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Geographical Coincidence of High Heat Flow, High Seismicity, and Upwelling, with Hydrocarbon Deposits, Phosphorites, Evaporites, and Uranium Ores

(petroleum/coal/oil/geothermal heat flow)

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ABSTRACT **Oil deposits occur in deep sediments, and appear to be organic matter that has been transformed through the action of geothermal heat and pressure. Deep sediments, rich in biological remains, are created by ocean upwelling, caused in part by high geothermal heat flow through the sea bottom. Such regions correlate with enhanced seismic activity. We look for correlations of seismicity, high heat flux, petroleum, uranium, phosphates, and salts, deposited from abundant plant life. These may be useful in discovering more petroleum and coal. We estimate that the known world reserves of petroleum and coal are about 10^{-4} of the total of buried biogenic carbon.**

The correlation of seismicity with oil seepage (1) reminds us of more general correlations of deposits of oil, gas, uranium, phosphates, coal, and salt with seismicity. We find a correlation between fertility in the sea and seismicity and geothermal heat flux. We suggest that this is due to vertical upwelling caused by the geothermal heat (2), which brings to the surface deep waters rich in phosphorus and nitrogen. The deep waters have been enriched by decay of sunken bio-organic material. Where upwelling occurs, surface sea life is abundant and dead bio-organic material on the bottom is likewise greatly increased. Its decay produces anoxicity, inhibiting decay, so that hydrocarbons are preserved, stored, and metamorphosed to petroleum, and phosphorus and uranium precipitate in bio-organic molecules in sedimentary rocks.

High geothermal heat fluxes correlate with enhanced seismicity, and with faulting, upwelling, and enhanced productivity of bio-organic material, phosphoritic and uranium-bearing rocks, and sediments containing hydrocarbons.

When such regions become dry land, there is a further coincidence with evaporites both from lakes and oceans.

Seismicity and bio-organic productivity in the United States

The bio-organic productivity of the sea (3) correlates with high seismicity (Fig. 1). Vast regions of the seas are almost barren of life, while productive areas occur where nutrients are brought to the surface by upwelling. Few data on sea bottoms are available, and, therefore, we study continental surfaces.

In the United States the presence of coal (4), oil (5), earthquakes (6), and salt (7) (Fig. 2), coincides.

Phosphorites in the United States

The oceans and seas are rich in phosphorus at depths of more than 500 meters, whereas the surface waters are depleted; the abundance of life is controlled by the availability of phosphorus (8, 9). Organic decay on the sea bottom accounts for the phosphorus enrichment of the deep water. Phosphorites are found on sea bottoms in areas of upwelling, for here surface organic productivity is high. The formation of phosphorites requires an abundance of decaying, phosphate-rich organic matter. Massive deposits of uncharted phosphorites do undoubtedly exist (10), e.g., phosphorite deposits have recently been found for 1300 miles, from San Francisco to the tip of Baja California, estimated at about 1 billion tons.

Land deposits of phosphorites occur where there were formerly seas of high productivity. Matheja and Degens (8, 9) describe a Permian deposit of about 1.7×10^{12} metric tons of P_2O_5 in the great Salt Lake region, which at that time was a shallow sea. This deposit contains more than five times the phosphorus in the oceans. Ruhlman (11) states that the Western United States phosphate field includes deposits in Idaho, Montana, Utah, and Wyoming that are rich enough to be economically worth mining. They are of marine origin, up to 180 feet (54.9 meters) thick, consisting of phosphatic shales, brown to black limestone, and black oölitic phosphate rock, of 10–40% P_2O_5 (Fig. 2).

Seismicity, high heat flow, hydrocarbon, salts, and phosphorus in other parts of the world

Seismicity and salt and phosphorus deposits coincide with oceanic upwelling along the west coast of South America (Fig. 3). Seismicity and salt, petroleum, gas, coal, and phosphorite deposits coincide in Australia (Fig. 4). Earthquakes and salt deposits coincide in the Mediterranean and the Middle East (Fig. 5). Around the world, seismicity coincides

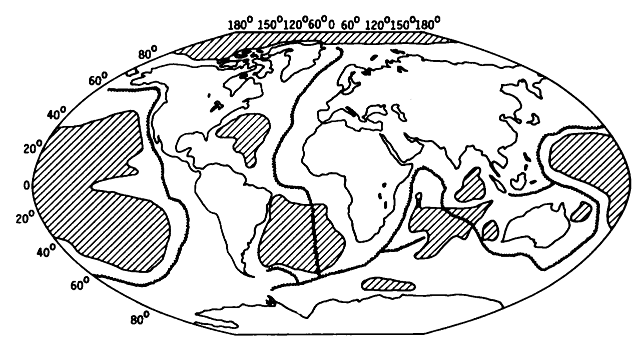

FIG. 1. World map showing the main seismic lanes (black jagged line) and desert areas of ocean (producing less than 100 mg of carbon per square meter per day; cross-hatched areas).

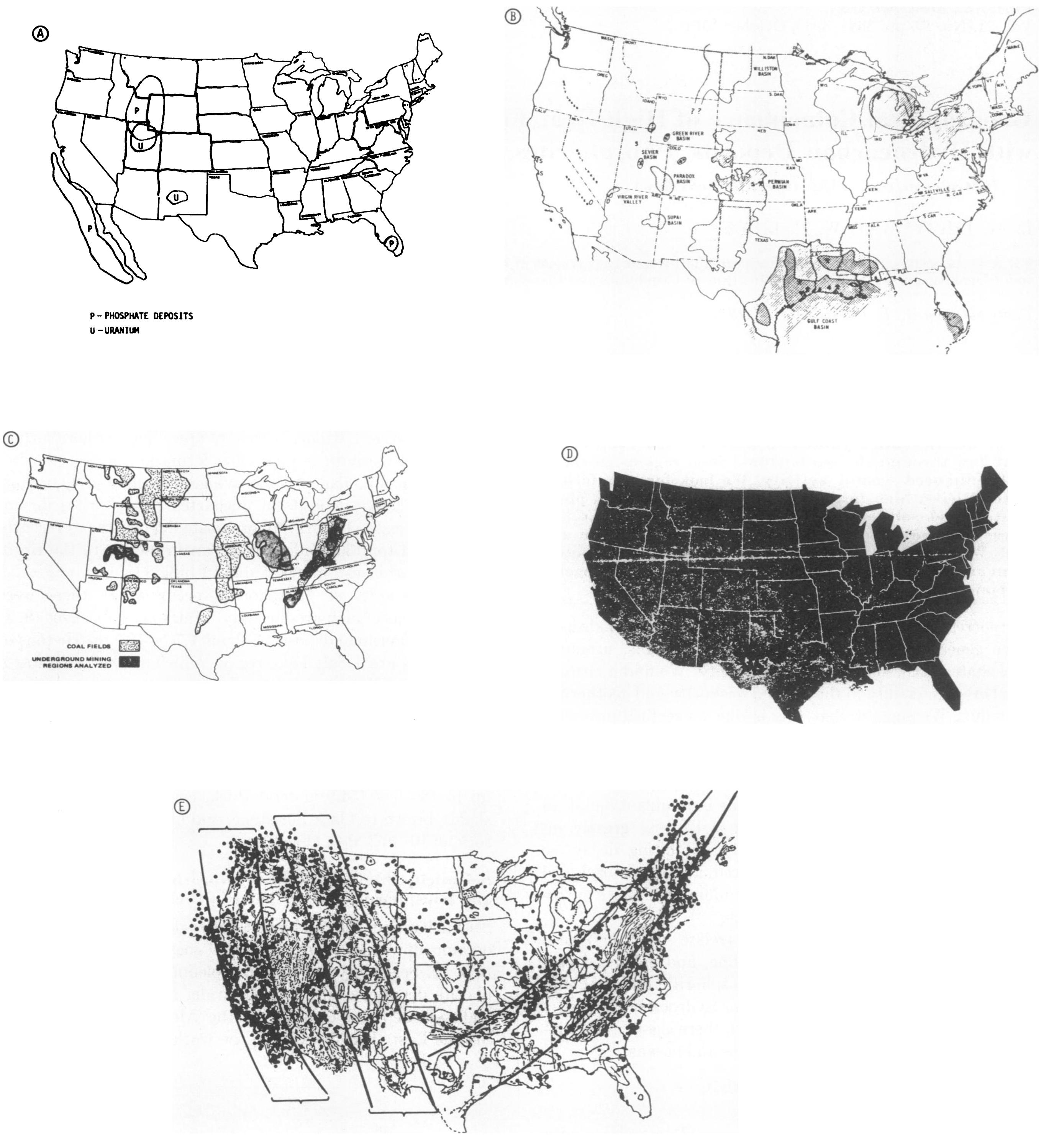

FIG. 2. (A) Phosphorus and uranium deposits of the United States. The large deposit of phosphorite nodules along the coast of Southern California has been recently discovered. (B) Salt deposits, (C) coal fields, and (D) oil fields of the United States. (E) Epicenters of earthquakes in the United States showing seismic lanes along the west coast, along the Rockies, and from Texas and Oklahoma through Illinois, Indiana, and Ohio and along the St. Lawrence River, as well as a fourth line along the east side of the Appalachians, through New York and the New England States. The eastern seismic lanes are not well recognized because the quakes are mostly of small magnitude, around Richter 3 or less.

with high heat flow and known major oil fields (Fig. 6). Deposits of petroleum, gas, coal, and salt lie along the seismic lane through the Middle East into Russia, past the Caspian and Lakes Balkash and Baikal, emerging into the Arctic Ocean through northern Siberia.

Uranium and vanadium

R. J. Wright (12) states that where black shales and phosphorites were deposited, reducing conditions prevailed, so that uranium, vanadium, and copper are deposited in marine black shales, phosphorites, and sandstones. Carbon is abun-

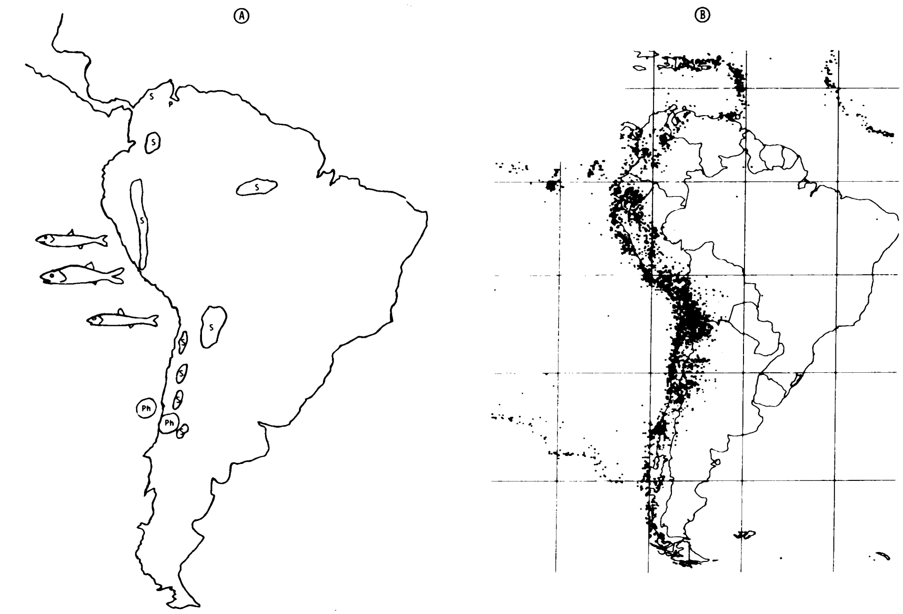

FIG. 3. (A) Salt (S) and phosphorus (Ph) deposits in South America, and regions of marked oceanic upwelling and high bioorganic productivity (fish). (B) Earthquake epicenters in South America.

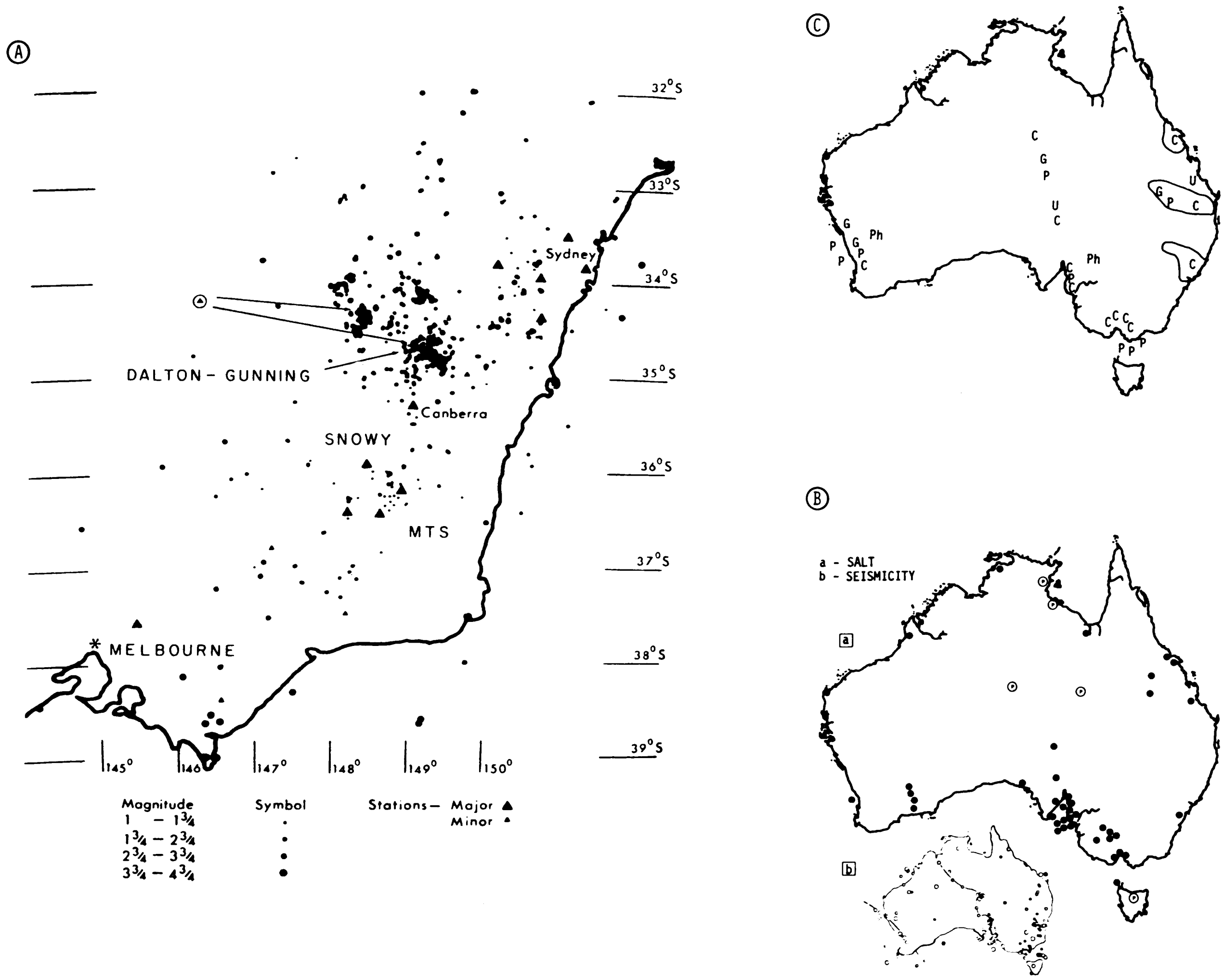

FIG. 4. (A) Earthquake epicenters in eastern Australia. (B) a, Salt deposits (filled circles and P, salt flats) and b, seismicity; (C) gas (G), phosphorus (Ph), uranium (U), coal (C), and petroleum (P) deposits in Australia.

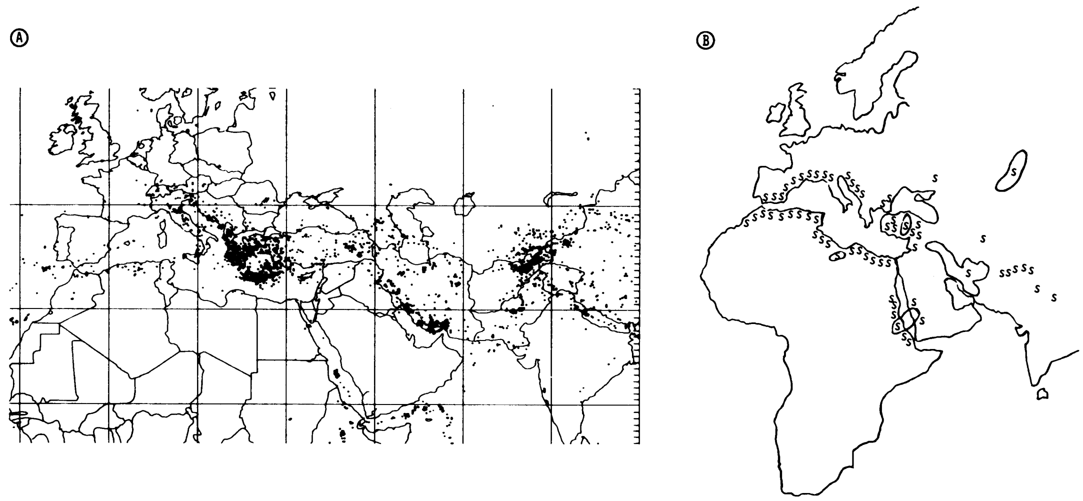

FIG. 5. (A) Earthquake epicenters and (B) salt deposits in the Mediterranean and Near Eastern countries.

dant in these rocks. Such rocks contain a large part of the earth's uranium. Vanadium has been produced commercially from black shales, and has been recovered as a byproduct of fertilizer manufactured from phosphorites. In black shales and phosphorites, the uranium content and the organic content vary together.

Lignite and coal ash contain several hundred parts per million of uranium; in coal and lignite the uranium is bound in organic complexes, indicating that the ore was formed in the presence of abundant decaying sea life (13, 14), e.g., a uranium-bearing hydrocarbon mixture called "thucolite" is distributed throughout Canada.

Most uranium deposits are found in coarse sediments; such sediments are more likely to contain uranium if they have a relatively large content of organic material (15). Uranium ores are found in Colorado, Arizona, Montana, New Mexico, and Utah. Lignites containing at least 0.1% uranium are found in North and South Dakota and in New Mexico. Asphaltic material with a density close to unity is found associated with the uranium (Figs. 2 and 4).

Evaporites

Association of petroleum with common salt, bromides, iodides, and black sulfurous shales results from anaerobic conditions in abundant decaying sea life (16) so that decay is arrested, and this material metamorphoses to oil. Upwelling is required to provide sufficient nourishment for abundant surface life. Heat aids upwelling, concentration of salts, and metamorphosis to oil. The association of bromides and iodides with oil may be caused by concentration of these halides in plankton, which formed the deposits.

Upper limit on world hydrocarbon deposits

The total amount of sedimentary rock for the entire world, and upper limits for the total world supply of oil-bearing rock, can be estimated from conclusions of W. W. Rubey (17) and W. F. Libby (18). Rubey (17) estimates the total CO_2 buried in sedimentary rocks at 9.2×10^{22} g.

The total world supply of organic carbon may be estimated as follows: Recently, a meteorite, Murchison (1969), was found to contain amino acids in racemic mixture and, hence,

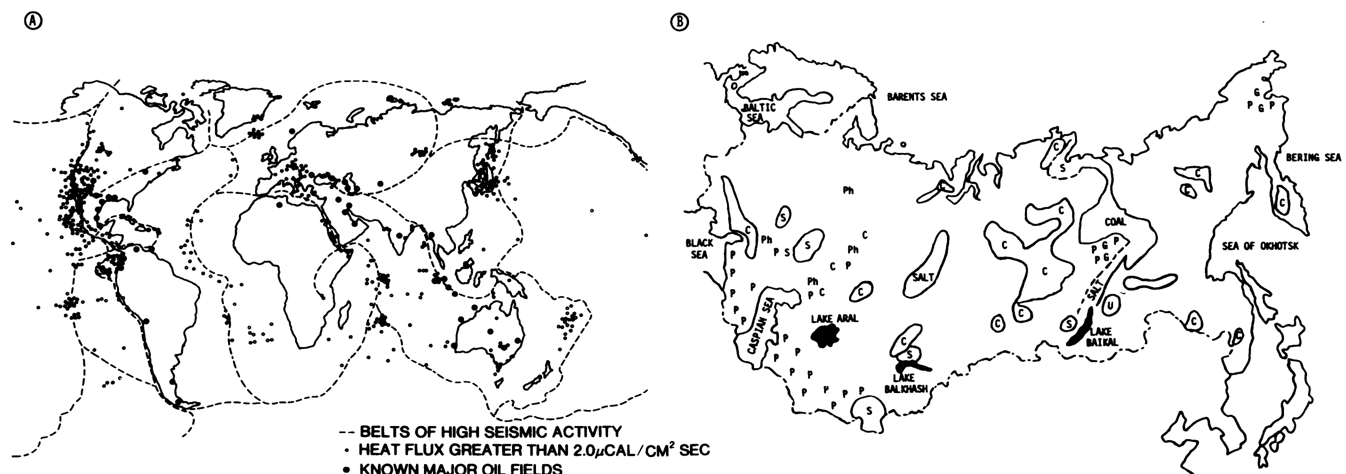

FIG. 6. (A) Coincidence of high heat flow and major oil deposits with seismic lanes of the world. (B) Coal (C), oil (G), salt (S), phosphorus (Ph), petroleum (P), and uranium (U) deposits in the U.S.S.R., showing correlation with the seismic lane running NE–SW through Siberia to the Caspian Sea.

not due to terrestrial contamination (19). Its C^{13}/C^{12} ratio might be taken as characteristic of primeval carbon for the planets, and in particular for the earth, although data on other meteorites raise doubts since some appear to differ from the Murchison value of −7 per mil on the PDB standard. Many meteorites cluster about the value for Murchison, however (20). Using the measured C^{13}/C^{12} ratios for terrestrial inorganic material in sediments, W. F. Libby (18) has concluded that the total amount of biogenic carbon is about one-half that in the carbonate sediments, corresponding to a total biogenic carbon of 1×10^{22} g. This would be an upper limit of hydrocarbon reserves, except for doubts on the C^{13}/C^{12} ratio of the meteorite and on the Rubey estimate for total carbon. By analogy with Venus, which is very similar to Earth and which has some 90 atmospheres of CO_2 in its atmosphere, we can estimate the total carbon to be 4.6×10^{23} g and raise the organic matter limit to 5×10^{22} g. We may compare these limits with the estimated world reserves: 9.7×10^{18} g of coal (21) and 8.3×10^{16} g of oil on the continents (22) and 4.0×10^{17} g of oil on the continental shelves, for a total of 1.0×10^{19} g. Of course, shale oil must account for a considerable part of the difference. Yet it seems there is hope that significant amounts of useful hydrocarbons remain to be discovered.

Continental drifts

Good correlation appears between known oil fields and the collision zones between plates (unpublished data).

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