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HOW CONTINENTAL COLLISIONS PRODUCE MAJOR HYDROCARBON ACCUMULATIONS

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Models that integrate the principles of plate tectonics with the requirements for the formation of hydrocarbon accumulations (source, maturation, expulsion migration, and entrapment) provide a way to compare and evaluate the world-wide distribution of oil and gas resources. Furthermore, these models provides insight into areas that might be underexplored, such as the foreland basin area along the east side of the Andes.

Attempts to relate petroleum resources to specific plate-tectonic settings are, however, hampered by both the variety of basin-classification schemes and the superposition of different tectonic settings in any given petroleum province (e.g. the Tertiary foreland basin of the Persian Gulf is superimposed upon a late Paleozoic-early Mesozoic, rifted continental-margin setting). The former problem is one of differing concepts while the latter reflects the actual changes of nature. Bearing these problems in mind, we nonetheless believe that the hydrocarbon generation process follows a predictable sequence of events during a continental collision as a result of thickening of continental crust. Furthermore, if we include tar sands (e.g. Alberta basin) and heavy oils (e.g. Orinoco basin), along with the estimates of more conventional oil and gas, we believe that the principal habitat for the world's petroleum resources is fold and thrust belts and their associated foreland basins.

The distribution of oil and gas in foreland basins is dictated by thermotectonic processes related to the collisional process (fig.1). In order to create the petroleum habitat of fold and thrust belts and forelands, continental shortening, or so-called A-subduction, is required. Such a tectonic regime can be produced by either of two distinct plate tectonic events: (1) accretion of one or more volcanic arcs to a continental margin, or (2) the collision of two continents. The former situation has produced such features as the Brooks Range and Cordillera of North America, while the latter has produced features such as the Appalachian-Ouachita-Marathon, Zagros, and Ural orogens.

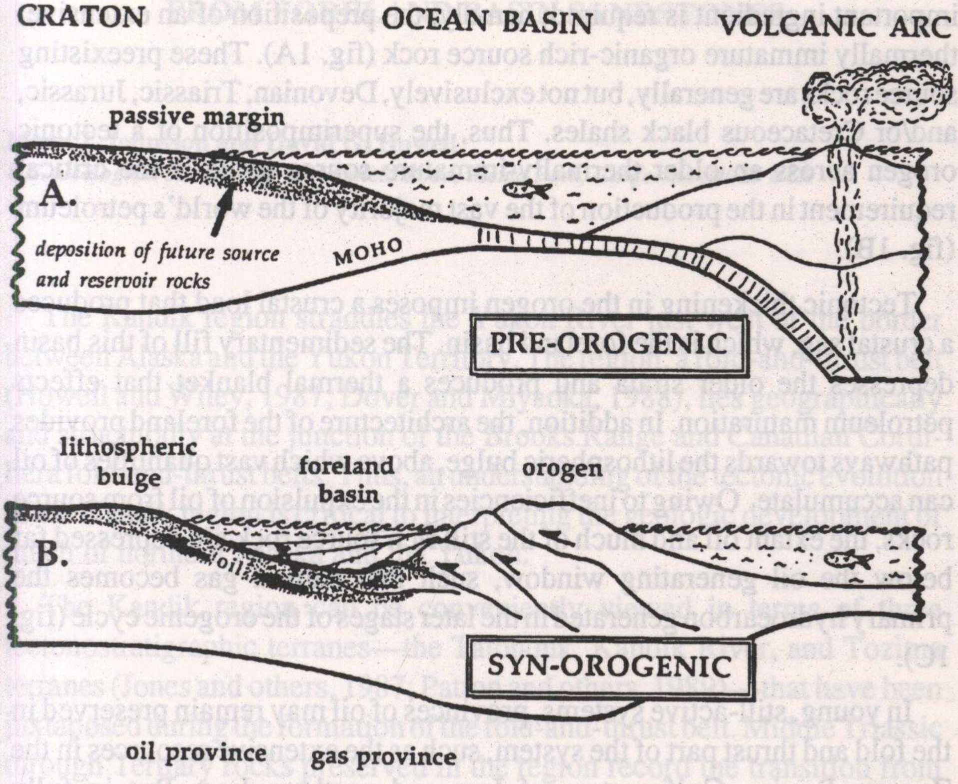

Fig.1— Generalized tectonic scenario depicting the events necessary for major accumulations of oil and gas: (A, Pre-orogenic) the deposition of organically rich source-beds and high quality reservoir-rocks on a passive or trailing continental margin, (B, Syn-orogenic) the superposition of a thermal blanket above immature source beds and the creation of the architecture for oil and gas migration and entrapment, (C, Post-orogenic) the tectonically mature stage where oil and gas resources are partitioned owing to differences in cracking temperatures.

Regardless of the plate tectonic process that triggers intracontinental shortening, the style of continental crustal deformation is essentially identical. But for these crustal shortening settings to be petroliferous, one important ingredient is required; namely, the preposition of an extensive, thermally immature organic-rich source rock (fig. 1A). These preexisting source rocks are generally, but not exclusively, Devonian, Triassic, Jurassic, and/or Cretaceous black shales. Thus, the superimposition of a tectonic orogen across an older thermally-immature source strata is the critical requirement in the production of the vast majority of the world's petroleum (fig. 1B).

Tectonic thickening in the orogen imposes a crustal load that produces a crustal sag, which is the foreland basin. The sedimentary fill of this basin depresses the older strata and produces a thermal blanket that effects petroleum maturation. In addition, the architecture of the foreland provides pathways towards the lithospheric bulge, above which vast quantities of oil can accumulate. Owing to inefficiencies in the expulsion of oil from source rocks, the extant oil and much of the still rich source rock are depressed far below the oil generating window, such that natural gas becomes the primary hydrocarbon generated in the later stages of the orogenic cycle (fig. 1C).

In young, still-active systems, provinces of oil may remain preserved in the fold and thrust part of the system, such as the extensive resources in the Zagros -Persian Gulf system of Iran and northern Iraq. But in fully developed orogenic areas, the consequence of multiple deformational events in the fold and thrust belt is the destruction of early-formed architecture of traps and seals. Thus, the initial oil either remigrates or cracks owing to increased temperatures to gas, in either case the new configurations become a gas habitat. The flux of gas continues long after the initial migration of oil. Thus, in tectonically mature fold and thrust belts, one would expect to find primarily oil accumulations in regions distal from the orogen and primarily gas accumulations in regions proximal to the orogen.

In the northern Andes, these conditions are exemplified in the Orinoco basin where the La Luna Formation provides the necessary pre-orogenic petroleum source strata. In the central and southern Andes, the tectonic architecture invites speculation regarding petroleum resources; the principal uncertainty concerns the nature and abundance of source rocks (fig. 1C).