Rationale for Deliberate Pursuit of Stratigraphic, Unconformity, and Paleogeomorphic Traps[1]

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Abstract Most basins contain facies changes, unconformities with resulting truncated beds, and buried erosional or constructive surfaces such as reefs, hills, channels, barrier sand bars, and other such phenomena—which form the basic requirements for the creation of subtle traps.

If folding, normal faulting, thrusting, and the formation of salt ridges and domes are added to the picture of an evolving but continuously filling basin, the resultant structural and stratigraphic patterns become much more complex. However, no matter how complex the history, those stratigraphic relations and lithologic changes which are conducive to the formation of stratigraphic, unconformity, and paleogeomorphic traps remain.

When hydrocarbon is expelled (primary migration) by pressure and heat from sediments which contain source material into adjacent reservoir rocks, it migrates through carrier beds (secondary migration) into sealed reservoirs, or traps. As long as the conditions necessary for secondary migration of a substantial amount of petroleum exist, migration will continue along strike and updip until all migrating hydrocarbons are either trapped in the subsurface or have escaped at the surface. As the petroleum moves, it will be captured by all traps—stratigraphic, unconformity, paleogeomorphic, structural, or a combination of these—which are in the path of migration.

Because paleogeomorphic, unconformity, and stratigraphic traps are related (1) to older geologic surfaces, (2) to the location of strata on and directly below an unconformity surface, and (3) to lithologic changes within and laterally adjacent to a stratum, it is suggested that, in general, the conditions which produce most subtle traps are present before development of structural traps. If migration of hydrocarbons through a particular region were to take place *before* structural movements, all petroleum trapped during this early migration would be in subtle traps.

Because subtle traps generally are formed as a result of constantly recurring depositional patterns which usually precede, or may be associated with, contemporaneous structural movement, petroleum basins probably contain more subtle traps than structural traps. Although much petroleum has migrated into structural traps, possibly more has accumulated in the earlier (and contemporaneously) formed subtle traps. Because subtle traps probably contain the large undiscovered domestic reserves needed for the future, explorationists must make the purposeful search for such traps an essential and substantial part of their exploration policy.

Introduction

The large onshore reserves of the future in this country will be found in stratigraphic, unconformity, and paleogeomorphic traps[2]—which are referred to herein as subtle traps. The logic behind such a broad statement is based on two observations:

1. Large petroleum accumulations do occur in stratigraphic traps (*e.g.*, the Jackson trend of South Texas and the Hugoton field, Kansas); in unconformity traps (*e.g.*, the East Texas field); and in paleogeomorphic traps (such as those associated with the buried hills in the Kraft-Prusa district, Kansas, and in most of the Mississippian oil fields in southeastern Saskatchewan, Canada).
2. Most of the relatively easy-to-find structural traps in explored basins of the conterminous United States probably have been found by intensive past exploration; however, geologists agree that large reserves are yet to be found in our domestic basins.

If both statements are valid, then a major part of the total petroleum originally contained in structural traps in these basins already has been discovered, and, if large reserves remain undiscovered in these petroleum provinces, it is logical to assume that they are contained in subtle traps, which probably occur in large numbers in all basins.

Occurrence of Subtle Traps

Most basins contain facies changes, unconformities with resulting truncated beds, and buried erosional or constructive surfaces such as reefs, hills, barrier sand bars, channels, and other related geologic phenomena—which form the basic requirements for the creation of subtle traps. Basins differ in lithologic characteristics; some may contain principally sandstones and shales, others carbonate rocks, and others combinations of these. The ultimate controls on lithologic characteristics are the sources of the deposits and the environments of deposition.

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[2] In previous lectures and papers I have referred to "subtle traps" as stratigraphic and/or paleogeomorphic. In this paper I have added the "unconformity" trap to the classification.

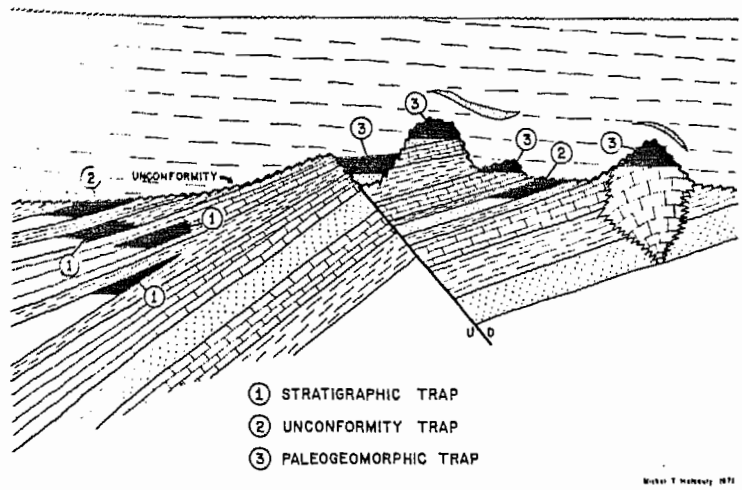

FIG. 1—Idealized portrayal of types of subtle traps. Note relations of stratigraphic traps to lateral changes in facies and relations of unconformity and paleogeomorphic traps to erosional surfaces and relief features buried beneath them.

In general, lateral lithologic changes within a given stratum are the result of crossing of depositional environmental boundaries, the nature of the provenance for the sediments, the type and configuration of the depositional basin, the depth of water at the site of deposition, *etc.* Moreover, there may be postdepositional effects on porosity and permeability within that stratum because of chemical and other reactions.

Stratigraphic traps are formed from lithologic changes which occur during and after deposition (Fig. 1). Included in this category are (1) depositional traps which are caused by lateral facies change from permeable to impermeable beds, or by pinchout of a reservoir rock which is not represented laterally by contemporaneously deposited strata, and (2) postdepositional traps caused by cementation or changes which take place in a reservoir bed after deposition. It should be intuitively clear—in view of the numerous possibilities for depositional and postdepositional changes within strata—that the conditions essential to the formation of stratigraphic traps must occur, and probably *abound*, in all basins.

Unconformity traps are formed where an impermeable bed on an erosional surface is in direct contact with a reservoir rock lying below the erosional surface and provides a seal for the trap. These traps usually occur in association with angular unconformities and *should be differentiated* from those paleogeomorphic traps which occur below erosional surfaces (*e.g.*, in a buried hill).

Since unconformity traps are a consequence of cycles of deposition, structural movement, and erosion, they should be prevalent in all petroleum basins. Their size can range from small local traps to regional ones such as the East Texas field.

Paleogeomorphic traps are formed where ancient subaqueous or land surfaces and the relief features on them (which are produced by geomorphic processes such as erosion, channeling, deposition, *etc.*) are buried by younger strata of a different lithology. Buried reefs, channels, barrier sand bars, and hills on erosional surfaces are examples of such features. Paleogeomorphic traps may occur above or below the erosion surface and may be directly or indirectly related to the buried feature. It is difficult to imagine an ancient basin that does not contain in at least one area, or within at least one stratigraphic interval, numerous and varied buried features which, directly or indirectly, may serve as traps for petroleum.

In the Gulf Coast embayment, the hundreds of salt domes may be considered to be mobile, paleogeomorphic features—impervious buried hills which, during geologic time, are capable not only of changing shape but also of moving laterally and vertically. At each position during their formation, they affect the depositional and structural placement of beds around and above them.

In contrast, a buried hill associated with ancient eroded topography is a stable feature. Its effect on depositional patterns produces a con-

sistency in pattern for the duration of time that the feature is being buried. After burial and compaction of that feature, the depositional pattern changes because the buried hill is no longer an important factor in the basin of deposition. However, the mobile salt dome usually has a much more complex effect on the surrounding and overlying strata. The extent of its effect depends on the mobility of the dome. An unusually mobile salt mass, in contrast to the stable, stationary buried hill, can affect depositional patterns for long periods of geologic time.

If folding, normal faulting, thrusting, and the formation of salt ridges and domes are added to the picture of an evolving but continuously filling basin, the resultant structural and stratigraphic patterns become much more complex. However, no matter how complex the history, those stratigraphic relations and lithologic changes which are conducive to the formation of stratigraphic, unconformity, and paleogeomorphic traps remain.

Subtle traps which develop prior to the beginning of structural movement in a region are, of course, subject to the effects of such movement. For example, a stratigraphic trap which originally consisted of a sandstone pinchout along strike on a monocline may be uplifted and superimposed above or on the flank of an anticline or dome; it may become part of a deep synclinal area; it may be faulted; or it may be tilted laterally with respect to the previous strike.

Whatever the structural effect, any petroleum which had accumulated in the original pinchout trap could, as a result of subsequent tectonic processes, migrate from its original position and relocate in another place or acquire a different pattern of accumulation within the same trap, or the accumulation could escape as a result of erosion which might accompany substantial uplift.

Petroleum Migration and Accumulation in Subtle Traps

There is general agreement among geologists that petroleum, in some form, is expelled by pressure and heat from sediments containing source materials into adjacent reservoir rocks (primary migration), and that hydrocarbons migrate through carrier beds into sealed reservoirs, or traps (secondary migration). In some fields it appears that little if any secondary migration occurred because impermeable strata surround the reservoir (closed reservoir).

The location and differential gravitational separation of oil, gas, and water within closed anticlines are sufficient proof that secondary migration does occur along carrier beds into reservoir rocks. Otherwise, petroleum would be required to originate from within the reservoir beds in the trap.

There are differences of opinion among geologists concerning the question of *how far* petroleum can migrate from the source area to the reservoir. The writer's opinion is that, as long as the requirements for secondary migration of a substantial amount of petroleum exist —pressure, heat, regional and local tilt, good-quality carrier beds with continuity to the reservoir rock—migration will continue along strike and updip until all migrating hydrocarbons have been trapped in the subsurface or have escaped at the surface.

Therefore, if stratigraphic, unconformity, paleogeomorphic, structural, or combination traps are in the path of migration, petroleum will be trapped in them. However, that part of the migrating oil or gas which is *not* trapped will continue updip to the surface through outcropping carrier beds.

Gulf Coast geologists are familiar with the similarity of electric-log resistance patterns or "kicks" for long distances along strike in wells drilled in the Anahuac (Miocene-Oligocene) marine shale wedge (also in other marine shale) of the Texas-Louisiana Gulf Coast. This subsurface shale wedge approximately parallels the present shoreline and increases in thickness from a few feet updip to several thousands of feet toward the Gulf of Mexico. The wedge separates the basal Miocene from the upper Frio (Oligocene); it has been considered to be the host rock for the source materials which generated the large petroleum accumulations found in sandstones of both the Miocene and Frio.

The similarity of electric-log patterns within the Anahuac shale wedge across long distances obviously means that each distinctive electric-log interval possesses electrical-response properties which are nearly constant through extended distances. Each such interval, therefore, must possess uniform lithologic characteristics through long distances along depositional strike, or in whatever direction the log pattern remains constant.

If a stratum's electrical-response patterns are related to the lithology, then the similarity of electric-log patterns across a long distance indicates that *this particular widespread stratum is a result of more or less simultaneous deposition of the same materials, including those from*

which oil and gas are generated. Moreover, for the Anahuac, these materials—lithologic and organic—were derived from the same sources and were deposited in a widespread, uniform marine environment.

It is very probable, therefore, that the Anahuac shale was deposited in widespread layers, some of which contained petroleum-generating materials. As the nature of the deposited material and the environment changed, the characteristics of the strata changed accordingly; these changes are reflected by different electric-log patterns in different strata.

If primary hydrocarbon migration can begin from source materials which are as widespread as they apparently were within the Anahuac shale, then it is apparent that secondary petroleum migration from such beds, once begun, can indeed traverse a very wide area if carrier rocks are contiguous.

As long as the conditions which control generation and migration are favorable, hydrocarbons will continue through geologic time to move across a wide geographic area, except where structural features such as regional noses, synclines, and faults divert the direction of movement. As the petroleum moves along strike and updip, it will be captured by all traps —stratigraphic, unconformity, paleogeomorphic, structural, or a combination of these—which are in the path of the migrating hydrocarbons. These traps may be adjacent to, near, or distant from the area where secondary migration is initiated.

Thus:

1. Petroleum migration *can* be widespread along strike and petroleum *can* move long distances updip, depending on the availability of source materials and on contiguous carrier rocks.
2. Migrating petroleum does not move preferentially into structural traps.
3. Petroleum will be captured along its migratory path by whatever phenomenon provides proper trapping conditions—*as long as such conditions are present at the time of migration.*

Because paleogeomorphic, unconformity, and stratigraphic traps are related (1) to older geologic surfaces, (2) to the location of strata on and directly below an unconformity surface, and (3) to lithologic changes within and laterally adjacent to a stratum, it is suggested that, in general, the conditions which produce most subtle traps are present *before* development of structural traps. If migration of petroleum through a particular region were to take place before structural movements, *all* trapped petroleum would be in subtle traps. If both subtle and structural traps were formed *prior* to migration, both types would become reservoirs. In either case, structural movements, even if post-migration, could influence accumulations formed previously in subtle traps and thereby change the location of the petroleum originally contained in such traps.

Consider the East Texas field, more than 45 mi (75+ km) long and as wide as 12 mi (20+ km; Fig. 2). The migration apparently was widespread laterally. If the east flank of the East Texas basin had been an approximate mirror image of the west flank, where the Woodbine Sandstone (Lower Cretaceous) beds crop out, most of the great reserves in that field might have escaped to the surface. The eastward migration through the Woodbine sandstones would have allowed the escape of all the migrating petroleum, except for that which might have been caught by existing structural and subtle traps. However, because the truncated eastern edge of the Woodbine Sandstone beds is wedged between impermeable beds on the west flank of the Sabine uplift, the widespread eastward migration was halted and the East Texas accumulation was formed.

The pertinent question may well be asked: Are there as many subtle traps in petroleum basins as there are structural traps? The answer is that there probably are *more*, because subtle traps generally are formed as a result of constantly recurring depositional patterns which usually precede structural movement, or which may be associated with contemporaneous structural growth.

Huge amounts of petroleum have been generated in petroleum basins. Much of it has been lost because of absence of trapping conditions; yet much has been trapped in structural anomalies and probably more has accumulated in subtle traps. The problem is to *find* these subtle reservoirs.

Importance of Subtle-Trap Exploration

Exploration for subtle traps has been neglected by the petroleum industry simply because structures are easier to find with present exploratory methods. Only recently has exploratory thinking begun to be oriented toward the subtle reservoir.

Recent events in the Middle East and North Africa have proved, much to the chagrin of some U.S. politicians, that foreign oil is not always going to be cheap, and that the United

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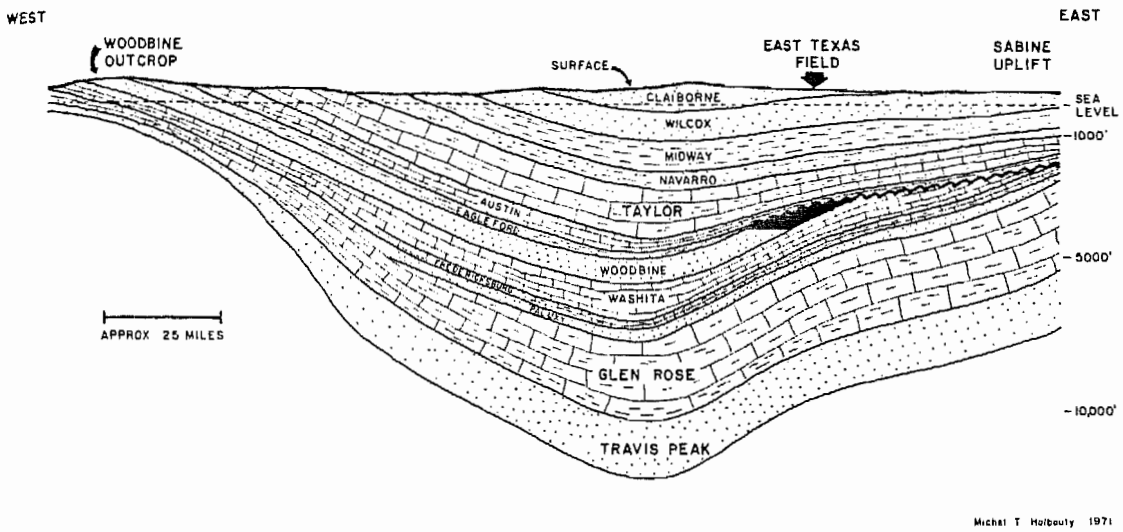

FIG. 2—Generalized cross section, East Texas basin, showing wedging of eroded Woodbine Sandstone between Austin and Washita limestones, forming trap for East Texas field on west flank of Sabine uplift. Note outcrop of Woodbine beds west of East Texas basin.

States cannot depend on such reserves in future emergencies because they can be cut off by circumstances beyond this country's political control.

The great need of the United States and of the domestic petroleum industry is to find a reliable source of oil and gas reserves. A *reliable* source necessarily is domestic. However, domestic reserves have been declining in the face of a continually growing demand for petroleum products.

Reserves are declining because exploration and drilling in this country have been decreasing for several years, and most of the exploratory effort continues to be directed toward the structural trap. Structures which remain undiscovered are becoming more difficult to find because they are smaller or less discernible than those structures found in the past.

Explorationists must make the *purposeful* search for subtle traps an essential and substantial part of their exploration policy. They will be required to make use of all basic earth studies which would shed light on ancient geologic environments that favored the formation of stratigraphic, unconformity, or paleogeomorphic traps.

If the thesis presented here is correct, it may be assumed that thousands of subtle traps, containing petroleum accumulations ranging in size from inconsequential to supergiant, are yet undiscovered in United States petroleum basins.

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