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Tectonic Models and Seismic Interpretation

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When the data are not definitive, seismic interpreters turn to tectonic models; hence many structure maps, despite 3D seismic, are only as good as the current tectonic paradigm.

Theories of tectonic evolution of the Earth have spanned the full spectrum from contracting to expanding and we are currently experiencing another radical paradigm shift. Maybe we can best evaluate the potential benefits to the seismic interpreter by looking at the history of earth models.

In 1664 Descartes considered the Earth to be de-gassing, the crust shortening by sinking through the atmosphere and then through the oceans. Folding on a cooling, contracting earth persisted for two hundred years as the principal global tectonic model.

At first this seems surprising since Bacon as early as 1620 noted the similarity of the eastern South American and western African coastlines and concluded that this could hardly be accidental. But the observation had no support as geology was not really a "science" until 1795 (Hutton's "Theories of the Earth").

It was 1858 when Snider recognised the geological similarities of the fit between these coastlines. The concept of dispersal of continents was considered outrageous and the Carboniferous similarities of the Gondwanan continents were attributed to sinking of the intervening oceanic areas.

Taylor proposed in 1910 a partial closing of the Atlantic as an explanation for Tertiary folding.

In 1911 Baker showed a distorted reconstruction of all the continents into a single continental mass. But it was Wegener's 1912 extensive geological and geophysical knowledge which in 1912 enabled him to not only reconstruct all the continents but also to show that the continental and oceanic crusts are fundamentally different. The Taylor-Wegener theory of continental dispersal, as it came to be known, had few supporters.

Even though his reconstructions were not accurate (he had only a minor eastern Tethys), Wegener was undoubtedly the founder of "plate tectonics". He attributed Pacific compression in the Andes and Indian compression in the Himalayas to the opening of the Atlantic and Indian Oceans on a constant radius earth. Most importantly he recognised tensional normal faulting in the East African rifts as a precursor to oceanic formation and hence also to basin formation.

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While significant quantities of oil are reservoired in fold belts, the importance of plate tectonic movements in also understanding the seismic expression of extensional basins and normal fault traps was important. Carey (1956) showed that listric normal faults could not sole-out in the rigid upper crust, yet very low angle faults became the norm in the North Sea in the 1980s. Low angle extensional faults can only occur in mobile sediments or on previous zones of weakness in the upper crust such as earlier thrust faults.

Similar problems still abound in plan view. Even though I showed in 1980 (in an international journal) that rotation about an Euler pole on a sphere required vastly different normal fault and shear geometries depending on the orientation of a rift relative to radii about the pole, the late 80s and 1990s have seen simple ridge/transform geometries peculiar to fluids (ocean crust) being imposed in continental crust to form sedimentary basins.

Despite the rejection of Wegener's theory at an AAPG convention in 1926 and his death in 1930, the German influence continued. Hilgenberg proposed an expanding earth in 1933 because he could reconstruct all the continents on a smaller globe, although his fit incorporated major distortions. He attributed orogenic folding to decreasing continental curvature. Kort in 1949 attributed the decreased size of the largest four-legged animals from the Cretaceous to Recent to an increase in "g", also on an expanding earth, hence an increase in mass.

Wegener's theory of continental dispersal was revived in 1945 by Carey who included Holme's 1928 upper mantle convection (subduction) in his constant radius earth. Carey's success lay in part in his recognition of substantial horizontal continental motion, the bending of compressional orogenic belts in plan view. Although plate tectonics has often been attributed to Hess (1962), a friend of Carey's, Carey abandoned subduction before his continental "drift" and expansion in 1956. His recently released book also professes diapiric mountain building, hence universal tension, 332 years after Descartes' universal compression.

Carey's Tethyan Shear between the northern, continental hemisphere and the southern, oceanic hemisphere and on an asymmetrically expanding earth emphasises the contribution of momentum and radial forces in global tectonics rather than mantle circulation required by plate tectonics. The answer probably lies between the two as suggested by Owens' 1976 reconstructions on an Early Jurassic Earth of 80% modern radius but which included considerable subduction.

In 1993 Arp, an astrophysicist, demonstrated that the Doppler red-shift of light was not attributable to recessional velocities as required by the Big Bang theory. Rather he attributed the phenomenon to an increase in mass with time. He told me that as I was proposing increase in mass for the Earth, it would almost certainly be pulsing, not a regular increase in radius as suggested by Carey, Owen and Hilgenberg.

The 1995 APEA Journal published my "Globally synchronous compressional pulses in extensional basins", ie. Hilgenberg-like basin inversion by upper crustal compression due to continental flattening (pulsed with the Vail eustatic cycle chart), and contemporaneous basin formation by lower crustal extension.

The ideas proposed in that paper imply that a radical change is required to normal fault models. Rather than simple, steady extensional movements causing basin-forming normal faults, such faults will tend to be steeper, intermittently compressed or wrenched due to pulses of compression (inversion) in the rigid crust which results from pulses of earth expansion (with subduction and with increasing mass).

3D seismic surveys are generally confined to individual fields and often the post-reservoir section is not available to the interpreter. This means the confirming wrench and compressional movements in the young

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section, reflecting earlier basin-forming faults, is often lost. The seismic interpreter must also be aware of the present regional compressional stress orientation in order to map the compressional features. Fortunately that direction appears to have varied little during the life of each basin despite major plate tectonic and expansion induced continental dispersal.