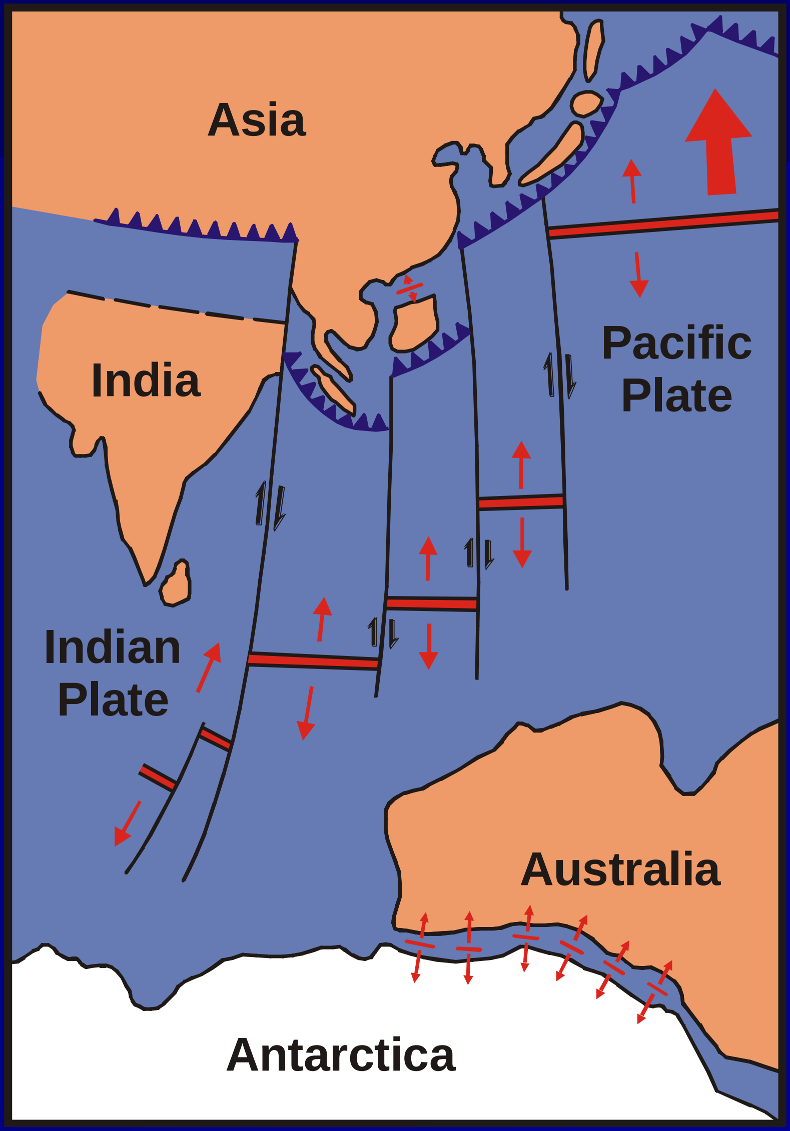
Geological History of Guam: Volcanic Deposition

BI 201 Natural History of Guam

Class Presentation 13

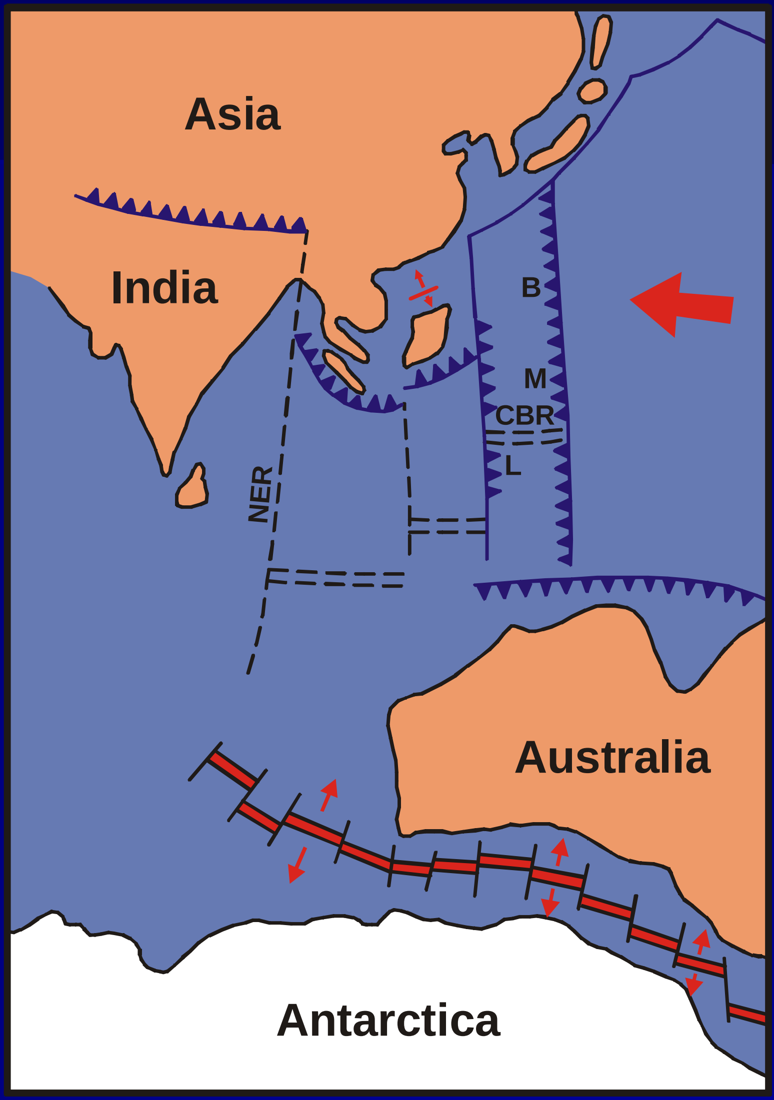
- Tectonic events leading to the birth of Guam
  - About 60 Mybp, the area that is now the Palau-Kyushu Ridge was a transform boundary between the Philippine Sea Plate and the Pacific Plate
  - The Pacific Plate was sliding northward past Philippine Sea Plate

65 Mybp

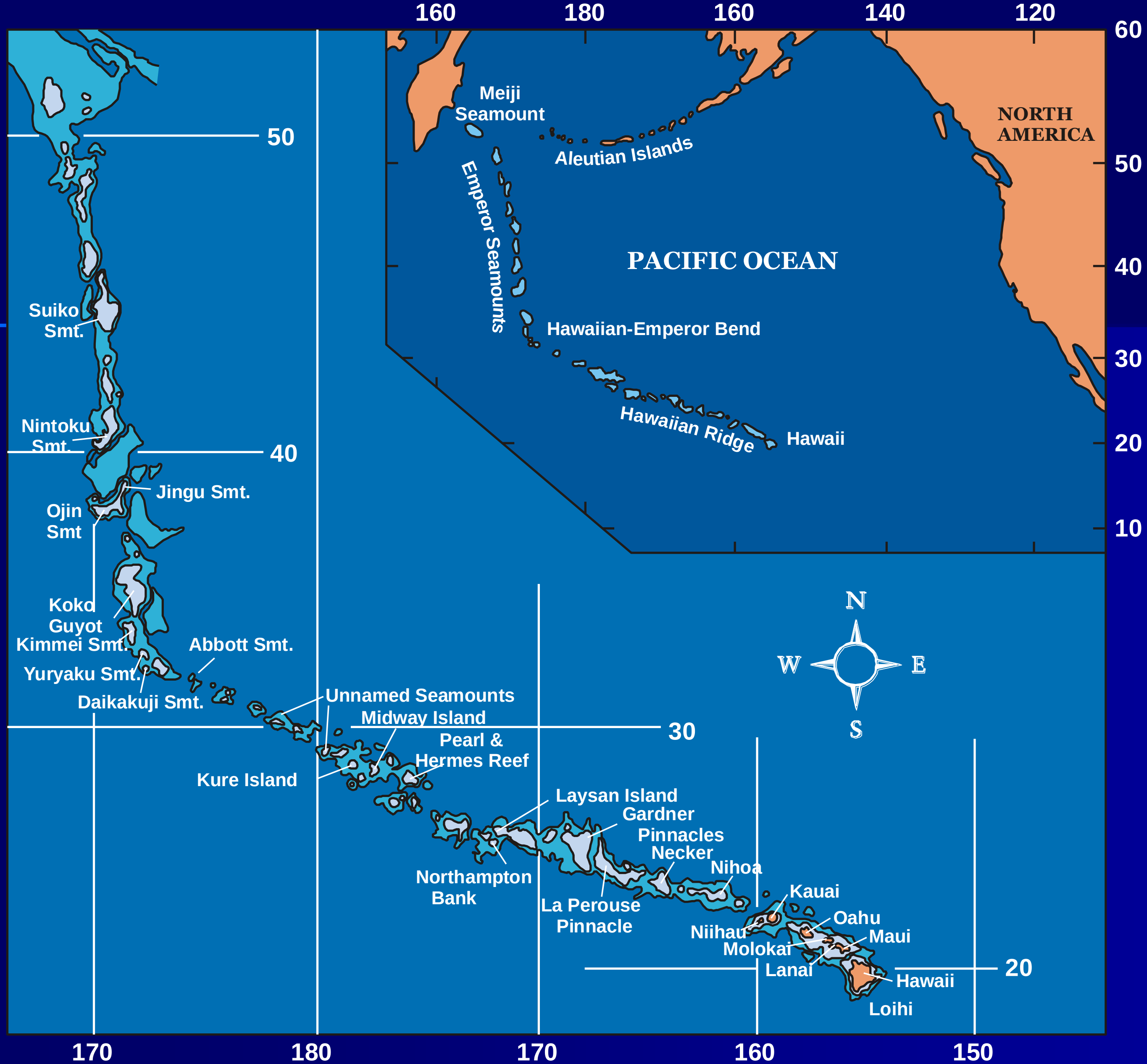


– About 43 Mybp, the Philippine Sea Plate-Pacific Plate transform boundary changed to a collision boundary, with the Pacific Plate subducted beneath the Philippine Sea Plate

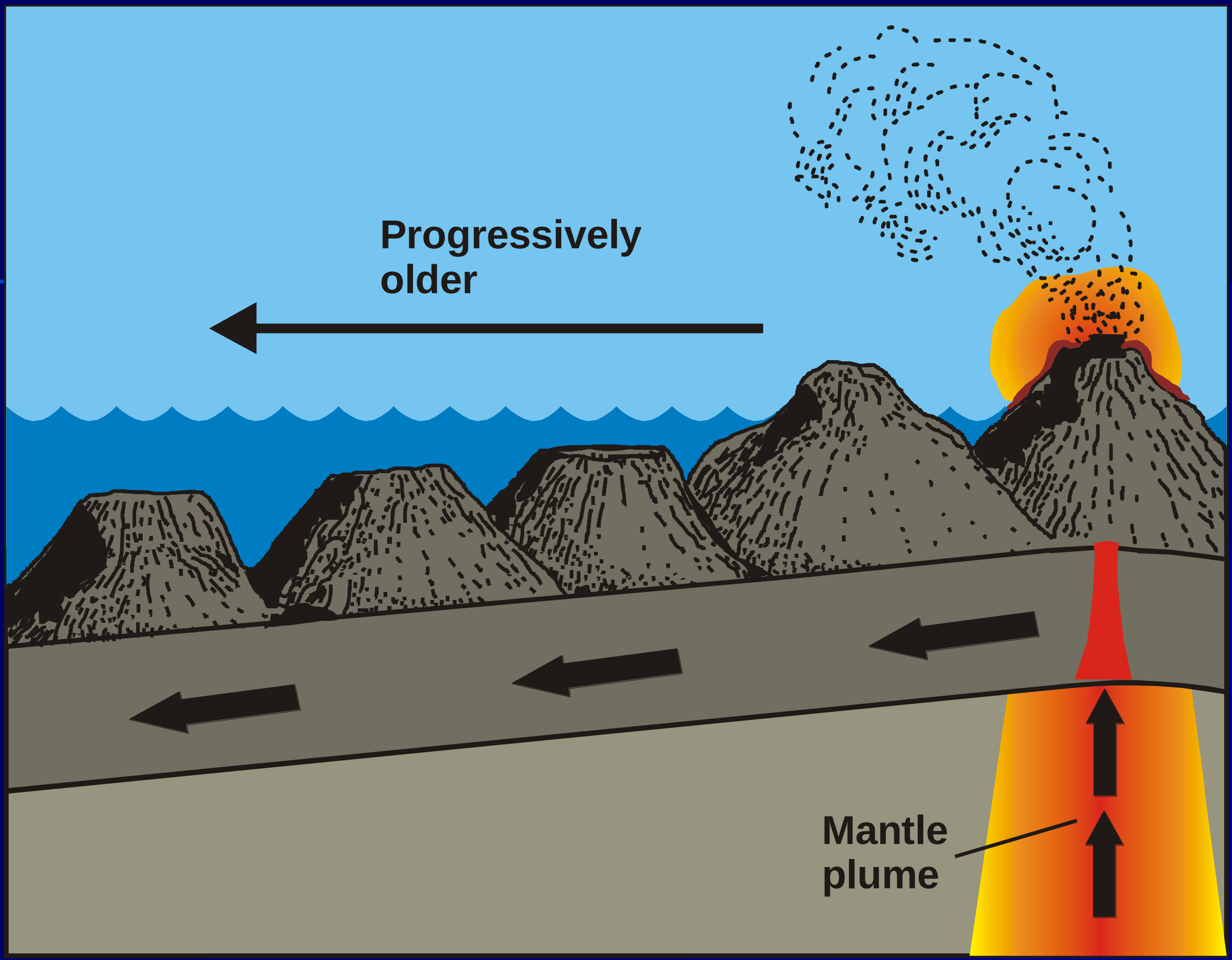
42 Mybp



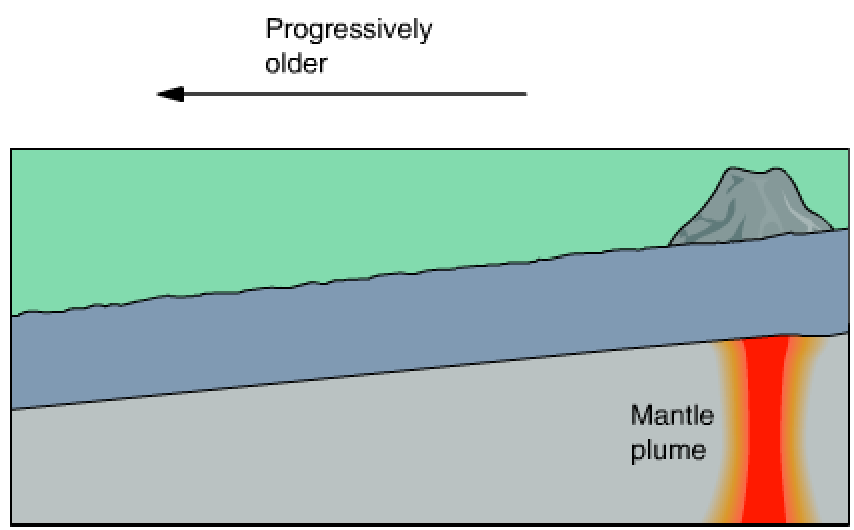
– What caused this change?
  - The change was probably the result of the Indian Plate colliding with the Eurasian Plate about that time
– How do we know this event occurred?
  - The change in direction of movement of the Pacific Plate is recorded by the Hawaiian Archipelago
  - The emergent Hawaiian Islands are arrayed from Hawaii (0 Mybp at Kilauea) in the southeast to Kure Atoll (27 Mybp) in the northwest
  - The Emperor Seamounts extend northward from Kure Atoll to Suiko Seamount (64.7 Mybp)



Bathymetry of the Hawaiian Emperor volcanic chain [adapted from Chase et al., 1970]. Inset shows the location of the chain in the central north Pacific. Contour interval is 1 km.



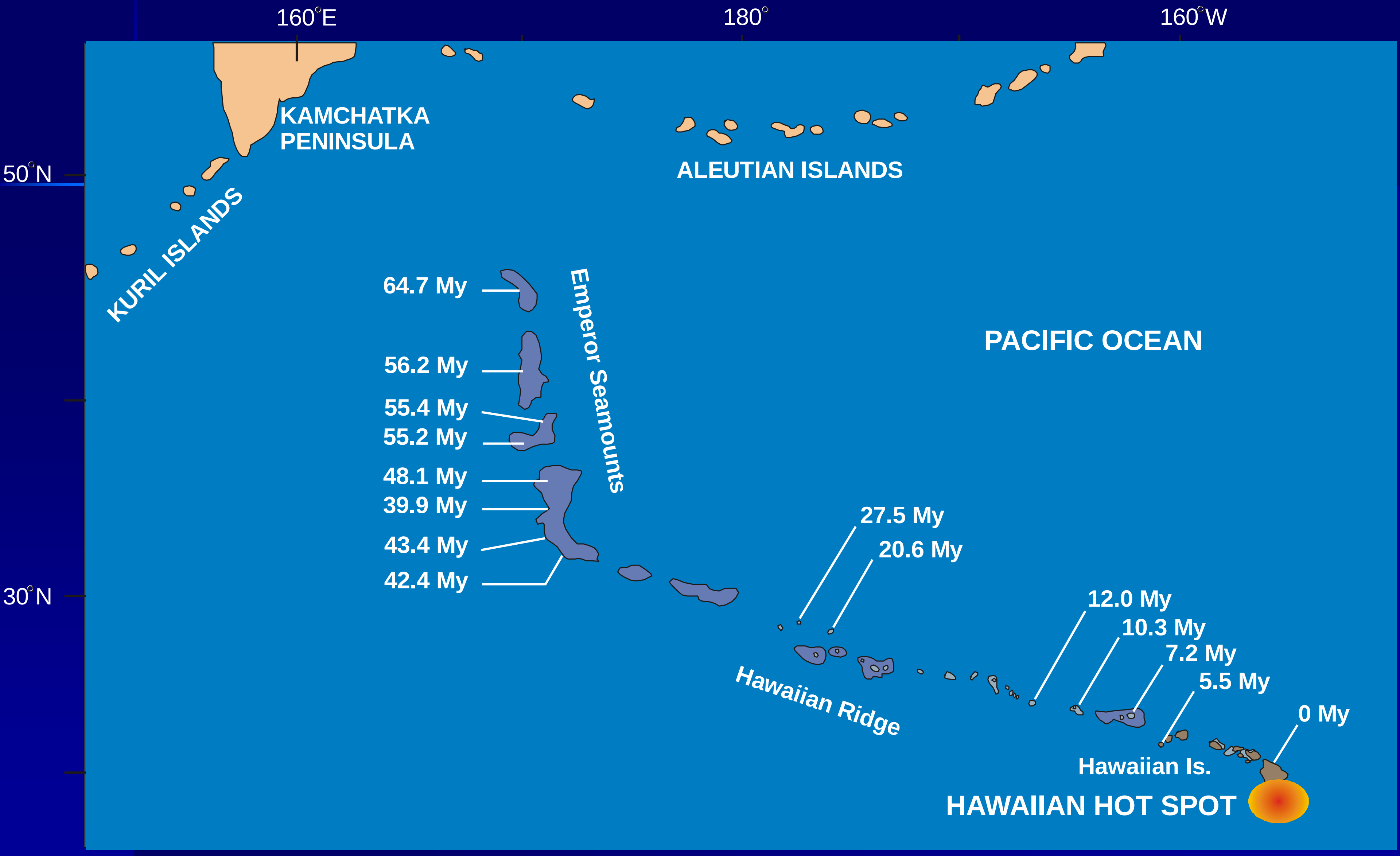
Seafloor crust moving over a mantle plume forms an aseismic ridge as a chain of volcanoes and guyots.



Progressively
older
Mantle
plume

- Subduction of the Pacific Plate signaled the beginning of the formation of Guam
  - The location of the island at its “birth” was probably south of the Equator, possibly 20° S of the present location, and considerably west of the present location, because Guam was originally part of the Palau-Kyushu Ridge

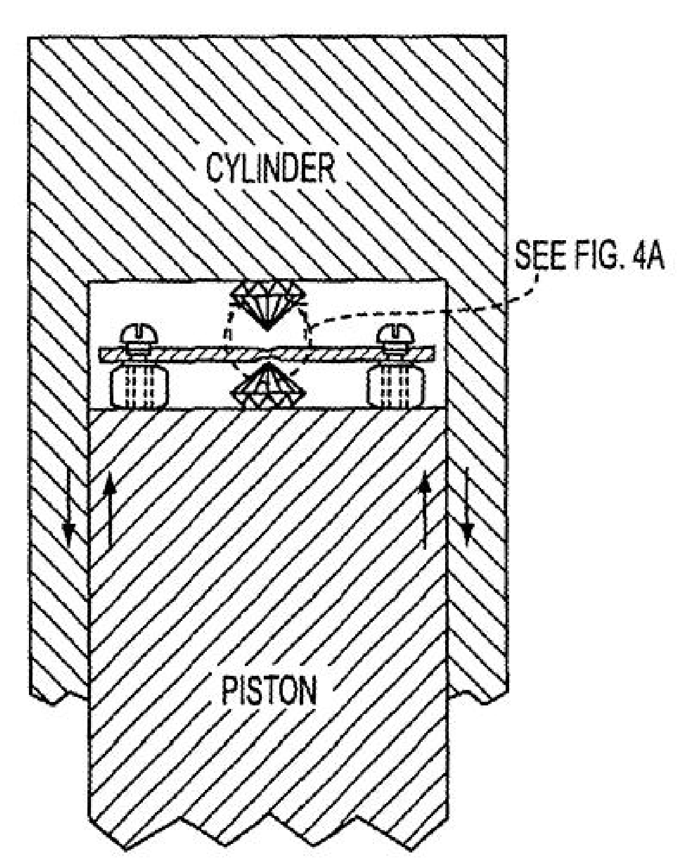
- The geological age at the bend in the Hawaiian-Seamount chain is 42.4 Mybp (Daikakuji Seamount), and the oldest rocks found to date in the Mariana Islands are about 43.6 Mybp



160°E
180°
160°W
50°N
30°N
KAMCHATKA PENINSULA
ALEUTIAN ISLANDS
KURIL ISLANDS
PACIFIC OCEAN
Emperor Seamounts
64.7 My
56.2 My
55.4 My
55.2 My
48.1 My
39.9 My
43.4 My
42.4 My
27.5 My
20.6 My
Hawaiian Ridge
12.0 My
10.3 My
7.2 My
5.5 My
0 My
Hawaiian Is.
HAWAIIAN HOT SPOT

- Subduction of the Pacific Plate initiated **forearc volcanism**
  - The cause of volcanism is associated with subduction
- ***Frictional Heating Hypothesis***
  - The subducted plate is subjected to intense pressures and high temperatures
  - Water subducting with the plate materials lowers the melting point of the rock, producing magma that rises and breaks through the crust to form a volcano

- Experimental evidence from the **high-pressure anvil** supports this hypothesis
  - **A high-pressure anvil, or *diamond anvil*, exerts forces and high temperatures (800–900 °C) that simulate conditions in the mantle**

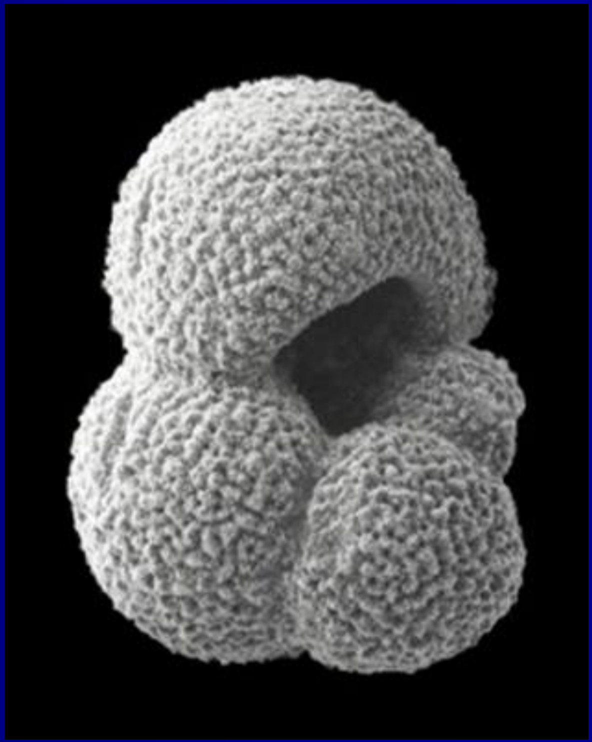


- Such experiments require a diamond anvil, because diamond is the only mineral that has a melting point (5000 °C) high enough to withstand those conditions
- Geologists tested ophiolites from seafloor crust and observed melting in support of the frictional heating hypothesis

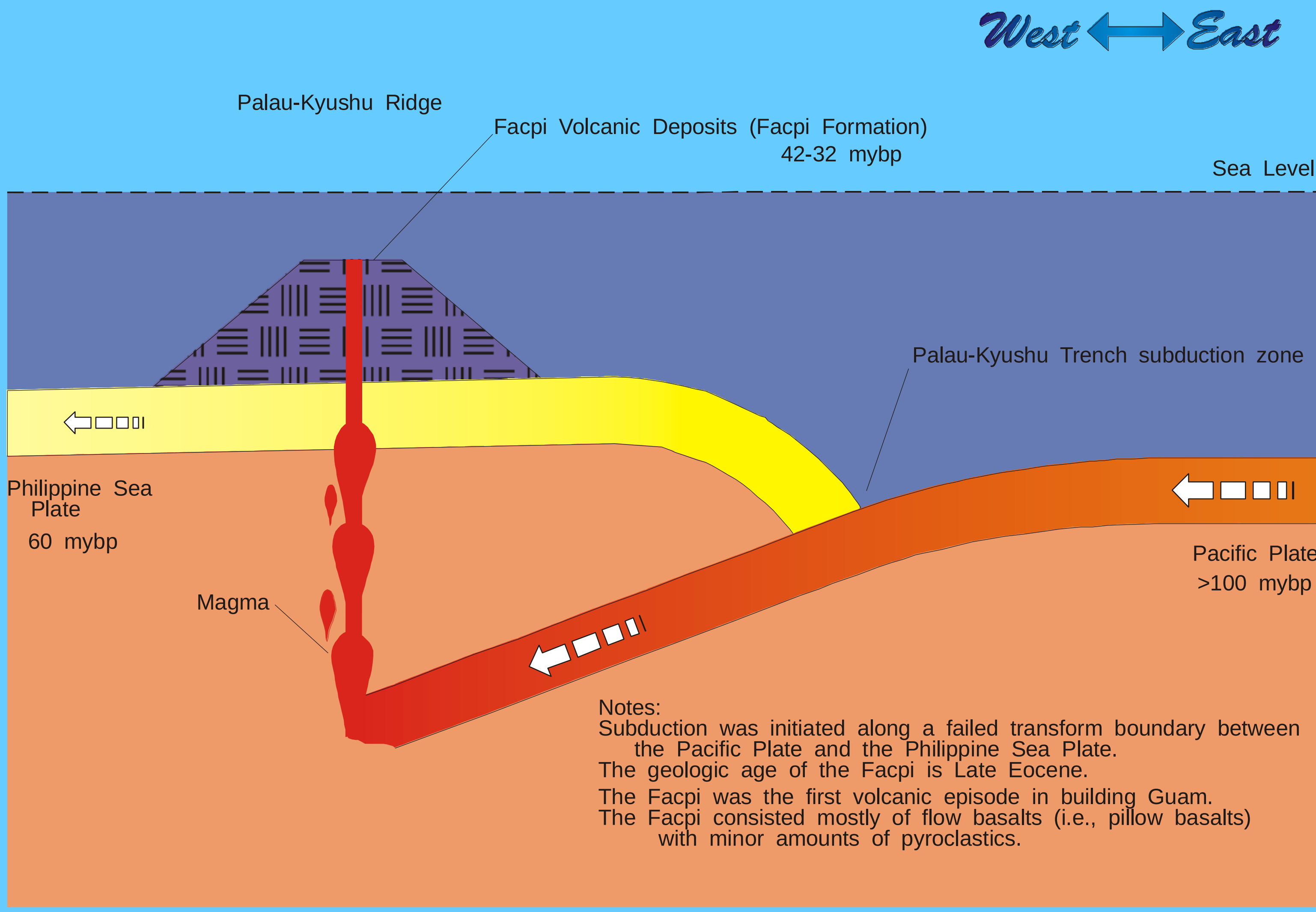
Volcanic Construction of Guam

A. Deposition of the **Facpi Volcanic Formation**
   - The initial phase of volcanic construction probably did not create an island above sea level
   - The evidence for this conclusion is the abundance of pillow basalts in Facpi volcanics, and pillow basalts are formed only under water

- Further evidence comes from the presence of the **foram** *Globigerina* [a single-celled marine protozoan with a carbonate test] found in Facpi basalts



Globigerina **sp.**



A. Deposition of the Facpi Volcanic Deposits

- – The geological age of the Facpi Formation is the late Eocene to early Oligocene 42–32 Mybp
- – Today, Facpi deposits are distributed along the southwest coast from Nimitz Channel to Merizo, extending inland from Facpi Point to Mt. Lamlam
- – Elsewhere, Facpi deposits are buried by younger deposits, because the Facpi Formation is the basement rock of Guam

View of Facpi Volcanic Formation rocks from Fort Soledad in Umatac

– Earlier deposits of the Facpi Formation differ from volcanic minerals deposited in the later phases of construction of the island

- Facpi deposits are mostly basaltic flows
  - Facpi deposits are characterized by about 70% basaltic flows, including pillow basalt and vesicular andesite
  - The other 30% of Facpi volcanics are pyroclastics, including volcanic breccia, tuffaceous sandstones & tuffaceous mudstones

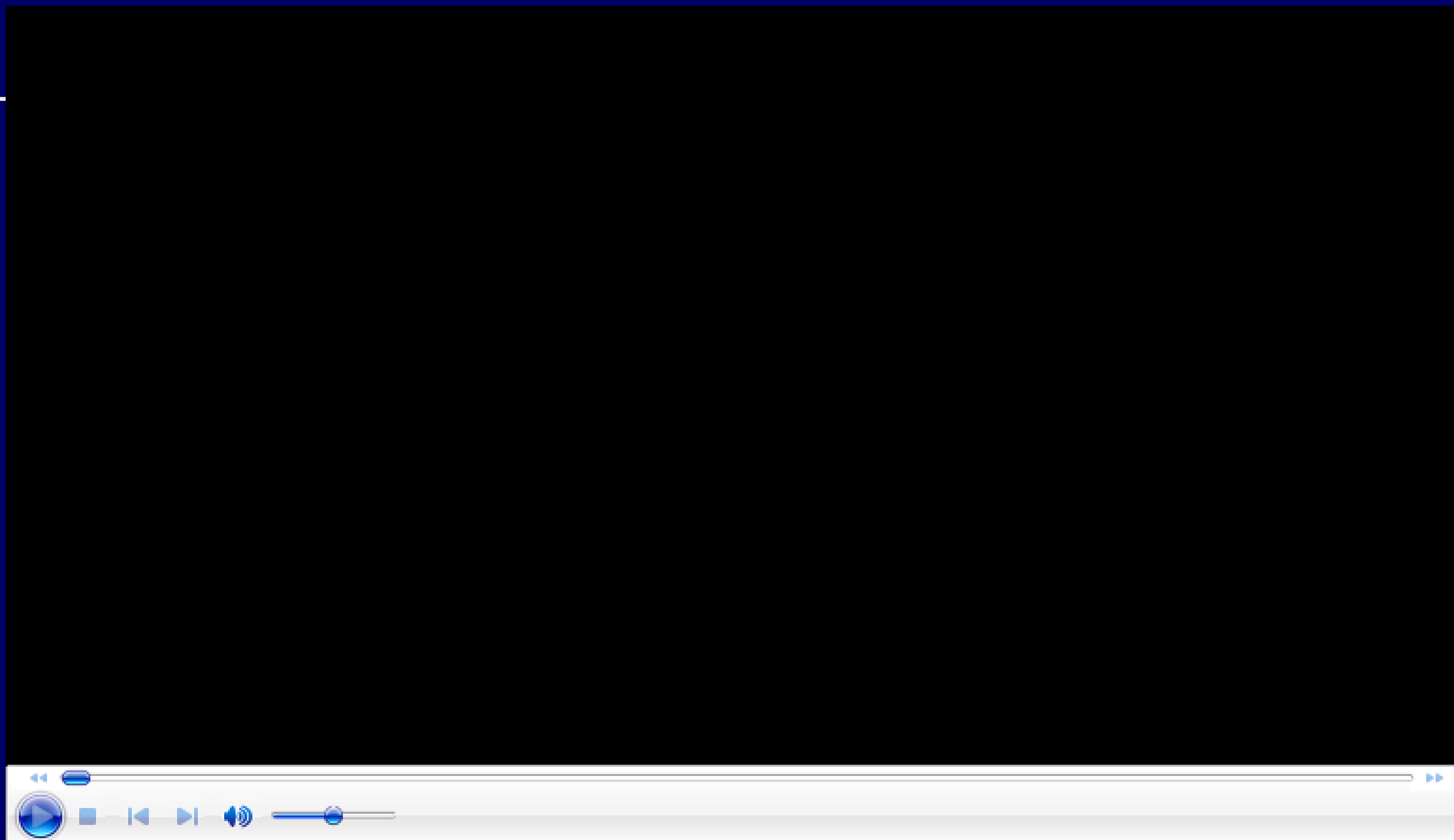
Pillow basalt on escarpment above the Sella Bay overlook

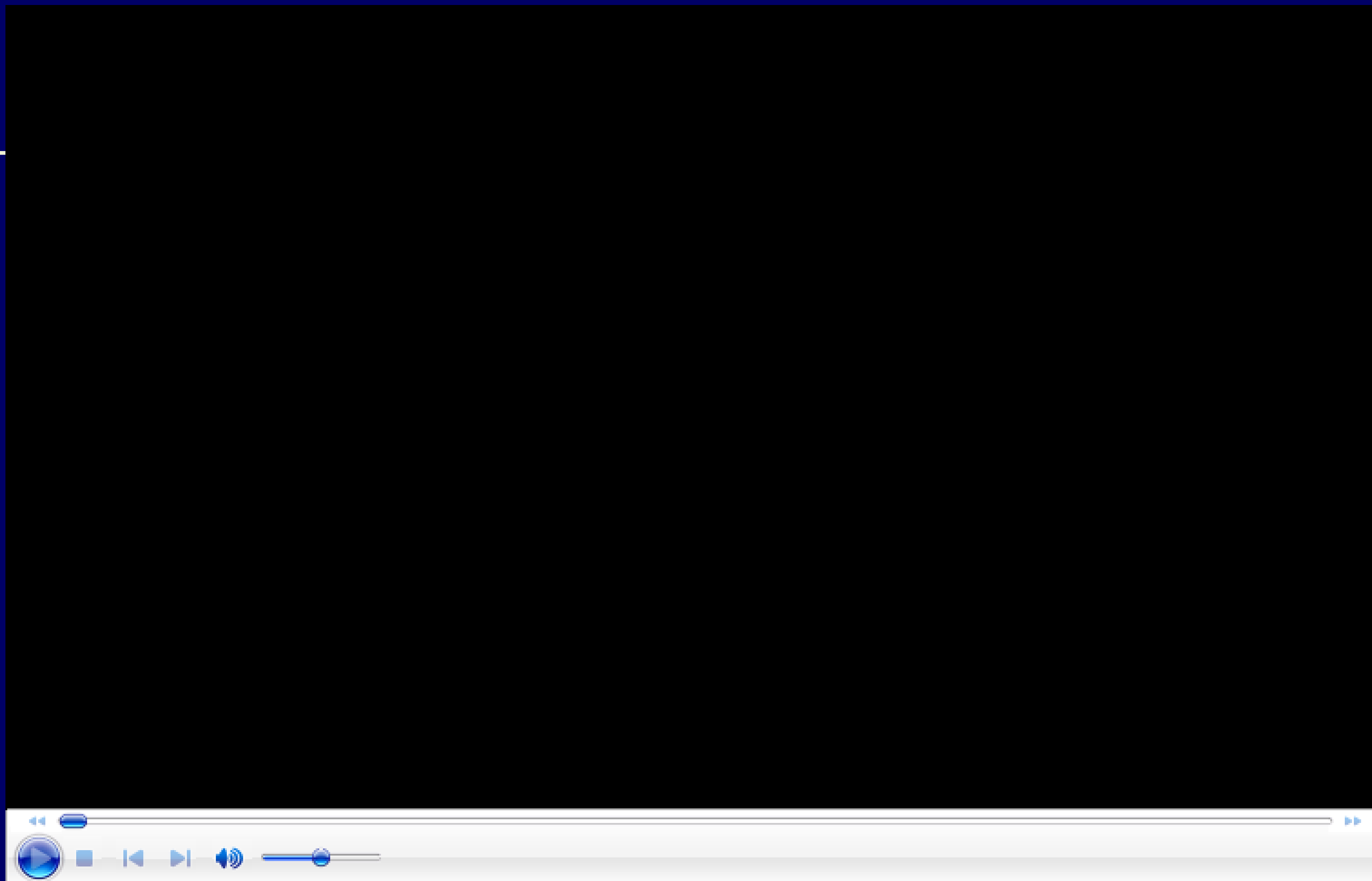
Internally, pillows have annular construction, with radial fractures and a volcanic glass rind

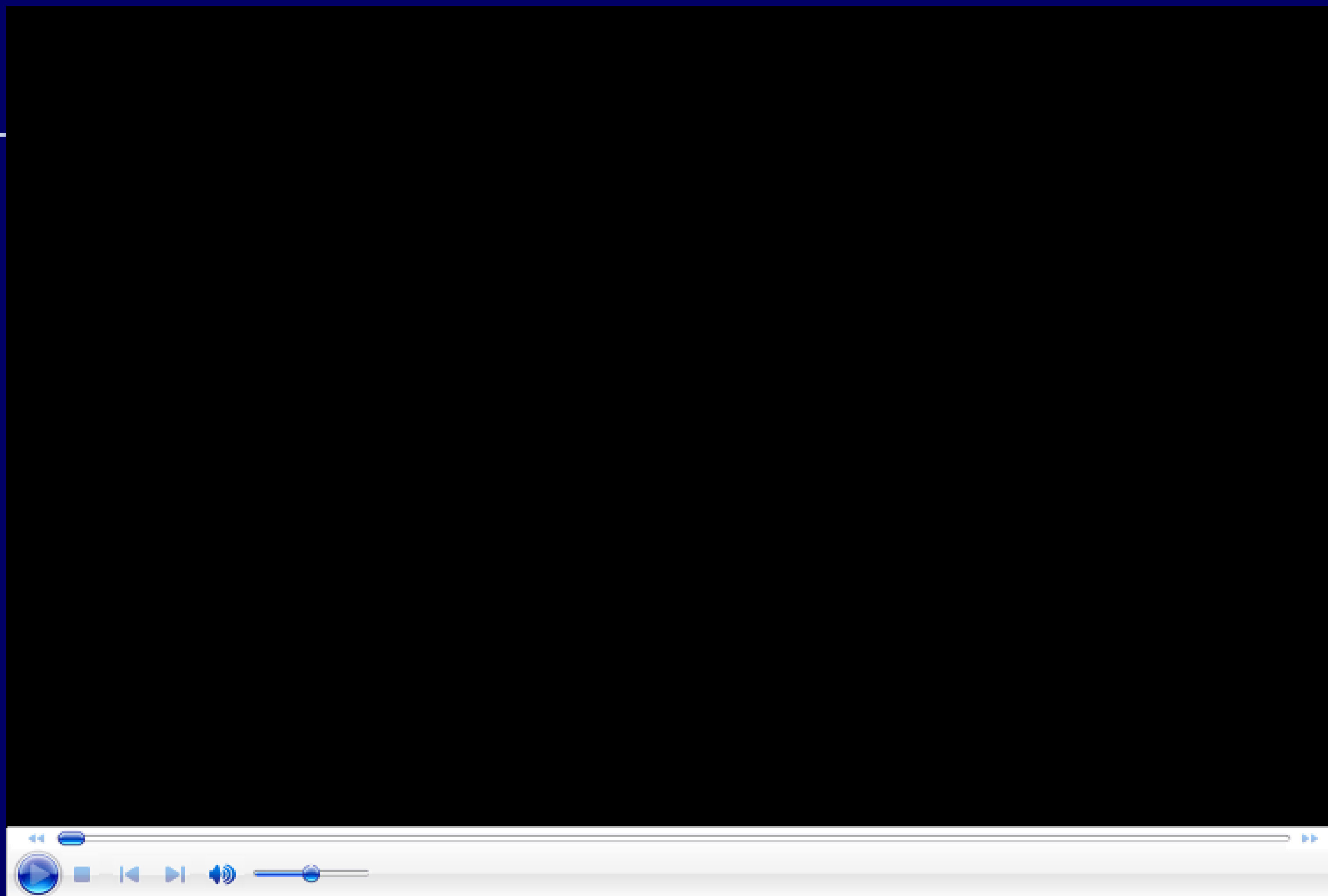
– Therefore, the Facpi eruptions are characterized as composite volcanism
– Facpi volcanism was quiescent by about 32 Mybp

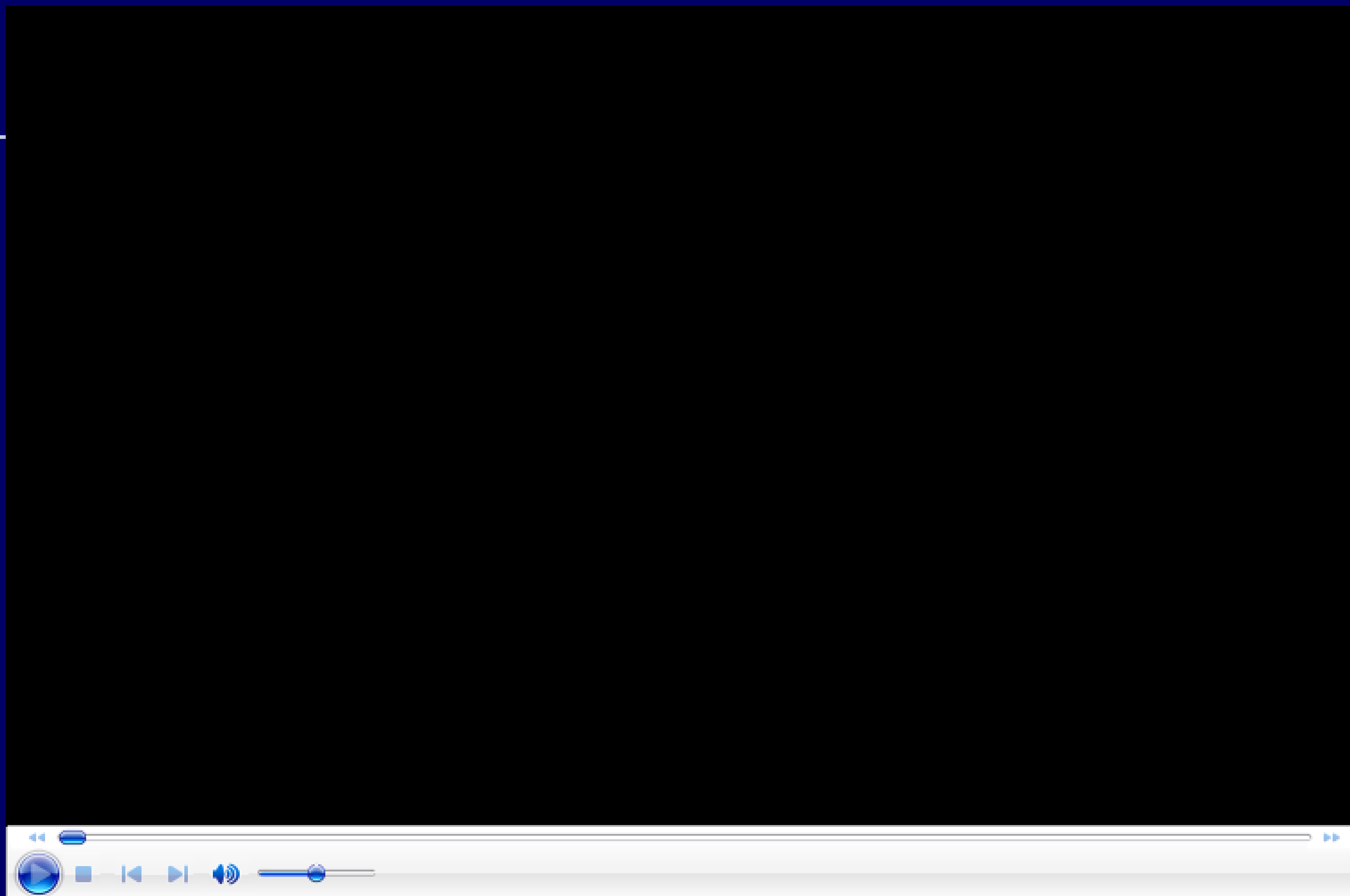
B. Deposition of **Alutom Volcanic Formation**

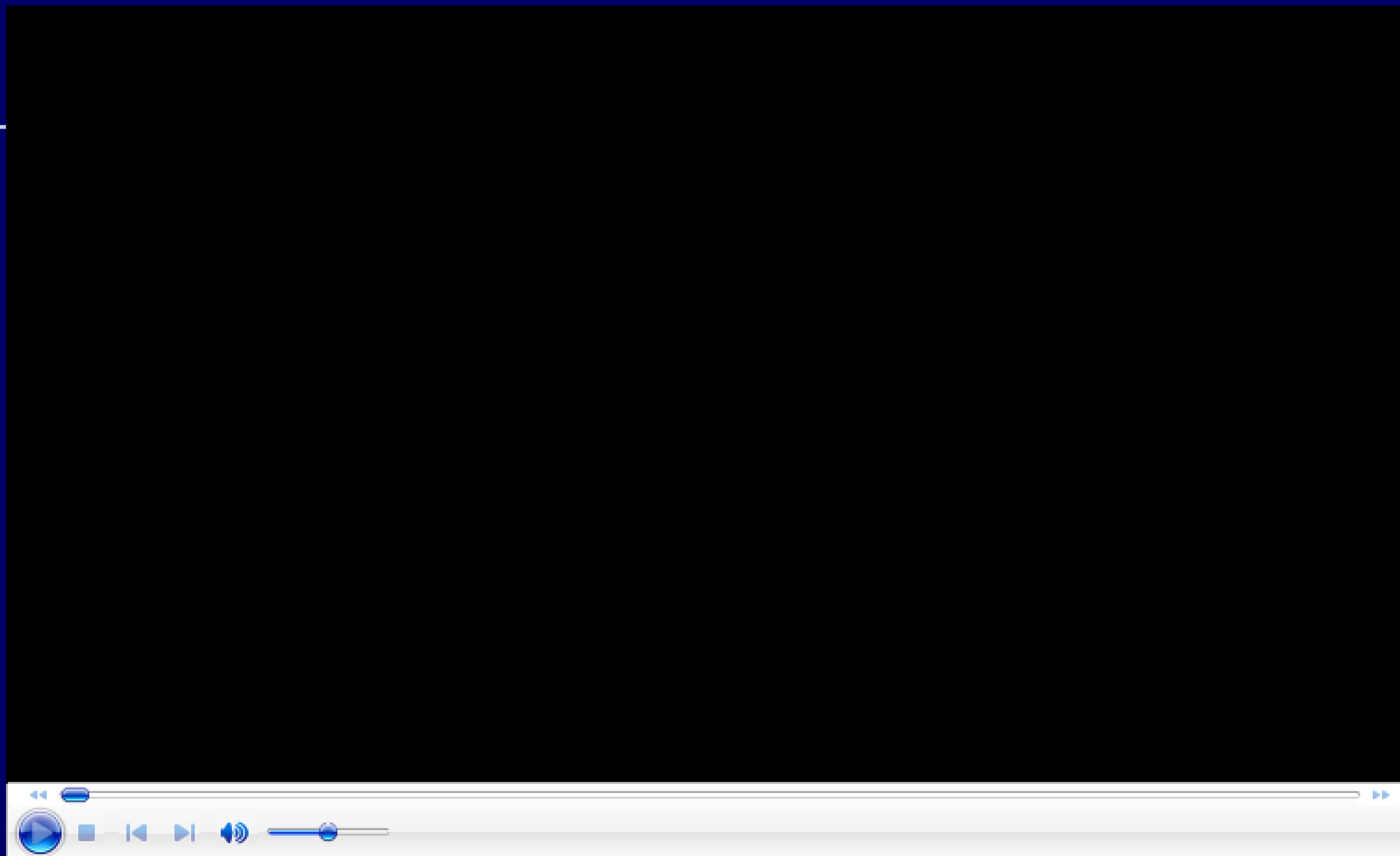
- The geological age of the Alutom Formation is Oligocene, 32–29 Mybp
- Alutom rocks show definite changes in composition of the volcanic deposits compared to Facpi rocks
- Alutom rocks indicate more volatile volcanism, containing more gases
- Composition of Alutom rocks indicates materials melting at greater depths
- Therefore, the Alutom contains more pyroclastic rocks than the Facpi











Anatahan eruption, May 11, 2003


N
Anatahan
Image NASA
Image © 2007 DigitalGlobe
2.01 mi
Pointer 16°20'56.90" N 145°40'18.61" E elev 906 ft Streaming |||||||||| 100%
Sarigan
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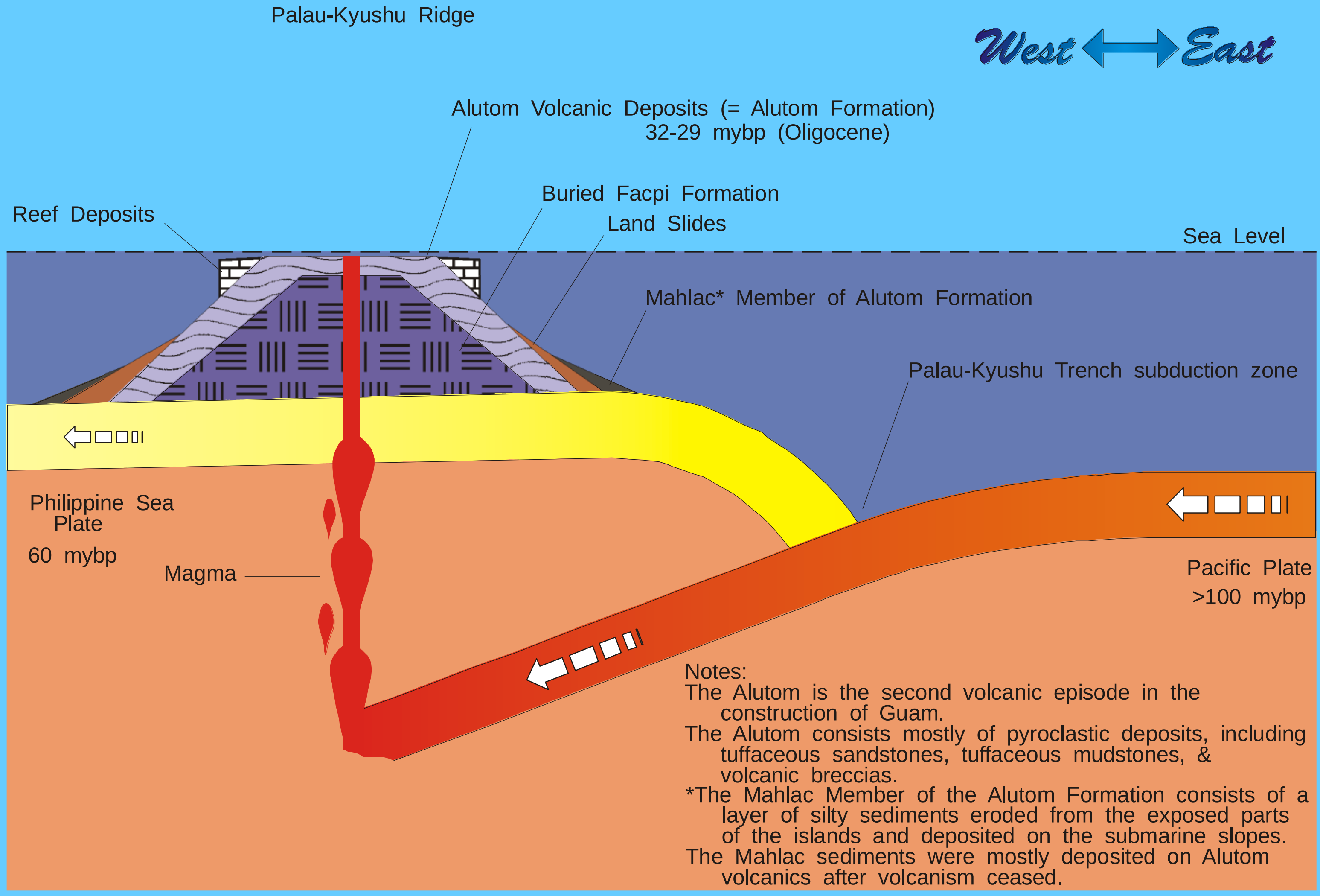


B. Deposition of the Alutom Volcanic Deposits and the Silty Sediments of the Mahlac Member.

- The Alutom phase produced abundant tuffaceous sandstones, plus tuffaceous mudstones and volcanic breccia
  - N.B., you cannot visually distinguish between sandstones from the Facpi and the Alutom
- Only minor amounts of flow basalts were deposited during the Alutom phase
  - One significant flow of the Alutom can be found in the Piti Veterans Cemetery

Tuffaceous sandstones of the Alutom Volcanic Formation on Mt. Alutom

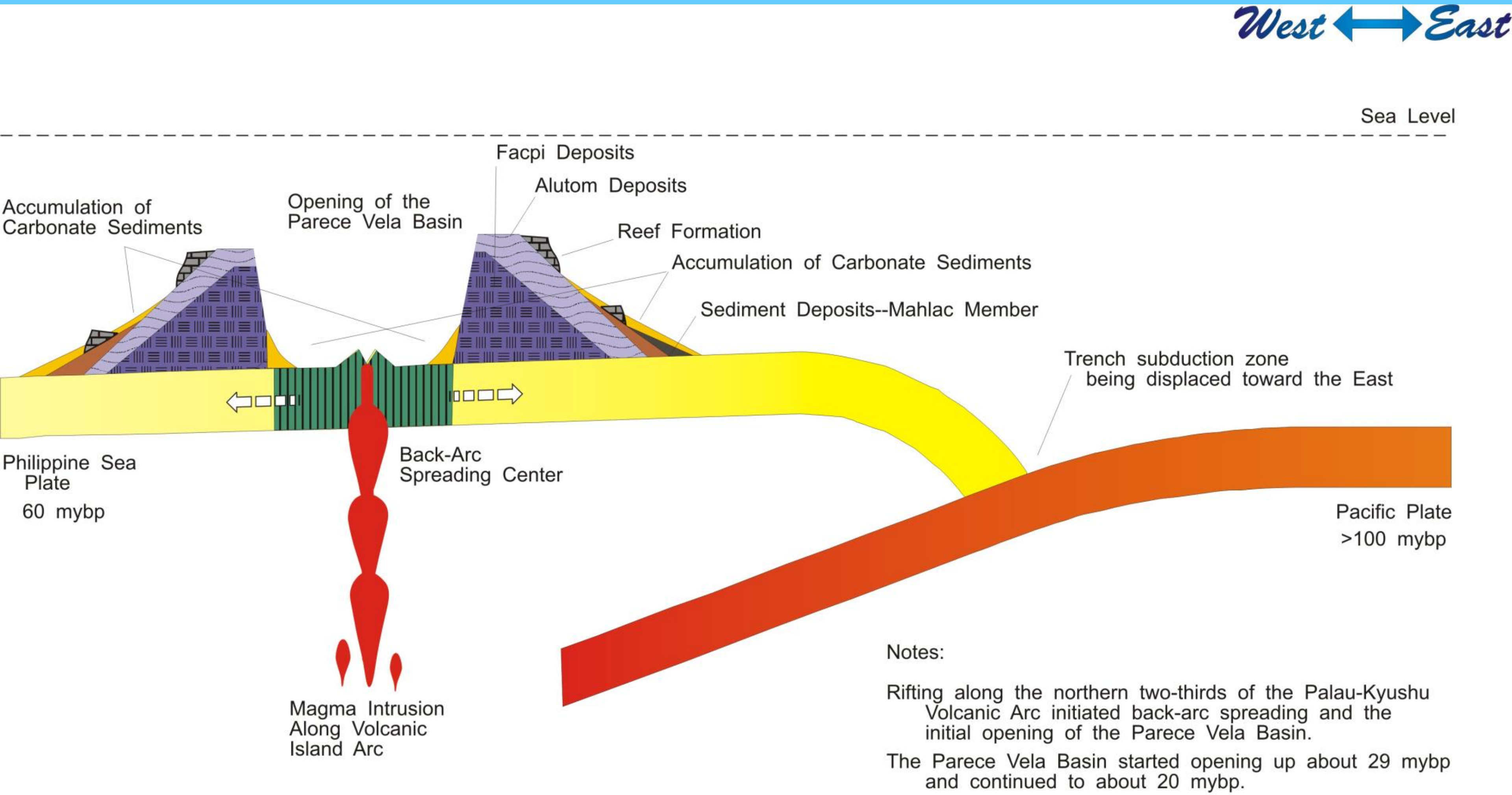
- The present distribution of the Alutom deposits is mostly in central Guam, Mt. Santa Rosa, and Matagua Hill
  - Therefore, there were probably two centers of volcanism
  - The main center of volcanism was west of Guam, as indicated by the tilt of Alutom rock layers towards the east

- After active volcanism ceased, the Alutom deposits underwent a period of erosion
  - Tephra of the Alutom phase was carried down slope by **turbidity currents** [i.e., gravitational]
  - Where deposited, the tephra formed **turbidites** when lithified

- These deposits are known as the **Mahlac Member** of the Alutom Formation
  - The layers of the Mahlac are contorted, not smooth
  - Therefore, these are sedimentary rock, because they are transported by submarine landslides

c. Initiating of rifting and opening up of the Parece Vela Basin

- When the Alutom eruptions ended, the Palau-Kyushu forearc ridge began to rift apart
- During rifting, there was no volcanism or very reduced volcanism
- The western remnants of the island were left behind on the Palau-Kyushu Ridge, and Guam was pushed eastward by rifting



Notes:

Rifting along the northern two-thirds of the Palau-Kyushu Volcanic Arc initiated back-arc spreading and the initial opening of the Parece Vela Basin.

The Parece Vela Basin started opening up about 29 mybp and continued to about 20 mybp.

C. Initiation of Rifting and Back-Arc Spreading Along The Northern Two-Thirds of the Palau-Kyushu Arc Ridge, Forming the Parece Vela Basin.

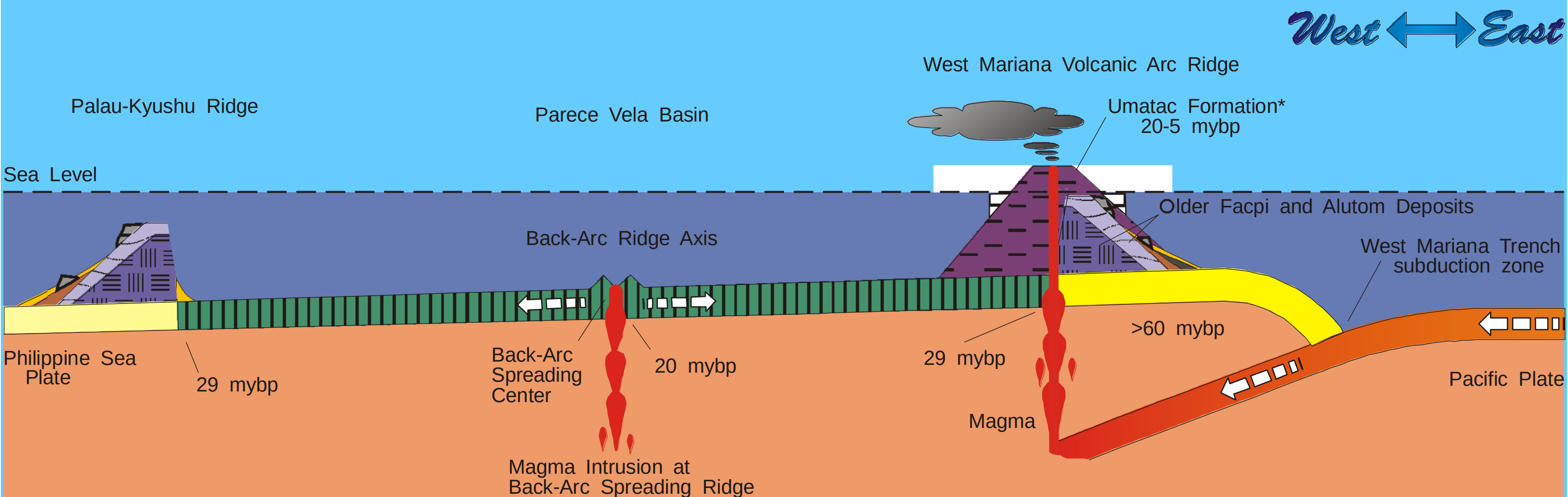
- During the rifting event, coral reef deposits formed on the slopes of the volcanic deposits
  - The limestones deposited during rifting are called the **Maemong Limestone Formation**
    - In this class, we consider this a formation, because its construction occurred during an inter-volcanic period
    - Please be aware, however, that Tracey believed the Maemong to be embedded in the Umatac Formation during a quiescent period

- The lower Maemong limestone was formed by shallow reef organisms, while later deposits were formed by forams and deep reef organisms
  - This indicates that the plate was subsiding during deposition
- The maximum thickness of the Maemong is 260 ft
- As Guam moved farther from the area of seafloor spreading, the volcanics cooled and became denser, resulting in some subsidence

The present distribution of Maemong limestones is primarily the hillside between Merizo and Umatac

The white rock sticking up on the slope is old, exposed Maemong reef

- Deposition of the **Umatac Volcanic Formation**
  - When subduction of the Pacific Plate resumed in the Miocene about 20 Mybp, forearc volcanism also resumed, resulting in the Umatac Volcanic Formation
  - The Umatac Formation is the last volcanic episode in the construction of Guam, lasting from 20–5 Mybp



Notes:

At this stage, the Palau-Kyushu Ridge, consisting of Facpi & Alutom deposits, is mostly submerged, except for the southern one-third.

The darker shaded region indicates crust formed by back-arc spreading that was initiated 29 mybp.

*The lower part of the Umatac Formation consists of limestone deposits called the Maemong Limestone Member. These deposits formed before the Umatac volcanism began, probably during the period in which the Parece Vela Basin formed.

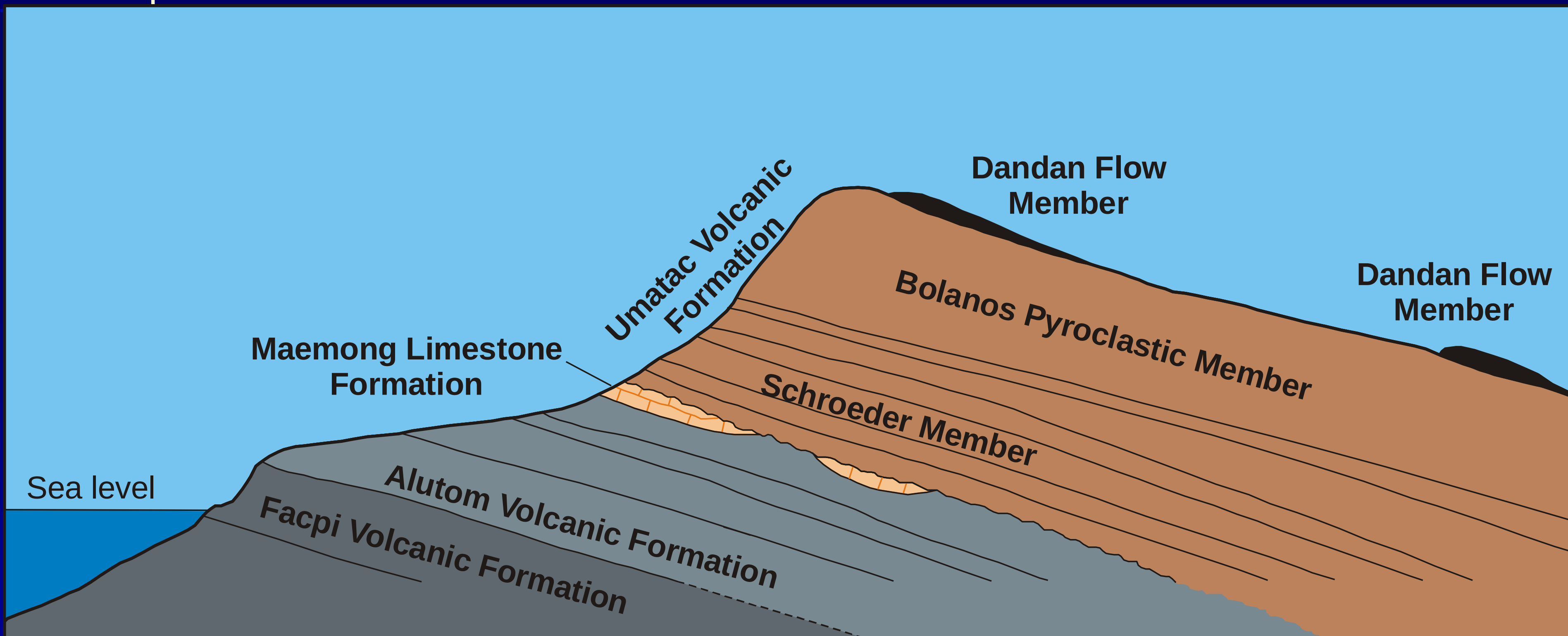
The Umatac Formation is the third episode of volcanism in the construction of Guam. The first volcanic deposits of the Umatac, called the Schroeder Member, consisted of basaltic flows alternating with pyroclastic deposits.

In later stages, the volcanism became more explosive, and mostly pyroclastics were deposited (tuffaceous sandstones & mudstones and volcanic breccias). These deposits are called the Bolanos Pyroclastic Member.

After the Bolanos pyroclastic deposits, basaltic flows were deposited, indicating a milder type of eruption. These deposits are called the Dandan Flow Member (= the last known volcanism on Guam).

D. Formation of the Parece Vela Basin and Deposition of the Umatac Formation Members.

- The Umatac Formation is divided in three members
  - The Schroeder Pyroclastic Member
  - The Bolanos Pyroclastic Member
  - The Dandan Flow Member



Relative stratigraphic positions of volcanic rock in the construction of Guam.
(Modified from Stark 1963)

– **Schroeder Pyroclastic Member**

- The Schroeder tuffs sit on Maemong Limestone
- This volcanic phase was mostly pyroclastic, with some flows
- Tuffaceous sandstones are particularly abundant in the Schroeder deposits
- The maximum thickness of the Schroeder Member is about 700 ft

– Bolanos Pyroclastic Member

- Bolanos Member deposits are almost all pyroclastics, and flow deposits are rare
- The present distribution of exposed Bolanos Member deposits is along the ridge crest and east slopes of southern Guam, where it overlies Facpi deposits
- The maximum thickness of Bolanos Member deposits is 750 ft

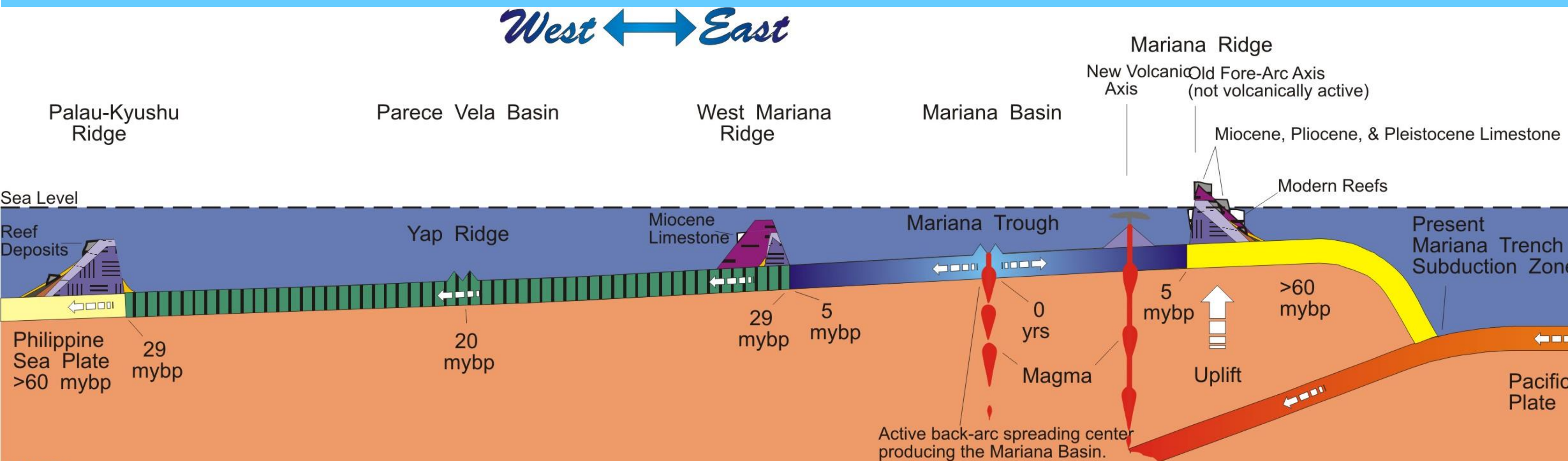
At Ija, the interface between the Schroeder Pyroclastic Member and the Bolanos Pyroclastic Member are exposed at the surface.

- **Dandan Flow Member**
  - The Dandan Member deposits are mostly eroded away today, and only patchily distributed southeastern slopes of Guam
  - The lower 10 ft of the Dandan Member consists of pyroclastics (volcanic breccia)
  - The upper 40–50 ft consists of basaltic flows
  - Therefore, the maximum thickness of the Dandan Member is 50–60 ft
- The Umatac Volcanic Formation was deposited when Guam was part of the West Mariana Ridge

Remanants of the Dandan Flow Member litter the hillside near Malojlog

- Rifting of the West Mariana Ridge and Opening Up of the Mariana Basin
  - After the Umatac volcanism ceased, the forearc ridge began rifting for the second time
  - The western portion of the island was left on the West Mariana Ridge, and the eastern portion began rifting towards the east

- This rifting event opened up the Mariana Basin, with the Mariana Trough forming the spreading ridge
- The Mariana Trough has been an active backarc spreading ridge for some 5 million yr



Notes:

The old fore-arc axis of the Mariana Ridge consists of:

a. Facpi and Alutom volcanic formations deposited when the ridge was part of the Palau-Kyushu Ridge.
b. Umatac volcanic formation and Miocene limestone deposits formed when the ridge was part of the West Mariana Ridge.
c. Pliocene and Pleistocene limestone deposits formed after the Mariana Basin began to develop.

The new volcanic axis of the Mariana Ridge has formed to the west of the old axis, and consists of recent volcanic deposits <2.0 mybp.

The West Mariana Ridge consists of Facpi, Alutom, and Umatac volcanic formations and Miocene limestone formations. This ridge has submerged with subsidence of the Parece Vela Basin.

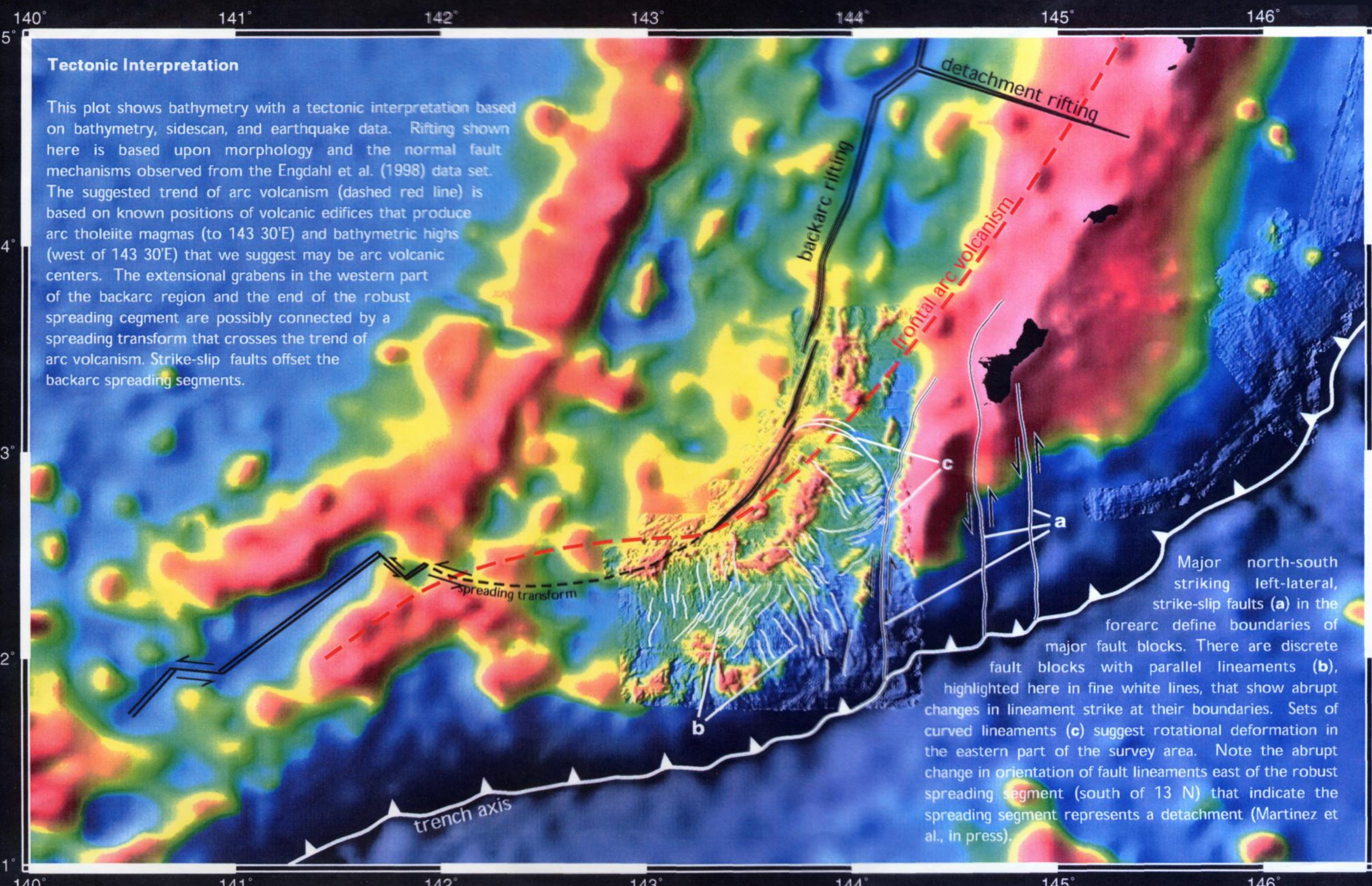
The Palau-Kyushu Ridge is submerged along the northern two-thirds of its length. This ridge consists of Facpi and Alutom volcanic deposits (43-32 mybp).

The Yap Ridge is an inactive back-arc spreading center that produced the Parece Vela Basin (29-20mybp).

E. Rifting of the West Mariana Ridge and Opening Up of the Mariana Basin by Active Back-Arc Spreading, and Deposition of Miocene, Pliocene, and Pleistocene Limestone Deposits.

- A possible transform fault north of Farallon de Medinilla has shifted the southern one-third of the Mariana Forearc Ridge eastwards of the active arc
- Volcanic activity has continued along the active arc over the past 1.5 My, as evidenced by eruptions of Uracus, Pagan, and Anatahan
- A line of submarine volcanoes continues the active arc all the way to the Mariana Trench southwest of Guam

- This line of active submarine volcanoes includes Esmeralda Bank, Tracey Seamount, and the recently discovered Northwest Rota submarine volcano


Tectonic Interpretation
This plot shows bathymetry with a tectonic interpretation based on bathymetry, sidescan, and earthquake data. Rifting shown here is based upon morphology and the normal fault mechanisms observed from the Engdahl et al. (1998) data set. The suggested trend of arc volcanism (dashed red line) is based on known positions of volcanic edifices that produce arc tholeiite magmas (to 143 30'E) and bathymetric highs (west of 143 30'E) that we suggest may be arc volcanic centers. The extensional grabens in the western part of the backarc region and the end of the robust spreading cegment are possibly connected by a spreading transform that crosses the trend of arc volcanism. Strike-slip faults offset the backarc spreading segments.
Major north-south striking left-lateral, strike-slip faults (a) in the forearc define boundaries of major fault blocks. There are discrete fault blocks with parallel lineaments (b), highlighted here in fine white lines, that show abrupt changes in lineament strike at their boundaries. Sets of curved lineaments (c) suggest rotational deformation in the eastern part of the survey area. Note the abrupt change in orientation of fault lineaments east of the robust spreading segment (south of 13 N) that indicate the spreading segment represents a detachment (Martinez et al., in press).
detachment rifting
backarc rifting
frontal arc volcanism
spreading transform
trench axis
a
b
c
140°
141°
142°
143°
144°
145°
146°
15°
14°
13°
12°
11°

- The end of volcanic deposition did not mark the end of the construction of Guam
- Tectonic uplift along the forearc produced shallowing throughout much of south central Guam and around Mt. Santa Rosa-Mataguac Hill
  - These areas were in the euphotic zone by the middle Miocene, enabling limestone deposition that has continued to the present