PETROLEUM PROSPECTS IN PRECAMBRIAN

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A RECENT issue of the Bulletin of the American Association of Petroleum geologists[1] carries a memorial on Wallace Everett Pratt (1885–1981), one of the distinguished geologists in the field of petroleum exploration. He was the first to establish the view that *hydrocarbons are normal constituents of marine sedimentary rocks*, a view which has profoundly influenced exploration for gas and oil since then. It was he, in 1947, who pointed to the existence of oil and gas in enormous quantities in the continental shelves of the world. We are told that he was an eternal optimist who declared "unless men can believe that there is more oil to be discovered, they will not drill for oil . . . *Where oil is first found, in the final analyses, is in the minds of men.* The undiscovered oil field exists only as an idea in the minds of some oil finder. When no man any longer believes more oil is left to be found, no more oil field will be discovered, but so long as a single oil finder remains with a mental vision of new oil field to cherish . . . , just so long new oil fields may continue to be discovered".

Reading these lines I am tempted to reflect on conditions prevailing in India. The average earth scientist in this country is poorly informed about petroleum and its mode of occurrence. Authoritative publications on the sedimentary basins of India and their petroleum possibilities, which could serve as a text for teaching students and making them take interest in petroleum exploration are woefully lacking.

According to Pratt 'we must maintain at all times an acute awareness of what we do not know . . . and if unconsciously we identify the unknown with the unfavourable, and if we explore only the areas we know to be favourable, we leave undiscovered many oil fields. An area should be presumed favourable until we have really proved it to be unfavourable'.

The splendid achievements of geologists aided by geophysicists of the ONGC and Oil India Ltd, in the discovery of oil and gas deposits during the last 20–30 years requires to be more widely known. Unfortunately, there is a general lack of awareness of this achievement and the scope that exists for further discoveries. A large volume of subsurface information has been collected by ONGC and Oil India through drilling, both on-shore and off-shore, in the various sedimentary basins of India. Excepting for occasional papers published in outside journals, there is no comprehensive publication analysing the valuable information collected so far. The absence of such a publication is keenly felt. It is high time that ONGC and Oil India Ltd bring out such a publication which is sure to generate great interest on the part of earth scientists in India as well as outside. Many more geologists than are presently engaged in the quest for oil should give their attention to oil exploration activity in our country.

An incident in the history of oil exploration is narrated by Pratt which is revealing. It appears that Kuwait, now recognised as the largest oil field in the world, was offered for a nominal consideration to leading petroleum companies of the world and that none of them thought it worthwhile to take over the property for exploration. This shows that the best of minds in the oil finding industry failed to recognise the world's greatest oil field before it was proved by drilling. What is worse, they were all convinced that it was no oil field at all! The oil companies declined to consider the prospect because they held to the belief that there was no oil in Arabia. Even for an advanced country like America, Kuwait is only one more instance in a long series of similar misjudgements. 'These mental attitudes', Pratt warns, 'act as a formidable barrier in oil exploration and impede the quest for truth everywhere. To assume that our knowledge of an area is complete when it is not, may be to conclude that there is no oil where there is oil'.

Take the case of Cambay in our own country. It was for a long time thought by many that no oil could be found there. But unbiased investigations, initially by the Geological Survey of India and subsequently by the ONGC led to the discovery of important oil fields in that basin.

Intelligent speculation is indispensable in geology. It is through patient collection of available data and speculative exercises and formulation of hypothesis that geologists have been able to build the past history of events on this Earth which is at once convincing and reliable. Based on such exercises they have been able to discover many mineral deposits of greatest benefit to mankind. Knowledge, it should be emphasized, should not make us over conservative and blind to understanding of what still remains unknown.

This leads me to the topic which I want to discuss—the prospects of finding oil in the Precambrian. The Precambrian formations can no longer be dismissed as devoid of relics of life. Evidences of primitive forms of life have been found in rocks as old as 3600 m.y. Some of the Precambrian formations like the banded iron quartzites and limestones are now believed to owe their origin primarily to the action of algae. Stromatolitic algal communities similar to modern forms have been reported from the Precambrian. These contain saturated aromatic and isoprenic hydrocarbons. Basic elements necessary for petroleum formation, therefore, have existed even during the Precambrian.

Whether the living forms which existed in the earlier periods when the atmosphere was rich in methane, were capable of forming lipids and other petroleum mother substances in the same way as their more modern descendents is not clearly known. Most oil has originated from single-celled marine organisms which lie buried in sediments, eventually creating oil under favourable environments. No perceptible difference is observed in sedimentary rocks formed during the Precambrian and those formed in later periods. Russian geologists have gone to the extent of claiming that the amount of dispersed organics (DO) in Precambrian strata considerably exceed those buried in the Phanerozoic deposits! They claim that 'gaseous hydrocarbon breathing has been taking place from the Precambrian up to the present'[2]. It is contended that carbon-bearing Precambrian rocks could be considered as one of the possible sources of hydrocarbons in the overlying sediments and that special attention, therefore, should be directed to the investigation of Precambrian complexes containing carbon-bearing sediments.

Murray *et al*[3] have emphasized the need for exploring unmetamorphosed Precambrian sediments for hydrocarbons. Laminated limestones are known to liberate hydrocarbons at some stage and it has been suggested that less deformed and heated sedimentary sequences could well be excellent oil source rocks. Giardini *et al*[4] contend that the upper 400 km of the Earth has outgassed 10^{15} tons of petroleum related fluid over past 300 m.y. and estimates that $\sim 10^{25}$ tons of non-biogenic petroleum still remains to be outgassed from the earth! Organic matter in sediments below anoxic water is shown by Demeison and Moore[5] to be commonly more abundant and more lipid-rich than under-oxygenated water, mainly because of benthic scavenging. Geochemical and sedimentological evidence seems to suggest that potential oil source beds are deposited in the geological past in anoxic conditions. Precambrian conditions are generally believed to be anoxic. Geochemistry assisted by palaeogeography, can, therefore, greatly help petroleum exploration by identifying palaeo-anoxic events and widespread oil shale and oil source-bed systems in the stratigraphic record.

It is true that Precambrian strata are highly disturbed and metamorphosed as compared to more recent sediments. This, however, is not always the case. We have in India extensive sediments of late Precambrian age in a least disturbed condition. These basins with sequences of undisturbed sediments should be the focus for detailed study and hydrocarbon exploration. Limestones in these sequences are known to be fractured and jointed and have permitted accumulation of considerable quantities of groundwater. We are, therefore, not justified in concluding that all Precambrian strata are massive and nonporous. They appear quite capable of acting as reservoir rocks. Substantial deep reserves of gas are likely to be found in the very deep portions of basins where carbonates are reservoir rocks. Halbouty[6] emphasizes that any exploratory concept which emerges from new activites, any place in the world, is applicable worldwide.

Let us see what is happening in other countries. Australians have explored Proterozoic sedimentary basins in Central Australia. A limited amount of success has been claimed. Minor amounts of methane and propane have been encountered, but the absence of limestone with appreciable porosity has prevented accumulation of commercial quantities of petroleum. The search, however, is continuing. Widespread evidences of indigenous hydrocarbons in the upper Precambrian (Riphaean) of Russia especially in the Siberian platform have been forthcoming, focussing attention on the possibilities of commercial accumulation of oil and gas in unmetamorphosed Precambrian sedimentary rocks. Crude oil has been reported from Nonesuch shales in northern Michigan, USA, indicating that hydrocarbons can be preserved for long periods of geological time. These stray evidences indicate that biological activity in late Precambrian was capable of producing hydrocarbons similar to those in more recent sediments.

I wish to draw attention to another recent development. This is the suspected occurrence of substantial quantities of non-biological methane deep down in the crust. Hydrocarbons are known to be the dominant carbon containing molecules in the solar system. Carbon in meteorites is in the form of complex hydrocarbons. The initial atmosphere which enveloped the earth is believed to have been dominantly of the character of methane, released from the differentiating earth at the time of core formation. It was in such a reducing atmosphere life is believed to have originated. Bulk of the carbon in the earth's crust is locked up in the form of carbonate rocks. This excessive carbon could only have been brought up from the interior of the earth in the form of methane and later oxidised to carbon-dioxide. Professor Tommy Gold[7] of Cornell University argues in favour of the existence of substantial quantities of methane deep down in the earth, in quantities far in excess of what is expected by biological accumulation of carbon. He has also raised doubts regarding the exclusive biological origin of petroleum[8]. Instead, he considers that a substantial portion of non-biological methane has contributed to the formation of petroleum. We understand that the Environmental Research Council of U.K. has appointed a committee to go into the question of deep source gas. The findings of this committee should prove to be of interest to us. Wakita and Suno[9] have recently reported CH_4-rich natural gas associated with volcanic activity and contend that primitive (inorganic) CH_4 should not be neglected as a possible source of natural gas. They point out that $^3He/^4He$ ratio in natural gas may provide a diagnostic tool in identifying primordial gas which has a higher $^3He/^4He$ ratio than gas produced by anaerobic bacterial decomposition with a less helium ratio. The possibility of older volcaniclastic material deposited in a submarine environment could release gases as a result of diagenetic and hydrothermal alteration.

Petroleum geologists of the present day do not perhaps rule out the possibility of finding petroleum in the Precambrian. The ultimate question is one of size and the likely quantities available. The giant sized deposits are possibly of biological origin but this should not make us blind to the possibility of abiogenic derivation of petroleum. More and more reports of gas emissions showing methane and heavier hydrocarbons from older strata are forthcoming.

Deep fissures in the earth's crust, represented by rift valleys do point to abnormal concentrations of methane. East African rift valleys are stated to contain some fifty million tons of dissolved methane. The Red Sea Basin is believed to contain 1000 times more methane than sea water. This excess could only have been contributed by methane escaping from the bottom of the rift which gave rise to the Red Sea. Oil accumulations are known to be concentrated along ancient fault lines. It is possible these have provided channel ways for methane escaping from deeper portions of the earth.

Petroleum rarely originates in the place where it has accumulated. It almost in all cases has migrate from an original source rock. No one can be dogmatic about the source rock for all petroleum.

I have thought it fit to bring some of these new developments to the notice of our readers with the object of entering a strong plea for building and strengthening schools of Sedimentology, Palaeontology and Organic Chemistry. These disciplines are neglected in most universities in our country. A larger number of sedimentologists should actively engage themselves in studying aspects like structure, depositional environment, diagenetic changes, porosity, metamorphism, unconformities, facies changes, provenance and such other factors relating to basin development. Such studies should not be confined to younger sedimentary basins only but extended to the Precambrian basins as well. Increasing number of Palaeontologists and organic chemists should engage themselves in studies of macro- and micro-fossils and evaluate their hydrocarbon content, aided by all the modern instrumentation techniques like electron microscopy, gas chromatography and the rest. Study of stable isotopes and helium ratios is also likely to provide important confirmatory evidence.

The study of early life-forms is closely associated with the basic question of the problem of the origin of life itself. This is a most exciting and active field of research, but very few in our country appear to be engaged in this all absorbing quest. We should not be satisfied with watching what others are doing, but get actively engaged in the quest ourselves. It is hoped that some positive action will be taken in this regard.

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ON POSITIVE AND NEGATIVE VALUED AUXILIARIES IN SURVEY SAMPLING

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SUMMARY

Auxiliary variates in sample surveys are occasionally positive and negative-valued. This introduces difficulties in using ratio or product methods of estimation. A simple translation is suggested to overcome the problem. Simple random sampling is assumed for illustration.

1. INTRODUCTION

CONSIDER estimating the total Y of a character y in a finite population of N units, based on a probability sample of n ($\leqslant N$) units. For illustration assume simple random sampling without replacement and let $\bar{y}$ be the sample mean. The commonly used ratio and product estimators are

$$\hat{Y}_r = N\bar{y}(\bar{X}/\bar{x}), \quad \hat{Y}_p = N\bar{y}(\bar{x}/\bar{X}); \tag{1.1}$$

where $\bar{x}$ is the sample mean of a character x auxiliary to y and it is assumed that the population mean $\bar{X}$ is known. Generally x is non-negative. But exceptions do occur. Examples are variates arising as differences, like savings and net revenue, which can be positive or negative. These variates cannot be directly used as auxiliaries in (1.1) since $\bar{X}$ and/or $\bar{x}$ may be close to zero.

The present note considers a simple translation of x to make it positive-valued, along with a shift for y so as to have proportionality between the values of the two variates. Thus define

$$u = x + a, \; v = y + b; \tag{1.2}$$

where a is chosen such that $u > 0$. For instance, let x_1 (< 0) be the smallest x-value. Then a must satisfy $|x_1| < a < \infty$. Thus the magnitude of the smallest x-observation in the population must be known atleast approximately in order to fix the choice for a. This should pose no problem since x is an auxiliary character on which information is supposed to be available easily. Next, b is chosen to control the mean squared error (MSE) of the estimator, as discussed in Section 3.

2. THE ESTIMATOR

Let $\bar{u} = \bar{x} + a$, $\bar{v} = \bar{y} + b$, $\bar{U} = \bar{X} + a$, $\bar{V} = \bar{Y} + b$. Then the usual ratio estimator of the total V is

$$\hat{V}_r = N\bar{v}(\bar{U}/\bar{u}) = N(\bar{y} + b)(\bar{X} + a)/(\bar{x} + a) \tag{2.1}$$

and hence Y may be estimated by

$$\hat{Y}_1 = \hat{V}_r - Nb. \tag{2.2}$$

The transformations (1.2), being only changes of origin, leave the variances, covariances and correlations unchanged. Also the standard theory for ratio estimators applies to $\hat{Y}_1$. Thus the bias and MSE of this estimator are, up to second order moments,

$$B(\hat{Y}_1) = (N - n)(RS_x^2 - S_{xy})/n(\bar{X} + a), \tag{2.3}$$

$$M(\hat{Y}_1) = N(N - n)(S_y^2 + R^2 S_x^2 - 2RS_{yx})/n, \tag{2.4}$$

where $R = (\bar{Y} + b)/(\bar{X} + a)$ and S_y^2 is the population variance of y, etc.

For given a, the b minimizing the MSE of the estimator $\hat{Y}_1$ upto second order moments can be obtained by differentiating with respect to b the expression for the MSE in (2.4) and equating it to zero. This leads to the condition $R = S_{yx}/S_x^2$ which implies $b_{\text{opt}} = B(\bar{X} + a) - \bar{Y}$ where $B = S_{yx}/S_x^2$ is the coefficient of regression of y on x in the population. For this choice of b, $\hat{Y}_1$ is almost unbiased for Y. And

$$M_{\min}(\hat{Y}_1) = N(N - n)S_y^2(1 - \rho^2)/n,$$