Evidence for drifting continents was mounting through the mid-century but the role of the oceans was not yet well understood.

How do magnetometers work? for dragging behind boat or plane

- fluxgate
- proton precession
- optical absorption

Strength of field is 25,000 - 65,000 nT

These instruments measure total field strength to +/- I nT Cryogenic magnetometers e.g. SQUID are extremely sensitive down to a few fT but only for use in very controlled lab conditions. studies on core, biological samples, other small samples.

The field we observe is the combination of the direct field coming from the geodynamo and the induced magnetic fields in crustal minerals. As the spatial variation in geology is much smaller lengthscale than the variation in the earth's magnetic field, we can interpret short lengthscale anomalies as due to variation in the composition, concentration, and alignment of both paramagnetic and magnetic minerals. The paramagnetic minerals show an induced field from the earth's field.

MARINE MAGNETIC MAPPING

West coast, Big Sur to Vancouver was published in 1961-1964. showed striping of reversing magnetic anomalies, and perpendicular offset lines inferred to be faults. these faults have strong topographic expression on the sea floor. lateral offset sometimes 1000s km.

Key attributes:

- stripes parallel ridge crests
- width distribution shows symmetry around ridge crests (sort of)
- width varies but on average 10-20 km
- anomalies recorded in volcanic rocks (Layer 2)

INSERT GEODYNAMO NOTES FROM PREVIOUS WEEK'S NOTES

Driving mechanism for spreading - mantle convection currents? consequence of spreading - new crust must be balanced by crust destruction

Dietz 1961 basically put it all together! Vacquier, Raff and Warren 1961 -fracture zones, lateral offset, based on sea floor maps

How to explain? On-land observations that rocks of some ages had a reversed magnetic remnant field (as if compasses were pointing toward the South Pole). In mafic rock with a lot of iron, there is a strong remnant field which can be seen even when it's competing with the induced field.

the time series of reversal dates are sufficiently well known that with very complete records, can match patterns and use these as a proxy for date. At least back to Jurassic (oldest oceans). terrestrial environments - less consistent deposition - average rates don't mean very much, pattern is not preserved. Best short records exist from continental flood basalt provinces. the patterns representing true field reversals are global.

Periods of consistent magnetic field = CHRONS (periods between reversals) Chrons were known on land but hard to date - marine sed record offered microfossil dates. Frequency of reversals varies a lot through out the Mesozoic and Cenozoic. There's a big long chron in the late Cretaceous of 20MY (superchron) but mostly every few 100KY.

in areas with constant volcanism/spreading, can expect the width of stripes to correlate to the time duration of the stable field between reversals by the relationship:

width of stripe = duration of stable mag field * average spreading rate

This gives us spreading rates of ocean ridges, which range from about 1-5 cm/yr. the appearance of these patterns in all the oceans shows that spreading has been pretty much continuous everywhere at least since the jurassic (allowing for local variations in rates).

TRANSFORMS

Motivated by space problems and non parallelism of all plates, need transform movement to accommodate rotations. needed to explain the ends of ridges where they just seemed to terminate in the oceans and pick up somewhere else. However - transforms have weird offset patterns. Not like regular faults.

Complicated geometries of triple junctions are possible. transforms have a unique length: displacement relationship with displacement varying along their lengths in stepwise fashion. since wallrock on either side of the transform is deforming, apparent offset cannot be trusted.

Transforms often called "fracture zones" because of their bathymetric expression have big earthquakes, some very frequent.

Patterns can be complicated by Ridge Jumps where segments trade off in activity rate through time.

Go Thos for on Tuesd

CHAPTER 5- THE FRAMEWORK OF PLATE TECTONICS

Original framework - plates are rigid, stresses translate across them. 3 types of plate boundaries - all will balance. On the largest scale, this model works, but in detail, complexities arise. Next several chapters will explore the complexities. Plate boundaries are located by seismicity, and many/most earthquakes will reflect the motion of the plate boundary. However, the complex structures of nearly every plate boundary result in convergent boundaries having normal faulting, and strike slip basins along extensional boundaries, etc. Convergent boundaries have the biggest earthquakes, and in general the most frequent earthquakes.

Biggest earthquakes involve continental crust because of lower geotherm. Plate boundary earthquakes are shallower than 70km, most in upper 40 km. Strange things happen at greater depths - volume changes and thermal instability become important. Temperature structure controls earthquakes, with shallower foci in extension areas where heat flow is high.

enter: Hot Spot Reference Frame

Lots of igneous centers - isolated ones (not along active chains) are called hot spots. In 1971 it was proposed that hot spots were the eruptive result of hot mantle plumes from the deep mantle or core-mantle boundary. This ignited a

debate that is still raging. Some hotspots fit this model better than others shallow mantle melt anomalies can be produced by stretching plates or extensional asthenospheric flow, and appear at the surface similar to plumes. Some hotspots have signatures such as heavy helium which people interpret to mean there is a core degassing signature. others do not show these fingerprints of deep origins. Kimberlites and other freak short lived deep-seated volcanic centers are pretty unuseful because no time series, and cause/source is not well understood.

Hot spot debate:

- long lived heat source
- sometimes appears stationary
- suggestions in tomography of low velocity "pipes" to cmb
- some are short lived
- some move relative to the others

- still no explanation as to how they start or why or what controls how long they persist

- some workers believe that the few % potential melt at the litho/astheno boundary can just get to surface through fractures, shallow process.

the several hotspots which have been apparently fixed with respect to each other for 200 MY create a "fixed" reference frame. Best evidence for these: big melt volumes (LIPs) of initial out pouring, continental flood basalts and rifting, there are about 10 who fit this description.

In fact there are 2 networks which stay constant relative to each other - one in the pacific and one in the Indian Ocean. Test for consistency is to use the plate circuits to predict the position of the hotspot on the plate through time - if it matches, then the hotspots are either stationary, or they all move together. If they diverge, then there is motion between them. the Pacific and Indian hot spot populations have been moving separately for the last 40-50 Ma, and even more separate before that.

*44 Ma is the age of the Emporer seamount bend. Some workers believe there was a plate reorganization at this time that affected the whole pacific and beyond. others think the hawaiian hotspot was moving at this time.

CRETACEOUS SUPERPLUME

There was a ton of volcanism in the cretaceous (see: any dinosaur movie). Some

have proposed a superplume from the D" layer. serc.carleton.edu/research_education/cretaceous/superplume.html has a summary.

The plume might be a hot droplet that broke away from D" and rose to the lithosphere boundary where it spread out thousands of km thick. This just happened once but the effects lasted +/-100 MY. During this time: Decrease in magnetic reversals

increased spreading rates/oceanic crust production, and eruption of many most of the pacific seamounts

hot climate, high sea levels, abundant oil/black shale - increased mantle carbon in atmosphere?

<show Tan et al. video>

Others argue that an upwelling in the pacific is basically geometrically required since there would be downwelling surrounding the plate at all the new subduction zones resulting from gondwana break up. so maybe nothing exceptional at the cmb is required. (Tan et al. 2002 G3)

If plumes form/persist/migrate/burn out similar to in Tan video, how good of a reference frame do they make? Short term - maybe 10s MY - same as apparent fit in the pacific vs. indian reference frames. Are those networks of hotspots related to one plume or a group of plumes?

PLATE MOTIONS

Euler Pole between two plates - true translation is concentric to the Euler pole (along small circles). Therefore, normals to fracture zones/transforms should be radii and should meet at the pole.

If offset rates are known along a plate boundary, gradients can point in the direction of the euler pole.

New plates can be discovered by: a) direct observations of motion discontinuities and b) known plate motions fail to close gaps. most were discovered by b, now we are in the time of a) by GPS.

Ridges tend to be normal to plate motion, locally off by 15-20% especially on slow spreading ridges, making a complicated striping effect. Transforms in the ocean are passive - always reflect local motion. On land, they are usually near the vector but the structures/strength of continental lithosphere may affect them somewhat. subduction zones not parallel to plate motion, setting up crazy partitioning effects.

Convention / fact? If all the motions of plates were accounted for, and added together, they should sum to zero. = NO NET ROTATION reference frame. Can use this for any number of plates as one circuit. In fact can't be tested without a point of reference that is not on any plates.

NEED TO SHOW 3-PLATE CIRCUIT HERE.

DIRECT MEASUREMENT OF PLATE MOTION

The only way to get around the problem of determining if plates are rigid or not (that is, if deformation is concentrated along plate boundaries or distributed across plates or regions of plates) is to be able to measure the spacing between many points within a plate, at as many time intervals as possible.

Requires - durable reference features GPS monuments other built objects Conserved geomorphology

Surveying - time consuming (50 years for india!) but obviously it worked!! could do again today and should see 5 m of shortening....

Better - satellites. I. GPS - campaign or continuous - "era of seismogeodesy"

2. Laser ranging -

Satellite shoots laser everywhere, takes 3D point cloud of surface. Subtracts one from the other to get interference pattern.

3. Interferometry.

VLBI - old school, uses space radio signals from spinning neutron stars to measure offset between two radio telescopes. Used through the 80s and 90s so provide useful data to compare to today's sliprates on faults to check for changes over short time scales (e.g. seismic cycle)

InSAR - inferferometric synthetic aperature radar.

We know slip rates on faults will vary over the seismic cycle - so are InSAR rates

related to plate rate? or local? Show Simons 2002 stuff - example of how InSAR works to detect surface motion

TRUE POLAR WANDER-

reconstructed from taking all the plate paths and where they just can't be matched with today's pole, moving the pole until it all fits.

ALSO NEED TO TAKE INTO ACCOUNT WHOLESALE SHIFTS IN THE MANTLE/LITHOSPHERE - as happened during Tohoku Earthquake. The TPW rate of 1°/last 20 years may require this as can't be explained by all continents shifting together; it's too fast.



Recall -

ridges = linear, radial to pole. never oblique

transforms = arcuate (concentric to pole) minor obliquity in continental, not in oceanic

trenches - every which way. can be highly oblique

Velocities are always relative. "aVb" is the velocity of b with a held constant. aVb should be the opposite of bVa.

GOT THIS FAR



Assumption of course is rigid plates - as long as plates are rigid, any three plates make a closed circuit.

TRIPLE JUNCTIONS

may be stable or unstable

Alpine fault is parallel to relative motion, currently holding it together while opposite subduction on either end.

** This discussion of stability is an artifact of going too far with the rigid plates idea. But the instability of certain configurations is still useful for thinking about not only local plate reconfigurations but also where plates are likely to break up into microplates...