Plate Tectonics
1.5 by - Today
Ancient Oceans & Continents
Plates Tectonics during the Last 1.5 billion years: An Atlas of Ancient Oceans and Continents

Introduction

The maps in this atlas are the first draft of a new set of plate tectonic reconstructions that will provide the framework for the revised paleogeographic and paleoclimatic maps that I am preparing for my book, "Earth History: Evolution of the Earth Systems". As the title of this work implies, the goal of this atlas is to identify the major continents and oceans back through time. Tables 1 and 2 list the names of the continents and oceans shown in this atlas. Names shown in bold are newly coined ocean and continent names. Figure 1 is a "tectonic phylogeny" that shows how these continents and oceans have developed through time.

Continents

Continents are defined to be regions of the Earth that are underlain by continental crust (~lithosphere). Continents may be “emergent” or “flooded” depending on sea level, which has varied from ~200 meters above modern sea level to ~200 meters below modern sea level. The continental regions on these maps are shown in two colors: gray and white. The gray areas represent extant regions of continental crust. The white regions represent areas of continental crust that have been removed by subduction (tectonic erosion), underthrusting beneath continents (like Greater India), or are simply squeezed and compressed into much narrower zones (e.g. the Rocky Mountains or the Central Asian collision zone).

Continents come in a variety of sizes and shapes. We reserve the name “continent” for regions of continental crust greater than 10 Mkm². The present-day continents are: Africa, Antarctica, Asia, Australia, Europe, North America, and South America. In the Early Ordovician the continents were: Baltica, Cathaysia, Gondwana, Laurentia, and Siberia. Regions with areas less than 10 Mkm² are either “subcontinents”, like the Indian subcontinent (4.6 Mkm²), or “island continents” like Greenland or Madagascar. Subcontinents are continental regions that are contiguous with a larger continent, but are considered to be a distinct region. India is subcontinent because it is separated from Asia by the Himalaya mountains and Tibetan plateau. Island continents, on-the-other-hand, are simply very large islands. Zealandia is an example of a mostly submerged an island continent. Finally, Regions of continental crust less than 1 Mkm² may be considered to be "microcontinents" (e.g., S. Orkney Islands, Seychelles, Rockall plateau, or Tasman Rise).

The naming conventions for continents …

Oceans

Ocean basins are defined to be regions of the Earth that are underlain by oceanic lithosphere. Ocean basins, together with the flooded portions of the continents, comprise the Earth’s oceans, seas, and seaways. It is interesting to note that following the definition of continent and ocean proposed here, there are regions of the Earth that can be considered to be both “continents” and “oceans”. These regions are the portions of the continents flooded by the sea. For example, the Grand Banks of eastern Canada is part of the continent of North America, but the water above the Grand Banks is part of the Atlantic Ocean. This duality is due to the fact that the landward boundary of the ocean is the shoreline, whereas the seaward boundary of the continent lies near the junction of the continental rise and continental slope. In the past, this duality has lead to a fair degree of confusion when it came to naming oceans and continents. Also, it should be noted that no attempt has been made to show past coastlines on the maps in this atlas.
The derivation of the names of the modern oceans generally falls into one of three categories: mythological names, location names, and descriptive names. For example, the Atlantic Ocean is named after the Greek god, Atlas; the Indian Ocean is named after the subcontinent of India; the Pacific Ocean was named by Francisco Pissarro, who thought that the Pacific Ocean looked “peaceful”. Some of Paleozoic and Mesozoic Oceans are named after Greek gods related to Atlas. Tethys was the XXX of Atlas. Iapetus was the XXX of XXX, a Rhea (Rheic Ocean) was the XXX of XXX. Because it is difficult to meaningfully continue these lineages, none of the new oceans are named after Greek gods. Instead we have adopted a dual naming convention. The names of the new oceans either reflect the local geography (e.g., the Mozambique Ocean once ran through most of East Africa, including Mozambique) or a related geologic/tectonic feature (e.g., the Grenville Ocean is the ocean basin that closed during the Grenville Orogeny (~1050 Ma) in eastern North America.

Coining new names for every new ocean, however, can be confusing. To avoid confusion and promote clarity we have tried to make slight modification to existing names, especially if there is a relation of inheritance. For example, originally there was just one ocean called the “Tethys Ocean”. However, we now know that there are three distinct oceans: ProtoTethys, PaleoTethys, and NeoTethys once existed in the Tethyan realm. Using this format, we have coined the new terms “PaleoPanthalassa” and “ProtoPanthalassa” to described earlier versions of the Panthalassic Ocean.

The names of these bodies of water may change slightly depending on the maturity of an ocean basin. A newly formed ocean basin, one that is still relatively narrow, may be called a “sea”, like the Red Sea, or if it connects two larger bodies of water, it may be called a “seaway”. The term “sea” is also used for bodies of water surrounded or partially enclosed by continents, like the Mediterranean Sea or Weddell Sea. Oceans as they age, gradually narrow as the continents on either side of the ocean approach each other (through subduction of oceanic lithosphere). Thus, it is possible for a once mighty “ocean” to become a narrow “sea” or “seaway” prior to its demise.

Plate Tectonics

Plate boundaries are also shown on these maps, but no attempt has been made to identify the plates (e.g., Pacific, Farallon, Nazca, etc.) or label the individual plate boundaries (e.g., Mid-Atlantic Ridge). (That will come later.) I think that it is important that we have different and distinct names for the continents and oceans, on the one hand, and the plates, which underlie them, on the other hand. For example, it is easy to confuse the “Pacific plate” with the “Pacific ocean”. The Pacific Ocean is currently made up of several plates (the Pacific plate, Nazca plate, and Cocos plate – to name a few); whereas there is only one “Pacific plate”.

Like an infuriatingly difficult jigsaw puzzle whose pieces change size and shape as you try to solve it, the continents constantly break apart as new ocean basins form, and then reassemble into new shapes as subduction zones bring them back together. The plate tectonic model that I have built has more than 500 “jigsaw puzzle pieces”. These puzzle pieces are called “tectonic elements” (Table 3). Figure XX. Is a modern map illustrating all of the tectonic elements used in this model. The major tectonic elements are also labeled on each of the plate tectonic maps (Maps 1 – 46).

(resume writing here)

Methodology & Previous Work

The methods used to reconstruct the past positions of the
continents and the configuration of the surrounding ocean basins varies, depending on the age of the reconstruction (Figure 1). As one might, the useful information decreases in both quantity and quality back through time.

Figure 1. Illustrates the various data and methods used to make the plate tectonic reconstructions.

For the Cenozoic, Cretaceous, and late Jurassic…

For the early Mesozoic,…

For the Paleozoic,…

For the Precambrian,…

(resume writing here)

Plate Tectonic History 1.5 Billion - Today

The maps in this report have been excerpted from the animation by Scotese and Elling (2017). The full-length version of this animation can be found at https://www.youtube.com/watch?v=IlnwyAbczog.

This animation focuses on the plate tectonic development of our planet during the last 1.5 billion years.

Some highlights:

(add 1.5 by to 750 Ma)

750 Ma - breakup of the supercontinent of Rodinia following the collision of the Congo craton and the closure of the Mozambique Seaway.

750 - 600 Ma - the opening of the Panthalassic Ocean

700 Ma - the opening of the Kipchak Ocean as continental arcs rift away from Siberia

600 Ma - the start of multiple subduction zones along eastern Australia and Antarctica, the north-facing margin of Siberia (Mongolia & Amuria), and the Cadomian region of northern Gondwana

600 – 580 Ma - the conversion of slow-spreading ridges in the Kipchak Sea to subduction zones

580 Ma - the opening of the Iapetus Ocean

580 – 520 Ma - 1500 km of dextral strike-slip motion between Siberia and Laurentia

530 Ma - subduction of the Panthalassic midocean ridge beneath the Tasman-TransAntarctic subduction zone (SZ)

515 Ma - the conversion of the Central Iapetus midocean ridge (MOR) into a subduction zone and the start of the Taconic island arc

510 Ma - subduction of the SW Iapetus MOR beneath the NW Amazonian SZ; and the rifting of the pre-Cordillera terrane from the southern margin of Laurentia

500 – 400 Ma - accretion and collision of island arcs in the Kipchak Sea to form core of Kazakhstania

495 Ma - the rifting of Avalonia from Amazonia resulting in the opening of the Rheic Ocean

485 Ma - subduction of the ProtoTethyan MOR beneath the easternmost Kipchak island arc
475 Ma - rifting of the Cathaysian continents (N.China, S. China, Indochina, & Tarim) from the Indo-Australian margin of Gondwana

465 Ma - collision of the Taconic arc with the eastern margin of Laurentia

455 Ma - westward, Andean-style subduction begins along the eastern margin of Laurentia; eastward-dipping subduction begins along the western margin of Laurentia

445 Ma - Avalonia collides along the southern margin of Baltica and subduction begins along the southern margin of Avalonia

440 – 425 Ma - 1500 km of sinistral strike-slip motion between Siberia and Laurentia

425 Ma - Baltica collides with Laurentia (Caledonian orogeny); Rheic MOR is subducted beneath Laurussia (Laurentia & Baltica); opening of Seventy Mile back-arc basin (BAB) along the western margin of LAurentia

420 Ma - subduction begins along northern margin of Gondwana

400 Ma - collision of southern Laurentia and northern South America (Acadian orogeny); Laurussia, reverses direction and head northward causing the conversion of MOR is the Seventy Mile Sea to convert to a subduction zone; Amuria begins to rotate counter-clockwise closing the Mongol-Okhotsk Seaway

370 Ma - initial collision between northern Gondwana (Armorican terranes) and Laurussia

360 Ma - collision of Seventy Mile island arc with western Laurussia (Antler /Caribou orogeny); Tarim collides with southern Kazakhstan (Tien Shan orogeny); northward dipping subduction begins beneath the Cathaysian continents (N.China, S. China, Indochina, & Tarim); South China (Yangtze craton) begins to rotate clock-wise closing the QinLing Ocean

360 – 300 Ma - 1000 km of dextral strike-slip collision between Armorican terranes of northern Gondwana and Hercynian Europe

300 Ma - closure of Central Asian Oceans (Altaids) and accretion of Kazakhstan between Europe and Siberia (Urals); subduction of PaleoTethyan MOR beneath Kazakhstan and Cathaysia; rifting of the Cimmerian continent (Sanandaj-Sirjan terrane of Iran, Sistan and Farah blocks of Afghanistan, Lhasa, QiangTang, and Sibumasu (Siam, Burma, Malaysia, and Sumatra) from the Indo-Australian margin of Gondwana; collision of LAurussia and Gondwana to form western half of Pangea (Alleghenian/Variscan orogenies); accretion of Chileana and Patagonian terranes of SW Gondwana (Cape orogeny)

260 Ma - collapse of Seventy Mile back arc basin and collision of Sonoma island arc along western North America; accretion of Marie Byrdland and Zealandia to East Antarctica and eastern Australia; Eruption of the Omeishan LIP in SW China;

255 Ma - closure of Solonker Sea between Amurian and North China

250 Ma - eruption of the West Siberia large igneous province (LIP)

245 Ma - opening of Cache Creek BAB as Wrangellia rifts away from northwestern South America; opening of Slide Mountain BAB as Stikinia rifts away from northern Mexico

240 Ma - Sibumasu collides with Indochina along Bangong-Nujiang Co collision zone

240 – 220 Ma - subduction begins along southern margin of Cimmeria (propogating east to west)
220 Ma - closure of QinLing Seaway and accretion of Songpan-Ganze as South China (Yangtze craton) collides with North China; initial rifiting in Central Atlantic region (Newark group)

200 Ma - eruption of Central Atlantic Magmatic Province (CAMP); PaleoTethyan MOR is subducted beneath Cimmeria; unknown sliver continent rifts away from northern margin of Gondwana; Mongol-Okhotsk seaway narrows; East Gondwana (Madagascar/India/Australia/Antarctica) begins to rift away from West Gondwana (South America/Africa)

195 Ma - Final closure of Paleotethys as Cimmeria accretes to Eurasia; BAB between QiangTang and Lhasa opens;

190 Ma - the Karoo LIP erupts (Walvis Ridge / Tristan da Cunha hot spot)

185 Ma - the Pacific plate is created at the Izanagi/Phoenix/Farallon triple junction

180 Ma - Seafloor spreading starts in Central Atlantic and proto-Caribbean, rifting in Gulf of Mexico and the Western and Eastern Mediterranean; sinistral strike-slip between Mexico and North America; rifting begins in the Canada Basin between the North Slope block and Arctic North America; extension in the southern regions of the North Atlantic (between North America & Greenland, between Greenland – Rockall); subduction begins along eastern margin of Asia (Yenshanian orogeny)

180 – 100Ma - Wrangellia moves ~3000 km northward closing Cache Creek BAB

175 Ma - spreading ridge in Slide Mountain BAB converts to subduction zone as North America is driven westwards;

170 Ma - Seafloor spreading between East and West Gondwana; seafloor spreading between Iberia and North America;

165 Ma - Caribbean (B”) oceanic crust is created near Izanagi/Phoenix/Farallon triple junction

160 Ma - NeoTethyan MOR is subducted beneath Eurasia; Izanagi MOR connects with new MOR north of Exmouth plateau as

150 Ma - Rifting in South Atlantic; Stikine terranes collide with North America closing the Slide Mountain BAB; Lhasa-Qiangtang BAB closes

150 – Today - North America moves westward and the Rocky Mts are thrust skyward (Sierra Nevada, Sevier and Laramide orogenies)

145 Ma - Gulf of Mexico stops opening

140 Ma - Seafloor spreading begins in southern South Atlantic

135 Ma - Eruption of the Etendeka (Namibia)-Serra Gerral (SE Brazil) LIPs

120 Ma - Rifting in east-central Africa (Chad / Sudan); complete closure of the Mongol-Okhotsk Seaway;

120 -90Ma - Eruption of large LIPs in the SW Pacific (Manihiki, Ontong-Java)

115 – 90 Ma - Creation of the Kerguelen plateau by voluminous reruptiosn at the Kerguelen hot spot (HS)

115 – 75Ma - Opening of the Olyutorska BAB of NE Siberia

110 Ma - Seafloor spreading begins in the northern South Atlantic; the Philippines island arc rifts away from the margin of S. China;
100 Ma - Wrangellia collides with western North America (British Columbia); collision of Caribbean oceanfloor with Mid-America SZ results in “capture” of Caribbean and start of west-dipping SZ along the eastern margin of the Caribbean plate; Rifting in the Tasman Sea as Zealandia begins to separate from eastern Australia;

105 Ma - Seafloor spreading stops in the Somali Basin and between NW India and the Lut block;

100 – 50 Ma - Dextral strike-slip along western North America carries Wrangellia and portions of the Stikine terranes, northward (~1500 km).

95 – 50 Ma - Australia slowly rifts away from Antarctica

90 Ma - India rifts away from Madagascar opening the Madagascar basin

90 – Today - Sinistral strike-slip along the northern margin of South America as Caribbean plate moves eastward along transpressive boundary; creation of the Ninety East Ridge by the Kerguelen HS

80 Ma - Obduction of ophiolites in Guatemala and Honduras as Caribbean plate collides with Central America

85 – 70 Ma - The oceanic lithosphere of the Bering Sea is created at the Izanagi MOR

75 - 35Ma - Sea Floor Spreading in the Philippine Sea

65 Ma - India, as it moves northward, collides with Lut block and carries it northward towards Eurasia; Eruption of the Deccan LIP;

60 Ma - Subduction of the Izanagi MOR beneath eastern Asia; Subduction of the NE Indian Ocean MOR north of Australia;

Collision of the island arcs that makeup Kamchatka with NE Siberia; Capture of the Sea of Okhotsk;

60 Ma – Today - Collision of Adria/Apulia to form the Alps; 55 Ma - The Pacific plate changes direction (from N to W-NW);

50 Ma - India begins to collide with Asia; Greater Antilles arc (Cuba & Hispaniola) collides with Bahamas platform opening the Yucatan basin; Caribbean plate begins to move eastward with spreading at Cayman Ridge;

50 - 25Ma - Sea floor spreading in the Caroline Sea

50 Ma – Today - The collision of India deforms south-central Asia and results in the southeastward “extrusion’ of SE Asia; Australia, together with India, rapidly rifts away from Antarctica

45 Ma - Extension begins in South China Sea

35 Ma - Extension begins in East Africa and Red Sea/Gulf of Aden;

30 Ma - Youngest ocean floor in South China Sea and Sea of Japan; closure of the deep marine connection between Tethys and the eastern Mediterranean;

30 – 15 Ma - Cosica and Sardinia rifts away from the southern coast of France opening the Ligurian Sea, and the Balearic islands rift away from the eastern coast of Spain opening the Balearic Sea (due to slab roll-back);

30 Ma – Today - Extension begins in the Basin and Range; Collision of Arabia and Ian to form the Zagros Mts.;

25 Ma - Subduction of the Farallon MOR beneath northern Mexico/southernmost California resulting in the rifting of Baja California from northwestern Mexico;
25 Ma – Today  - Baja California and California west of the San Andreas Fault are carried northwestwards with the Pacific plate; continuing extension in the Basin & Range.

20 Ma  - Seafloor spreading (oldest ocean floor) in the Gulf of Aden;

15 – 0 Ma  - Calabria rifts away from Sardinia opening the Tyrrhenian Sea (due to slab roll-back); ~500 km of dextral motion along the North Anatolian Fault as Turkey is squeezed westwards between Arabia and Eurasia;

10 Ma – Today  - The extension in the Aegean Sea; ~150 km sinistral displacement along the Dead Sea Fault;

Seaway – a narrow oceanic region that is connected to open ocean, but is largely surrounded by continents.

Block – A small region lithosphere, usually continental, that is bounded by unspecified tectonic boundaries.

Terrane – a lithospheric region bounded by identifiable tectonic boundaries that possesses a coherent stratigraphic record.

Plate – A region of lithosphere bounded by one or more of the following tectonic boundaries: midocean ridge (MOR), subduction zone (SZ), or strike-slip fault (transform or transcurrent).

Tectonic Element – A plate, terrane, or block that has had a unique history of independent movement.

Abbreviations Used:

HS – hot spot (i.e. the surface expression of a mantle plume)

MOR - Midocean Ridge

SZ - Subduction Zone

BAB - Back-arc Basin

LIP - Large Igneous Province

Credits

These plate tectonic reconstructions and animations are based on the PALEOMAP Global Plate Tectonic Model, developed by C.R. Scotese. The were visualized using the program, Gplates, developed by R.D. Müller and EarthByte team.

(insert Gplates logo)

References Cited

(to be added later)
### TABLE 1. Oceans

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* also Neo-Tethys, Neotethys,
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* also Gondwana-Land
Early Mesoproterozoic
Early Mesoproterozoic
1,300 Ma

A Grenvillia
B Chimeria
C BundelWAus
D Aravavaria
E Dharayner
F Greater Amazonia

Middle Mesoproterozoic
1,000 Ma

PALEOPANTHALASSIC OCEAN

MOZAMBIQUE OCEAN

Early Neoproterozoic

A Rodinia
B Congo continent
700 Ma

PANTHALASSIC OCEAN

PROTOTETHYS OCEAN

Kipchak Sea

Uralian Sea

N. Slope

Siberia

Kolyma

Aegir Sea

Amfibia

Congo continent

A. N. Rodinia

B. Congo continent

C. S. Rodinia

Early Cryogenian
20 Ma

Early Miocene

NORTH ATLANTIC OCEAN

SOUTH ATLANTIC OCEAN

INDIAN OCEAN

PACIFIC OCEAN

North America

South America

Africa

Eurasia

Arabia

India

China

Australia

Zealandia

Antarctica