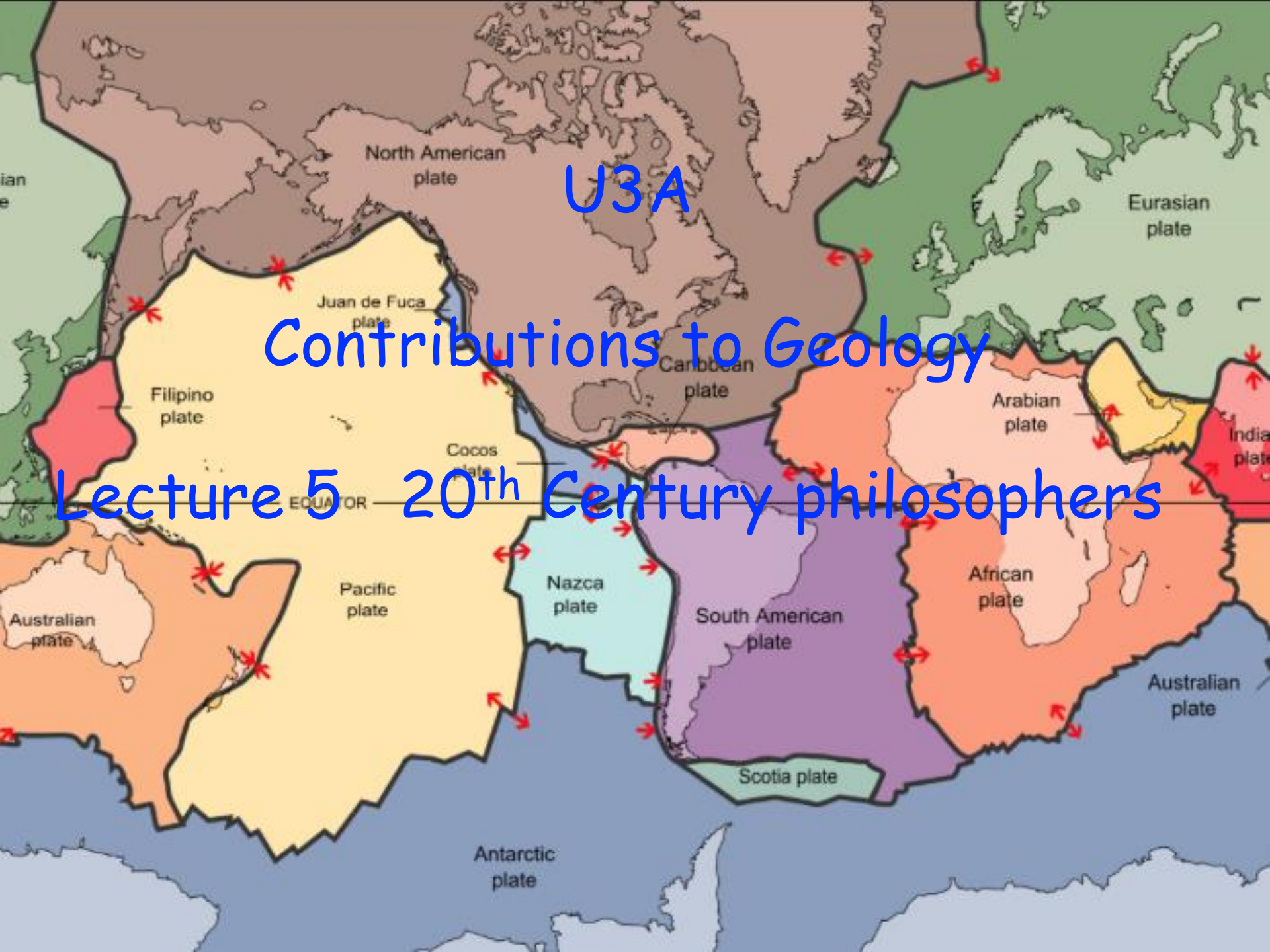


U3A

Contributions to Geology

Lecture 5 20th Century philosophers

Third term presentations

24/7 Contributions to Geology 5

7/8 Regolith geology

21/8 Geology of coal and gas

4/9 Geology of Cu

18/9 Geology of Pb-Zn

Introduction

- By the beginning of the 20th century, geology was well established as a progressive science
- new technologies enabled advances such as the age determination of rocks and accurate analyses of rocks and minerals
- there were however, still mysteries to be solved, particularly on the internal structure of Earth, its history and how our planet works
- new branches of geoscience came to fore → geophysics, planetary geology, remote sensing
- these questions were largely answered in the 20th century but not without controversy

Alfred Wegener

Alfred Wegener (1880-1930)

Alfred Wegener

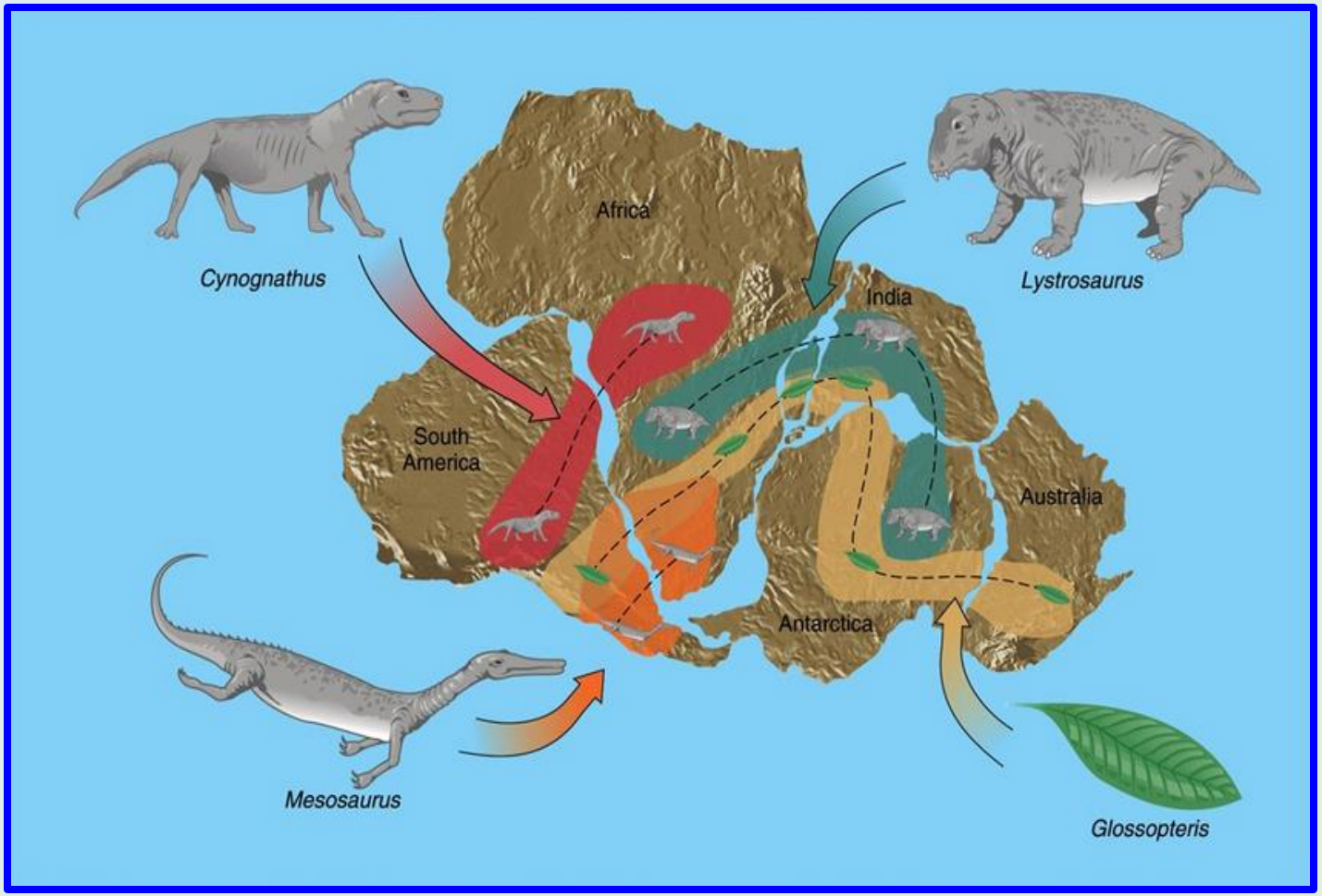
- German meteorologist, geologist and explorer
- Pioneered the use of balloons for tracking air circulation, wrote meteorology textbook
- from 1909 lectured in meteorology and astronomy at the University of Marburg, Germany
- made 4 major expeditions to Greenland to study polar meteorology
- strongly supported theory that the continents were once joined (1912)
- Wegener called the dispersal process continental drift

Theory of continental drift

- Wegener showed that by reconstructing a former large continent the geology supported the fit
- he proposed that continents formed one landmass → super-continent he called Pangea and were dispersed
- Wegener noted a close fit between the coastlines of Africa and South America was consistent with similarities in fossil fauna and flora on opposite sides of the Atlantic
- to support his theory he looked at the geology of the two continents noted that large-scale, geological features on the continents often closely matched
- dismissed theory of land bridges connecting continents

Gondwana fossil evidence

- Growth of oceans between continents → prevented migration between them by Permian and Triassic tetrapods



Evidence from matching mountain belts

- Wegener noted that large scale features on separated continents often closely matched e.g. Appalachian-Caledonian mountain belt → remnant of a major mountain chain

- argued against cooling, contracting -Earth theory of the formation of Earth's mountains

- not consistent with bands mainly formed along edges of continents

- he proposed that they formed by past collision of continents → compression, folding

Precambrian geology of South America and Africa

- Good match between Precambrian rock types and structures in South America and Africa on either side of the Atlantic

Precambrian rocks

Wegener's theory of continental drift

- Ideas based on fit of continents and continuity of geological features across juxtaposed continental boundaries
- noted similarities in fossils in Brazil and Africa → animals that could not swim or could only swim small distances
- his reconstructed landmass Pangea → matched other geological features (rock formations, mountain belts)
- his evidence implied → continents were once joined

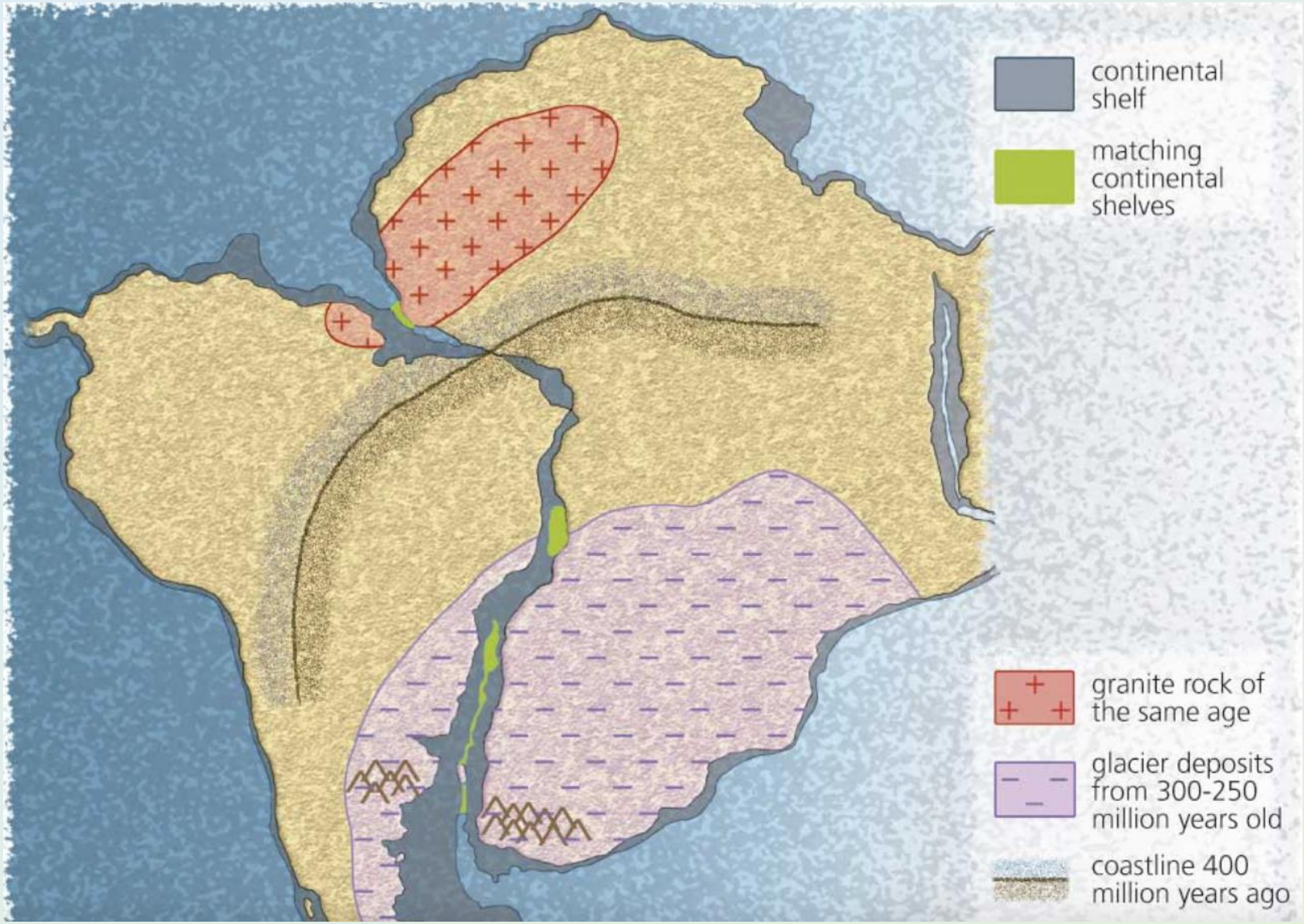
Theory of Continental Drift

- Proposed by Alfred Wegener in 1915 → continents float on the underlying interior of the Earth periodically break up, drift apart
- in 1915 published book "The Origin of the Continents and Oceans"
- he thought mountains formed when the edge of drifting plates crumpled and folded such as India colliding with Asia
- he proposed that an ancient continent (he called Pangea) had existed in the past
- 300mya → all of the continents were joined together → formed super continent Pangea

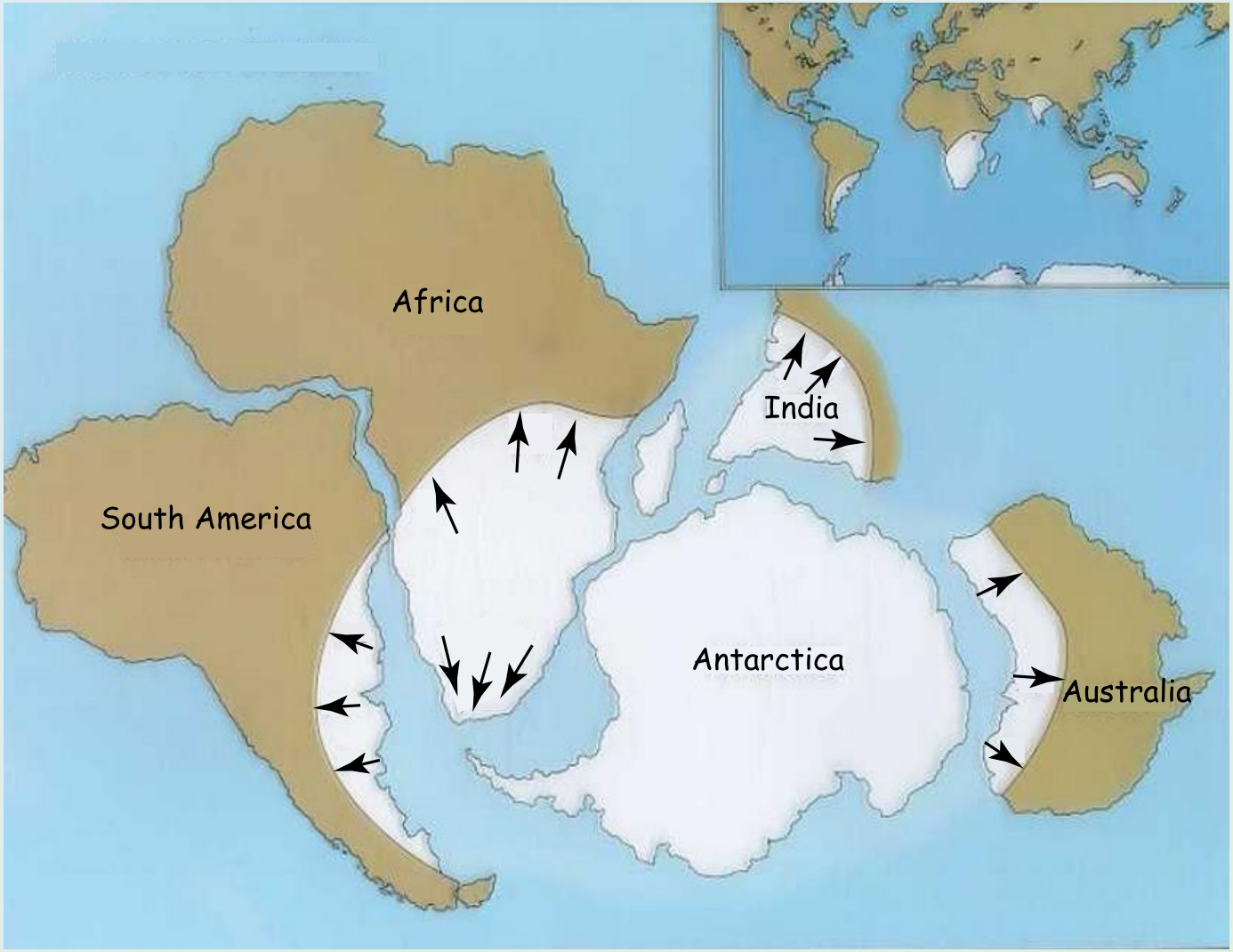
Theory of continental drift

- ~180mya Pangea broke up to form a number of smaller continents migrated to other regions of the globe
- in 1926 he was invited to New York to present his theories
- his theories were met with derision from the scientific community only support from South African geologist Alexander du Toit and Swiss geologist Emile Argand (plate collision → orogenesis)
- criticism → unable to provide a satisfactory mechanism for how the process of continent dispersal could occur
- his reconstruction of Pangea explained distribution of Permo-Carboniferous glacial features clustered around South pole

Geological evidence



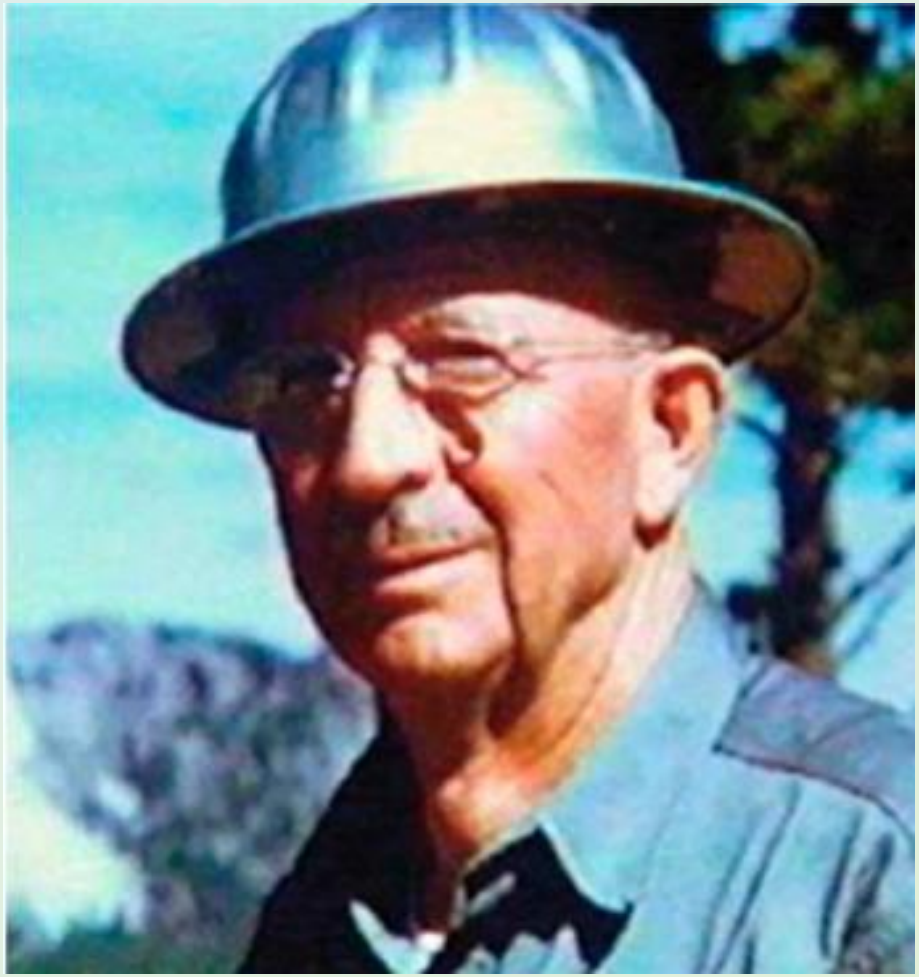
Distribution of Permian glacial deposits



Evidence of the Permo-Carboniferous ice age era scattered over most of the world → clustered around South Pole on Wegener's reconstruction

J Harlen Bretz (1882-1981)

American geologist best known for his research that led to the acceptance of the Missoula floods and sculpting of the Channeled Scablands in East Washington State



J Harlen Bretz

J Harlen Bretz

- Graduated from Albion College, Michigan with geology degree (1905)
- began studying glacial geology in western Washington State
- completed PhD in geology at University of Chicago in 1913
- became assistant professor of geology firstly at University of Washington and then at University of Chicago
- from 1922-29 conducted field research on erosion of the Columbia River plateau
- published paper in 1923 arguing that erosional areas he called the Channelled Scablands were caused by past massive flooding
- his theories at the time conflicted with the philosophy of gradualism

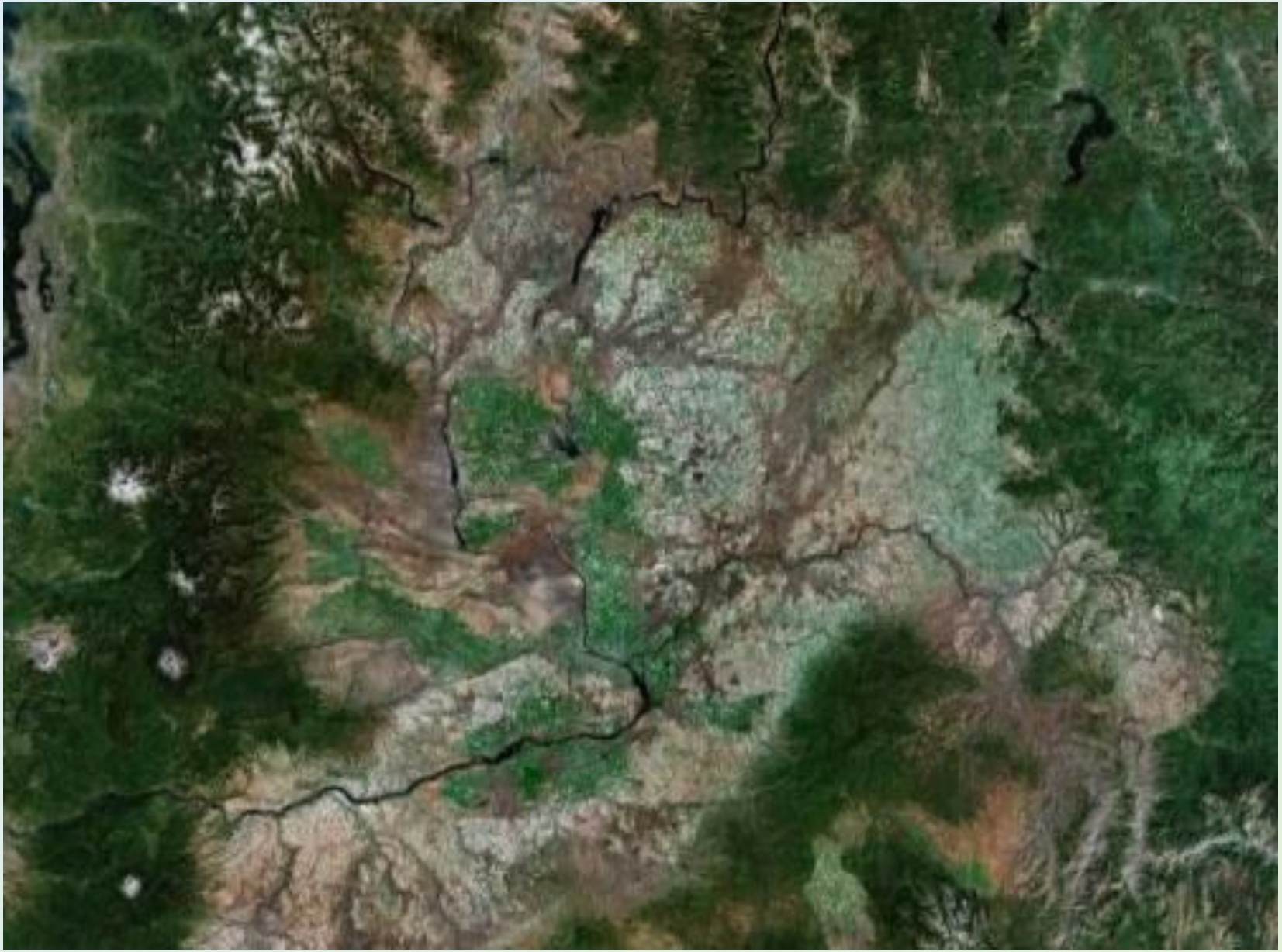
Channelled Scablands

- Area of uniquely sculptured terrain (>4000km^2) in eastern Washington State (extends from Spokane in the north to south of Pasco and west to Vantage)
- characterised by anastomosing channels, flat-topped hills, gigantic ripples, dry cataracts and very few trees
- formed towards the end of the last glaciation by enormous flood(s) caused by the failure of a gigantic ice dam
- erosion occurred over a very short period of time
- theory of formation first proposed by Bretz in 1920s

Scablands stratigraphy

- Scabland region underlain by thick sequence of basalt lava flows up to 2km thick (6 - 14.5myr old)
- unconformably overlying the basalts are fluvial silts and sands
- during arid glacial periods sand and silt loess formed a large area of rolling, grass covered hills → Palouse Hills
- flood erosion stripped off most of the loess, dissected the underlying basalt forming steep-sided coulees
- the Hansford formation comprises coarse gravels and sands deposited by glacial floods

Satellite image of channelled scablands

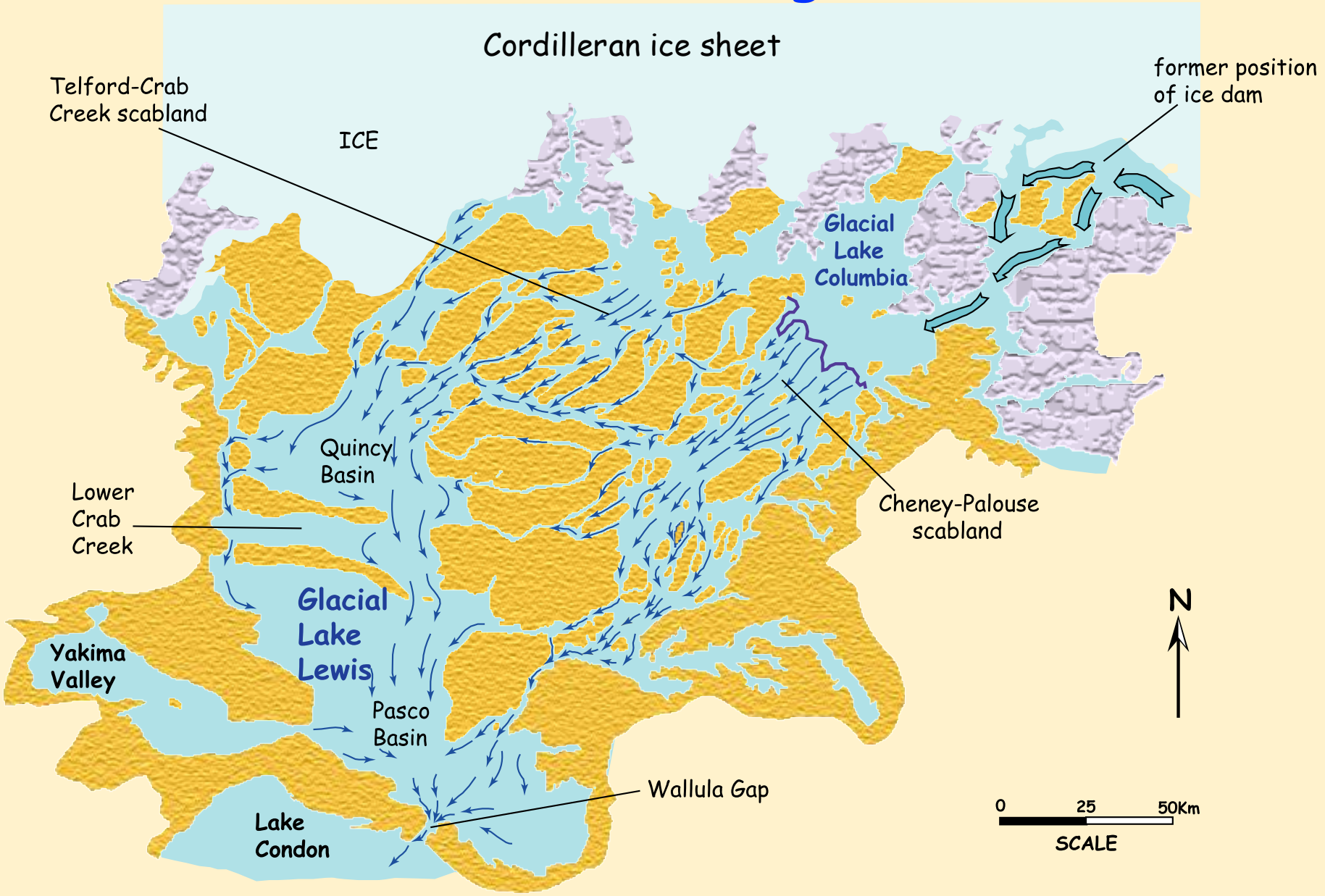


Channelled Scablands

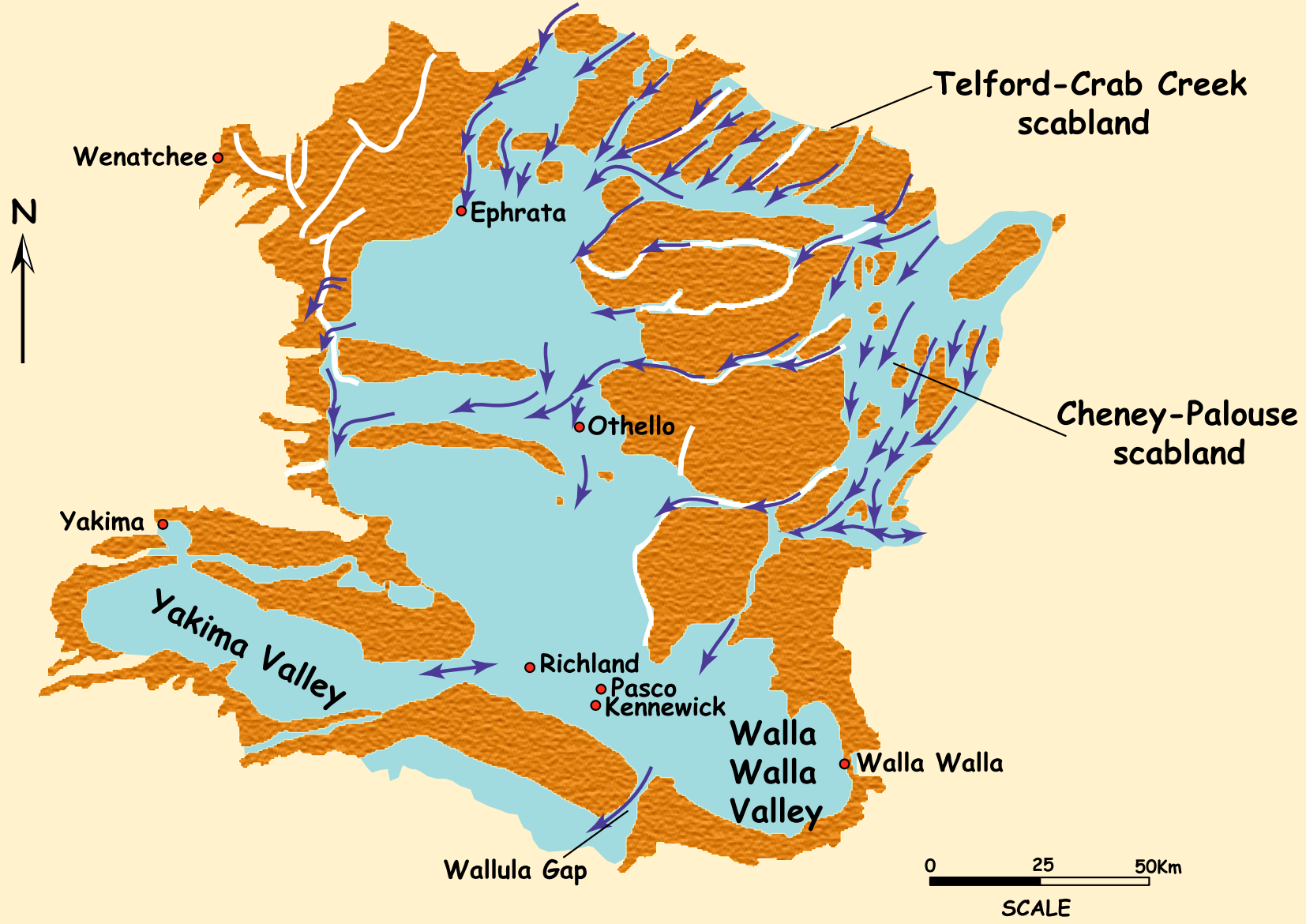
Anastomosing coulees eroded into Columbia River basalt

Channels and coulees – Drumheller channels

Missoula flood waters through the Scablands



Waterflow into and out of Lake Lewis



J Harlen Bretz

- In 1927 he attended a meeting of the US Geological Society in Washington, DC where his theories were aggressively challenged
- one of the shortcomings of his story → couldn't explain origin of floodwaters
- another geologist at the meeting (Joseph Pardee) knew the source of the floods but kept silent during the debate
- Pardee later revealed that Lake Missoula was the source of the floods and worked with Bretz
- Bretz's theories were finally accepted in the 1970s → awarded Penrose medal for geology at the age of 97

Bertram Boltwood (1870-1927)

- American physicist, pioneer of radiochemistry, born in Massachusetts
- As a boy was interested in mechanical gadgets, photography and minerals
- graduated with high honours in chemistry from Yale in 1892
- studied in Germany for 2 years prior to gaining PhD back at Yale in 1906
- developed friendship and collaborated with Ernest Rutherford

Bertram Boltwood

Bertram Boltwood

- Graduated with high honours in chemistry from Yale in 1892
- studied in Germany for 2 years prior to gaining PhD back at Yale in 1906
- appointed professor in Yale radiochemistry department in 1910
- developed friendship and collaborated with Ernest Rutherford
- established that Pb was the final product of U radioactive decay
- observed that the Pb-U ratios were higher in older rocks
- found that Pb was always present in U and Th ores
- first to measure the age of rocks by the decay of U to Pb in 1907

Dating geological samples

- Uranium-Thorium-Lead methods

  Decay through a complex chain of α decays and Y emissions

  $^{238}U \rightarrow {}^{206}Pb$ decay chain Half-life = 4,468 Ma

  $^{235}U \rightarrow {}^{207}Pb$ decay chain Half-life = 704 Ma

  $^{232}Th \rightarrow {}^{208}Pb$ decay chain Half-life = 1,410 Ma

- used for measurements on:

  - U-Th-bearing minerals e.g. zircon, sphene, monazite

  - Uranium ore minerals e.g. uraninite, pitchblende

- modern mass spectrometers accurate to 10 decimal places with accuracy of 0.1%

Charles Richter (1900-1985)

American seismologist and physicist (who along with Beno Gutenberg), created the Richter scale measurement of earthquakes whilst working at the California Institute of Technology where he worked from 1937 to 1970 teaching physics and seismology

Charles Richter

Charles Richter

- Born in Ohio to German parents in 1900
- attended Stanford University and received his undergraduate degree in 1920
- began working on a PhD in theoretical physics at California Institute of Technology
- before finishing, was offered a position at the Carnegie Institute in Washington DC a position he held (1927-36)
- became interested in seismology
- taught physics and seismology at Caltech (1937-70) while working in seismological laboratory

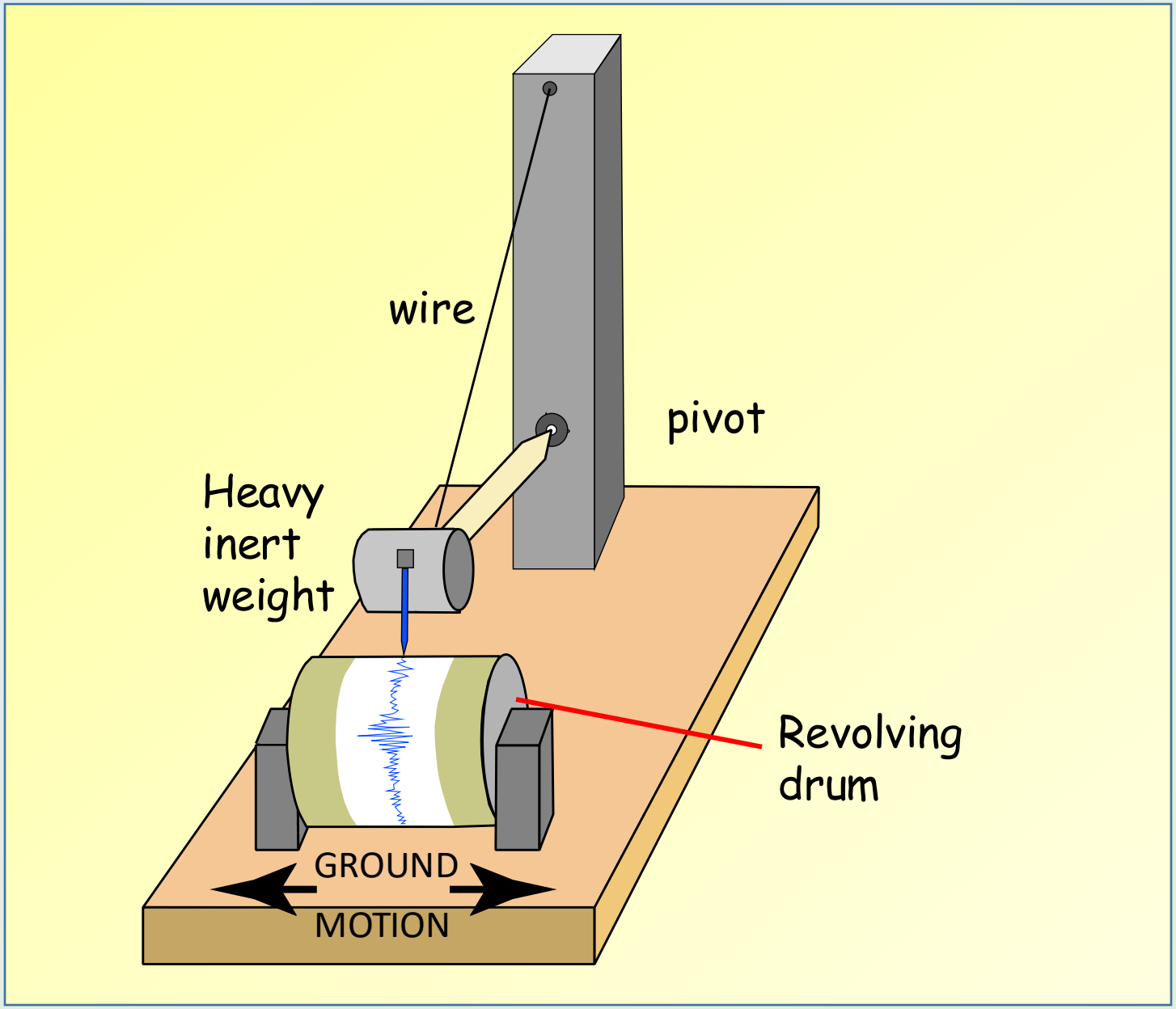
Richter magnitude scale

- The Richter scale (unlike the Mercalli scale) is an absolute measure of earthquakes
- it is a logarithmic scale based on measuring the quantitative displacement of the Earth by seismic waves
- measurement is made on a seismograph consisting of an unwinding roll of paper on a rotating drum and a pendulum with a marking device to record actual Earth movement

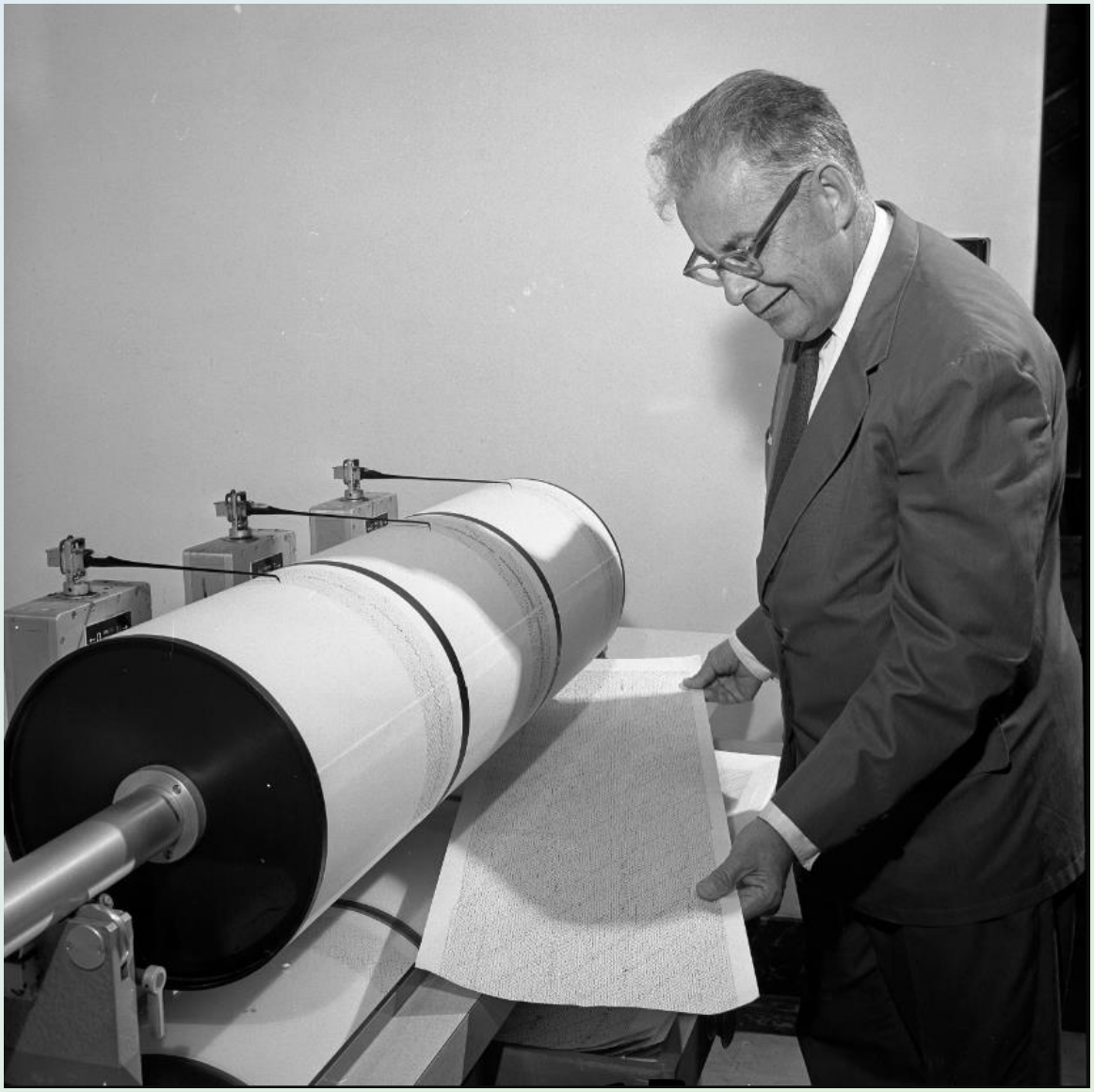
Seismographs

- Seismographs are instruments used to measure earthquake activity quantitatively (irrespective of damage caused)
- a seismogram is the record that seismographs produce of the arrival times and magnitude of seismic waves
- seismographs do not have to be in immediate vicinity of quake → can be remote, not even in area of human detection
- seismographs enable us to measure the size of earthquakes and locate them accurately from the arrival time of seismic waves

Mechanical seismograph

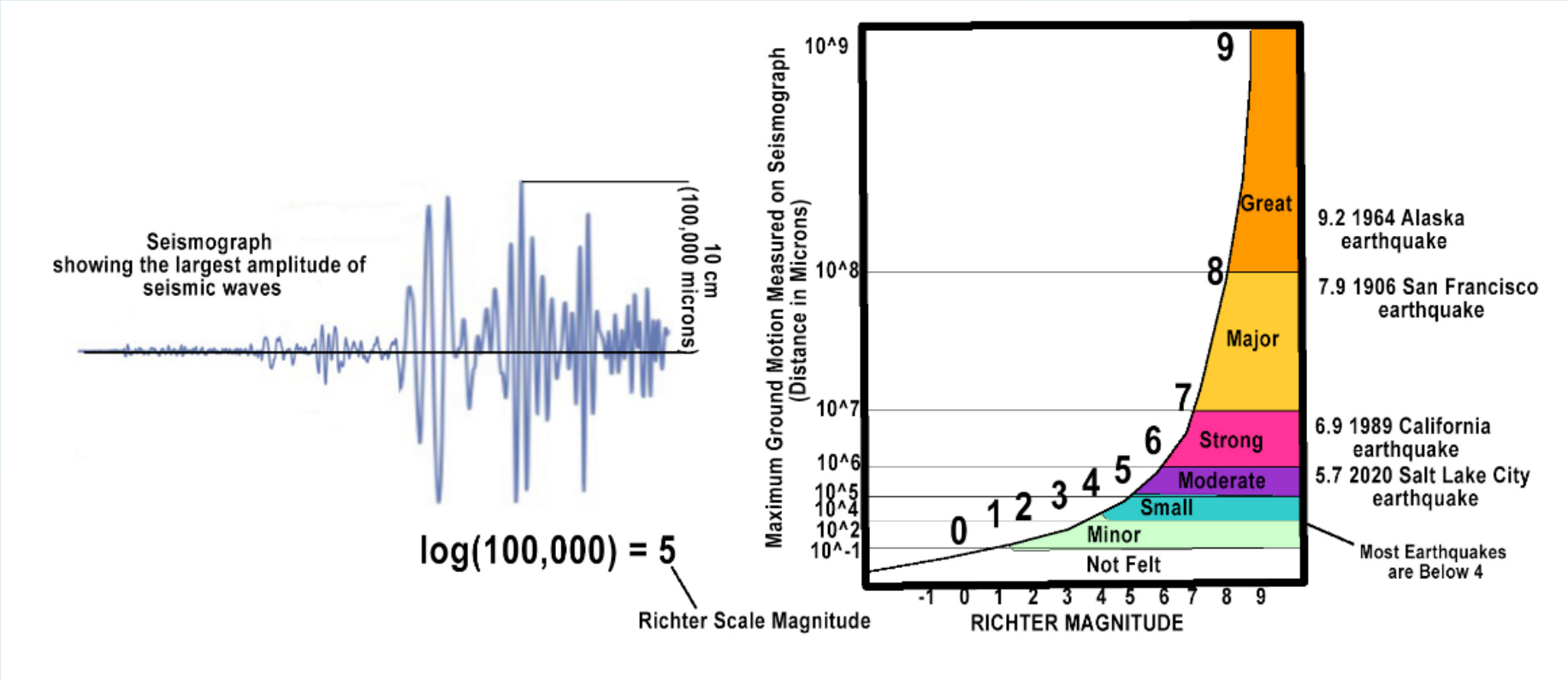


Charles Richter with a seismograph



How the Richter Scale is determined

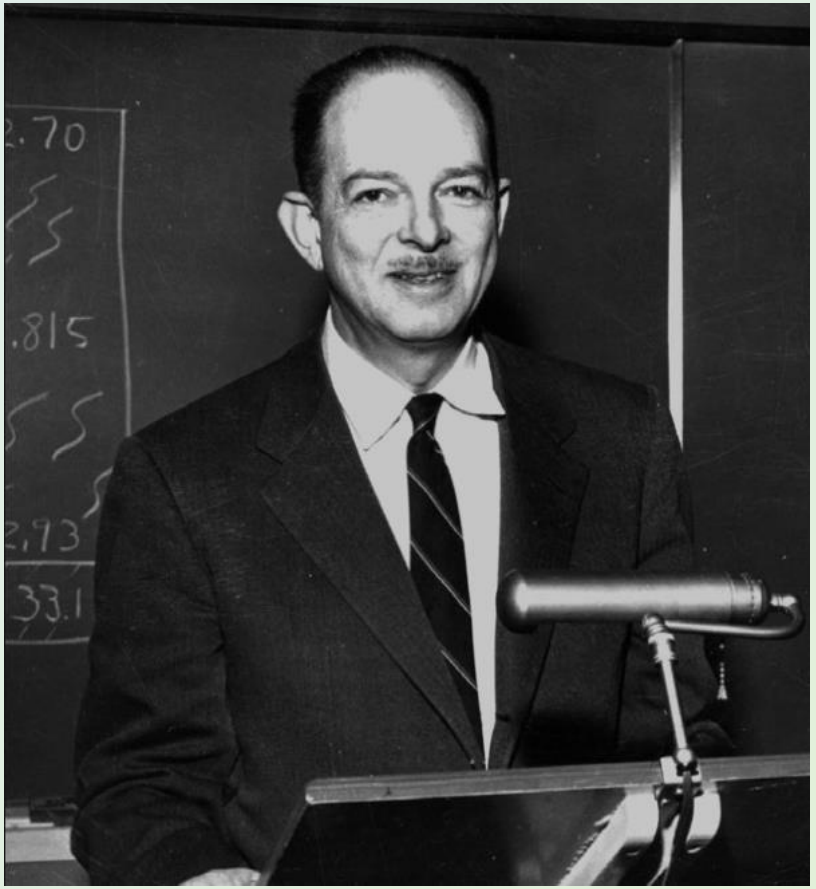
The Richter scale is logarithmic e.g. a magnitude 7 earthquake is 10 times stronger than a magnitude 6 and 100 times stronger than a magnitude 5



Richter scale = log (number of microns of displacement amplitude)

Harry Hess (1906-1969)

- Born in New York in 1906
- US geologist and Navy officer considered one of the founding fathers of the theory of plate tectonics
- man who first proposed seafloor spreading



Harry Hess

Harry Hess

- Entered Yale University in 1923 to study Electrical Engineering
- graduated from Yale University in 1927 with a geology degree
- worked as exploration geologist for 2 years in Northern Rhodesia
- obtained a PhD in geophysics from Princeton University in 1932
- conducted research in geophysical laboratory at Carnegie Research Institute of Washington
- joined faculty of geophysics at Princeton in 1934 and remained there for the rest of his career (war service excepted)

Harry Hess

- During WWII as a commander of an attack transport → mapped ocean floor in North Pacific using state of art sonar technology
- identified guyots using sonar
- identified that oceans are shallower in the middle and identified mid-ocean ridges
- discovered that the deepest parts of the ocean were close to continental margins forming deep trenches
- published "History of Ocean basins" 1962 → proposing the theory of seafloor spreading in support of continental drift

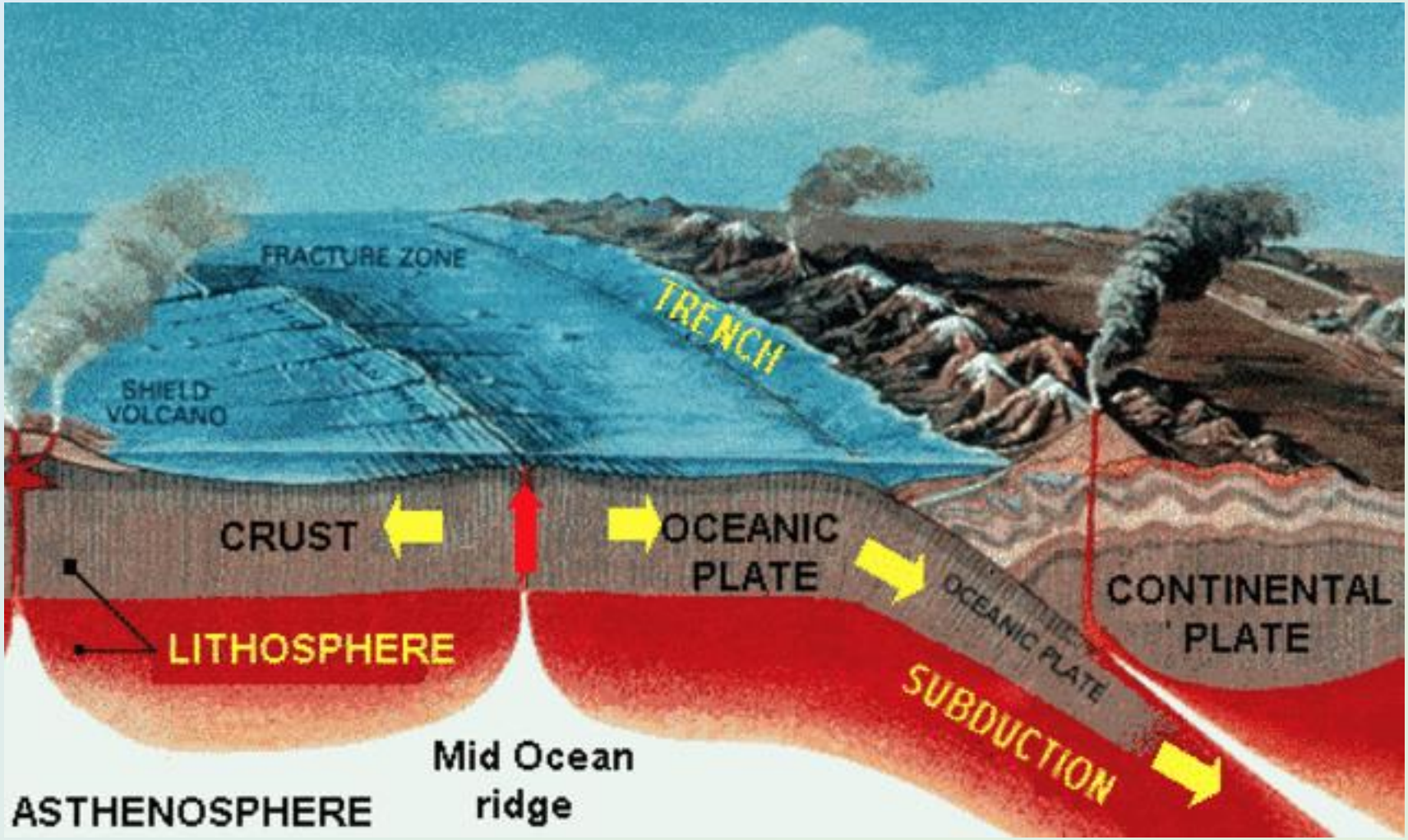
Harry Hess

- Hess described how magma would rise and intrude along the Great Global Rift
- when magma cooled it would expand and push crust apart
- he also concluded that trenches were locations where ocean floor was destroyed
- in 1950, Hess advanced the theory that the Earth's crust moved laterally away from volcanically active ocean ridges
- his theory was further strengthened when dating of seafloor showed that the oceanic crust increased in age away from the ridge crests

Seafloor spreading

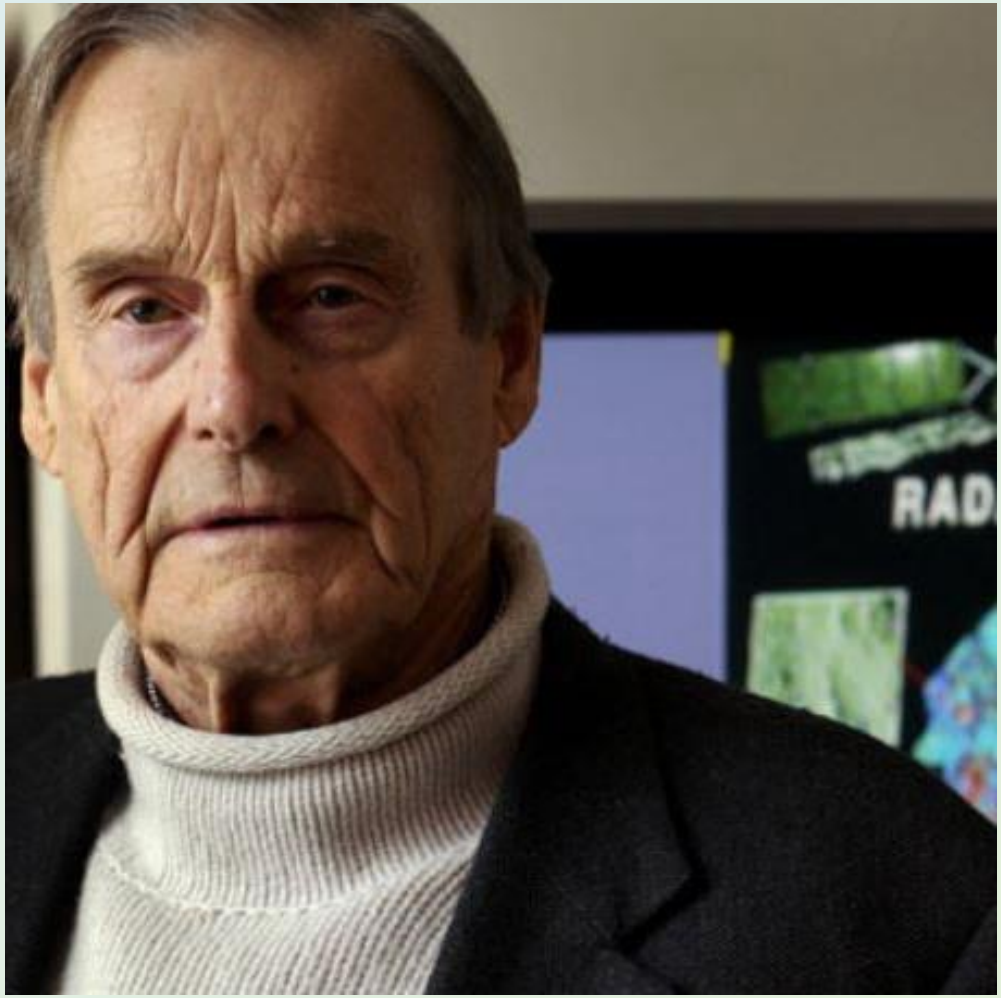
- Sea floor spreading → process that occurs at mid-ocean ridges where new ocean crust forms through volcanic activity
- key to explaining continental drift
- at spreading centres, magma is injected into fissures in the ocean crust
- age of oceanic crust increases away from spreading centre
- idea of seafloor spreading proposed by Harry Hess based on topography of the sea floor

Sea floor spreading



Lawrence Morley (1920-2013)

Canadian geophysicist and remote sensing pioneer



Lawrence Morley

Lawrence Morley

- Studied physics and geology at the University of Toronto gained MSc and PhD in geophysics
- worked on the theory of sea floor spreading and seafloor magnetism in parallel with English geologists Vine and Matthews
- demonstrated the presence of magnetic patterns in igneous rocks on the sea floor independently of Vine and Matthews
- in 1962 he submitted his theory of sea floor spreading that was rejected
- created remote sensing techniques to map the Earth's surface from satellites and aircraft

Fred Vine and Drummond Matthews

Developed theory of seafloor spreading in parallel with Morely

Fred Vine on left, Drummond Matthews on right

Drummond Matthews (1931-1997)

- British marine geologist and geophysicist who was an important contributor to the theory of Plate Tectonics
- graduated from King's College, Cambridge with a geology degree
- worked as a geologist in Falkland Islands (1957-1959)
- completed PhD at Cambridge in 1962 → became a Research Fellow
- conducted a magnetic survey across the Carlsberg Ridge in the NW Indian Ocean
- the survey revealed a pattern of magnetic anomalies running in parallel stripes symmetrical on either side of ridge
- Matthews and his student (Fred Vine) proposed that magma injected along the mid-ocean ridge retained the polarity and strength of Earth's magnetic field at the time of emplacement

Fred Vine (1939-2024)

- British marine geologist and geophysicist and student of Drummond Matthews
- graduated from King's College, Cambridge with PhD in geophysics
- together with Drummond Matthews originated hypothesis that supported Harry Hess's sea floor spreading theory
- collaborated with Matthews to show that magnetic reversals preserved in ocean floor basalts can be seen as parallel stripes on either side of the mid-ocean ridge
- had their theory published in Nature in 1963

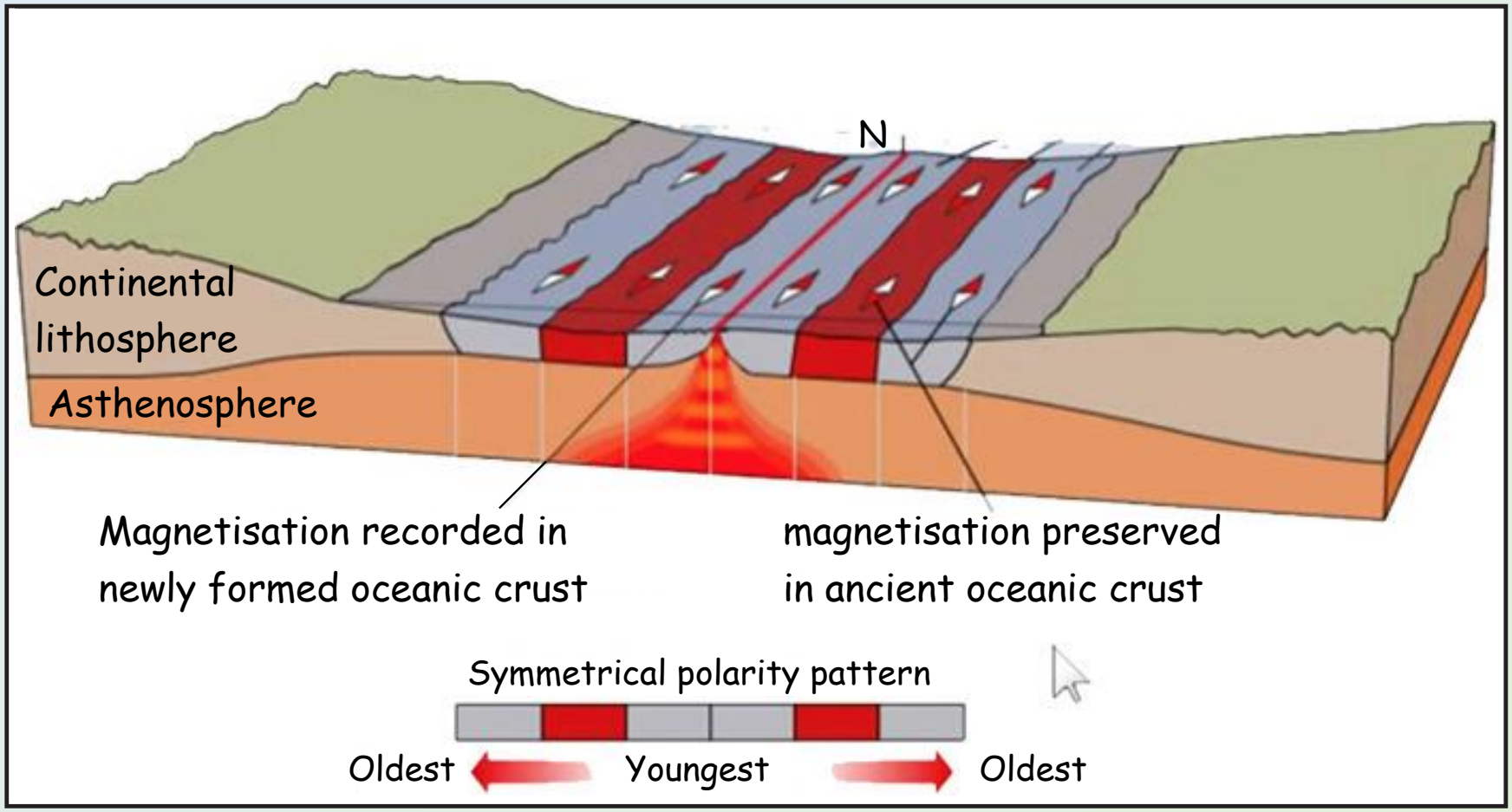
Morley-Vine-Matthews hypothesis

- Proved that Hess's theory of sea floor spreading was factual
- identified magnetic anomalies in the oceanic crust due to alternating strips of new ocean crust formed at different times
- new crust formed at spreading ridge preserves polarity and magnitude of the Earth's magnetic field at the time of intrusion
- data indicates periods of reversed polarity over time → symmetrical magnetic patterns on the sea floor
- research led to creation of palaeomagnetic time-scale

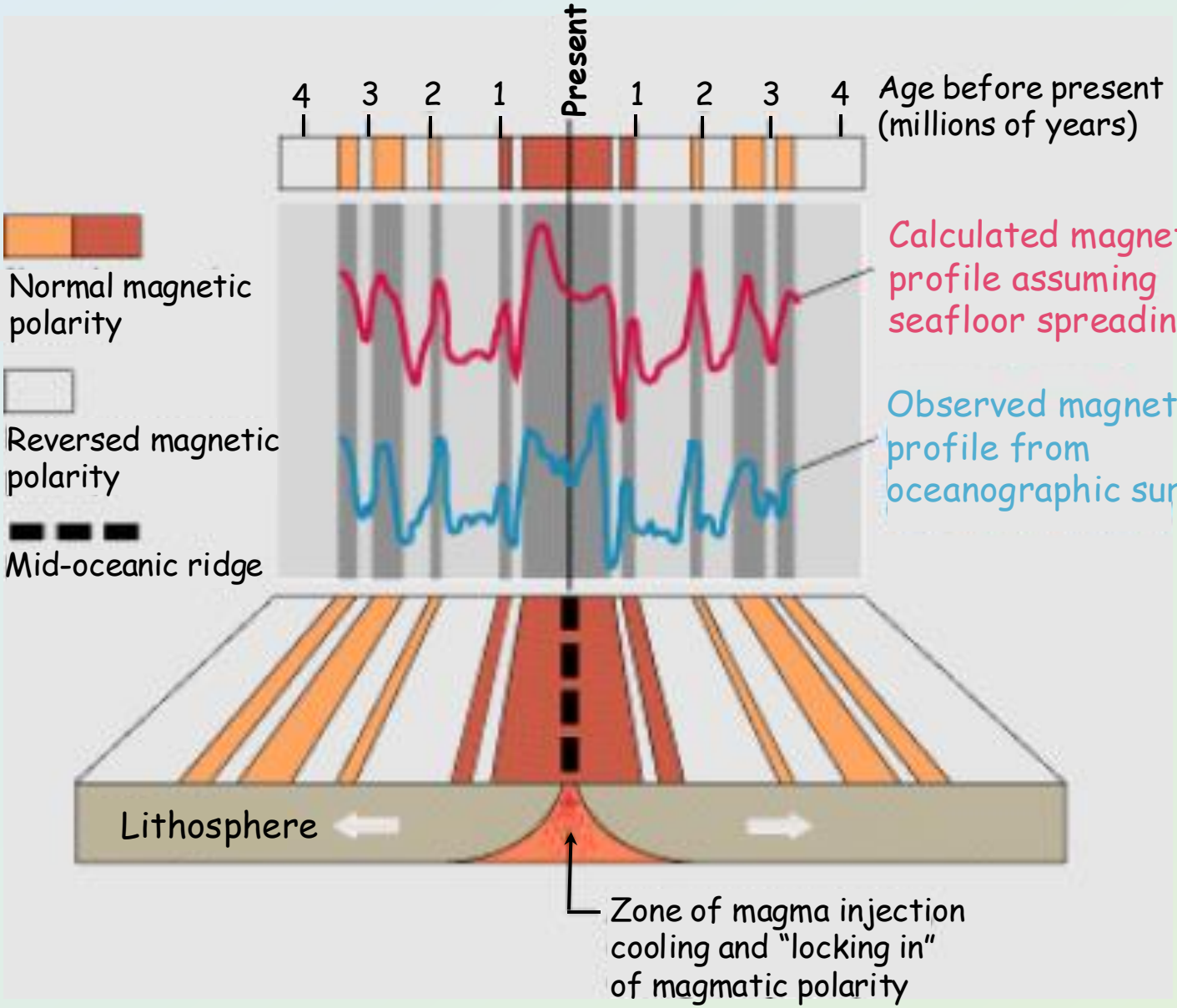
Morely-Vine-Matthews hypothesis

- New oceanic crust develops beneath median rift
- rocks become magnetised with field direction and strength of Earth's magnetic field preserved
- moving further away from rift, on either side, older rocks preserve magnetic field of last magnetic field reversal
- reversed magnetic field produces a negative magnetic anomaly
- the hypothesis correlates symmetrical magnetic patterns on seafloor with seafloor spreading

Morley-Vine-Matthews hypothesis

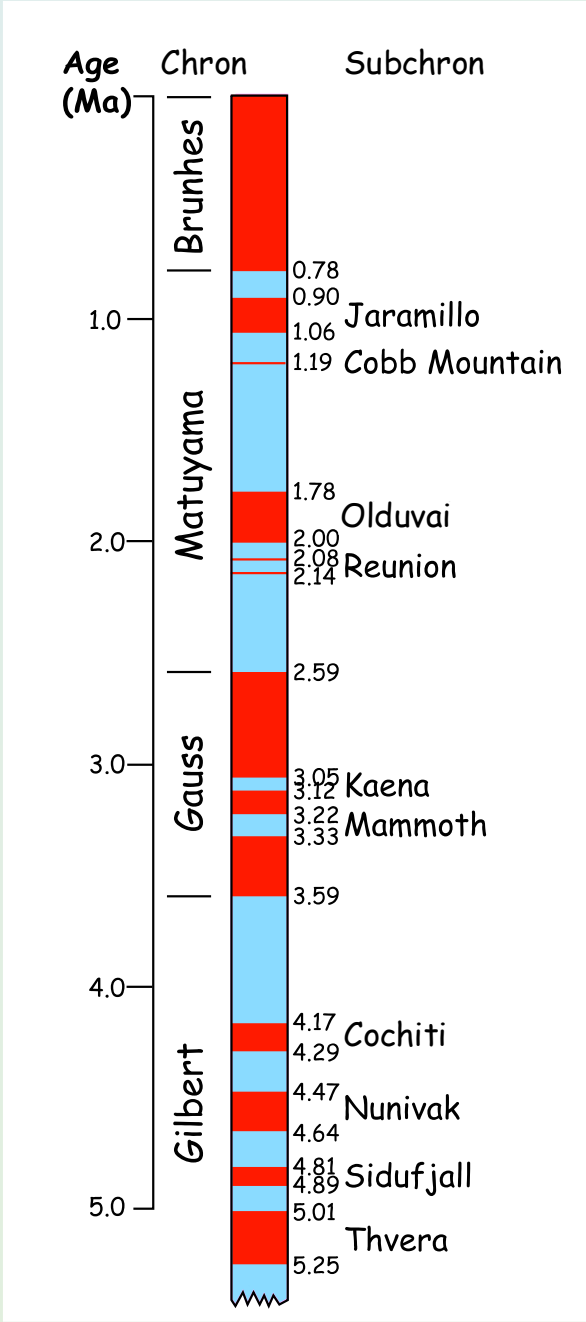


Magnetic profile around mid-ocean ridge



Geomagnetic reversal

- Occurs when magnetic north and magnetic south are interchanged
- large periods are called chrons
- smaller periods are called subchrons
- transition periods → 1,000 – 10,000years but as short as decades
- magnetic fields of planets generated by dynamo action in core
- instability causes magnetic field to flip
- Solar magnetic field reverses every 9-12years



Earth's geomagnetic polarity during the last 5myr