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Mechanisms to Explain the Formation of Geochemical Anomalies Over Oilfields

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Several oil and gas field reflect geochemical and geophysical anomalies formed due to the migration of hydrocare water and salt. These anomalies which include hydrocarbons, mineralization, paraffin dirt, waxes, salts, metals, gases, microbes, etc., are commonly found either at the edges or up to 3km outside the limits of production. Geochemical and geophysical anomalies may result from enrichment or depletion of a wide range of elements, salts, gases, minerals and hydrocarbons themselves, forming apical or annular trends, modified by local conditions. These anomalies may occur at various levels throughout the overlying stratigraphic column. The shape of anomalies can reflect the nature of hydrocarbon trap. Faults can produce apical highs. Reef, anticlinal and stratigraphic traps would reflect lows bordered by highs (halo effect). A combination of these structures may produce a combined apical and halo effect. Based on data from Redwater Oil Field, Ten Section Oil Field, L'Assomption Prospect and other areas, mechanisms to explain the formation of geochemical and geophysical anomalies based on the presence of fractures (macro/micro) which provide passages for the migration of hydrocarbons (oil and gas), water, gases, salts and ions, in the form of microbubbles and with CO_2 and other gases acting as a carrier gas to carry the mineral matter to the surface are presented.

The development, trends and shapes of fractures depend upon the nature of trap and tectonic setting. Fractures developed in older rocks often continue upward through younger, overlying rocks, even through unconformities. Fractures provide passages for the migration of hydrocarbons, water, salts and other ions towards areas of lower pressure, most commonly the surface.

CARRIER MATERIALS:

Hydrocarbons: Changes in pH greatly affect the mobility of heavy metals. Low pH increases solubility, and high pH enhances the chances of precipitation of many dissolved substances. The normal range of pH for surface water and soils is 4 to 9. Soils rich in lime and organic matter, from Redwater, Ten Section and other areas, showed a drop in the radiation intensity. Changes in Eh will also affect the mobility of cations and hence the shape of geochemical anomalies. An ion in one oxidation state may be insoluble, but in another state it may become very soluble. For example, U^{+4} is precipitated in a reducing environment, but with an increase in the oxygen content, it forms U^{+6} and $U0_2^{+2}$, which are very soluble in water. Similarly other multivalent elements will also be affected by the changes in the oxidation and reduction potential. Liquid or gaseous hydrocarbons, or H_2S, in contact with surface water may cause a rapid decrease in the Eh of these waters. This decrease in Eh will result in the precipitation. The change in Eh could be from 0 to -0.45 volts depending upon the methane content. The other possibility is that liquid hydrocarbons at the surface, on weathering, leave asphaltic or bituminous material, which can extract uranium and other elements in ground water solutions. Uraniferous asphaltites and bituminous deposits are known to exist.

Roles of Geogases: Geogases contain sulphur compounds, Rn, He, N_2, O_2, CH_4, Ar, CO_2, and heavier hydrocarbons. Gold and Soter (1980) have proposed mantle degassing through faults and fractures as a possible origin of some of these gases. Local streaming is caused by pressure gradients, pressure shocks and other disturbances that may give rise to local regions of oversaturation. The gas bubbles may form in these regions and move upward through fissures. Carbon dioxide may act as a carrier gas to carry radon and other mineral matter (elements) to the surface. The formation of free gas bubbles may be initiated by alpha particles produced by decay of U, Th and their daughter products. The carrier gas can also transport other atoms, molecules or small aggregates of matter towards the surface. The transport may be brought about by very weak streams of gas bubbles which pass vertically or along bedding planes, fractures and faults.

K^{40} anomalies observed over oil fields and gas and mineral deposits, are related to formation of illite and hydromicas (muscovite). Brines and petroleum contain large quantities of dissolved gases. Predominant among these gases are carbon dioxide, methane, nitrogen, hydrogen sulfide, and hydrogen. Carbon dioxide is generally very abundant, sometimes exceeding 90% of the dissolved gases. The amount of dissolved CO_2 and N_2 controls the content of other gases. Carbon dioxide under pressure can be a strong leaching agent. Carbonic acid formed from CO_2 will react with clays and shales to release potassium, which can migrate upwards in solution through fractures to form K anomalies at the surface and at various stratigraphic levels.

Halides: Several elements may also be transported as halides, arsenides and organometallic complexes, as colloids adsorbed on organic matter.

Microbiological reactions: Microbes play an important part in the degradation of hydrocarbons. Sulfate and nitrifying bacteria have been observed at depths of 4200 m. Bacteria degrade hydrocarbons by anaerobic reactions, releasing CO_2, H_2S and H_2O, and by aerobic reactions releasing CO_2 and H_2O. CO_2 forms carbonic acid, which reacts with clays and shales, releasing potassium, uranium, other radioactive elements and other ions from the mineral lattices. CO_2 also forms carbonate cements giving rise to Delta-C anomalies. H_2S reduces uranyl ions to uraninite and also forms diagenetic magnetic minerals, producing magnetic anomalies. Silicic acid released is precipitated as silica (see Sikka and Shives, 2001 in press and references there in).

ELECTROCHEMICAL PROCESSES: The earth behaves like an electrochemical cell. According to Clark (1997), "oxidation anomalies appear to be caused by very subtle electrochemical cells that develop at the top of reduced bodies in the subsurface...." He hypothesized that electrochemical gradients appear to produce differentiation patterns for the halogens, based on differing electrode potentials required to oxidize chloride, bromide and iodide to Cl_2, Br_2 and I_2. The CO_2 produced as a result of electrochemical reactions acts as a carrier gas to carry the volatiles of the oxidation suite to the surface. Anomalies of these elements have been observed around oil and gas pools (Clark, personnal communication, and 1997).

Rates of Migration: The earth periodically has undergone a series of diastrophic movements, and is currently being affected by plate tectonics, earthquakes, earth tides, isostatic adjustments, meteorite showers and various other forces, which collectively cause crustal strain. Some of these forces are periodic in nature, and their apparent effect would be small, but the cumulative effects in geologic time can be very large. It is these forces which could create and reactivate early formed fractures. As a result these fractures probably would never completely close. During increased activity of various types of diastrophic forces (earth tide, earthquake, seismicity, typhoons, tornadoes, hurricanes, meteoritic impact) the hydrocarbons, gases and water would migrate rapidly. During quiescent periods, migration would be slower.

Migration Rates: The velocity of vertical gas migration be of the order of 75 m to 300 m per year through unfaulted sediments from normally pressured reservoirs. When driven by increased pressures and temperatures, the rates of anomaly formation and disappearance can be surprisingly fast, measurable in a few months or years. Geogas streaming along structures may be initiated or enhanced by a variety of crustal-scale processes. Seasonal variations have been observed in the ethane content over Hastings Oil Field, Texas and over the Sabinville gas reservoir. Soil-gas hydrocarbon concentrations can vary throughout the year and sometimes can vanish completely. These rapid changes provide evidence of relatively fast migration rates.

WORKING MODEL

Geophysical and geochemical patterns, including radiometric anomalies, are formed by complex interactions between various components, as described above. Structures play a critical role in the presence and shape of surface anomalies related to subsurface hydrocarbon pools. Channeling of fluids and other materials along structures significantly affects the surface distributions. Anomalies may appear as enrichment or depletion patterns in a wide range of elements, salts, gases, and hydrocarbons themselves, forming apical or annular trends, modified by local conditions. Radiometric anomalies due to K^{40}, uranium and thorium families, and anomalies due to Delta-C, occluded hydrocarbons, magnetic minerals, various trace elements, and halides (Br_2, Cl_2, I_2) would probably occur throughout all stratigraphic levels. Various reactions due to bacterial and chemical activity in the hydrocarbon (liquid/gas) seepage and microseepage environment, give rise to various micro-indices which cause geochemical anomalies, as shown in Figure 1 (see Sikka and Shives, 2001, in Press).

Assumptions: The proposed working model (Figure 1) for the formation of hydrocarbon, radiometric and geochemical anomalies at the earth's surface is based on the following assumptions:

1. Micro and macrofractures provide channelways for gases and hydrocarbons (oil, gas), water and salts.
2. The processes of migration are effusion, diffusion to a limited extent, and solution movement. Where liquid hydrocarbons or elements are encapsulated and carried by earthgases, the rate of migration would be enhanced. The liquid hydrocarbons are carried on the inner walls of gas bubbles.
3. Liquid hydrocarbons and water carry radioactive elements in solution.
4. Hydrocarbons (oil, gas) and water migrate vertically in the form of microbubbles and in colloidal form towards the surface.
5. Gases such as CO_2, N_2, CH_4, and H_2 and minor quantities of He, Ar, Rn, Hg, H_2S, SO_2, I, Br, Cl, migrate towards the surface in gaseous form as microbubbles and in solution. Gases encapsulate Rn, liquid hydrocarbons and other trace elements, such as As, Ag, Ba, Cd, Ce, Co, Cr, Cu, Ga, Ge, La, Li, Mn, Mo, Nd, Ni, Pb, Pr, Rb, Sb, Sc, Sl, Sm, Sn, Se, Ti, Th, U, V, W, Y, Zn and carry them to surface.
6. Various elements form compounds with halides and organometallic complexes and migrate in solution or as colloids towards earth surface.
7. Microbiological reactions cause hydrocarbon degradation and mineral precipitation.
8. Electrochemical gradients influence movement of anions and cations.

FOR REFERENCES SEE

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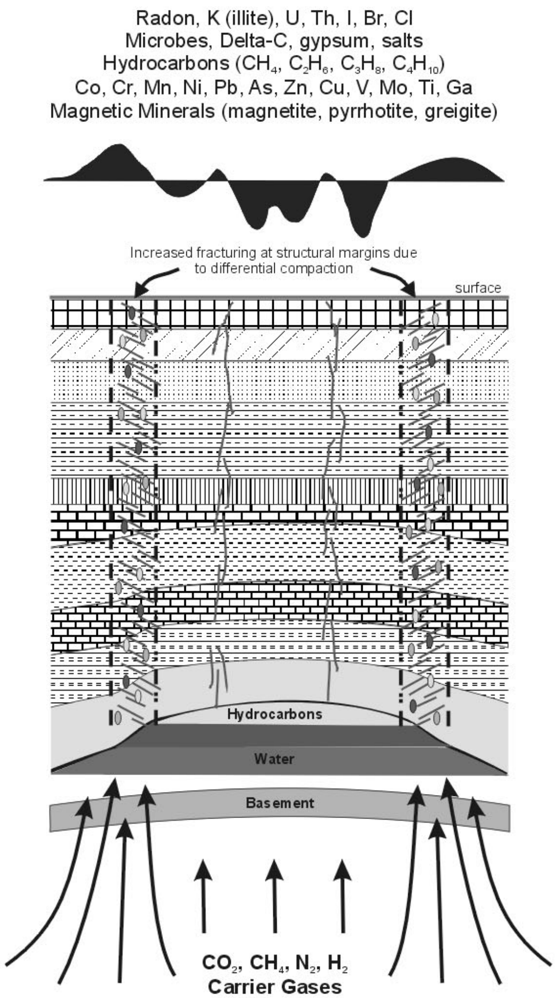

Structures play a critical role in the presence and shape of observed surface anomalies related to subsurface hydrocarbon pools, as micro and macrofractures provide channelways for gases, hydrocarbons (oil, gas), water and salts. Geophysical and geochemical patterns, including radiometric anomalies, are formed at the earth's surface and throughout the stratigraphic column, in response to complex interactions between various components. Anomalies may appear as enrichment or depletion patterns in a wide range of elements, salts, gases, and hydrocarbons themselves, forming apical or annular trends, modified by local conditions.

Migration occurs by effusion, diffusion to a limited extent, and solution movement, driven at variable but sometimes very fast rates, by pressure and temperature gradients related to diastrophic forces (earthtides, earthquake, seismicity, typhoons, tornadoes, hurricanes, meteoritic impact). Where liquid hydrocarbons or elements are encapsulated and carried on the inner walls of microbubbles of earthgases, migration rates are enhanced.

Various elements form compounds with halides and organometallic complexes and migrate in solution or as colloids towards earth surface. Microbiological reactions cause hydrocarbon degradation and mineral precipitation. Electrochemical gradients influence movement of anions and cations.

To improve success, modern hydrocarbon exploration techniques must incorporate an integrated, multielement, multimedia, multisensor approach. Although data interpretation may be complex, our model provides a framework for understanding the roles of various geochemical indicators, and can be used to augment traditional, predominantly geophysical, hydrocarbon exploration techniques.

Digital drafting: R. Shives

Figure 1