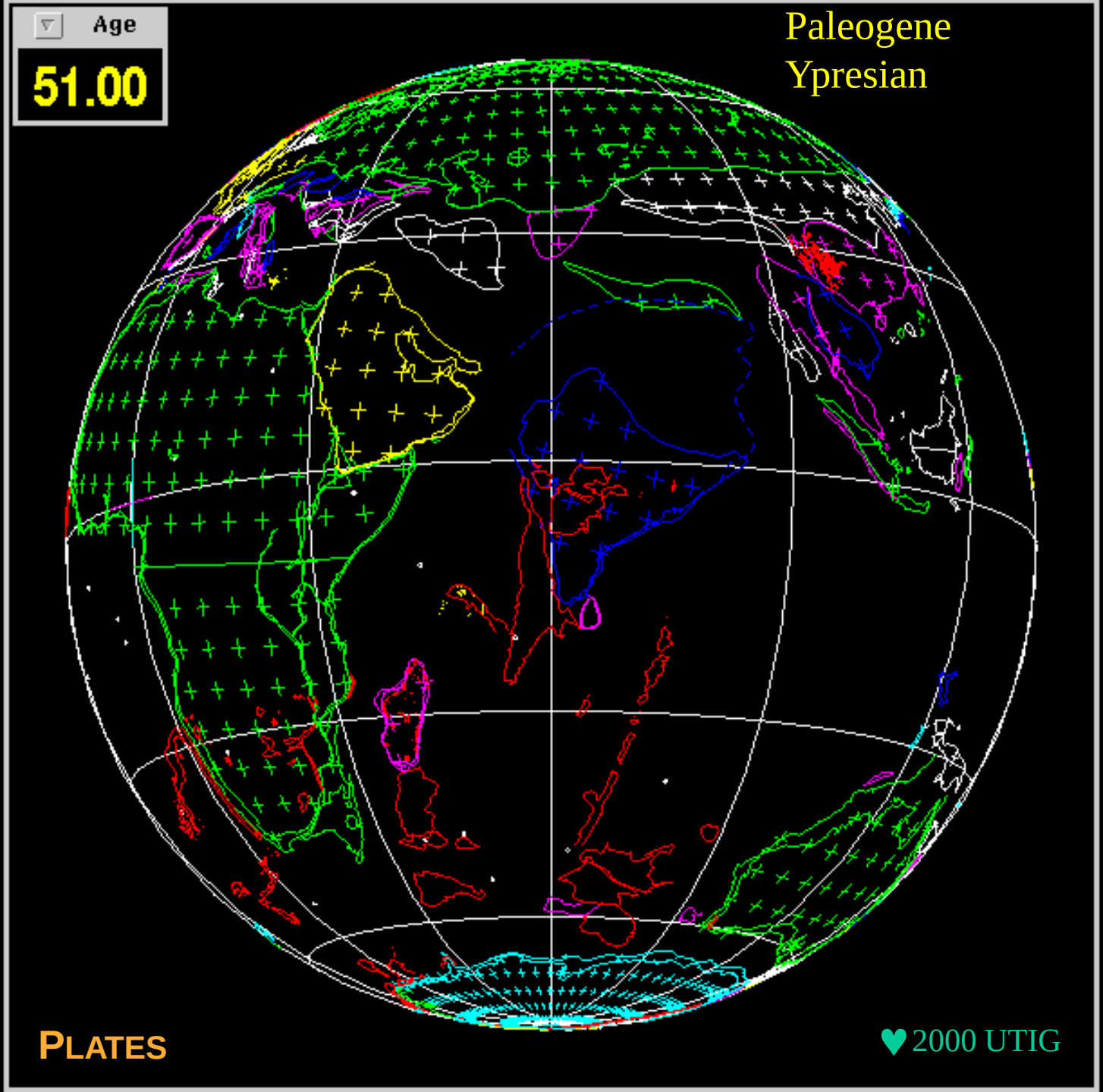

Age
56.00
Paleogene
Thanaetian
PLATES
♥2000 UTIG

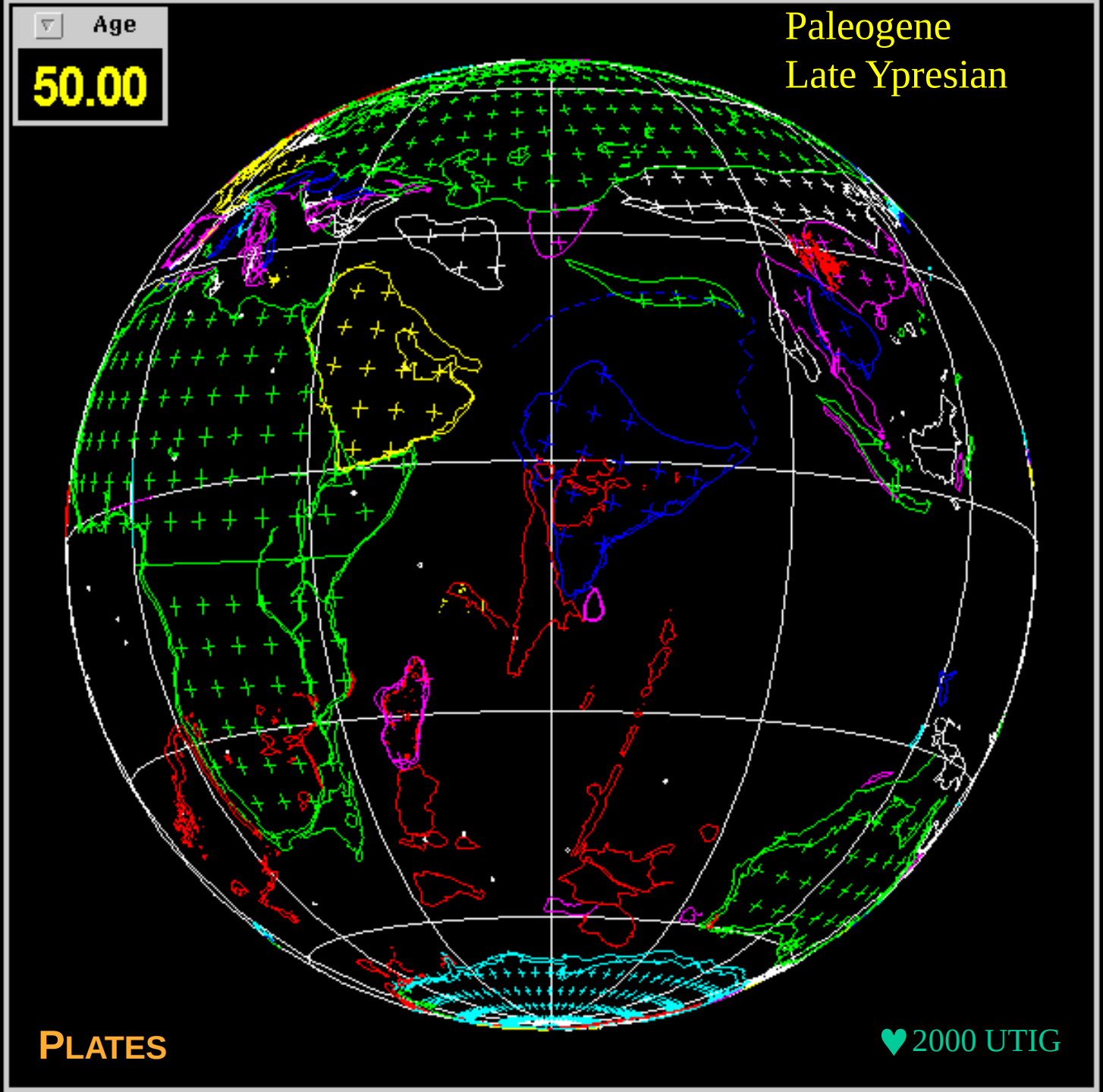

Age
55.00
Paleogene
Thanaetian
PLATES
♥2000 UTIG

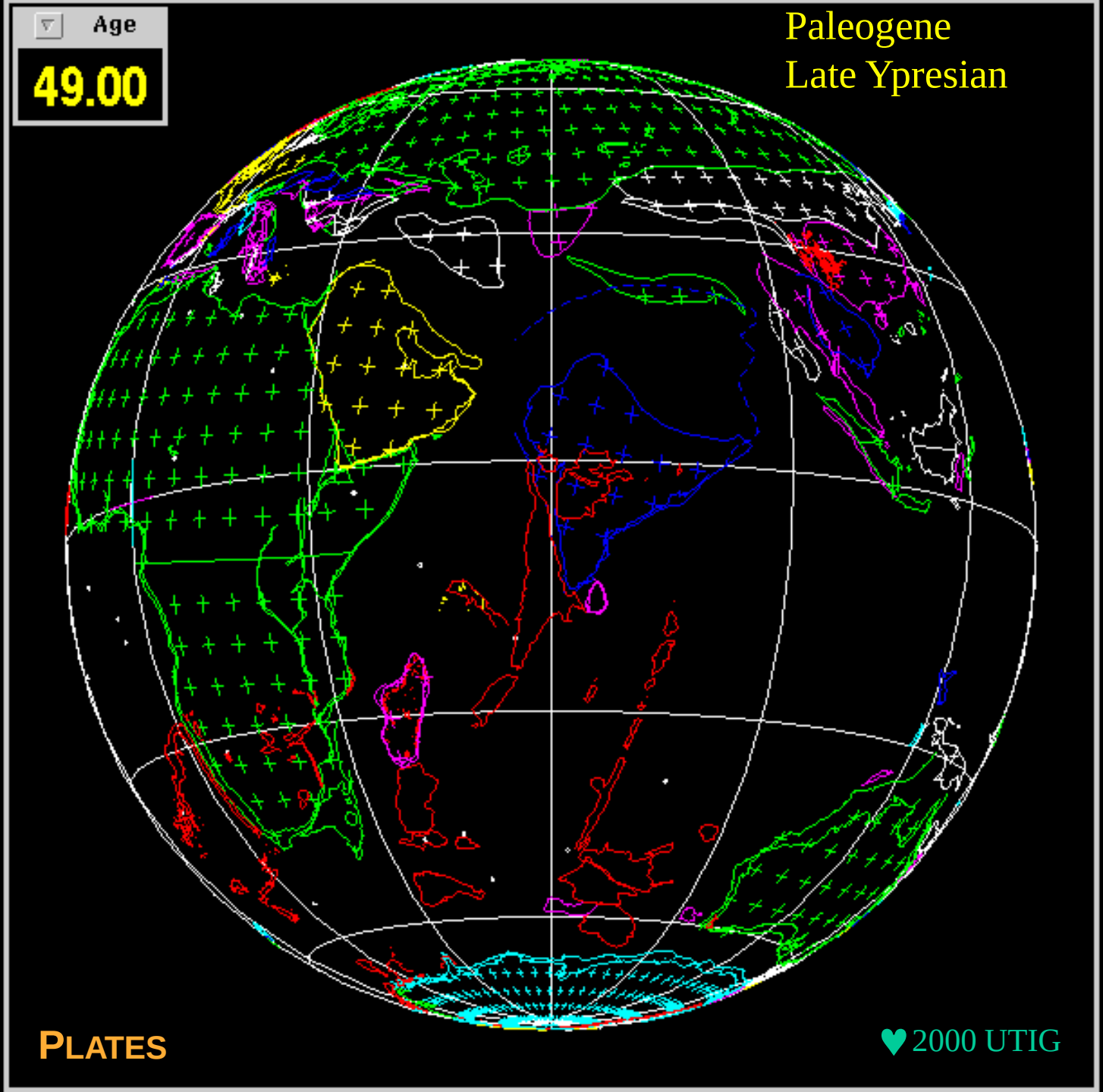

Age
54.00
Paleogene
Early Ypresian
PLATES
♥2000 UTIG

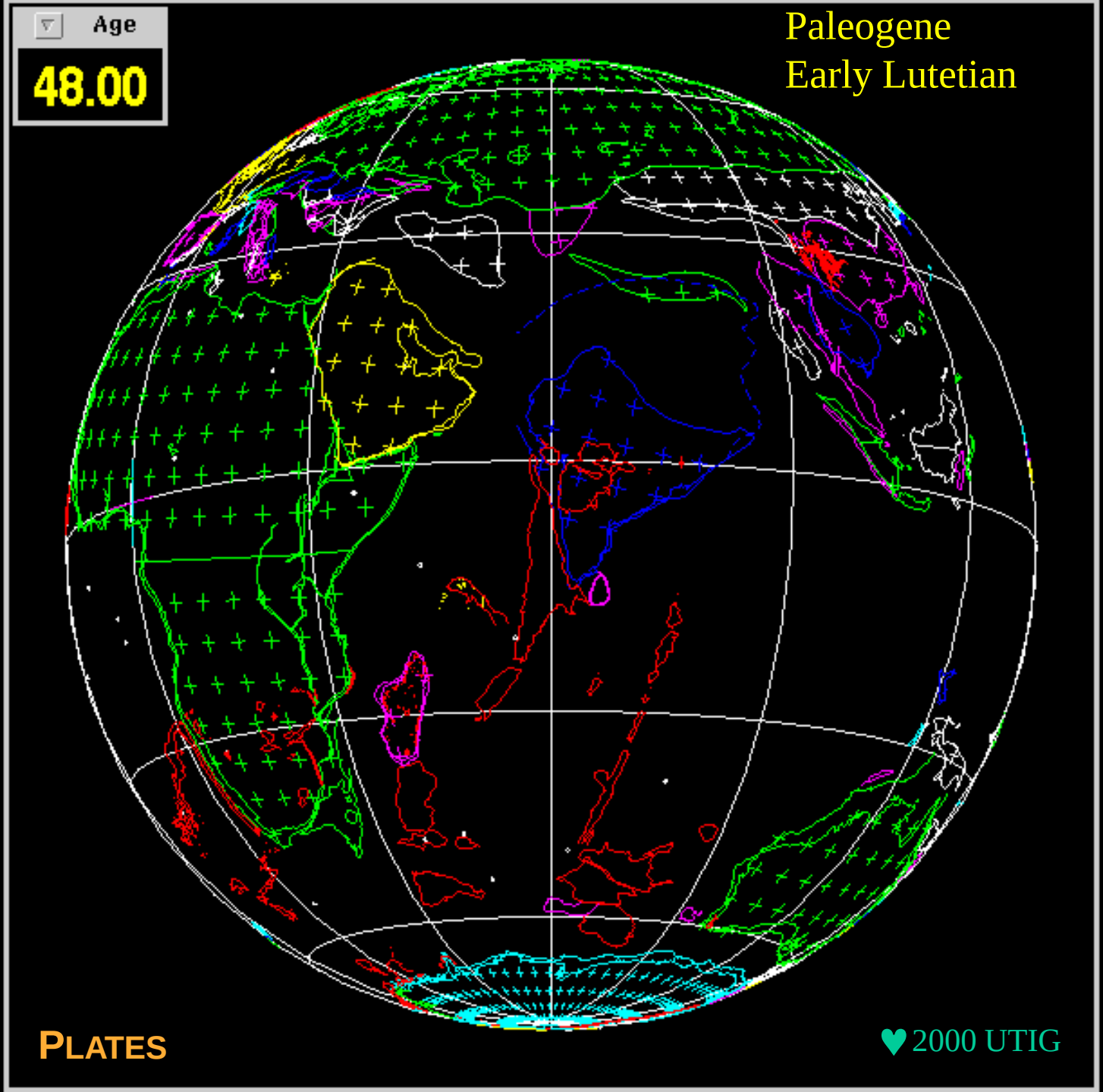

Age
53.00
Paleogene
Early Ypresian
PLATES
♥2000 UTIG

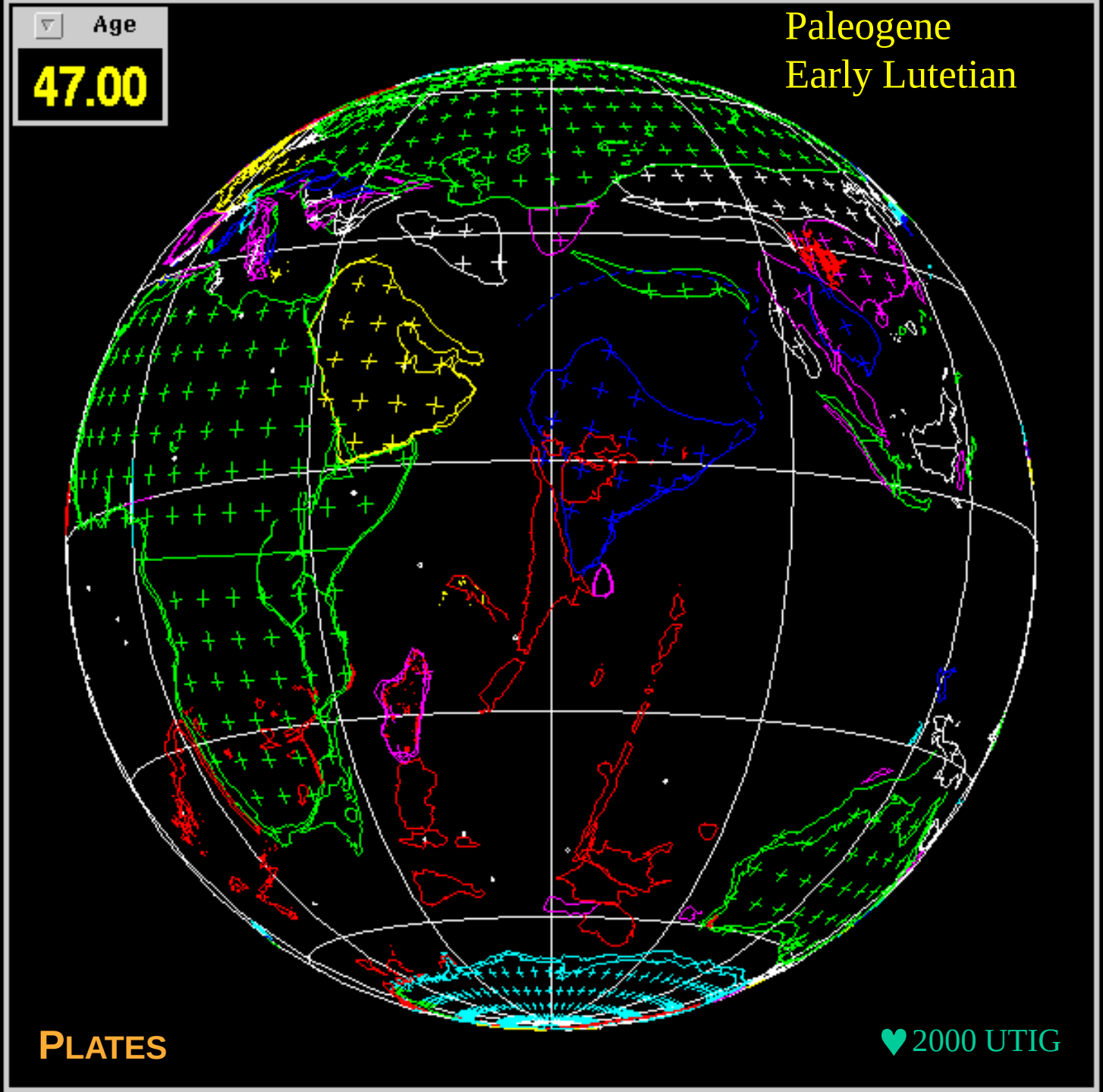

Age
52.00
Paleogene
Ypresian
PLATES
♥2000 UTIG

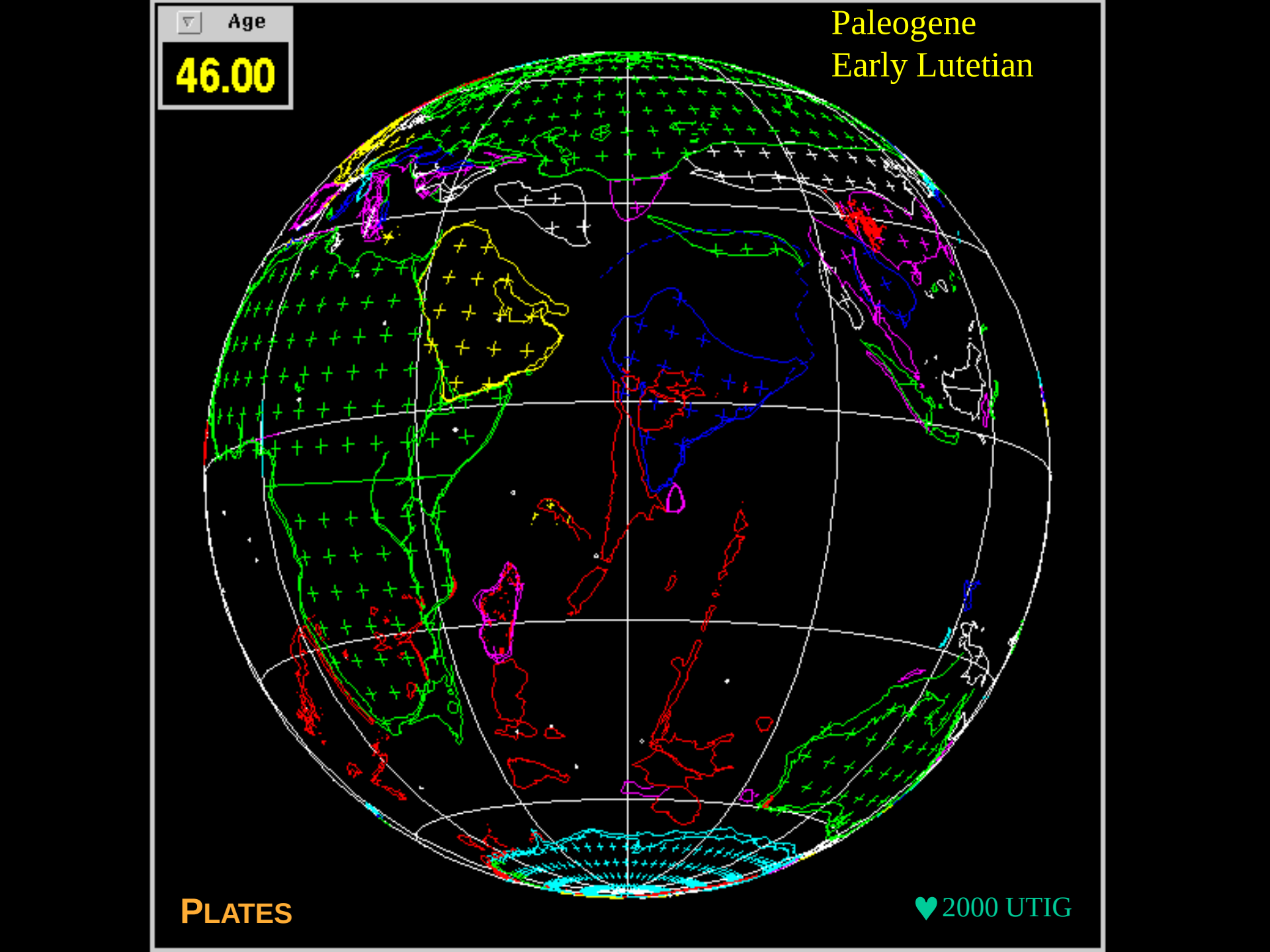

Age
51.00
Paleogene
Ypresian
PLATES
♥2000 UTIG

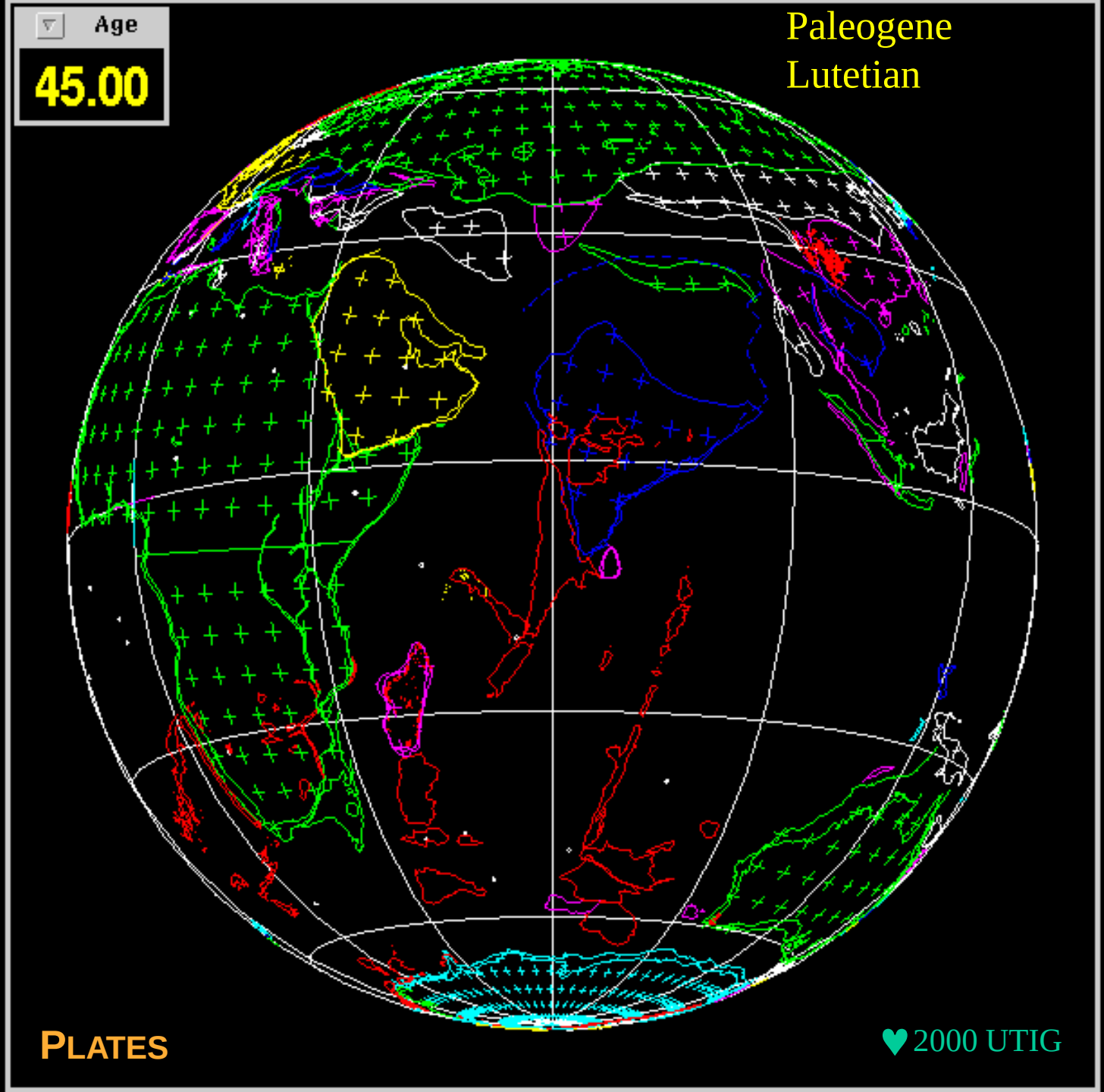

Age
50.00
Paleogene
Late Ypresian
PLATES
♥2000 UTIG

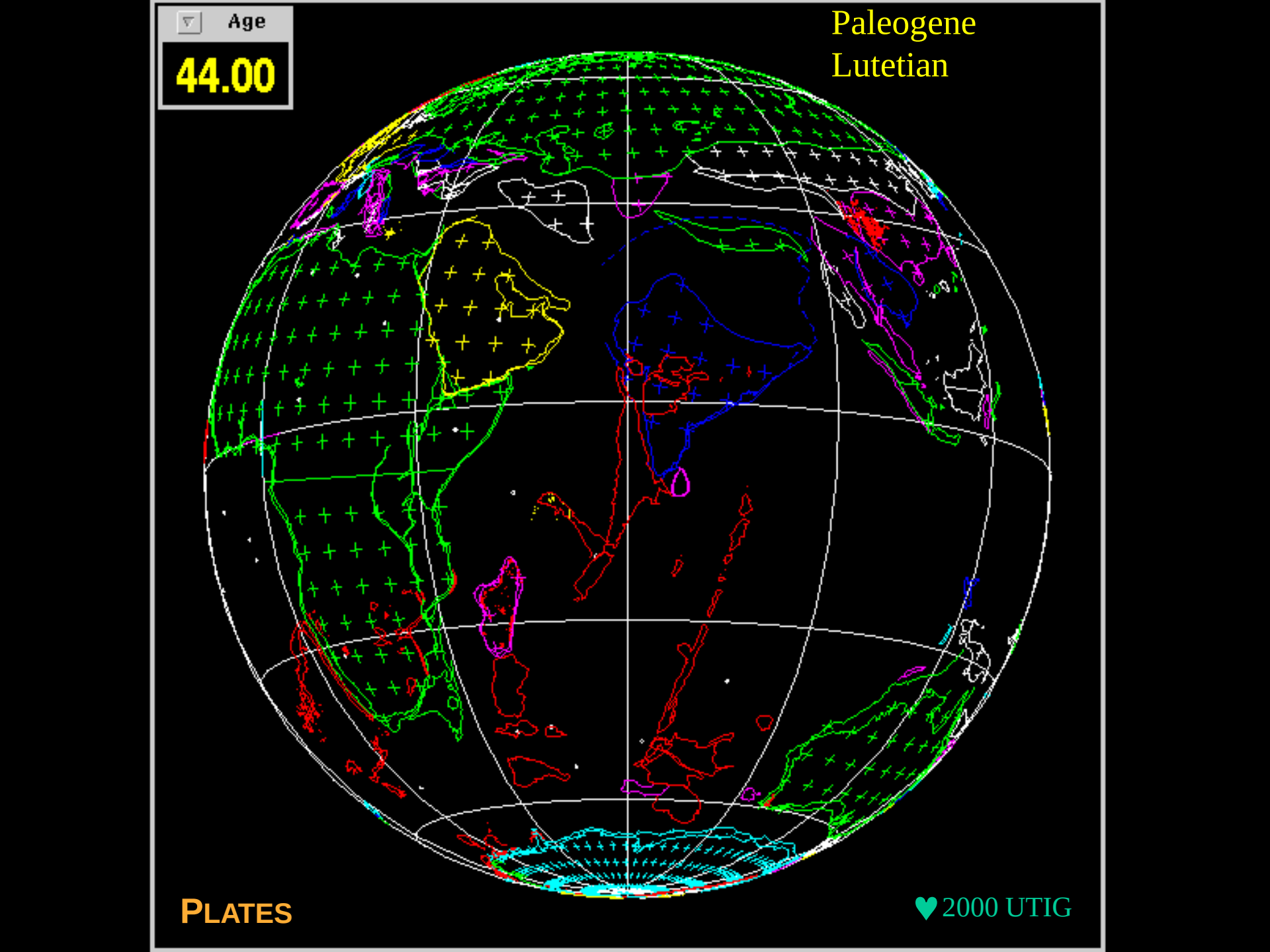

Age
49.00
Paleogene
Late Ypresian
PLATES
♥2000 UTIG

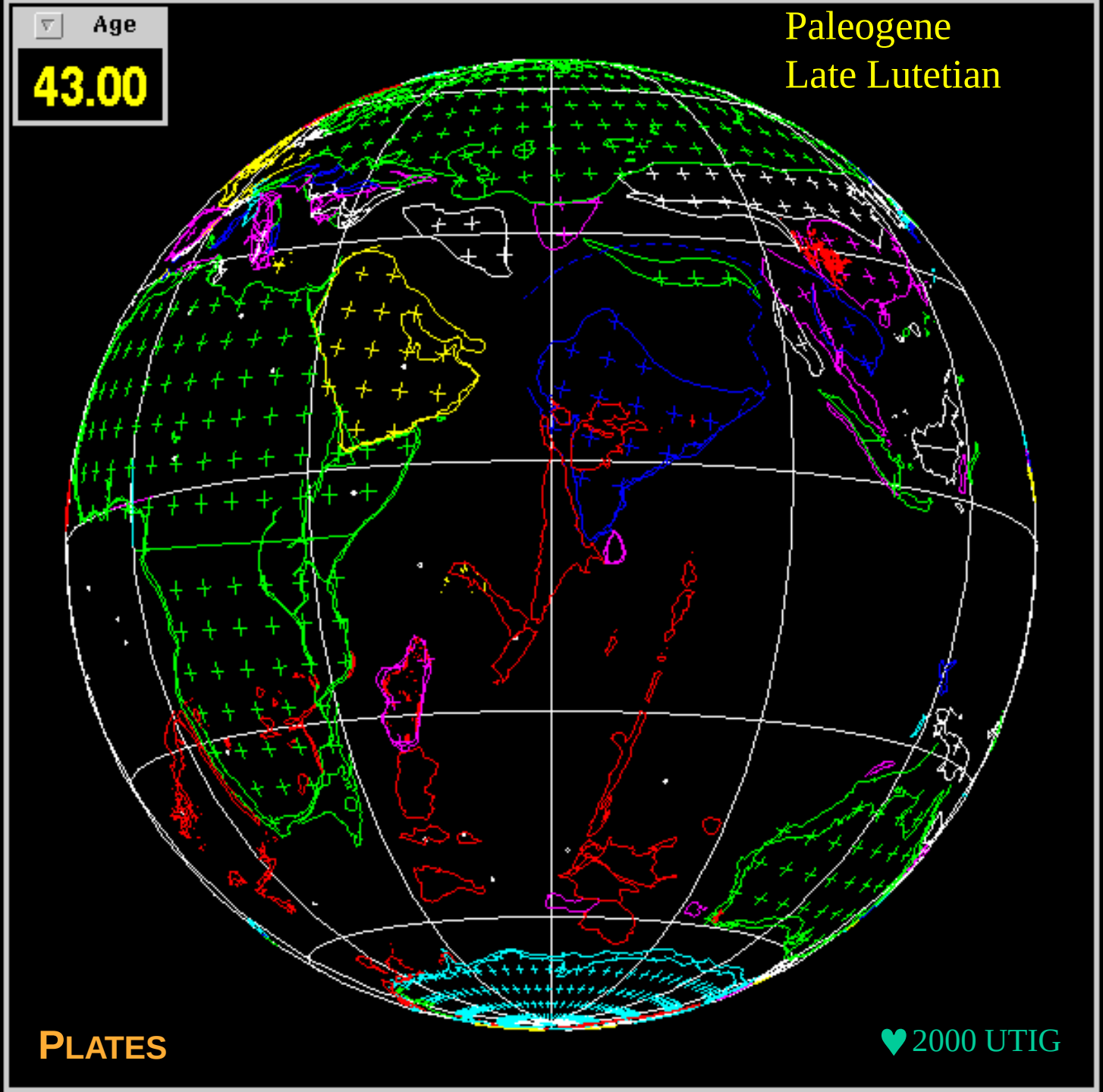

Age
48.00
Paleogene
Early Lutetian
PLATES
♥2000 UTIG

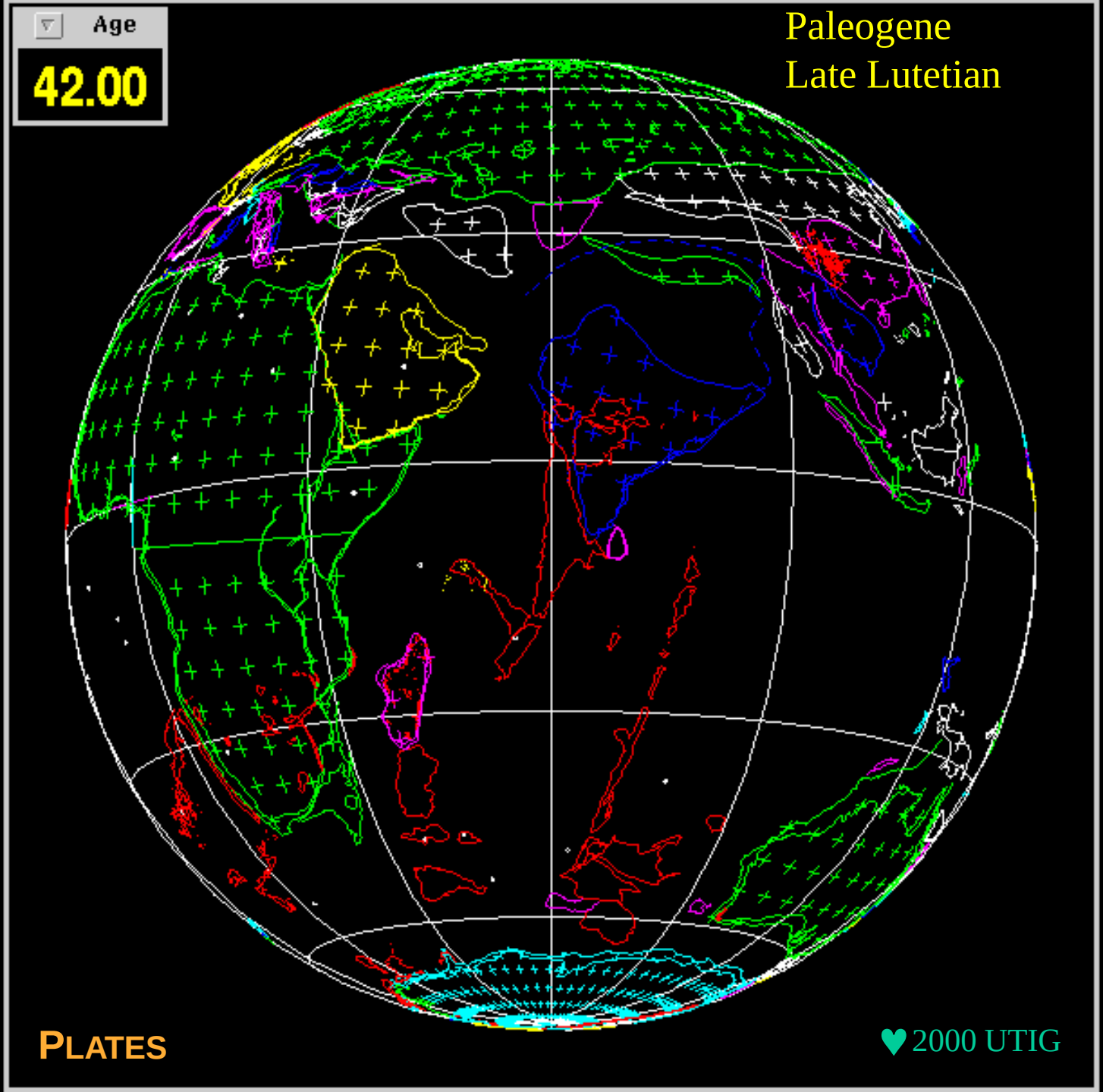

Age
47.00
Paleogene
Early Lutetian
PLATES
♥2000 UTIG

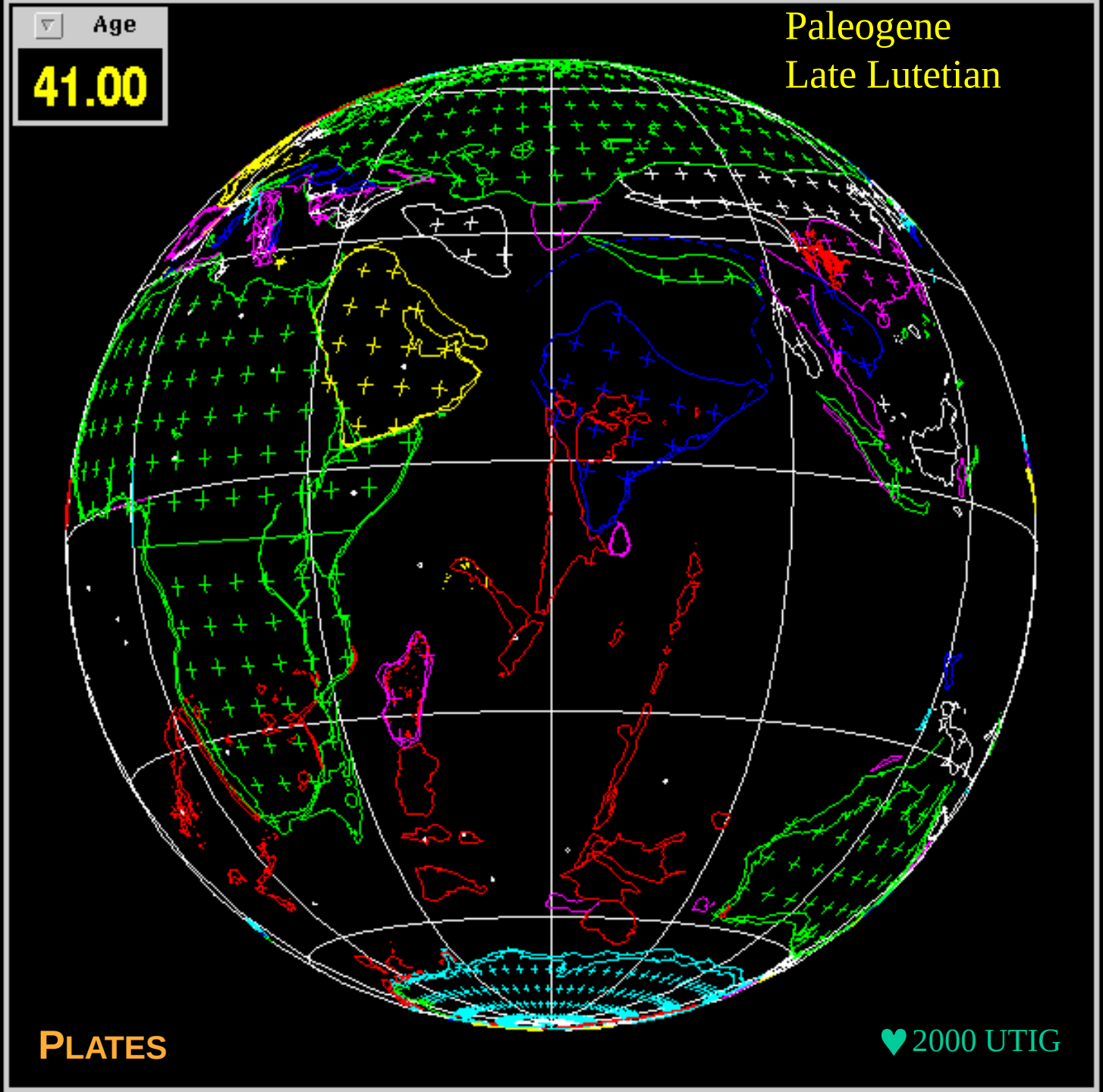

Age
46.00
Paleogene
Early Lutetian
PLATES
♥2000 UTIG

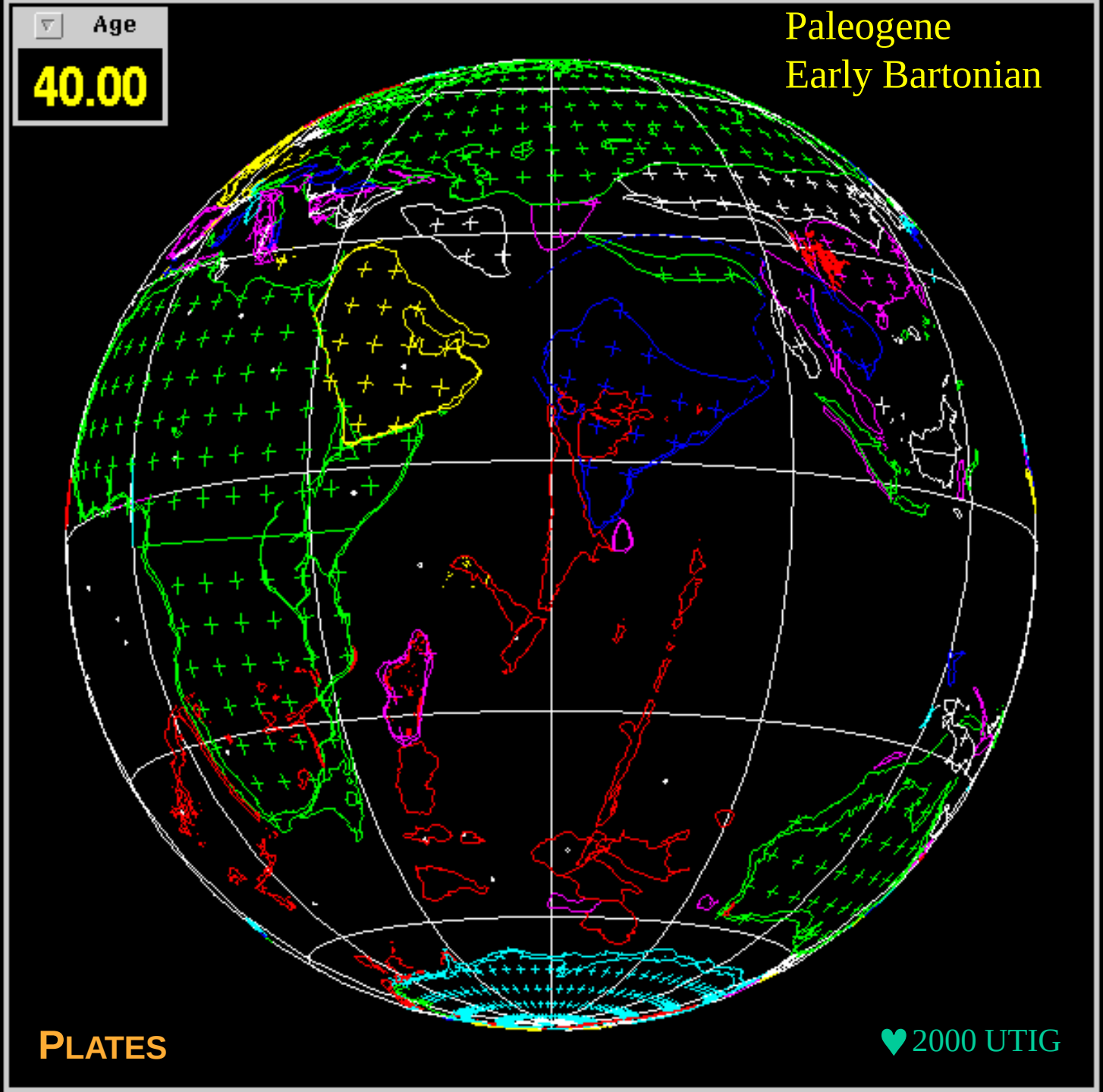

Age
45.00
Paleogene
Lutetian
PLATES
♥2000 UTIG

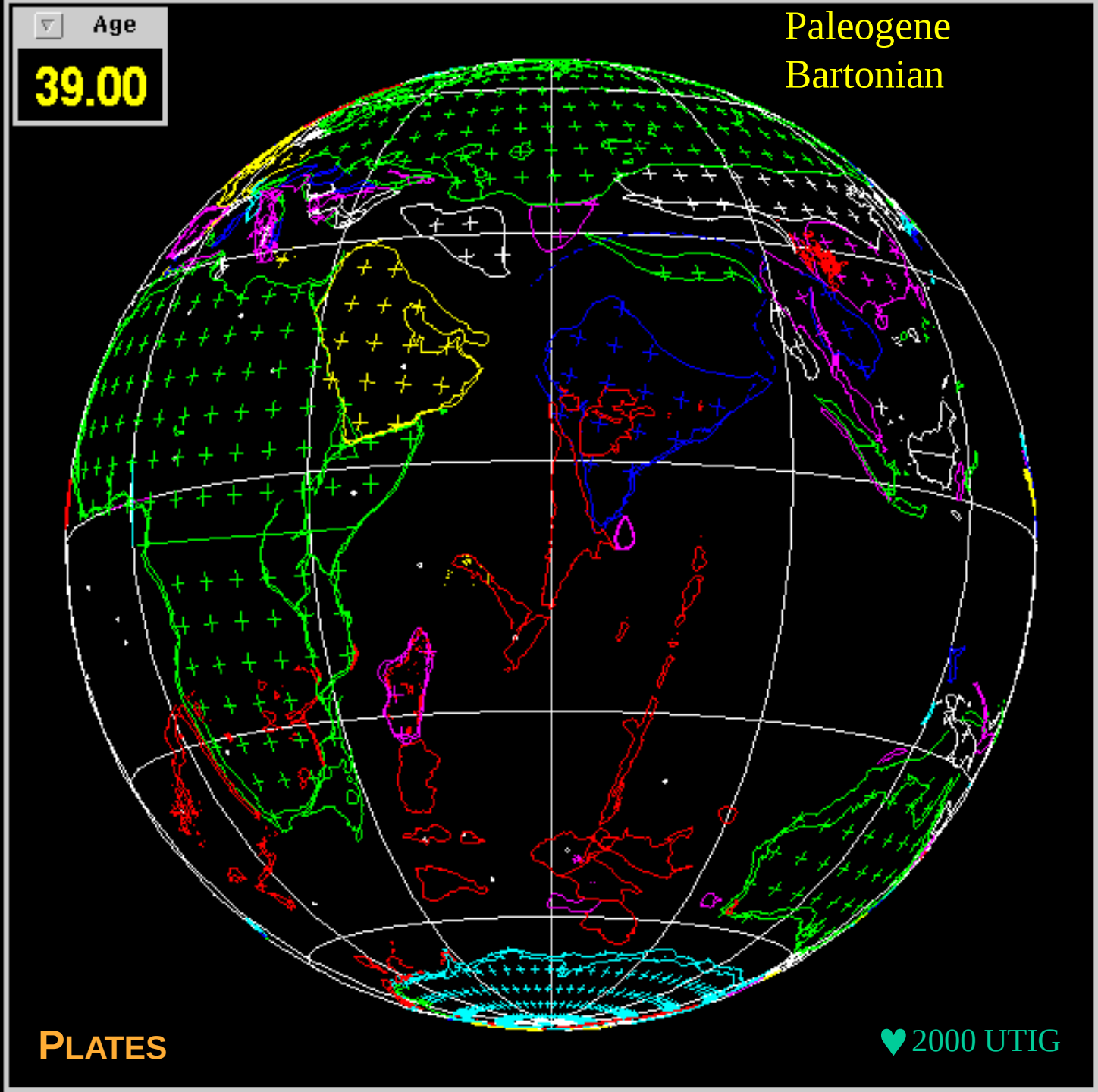

Age
44.00
Paleogene
Lutetian
PLATES
♥2000 UTIG

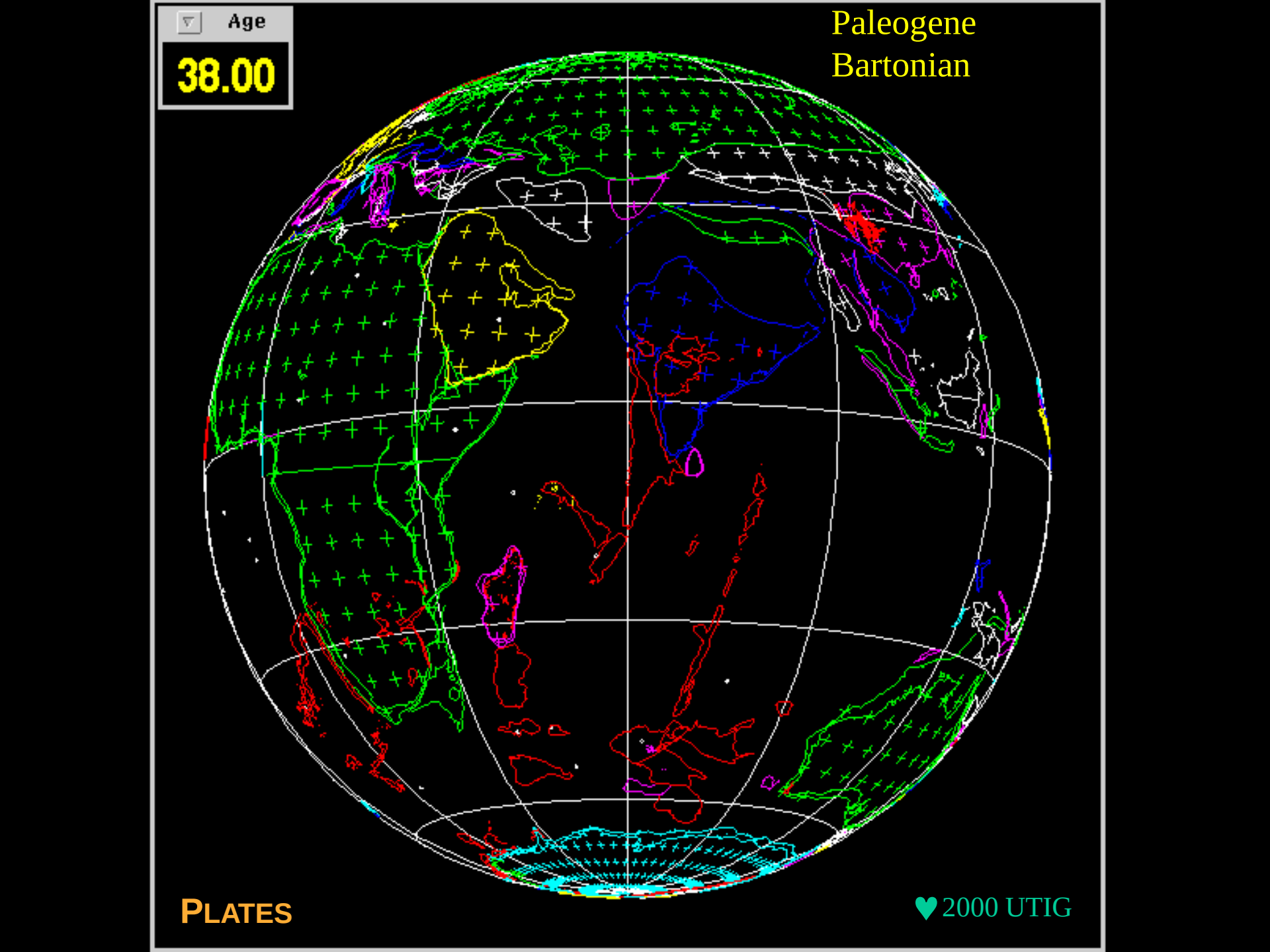

Age
43.00
Paleogene
Late Lutetian
PLATES
♥2000 UTIG

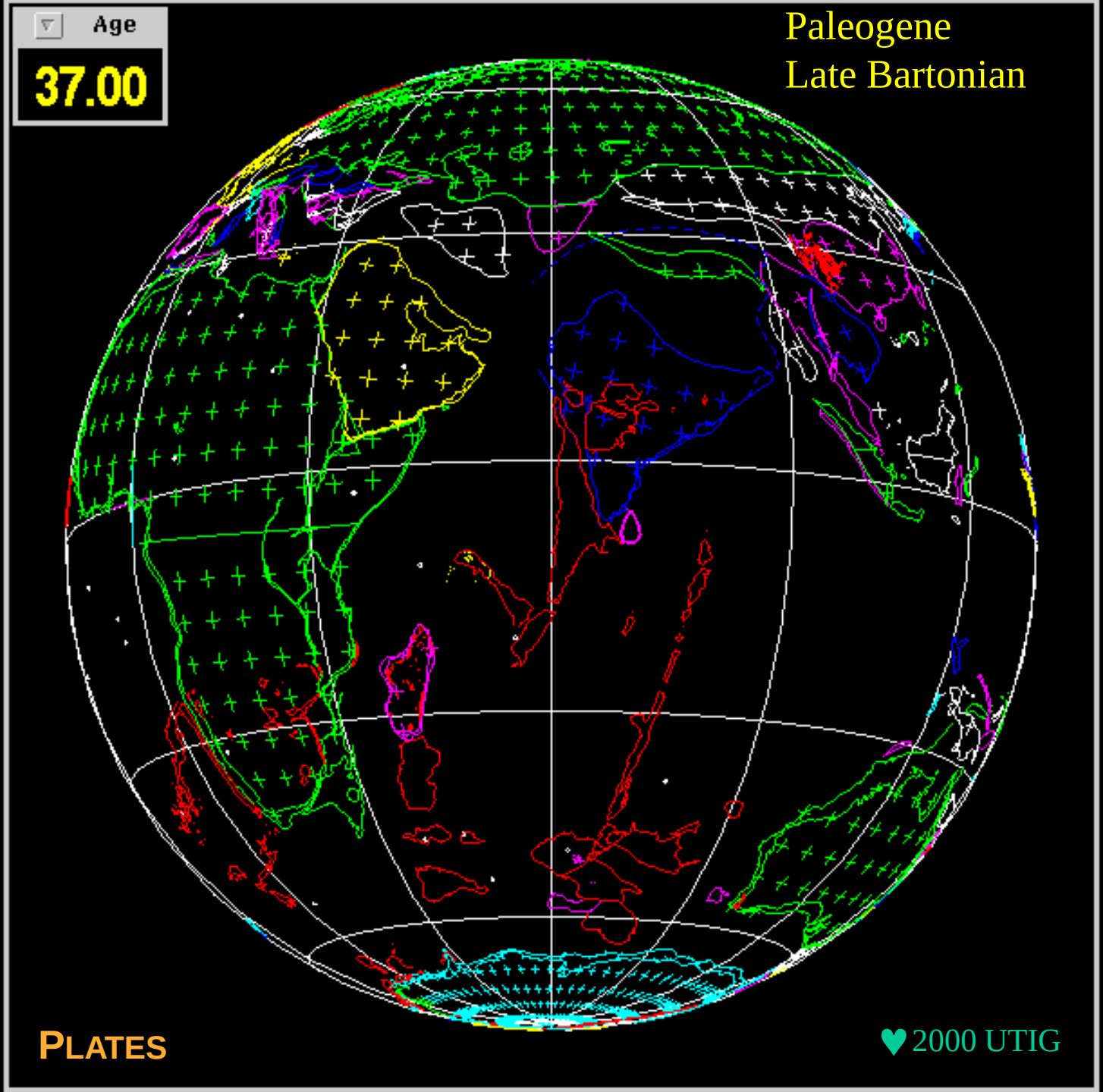

Age
42.00
Paleogene
Late Lutetian
PLATES
♥2000 UTIG

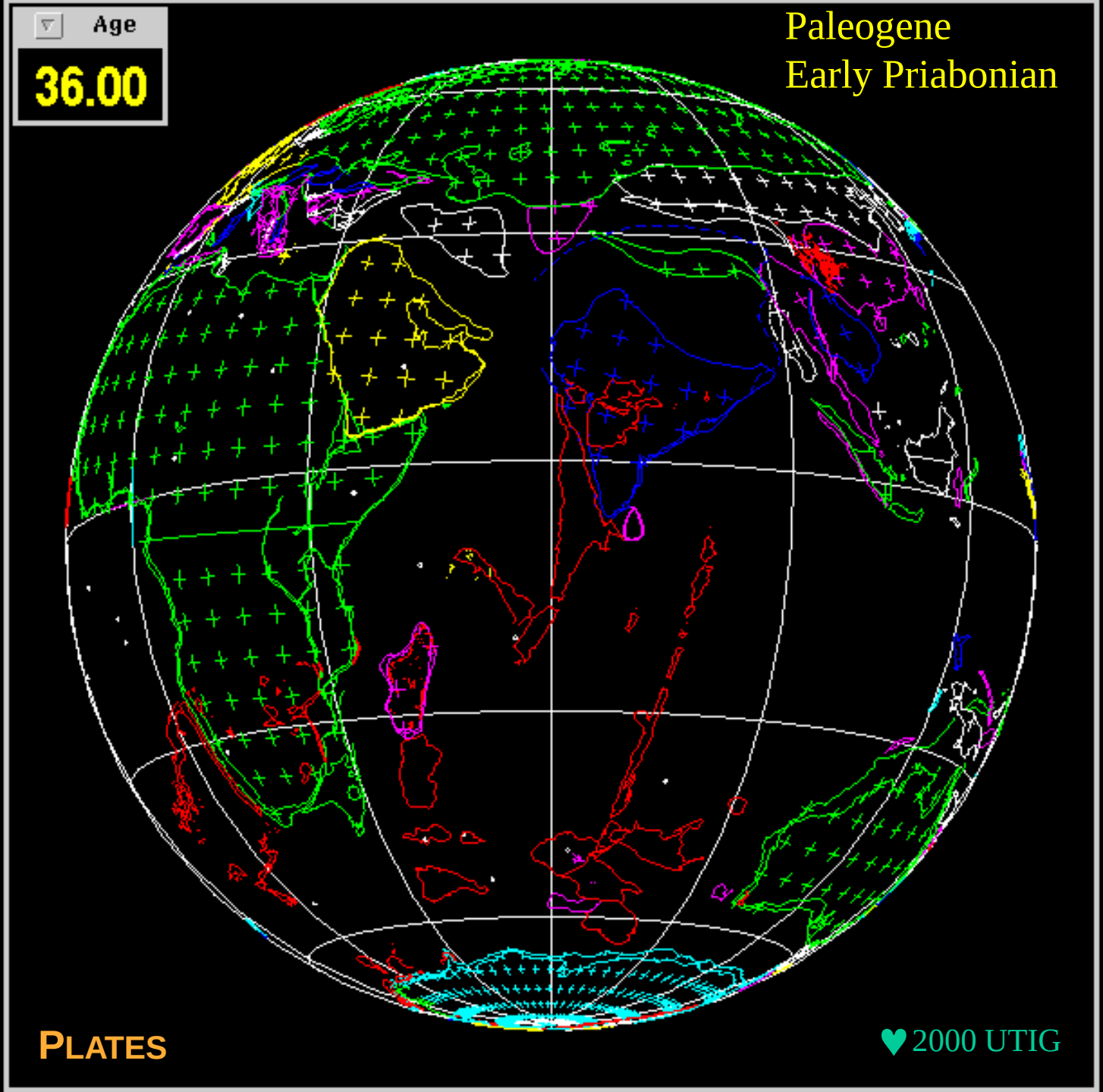

Age
41.00
Paleogene
Late Lutetian
PLATES
♥2000 UTIG

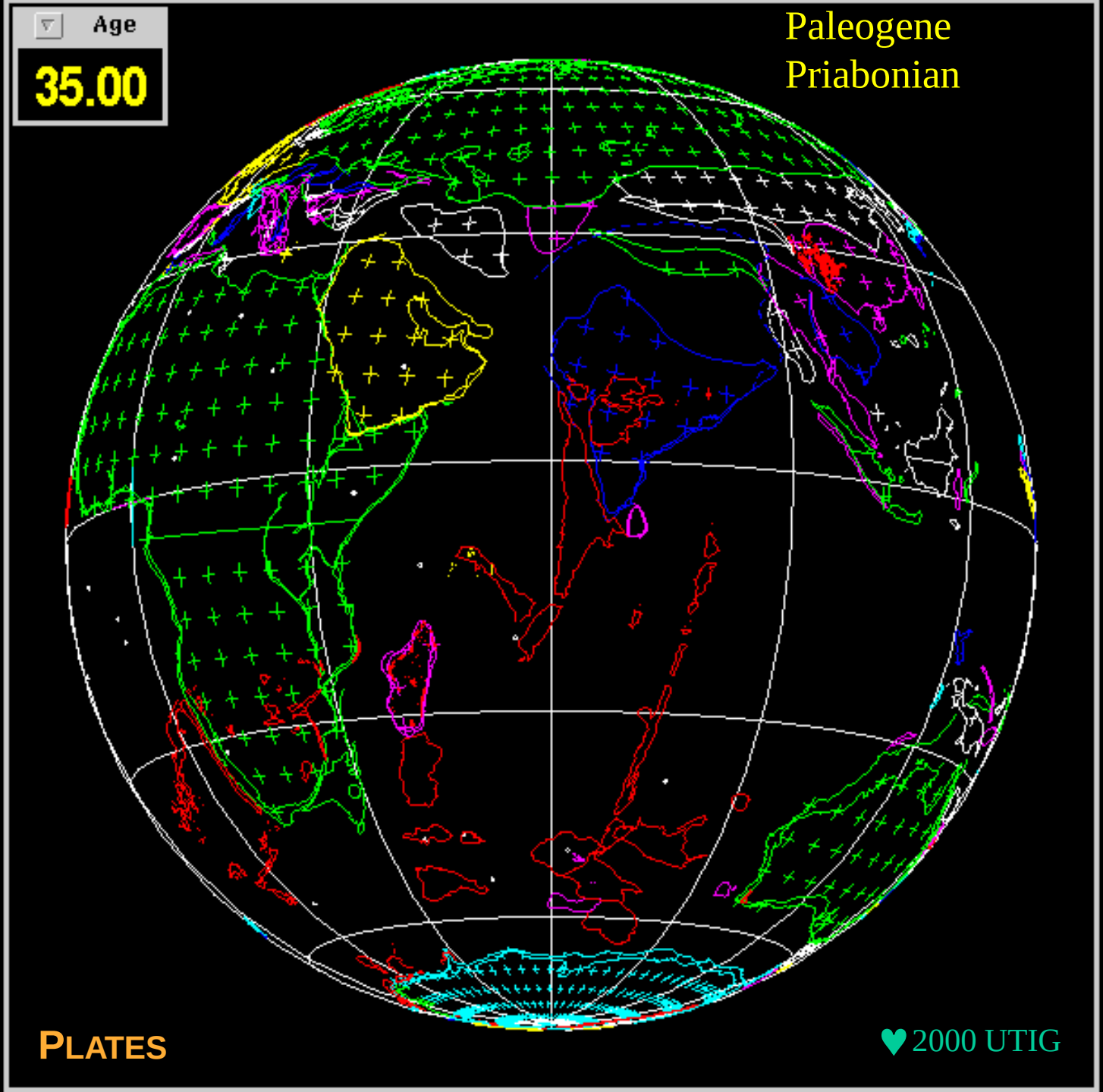

Age
40.00
Paleogene
Early Bartonian
PLATES
♥2000 UTIG

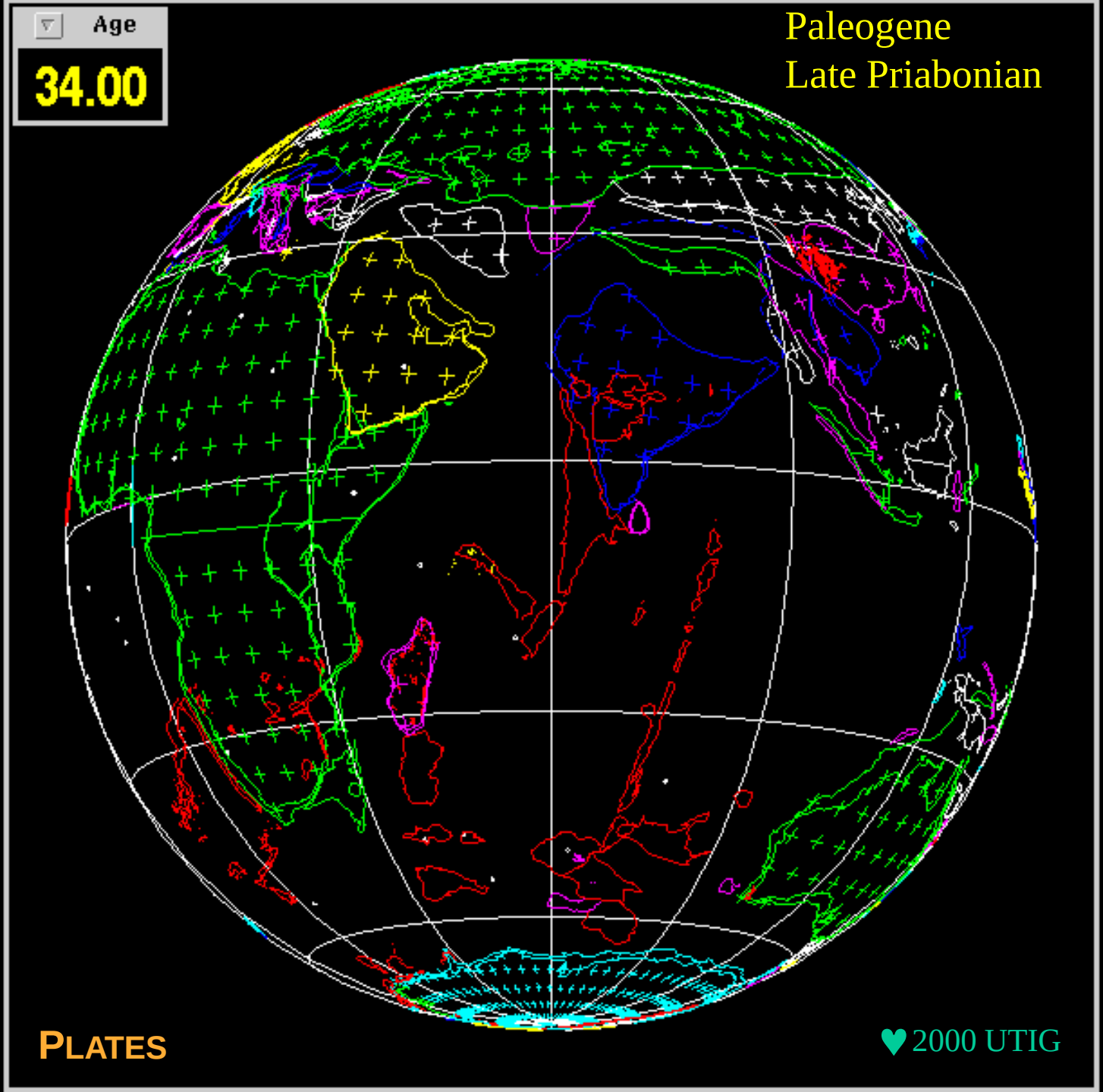

Age
39.00
Paleogene
Bartonian
PLATES
♥2000 UTIG

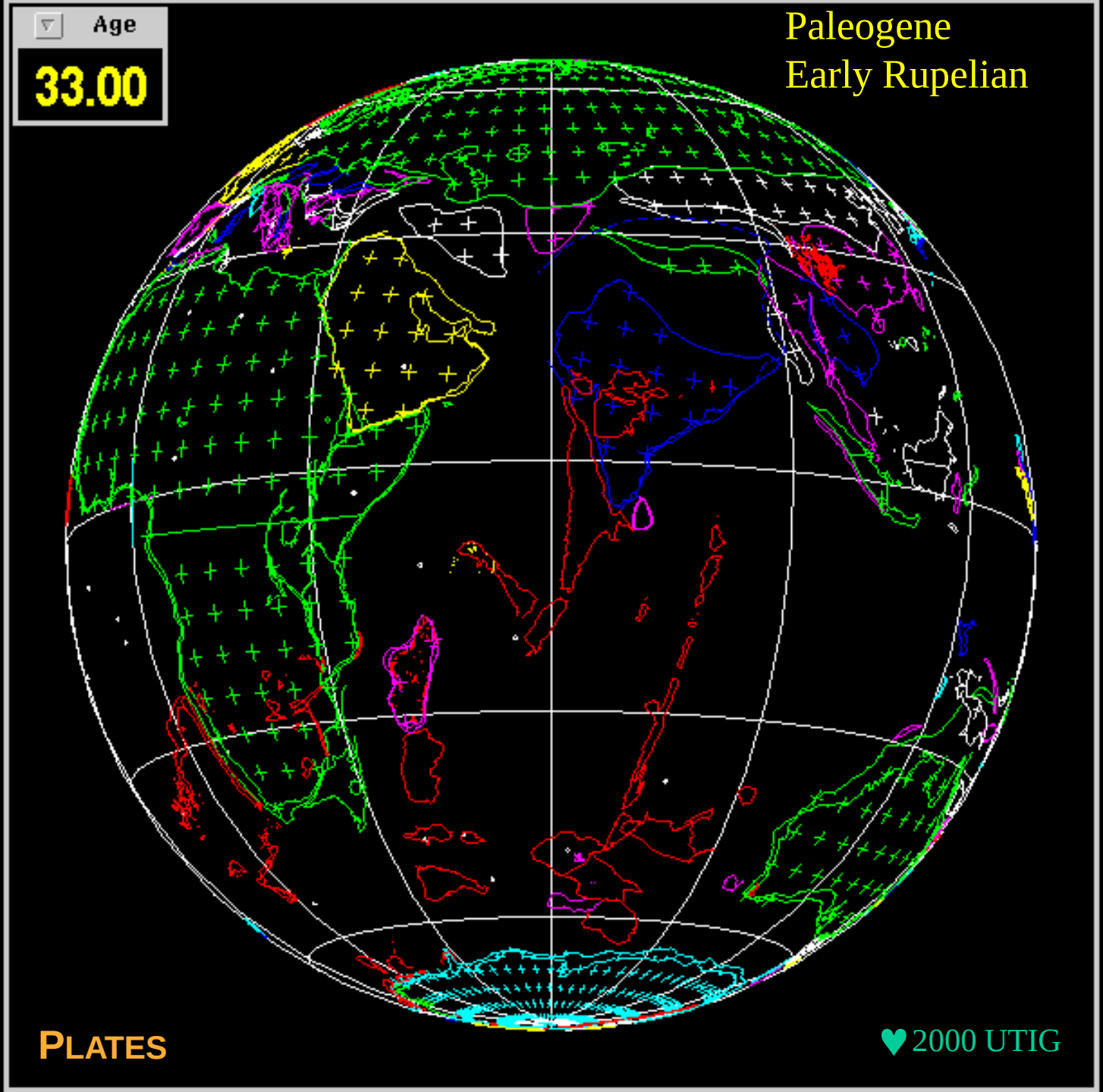

Age
38.00
Paleogene
Bartonian
PLATES
♥2000 UTIG

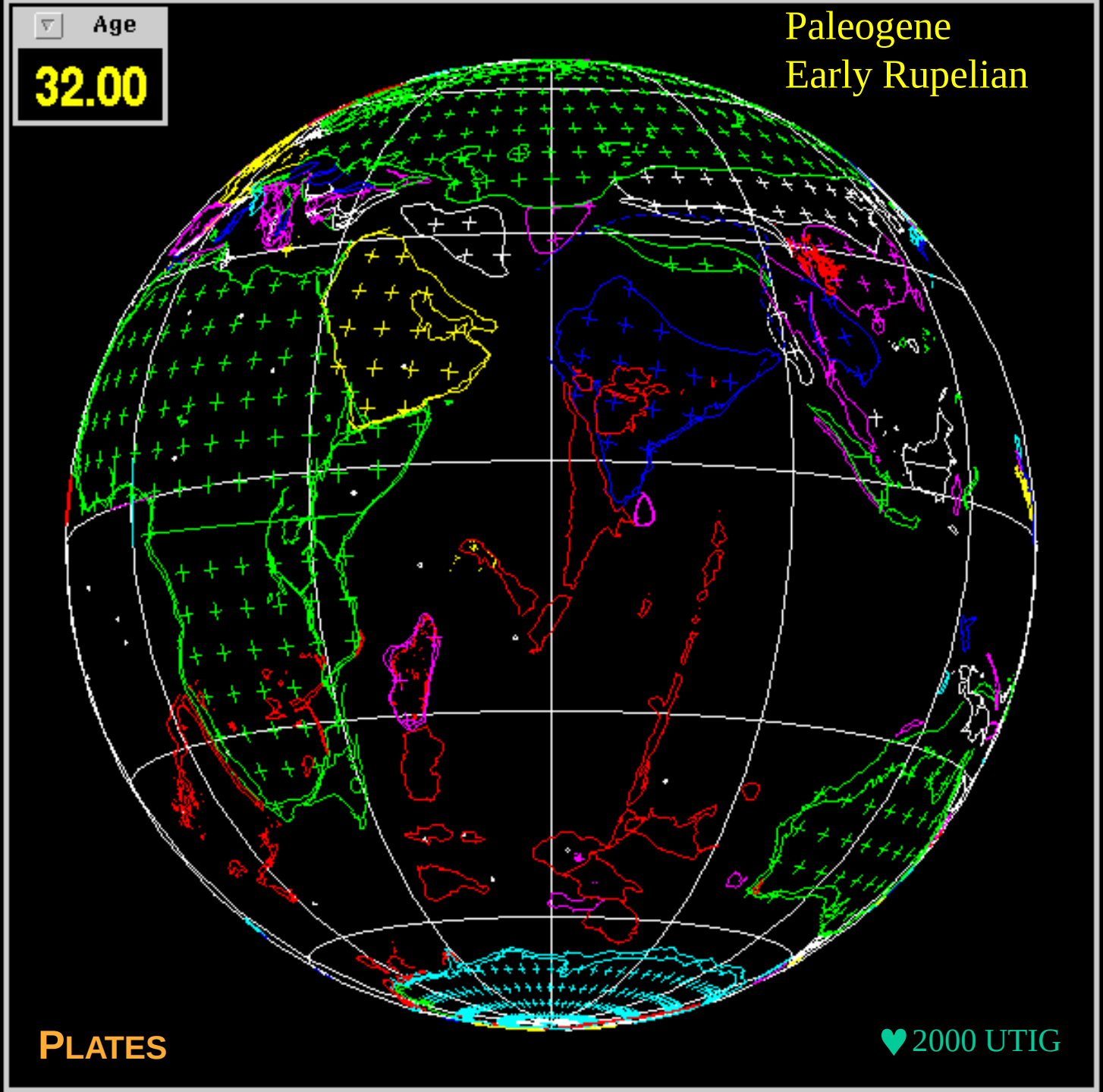

Age
37.00
Paleogene
Late Bartonian
PLATES
♥2000 UTIG

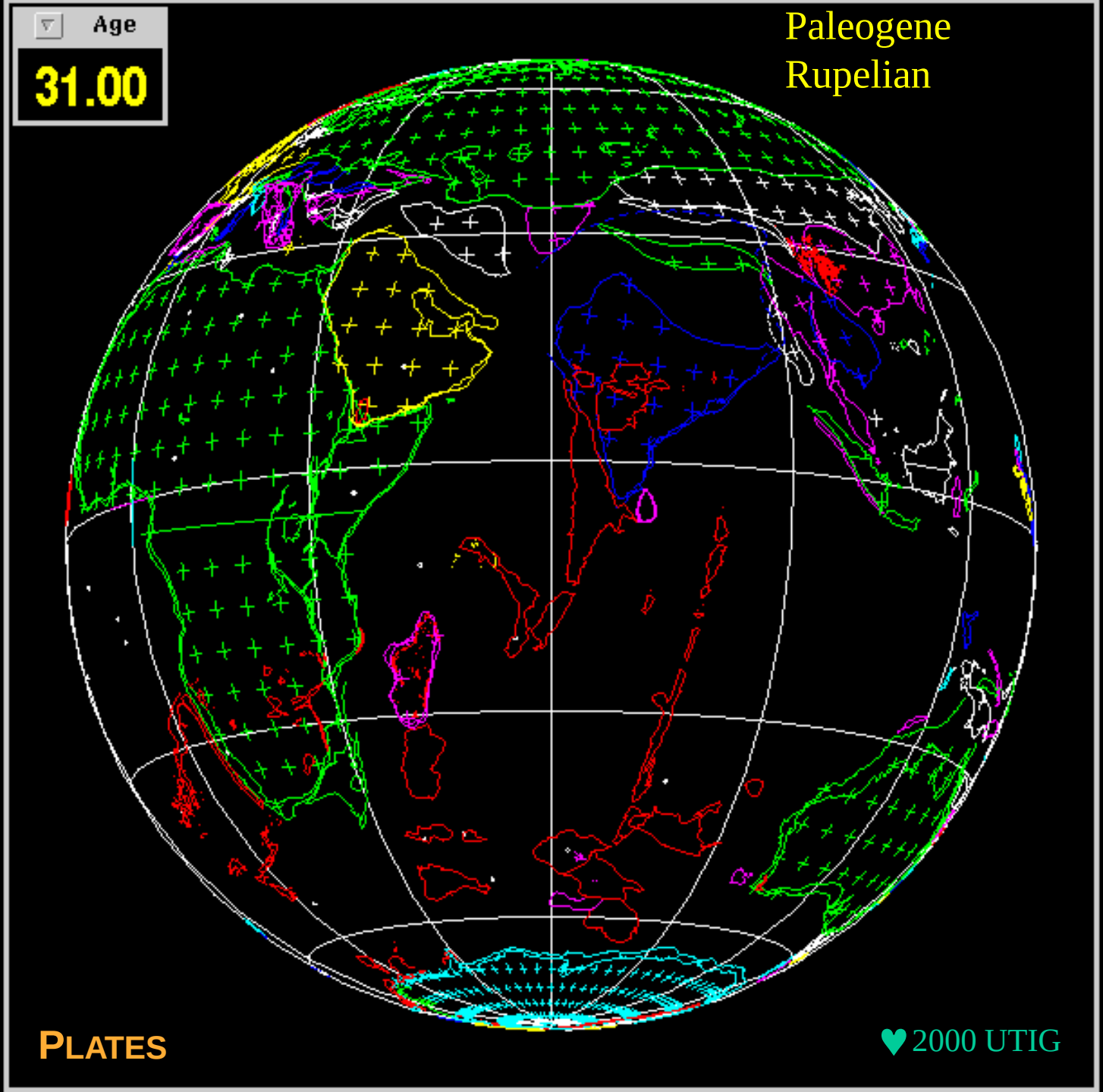

Age
36.00
Paleogene
Early Priabonian
PLATES
♥2000 UTIG

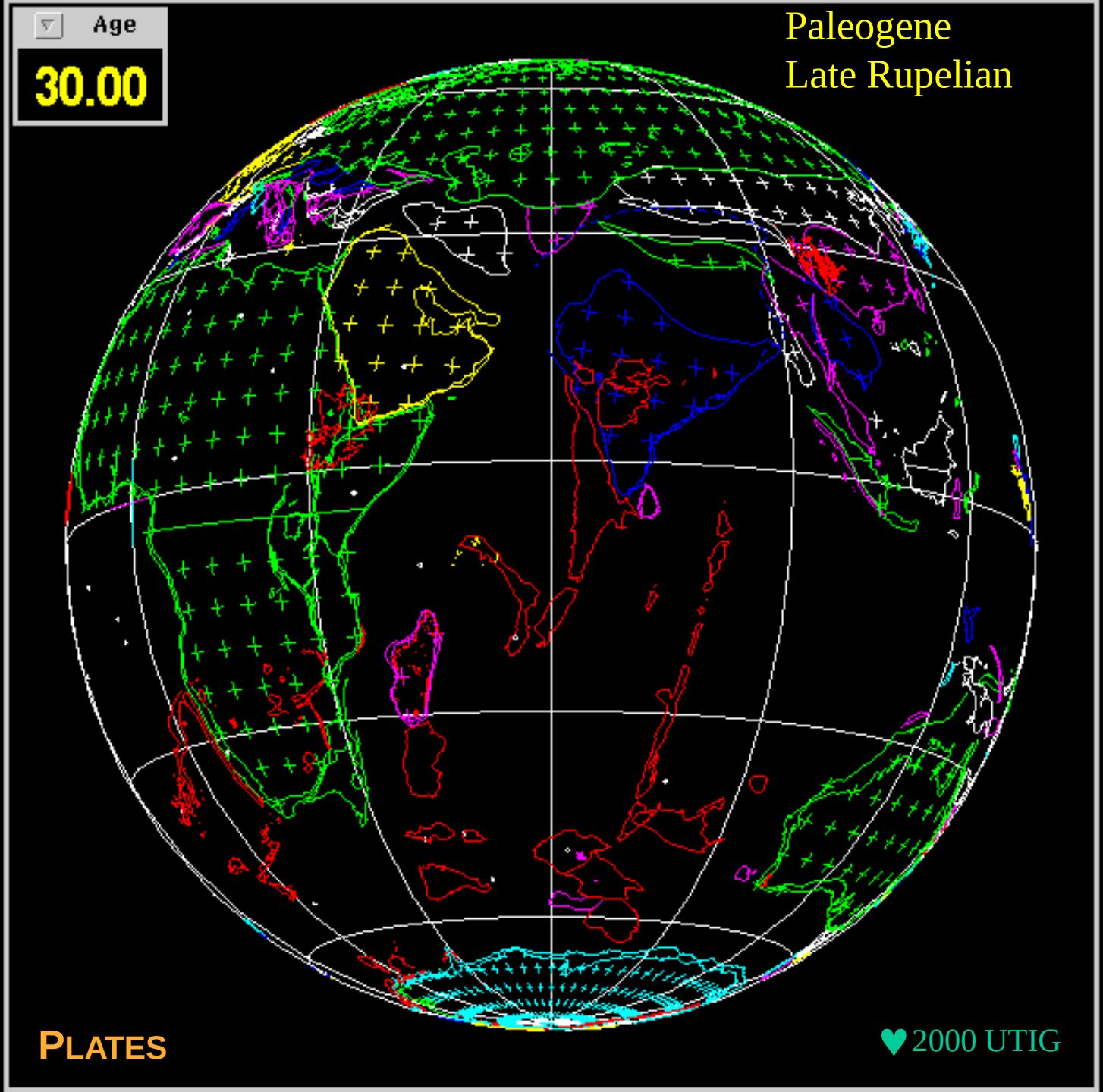

Age
35.00
Paleogene
Priabonian
PLATES
♥2000 UTIG

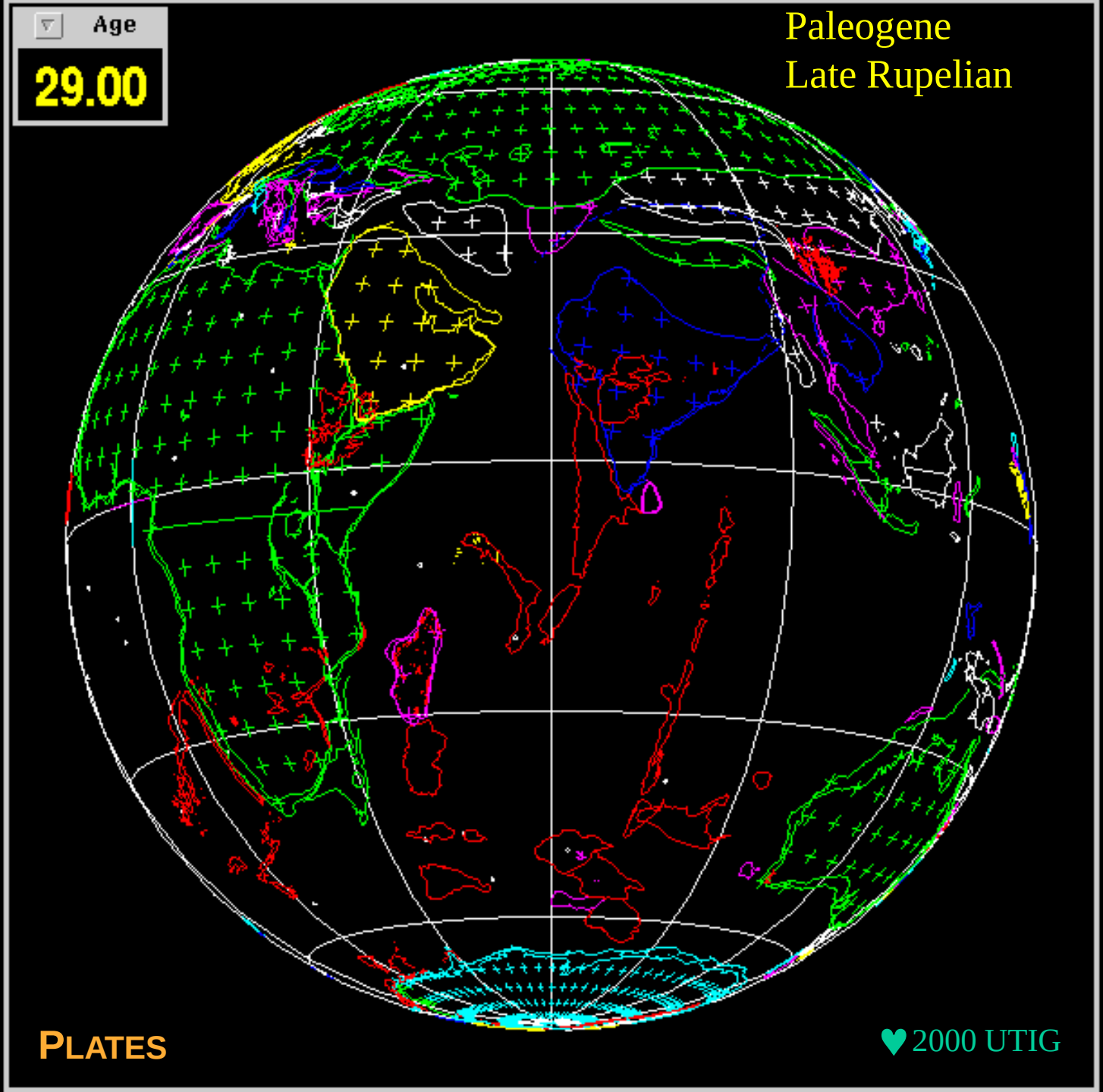

Age
34.00
Paleogene
Late Priabonian
PLATES
♥2000 UTIG

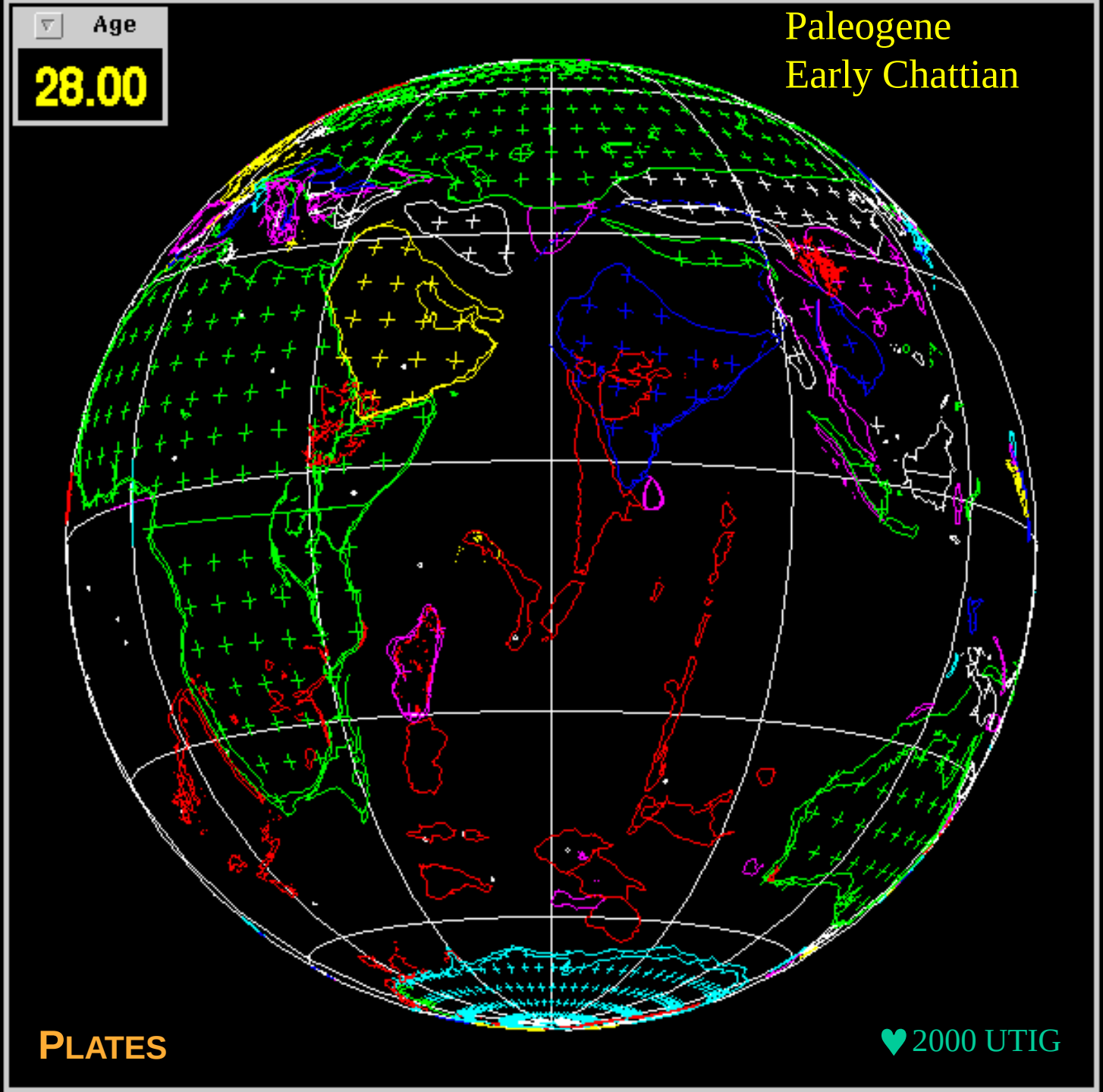

Age
33.00
Paleogene
Early Rupelian
PLATES
♥2000 UTIG

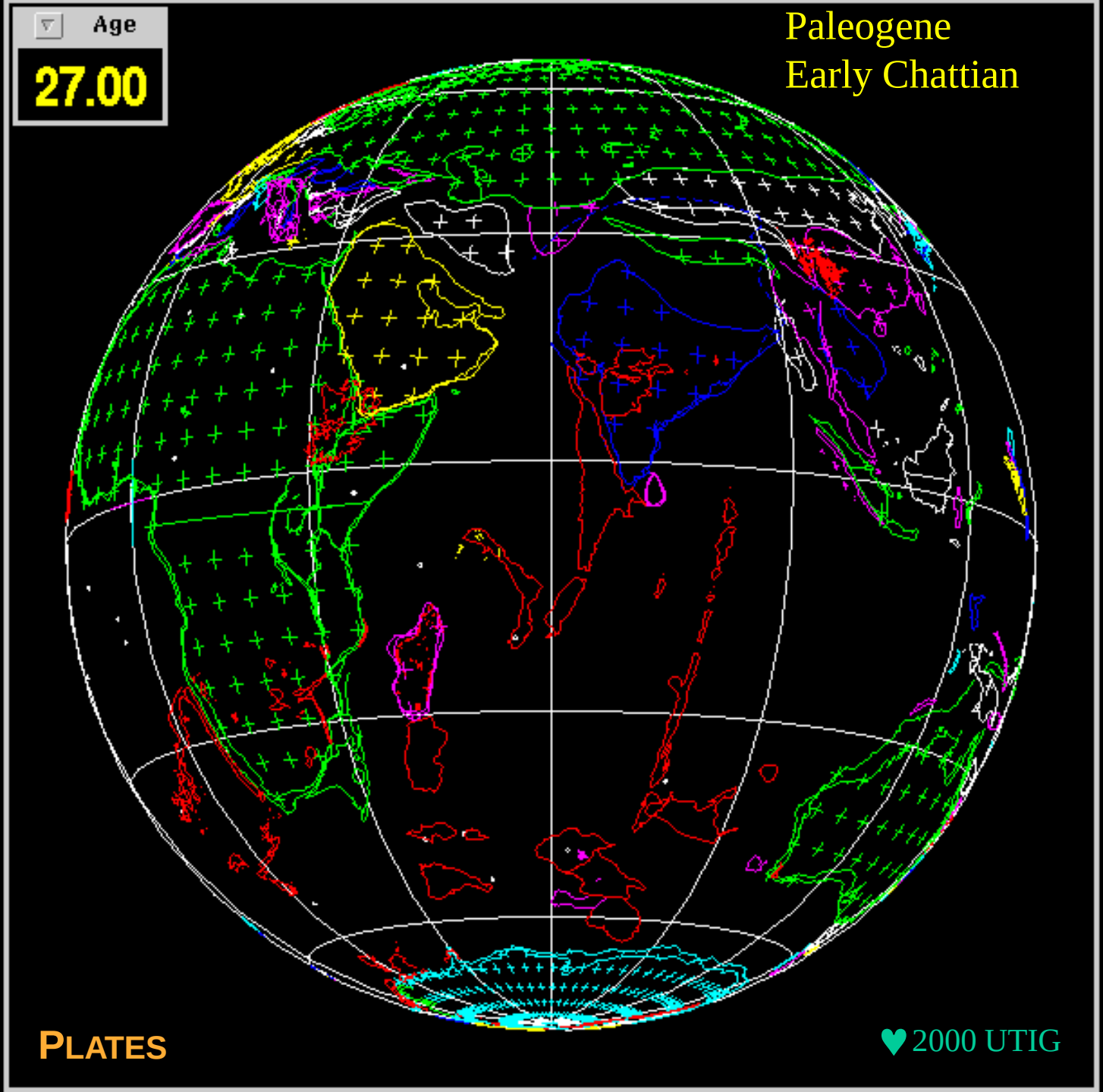

Age
32.00
Paleogene
Early Rupelian
PLATES
♥2000 UTIG

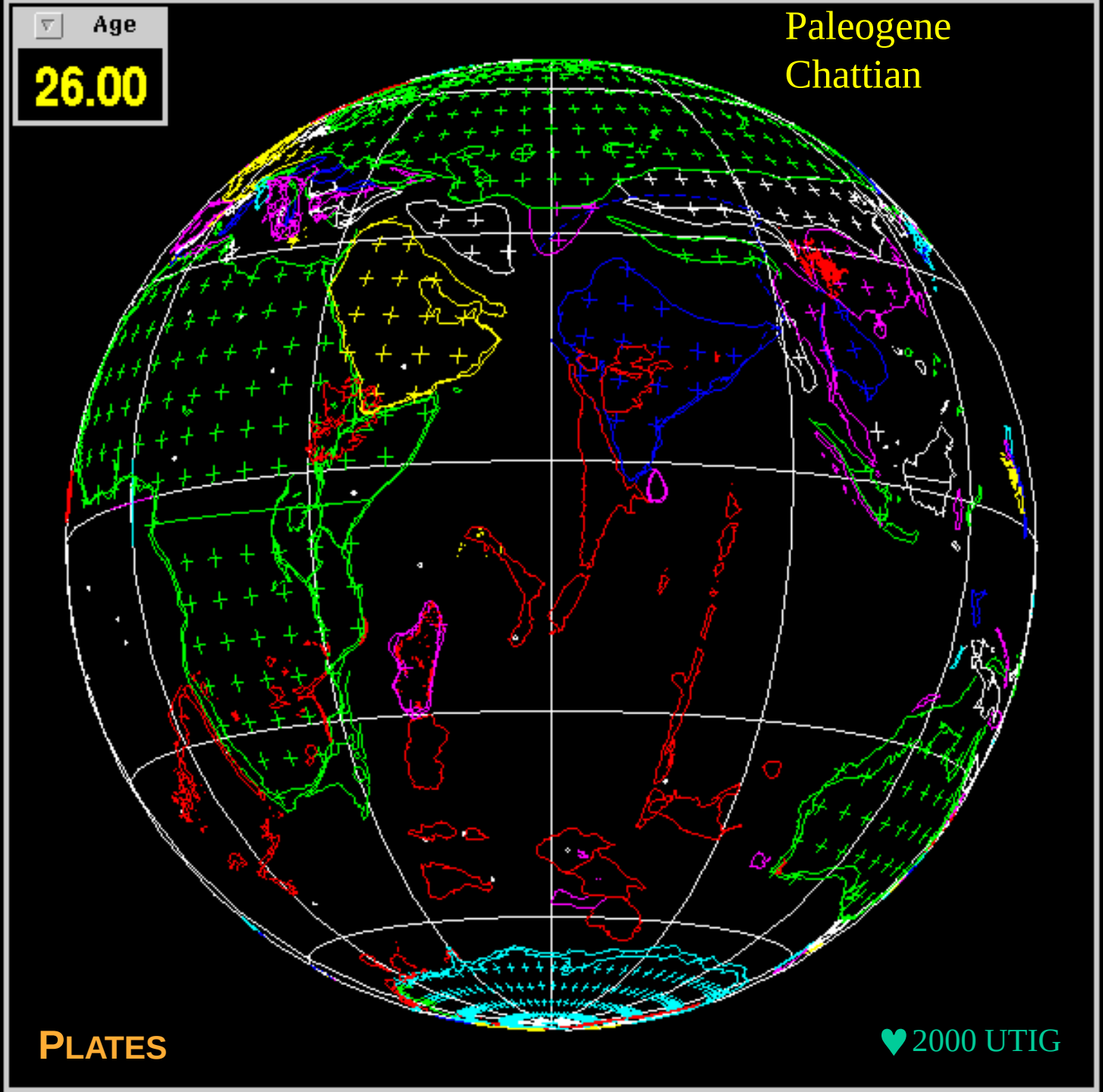

Age
31.00
Paleogene
Rupelian
PLATES
♥2000 UTIG

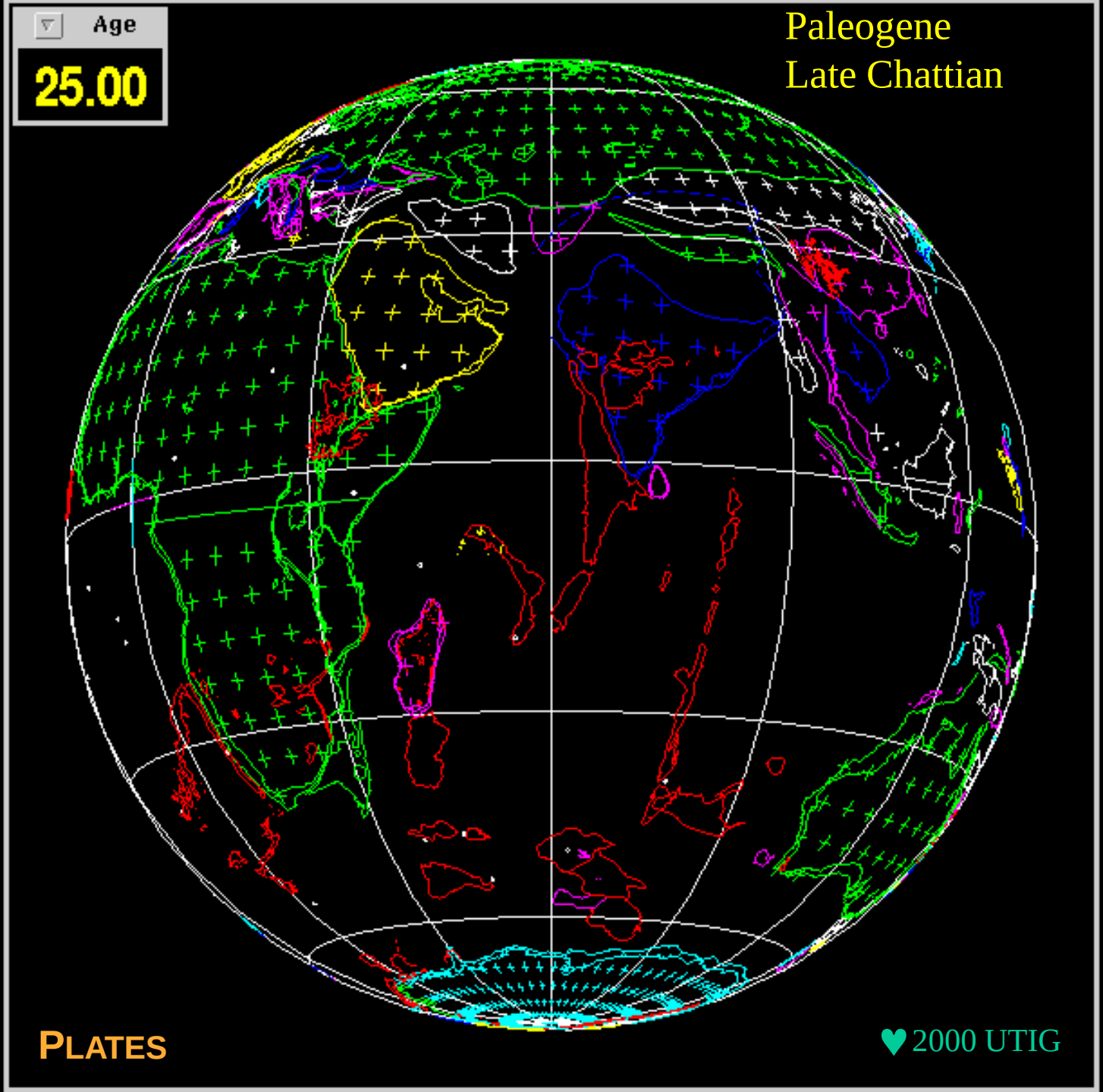

Age
30.00
Paleogene
Late Rupelian
PLATES
♥2000 UTIG

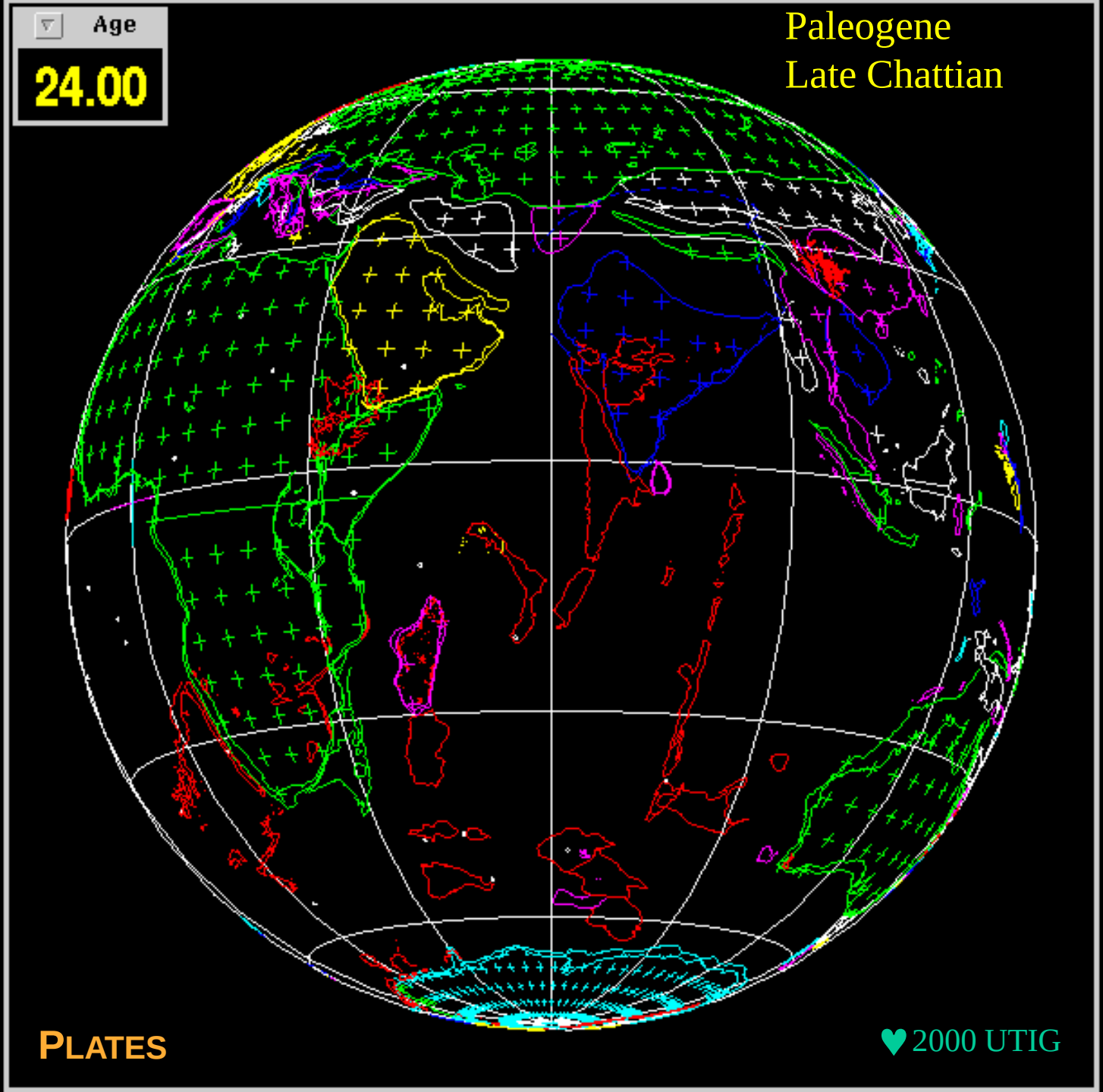

Age
29.00
Paleogene
Late Rupelian
PLATES
♥2000 UTIG

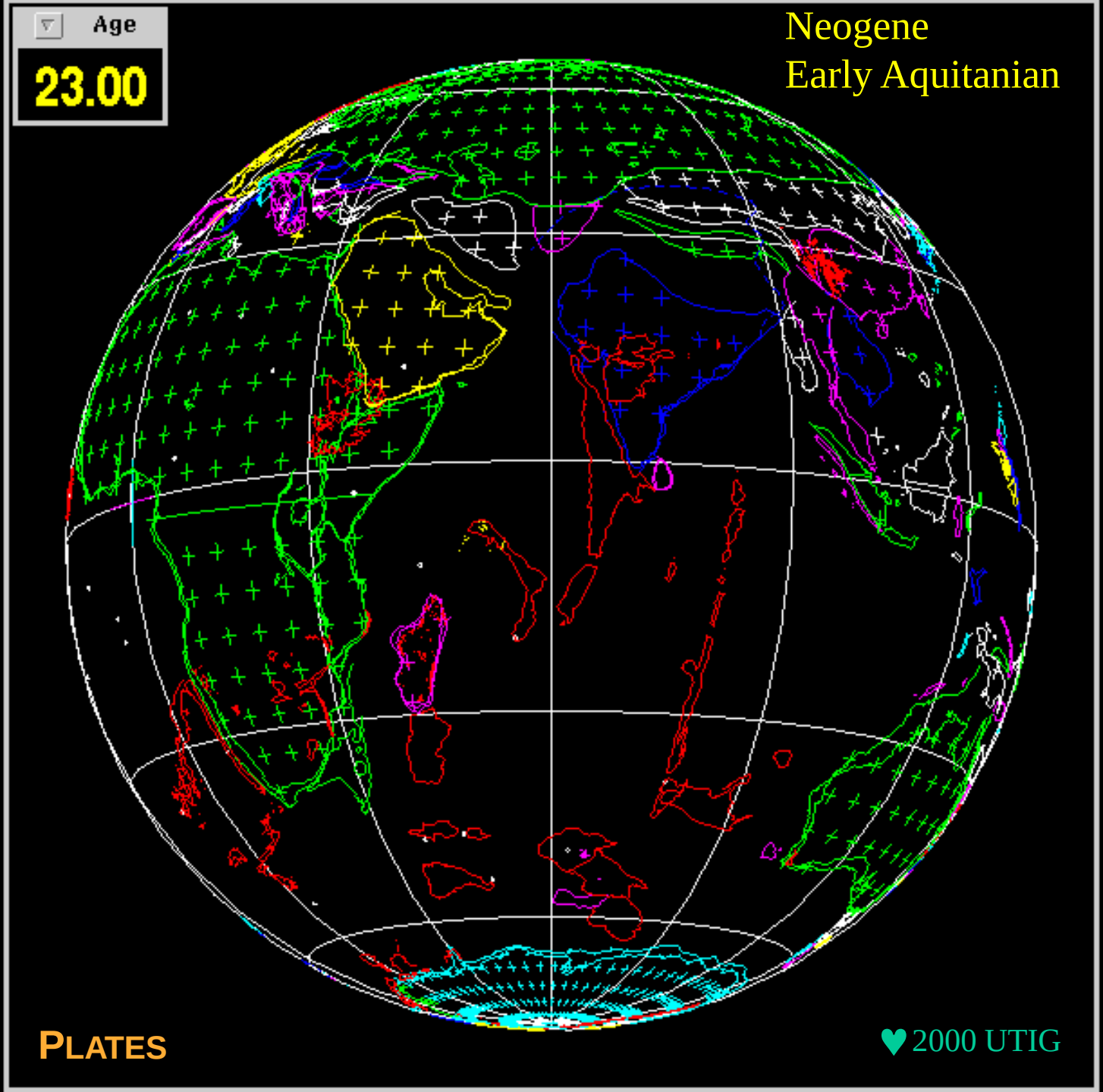

Age
28.00
Paleogene
Early Chattian
PLATES
♥2000 UTIG

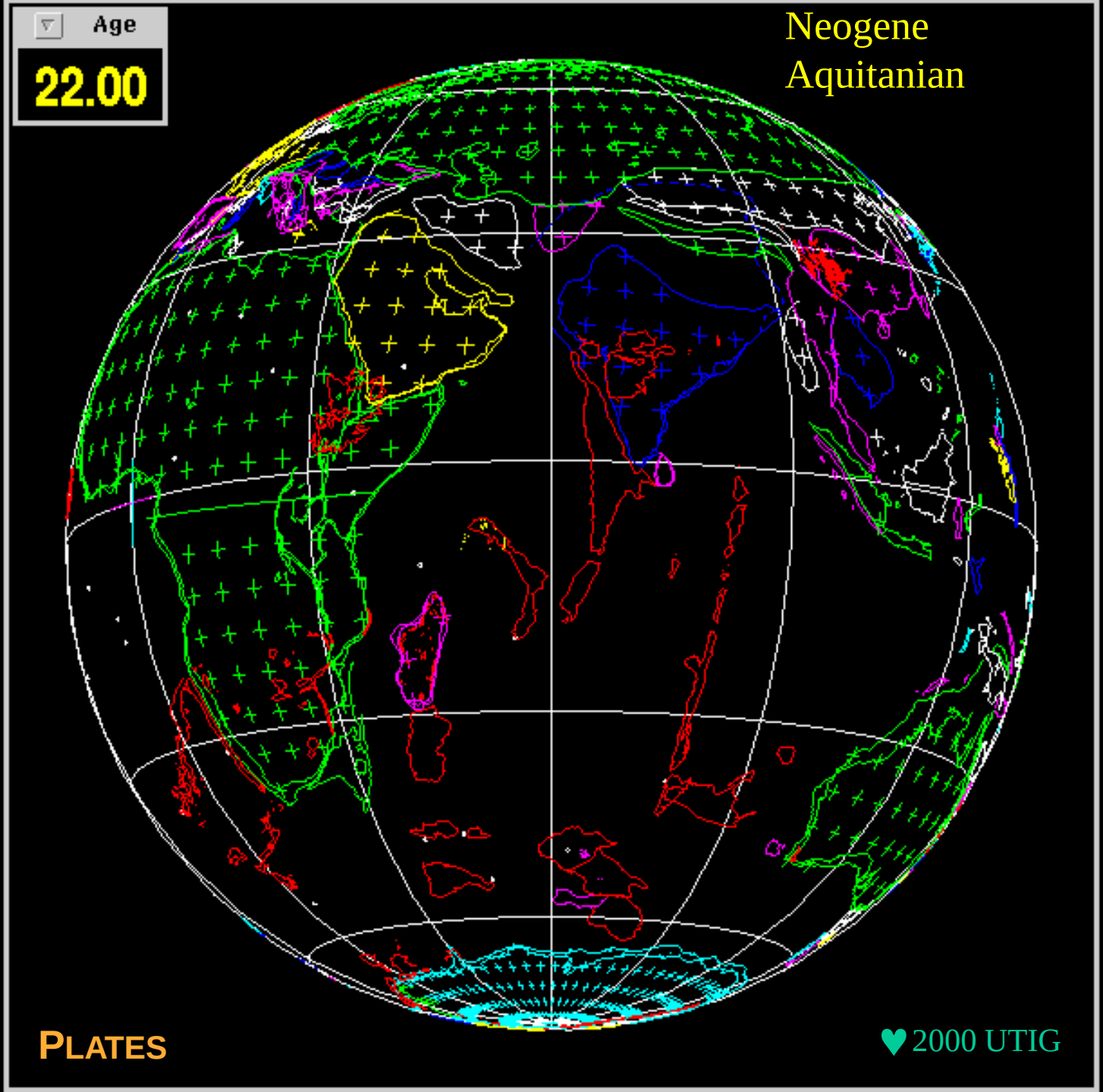

Age
27.00
Paleogene
Early Chattian
PLATES
♥2000 UTIG

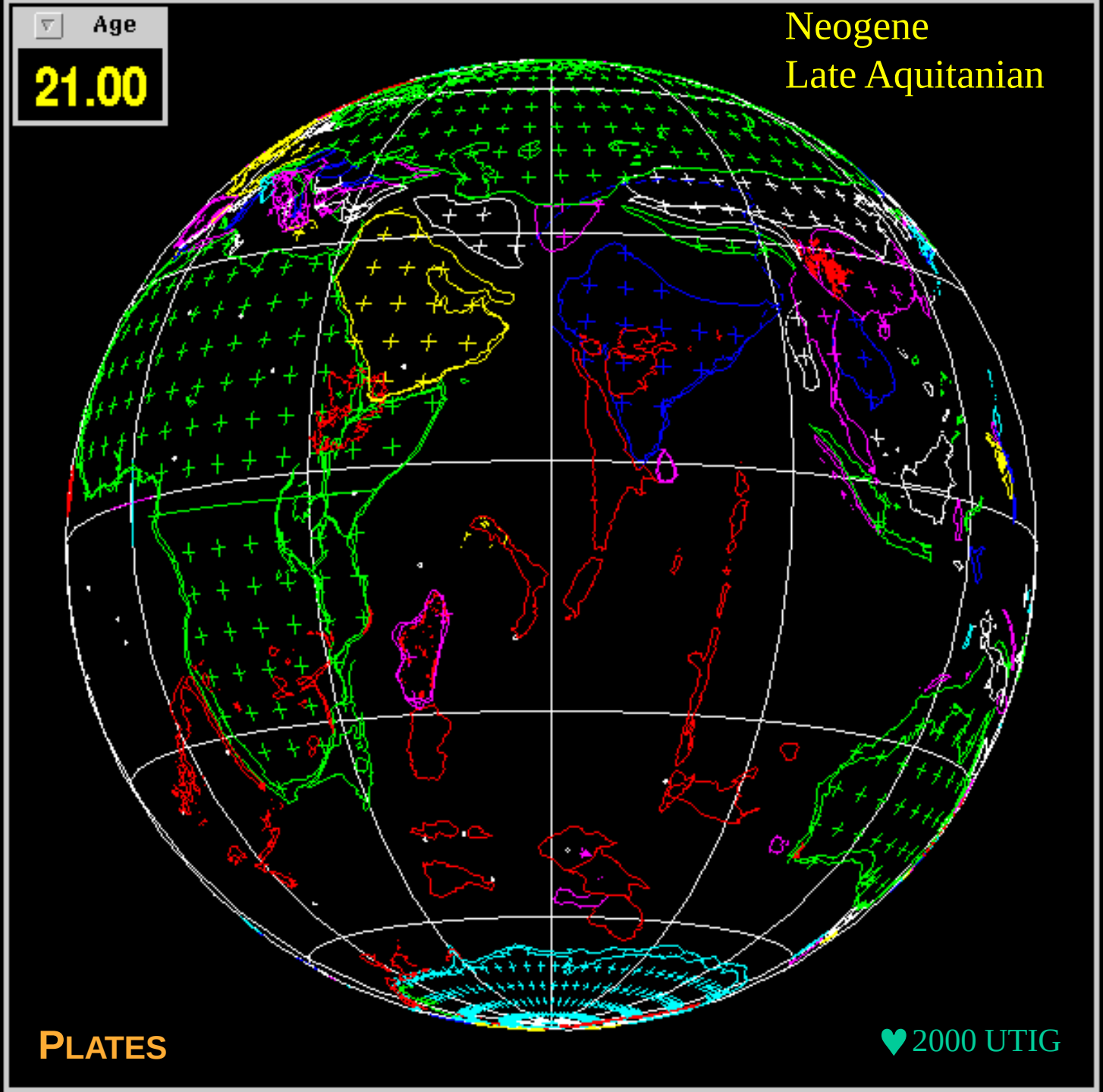

Age
26.00
Paleogene
Chattian
PLATES
♥2000 UTIG

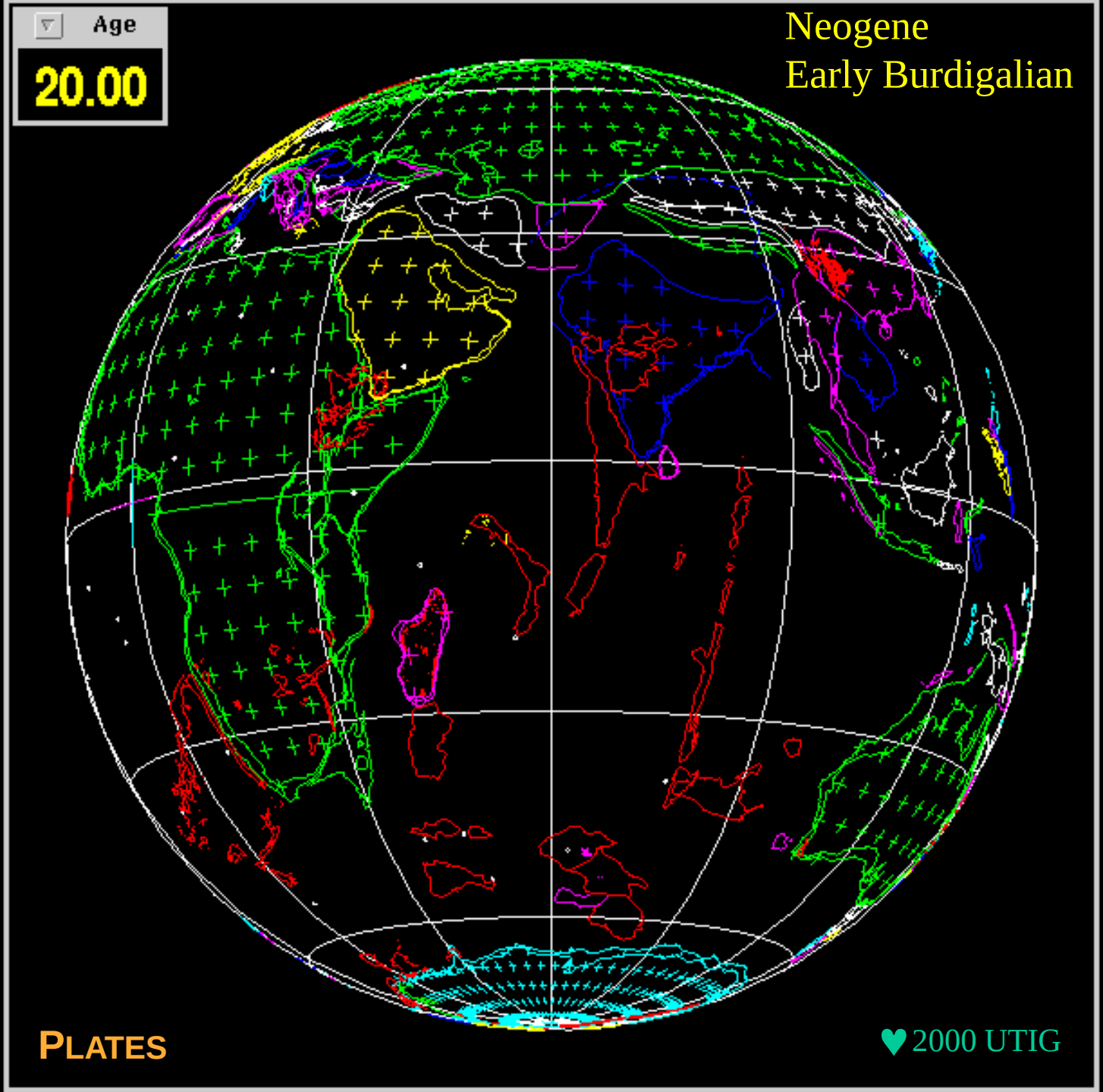

Age
25.00
Paleogene
Late Chattian
PLATES
♥2000 UTIG

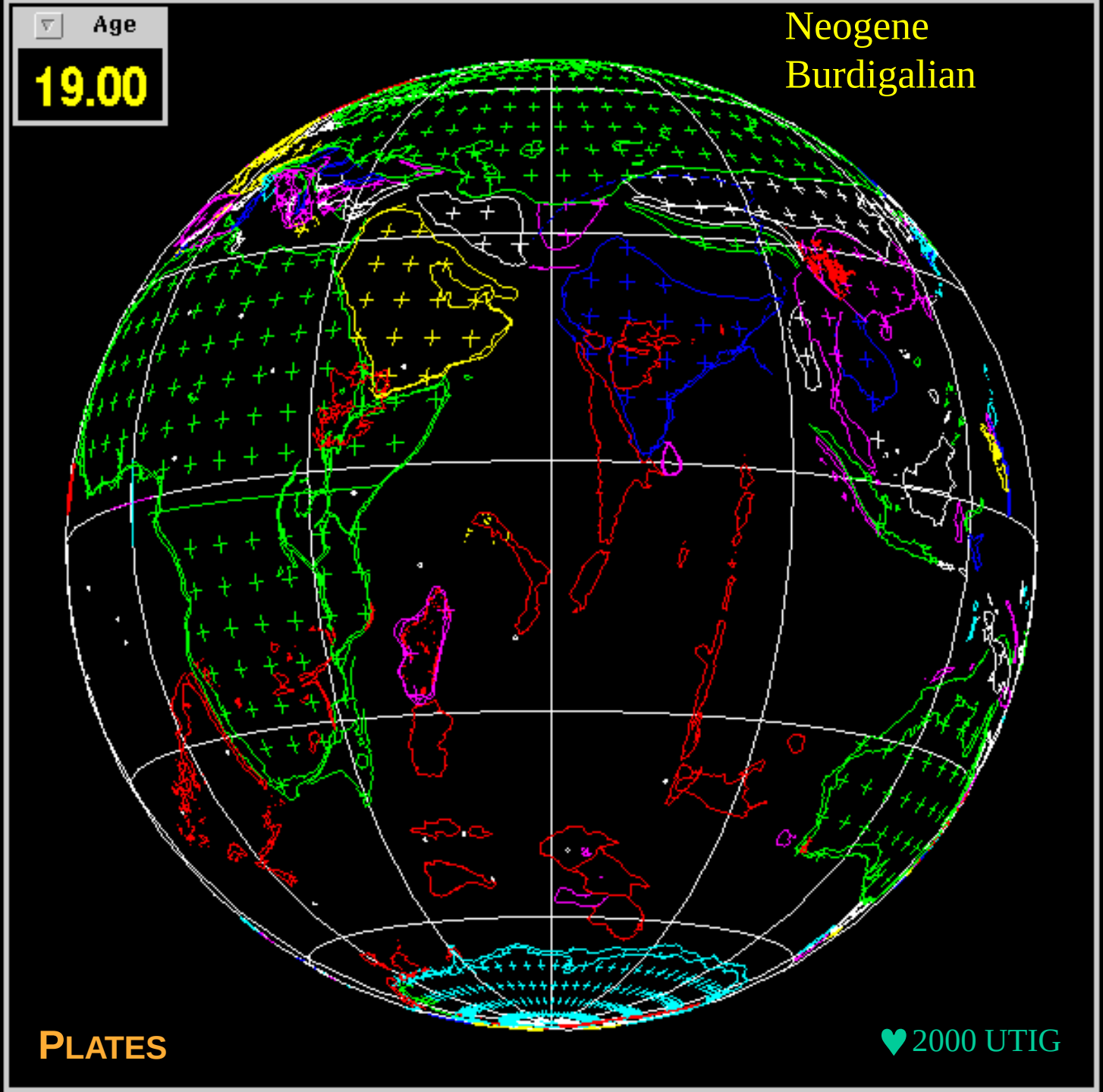

Age
24.00
Paleogene
Late Chattian
PLATES
♥2000 UTIG

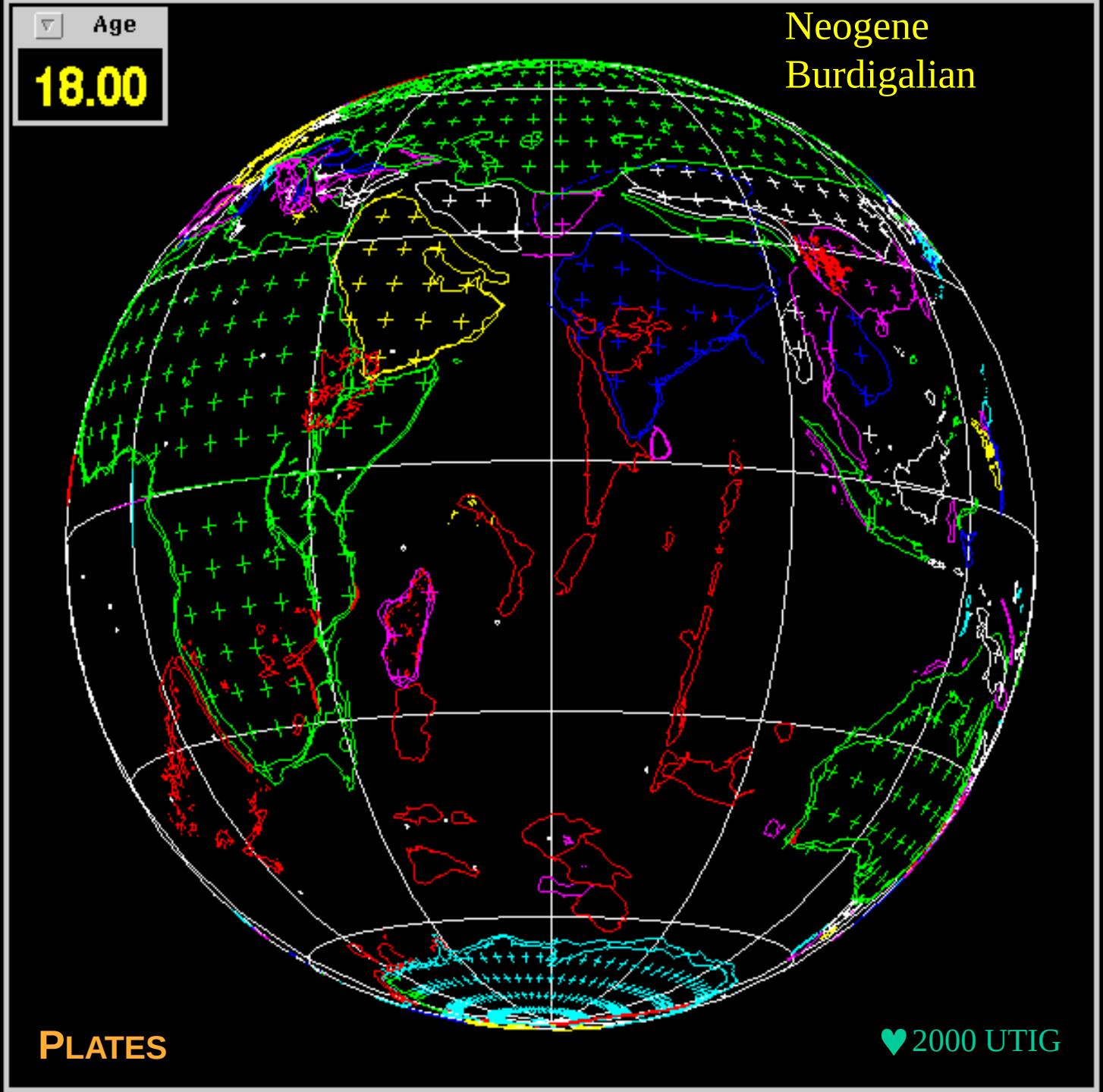

Age
23.00
Neogene
Early Aquitanian
PLATES
♥2000 UTIG

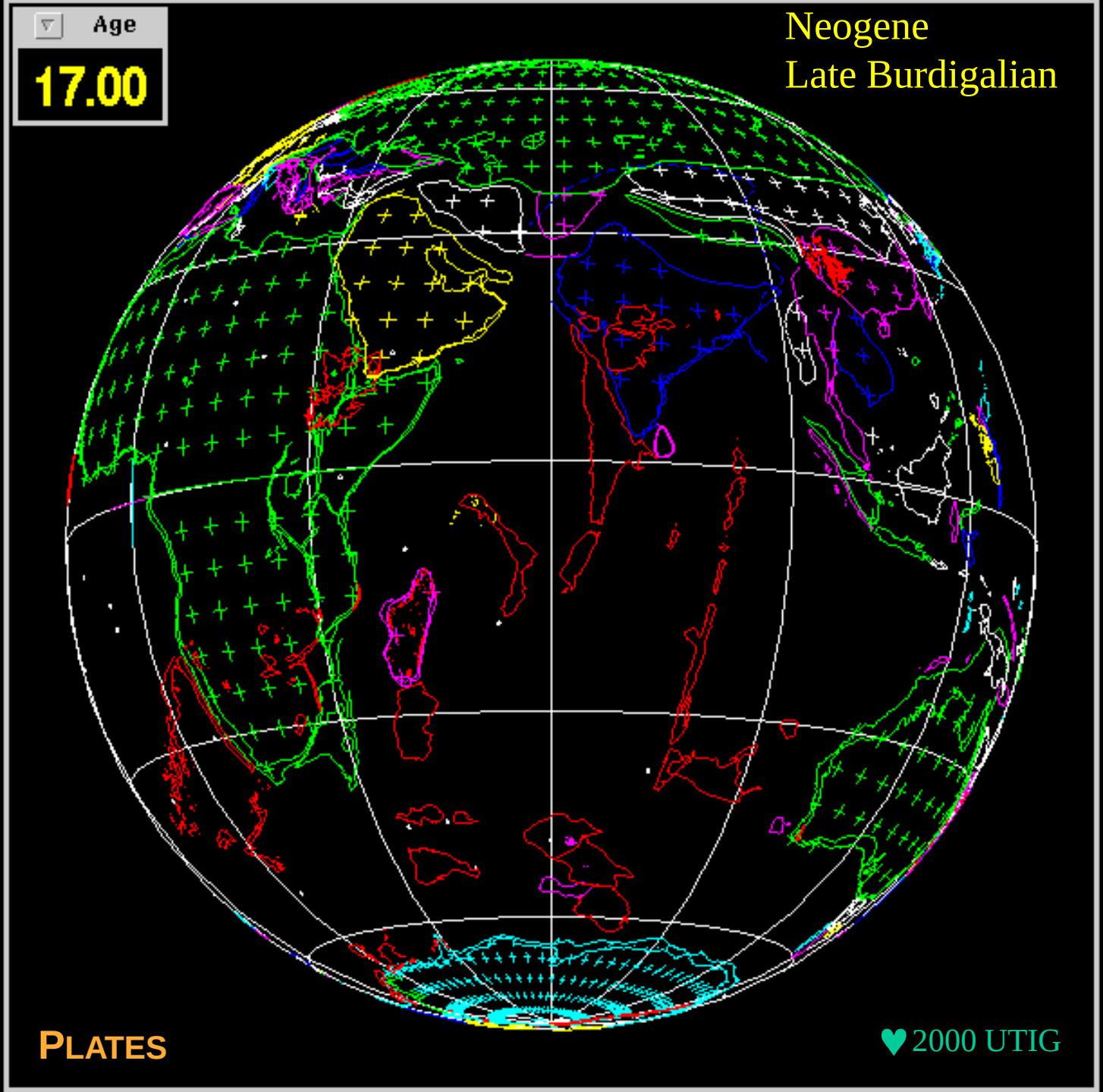

Age
22.00
Neogene
Aquitanian
PLATES
♥2000 UTIG

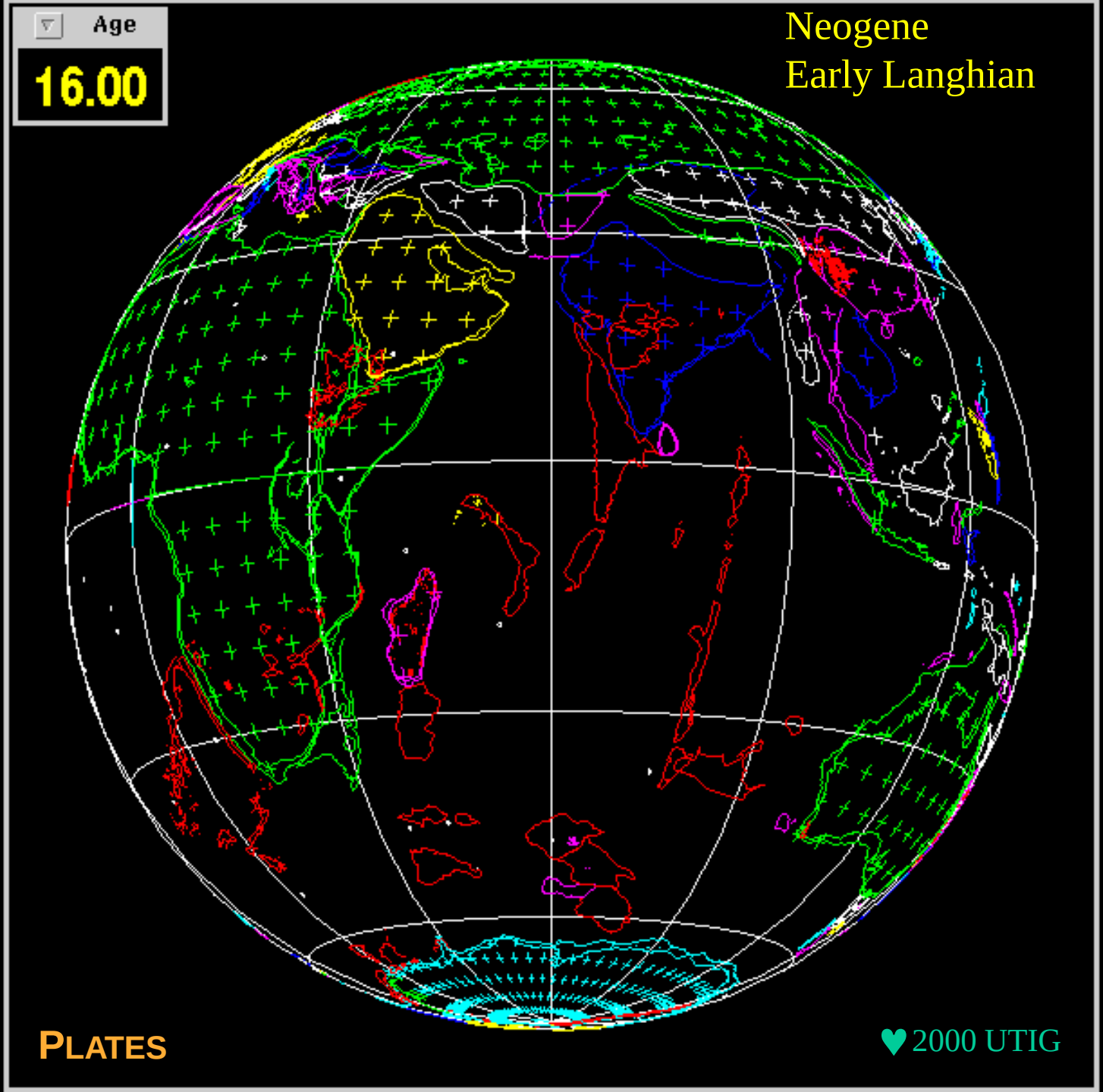

Age
21.00
Neogene
Late Aquitanian
PLATES
♥2000 UTIG

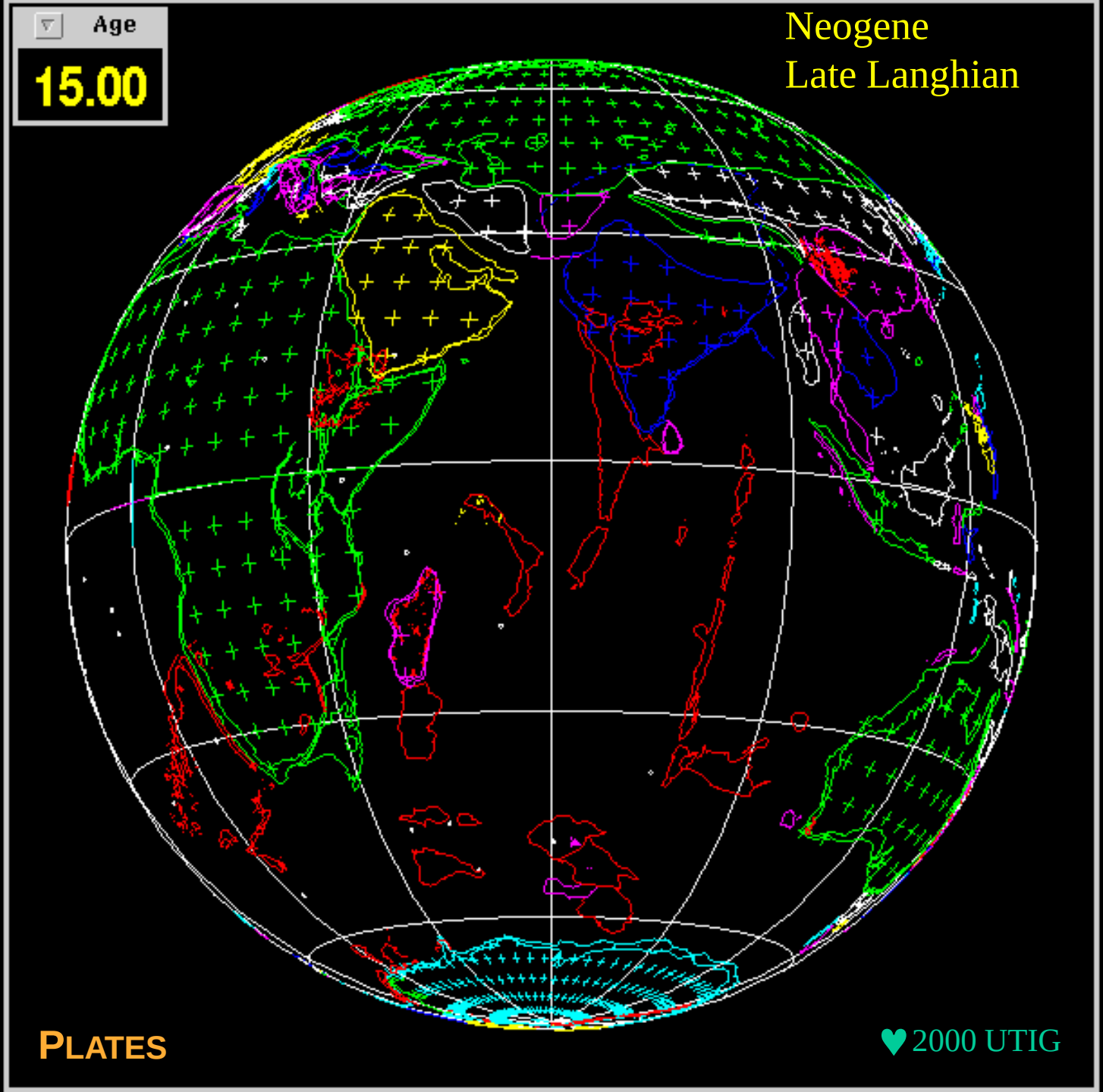

Age
20.00
Neogene
Early Burdigalian
PLATES
♥2000 UTIG

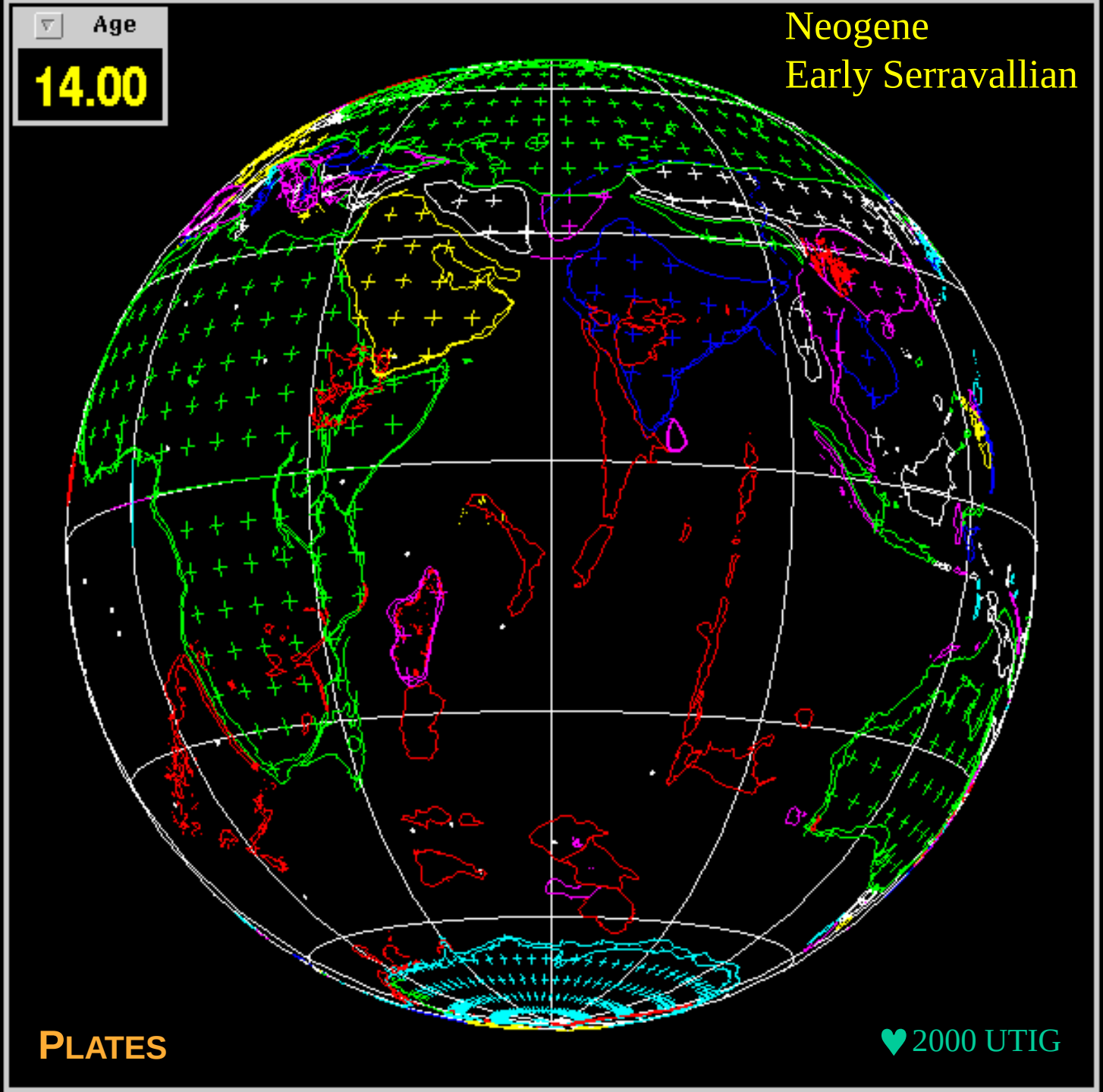

Age
19.00
Neogene
Burdigalian
PLATES
♥2000 UTIG

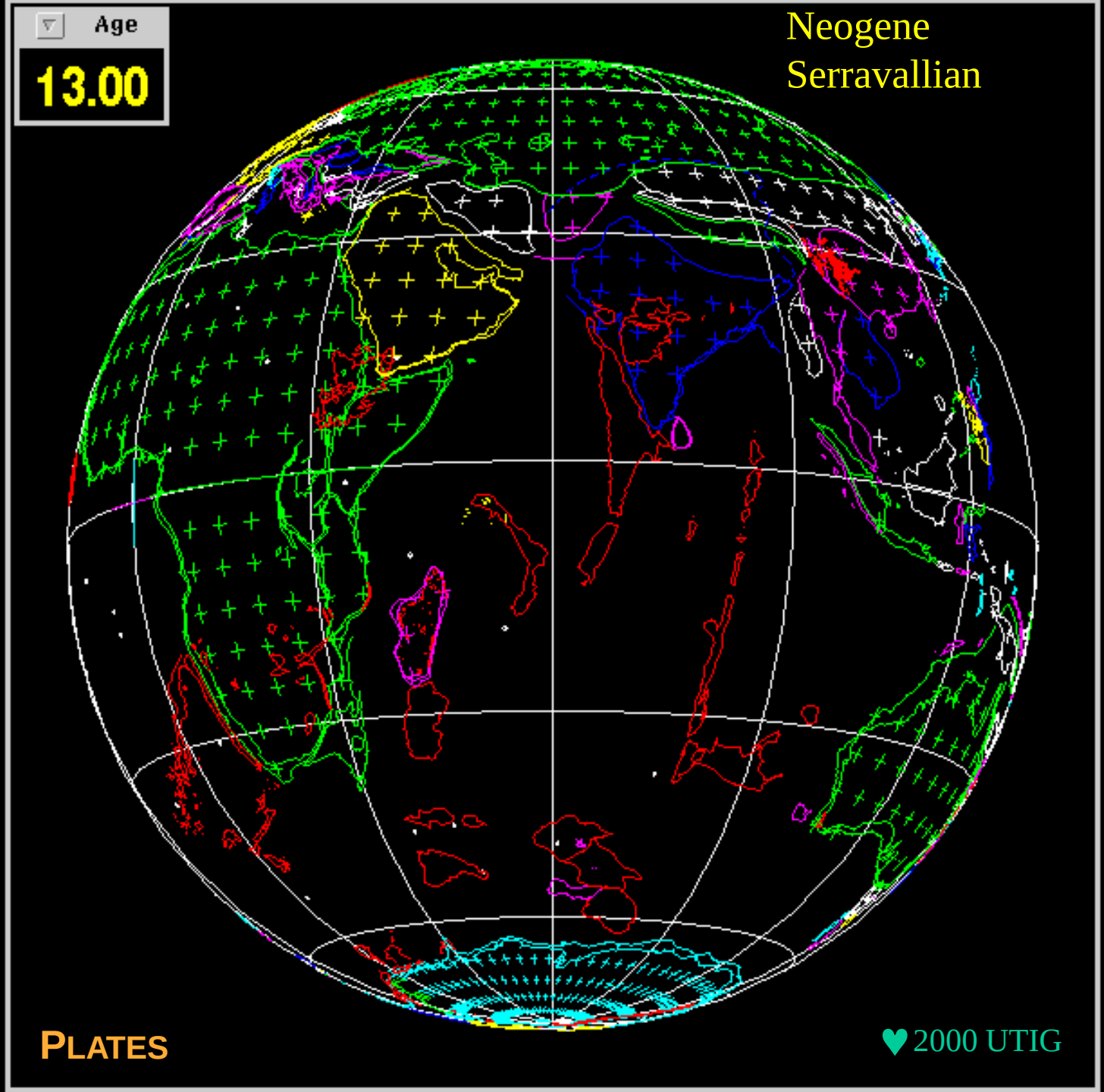

Age
18.00
Neogene
Burdigalian
PLATES
♥2000 UTIG

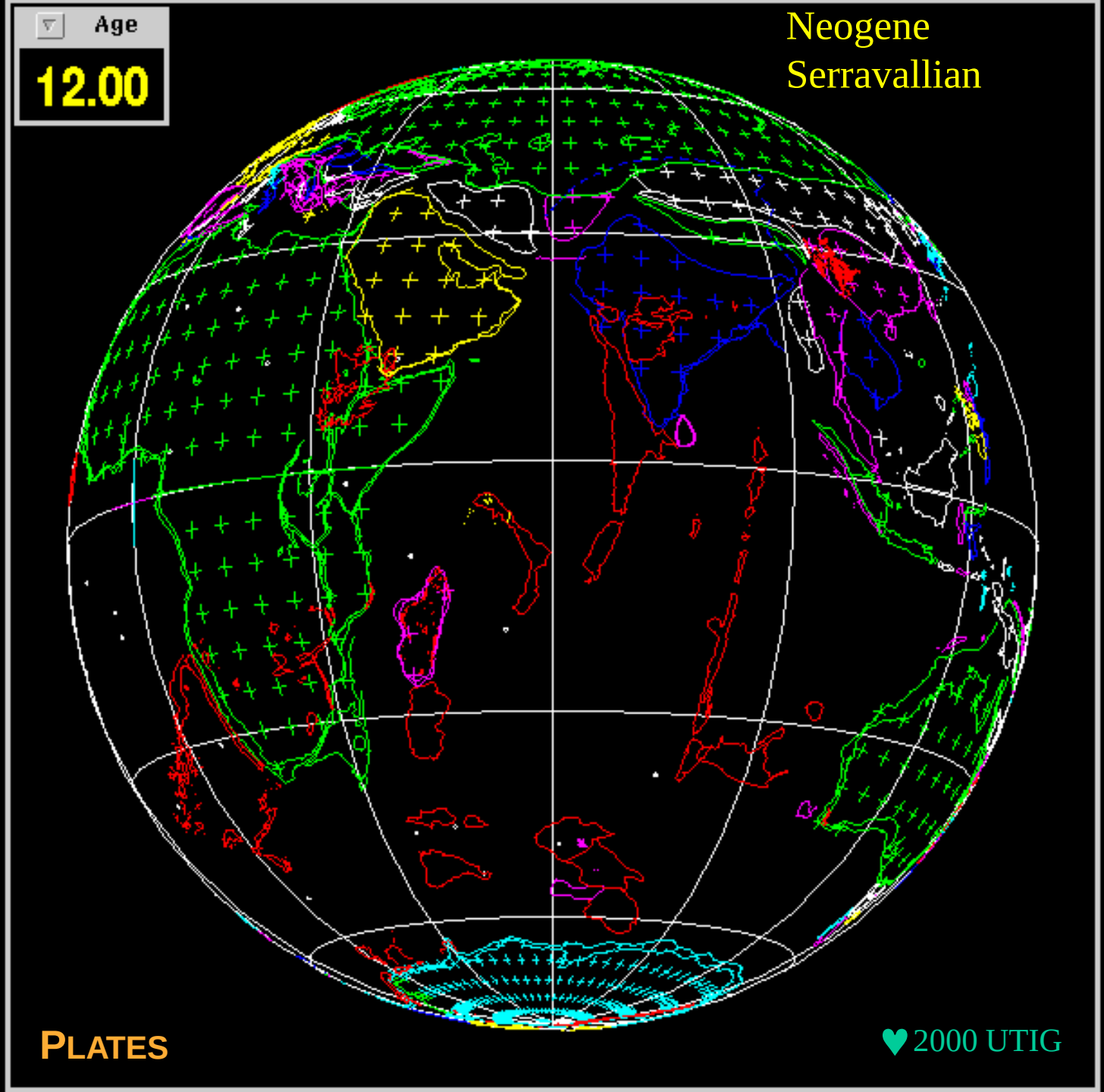

Age
17.00
Neogene
Late Burdigalian
PLATES
♥2000 UTIG

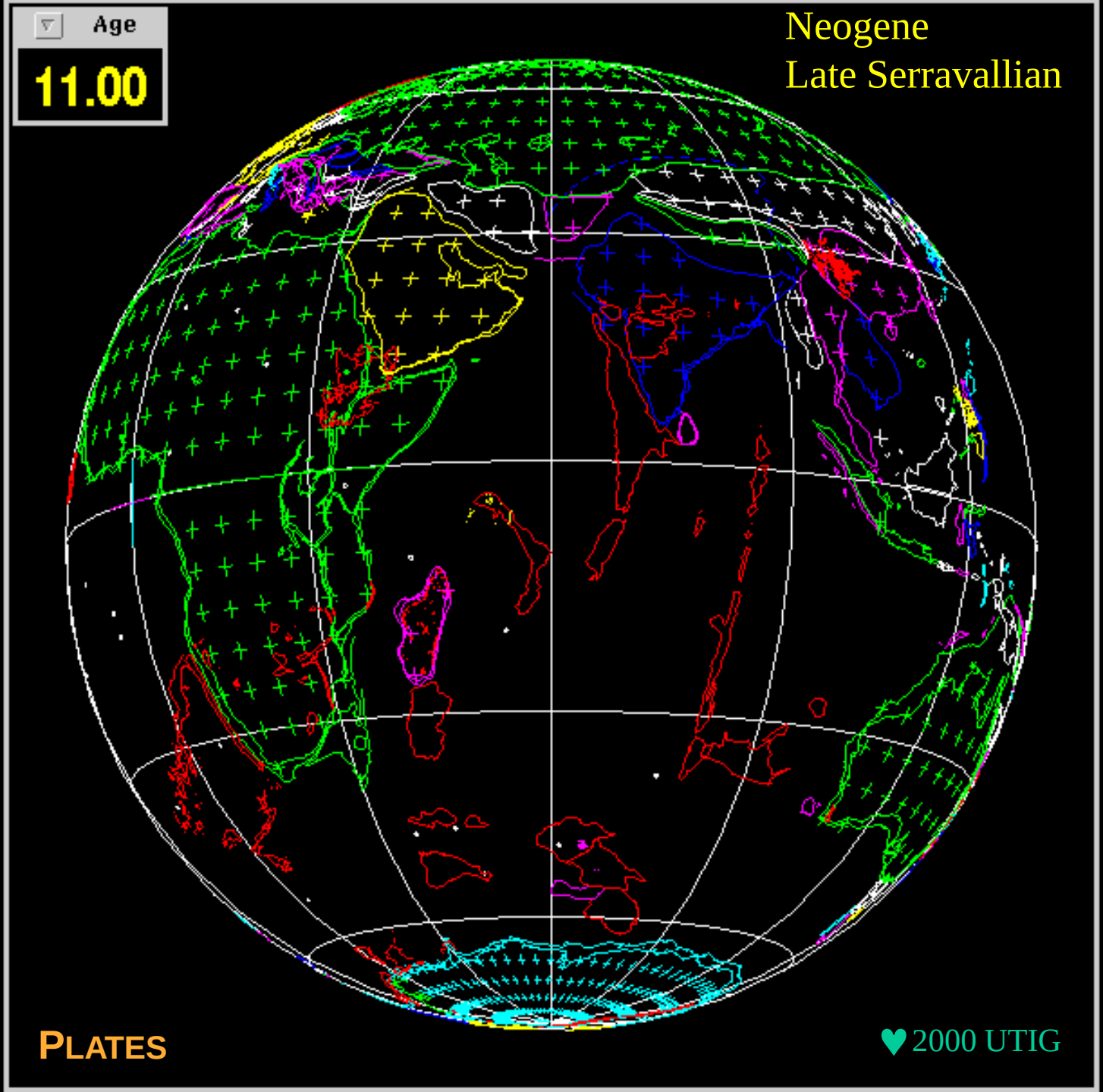

Age
16.00
Neogene
Early Langhian
PLATES
♥2000 UTIG

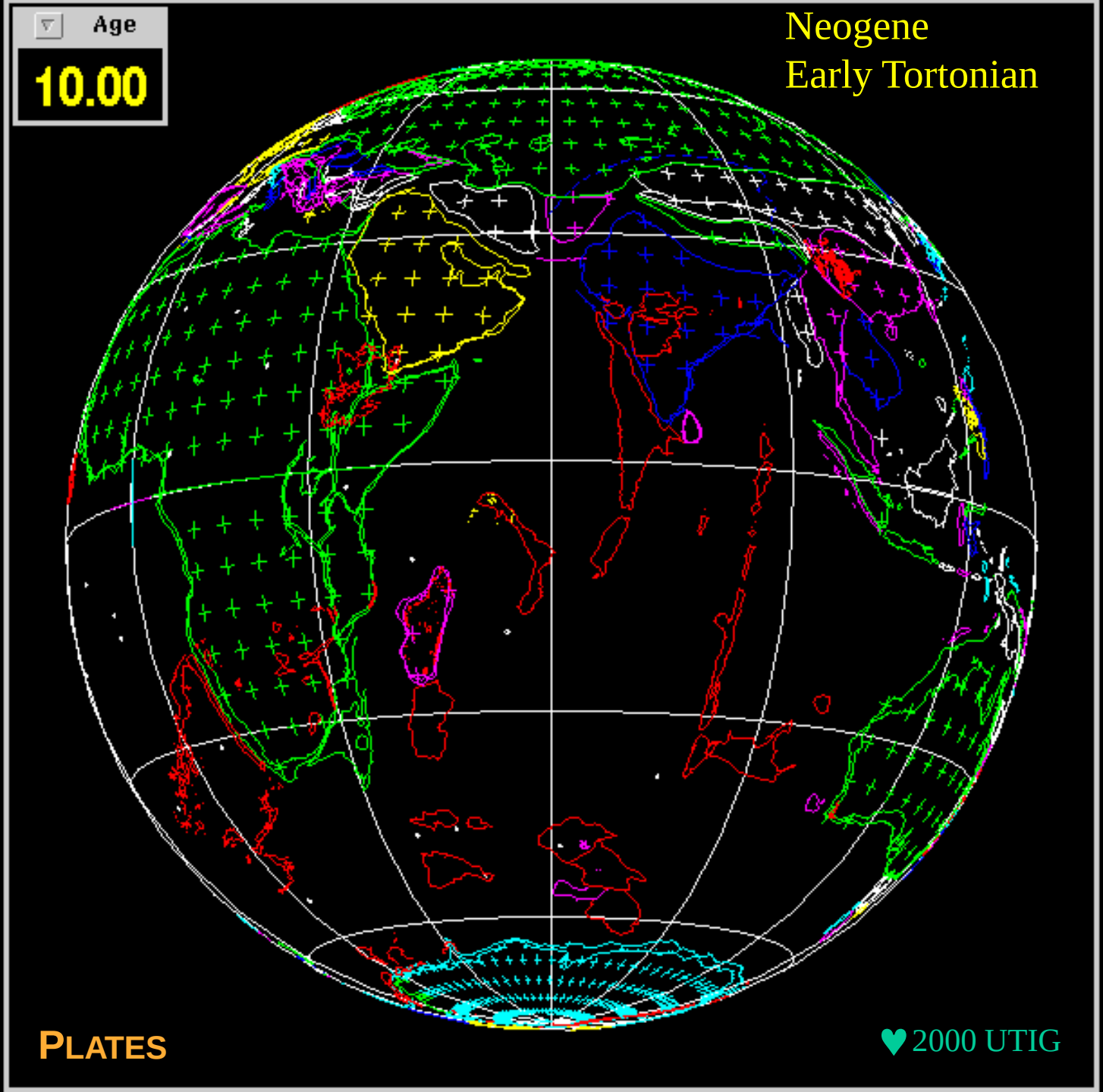

Age
15.00
Neogene
Late Langhian
PLATES
♥2000 UTIG

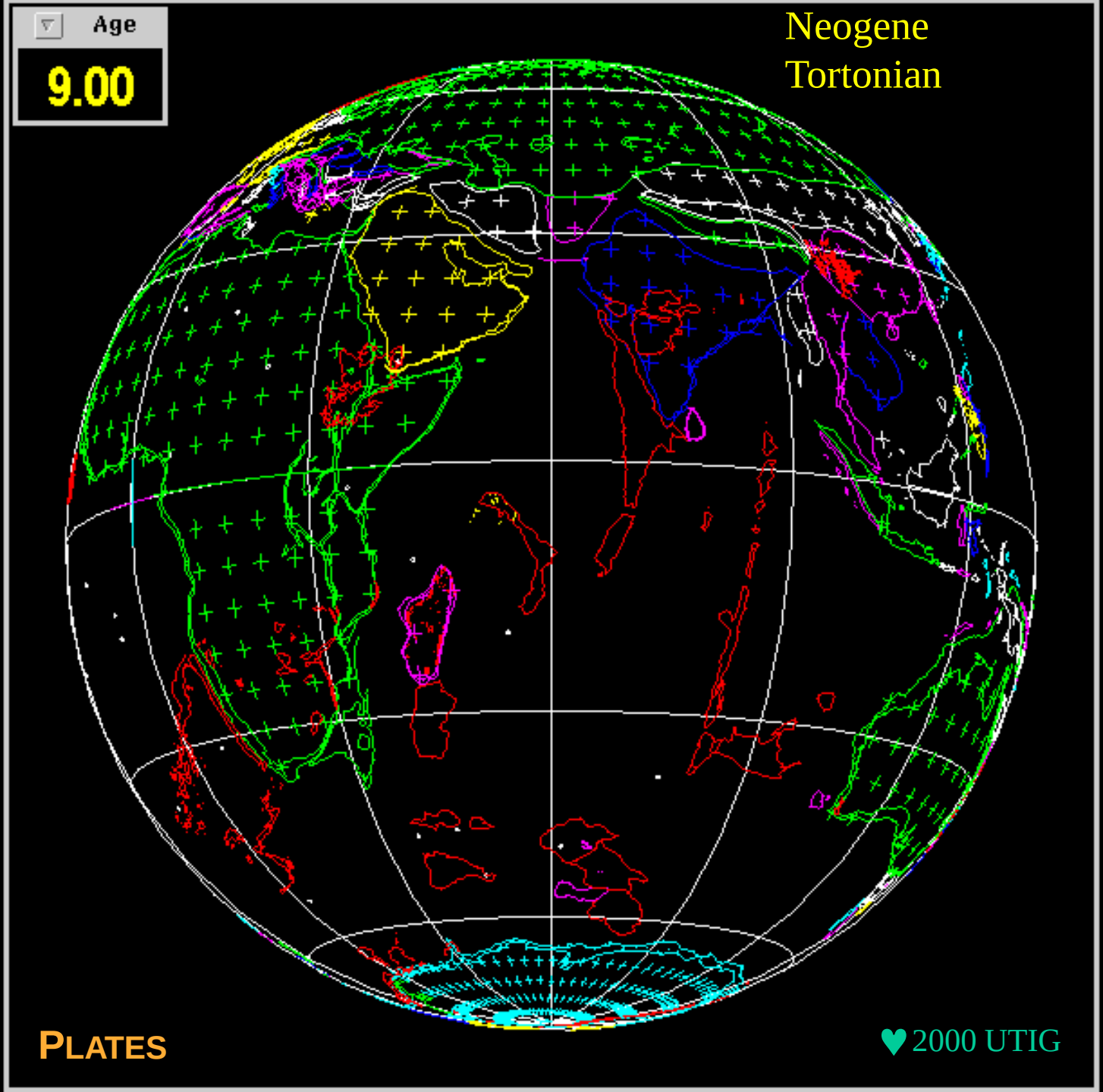

Age
14.00
Neogene
Early Serravallian
PLATES
♥2000 UTIG

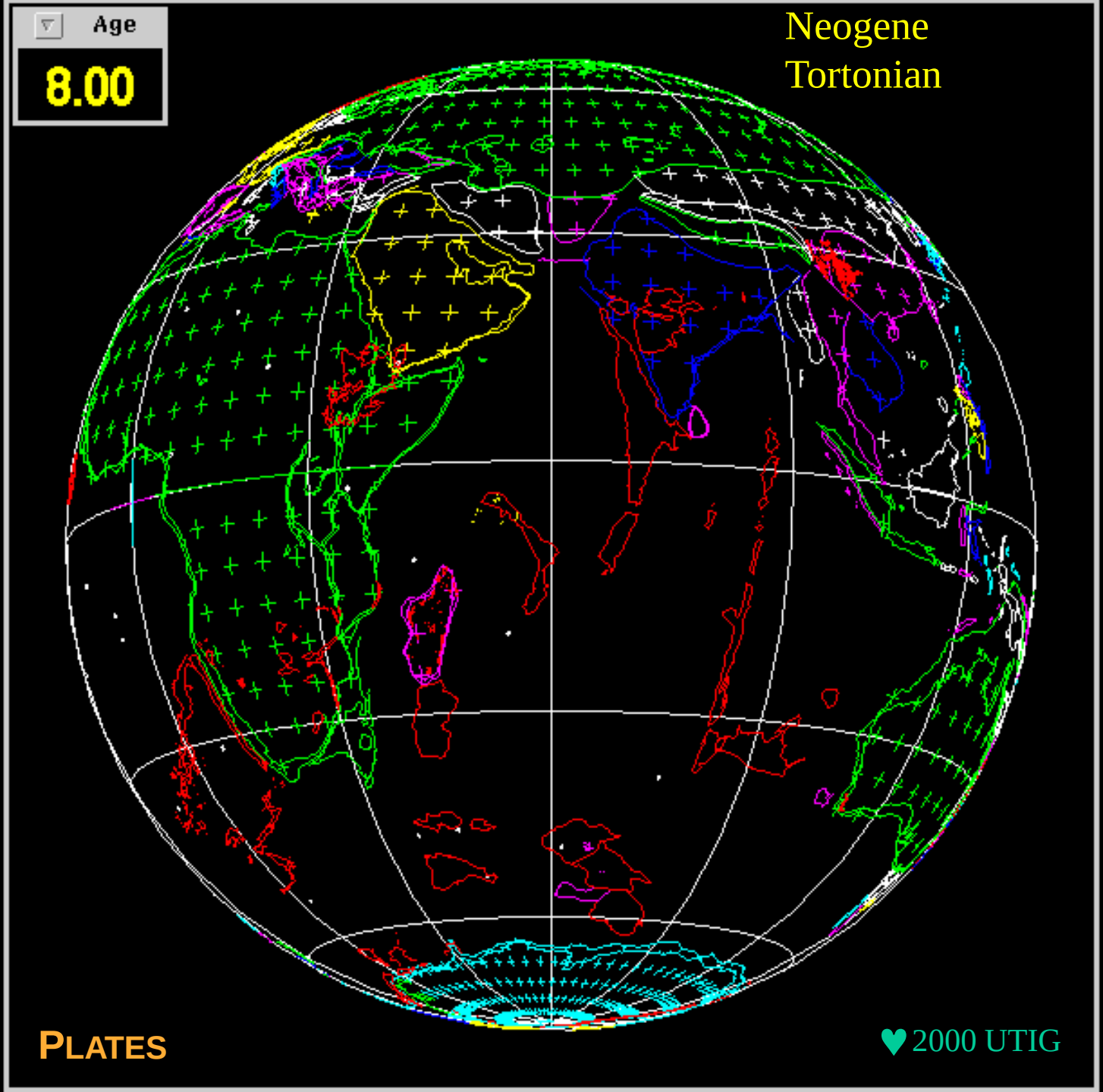

Age
13.00
Neogene
Serravallian
PLATES
♥2000 UTIG

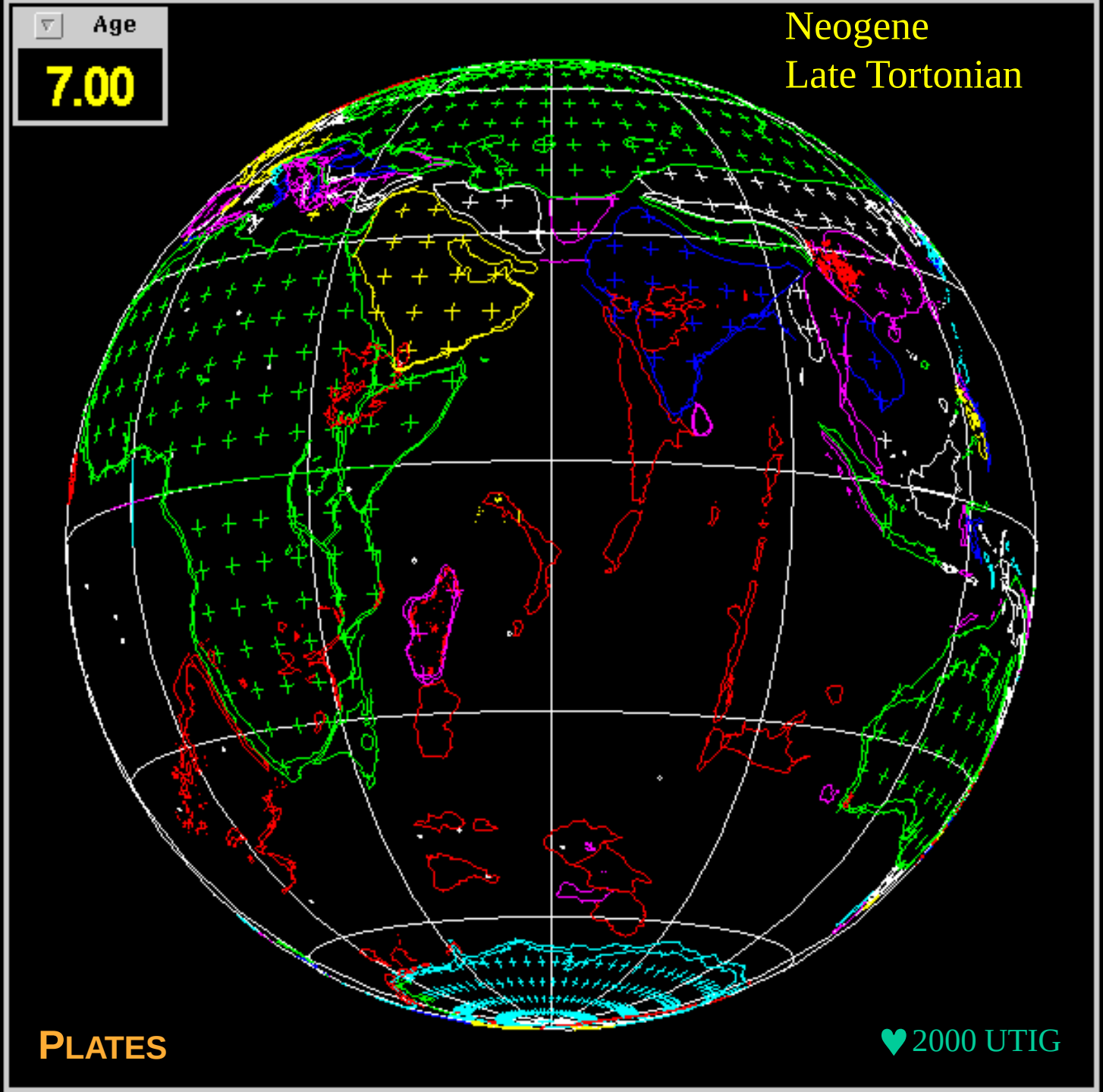

Age
12.00
Neogene
Serravallian
PLATES
♥2000 UTIG

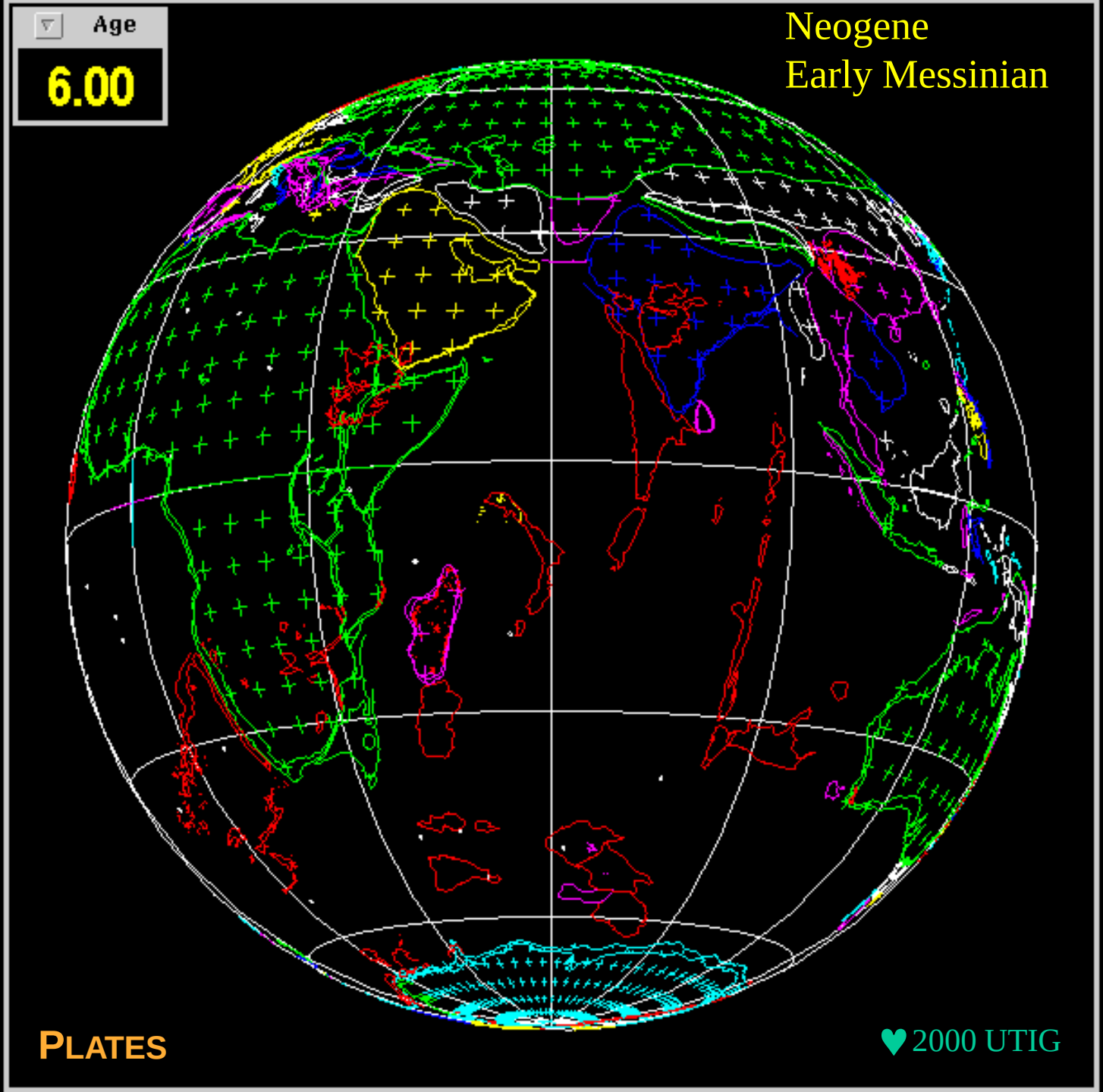

Age
11.00
Neogene
Late Serravallian
PLATES
♥2000 UTIG

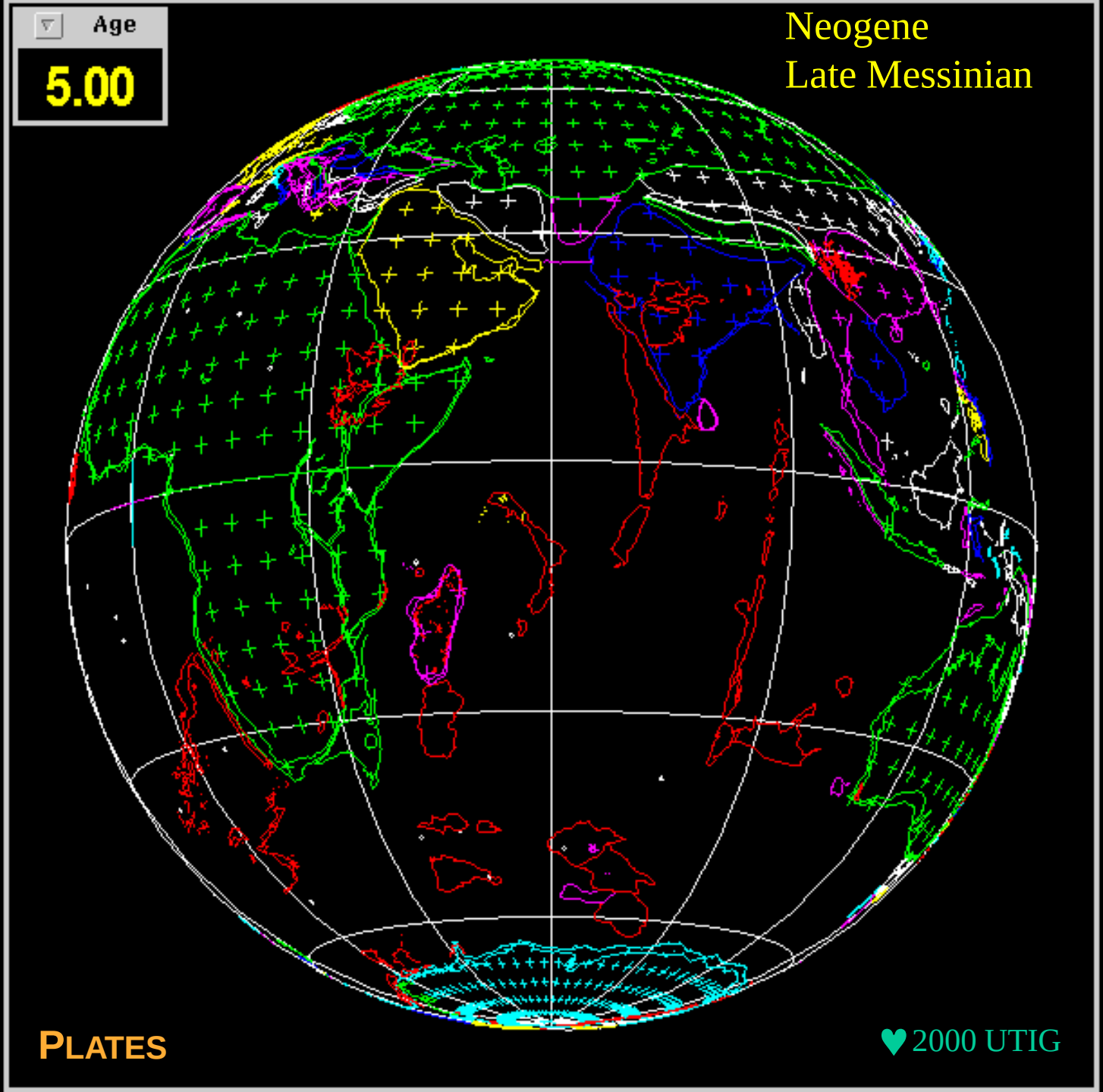

Age
10.00
Neogene
Early Tortonian
PLATES
♥2000 UTIG

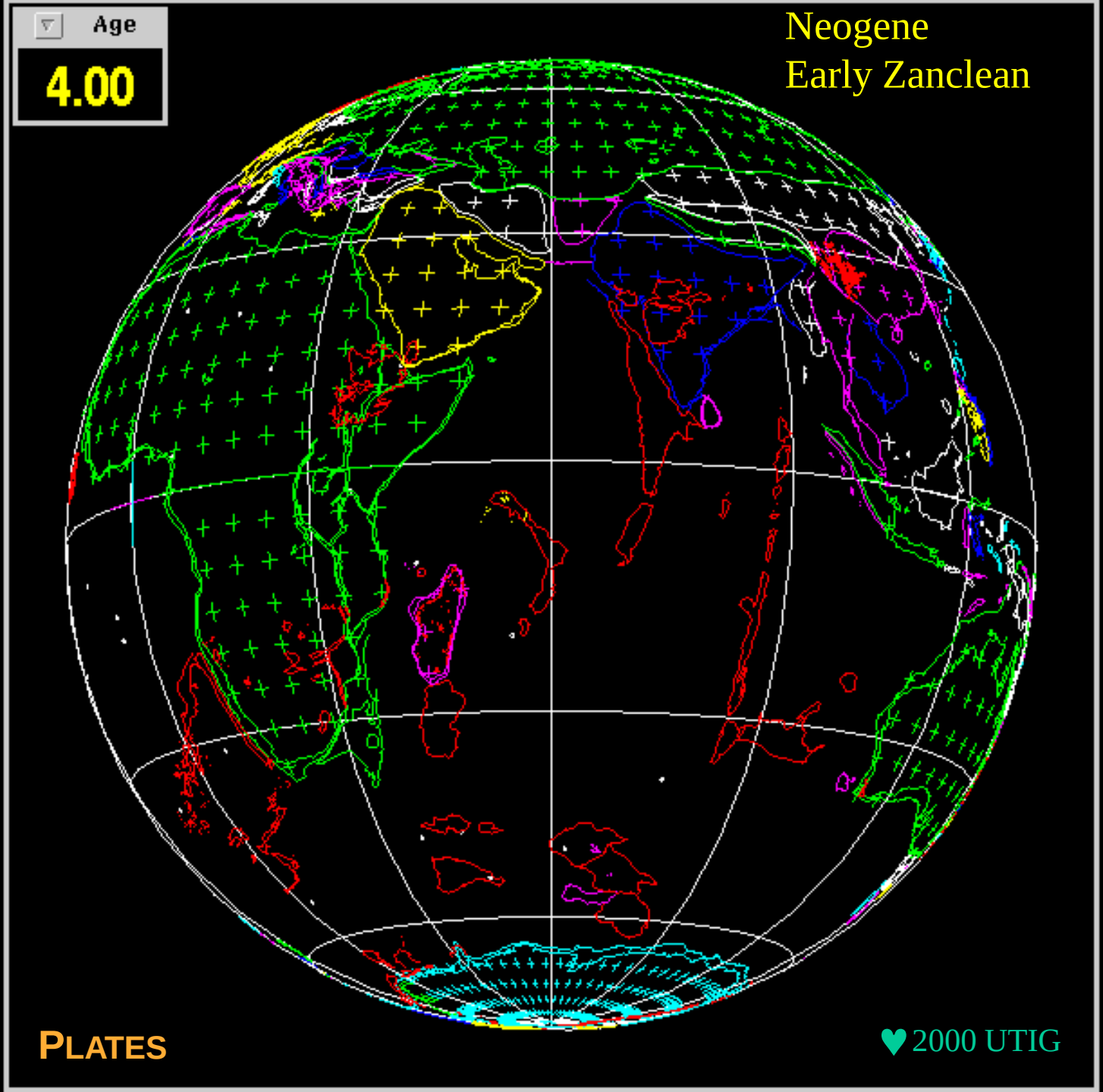

Age
9.00
Neogene
Tortonian
PLATES
♥2000 UTIG

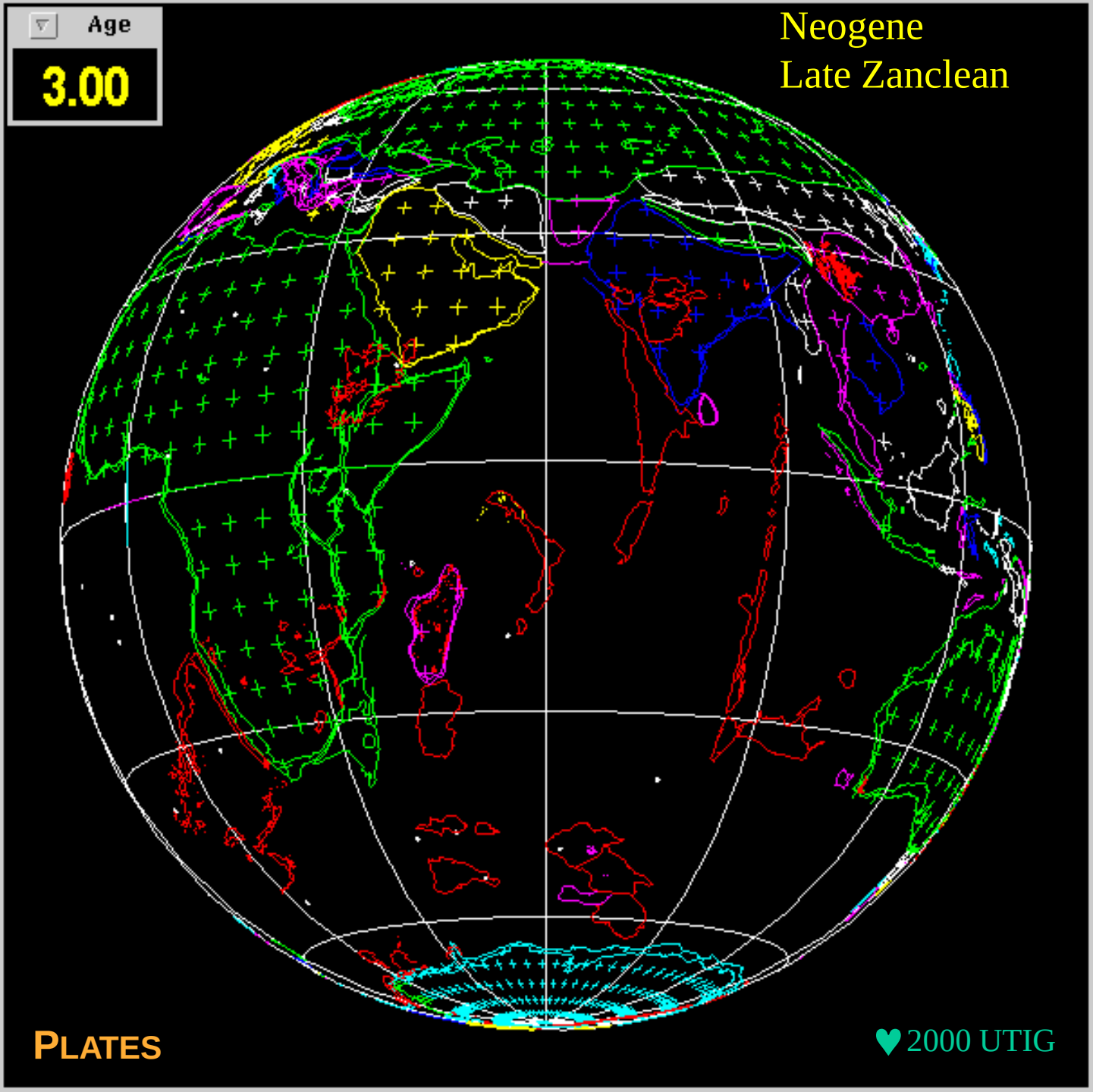

Age
8.00
Neogene
Tortonian
PLATES
♥2000 UTIG

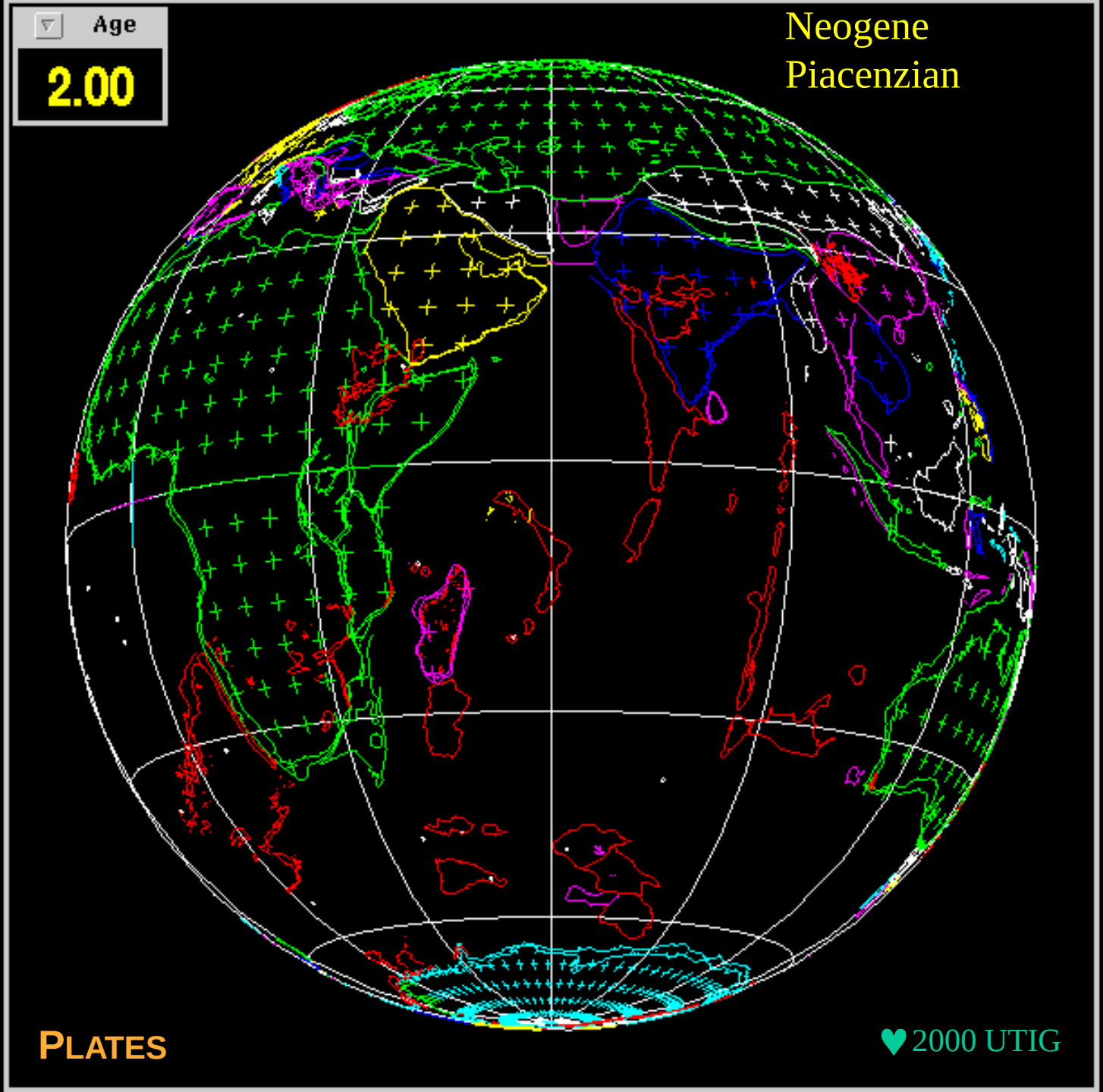

Age
7.00
Neogene
Late Tortonian
PLATES
♥2000 UTIG

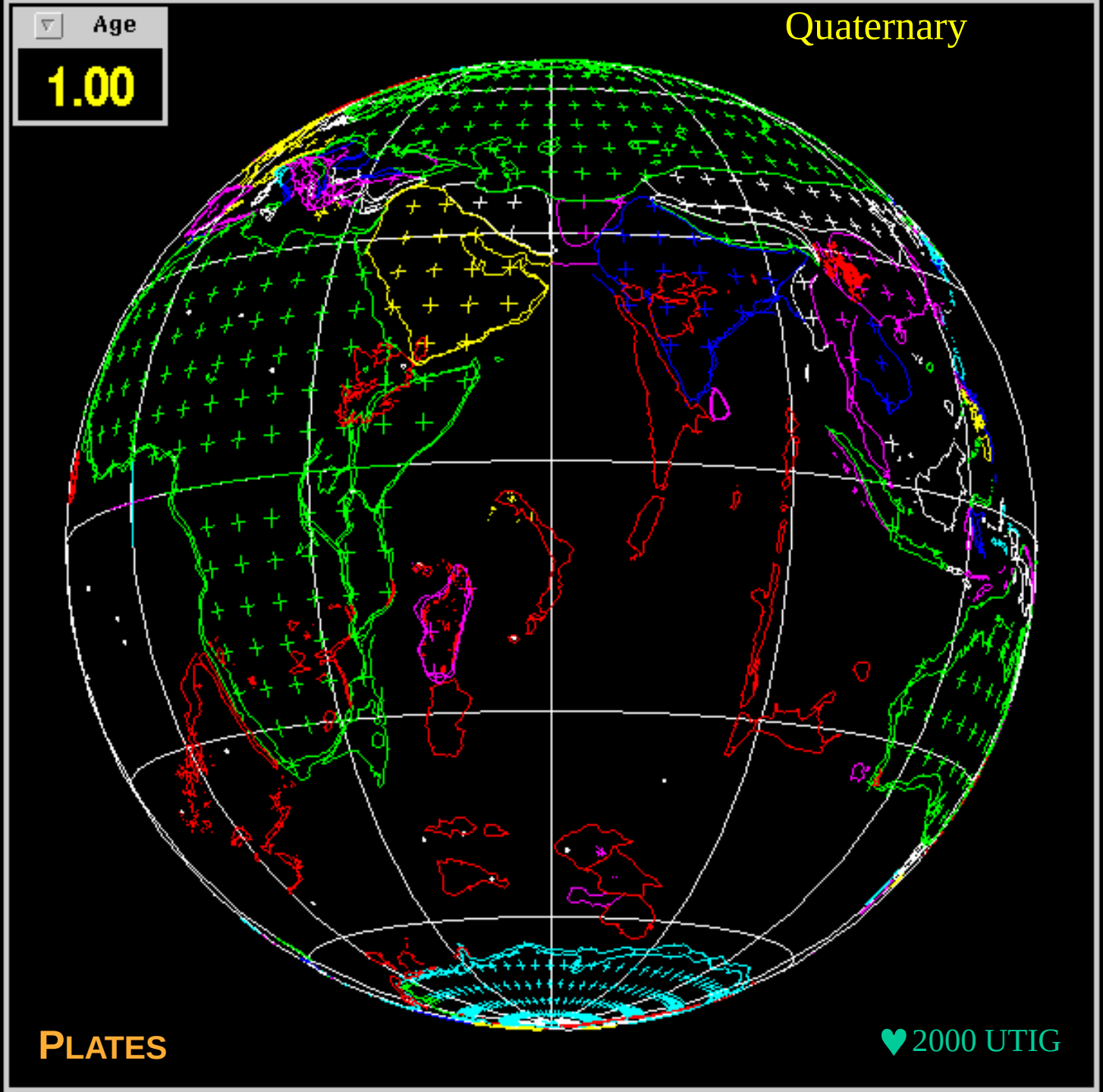

Age
6.00
Neogene
Early Messinian
PLATES
♥2000 UTIG

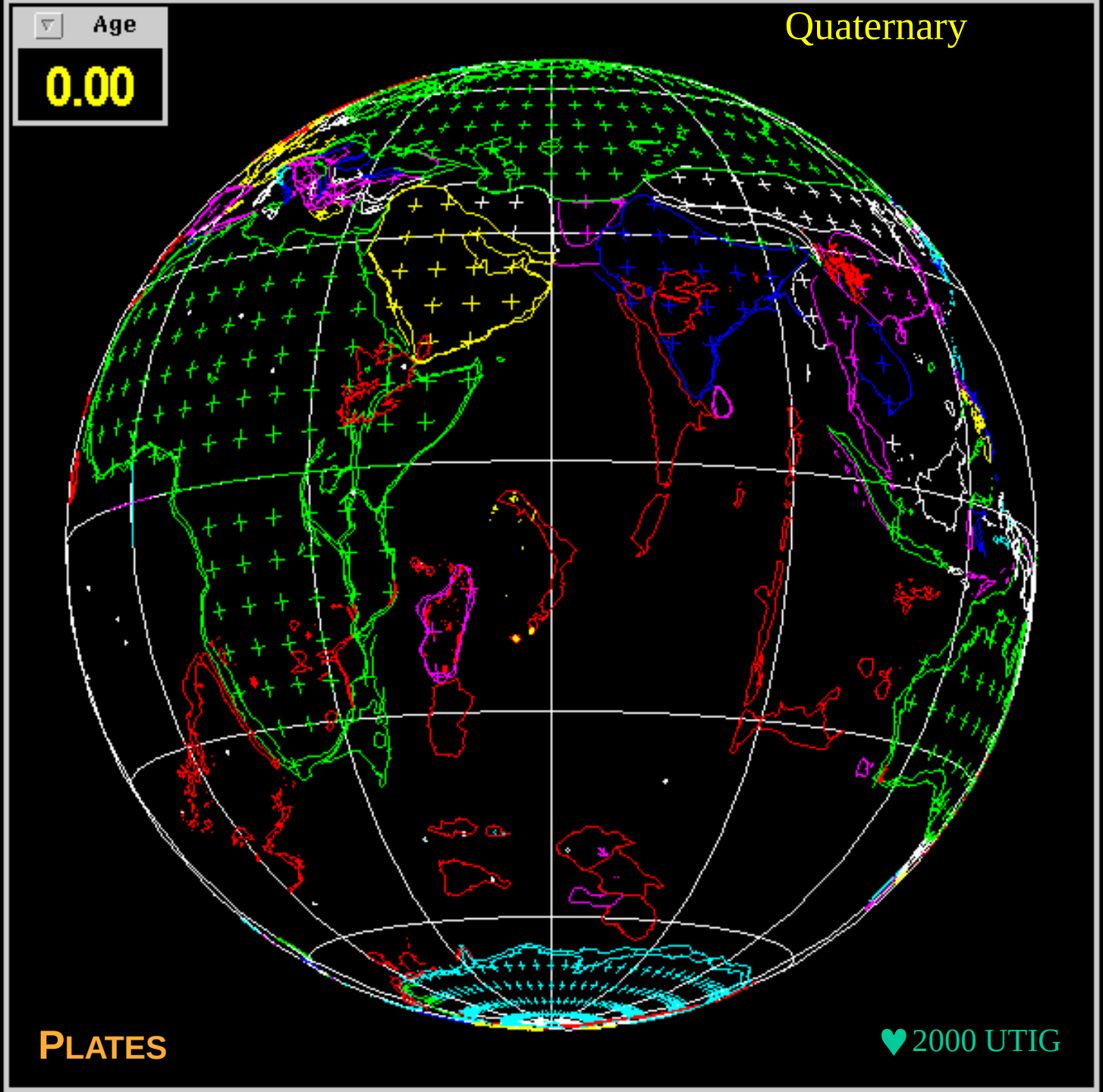

Age
5.00
Neogene
Late Messinian
PLATES
♥2000 UTIG


Age
4.00
Neogene
Early Zanclean
PLATES
♥2000 UTIG

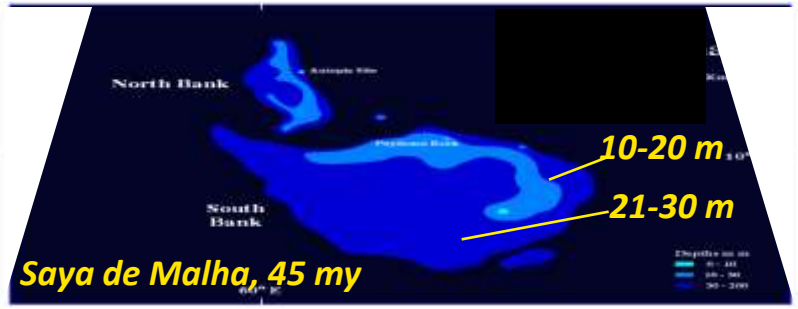

Age
3.00
Neogene
Late Zanclean
PLATES
♥2000 UTIG


Age
2.00
Neogene
Piacenzian
PLATES
♥2000 UTIG

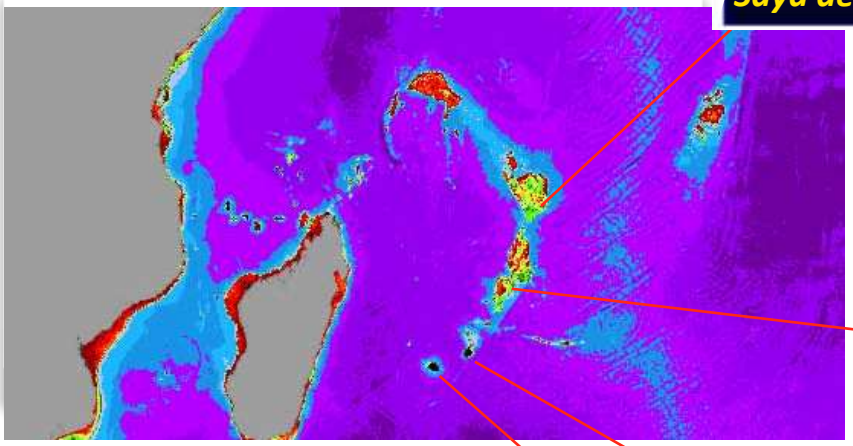

Age
1.00
Quaternary
PLATES
♥2000 UTIG

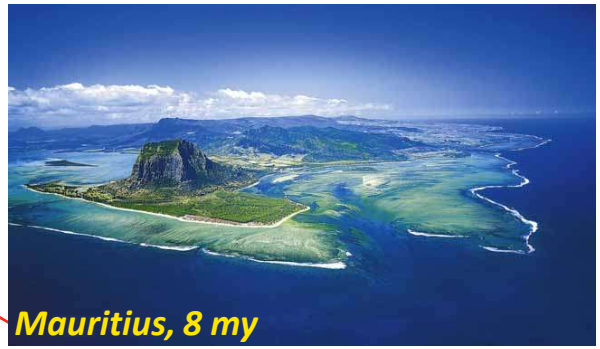

Age
0.00
Quaternary
Restart
animation
PLATES
♥2000 UTIG

Mascarene-Reunion hotspot



sland height and mass decrease with age and crust subsidence, ending in coralline atolls, banks and submerged platforms (guyots)





la Reunion - Piton de la Fournaise

70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Paleogene 66-23 my

Neogene 23-2.6 my

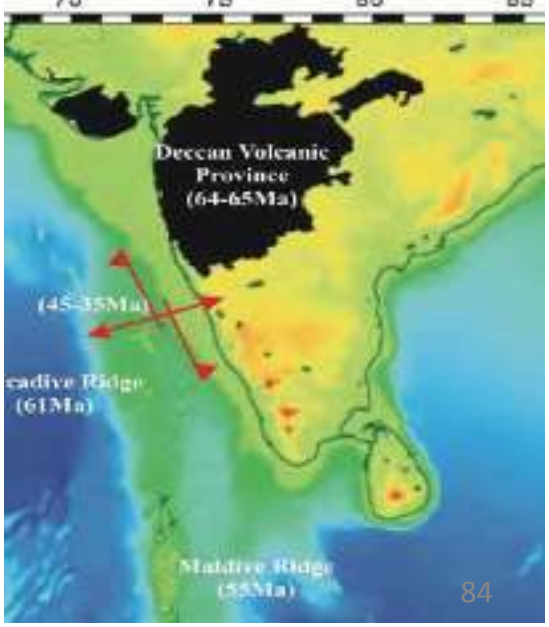
Quarternary 2.6-0

Cretaceous-Tertiary mass extinction

Deccan Traps superplume event

A superplume is an extraordinary extrusion of magma, forming Large Igneous Provinces (e.g. Deccan Traps, India), sometimes associated with major geological and evolutionary tipping points (e.g. K-T extinction).

Dyment 2007, Sheth 2009



Mascarene-Reunion hotspot activity
Deccan Traps to Reunion

70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Paleogene 66-23 my

Neogene 23-2.6 my

Quarternary 2.6-0

Deccan Traps 66-68

Lakshadweep 60

Maldives 57

Chagos 49

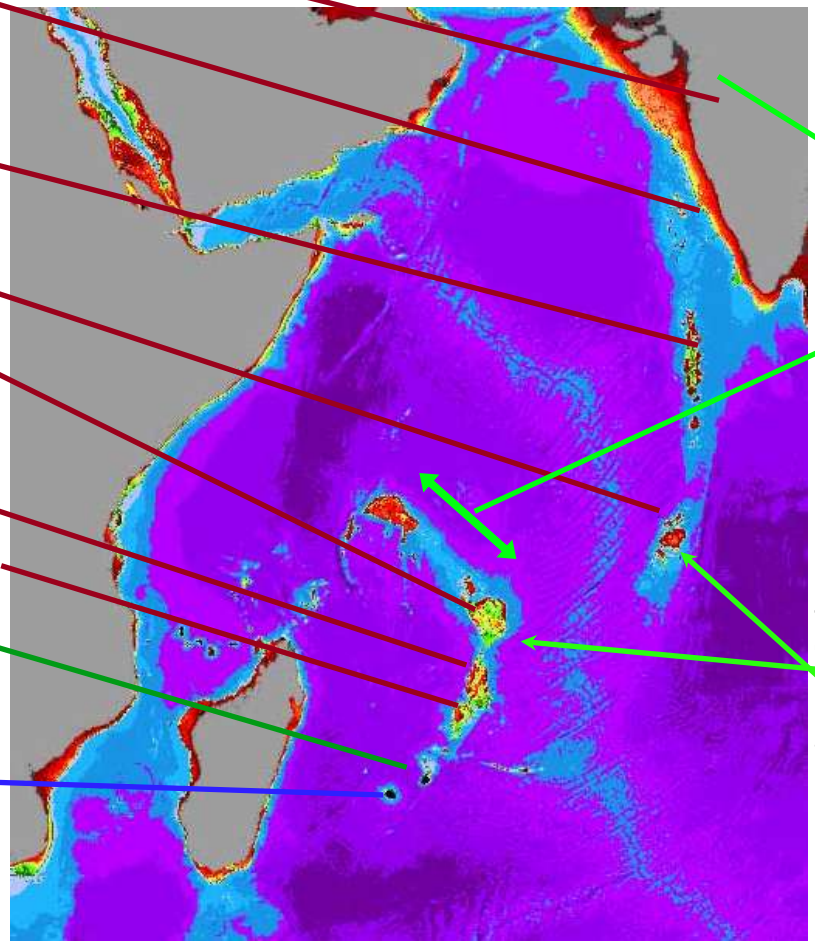
Saya de Malha 45

Nazareth 31-33

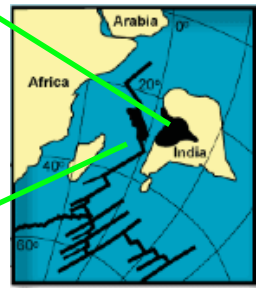
Cargados Carajos

Mauritius 8

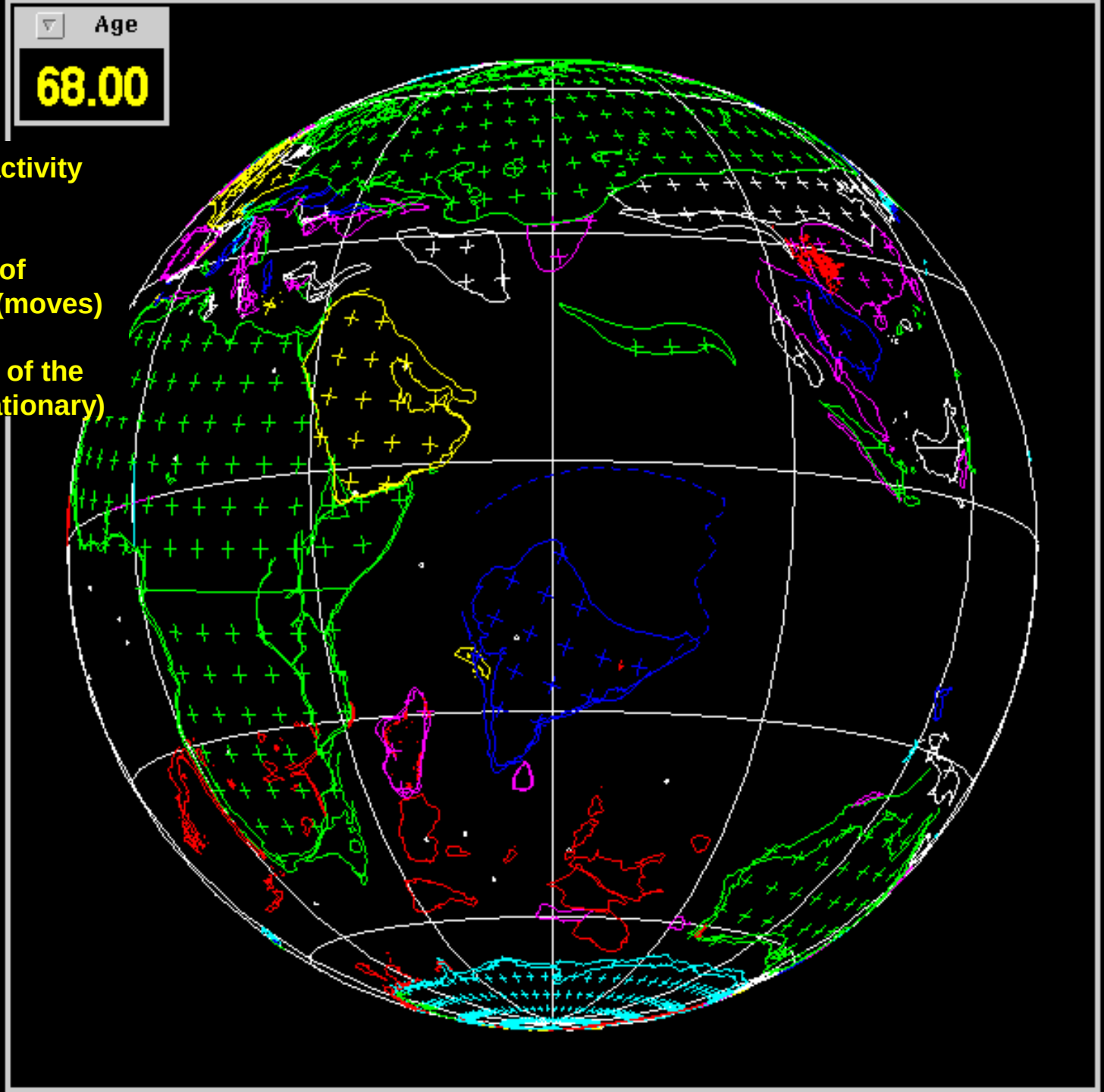
Reunion 2



Seychelles granitics/Deccan basalts



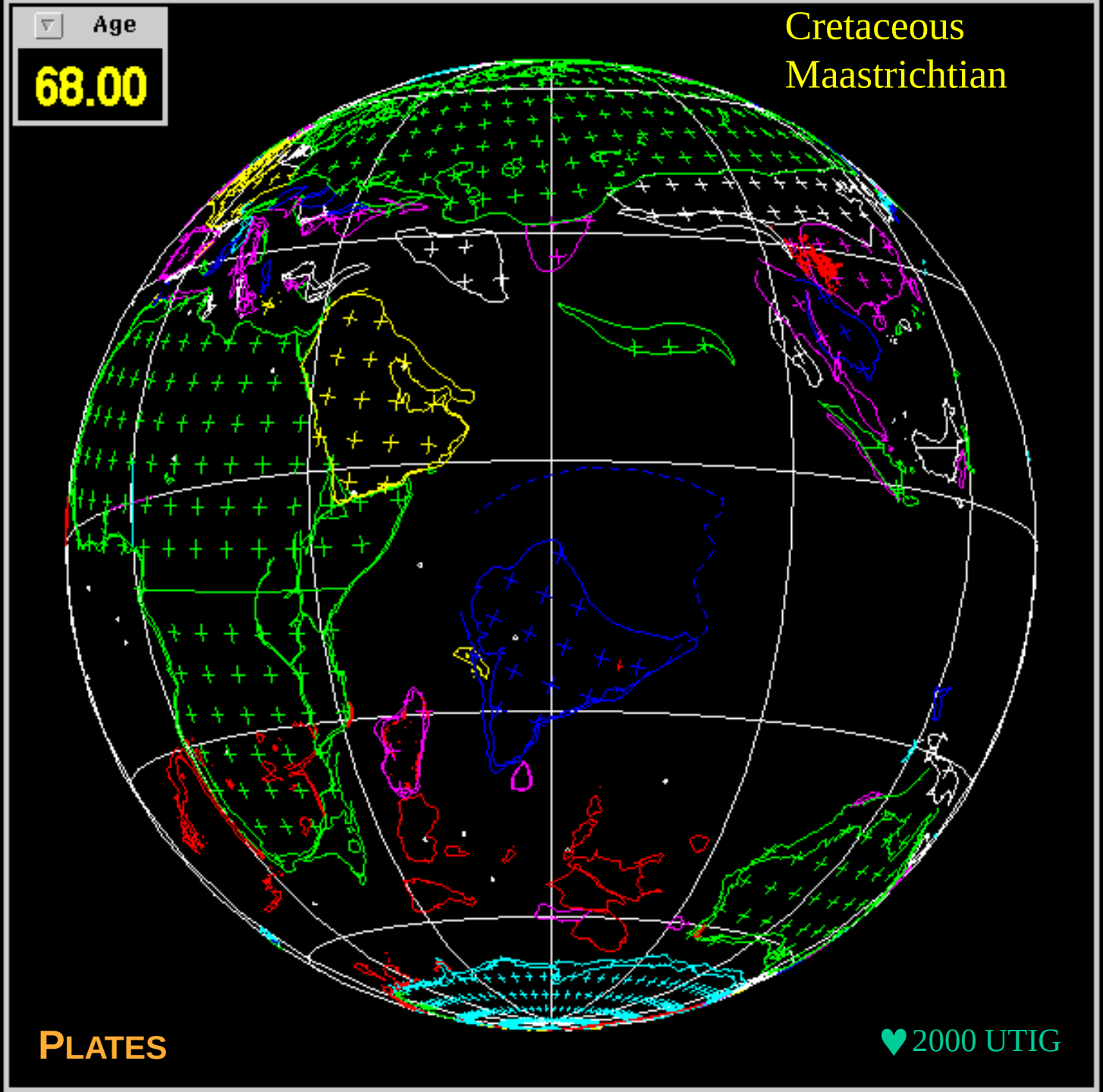
Split between Chagos and Saya de Malha as the spreading ridge passed over the hotspot

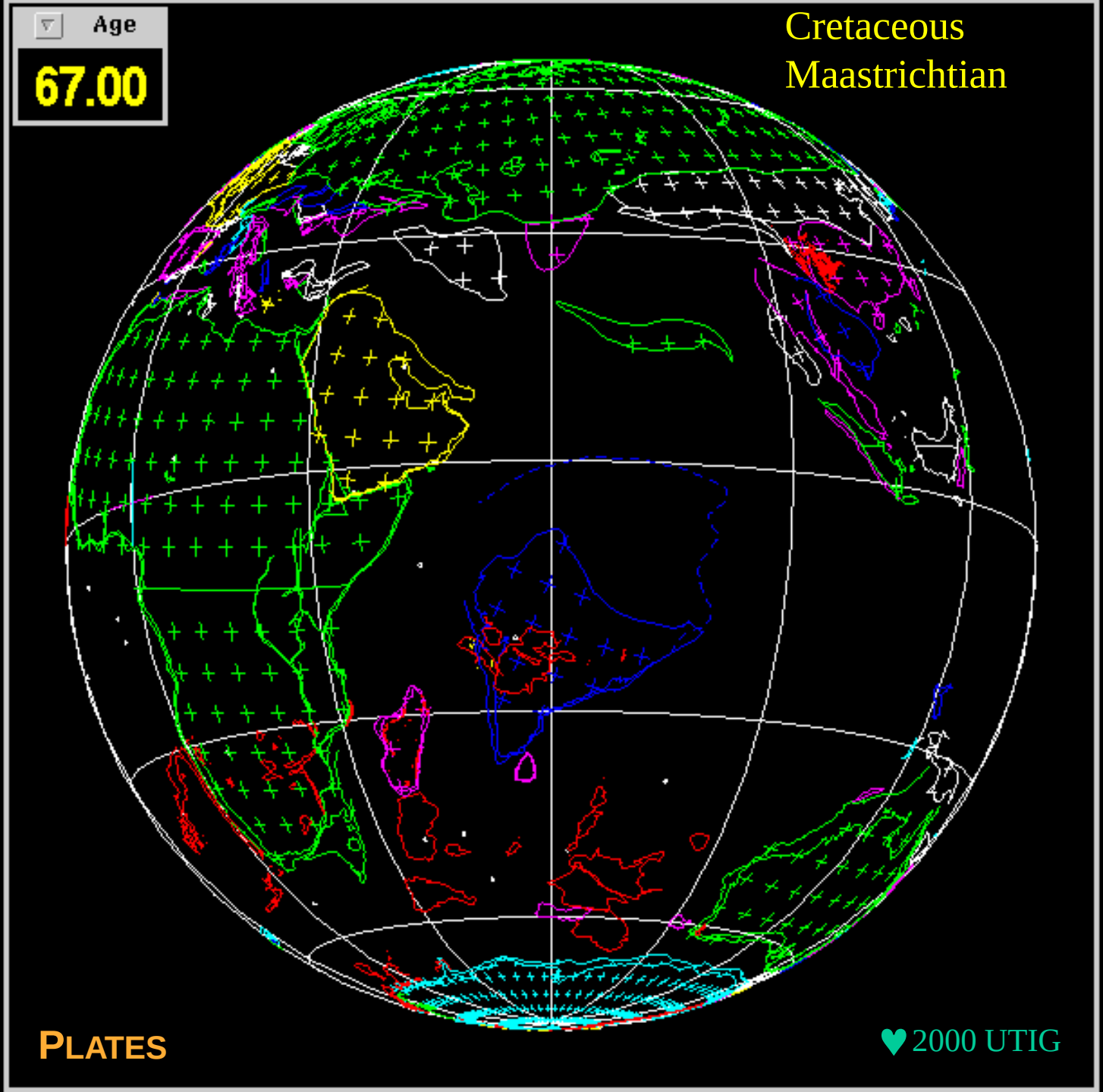


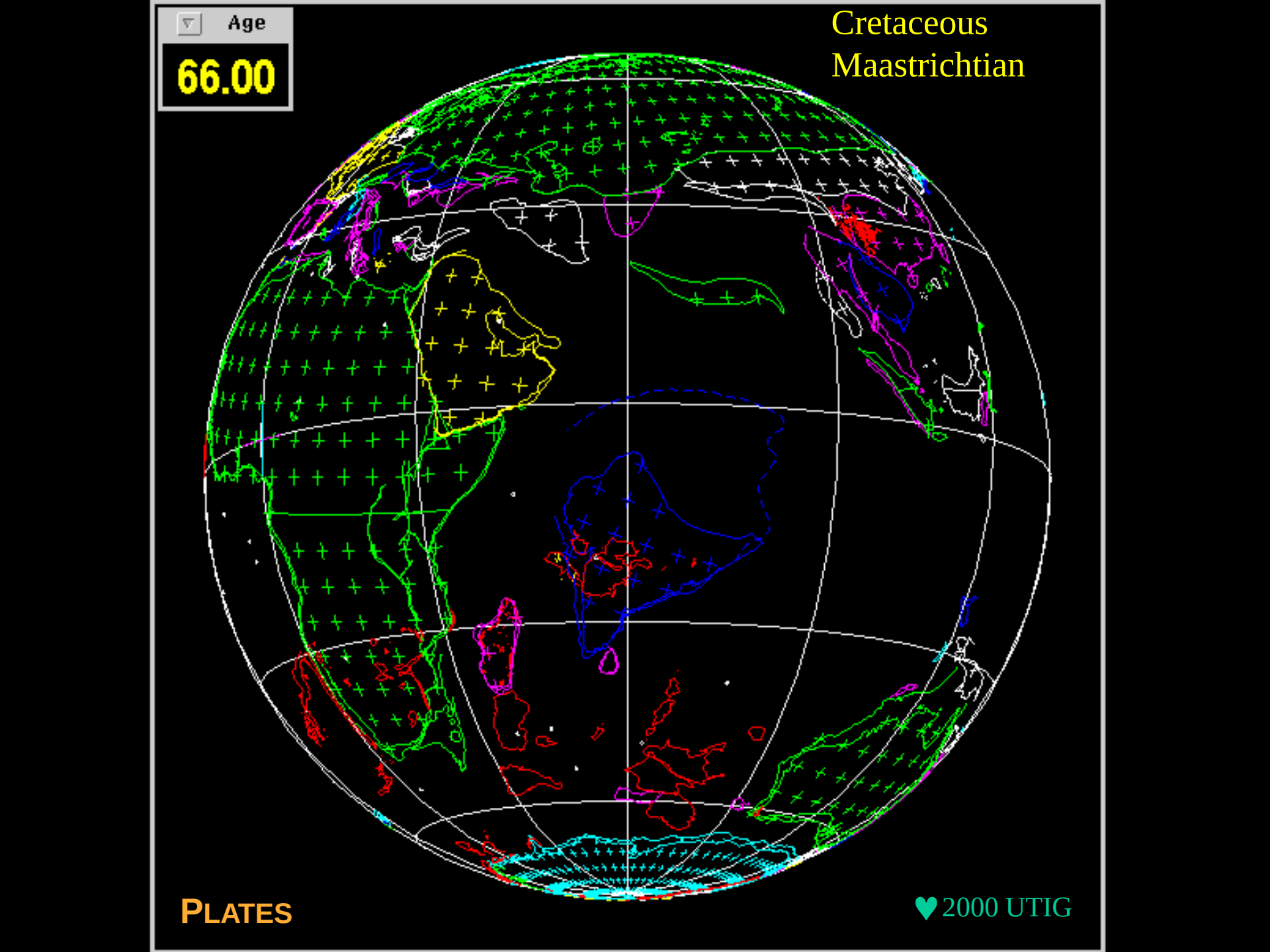
i - hotspot activity (red lines)

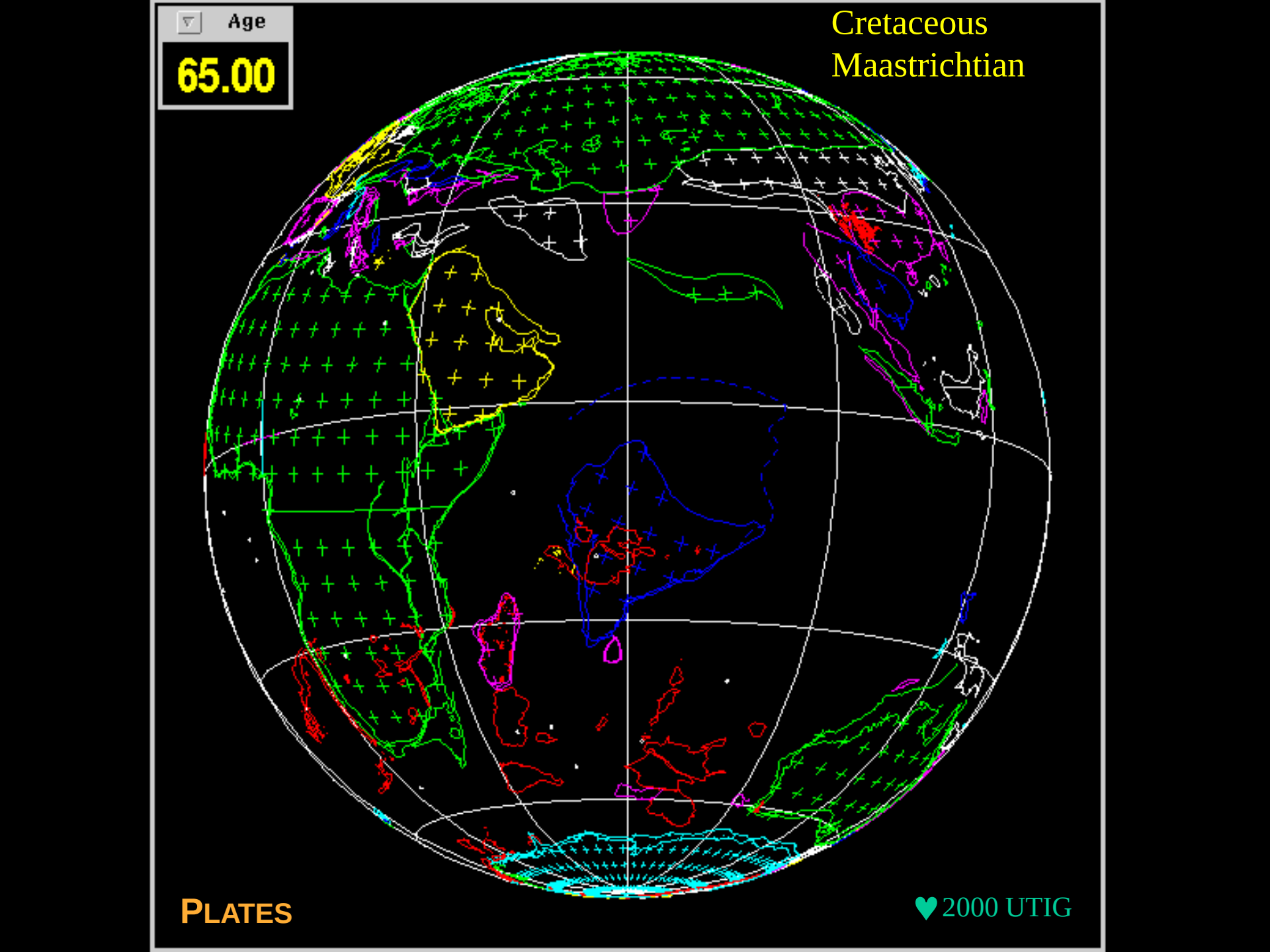
ii - position of Seychelles (moves)

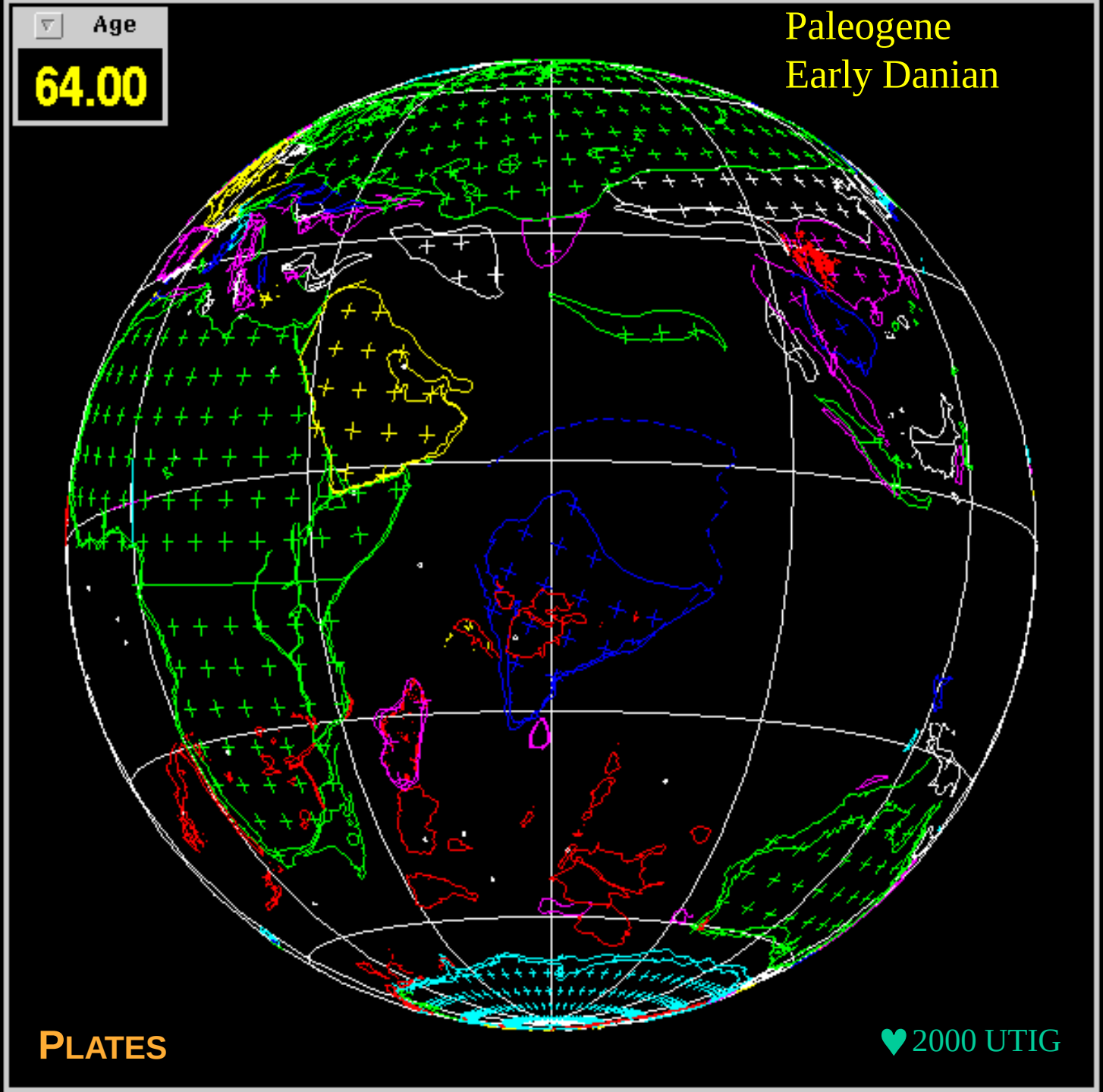
iii - position of the hotspot (stationary)

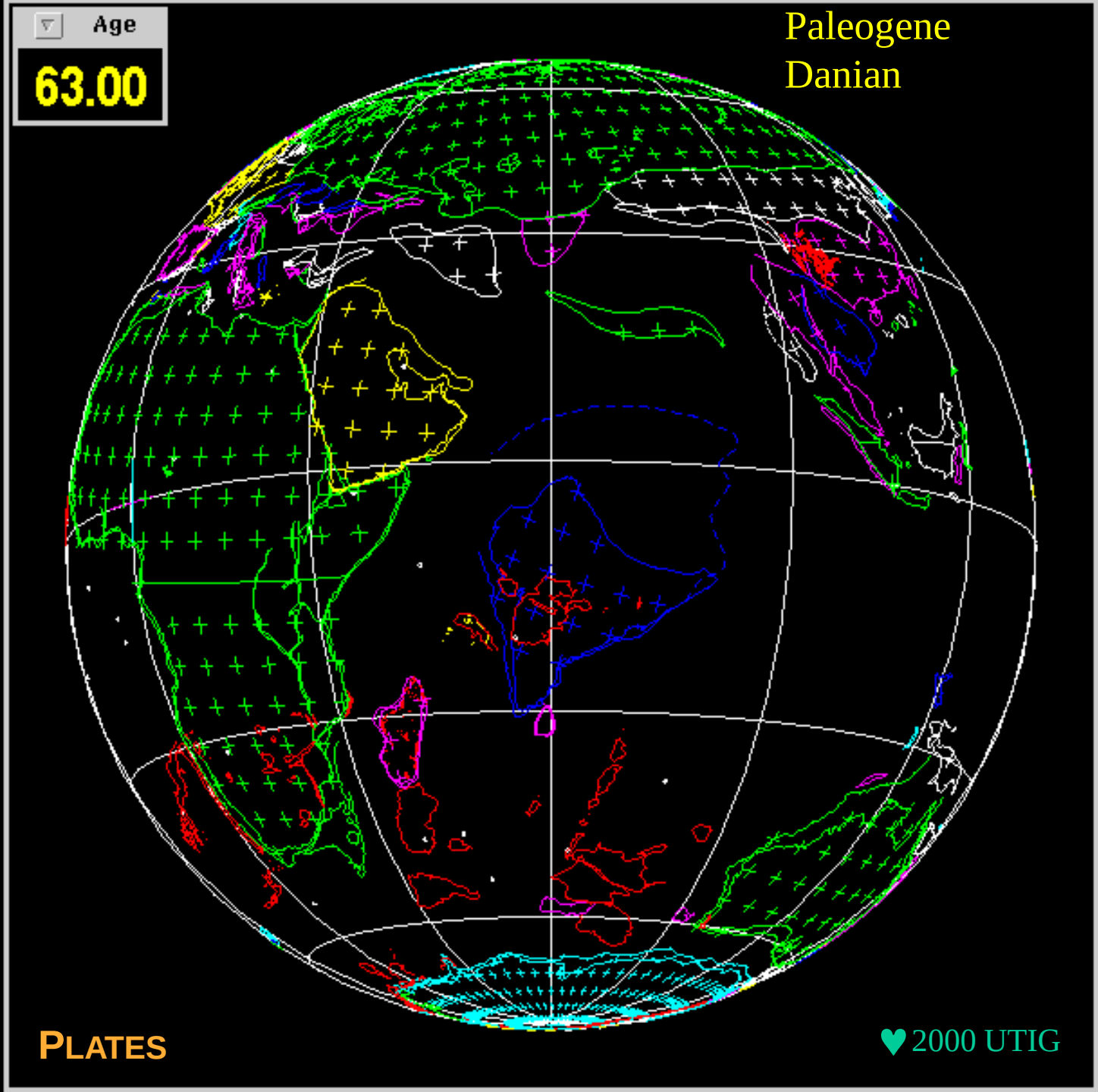

Age
68.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

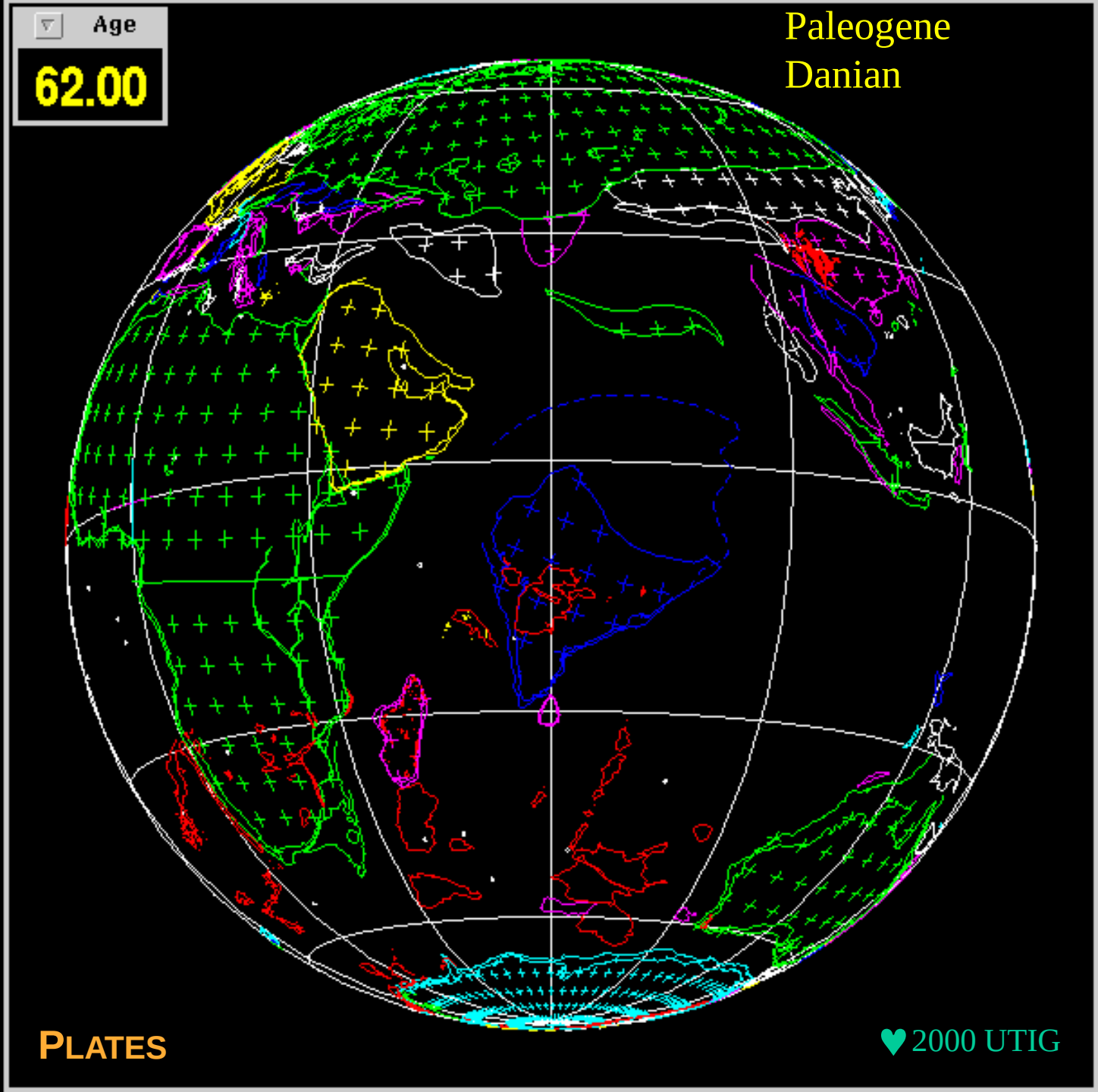

Age
67.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

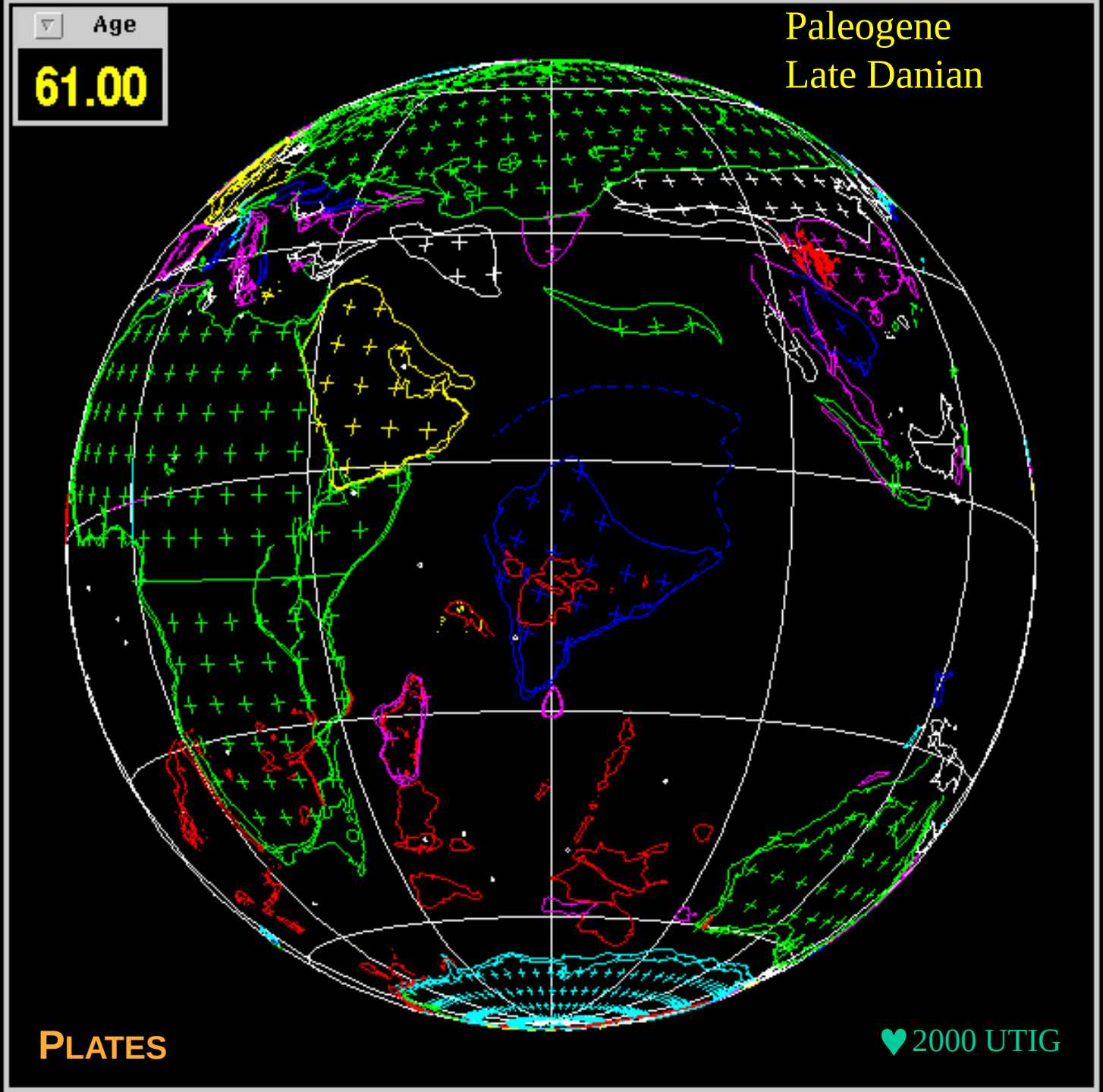

Age
66.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

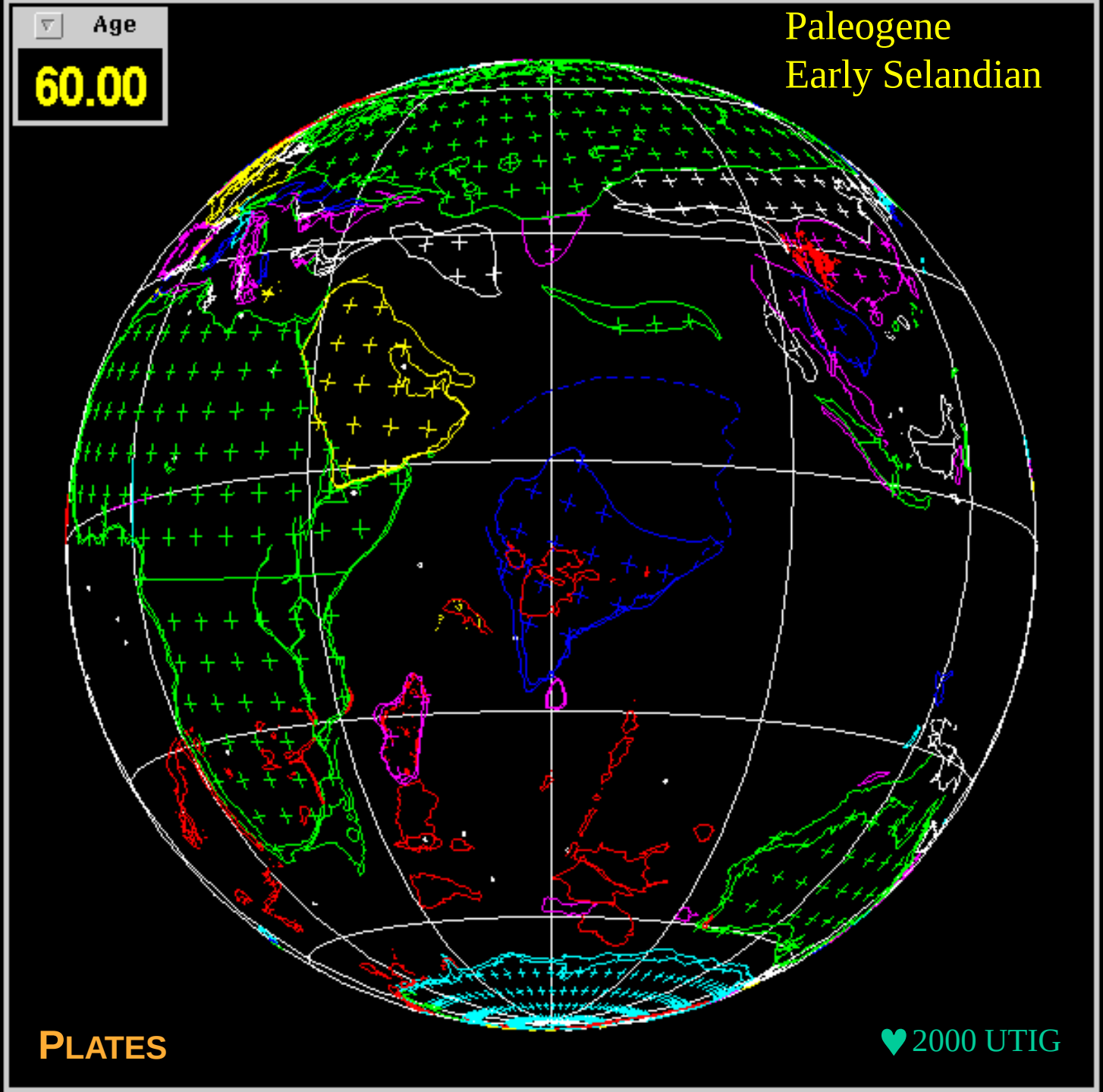

Age
65.00
Cretaceous
Maastrichtian
PLATES
♥2000 UTIG

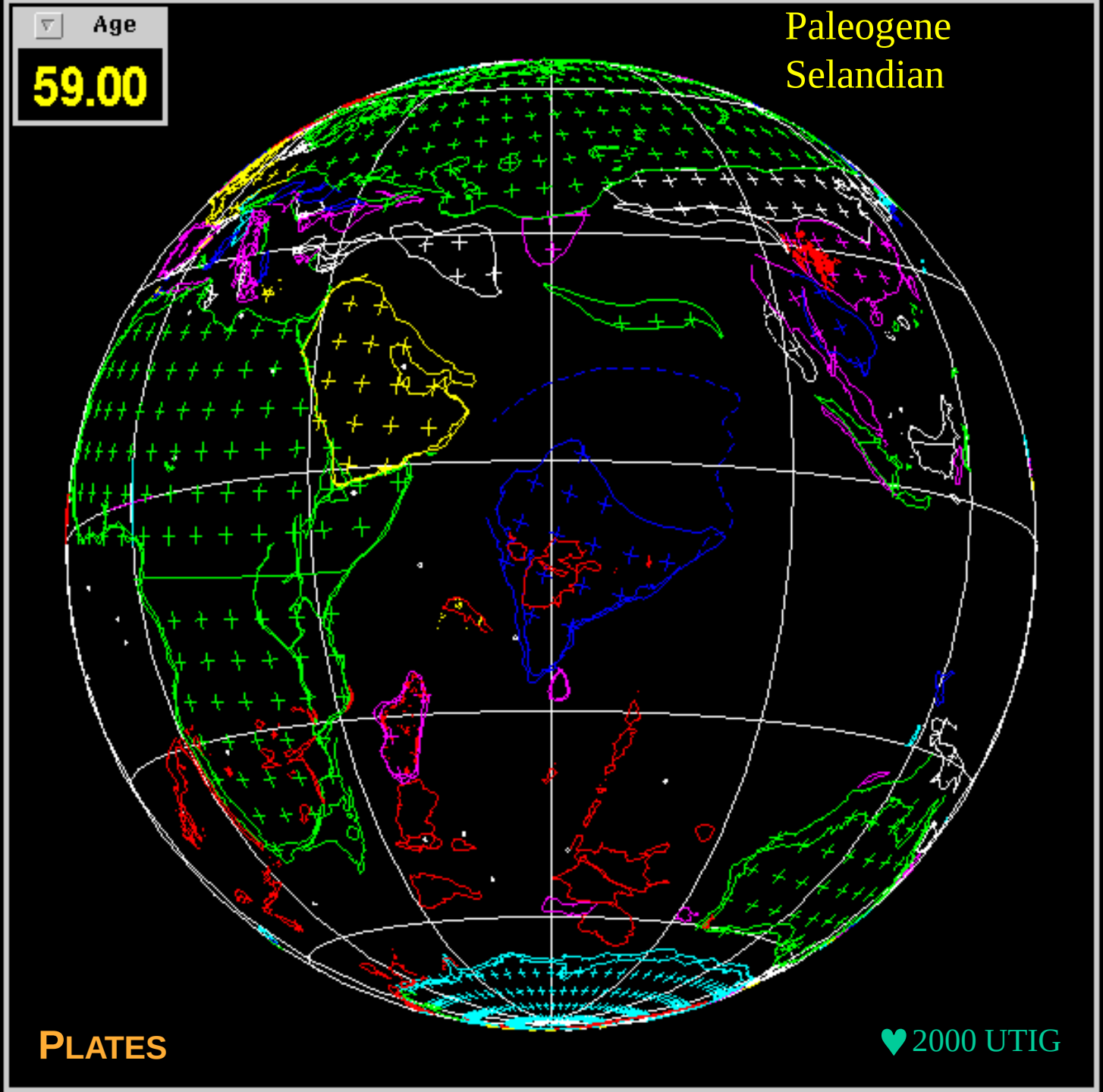

Age
64.00
Paleogene
Early Danian
PLATES
♥2000 UTIG

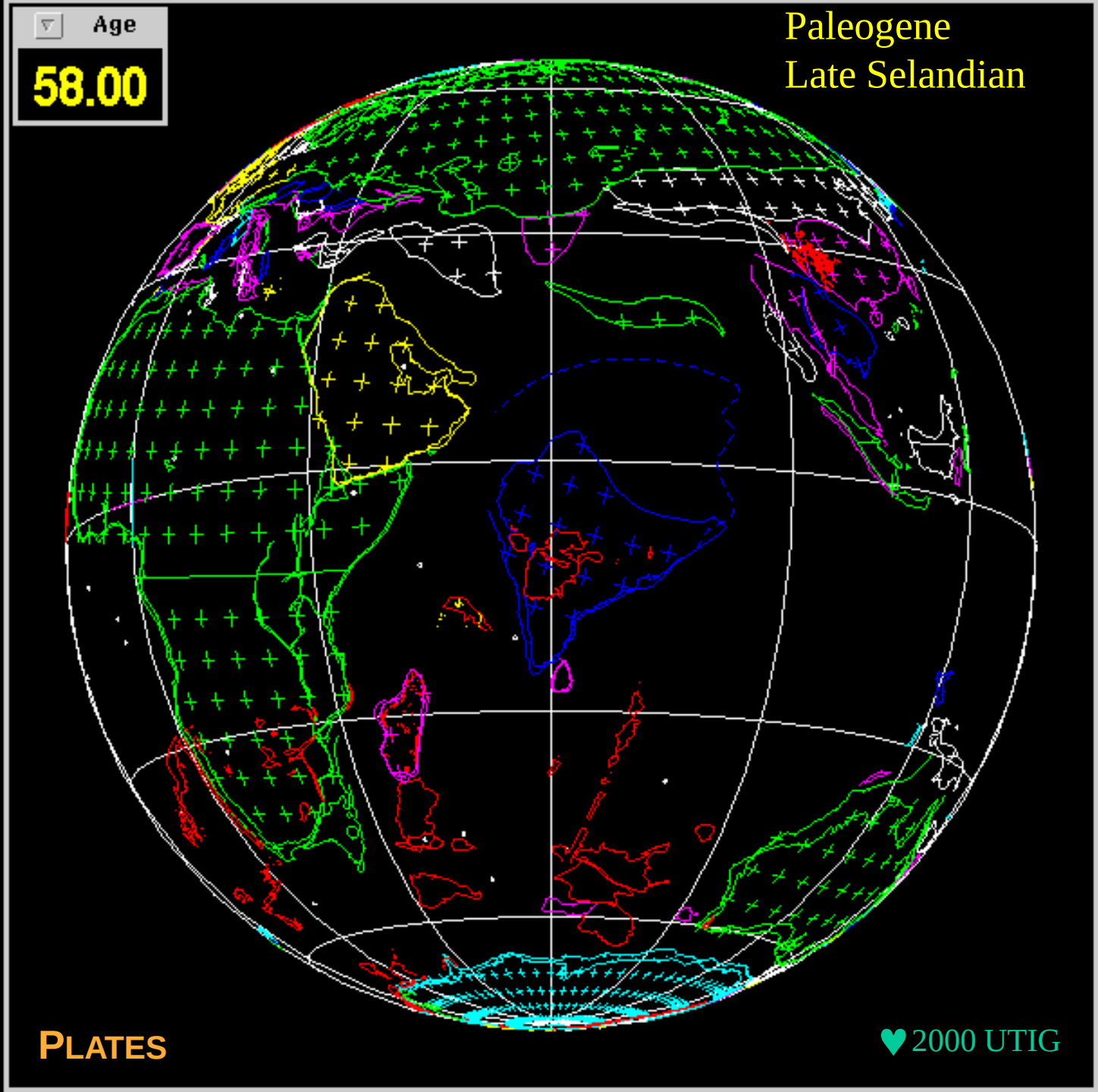

Age
63.00
Paleogene
Danian
PLATES
♥2000 UTIG

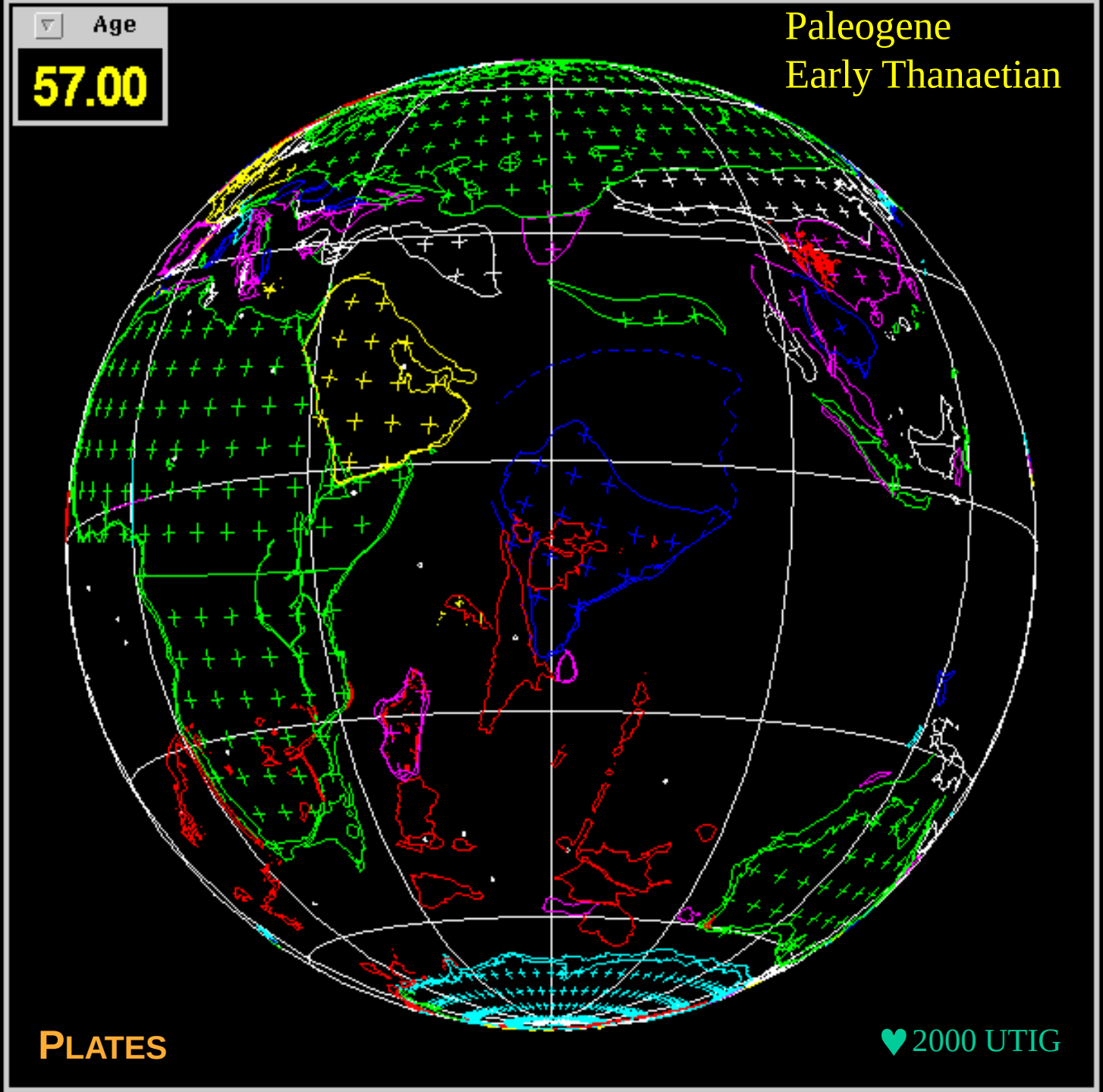

Age
62.00
Paleogene
Danian
PLATES
♥2000 UTIG

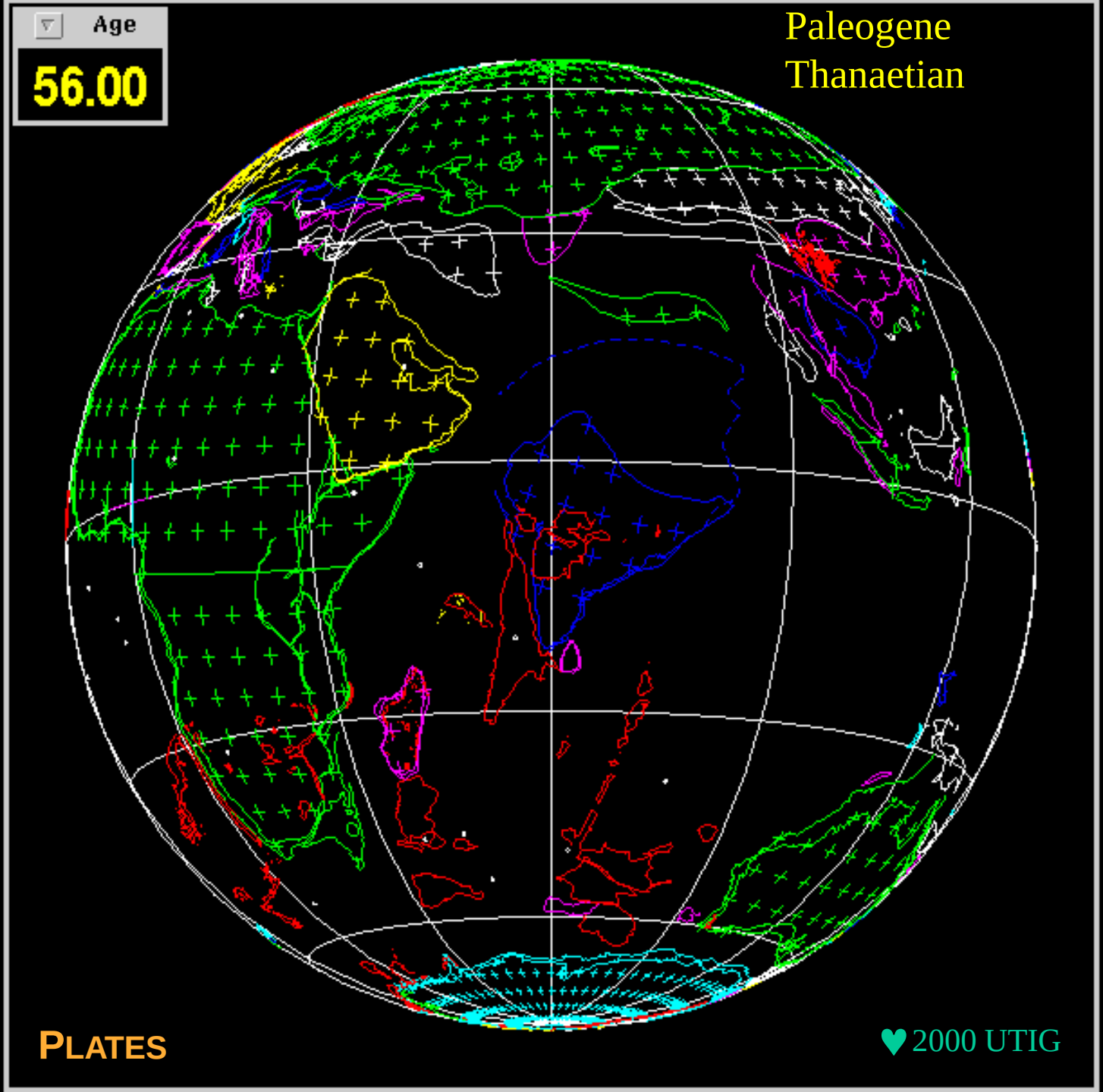

Age
61.00
Paleogene
Late Danian
PLATES
♥2000 UTIG

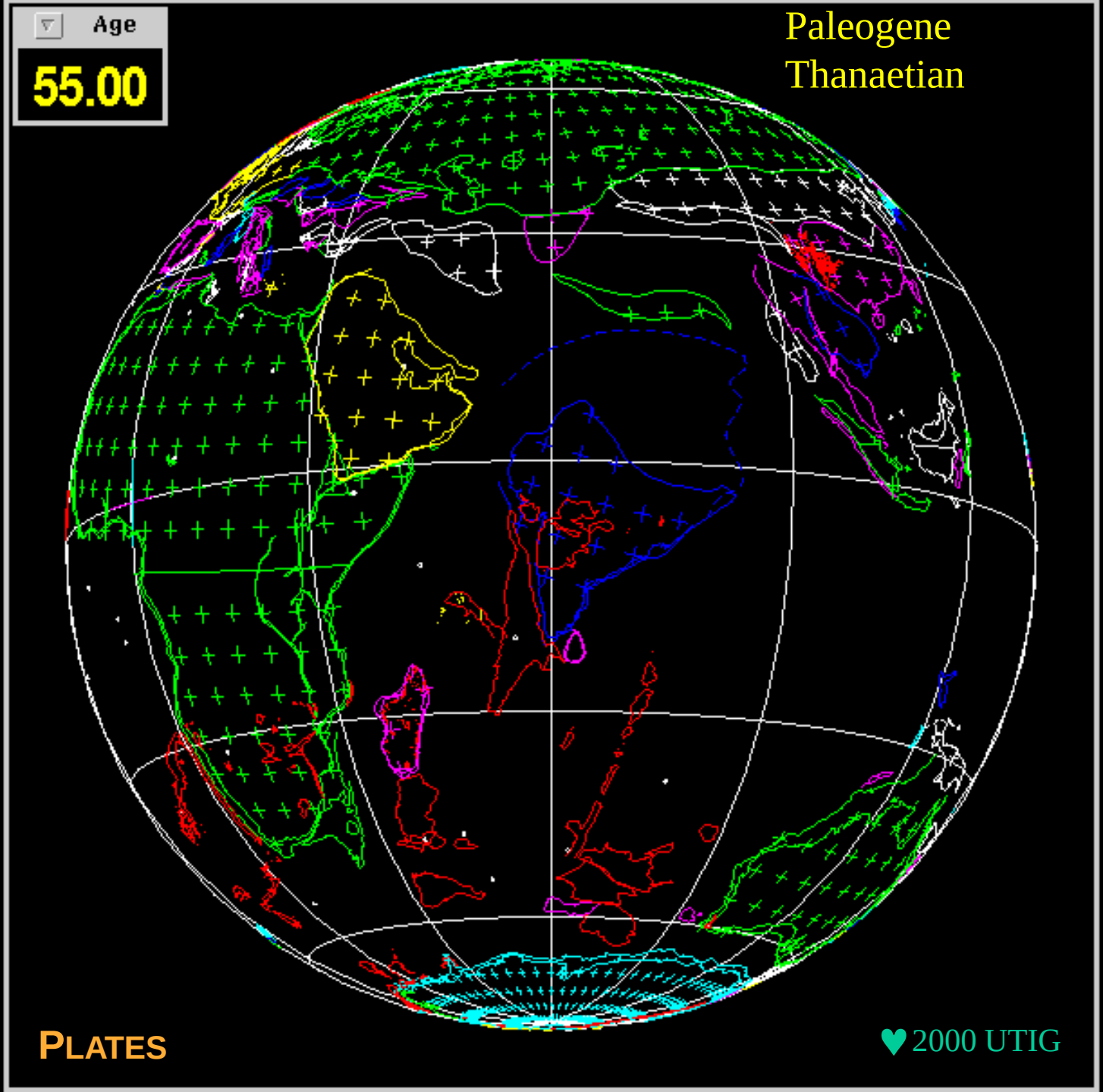

Age
60.00
Paleogene
Early Selandian
PLATES
♥2000 UTIG

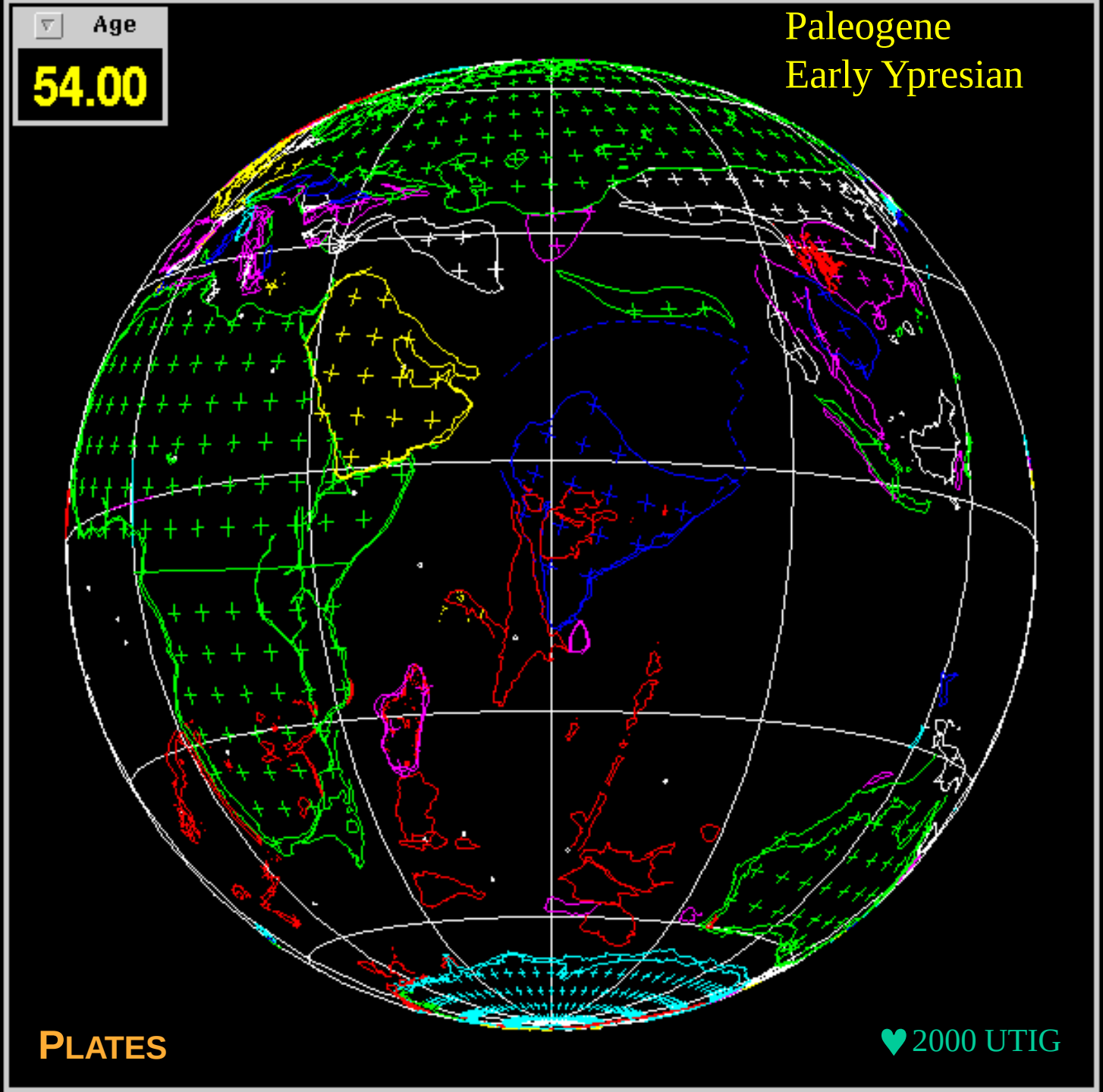

Age
59.00
Paleogene
Selandian
PLATES
♥2000 UTIG

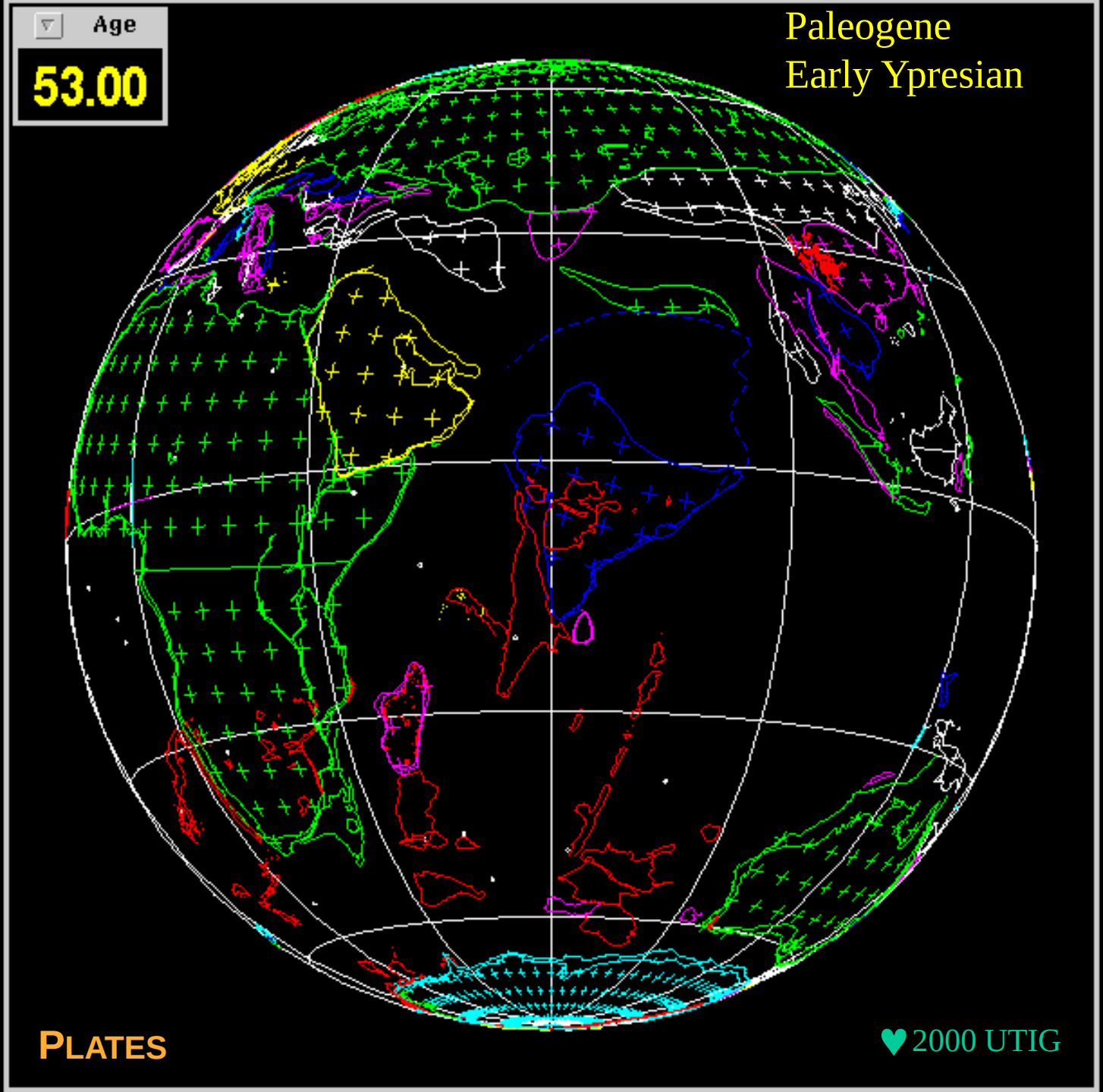

Age
58.00
Paleogene
Late Selandian
PLATES
♥2000 UTIG

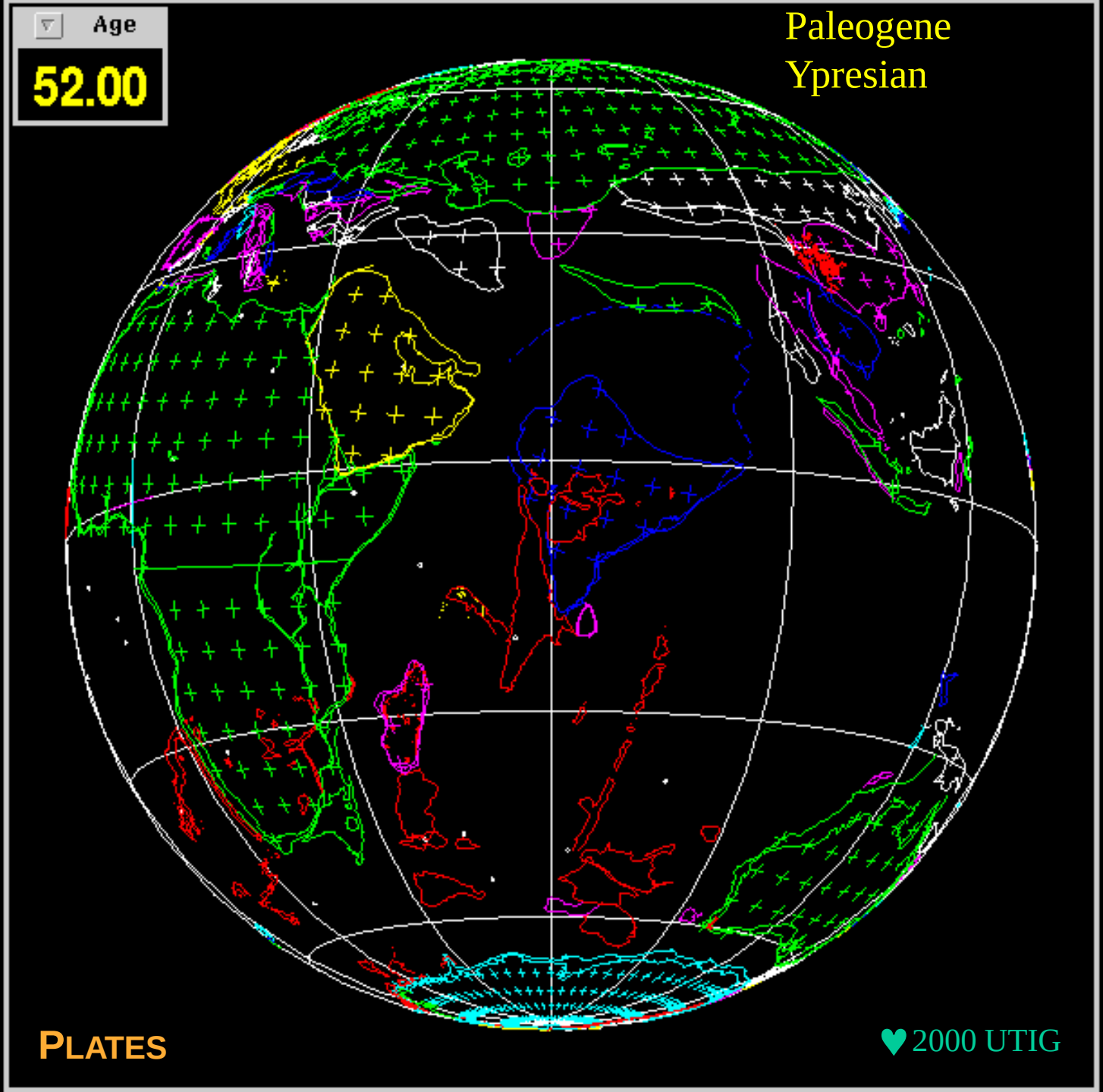

Age
57.00
Paleogene
Early Thanaetian
PLATES
♥2000 UTIG

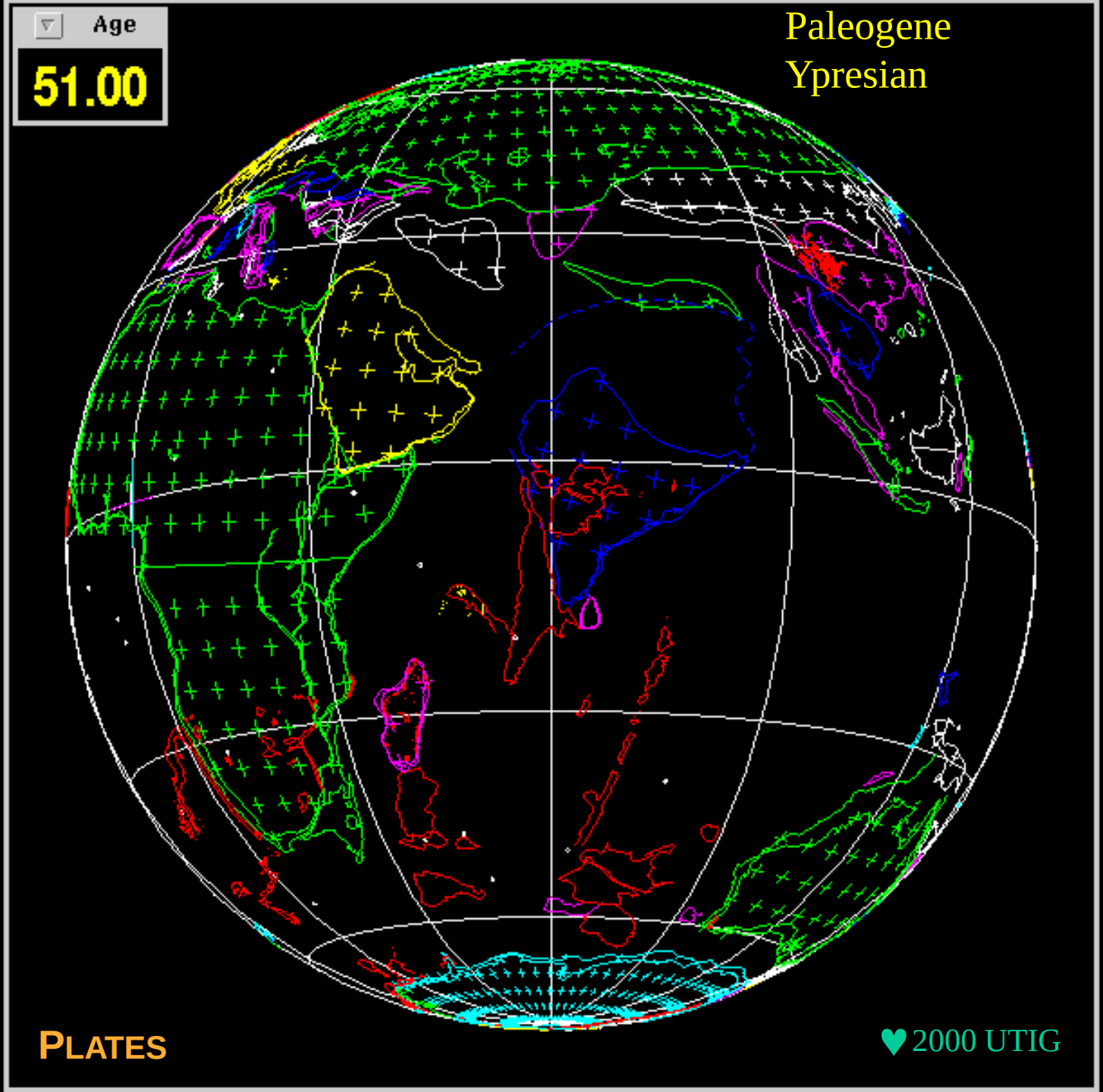

Age
56.00
Paleogene
Thanaetian
PLATES
♥2000 UTIG

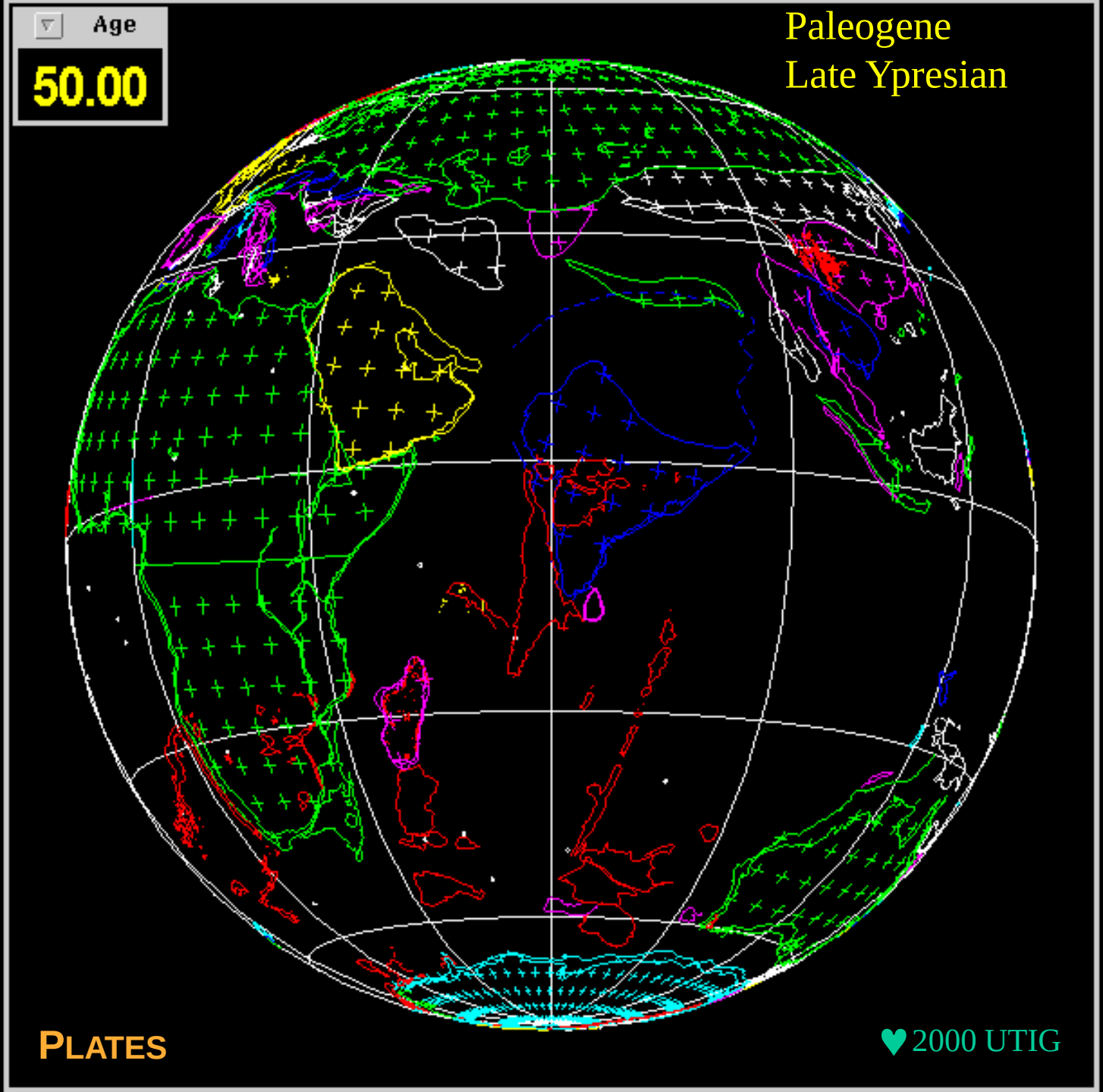

Age
55.00
Paleogene
Thanaetian
PLATES
♥2000 UTIG

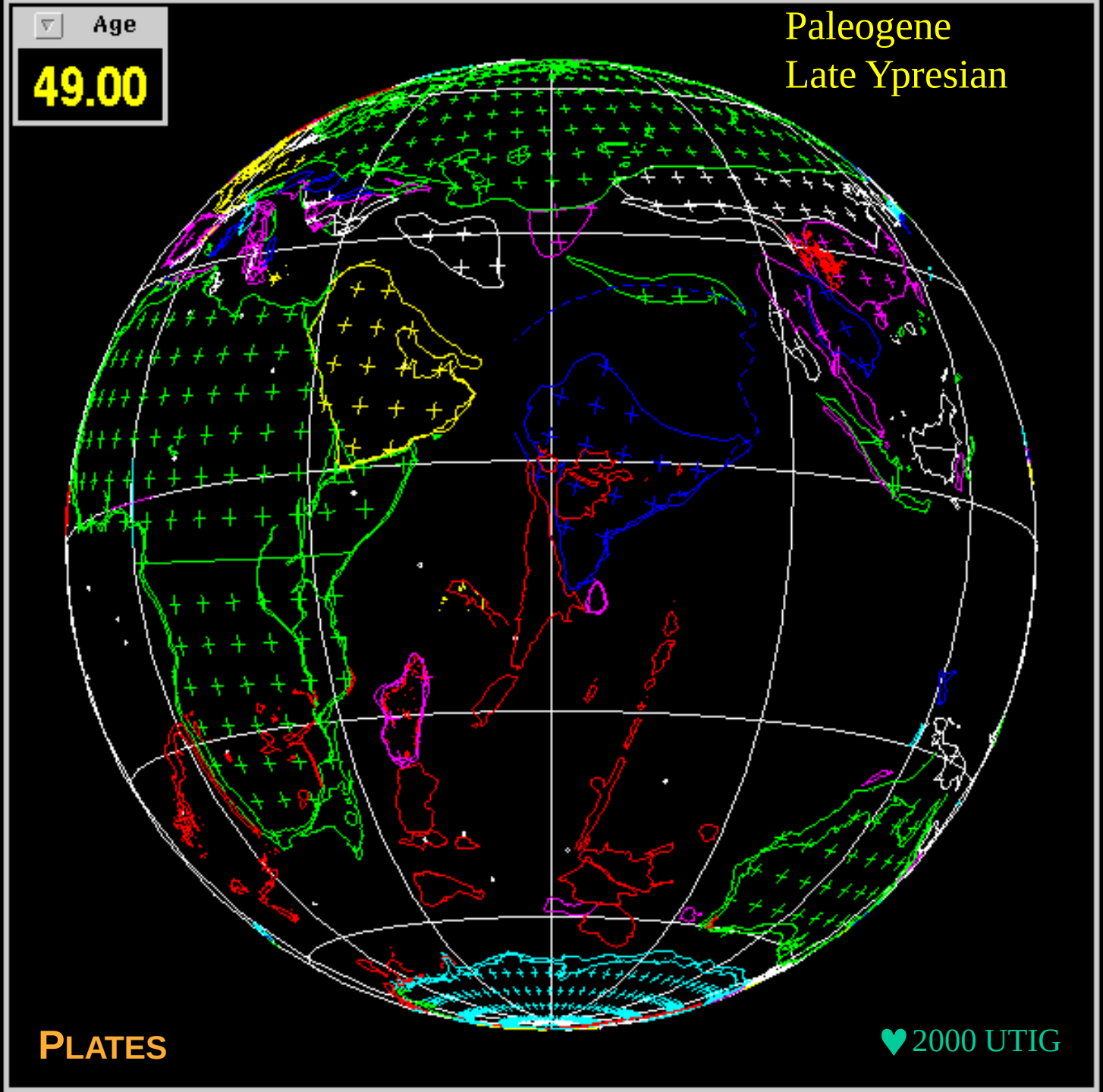

Age
54.00
Paleogene
Early Ypresian
PLATES
♥2000 UTIG

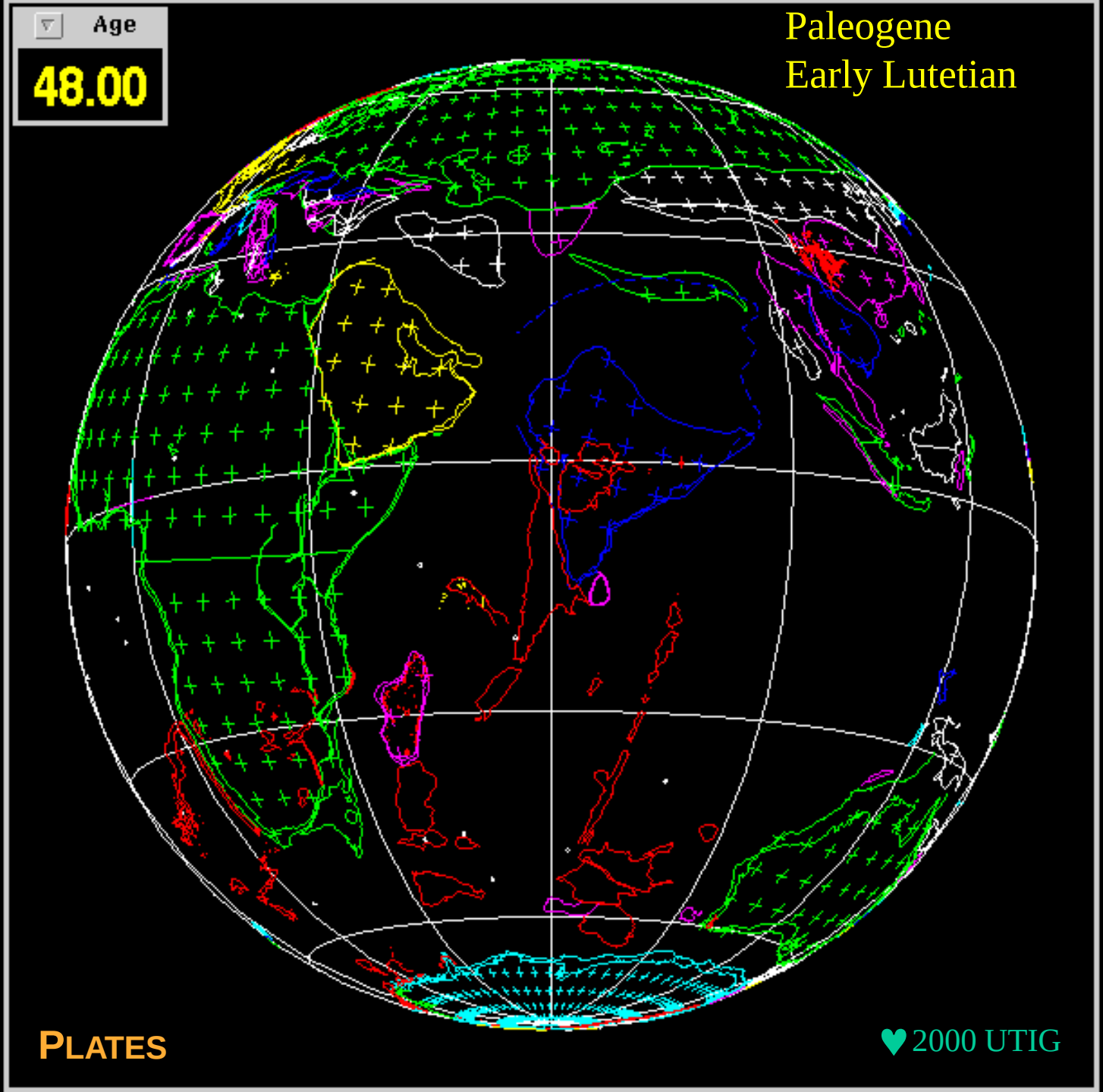

Age
53.00
Paleogene
Early Ypresian
PLATES
♥2000 UTIG

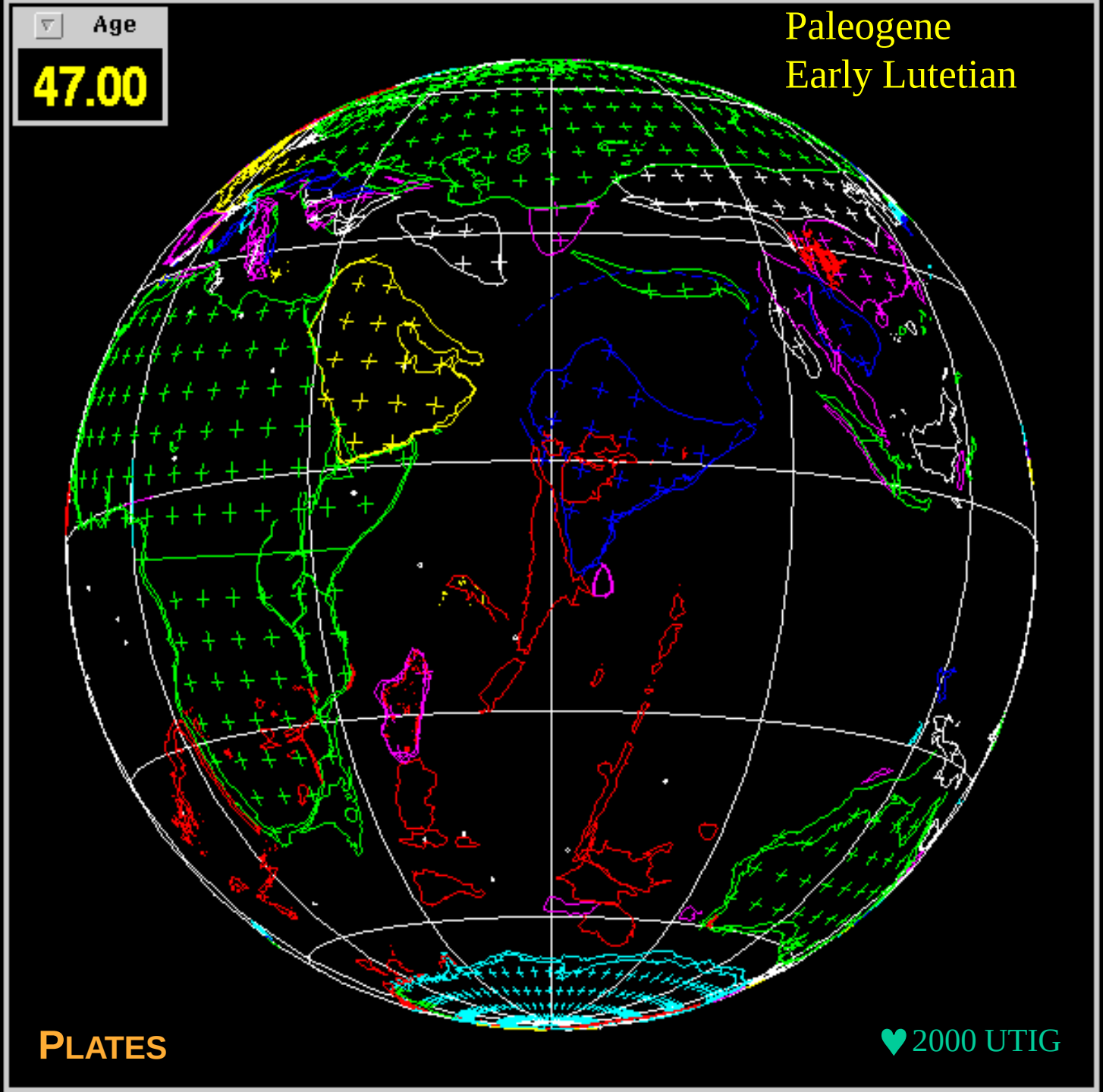

Age
52.00
Paleogene
Ypresian
PLATES
♥2000 UTIG

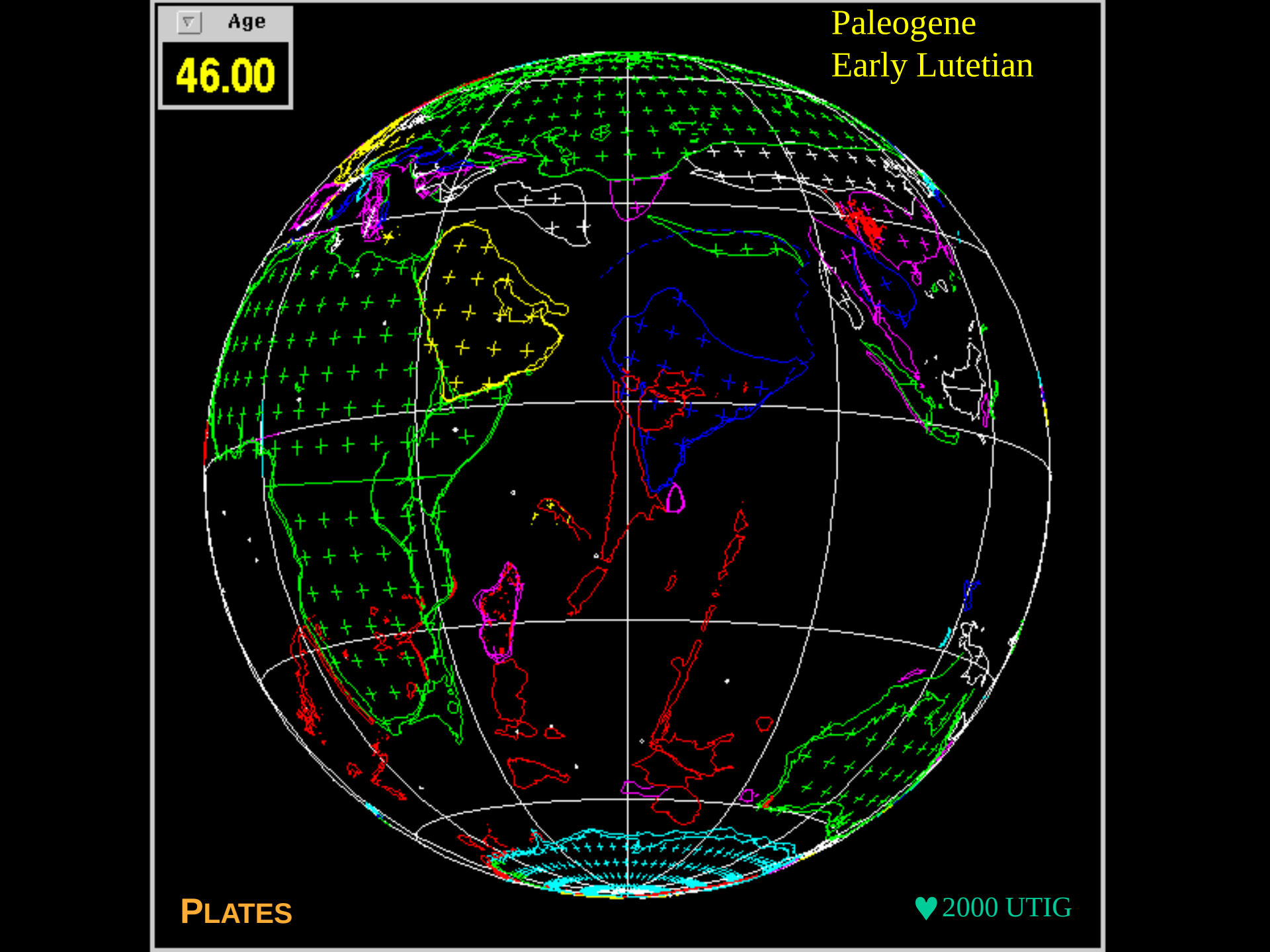

Age
51.00
Paleogene
Ypresian
PLATES
♥2000 UTIG

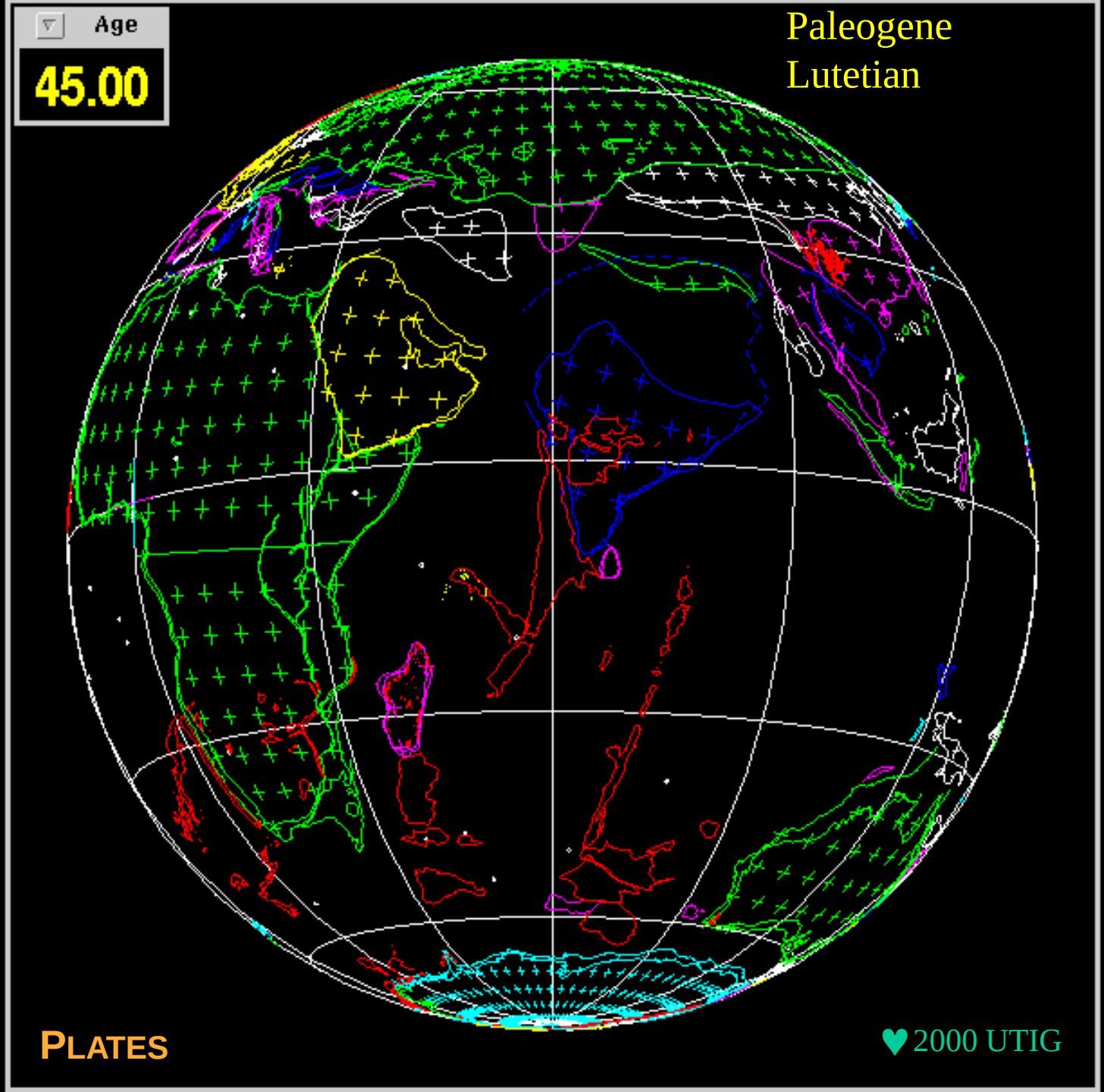

Age
50.00
Paleogene
Late Ypresian
PLATES
♥2000 UTIG

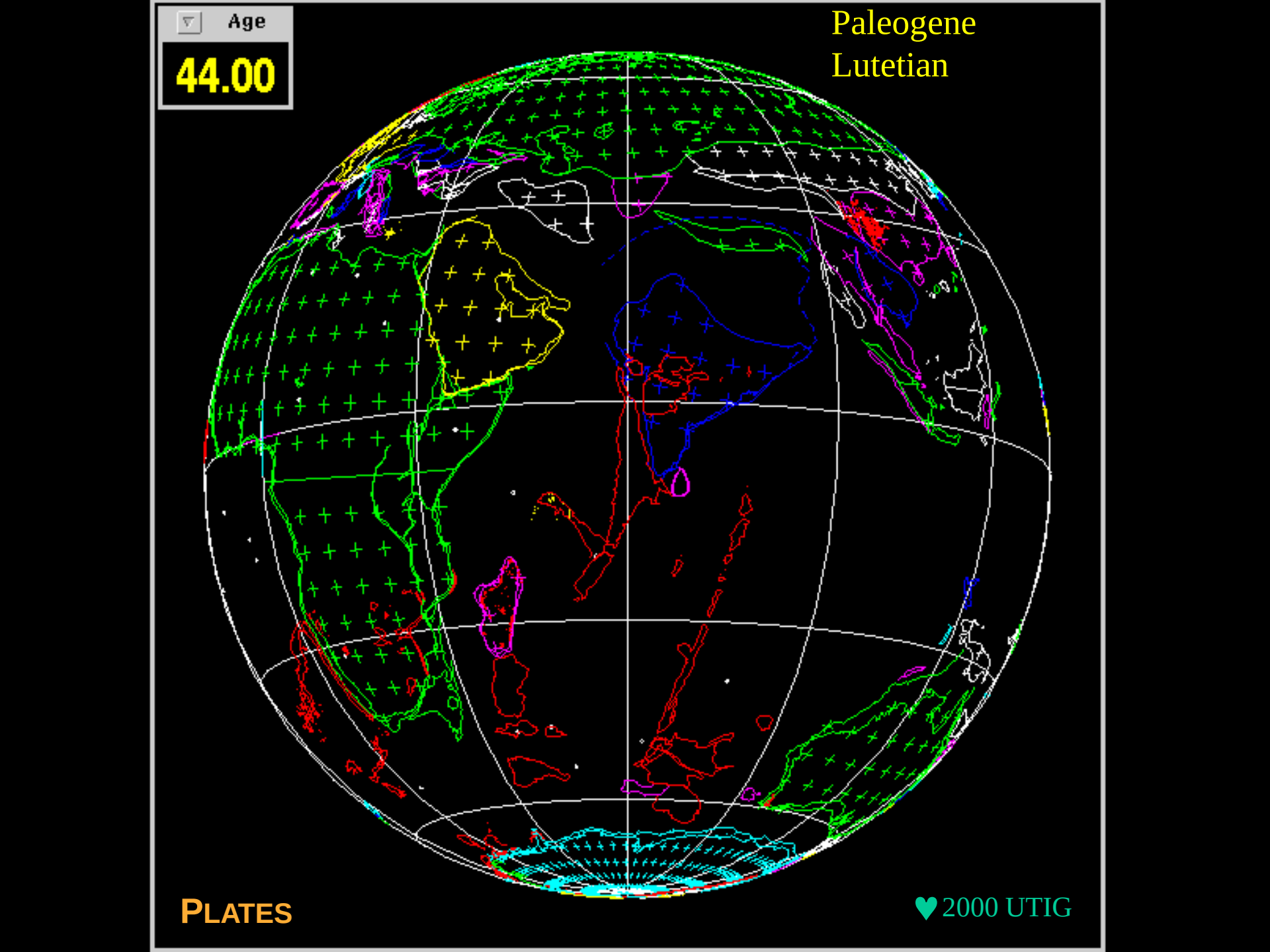

Age
49.00
Paleogene
Late Ypresian
PLATES
♥2000 UTIG

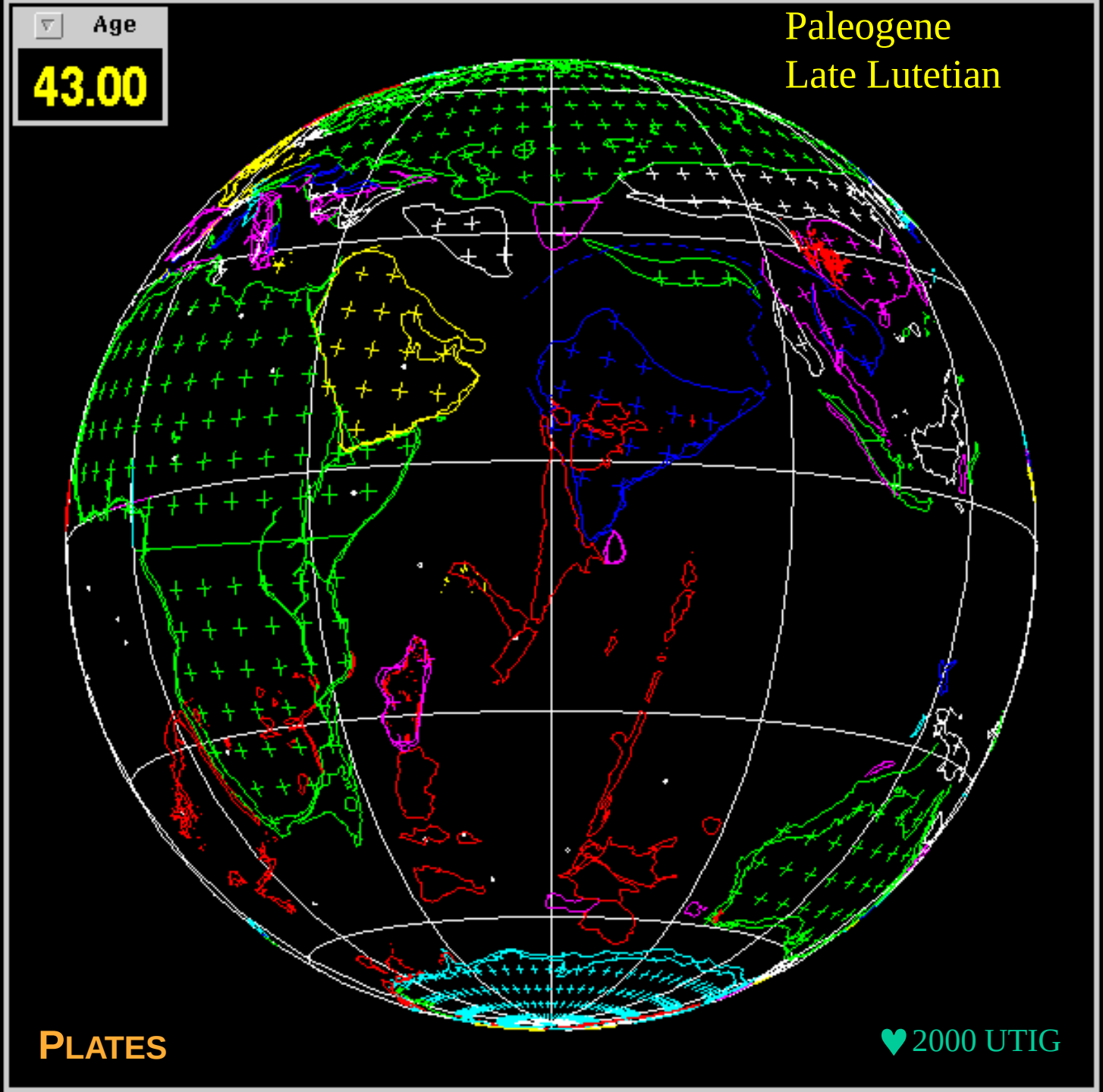

Age
48.00
Paleogene
Early Lutetian
PLATES
♥2000 UTIG

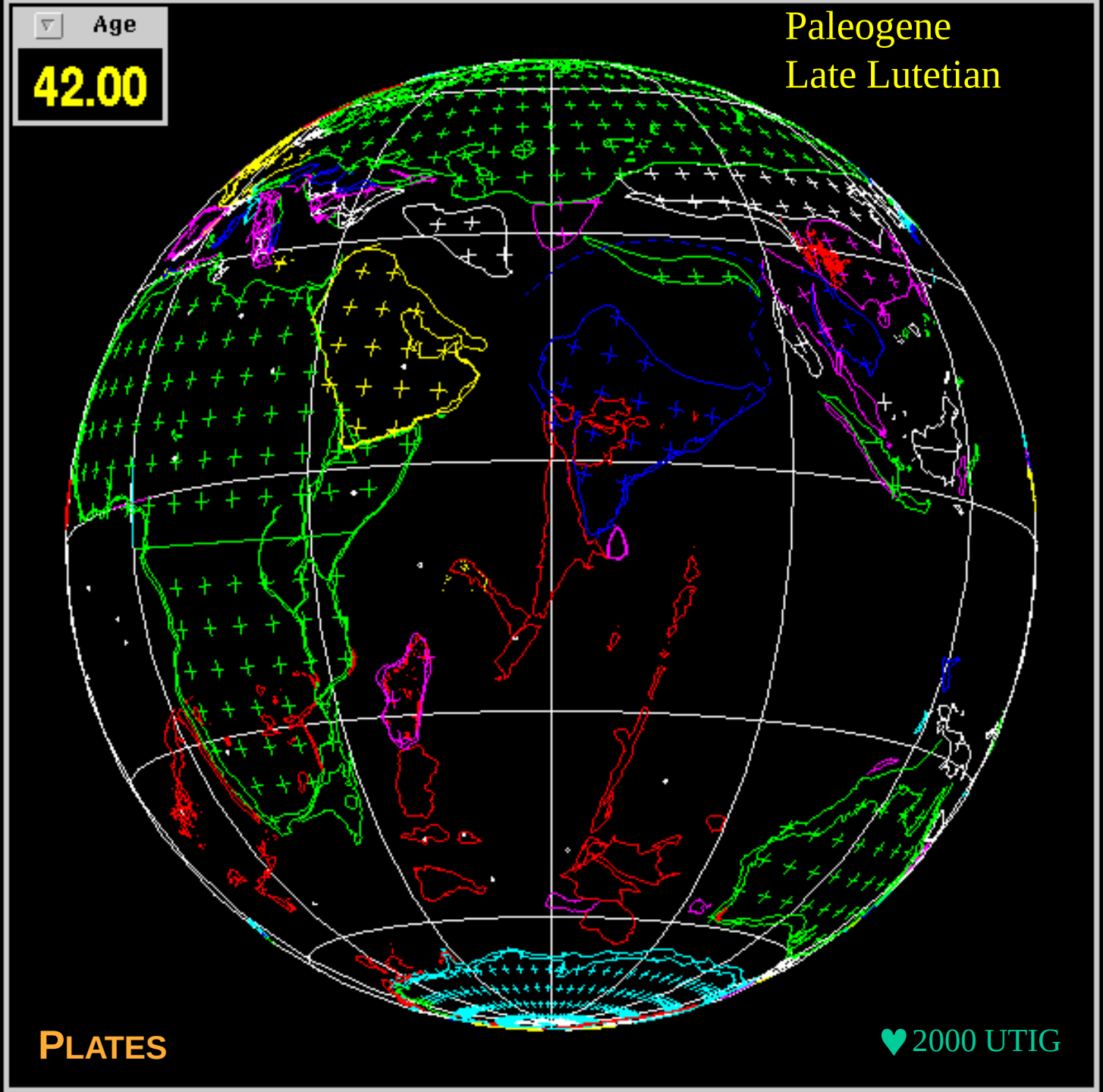

Age
47.00
Paleogene
Early Lutetian
PLATES
♥2000 UTIG

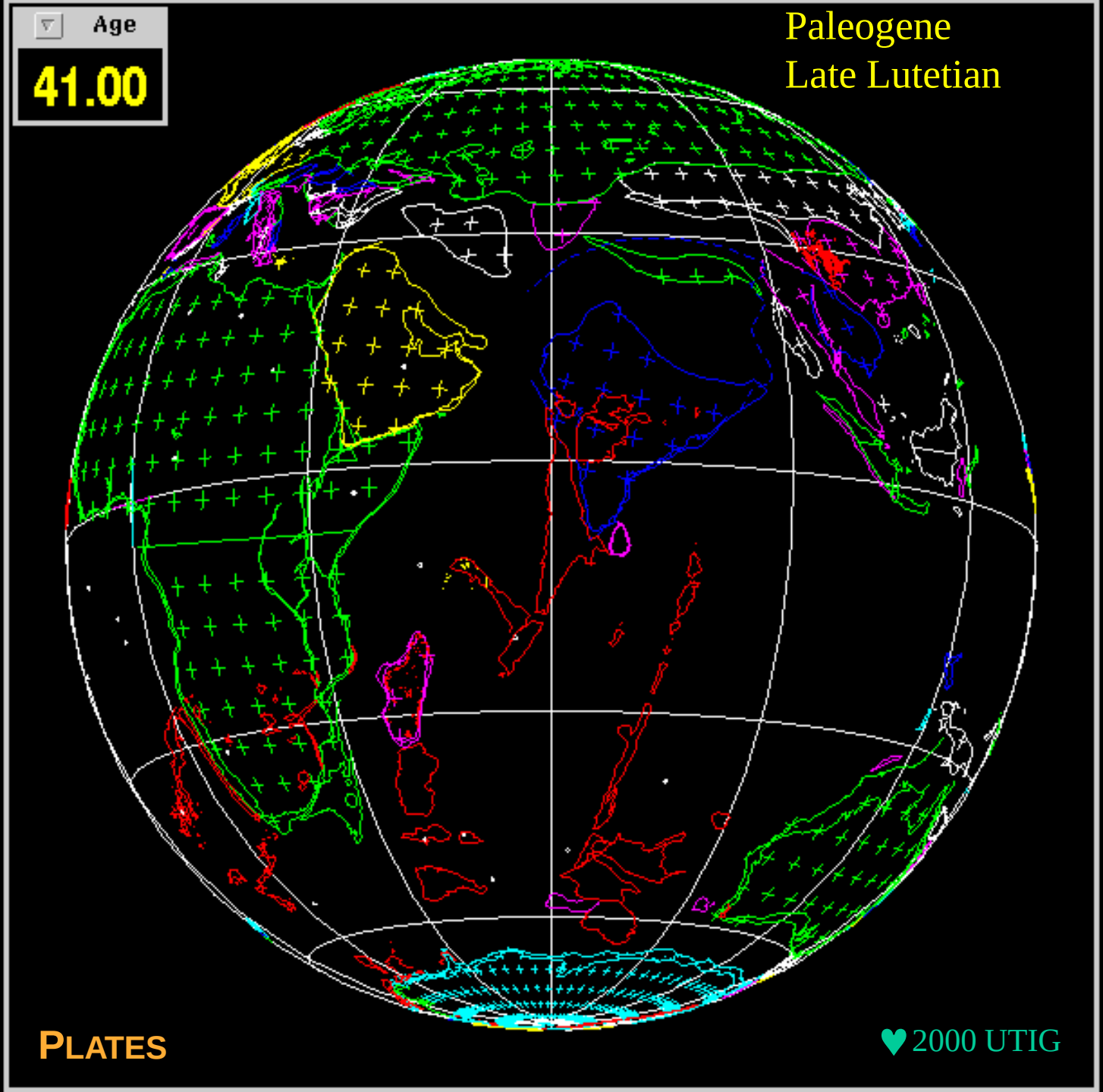

Age
46.00
Paleogene
Early Lutetian
PLATES
♥2000 UTIG

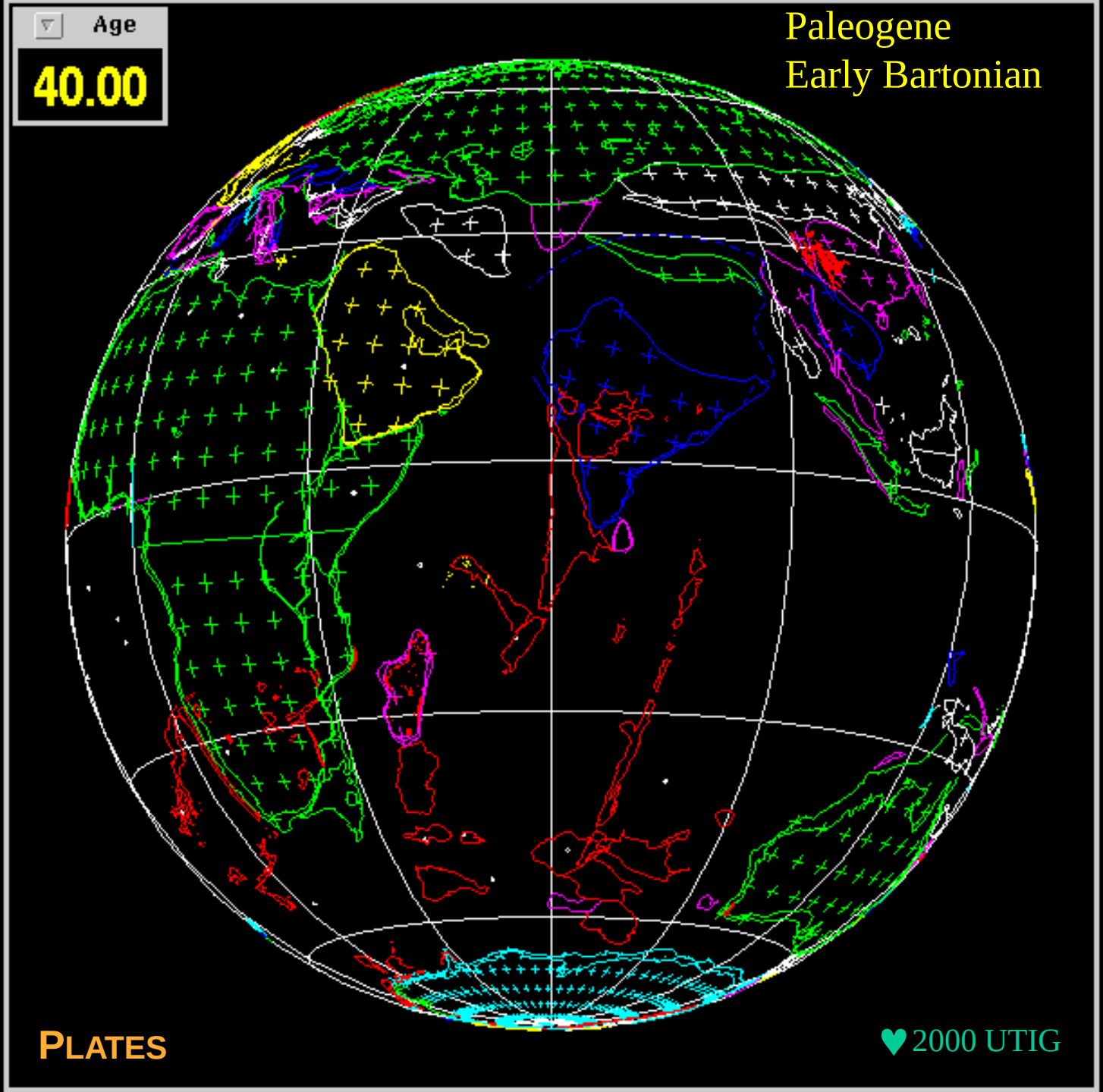

Age
45.00
Paleogene
Lutetian
PLATES
♥2000 UTIG

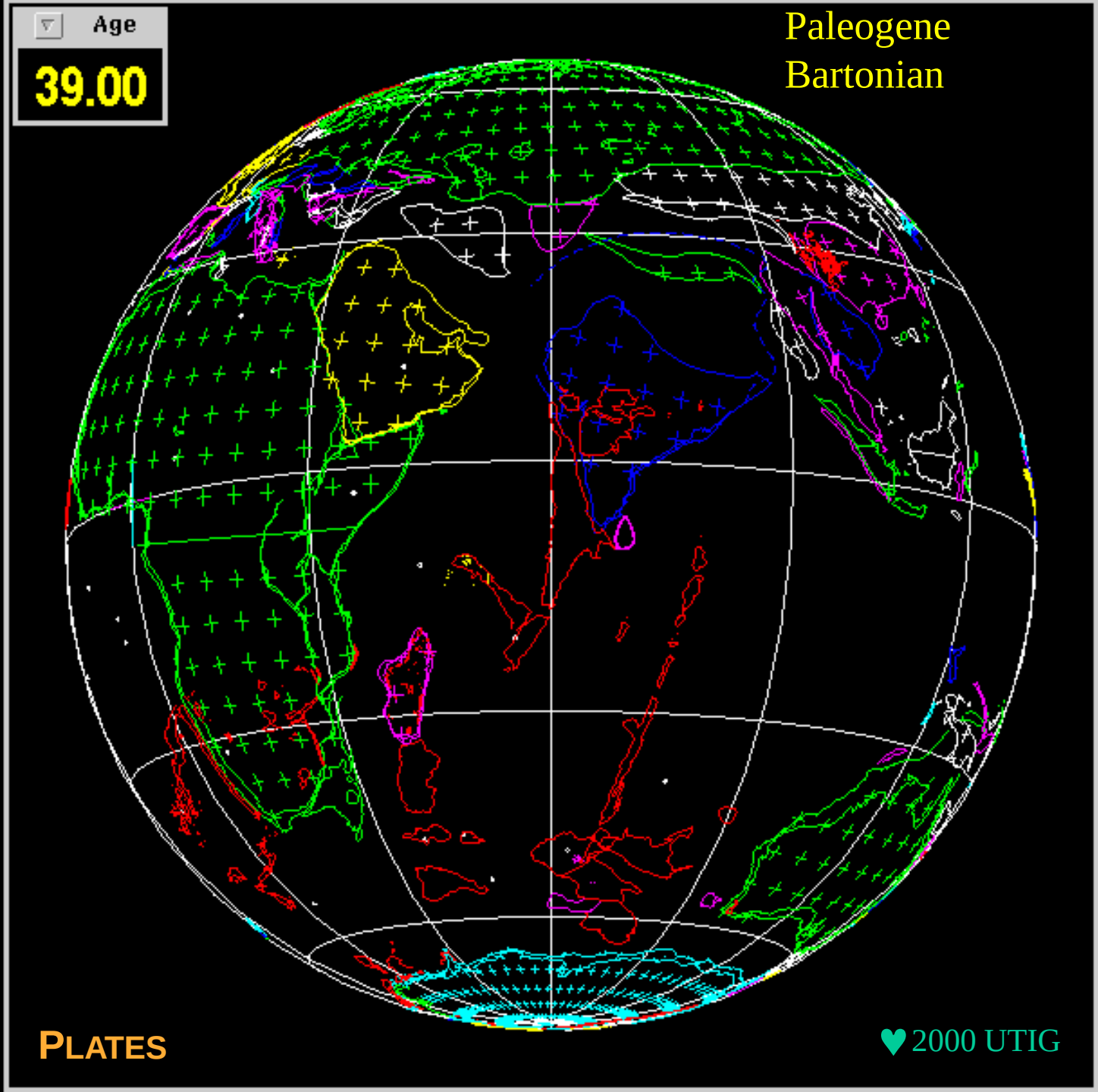

Age
44.00
Paleogene
Lutetian
PLATES
♥2000 UTIG

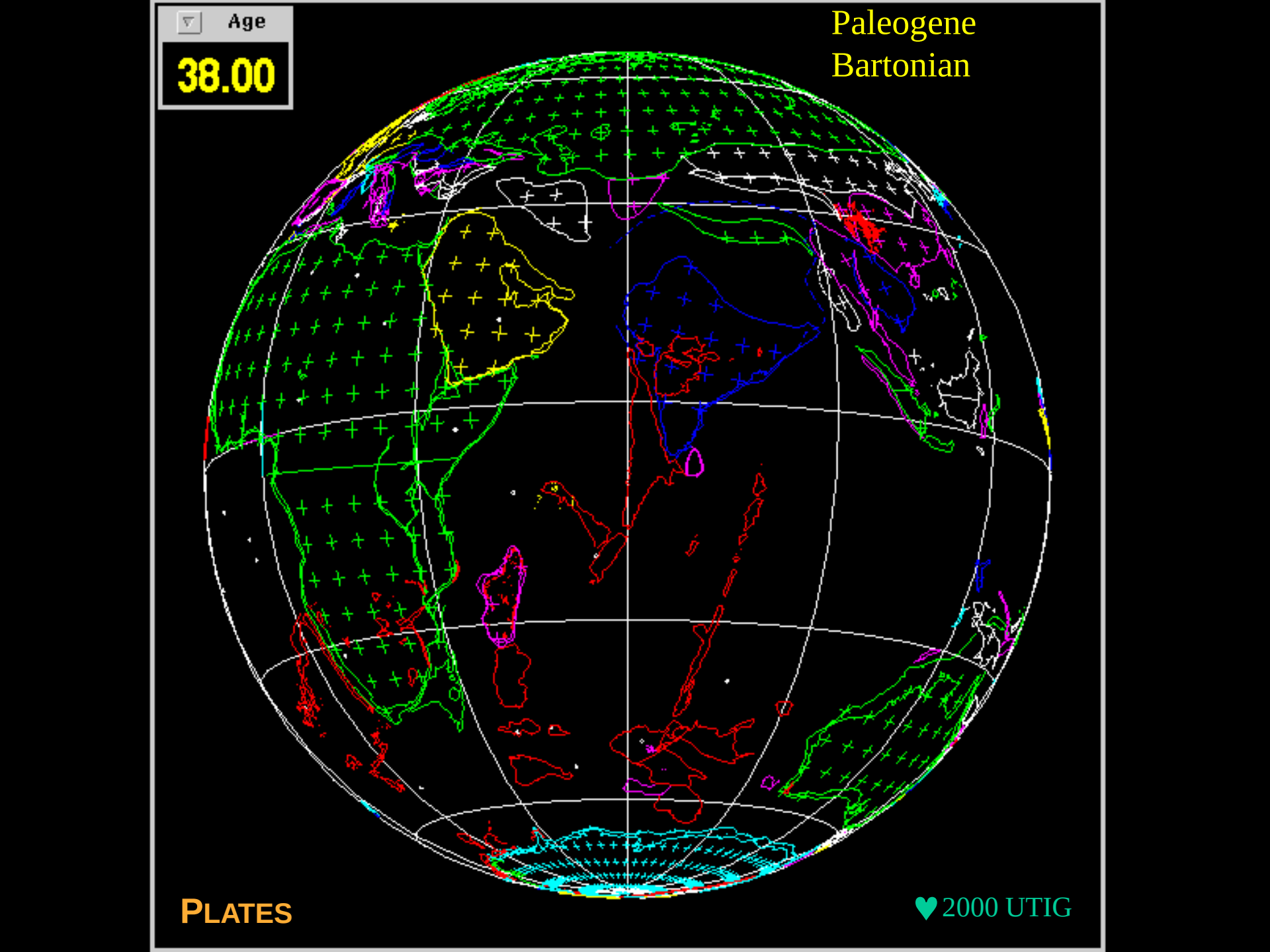

Age
43.00
Paleogene
Late Lutetian
PLATES
♥2000 UTIG

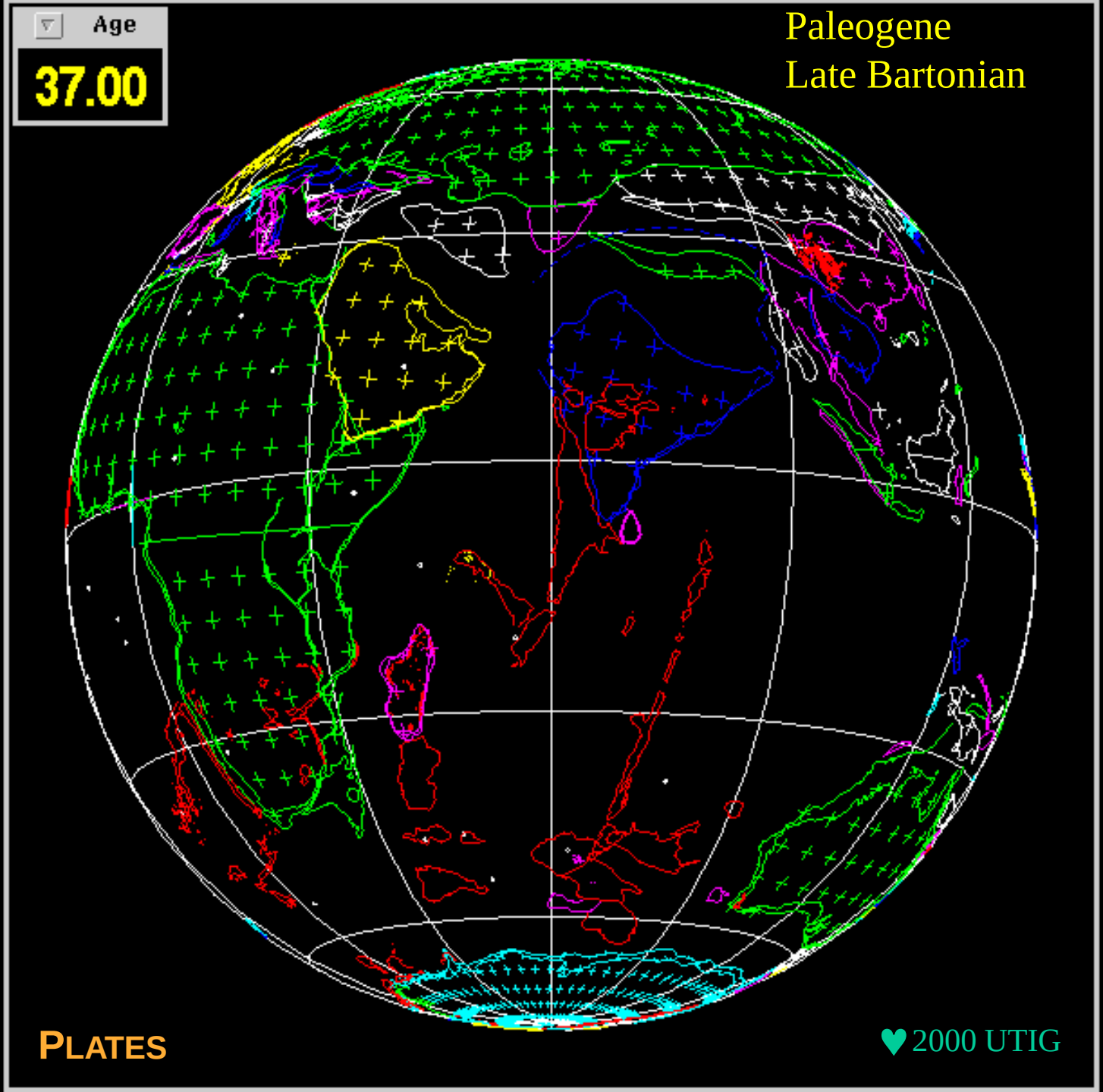

Age
42.00
Paleogene
Late Lutetian
PLATES
♥2000 UTIG

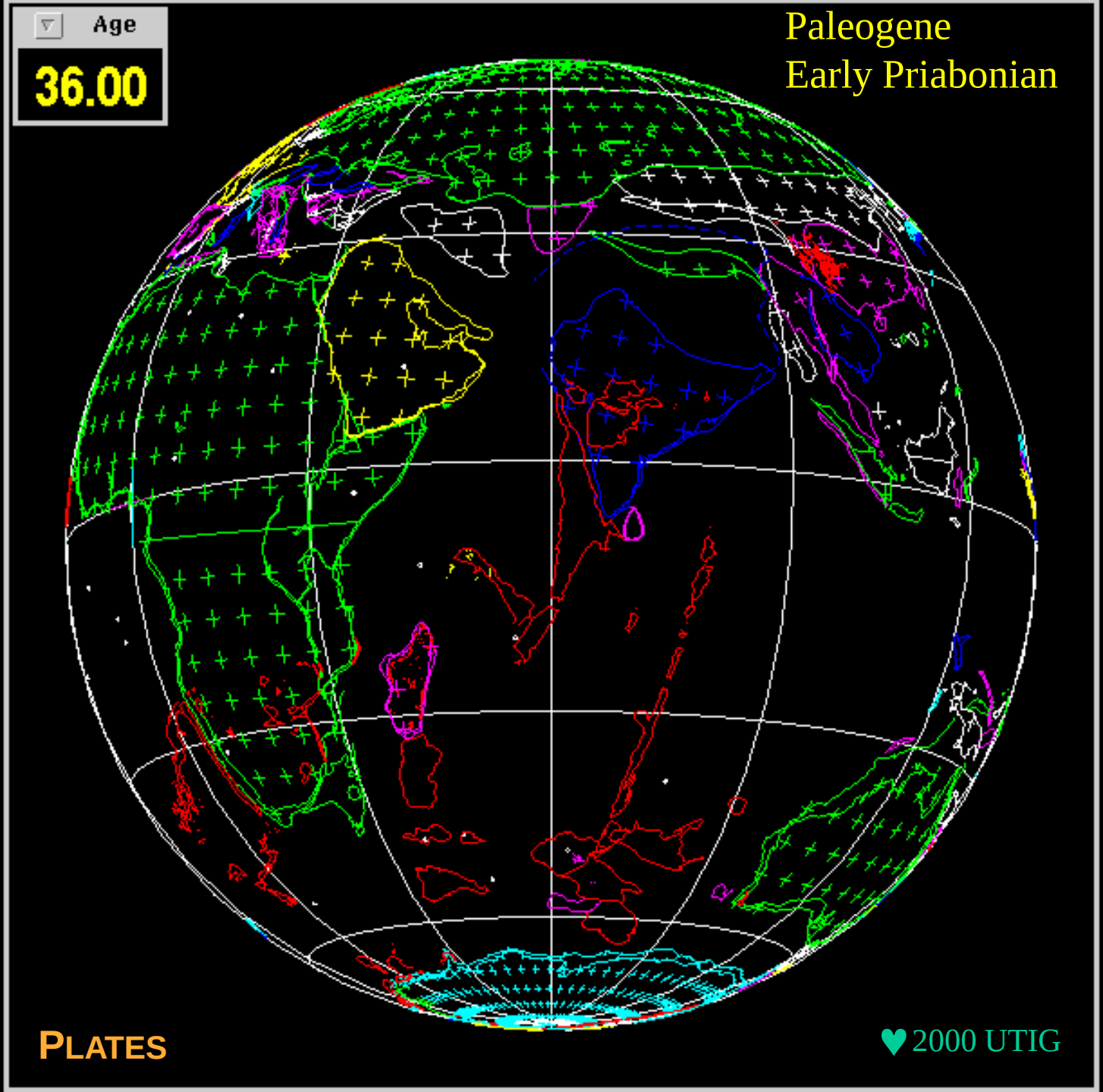

Age
41.00
Paleogene
Late Lutetian
PLATES
♥2000 UTIG

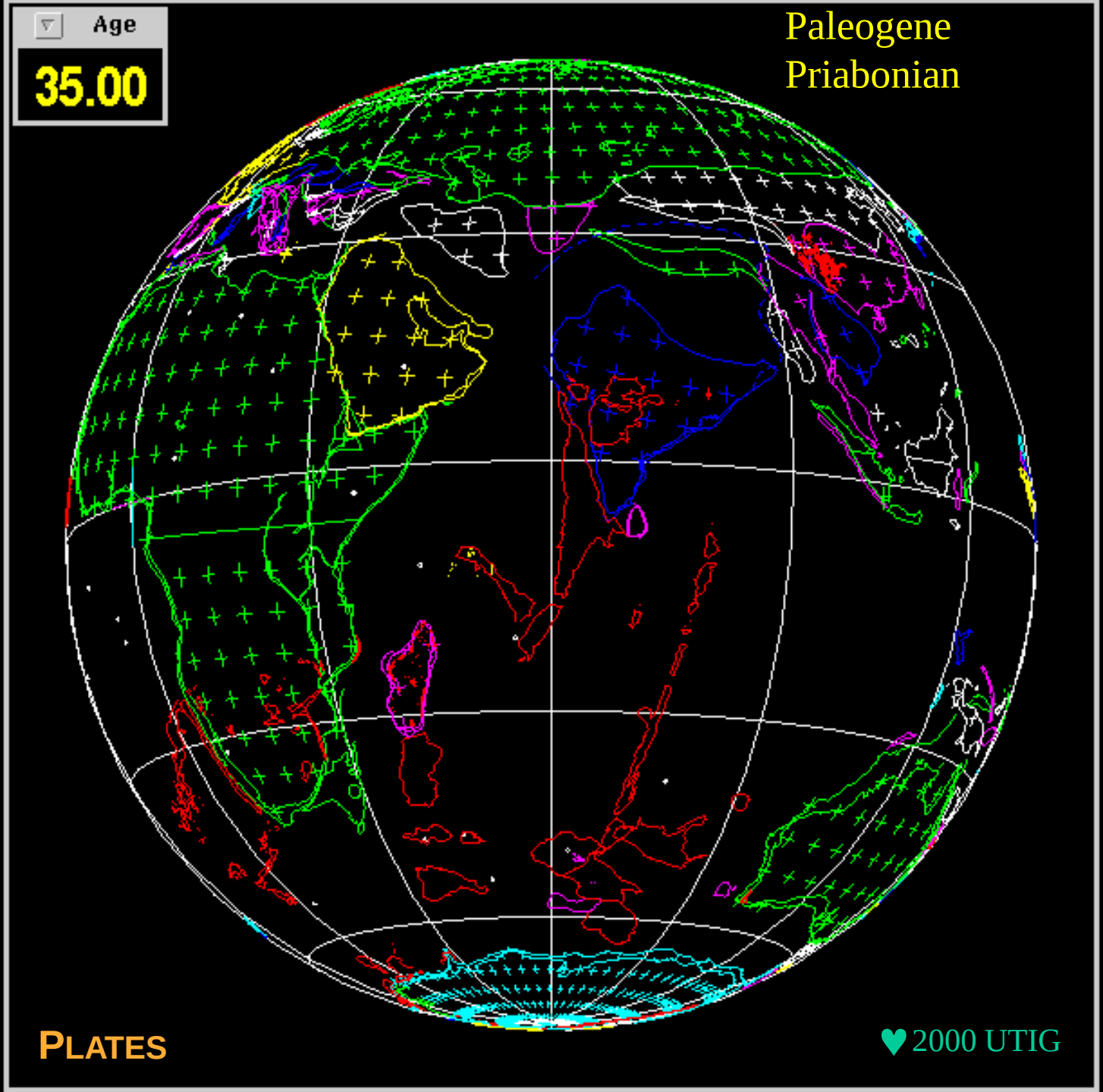

Age
40.00
Paleogene
Early Bartonian
PLATES
♥2000 UTIG

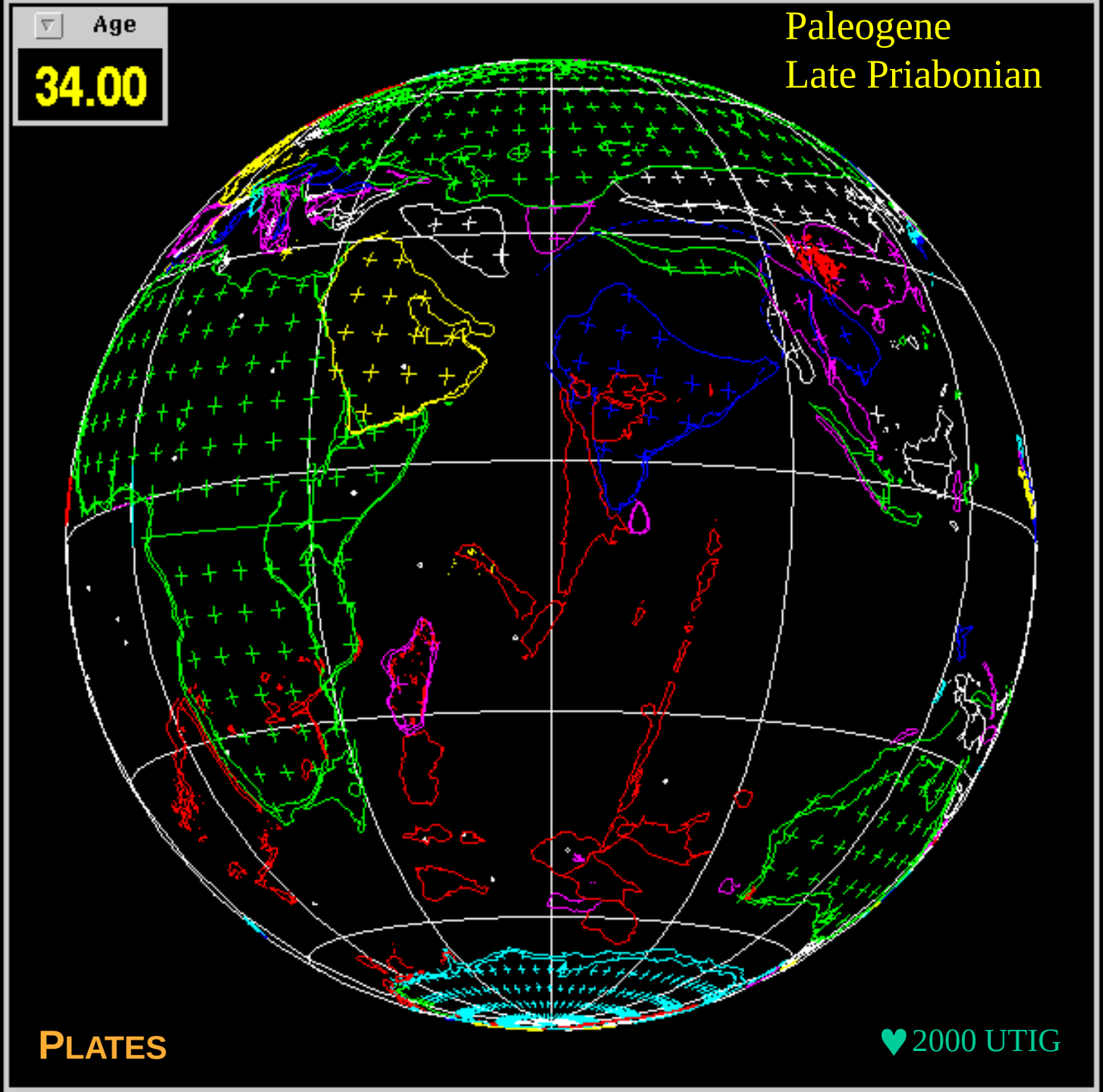

Age
39.00
Paleogene
Bartonian
PLATES
♥2000 UTIG

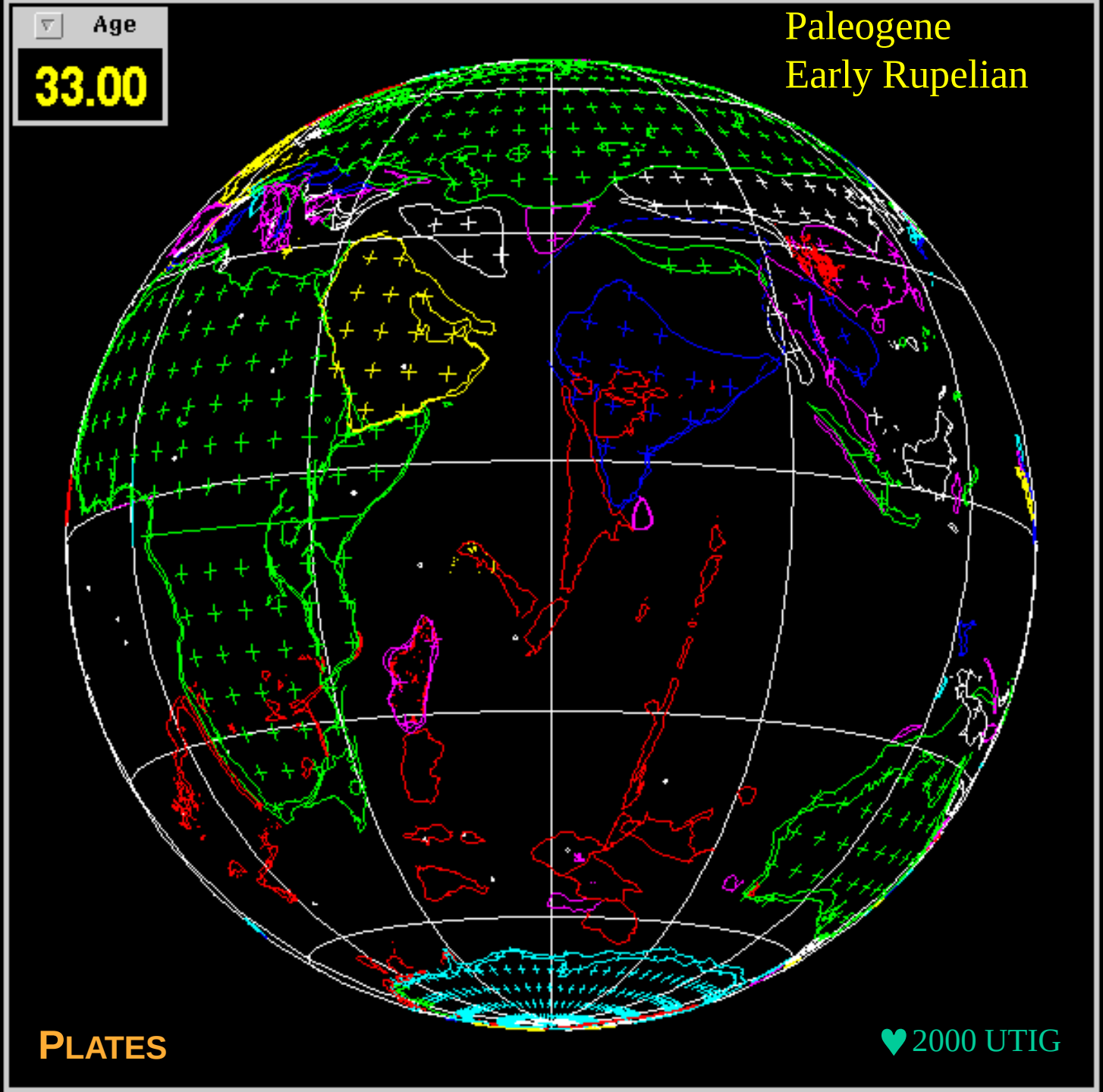

Age
38.00
Paleogene
Bartonian
PLATES
♥2000 UTIG

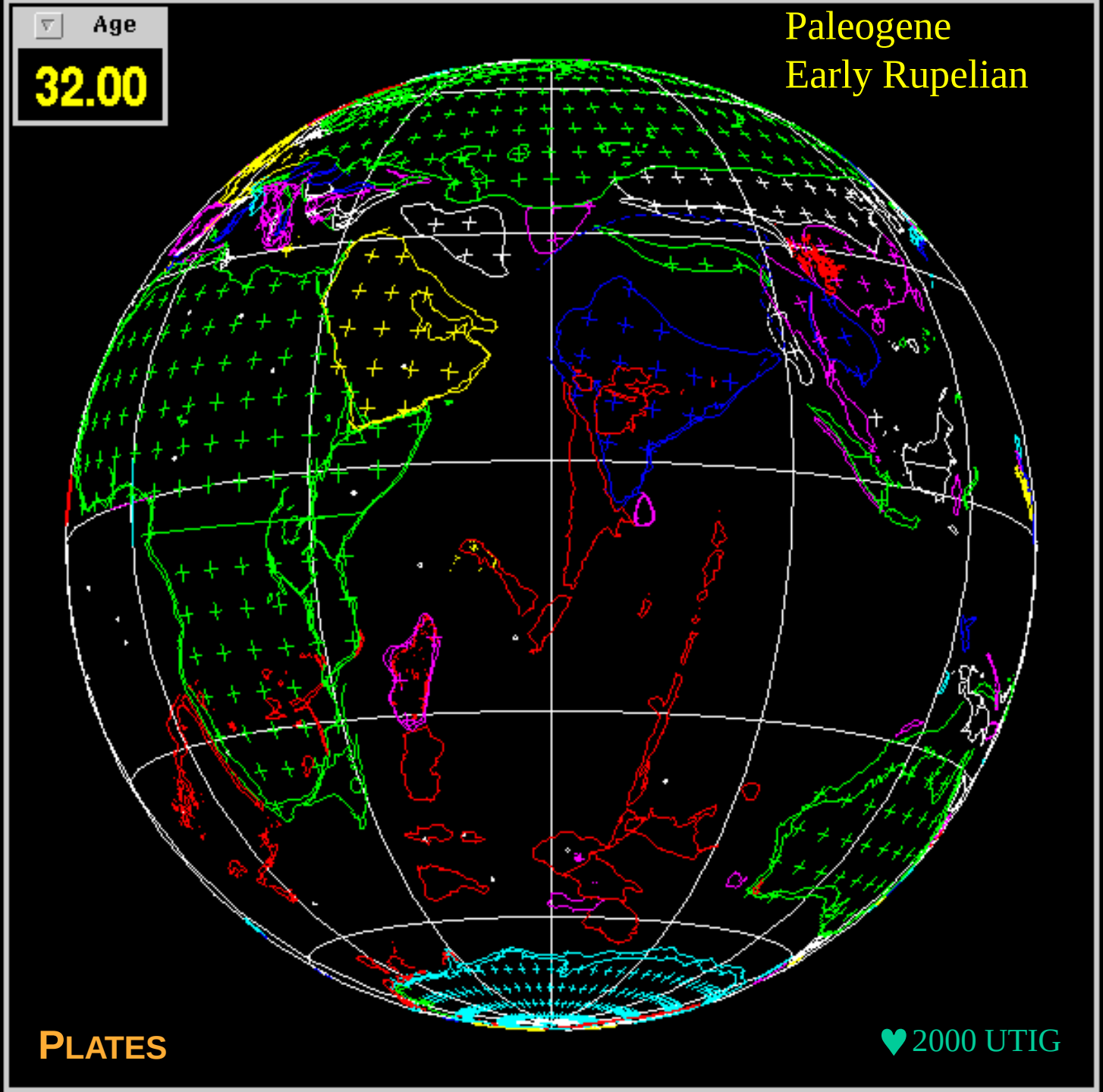

Age
37.00
Paleogene
Late Bartonian
PLATES
♥2000 UTIG

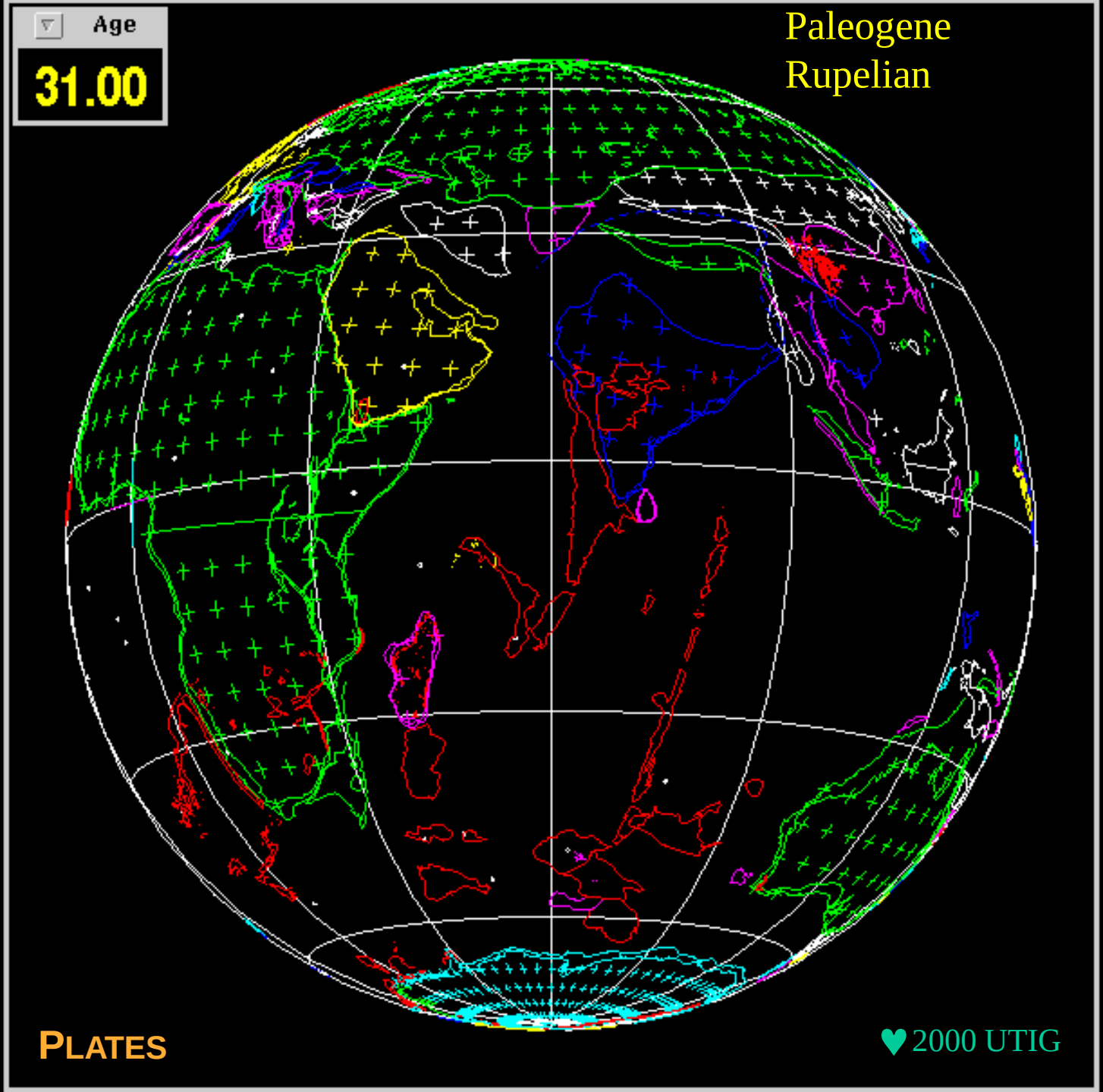

Age
36.00
Paleogene
Early Priabonian
PLATES
♥2000 UTIG

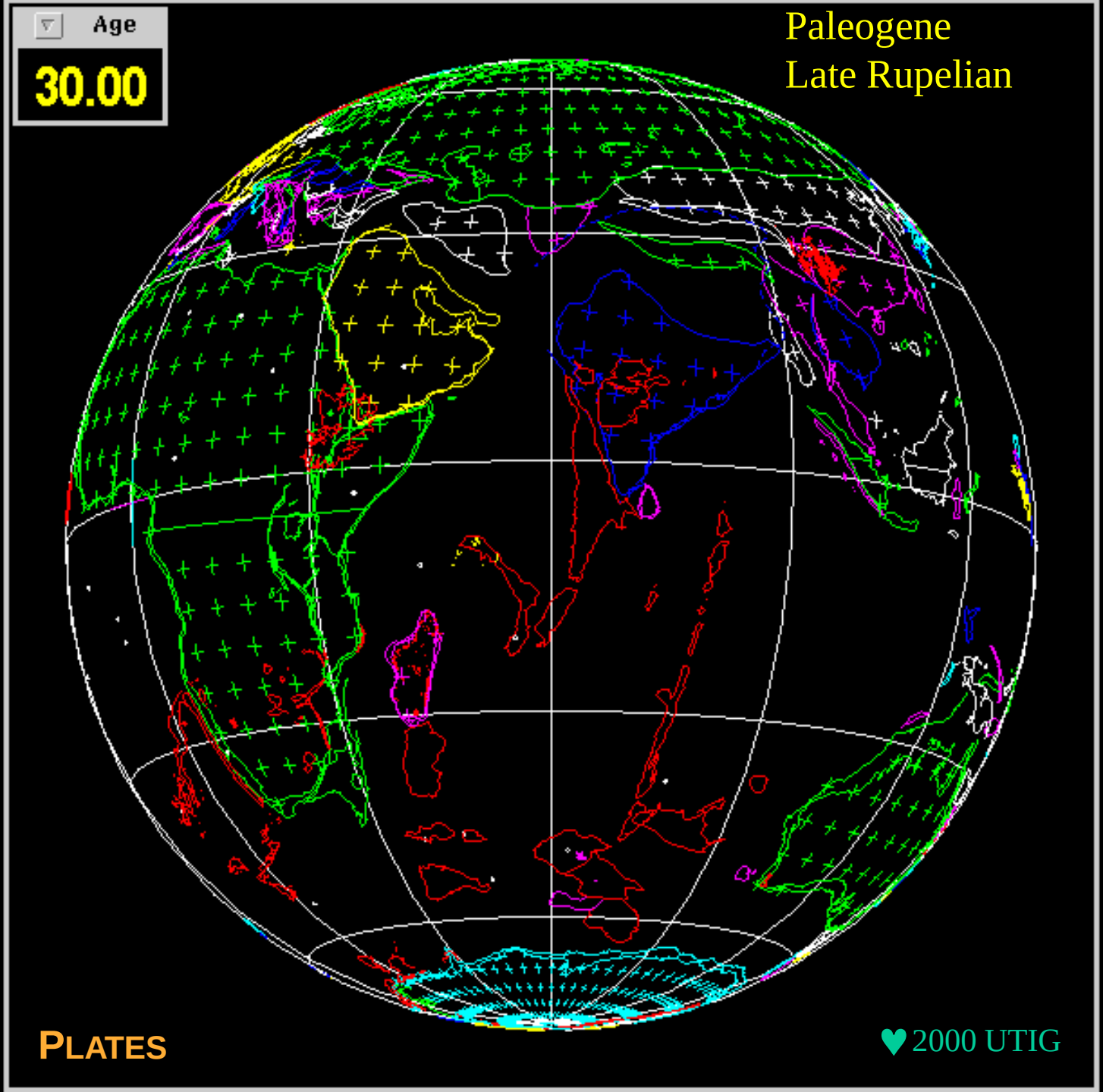

Age
35.00
Paleogene
Priabonian
PLATES
♥2000 UTIG

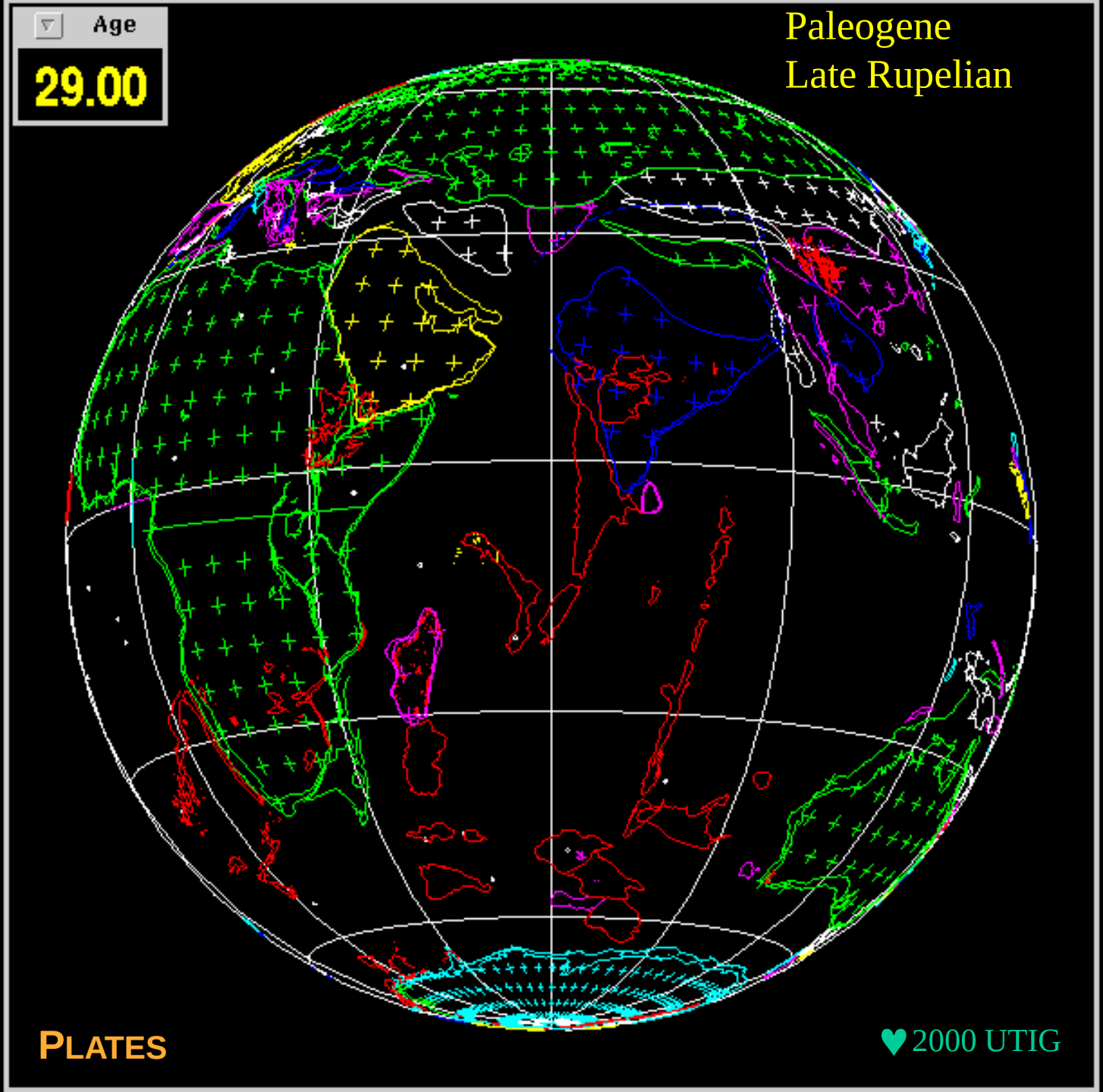

Age
34.00
Paleogene
Late Priabonian
PLATES
♥2000 UTIG

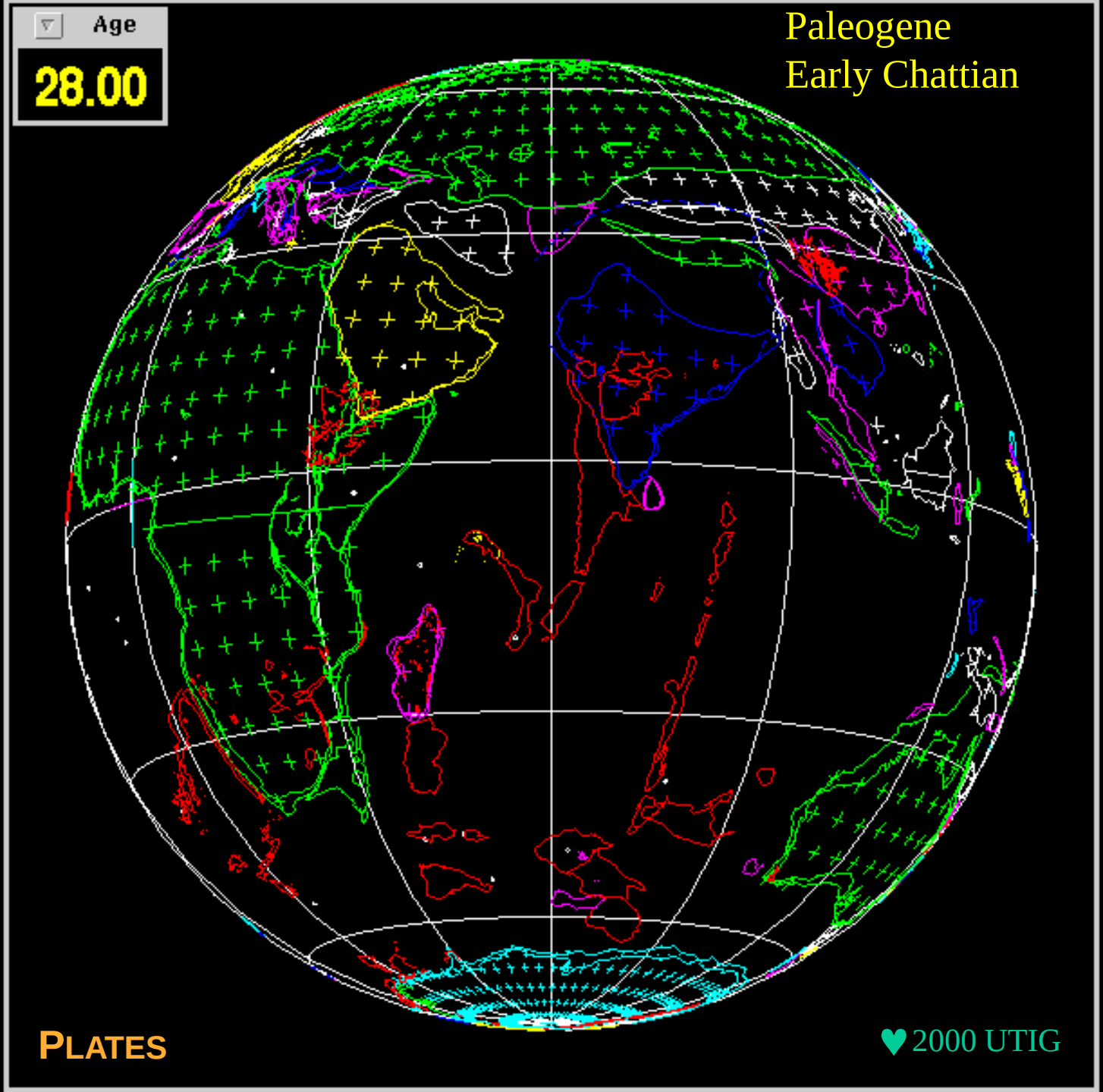

Age
33.00
Paleogene
Early Rupelian
PLATES
♥2000 UTIG

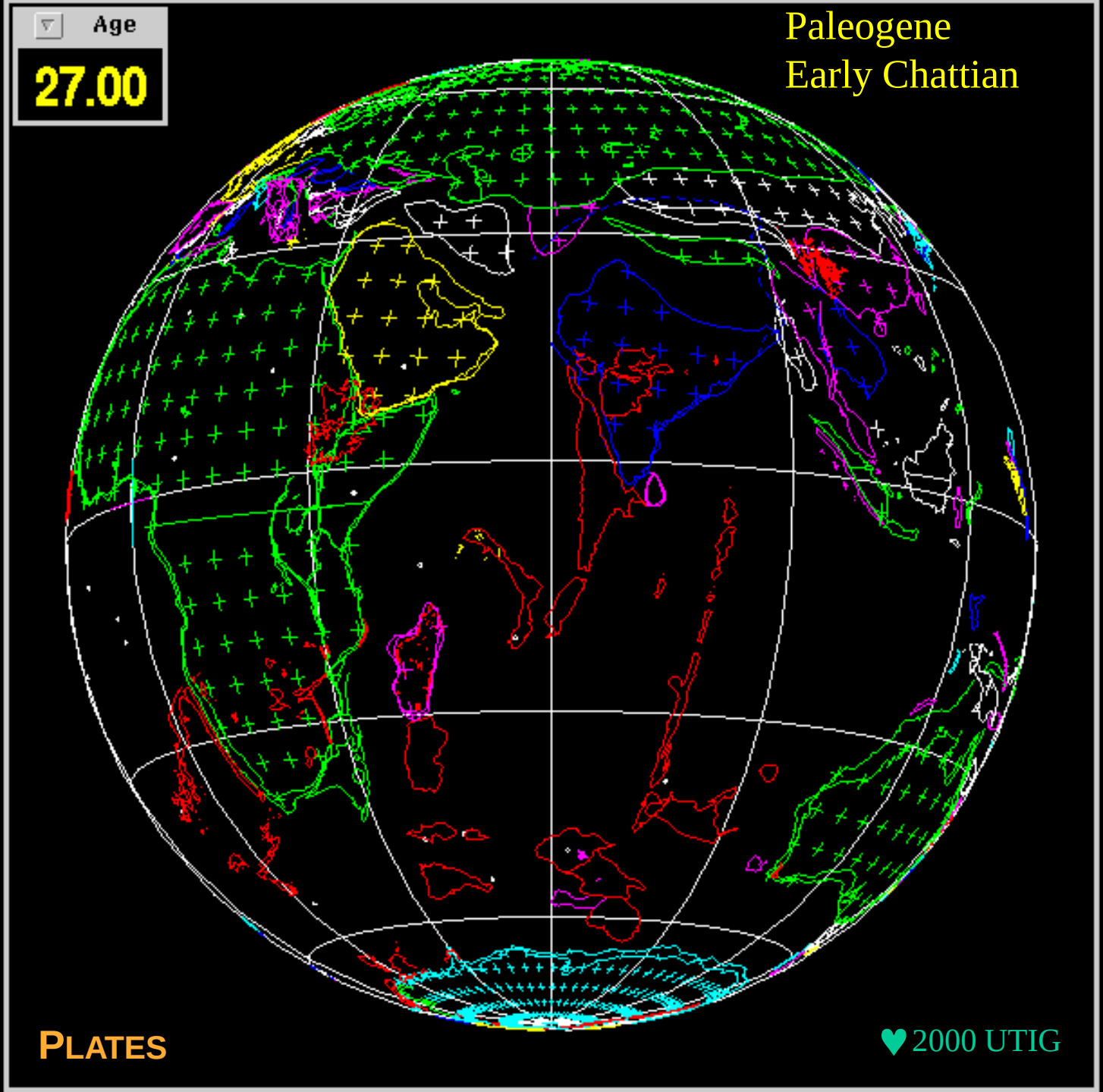

Age
32.00
Paleogene
Early Rupelian
PLATES
♥2000 UTIG

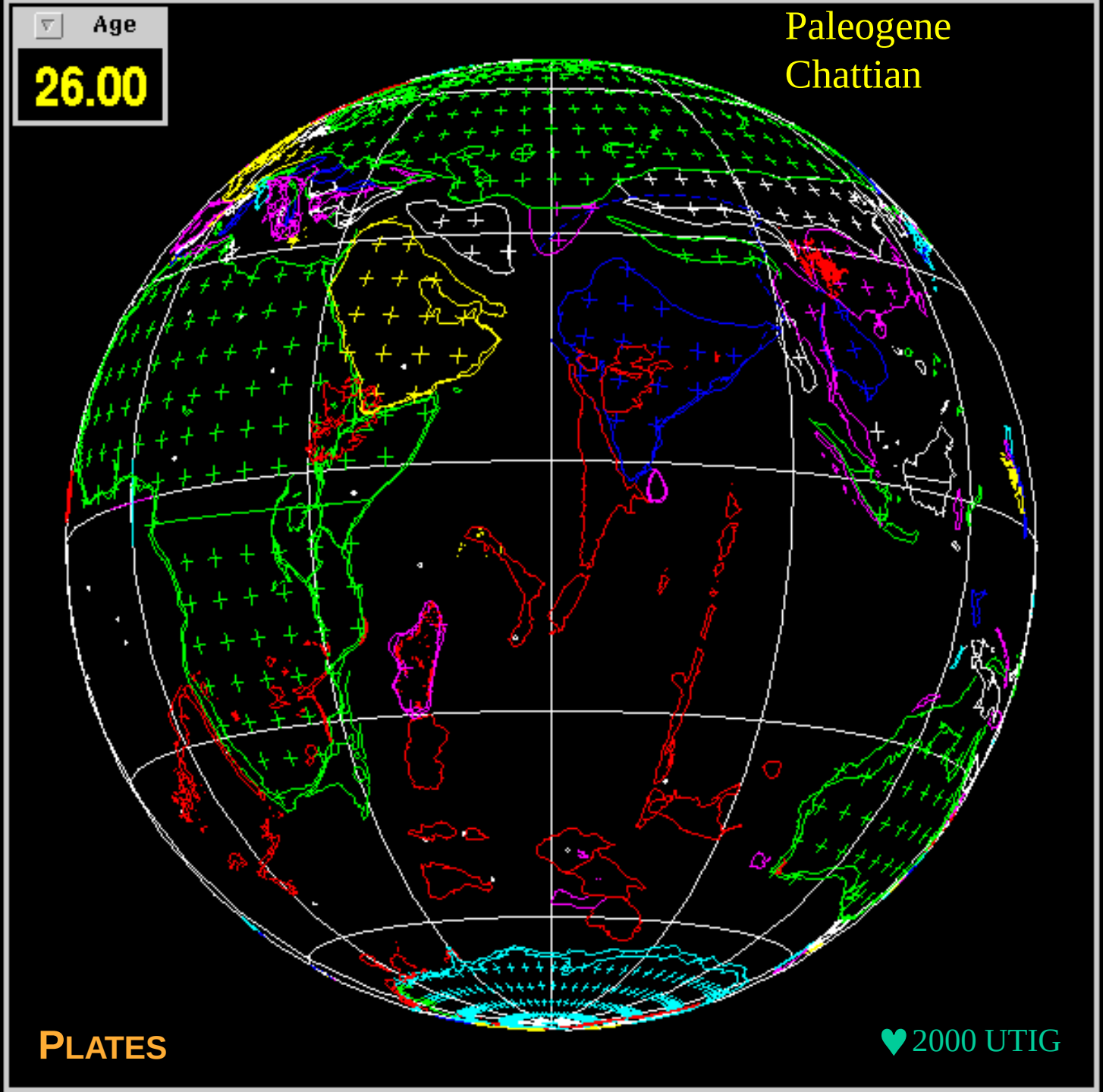

Age
31.00
Paleogene
Rupelian
PLATES
♥2000 UTIG

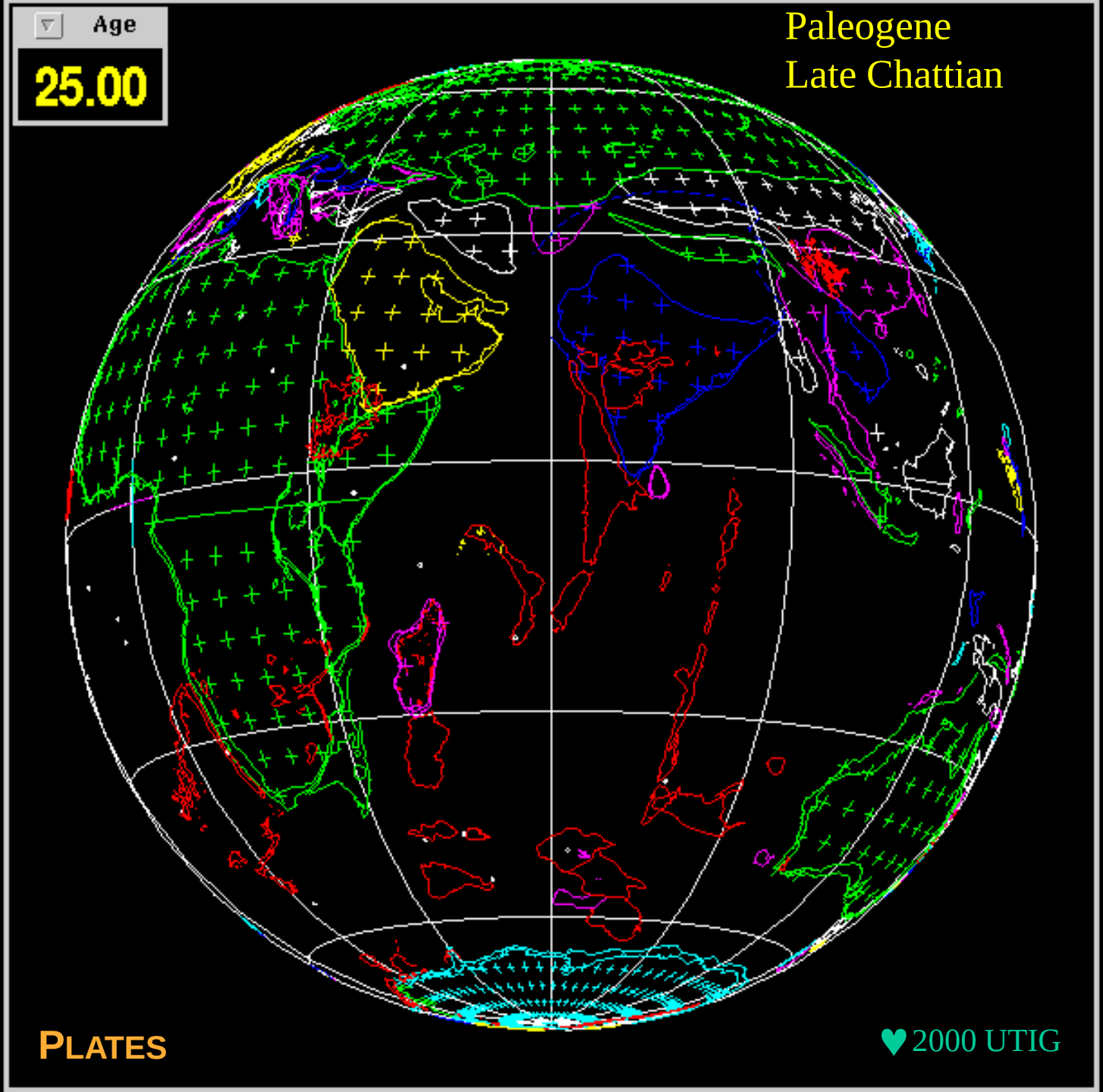

Age
30.00
Paleogene
Late Rupelian
PLATES
♥2000 UTIG

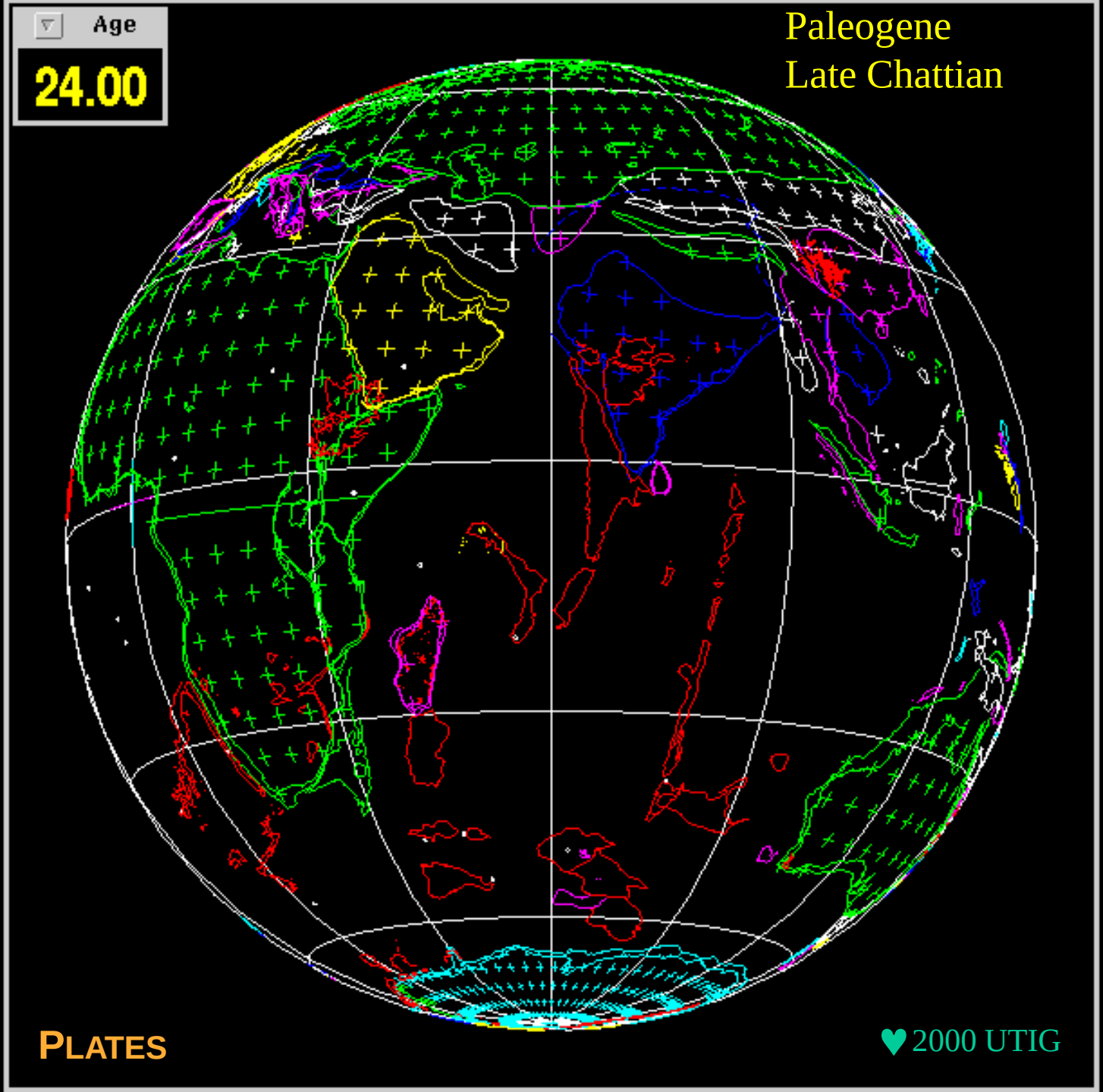

Age
29.00
Paleogene
Late Rupelian
PLATES
♥2000 UTIG

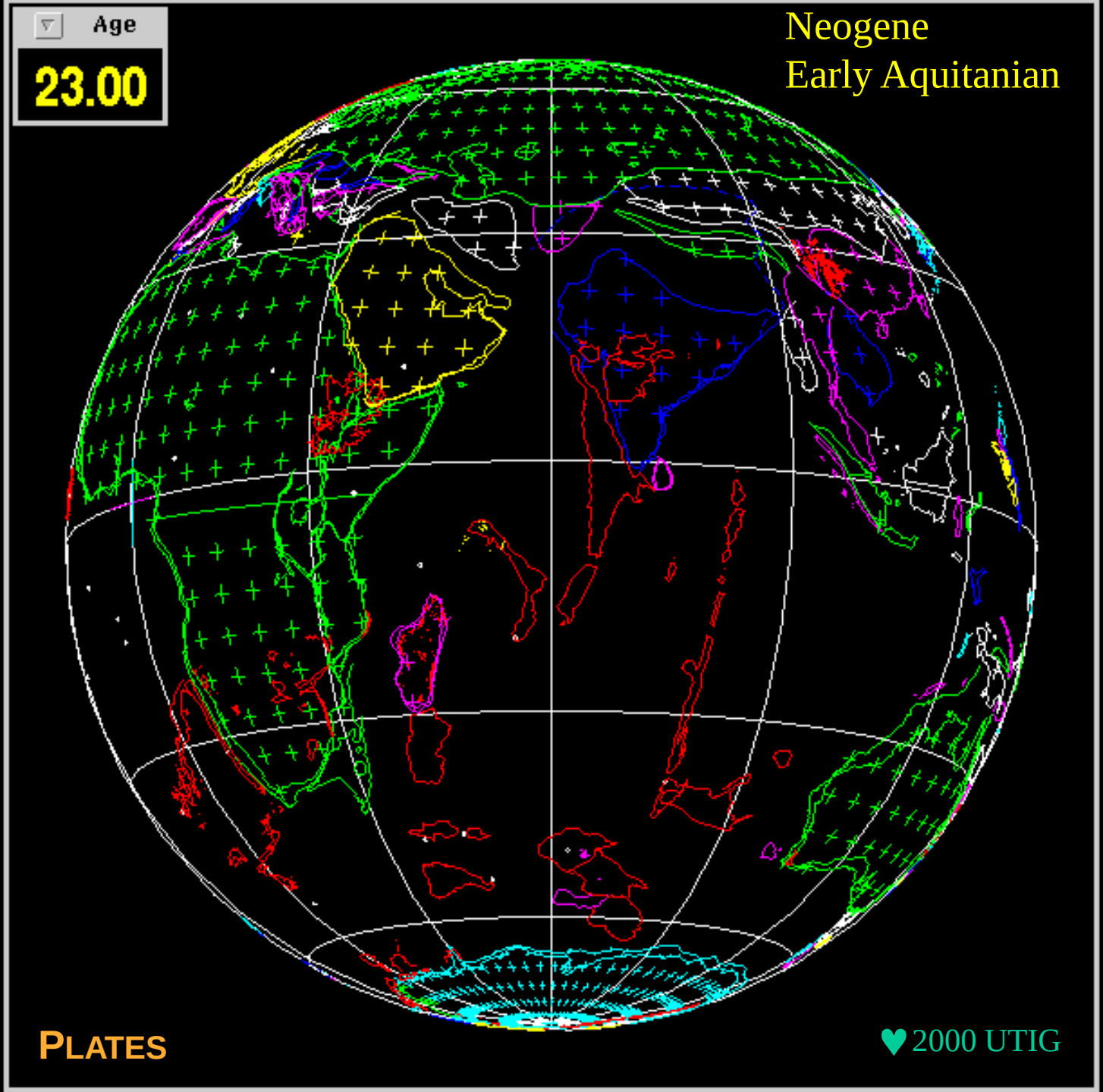

Age
28.00
Paleogene
Early Chattian
PLATES
♥2000 UTIG

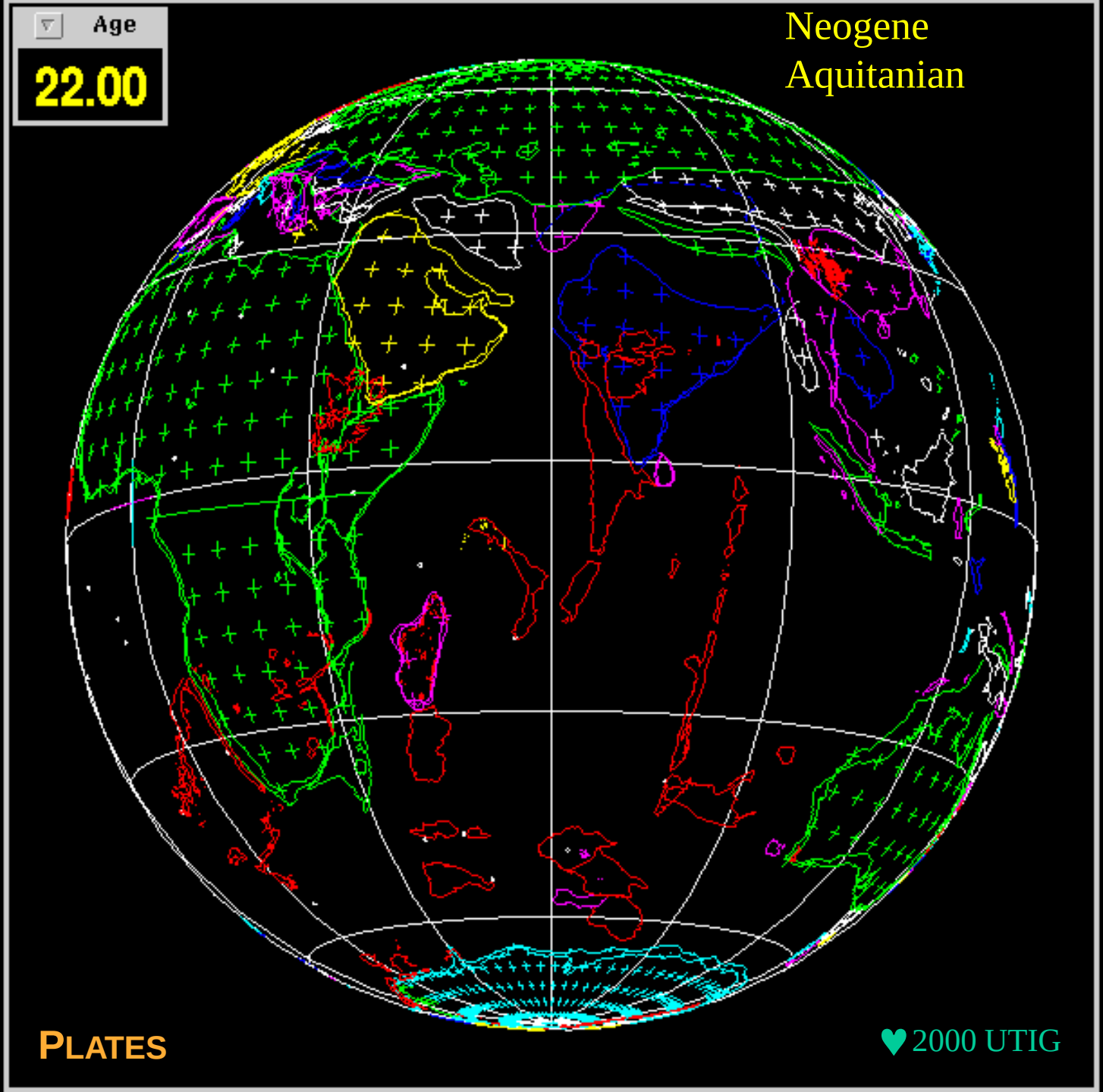

Age
27.00
Paleogene
Early Chattian
PLATES
♥2000 UTIG

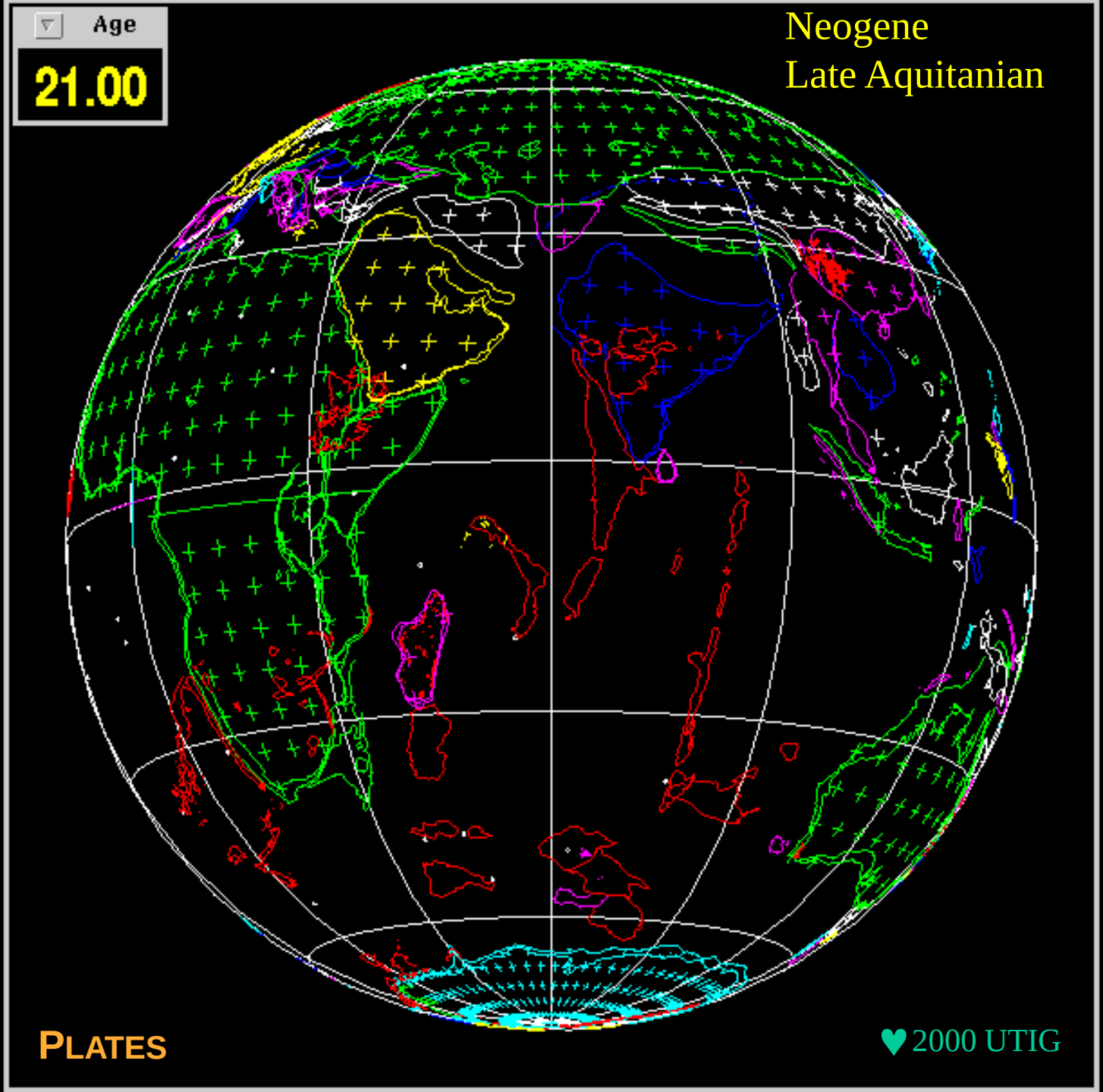

Age
26.00
Paleogene
Chattian
PLATES
♥2000 UTIG

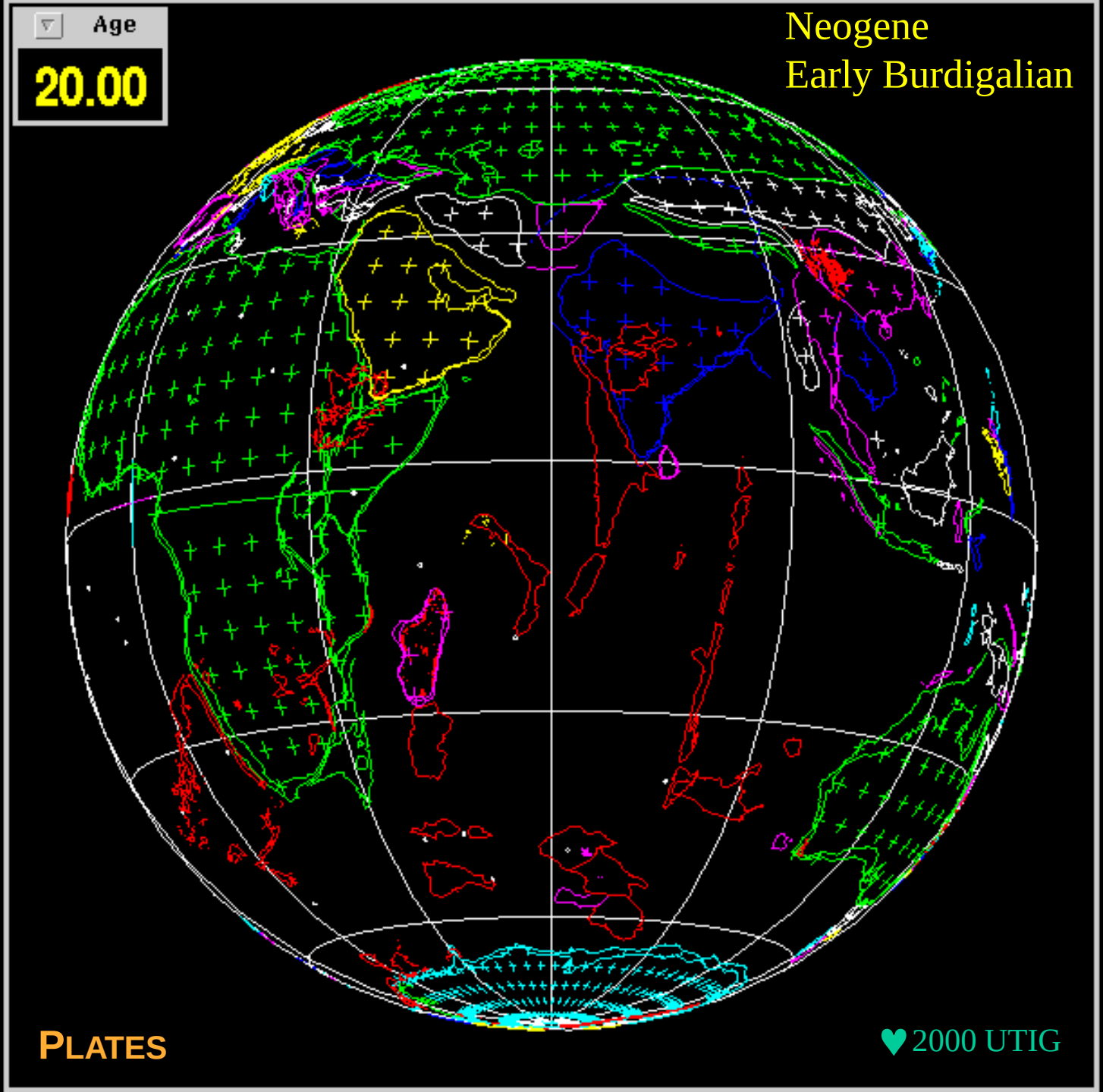

Age
25.00
Paleogene
Late Chattian
PLATES
♥2000 UTIG

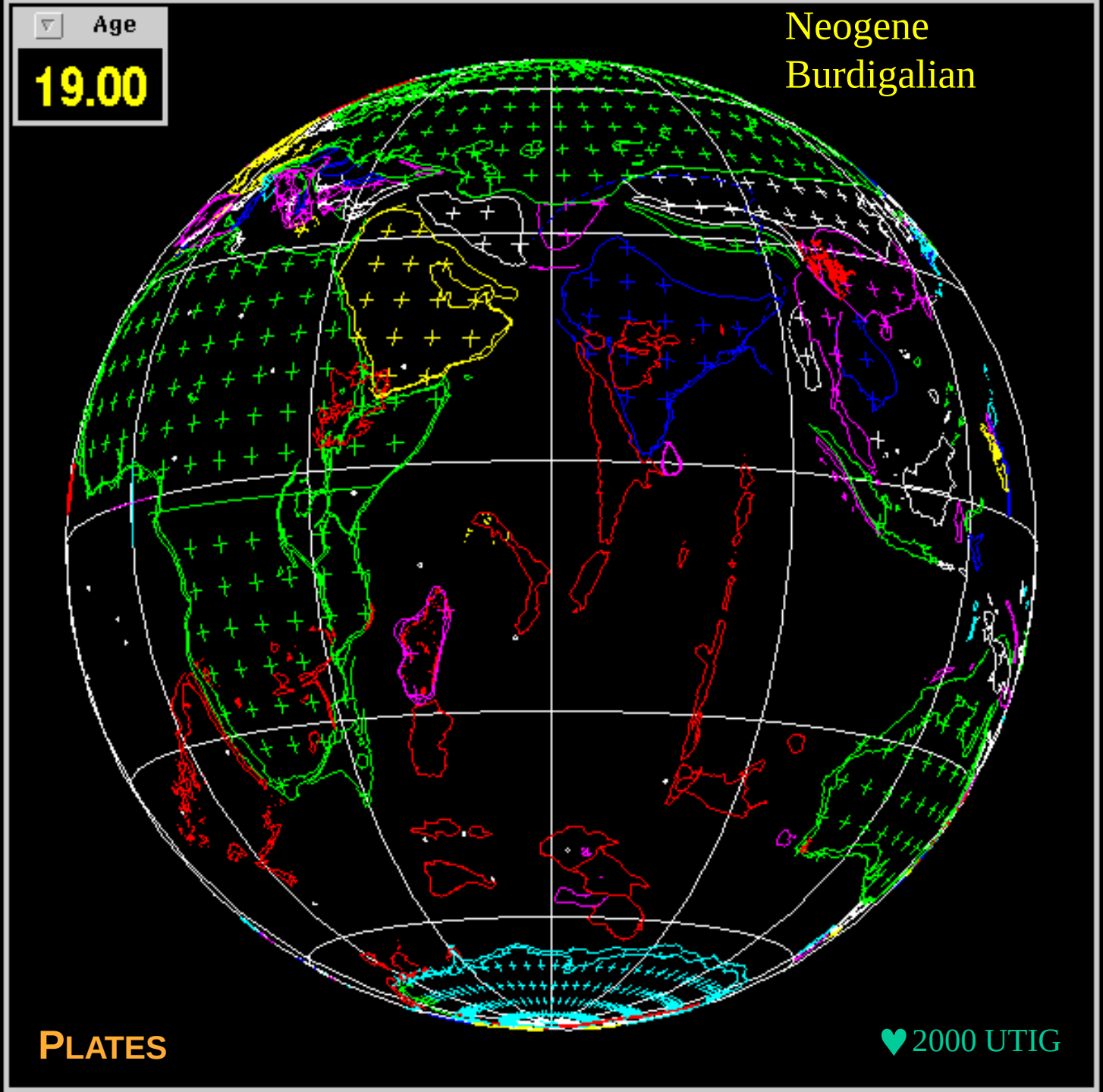

Age
24.00
Paleogene
Late Chattian
PLATES
♥2000 UTIG

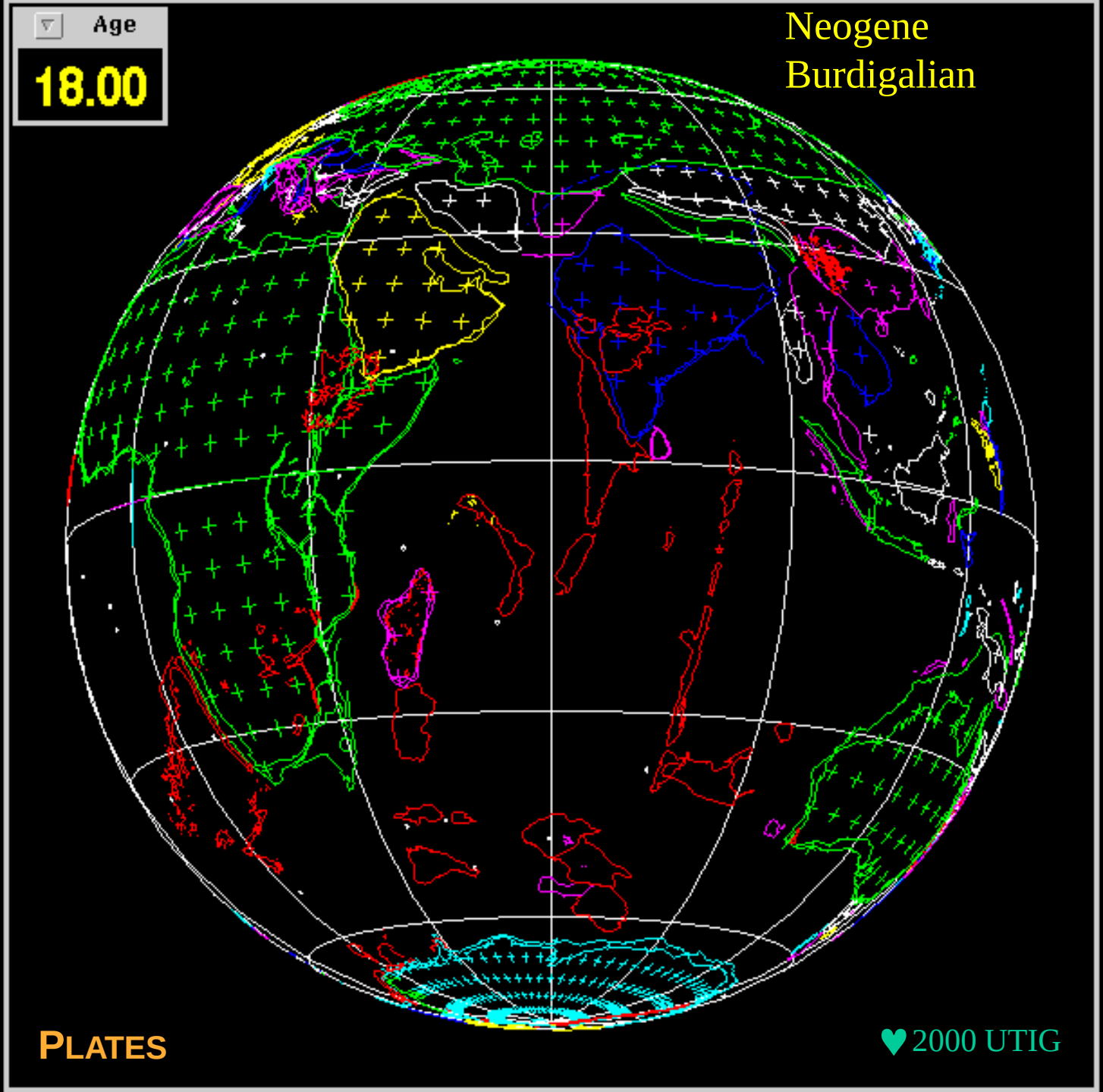

Age
23.00
Neogene
Early Aquitanian
PLATES
♥2000 UTIG

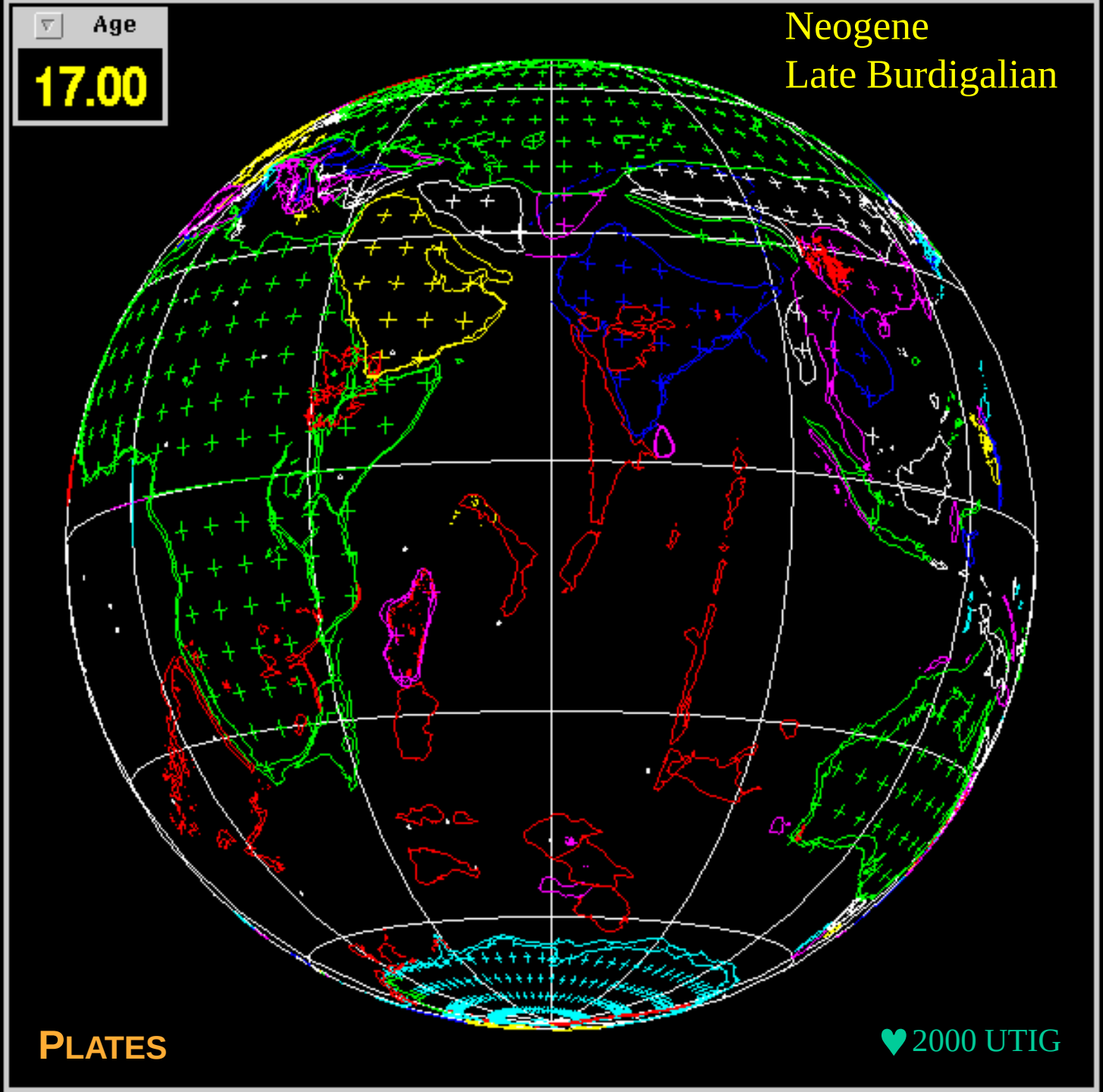

Age
22.00
Neogene
Aquitanian
PLATES
♥2000 UTIG

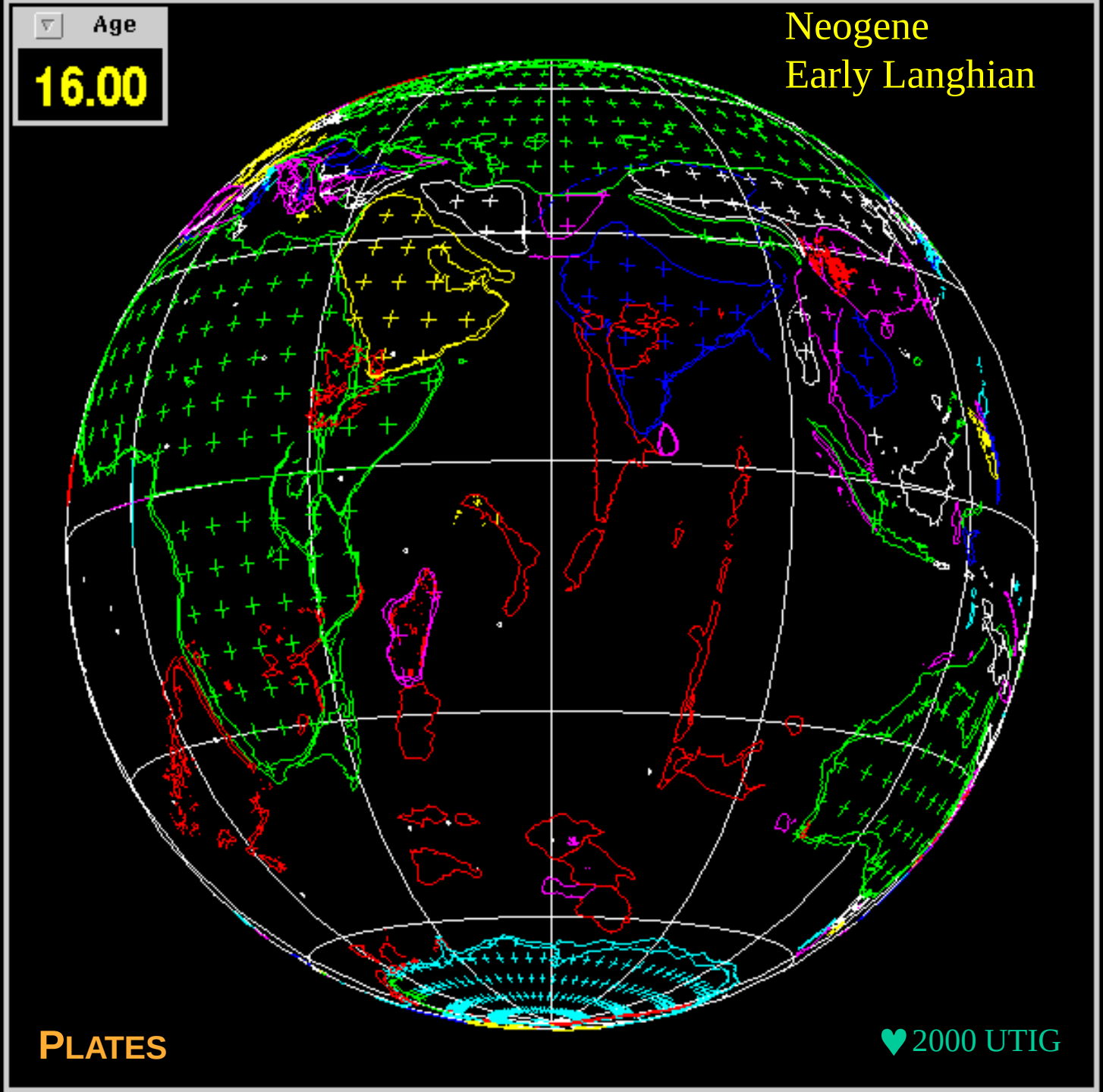

Age
21.00
Neogene
Late Aquitanian
PLATES
♥2000 UTIG

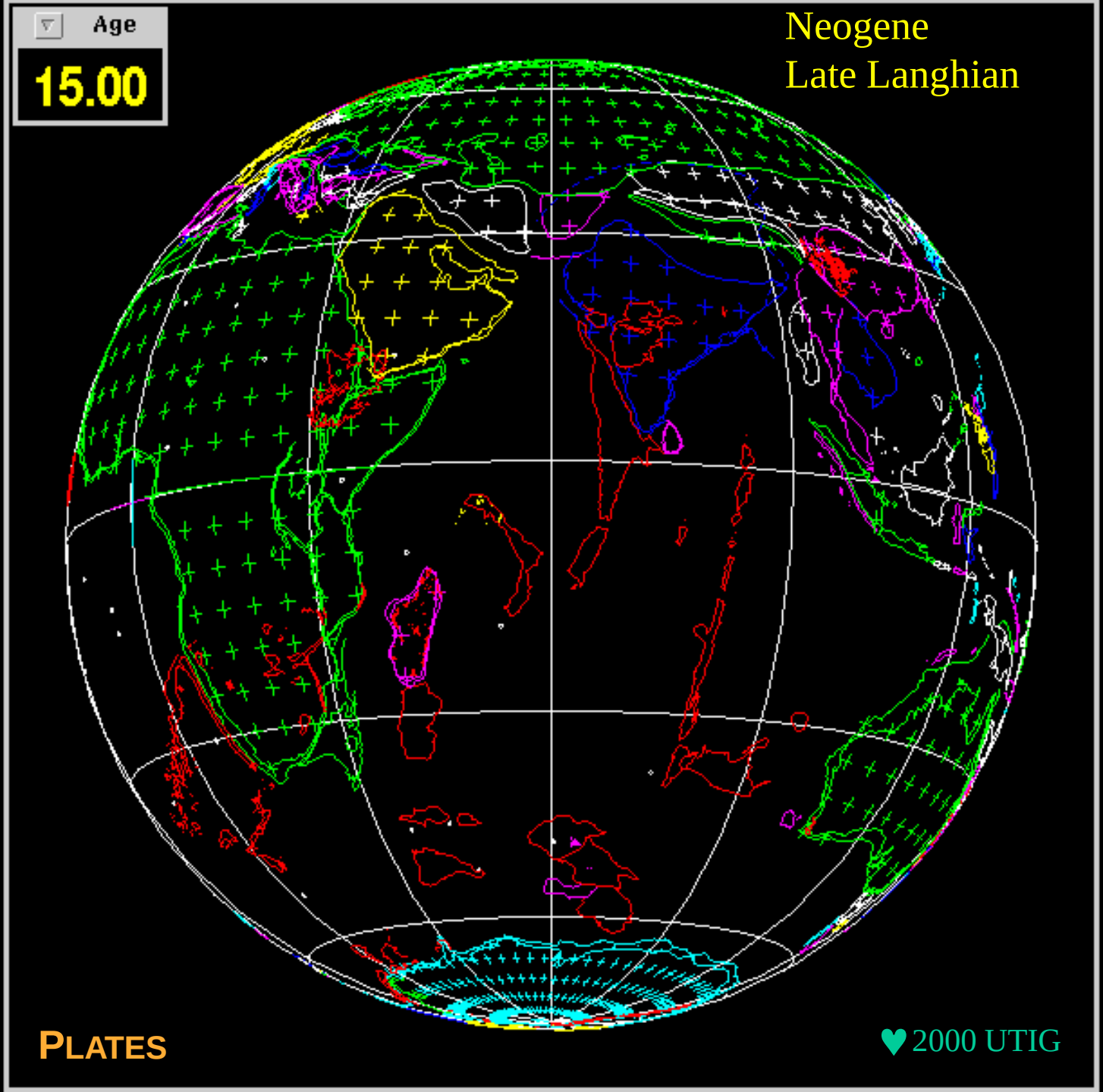

Age
20.00
Neogene
Early Burdigalian
PLATES
♥2000 UTIG

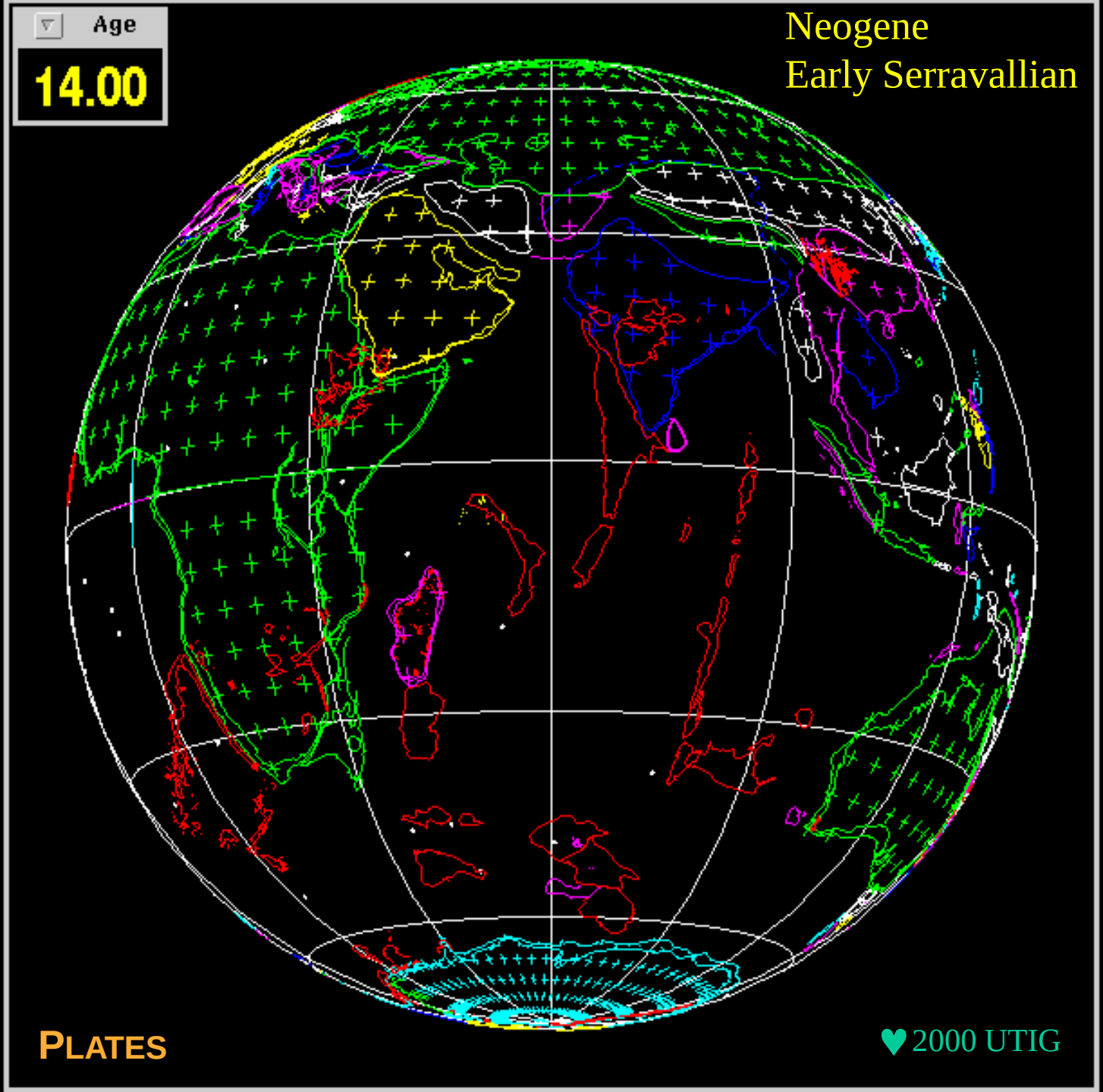

Age
19.00
Neogene
Burdigalian
PLATES
♥2000 UTIG

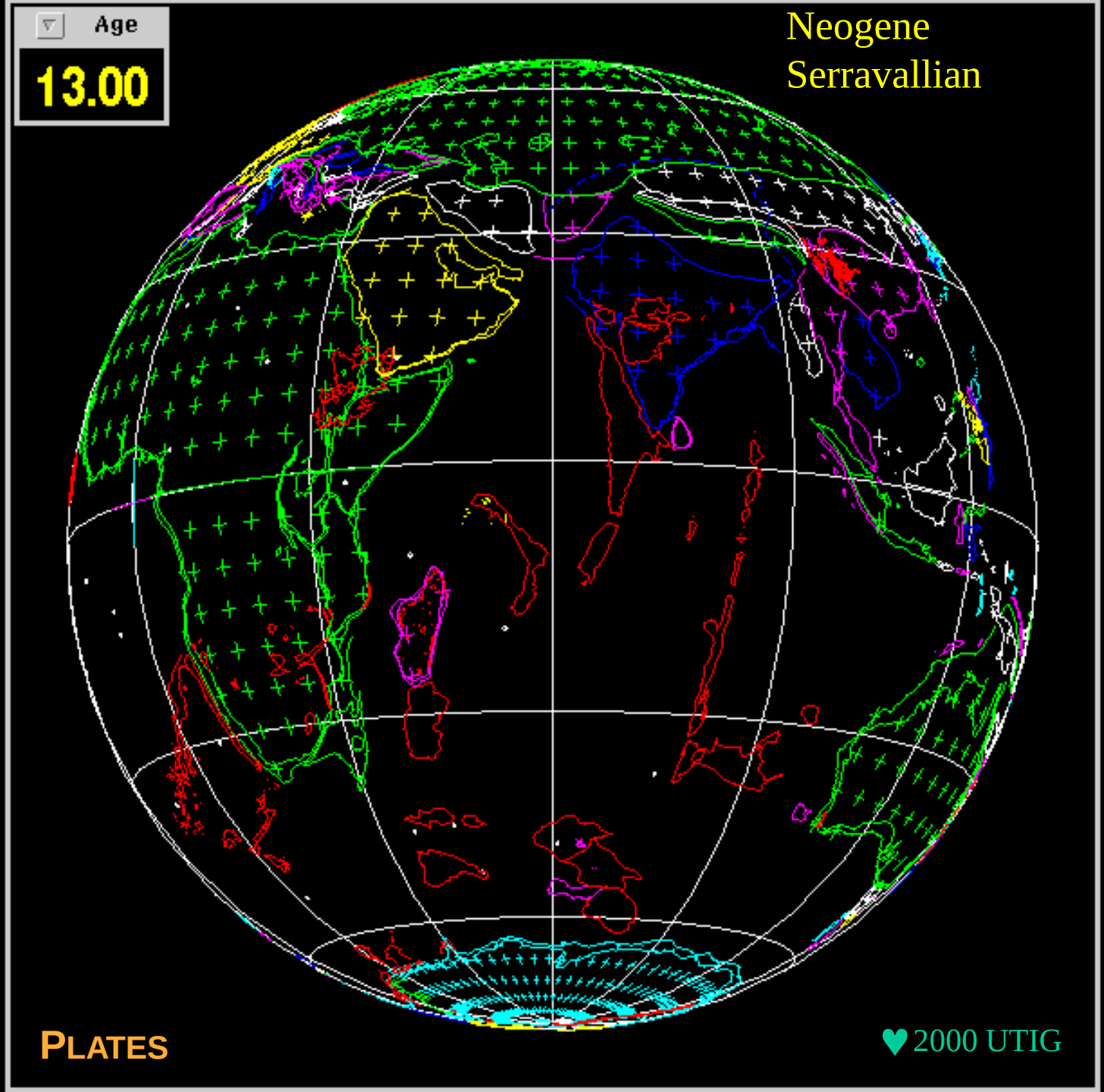

Age
18.00
Neogene
Burdigalian
PLATES
♥2000 UTIG

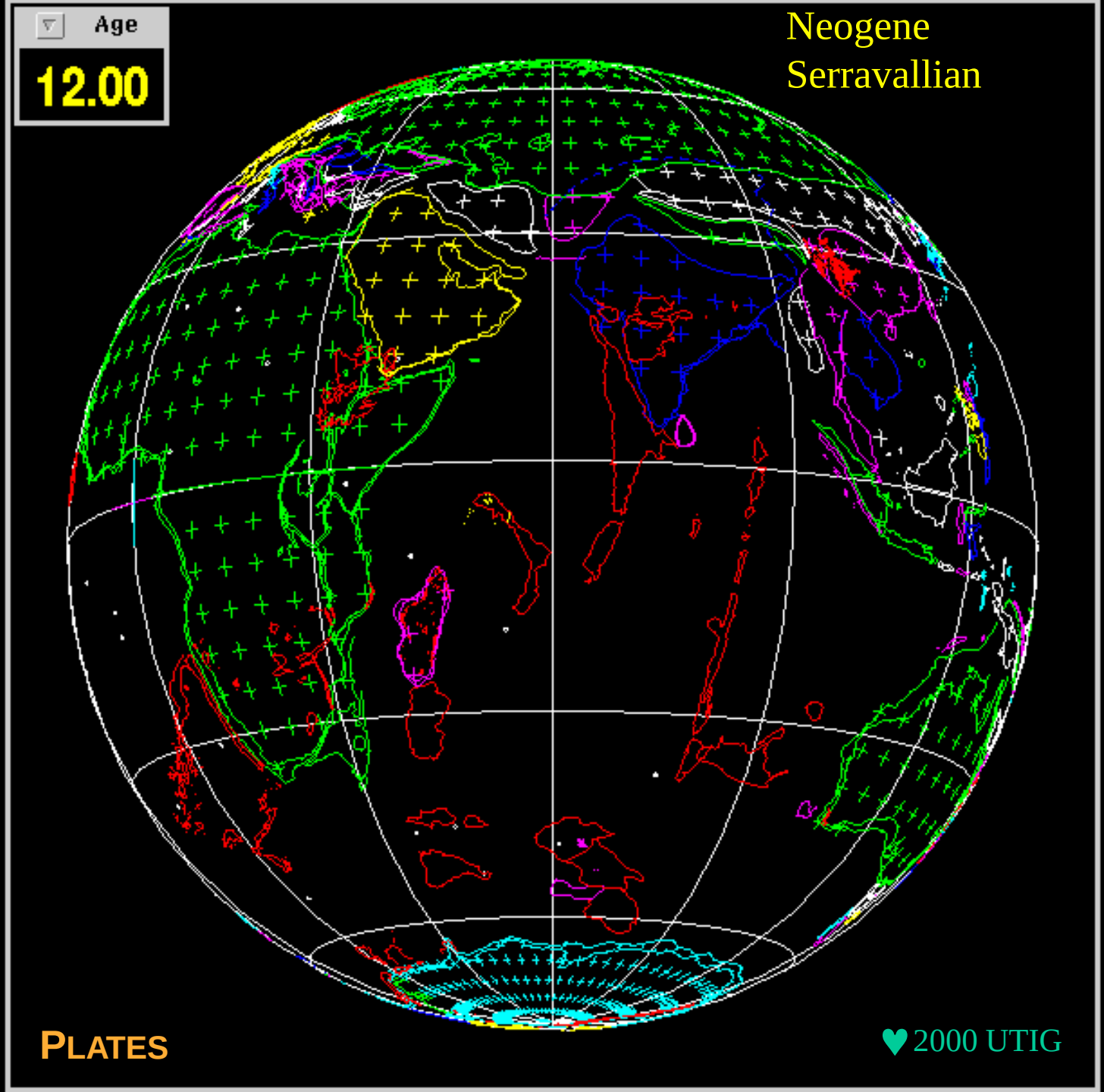

Age
17.00
Neogene
Late Burdigalian
PLATES
♥2000 UTIG

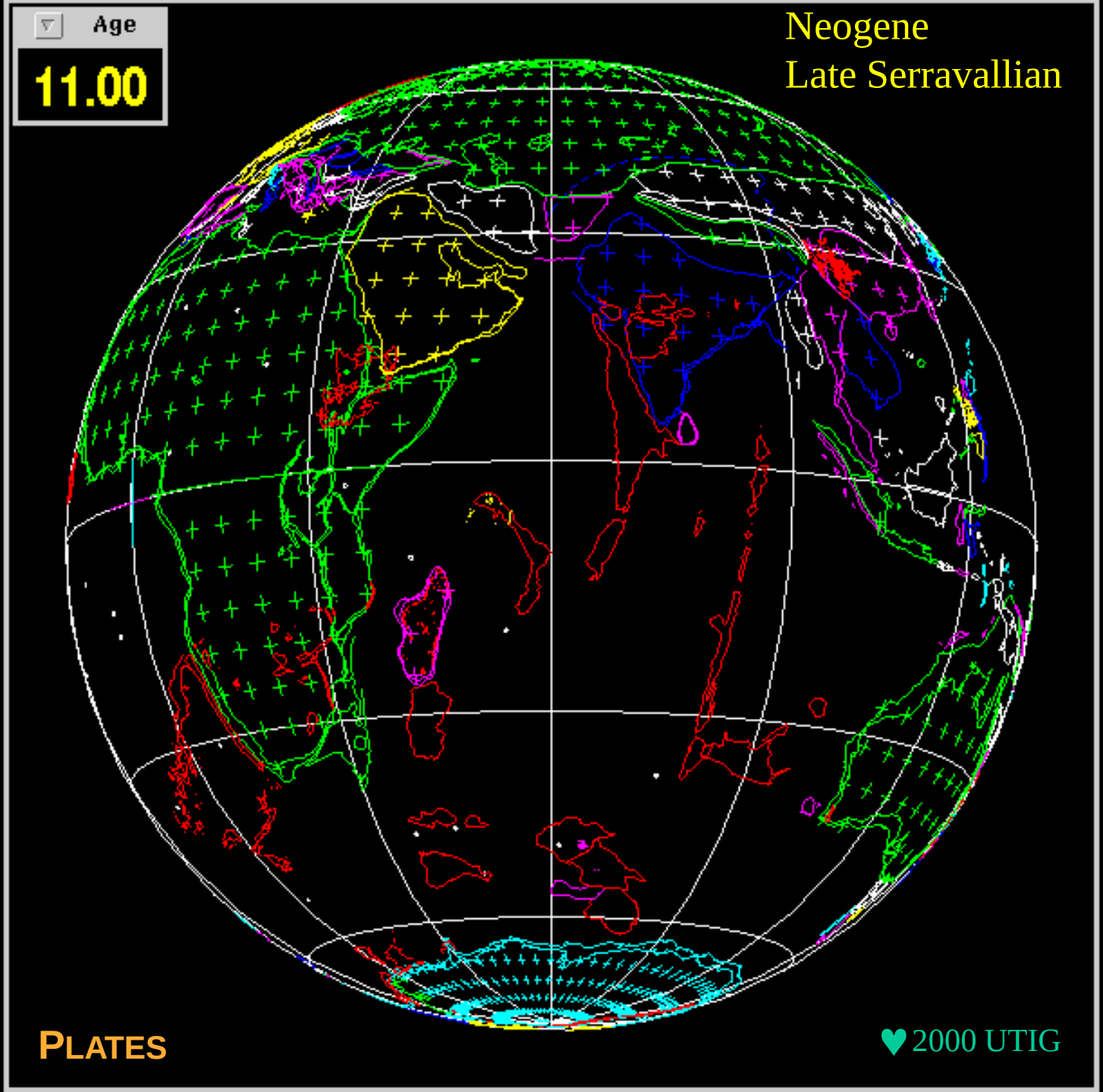

Age
16.00
Neogene
Early Langhian
PLATES
♥2000 UTIG

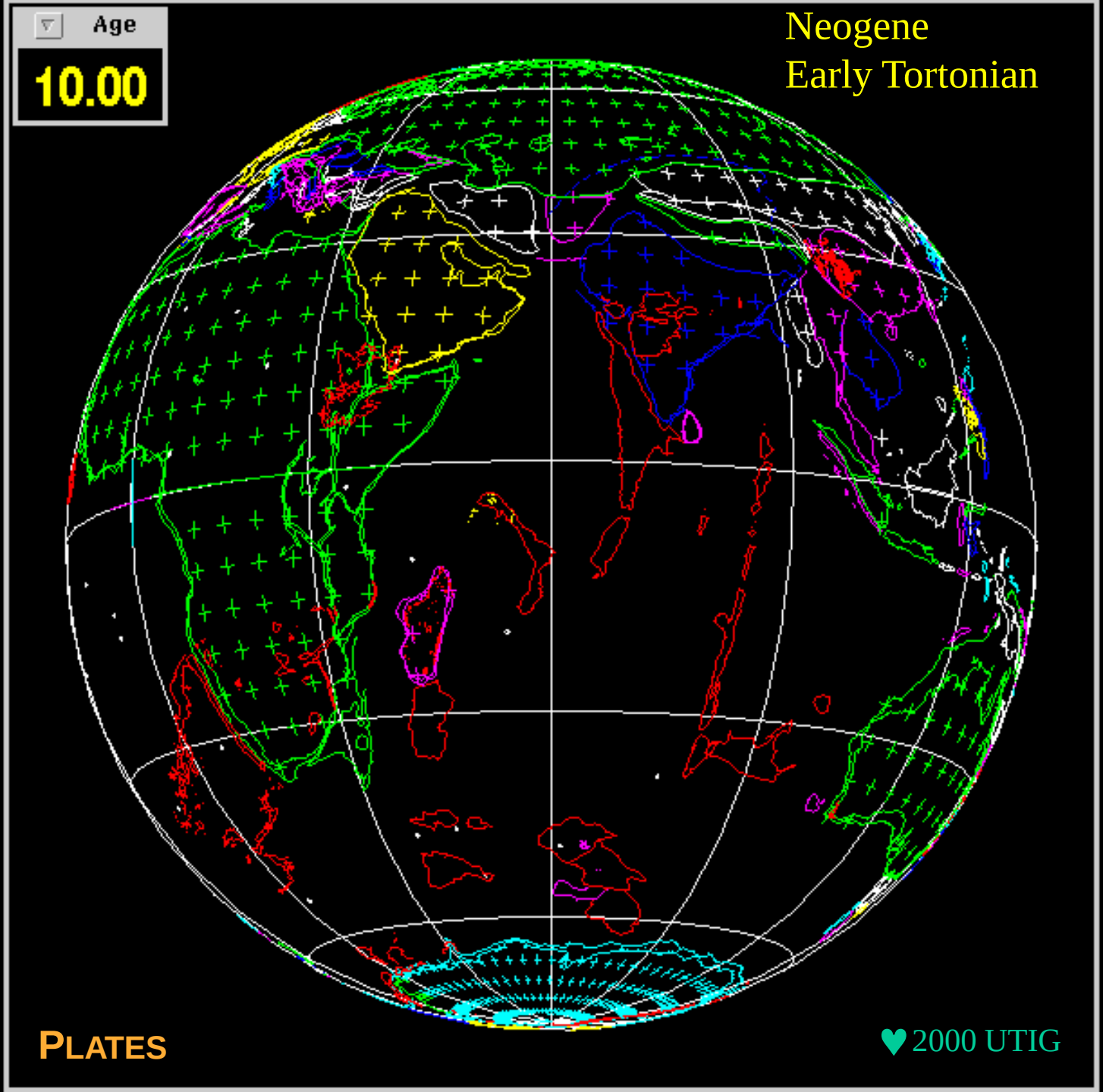

Age
15.00
Neogene
Late Langhian
PLATES
♥2000 UTIG

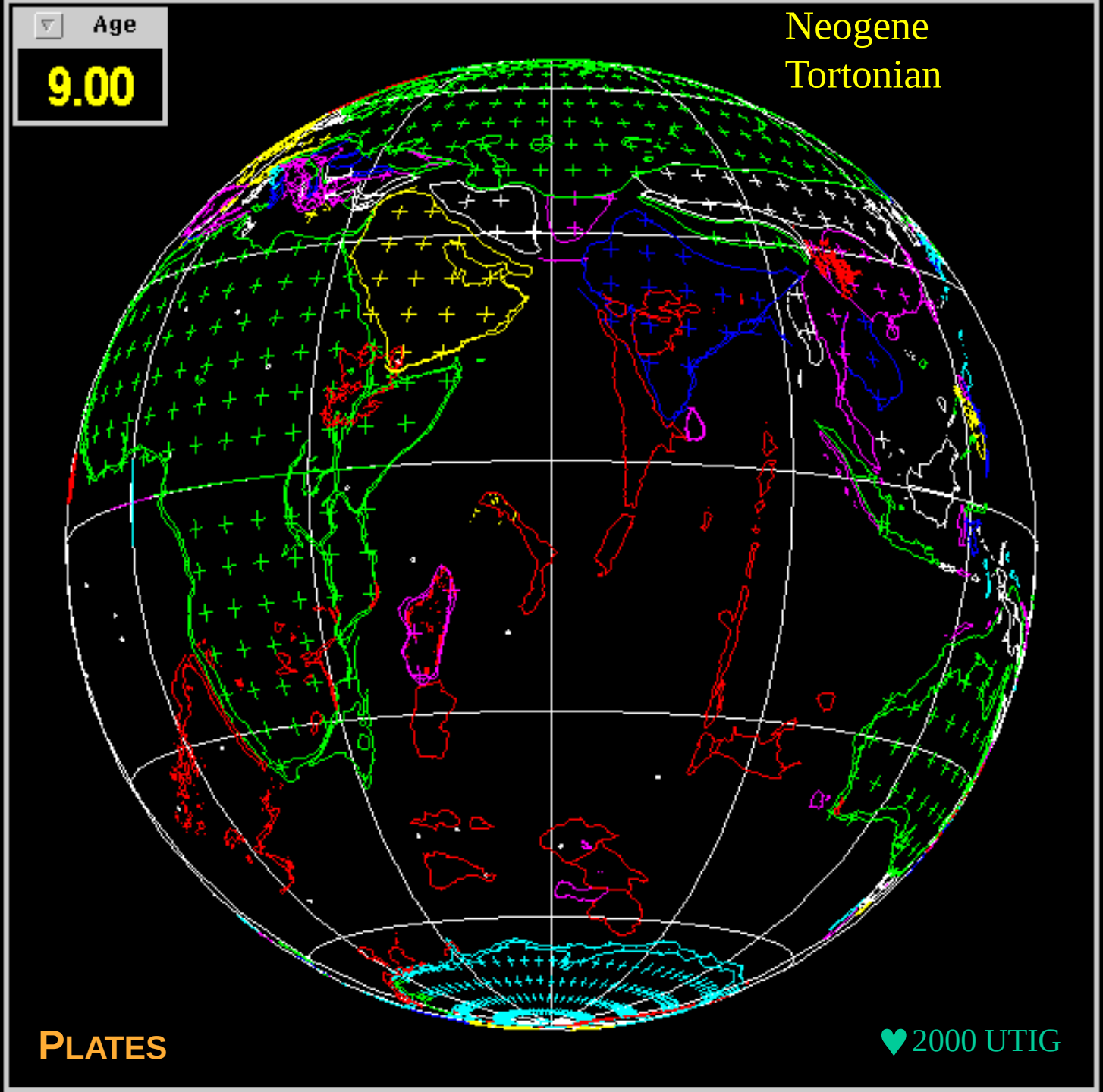

Age
14.00
Neogene
Early Serravallian
PLATES
♥2000 UTIG

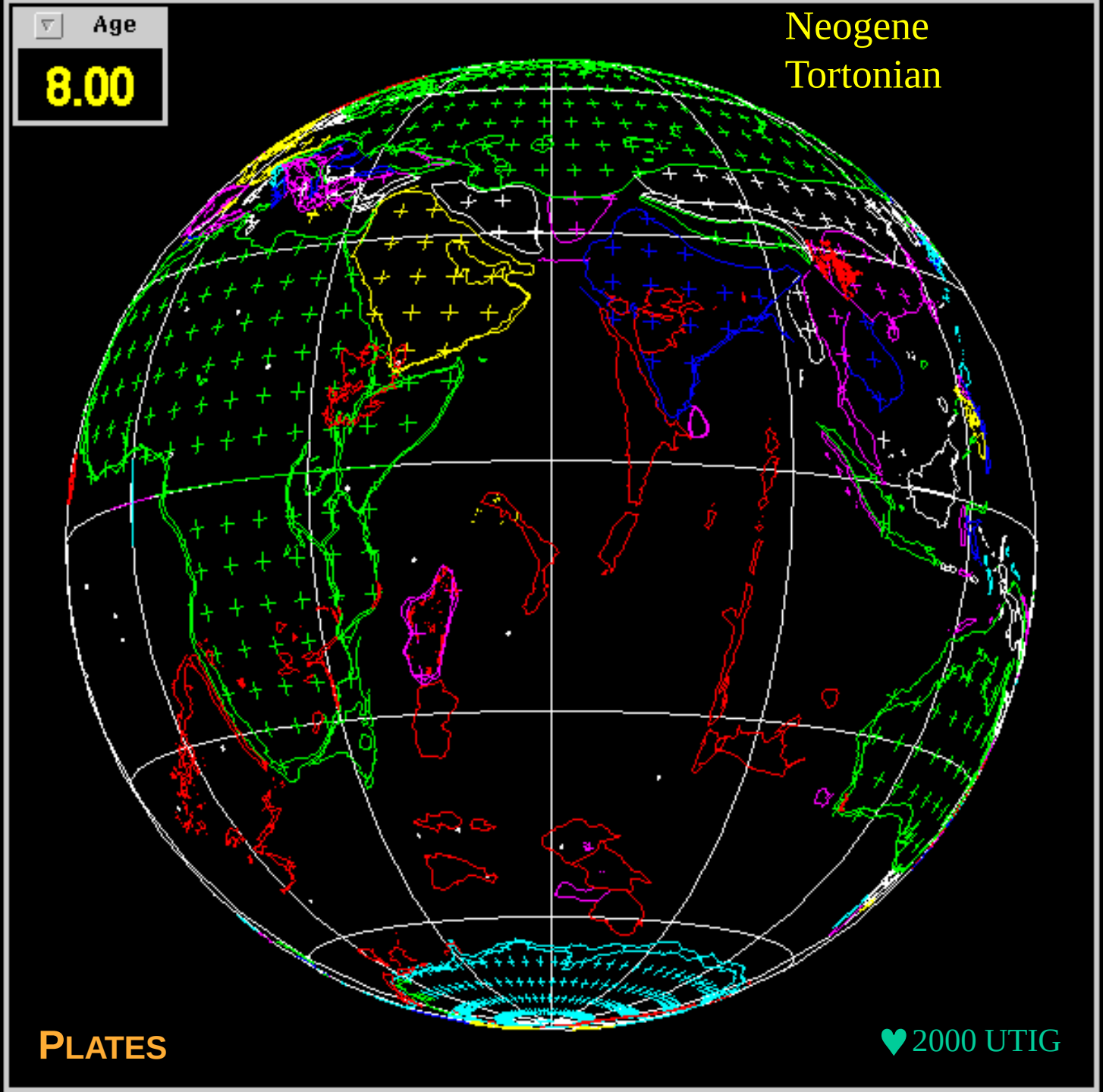

Age
13.00
Neogene
Serravallian
PLATES
♥2000 UTIG

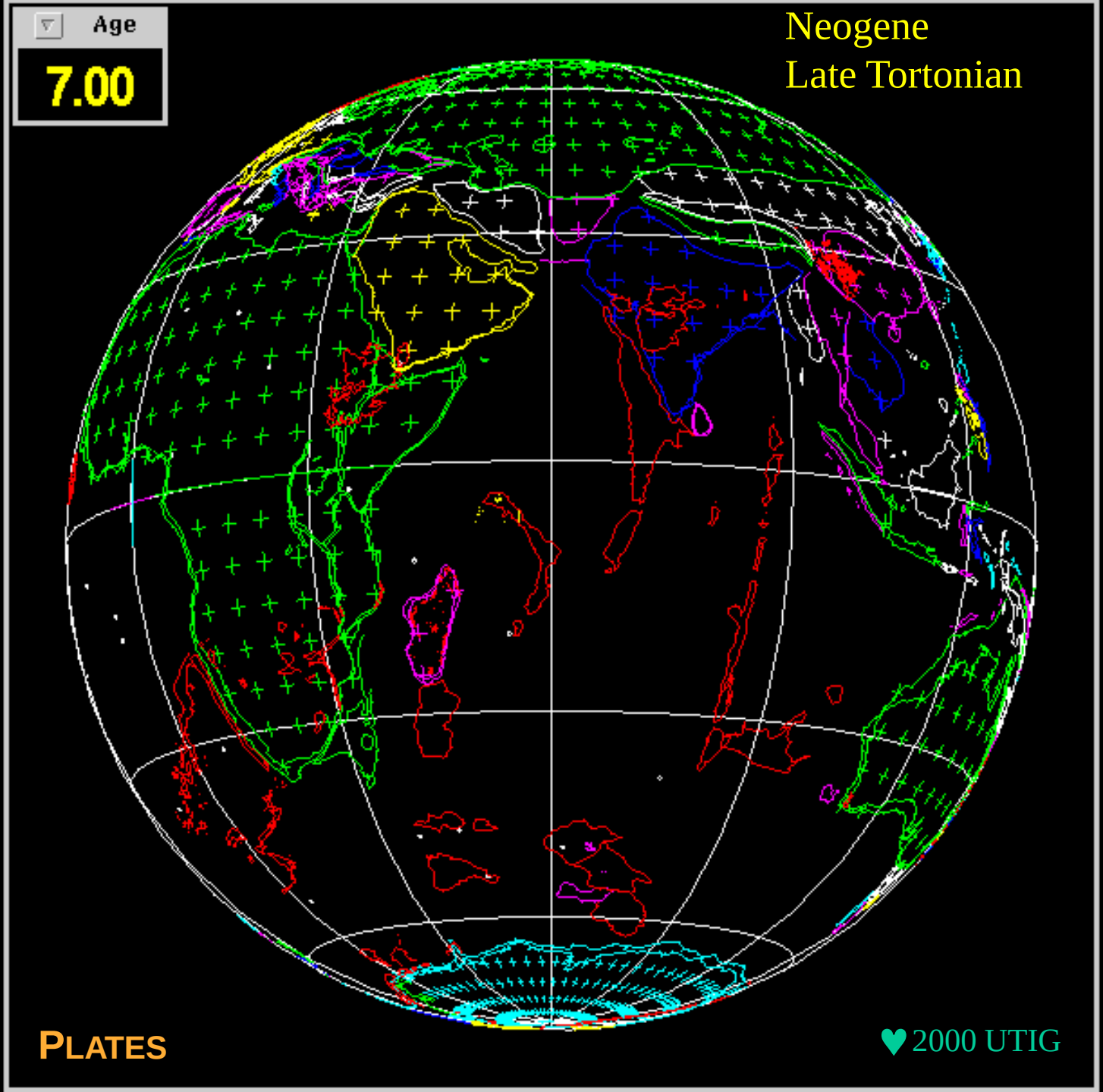

Age
12.00
Neogene
Serravallian
PLATES
♥2000 UTIG

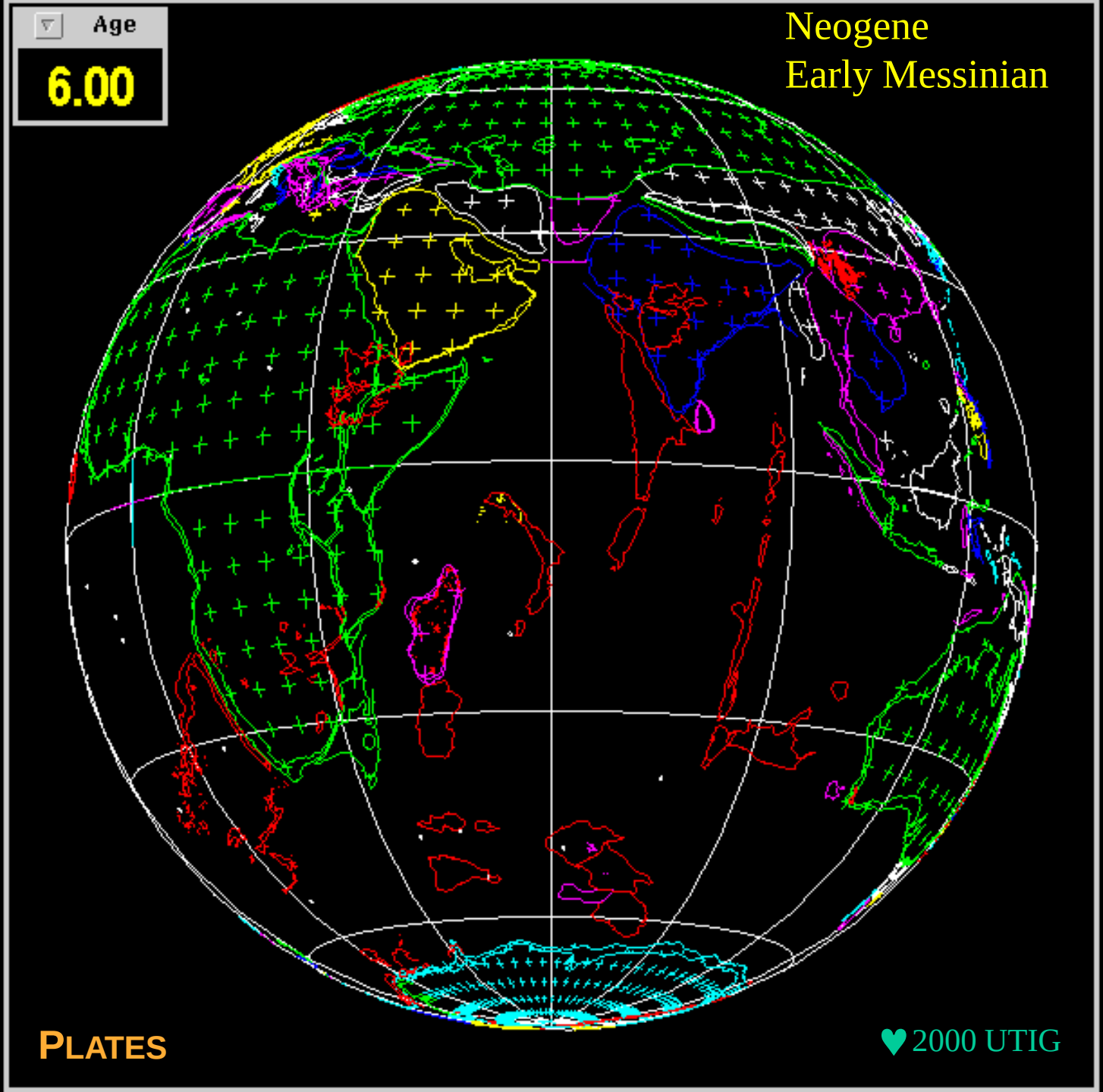

Age
11.00
Neogene
Late Serravallian
PLATES
♥2000 UTIG

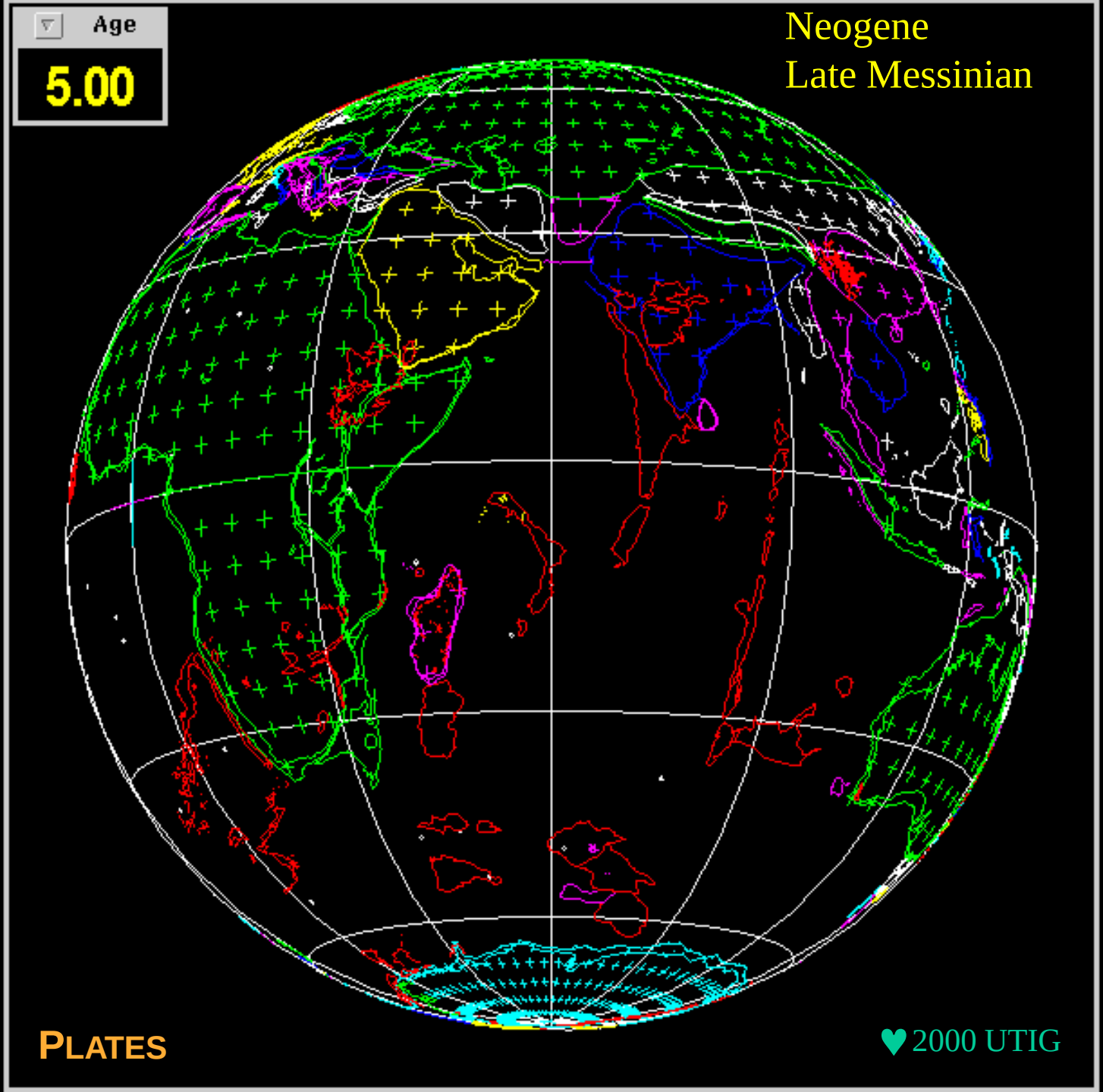

Age
10.00
Neogene
Early Tortonian
PLATES
♥2000 UTIG

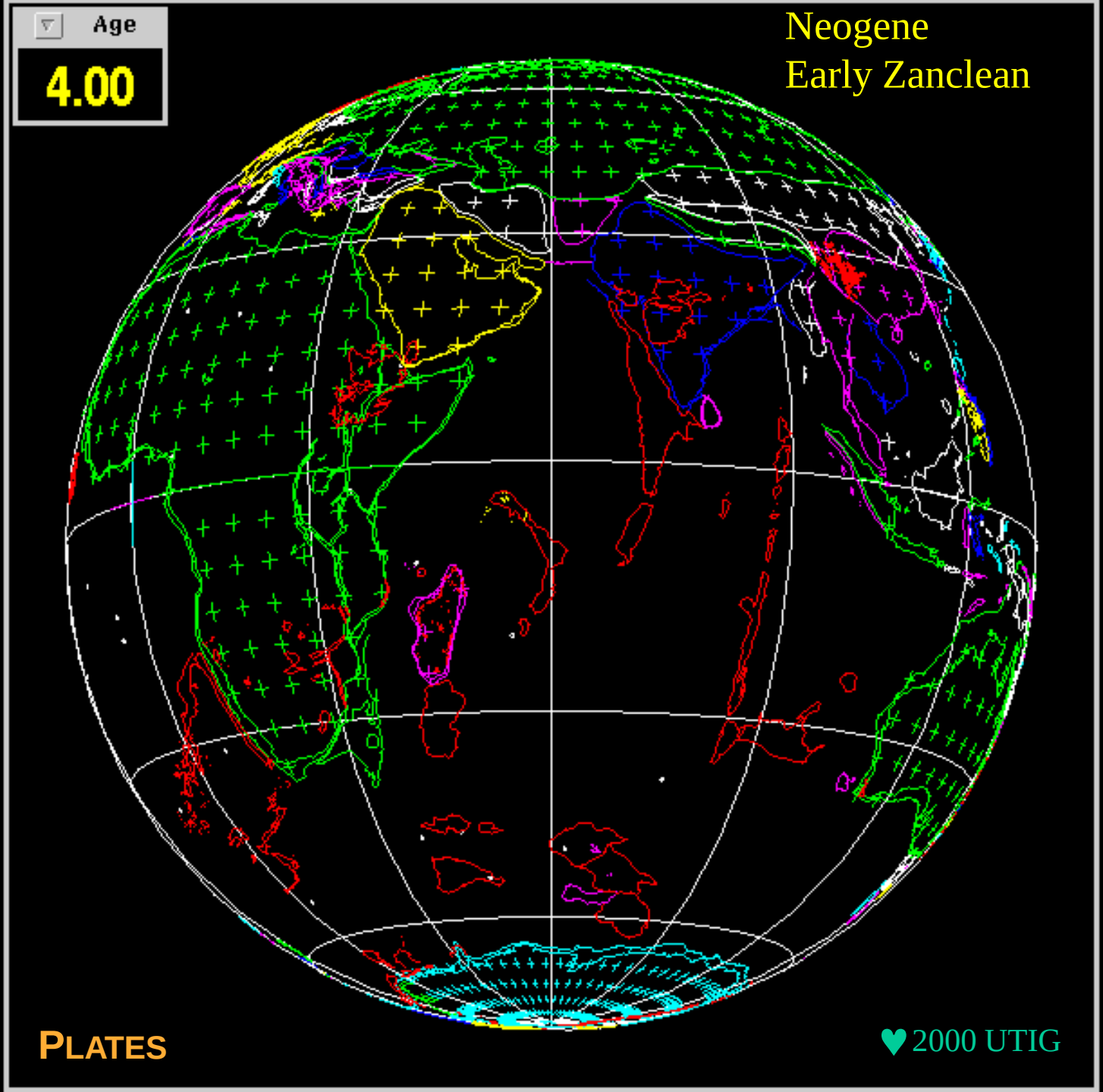

Age
9.00
Neogene
Tortonian
PLATES
♥2000 UTIG

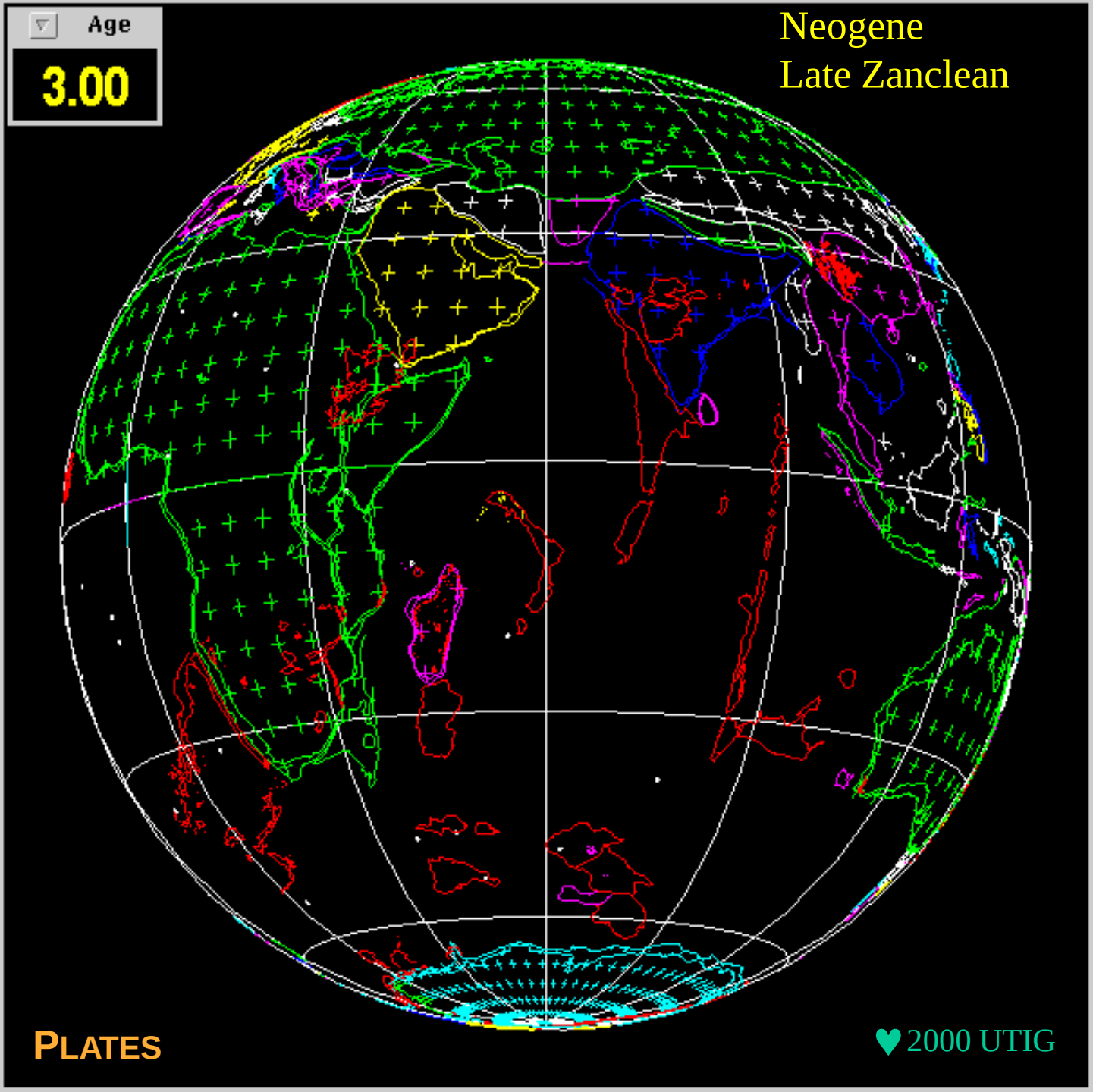

Age
8.00
Neogene
Tortonian
PLATES
♥2000 UTIG

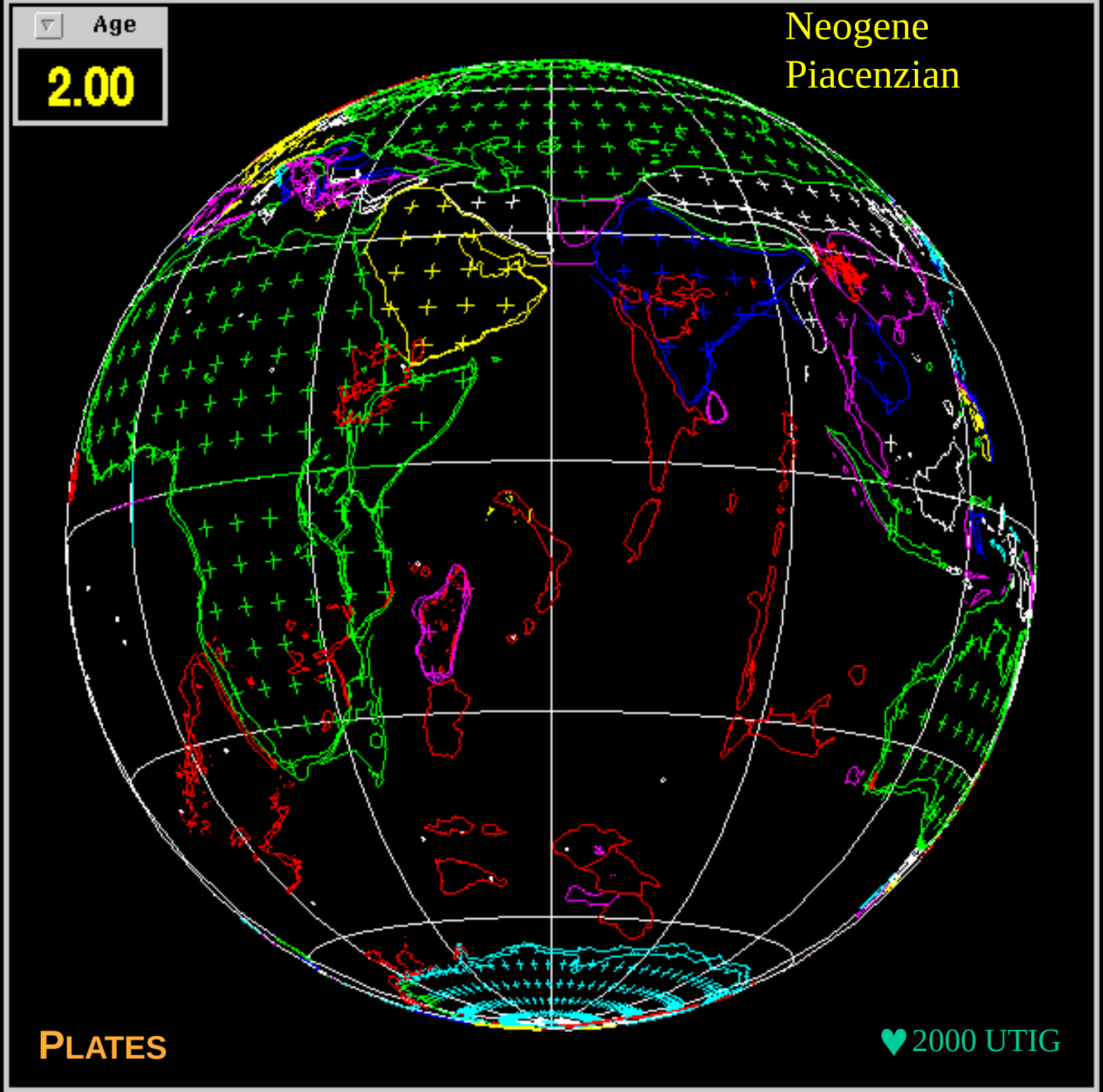

Age
7.00
Neogene
Late Tortonian
PLATES
♥2000 UTIG

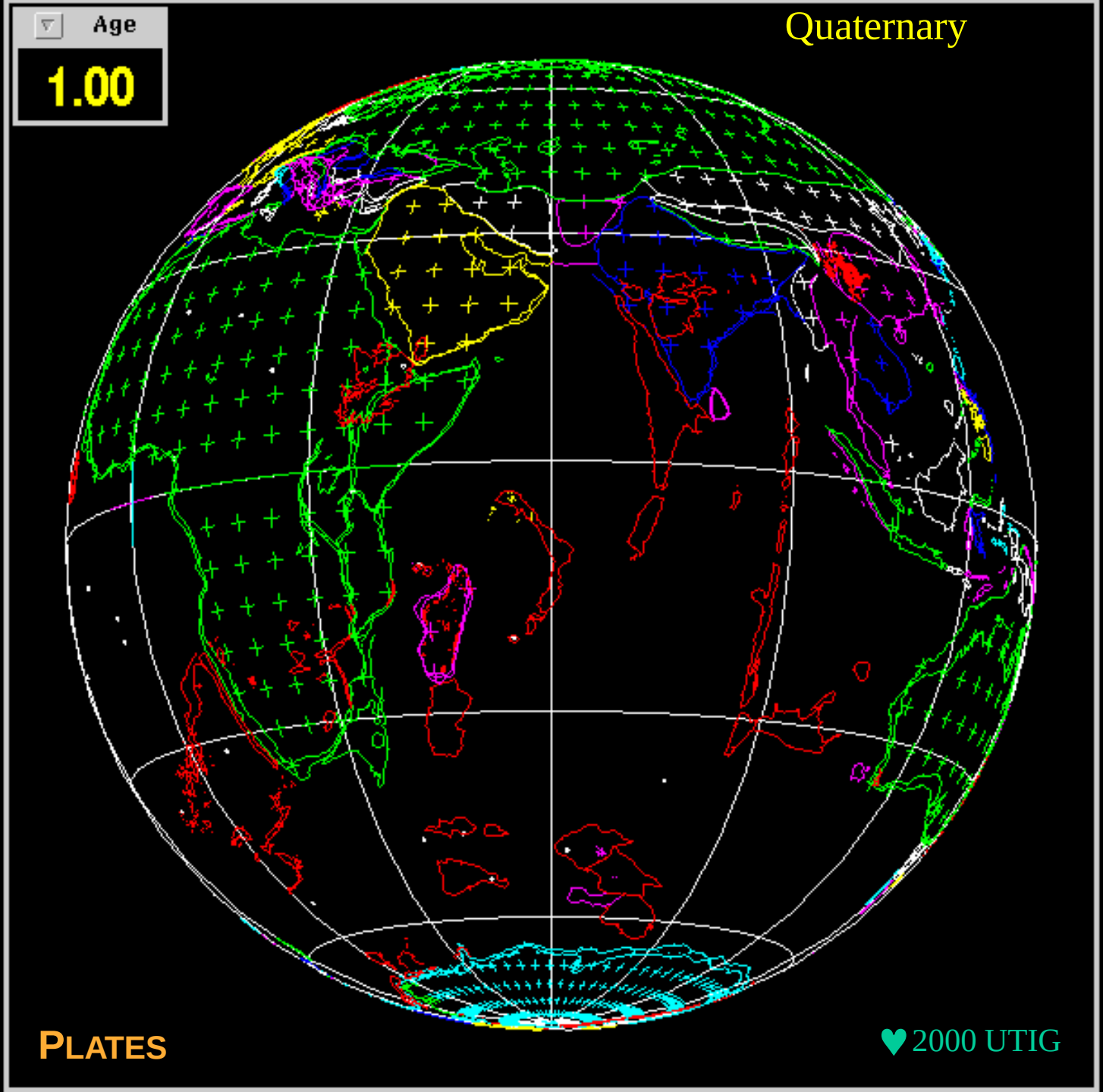

Age
6.00
Neogene
Early Messinian
PLATES
♥2000 UTIG

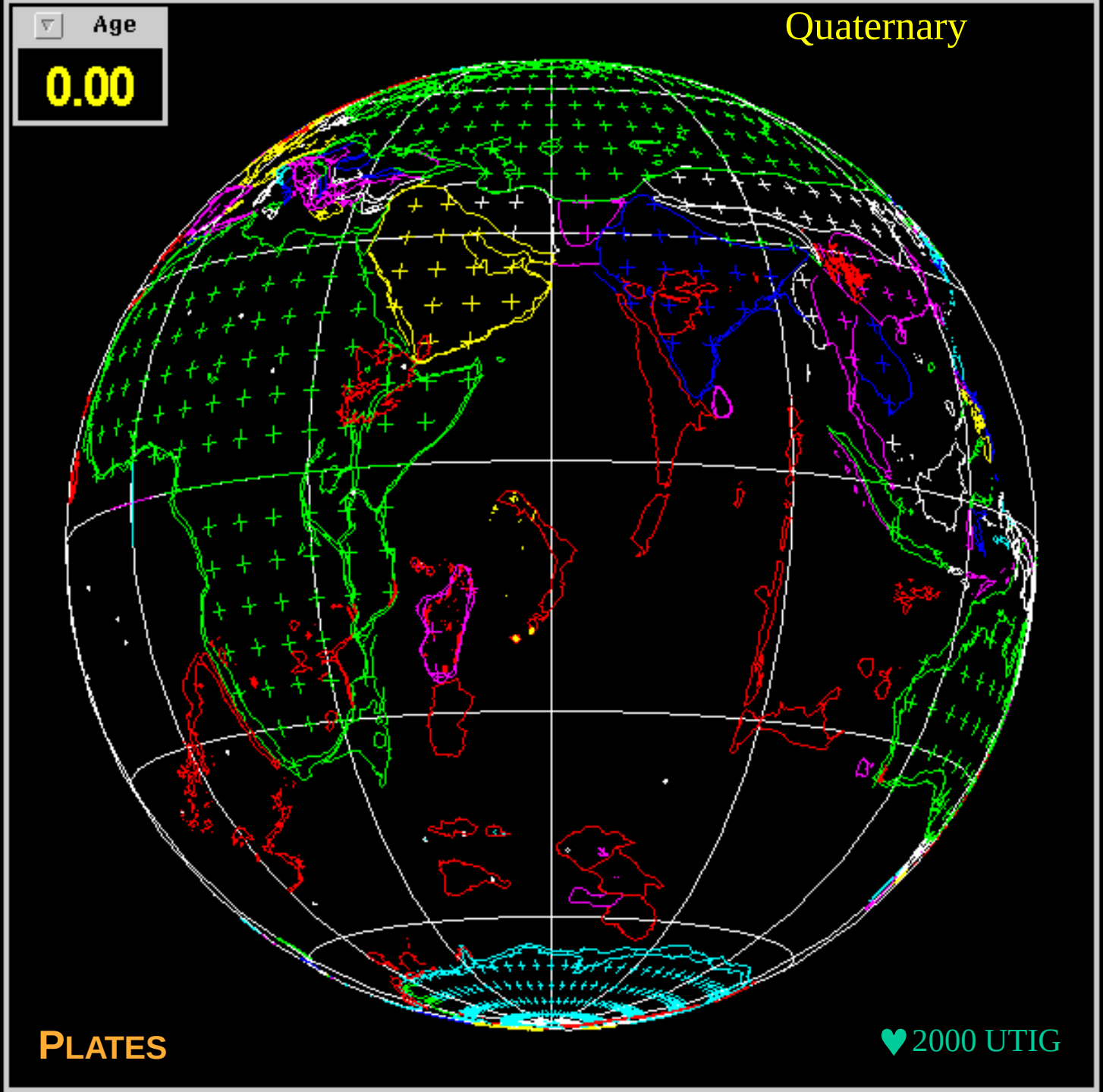

Age
5.00
Neogene
Late Messinian
PLATES
♥2000 UTIG


Age
4.00
Neogene
Early Zanclean
PLATES
♥2000 UTIG

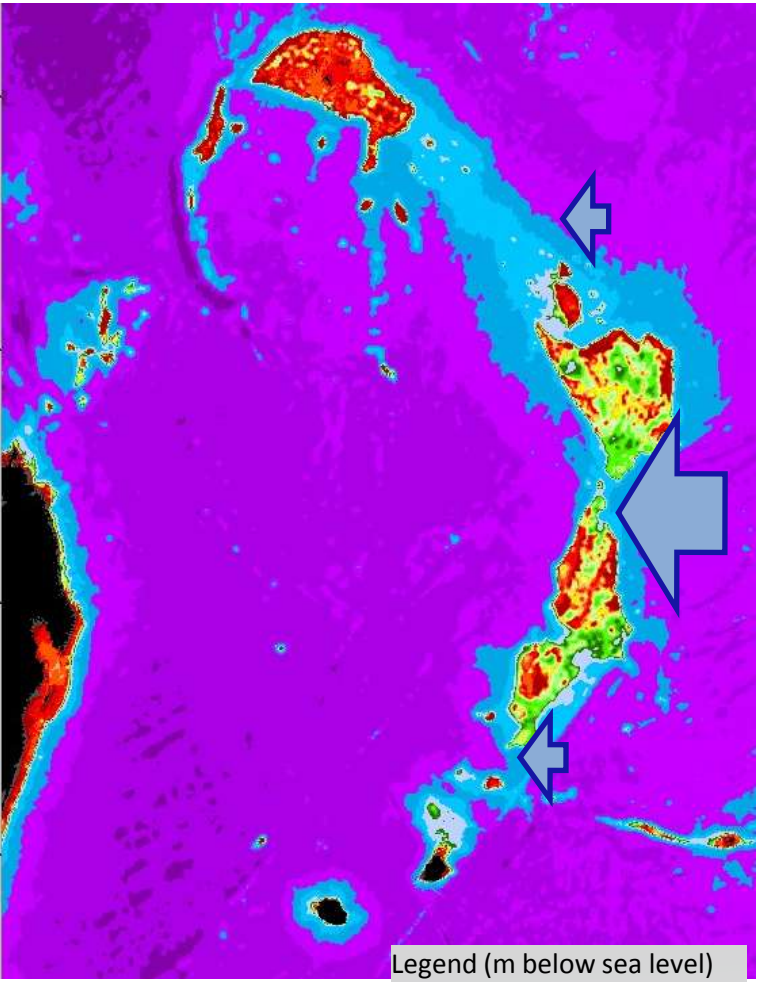

Age
3.00
Neogene
Late Zanclean
PLATES
♥2000 UTIG


Age
2.00
Neogene
Piacenzian
PLATES
♥2000 UTIG


Age
1.00
Quaternary
PLATES
♥2000 UTIG


Age
0.00
Quaternary
Restart
animation
PLATES
♥2000 UTIG

What influence have the banks had on WIO currents and evolutionary processes?



Legend (m below sea level)
Yellow-red: 125 - 0
Greens: 500 - 125
Blues: > 500

At younger ages, these banks may have been emergent land masses higher than Reunion and 100s of km in extent, and may have formed a more continuous land mass than at present.

One of the biggest question marks

70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Paleogene 66-23 my

Neogene 23-2.6 my

Quarternary 2.6-0

Paleoclimate & carbonates

End of the Tethyan era was warm, associated with lower pH of seawater - less formation of carbonates, and favouring foraminifera, bivalves.

Mass extinction at K-T boundary = fewer species to fossilize

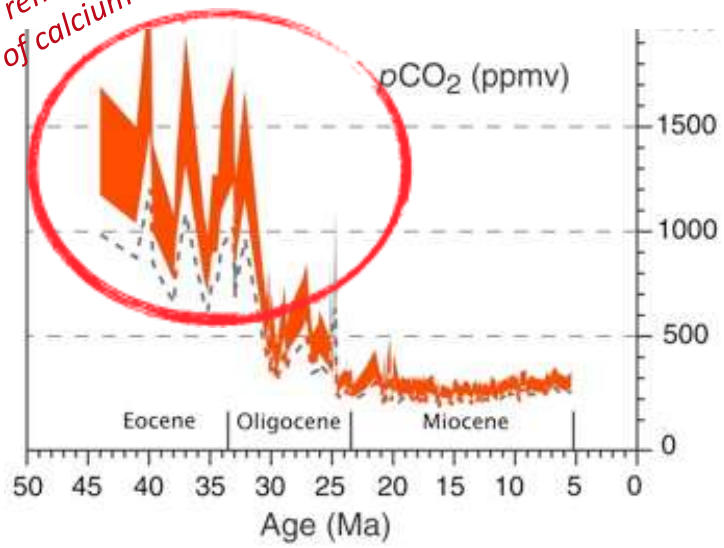
"Paleogene gap" in fossil record.

Almost no records of Tertiary carbonate deposits in WIO region. Closest are in Somalia (later mention of *Acropora* fossils).

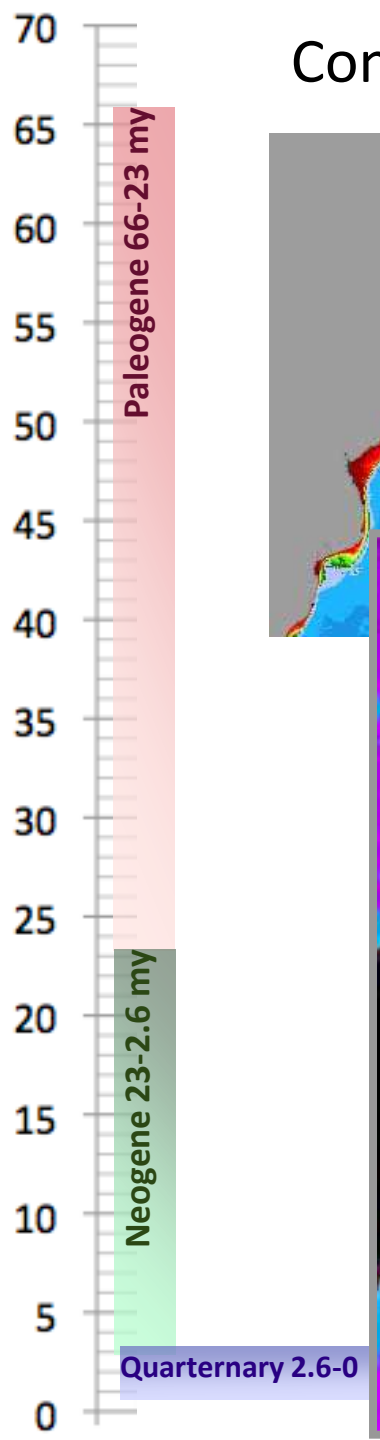
During this warm period, corals may have found refuge at higher latitudes (cooler, less acidic)

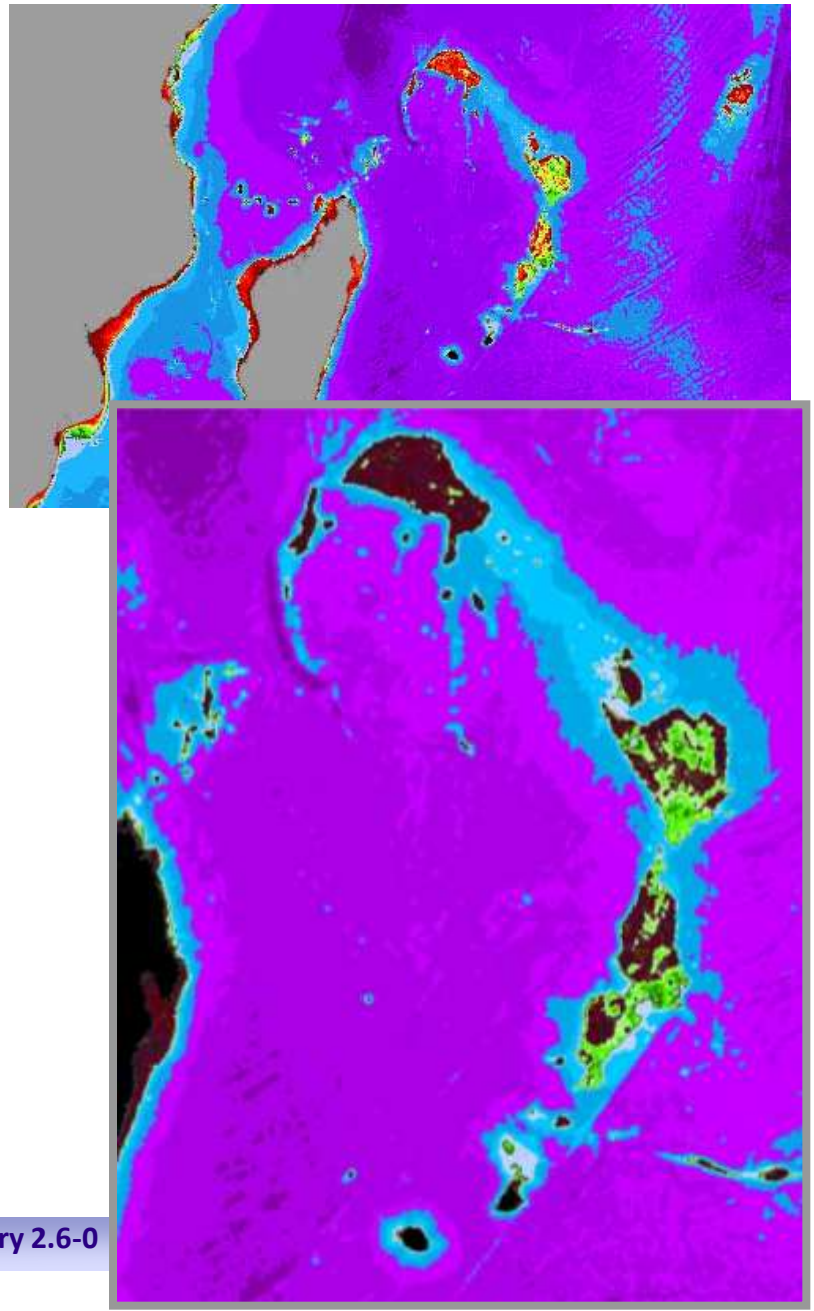
The northern Mozambique Channel was at higher latitudes - may have remained in a consistent climatic zone.

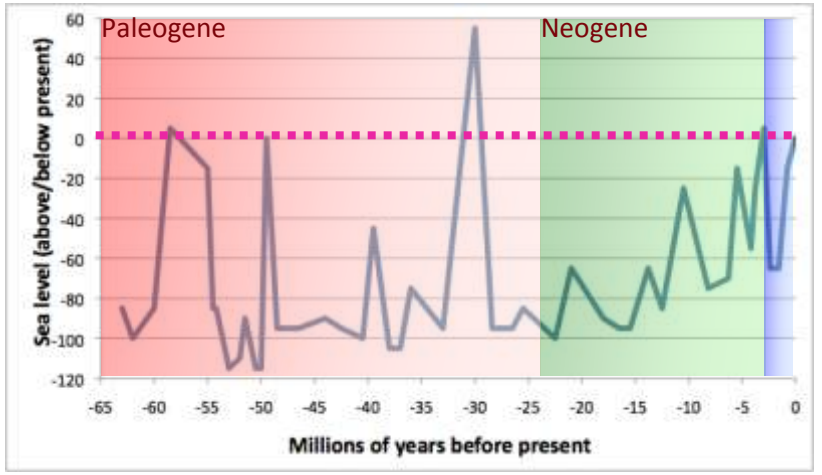
"Paleogene gap" - few fossils remain due to high acidity and dissolution of calcium carbonate skeletons



Continental shelves, banks and sea level change







Bathymetry less than 125 m below current sea level
Approximate reconstruction of Tertiary sea levels

Steep, simple continental shelves indicate little change in coastline shapes - stable refuges from change elsewhere

At lower sea level stands, the Mascarene banks would have been islands several 100s km wide - fluctuating connectivity/isolation and a possible diversity pump

Ocean currents and connectivity

70
65
60
55
50
45
40
35
30
25
20
15
10
5
0

Paleogene 66-23 my

Neogene 23-2.6 my

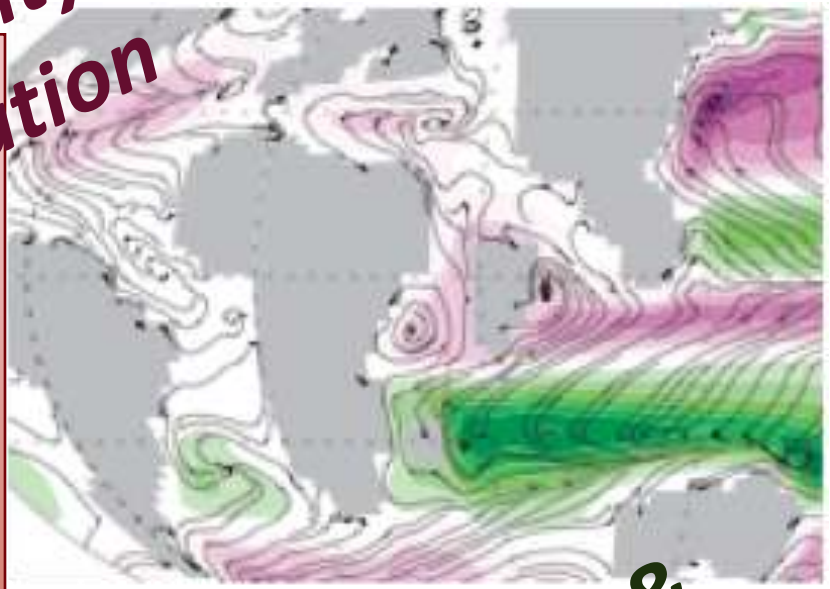
Quarternary 2.6-0

Coral triangle formed

stability & isolation

- Eocene, 55-35 mya
- India migrating across central IO and bumping into Asia
- E-W flow into WIO blocked by India and banks
- Early in this period, limited connectivity with Tethys and the north
- Bank formation possibly isolating the WIO as a semi-contained sea

Huber and Ali 2008

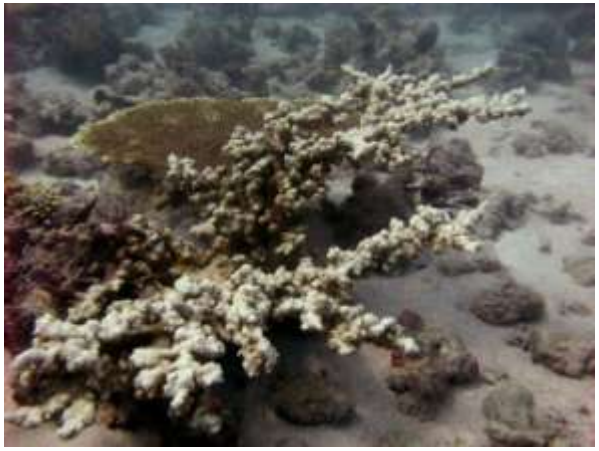


change & openness

- Miocene, 20-10 mya
- Isolation from diminishing Tethys
- Species diversification in 'coral triangle' starts
- E-W connectivity being established
- E-W connectivity altered by banks and sea level fluctuations

Coral species phylogeny

Acropora

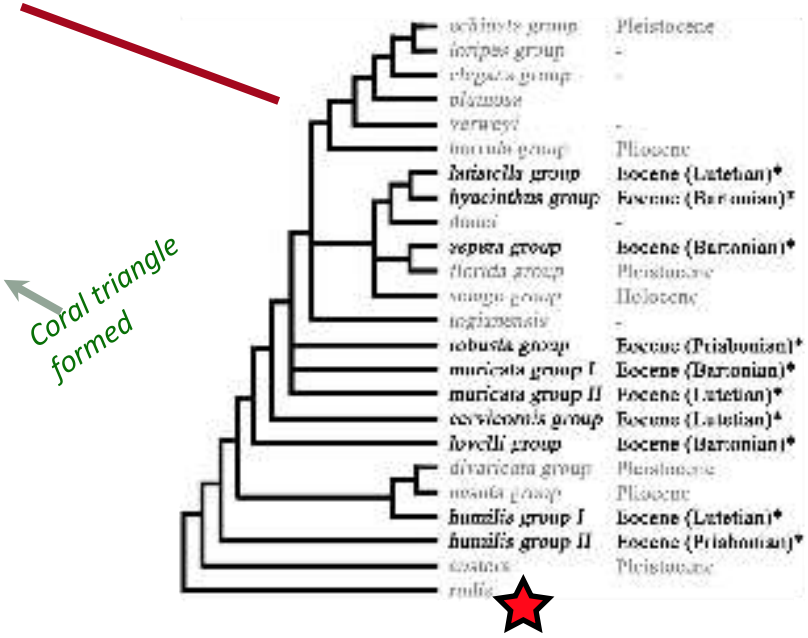


First *Acropora* fossil from Somalia, Late Paleocene (Carbone et al. 1994)

Eocene fossils from European locations, of 9 of the 20 extant species groups (shown in bold, Wallace and Rosen 2006)

- most diverse family (Acroporidae) and genus with > 120 species
- highest diversity and endemism in the Coral Triangle, suggesting that this may have been its center of origin, as well as current center of diversity

Acropora species groups



These are indicative of a Tethys Sea origin and diversification, long before the Coral Triangle region was formed

Other groups with apparent Tethyan origins and diversification

Siderastrea

- phylogenetic tree suggests Indo-Pacific species (*S. savignyana*) is differentiated into two separate species, by samples from Oman/Kenya, versus Taiwan/Australia.
- Oman/Kenya ancestral, and close to the Atlantic species

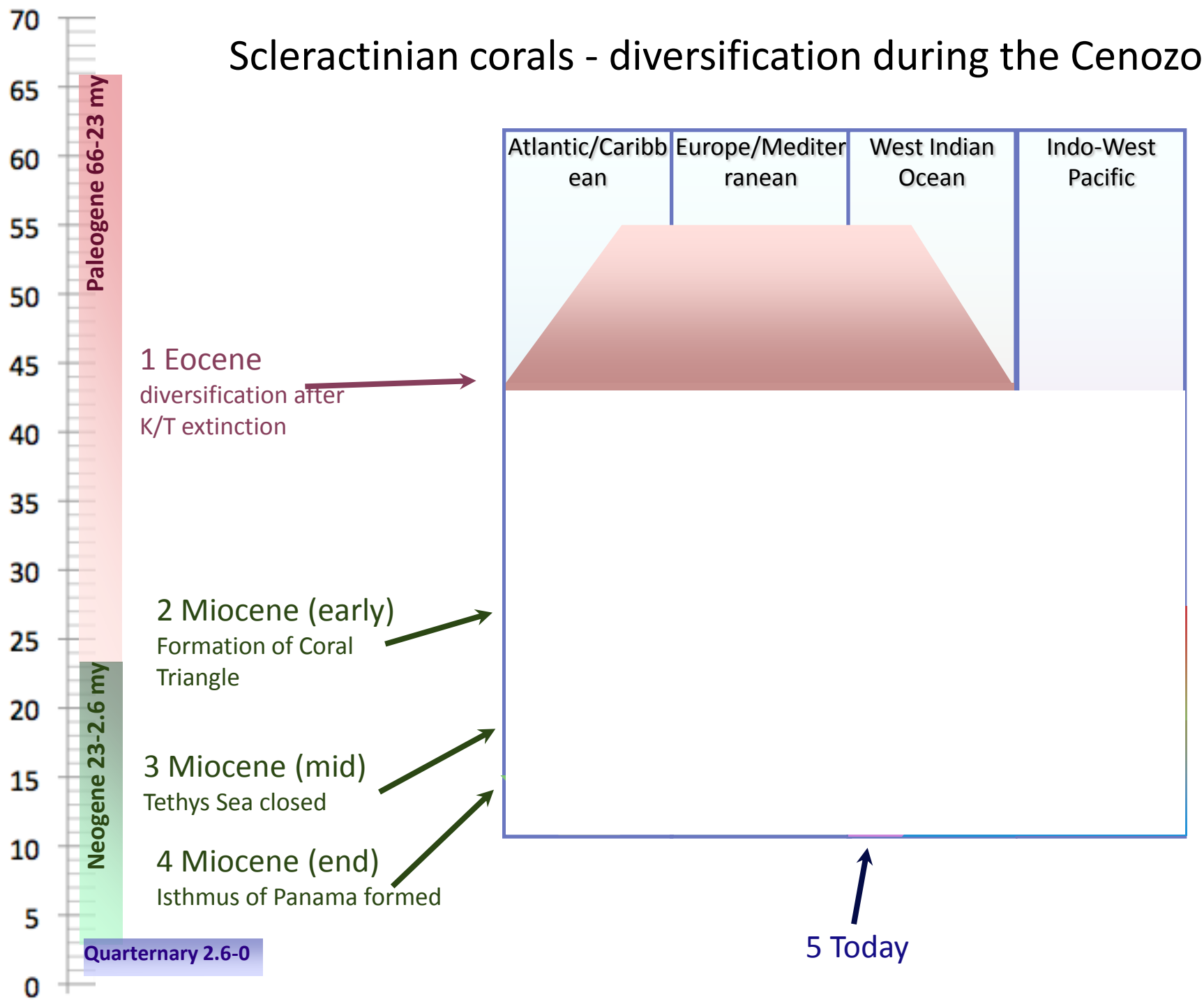
Stylophora

- Three branching morphs are distinguished (Stefani et al. 2010), with most nominal spp split among two of these.
- Most diverse in the WIO (Flot et al. 2011)
- Ancestral species in the Red Sea (Chen and colleagues, unpublished)

Regional endemics

Possible that these reflect an older paleo-geology (Tethyan) and paleo-oceanography (isolation of WIO)?

Scleractinian corals - diversification during the Cenozoic



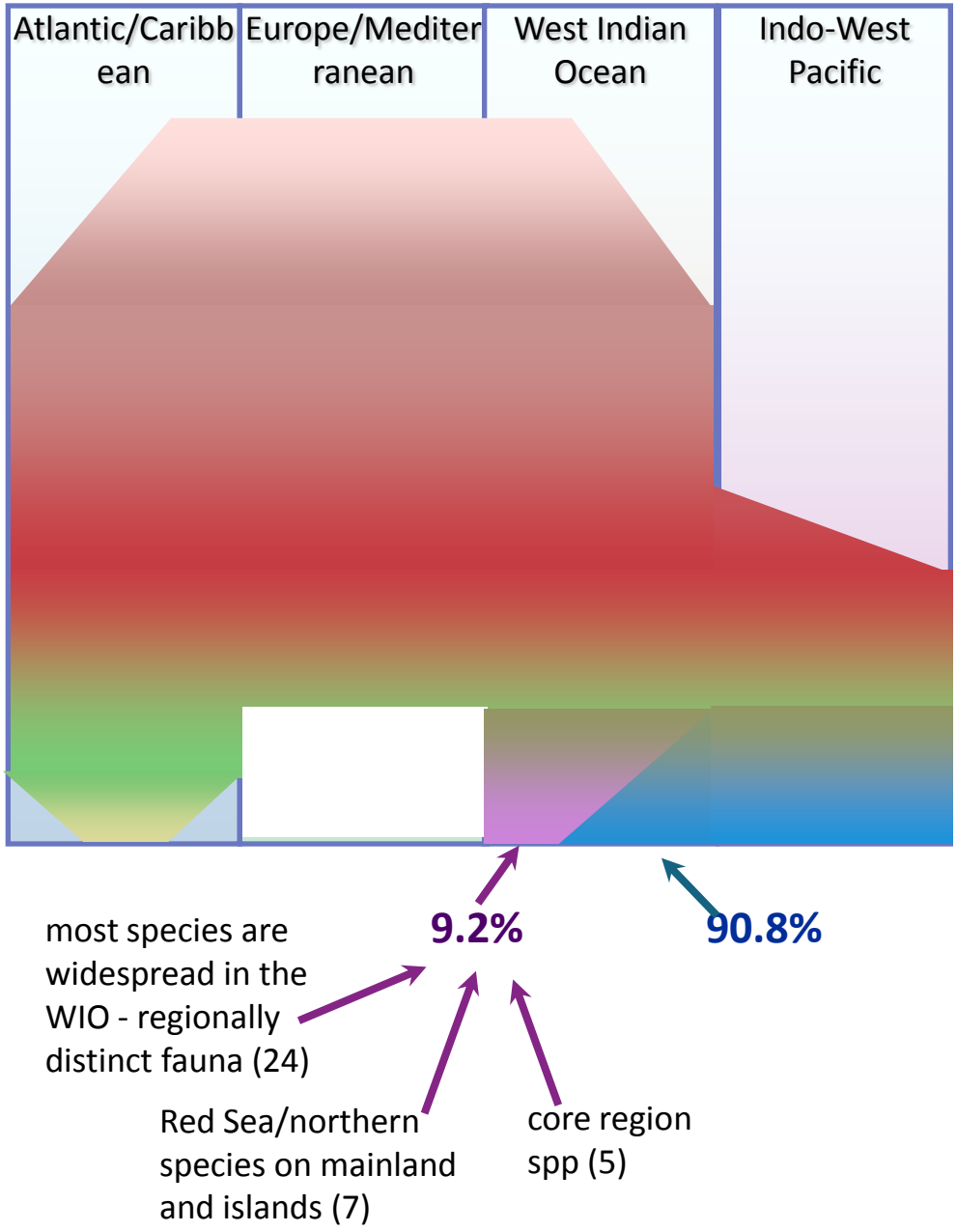
What are the regional affinities of the Indian Ocean-restricted corals in the WIO?

Coral species samples from 24 sites in the WIO

Total of 413 species:

375 (90.8 %) are broadly distributed in the Indo-Pacific

38 (9.2 %) are found only in the West Indo-Pacific Realm



Outline

1) TODAY

Distinct regional faunal identity, encompassing the WIO, northwest Indian Ocean and Red Sea/Gulfs regions

High diversity core region centred on the NMC (corroborated by other studies)

Currents that distinguish the NMC as an accumulation point, and source for other regions within the WIO

J. Biogeography - MS submissions

2) EVOLUTIONARY HISTORY

Tethys as a center of origin for modern coral lineages

The WIO contains distinct evolutionary lineages from the Tethys

Fluctuating connectivity/isolation of the WIO as a result of the Mascarene banks and islands

The northern Mozambique Channel as a stable refuge in a dramatically changing Ocean basin

Dominance of West-Pacific fauna is a recent function of E-W transport in the SEC, masking a regionally-specific fauna

Book proposal - WIOMSA/independent publication

3) SO WHAT?

Conclusions

Relevance

Conclusions - conservation biology

"Museum" hypothesis

- the Mozambique channel

- has the oldest coastlines in the Indian Ocean/WIO
- stable with respect to climatic zone (northward migration of Africa/Madagascar)
- stable with respect to habitats and SL change

- the WIO

- has a relict fauna from the Tethys Sea

Refuge/preservation of genetic material/species - remnant lineages, endemic species

"Diversity pump" - Mascarene-Reunion hotspot/tectonics

- diversification following K-T extinction in the shallow Tethys
- relative isolation as India migrated northwards
- fluctuating isolation due to banks/islands

Speciation of WIO regional fauna - endemics

"Species sink" - 'recent' oceanography (20 my)

- accumulation of species from West-Pacific/Eastern IO
- retention of genetic material in Mozambique channel gyres/eddies

Homogenization of fauna with broader Realm/Biome

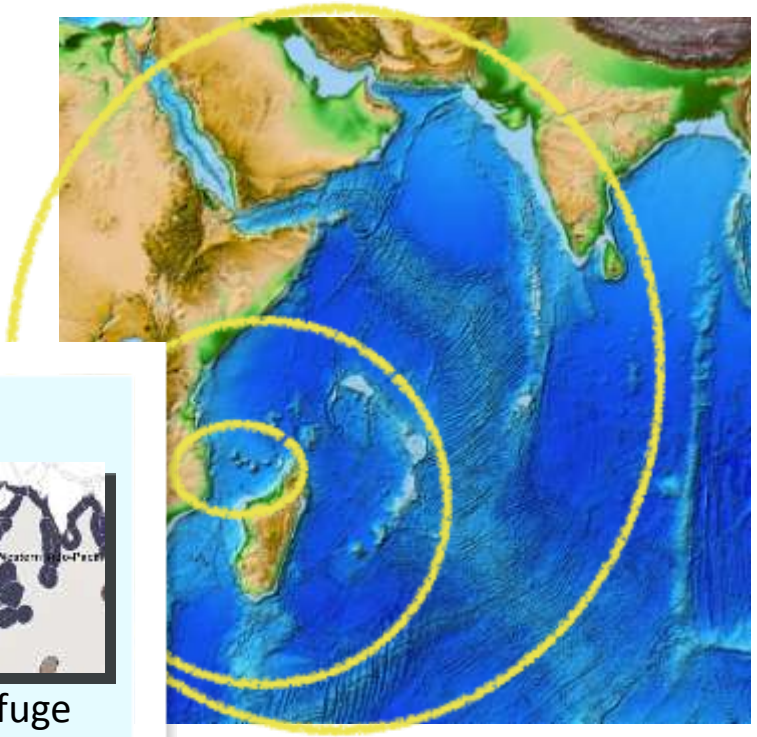
Relevance

Geo-physical integrity (geology, oceanography)

Ecological integrity (connectivity, productivity, diversity)

Historical integrity (evolutionary dynamics)

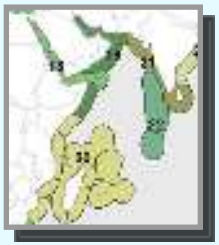
Human affairs (politics, culture, history)



Marine Ecoregions of the World (MEOW)

Realm - West Indo-Pacific
- Tethyan origins, deep evolutionary history

Province - Western Indian Ocean
- Tethyan origins - continental coasts and core region = refuge
- banks and connectivity - diversity pump



Ecoregion

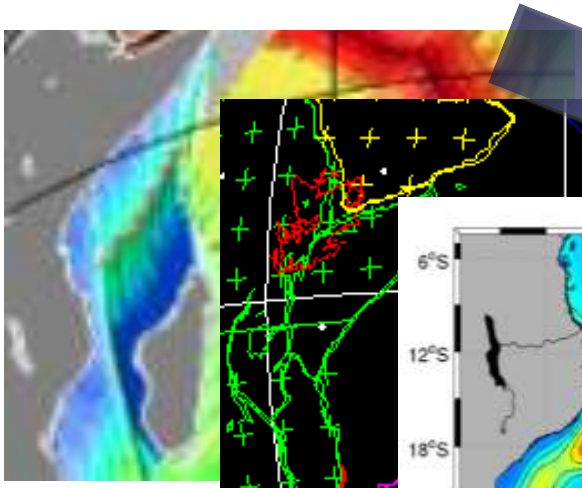
Northern Mozambique channel
- refuge over multiple scales of evolutionary time
- species accumulation
- high connectivity, source region
- core ecoregion for the WIO

Other ecoregions

Mascarene banks and islands, southern Mozambique channel, northern Monsoon coast

Coping with Global Change and threats ...

Regional marine science and conservation in an evolutionarily consistent framework ...

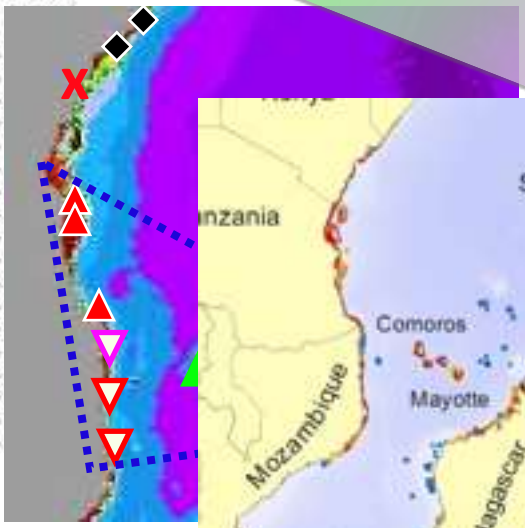


Tectonics

Geology

Oceanography

Phylogeny



Biogeogra

Current status

This knowledge supports ...

- Policy cohesion (Nairobi Convention, ICRI, etc)
- Scientific integration (WIOMSA, ASCLME, etc)
- Increasing and sustaining financing

Many new questions posed ...