Stratigraphic-Trap Classification[1]

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Abstract A trap for hydrocarbons requires the simultaneous existence of (a) a reservoir, (b) an isolated region of low potential in the reservoir, and (c) a barrier (or seal) with high enough entry pressure to retain a commercially producible volume of hydrocarbons. Three kinds of traps exist—structural, stratigraphic, and hydrodynamic. All three kinds have a reservoir bounded by a barrier but differ in what causes the isolated area of low potential. In classification of hydrocarbon accumulations, the conditions that determined the present location of the accumulation should be used where they can be ascertained.

In the stratigraphic-trap classification suggested here, primary emphasis has been placed on usability—*i.e.*, will the groupings help in the search for new hydrocarbon accumulations, and is the suggested terminology simple and descriptive enough to be accepted? A classification using the time relations between barrier and reservoir was considered and rejected.

The suggested classification starts with the simple concept that stratigraphic traps are adjacent to unconformities or they are not. For traps that are not adjacent to unconformities, the reservoir and barrier may be (I) primary (depositional, usually facies-related) or (II) wholly or in part secondary (diagenetic). Those traps in contact with unconformities may be (III) below the unconformity surface or (IV) above it, or (V) both below and above it. This approach uses some of Levorsen's ideas and eliminates some inconsistencies in his classification. Subdivision of these four major classes (facies-change traps, diagenetic traps, traps below unconformities, and traps above unconformities) allows more precise description of the different types of traps.

Introduction

What is a stratigraphic trap? Before one can classify such traps, one must decide what they are.

Although the existence of nonstructural traps was recognized as early as 1880 by Carll, and "Reservoirs closed because of varying porosity of rock" were distinguished by Wilson (1934) in his classification of oil and gas reservoirs, the term "stratigraphic trap" was proposed first by Levorsen (1936), who stated (p. 534):

> A stratigraphic trap may be defined as one in which a variation in the stratigraphy is the chief confining element in the reservoir which traps the oil.

In differentiating stratigraphic from structural traps, he explained (p. 524) that, in stratigraphic traps,

> . . . the dominant trap-forming element is a wedging or pinching-out of the sand or porous reservoir rock, a lateral gradation from sand to shale or limestone, an uplift, truncation and overlap, or similar variation in the stratigraphic sequence.

Under this definition, there would be general agreement that a pod of porous and permeable sandstone completely surrounded by shale of essentially the same age and completely filled with oil or gas is a stratigraphic trap. However, if the pod were not completely filled, depositional or regional dip might determine where in the pod the hydrocarbons occur. Depositional tilt certainly would be considered as stratigraphic control; regional tilt, however, would add a structural element. Such regional tilt generally has been accepted as a component—usually a necessary component—of stratigraphic trapping.

Local, in contrast to regional, structural movements provide complications. The pod might coincide with the culmination of an anticline, might be restricted to one flank, or might be in a syncline—or the pod could have been separated into two or more parts by faulting. In his foreword to *Stratigraphic Type Oil Fields*, Levorsen (1941, p. x) clarified this by stating:

> A stratigraphic pool is bounded on one or more than one side by non-porosity, whatever the cause, unless the non-porosity is altogether coincident with local structural deformation. Thus, a field would not be included if due to an interruption of stratigraphic continuity because of faulting, nor would one in which the porosity was a result of fracturing and brecciation be considered as a stratigraphic type pool. Neither would pools in which the area of accumulation was determined by a local uplift or deformation be classified as stratigraphic even though the reservoir rocks were pinched or wedged out.[2]

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[2] Concerning porosity due to fracturing, Levorsen does not distinguish between fracturing caused by, and coincident with, local structural deformation and that which is not. A distinction between the two is made in this paper (see succeeding sections).

Under this definition, as commonly applied, the accumulation in the pod on the crest of the anticline would be considered as structural and the accumulation on the flank as either structural or, under Levorsen's (1954) later classification, combined stratigraphic-structural. However, what if the hydrocarbons had accumulated before the local structural deformation occurred and their positions in the pod had not been shifted materially because of it? The accumulations thus would be stratigraphically controlled and the relation to structure would be entirely coincidental. The words "*determined* by a local uplift or deformation" (italics added) in Levorsen's 1941 definition clearly cover this possibility, but in practice the geographic and not the time relations have been used. It may be important, not only in classification but also in exploration, to determine the time relations.

Until 1966 there also would have been general agreement that a carbonate reef, such as the Redwater reef in Alberta, was a stratigraphic trap, although the hydrocarbon distribution in it is controlled in part by regional tilt. In that year, however, Martin (1966, p. 2278) pointed out that reefs, erosion surfaces, and other types of reservoir rocks that are bounded laterally by air or water at the time of their formation become traps only as a result of subsequent deposition of younger strata adjacent to (and above) them. He proposed the term "paleogeomorphic" for such traps and believed the term "stratigraphic trap" should be limited to those traps caused by lateral change in reservoir properties within a given (single) stratum. If Martin's proposal were accepted, most traps previously considered as stratigraphic would be in his paleogeomorphic category. Should such traps, or some part of them, be considered a separate category of traps, or are they a kind of stratigraphic trap?

Hydrodynamics is another factor that should be reconsidered in deciding, "What *is* a stratigraphic trap?" Levorsen (1954, p. 142) included one hydrodynamic aspect when he expanded his earlier definition of a stratigraphic trap by stating: "The pool may rest on an underlying water table, which may be either level or tilted. . . ." However, hydrodynamics may have effects other than just tilting the hydrocarbon-water contact. As pointed out by Hill *et al.* (1961) and McNeal (1965, p. 325), it is possible that an updip pinchout in a stratum might hold hydrocarbons if the water flow is downdip, but might not hold them if the water flow is updip or if the water is static. Should such a trap be considered as stratigraphic?

Another factor that needs reconsideration is fracturing. In his 1941 discussion, Levorsen specifically excluded pools in which the porosity was the result of fracturing and brecciation. In 1954, however, he included the Santa Maria field in California as a stratigraphic trap even though "The porosity is the result of the fracturing of the brittle Monterey shales (Miocene) and siltstones . . ." (p. 243). Also, in the Spraberry trend in West Texas, where fractures and production are not related to local structures, the fractures are considered to act as "feeders" from rocks that are too impermeable to have extensive commercial production if unfractured (Wilkinson, 1953). In defining a stratigraphic trap, should we be concerned with how the porosity or permeability of the reservoir developed, or should we be concerned with what controls the boundaries of the trap itself? It is my contention that the boundary controls should be the determining factor. Thus, fracture-porosity traps unrelated to local structure would, indeed, be stratigraphic traps.

Types of Traps

Before considering structural, stratigraphic, paleogeomorphic, and hydrodynamic aspects of traps, it is appropriate to determine the basic requirements for a trap. Hubbert (1953, p. 1954) summarized trapping of hydrocarbons in terms of energy potentials as follows:

> Oil and gas possess energy with respect to their positions and environment which, when referred to unit mass, may be termed the potential at any given point of the fluid considered. When the potential of a specified fluid in a region of underground space is not constant, an unbalanced force will act upon the fluid, driving it in the direction in which its potential decreases. Hence, oil and gas in a dispersed state underground migrate from regions of higher to those of lower energy levels, and come ultimately to rest in positions which constitute traps, where their potentials assume locally minimum or least values. In nearly all cases traps for petroleum are regions of low potential which are enclosed jointly by regions of higher potential and impermeable barriers.

As to permeability barriers, Hubbert (1953, p. 1979) stated:

> Reference to Table I shows that the capillary pressure of oil in a shale is the order of tens of atmospheres, while in a sand it drops to the order of tenths. Hence a slug of oil extending across such a boundary would be expelled from the shale into the sand by an unbalanced pressure of the order of tens of atmospheres.
>
> This formidable energy barrier, therefore, makes a shale-sand interface appear as a surface of unidirec-

tional conductivity to oil (or gas). Across such a boundary the oil can flow in the direction from the shale to the sand without hindrance other than viscous drag; in the opposite direction it can not flow at all unless a pressure is applied to the oil in the sand greater than the opposing capillary pressure against the oil in the shale.

There can, of course, be all gradations in pressures that permit entry of oil or gas—from pressures in shales through those in siltstones to those in shaly sandstones and sandstones of increasing grain size. Sandstones of the same median grain size may differ in entry pressure because of sorting, partial compaction, or partial cementation. As hydrocarbons accumulate, the pressure upward in the accumulation will increase, until in some situations the entry pressure of some part of the formerly impermeable barrier is exceeded and hydrocarbons will pass through it. Equilibrium is established and, if migration continues, hydrocarbons leave the trap at the same rate at which they enter it. Thus, the extent of difference in entry pressure between reservoir and barrier may control the height of the hydrocarbon column and, in consequence, the lateral extent of the accumulation. The same effect may result if fractures in the barrier rock or faults bounding the accumulation have lower entry pressures than the unfractured barrier rock. Hill *et al.* (1961) and Smith (1966) and others have discussed this aspect of hydrocarbon trapping.

Thus, except in a relatively few cases, a hydrocarbon trap requires the simultaneous existence of (a) a reservoir, (b) an isolated region of low potential in the reservoir, and (c) a barrier (or seal) with high enough entry pressure to retain a commercially producible volume of hydrocarbons. An isolated pod of sandstone *completely* filled with hydrocarbons may be an exception to (b); there appear to be no exceptions to (a) and (c).

It should be emphasized that high entry pressure (c, above) is not synonymous with low porosity or nonporosity. Some shales that form trap barriers, for example, are more porous than the adjacent reservoirs that contain the hydrocarbons. The size of the pores or the size and shape of the connections between them, not the amount of porosity, are the important factors.

In order to distinguish various types of traps, we need to decide what the term "stratigraphic" means. Should we limit ourselves to a "given stratum" as suggested by Martin (1966), or is the term broader? Stratigraphy has been defined as:

"1. That branch of geology which treats of the formation, composition, sequence, and correlation of the stratified rocks as parts of the earth's crust. 2. That part of the descriptive geology of an area or district that pertains to the discrimination, character, thickness, sequence, age, and correlation of the rocks of the district. (La Forge)" (*Glossary of Geology and Related Sciences*, Am. Geol. Inst., J. V. Howell, chm., 1957, p. 281)

"a The arrangement of strata, esp. as to position and order of sequence." (Webster's New International Dictionary, Unabridged, 2nd ed., 1956, p. 2491)

It seems clear from these definitions that *stratigraphy*, and consequently *stratigraphic*, is a broader term applying to strata and not just to a bed or group of beds that constitute a stratum. Nor are there any restrictions in time relations between rocks that may be laterally or vertically adjacent. Under this broader interpretation, paleogeomorphic traps are kinds of stratigraphic traps. In retrospect, one might wish that another term—perhaps "permeability trap"—had been proposed instead of stratigraphic trap. However, stratigraphic trap, or "strat trap," is so widely accepted and used that an attempt to change to a more descriptive term now probably would lead only to confusion.

From the foregoing discussion it appears that three basic kinds of traps exist—namely, structural, stratigraphic, and hydrodynamic—and that there may be combinations of any two or of all three kinds. The three basic kinds have a reservoir bounded by a barrier with high enough entry pressure to retain a commercially producible volume of hydrocarbons. Each kind also is in an isolated area of low potential, but they differ as to what causes the isolation. In a structural trap, isolation results from local structural deformation; in a stratigraphic trap it results from a nonstructural lateral change in entry pressure that creates the barrier; and in a hydrodynamic trap it results from the rate of water flow. Regional dip may be a component of stratigraphic traps: change in regional dip (terracing) may be a component of hydrodynamic traps.

Traps of all three categories may be filled to capacity or be partially filled or may contain no hydrocarbons. As a colleague of mine has put it, "A trap is a trap, whether or not it has a mouse in it" (W. C. Finch, personal commun.). Those traps containing hydrocarbons might well be designated as structural, stratigraphic, or hydrodynamic pools or accumulations; those containing no hydrocarbons, as potential hydrocarbon traps.

In classification of hydrocarbon accumulations, the conditions that determined the present location of the accumulation should be used if they can be determined. Thus, a stratigraphically trapped pool (such as an accumulation in an isolated pod of sandstone) which happens to be located on a post-accumulation local uplift would be classified as a stratigraphic pool. If, in contrast, accumulation occurred after the uplift and hydrocarbons migrated into the trap because of its locally high structural position, the controlling factor would be structure. In other places, where accumulations were trapped due to stratigraphic factors and later local uplift completely or materially shifted the position of the accumulations within the reservoir, the accumulations would be structural or combined stratigraphic-structural.

In some cases, the relative times of accumulation and structural growth will not be known. If no attempt has been made to determine these relative times, there is no basis for classification and none should be attempted. If an attempt has been made but the results are inconclusive, I suggest either "structural(?)" or "stratigraphic(?)," depending on which appears more likely. This method allows a judgment based on the weight of evidence available, but the "(?)" alerts others to the uncertainties involved.

The present position of many pools is the result of some combination of structure, stratigraphy, and hydrodynamics, and it seems appropriate, as previously suggested by others, that these traps be designated as combinations. The distinctions suggested by Sanders (1943), appropriately expanded to include hydrodynamics, would appear to provide a good basis for designating such combination traps. Certainly, the relative importance of structural, stratigraphic, and hydrodynamic factors needs to be recognized and clearly indicated.

Bases for Stratigraphic-Trap Classification

Bases that have been suggested or used in describing or classifying stratigraphic traps include:

1. Time of trap formation, *i.e.*, primary—a direct product of the depositional environment—vs. secondary—developed after deposition and diagenesis of the reservoir; mainly unconformity traps.
2. Kind of reservoir rock, *i.e.*, clastic and igneous vs. chemical.
3. Kind of porosity, *i.e.*, interparticle vs. leached vs. fracture.
4. Genesis of the reservoir rock, *i.e.*, alluvial vs. bar vs. dune, *etc.*
5. Relation to regional dip, *i.e.*, open—not dependent on regional dip—vs. closed—where one boundary results from regional dip.
6. Geometry of the reservoir rock, *i.e.*, shoestring sands, *etc.*
7. The way the impermeable barrier formed, *i.e.*, low original permeability (deposition) vs. diagenetic plugging of the reservoir pores by tar, clay, or mineral cement.

The real problem with stratigraphic-trap classification is that it, like Topsy, has just "growed." Originally, differentiation of traps was between structural and nonstructural. As knowledge grew, more kinds of nonstructural traps were recognized and attempts were made to fit them into preexisting broad subdivisions.

Probably the best-known classification is that of Levorsen (1954), which is summarized briefly below.

I. Primary stratigraphic traps—formed during the deposition and/or diagenesis of the rock. These include
    - A. Lenses and facies of clastic rocks
    - B. Lenses of volcanic rock
    - C. Stratigraphic traps in chemical rocks
        - 1. Porous facies
        - 2. Porous mound- or lens-shaped carbonate masses

II. Secondary (unconformity) stratigraphic traps—resulting from some stratigraphic anomaly or variation that developed after deposition and diagenesis of the reservoir rock; almost everywhere associated with unconformities. Traps above and below the unconformities are included as secondary.

There are several inconsistencies in this classification and its application. One is that Levorsen would include as primary many traps that are wholly or in part of secondary diagenetic origin. Examples are traps resulting from secondary dolomitization or those due to cementation.

A second inconsistency is inclusion of stratigraphic traps above and below unconformities in the same category. Levorsen (1954, p. 239) stated:

> Traps bounded by an unconformity are broadly classed as stratigraphic, and they are also classed as secondary stratigraphic because they are formed after the lithification and diagenesis of the reservoir rock.

However, many traps above unconformities have had no significant lithification or diagenesis of the *reservoir* rock or the barrier that overlies it. For many traps above unconformities, the unconformity merely provides part of the impermeable barrier. If the rock below the unconformity is sufficiently permeable and extends far enough updip, there is no trap. It is true that in some places the barrier may be a former reservoir rock in which permeability has been reduced by diagenetic processes, but more commonly the rock below the unconformity was originally of low permeability and has remained so. In many other traps above unconformities, relief on the erosional surface has controlled where reservoir beds were deposited.

I believe the suggested classification of stratigraphic traps will eliminate these inconsistencies. In the succeeding discussion and in the suggested classification, primary emphasis has been placed on usability—*i.e.*, will the groupings help in searching for new hydrocarbon accumulations, and is the suggested terminology simple and descriptive enough to be accepted?

Extensive consideration was given first to use of the time relations between barrier and reservoir as a first-order subdivision. Because the existence of a barrier above an oil or gas accumulation is common to all traps, the relation of the reservoir to the *lateral* barrier—which restricts both updip and sideways movement of the hydrocarbon out of the trap—would usually be the critical one.

Three simple relations are possible:

1. Barrier and reservoir formed at the same time;
2. Barrier formed before the reservoir;
3. Barrier formed after the reservoir.

For such simple relations, a reservoir-barrier basis for classification would have practical advantages in exploring for stratigraphic traps. If barrier and reservoir were formed at the same time, and thus were genetically related deposits, they could be studied together as a genetic couplet and a facies-"model" concept of alluvial, deltaic, shallow-marine, or turbidite deposition could be applied if the expected reservoirs were sandstones. In contrast, different exploratory concepts would be used (relation 2) where the barrier formed before the reservoir, as where a youthful valley cut in shale was filled with sand, or (relation 3) where the barrier formed after the reservoir, as where a hill or an organic reef was buried by mud or other sediment which forms relatively impermeable rocks.

Many stratigraphic traps, however, have more complex reservoir-barrier relations because different parts of the barrier formed at different times. In addition to the three simple relations, four combinations are required to satisfy all possible relations. They are:

4. Barrier formed partly before and partly at the same time as the reservoir;
5. Barrier formed partly after and partly at the same time as the reservoir;
6. Barrier formed partly before and partly after the reservoir;
7. Barrier formed partly before, partly at the same time, and partly after the reservoir.

When these four combinations were explored, two serious complicating factors were found. The first is illustrated in Figure 1. If the hydrocarbon column is short (Fig. 1A), the barrier to lateral migration is entirely later, or younger, than the reservoir (relation 3). In contrast, if the hydrocarbon column is long (Fig. 1B), the barrier is formed partly by the post-unconformity shales, partly by the stratigraphically younger limestone, and partly by the stratigraphically older shale (relation 7). In this and other cases, the length of the hydrocarbon column would determine the classification. As a further complication, one might reasonably ask how a *potential* trap, one not containing any hydrocarbons, would be classified.

The second complicating factor is illustrated by Figure 2. The hydrocarbons in the bar (Fig. 2A) deposited on an essentially horizontal unconformity surface are restrained from lateral migration by genetically related open-marine and lagoonal shales (relation 1). After tilting (Fig. 2B), however, the rock below the uncon-

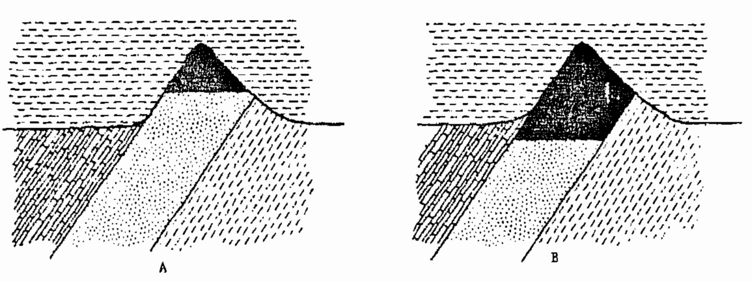


FIG. 1—Relation of age of barrier to hydrocarbon column height. **A.** For short columns, barrier is formed entirely by post-unconformity shales. **B.** For long columns, barrier is partly post-unconformity shales, partly pre-unconformity, post-reservoir limestone, and partly pre-unconformity, pre-reservoir shales.

formity has become part of the barrier (relation 4). Had the pre-unconformity rock been sufficiently permeable, the trap capacity would have been reduced. In this and other cases, regional tilting would determine the classification.

These two complications were among the factors that led to rejection of time relations between barrier and reservoir as a basis for stratigraphic-trap classification.

Suggested Classification

What I now believe to be the best classification system uses some, but not all, of Levorsen's ideas. I suggest starting with the simple concept that stratigraphic traps are either adjacent to unconformities or they are not. Those traps in contact with unconformities[3] can be below the unconformity surface, above it, or both. For traps not adjacent to unconformities, either (I) the reservoir and barrier both may be primary (depositional), or (II) the reservoir or the barrier may be wholly or in part secondary (diagenetic). Most of the primary traps not related to unconformities consist of genetic juxtapositions of coarse and fine (very high- and low-permeability) sediments; consequently, I suggest that they be designated "facies-change traps." This designation will help to distinguish them from traps adjacent to unconformities (classes III and IV) that also have primary (depositional) reservoirs but commonly have one or more boundaries not genetically related. Four major classes are each split into two subclasses as shown in Table 1, and these subclasses are subdivided further as shown in Table 2.

[3] The term "unconformity" is defined (AGI *Glossary of Geology and Related Sciences*, 1957, p. 308) as "A surface of erosion or nondeposition—usually the former—that separates younger strata from older rocks." "Unconformity" as used herein would not refer to a depositional break or hiatus of assumed minor duration (a diastem) during which erosional modification of the surface was minor.

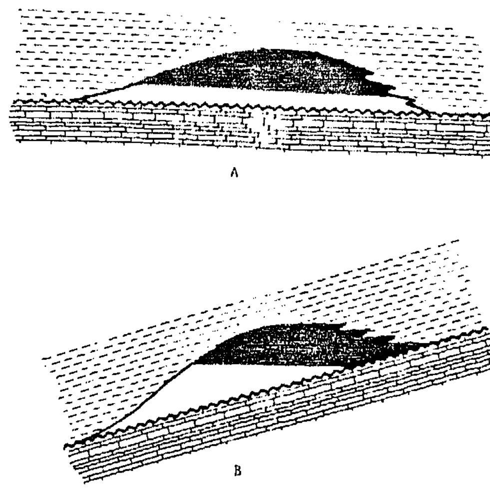


FIG. 2—Diagrammatic cross sections of barrier bar showing control of accumulation by facies-related shales before regional tilting (A) and by facies-related shales and pre-unconformity limestones after regional tilting (B).

I. Facies-Change Traps

The suggested first-order subdivision of facies-change traps is based on the depositional origin of the reservoir rock, *i.e.*, whether significant transport of particles by currents has occurred. "Current-transported" thus would imply mechanical transportation of particles or fragments of the reservoir rock to the site of deposition by water or wind currents. The mineral composition of the grains would not be critical; they could be quartz, feldspar, rock fragments, skeletal or nonskeletal carbonate particles, volcanic glass, or some combination of these. Some carbonate rocks in which traps occur thus would be in this current-transported category. "Not current-transported" would imply little or no transportation of particles, or movement due to gravity only.

Table 1. Major Subdivisions in Proposed Stratigraphic-Trap Classification

Stratigraphic traps	Not adjacent to unconformities	I. Facies-change traps	A. Current-transported reservoir rock
			B. Reservoir rock not current-transported
		II. Diagenetic traps	A. Change of nonreservoir to reservoir rock
			B. Change of reservoir to nonreservoir rock
	Adjacent to unconformities	III. Traps below	A. Seal above unconformity
			B. Seal below unconformity
		IV. Traps above	A. Reservoir location unconformity-controlled
			B. Reservoir location not unconformity-controlled (transgressive)
		V. Traps below and above	

Table 2. Suggested Stratigraphic-Trap Classification

Not Adjacent to Unconformities

I. Facies-change traps
- A. Current-transported reservoir rock
  - 1. Eolian
    - a. Dune (coastal, inland)
    - b. Eolian-sheet
  - 2. Alluvial-fan
  - 3. Alluvial-valley
    - a. Braided-stream
    - b. Channel-fill
    - c. Point-bar
  - 4. Deltaic (lacustrine, bay)
    - a. Distributary-mouth bar
    - b. Deltaic-sheet
    - c. Distributary channel-fill
    - d. Finger-bar
  - 5. Nondeltaic coastal (lacustrine, bay)
    - a. Beach
    - b. Barrier-bar
    - c. Spit, hook, *etc.*
    - d. Tidal-delta
    - e. Tidal-flat
  - 6. Shallow-marine
    - a. Tidal-bar
    - b. Tidal-bar belt
    - c. Sand-belt
    - d. Washover
    - e. Shelf-edge
    - f. Shallow-winnowed-crestal
    - g. Shallow-winnowed-flank
    - h. Shallow-turbidite
  - 7. Deep-marine
    - a. Marine-fan
    - b. Deep-turbidite
    - c. Deep-winnowed-crestal
    - d. Deep-winnowed-flank
- B. Reservoir rock not current-transported
  - 1. Gravity
    - a. Slump
  - 2. Biogenic carbonate
    - a. Stratigraphic reef
      - 1. Shelf-margin
      - 2. Mound (patch-reef, mud, algal, *etc.*)
    - b. Blanket (crinoidal, tidal-flat, lagoonal, *etc.*)

II. Diagenetic traps
- A. Nonreservoir to reservoir rock
  - 1. Replacement (and leached)
    - a. Dolomitized shelf-margin
    - b. Dolomitized mound (patch-reef, mud, algal, *etc.*)
    - c. Dolomitized blanket (crinoidal, tidal-flat, *etc.*)
    - d. Dolomitized current-transported deposit (facies or lithologic type)
  - 2. Leached
    - a. Leached shelf-margin
    - b. Leached mound (patch-reef, mud, algal, *etc.*)
    - c. Leached blanket (crinoidal, tidal-flat, *etc.*)
    - d. Leached current-transported deposit (facies or lithologic type)
  - 3. Brecciated
  - 4. Fractured (lithologic type)
- B. Reservoir to nonreservoir rock
  - 1. Compaction
    - a. Physical compaction
    - b. Chemical compaction
  - 2. Cementation

Adjacent to Unconformities

III. Traps below unconformities
- A. Seal above unconformity
  - 1. Topography young
    - a. Valley-flank
    - b. Valley-shoulder
  - 2. Topography mature
    - a. Crestal
    - b. Dip-slope

Table 2. (*Continued*)

    - c. Escarpment
    - d. Valley
  - 3. Topography old
    - a. Beveled
- B. Seal below unconformity
  - 1. Mineral cement (anhydrite, calcite, *etc.*)
  - 2. Tar-seal
  - 3. Weathering product (weathered-feldspar, weathered-tuff, *etc.*)

IV. Traps above unconformities
- A. Reservoir location unconformity-controlled
  - 1. Two sides
    - a. Valley-fill
    - b. Canyon-fill
    - c. Blowout-fill
  - 2. One side (buttress)
    - a. Lake-cliff
    - b. Coastal-cliff (fault–coastal-cliff)
    - c. Valley-side (fault–valley-side)
    - d. Hill-flank (fringing-reef, mound, blanket, *etc.*)
    - e. Structure-flank (fringing-reef, mound, blanket, *etc*).
- B. Reservoir location not unconformity-controlled (transgressive)

  Facies terms followed by (*unconformity*) or (unconformity) where applicable (See text for explanation.)

V. Traps below and above unconformities

A second-order subdivision of current-transported reservoir rock can be made on the basis of depositional process or environment, a third-order subdivision on type or location of deposit, and a fourth-order subdivision, if needed, on lithology. Thus, under the "facies-change, current-transported" category (Table 1, class IA), one possibility would be a trap in which the reservoir rock is a shallow-marine (second order) tidal-bar belt (third order) of oolitic lithology (fourth order), which would be called an "oolitic tidal-bar–belt trap" (Table 2, class A6b). Facies change, current transport, and shallow-marine conditions would be implied.

Many of the suggested terms are in common usage and require no definitions or explanation. For others, additional comments appear desirable.

It is recognized that additional subdivisions will be required as our knowledge of sedimentary rocks and stratigraphic traps in them increases. We know much more about deltaic and interdeltaic deposits, for example, than about shallow- and deep-marine accumulations, largely because of the availability for detailed study of modern counterparts. Subdivision of such sedimentary complexes as alluvial fans, tidal deltas, and marine fans may prove desirable if many stratigraphic traps are found in them. It seems advisable to propose a framework in which such subdivisions can be made later as needed.

It is also recognized that inclusion of some terms, particularly dune and eolian sheet, in the facies-change category is questionable, because such bodies probably would be deposited most commonly on unconformity surfaces. Also, where dunes or eolian sheets are deposited during regressions and thus are not unconformity-related, the overlying units usually would not be genetically related.

Deltaic and nondeltaic coastal deposition occurs at or near a land-water interface. This interface may be between the land and a lake, bay, lagoon, estuary, or the ocean. Making a distinction between these types of interfaces may be important in searching for stratigraphic traps. The "(lacustrine, bay)" following both deltaic and nondeltaic coastal in Table 2 means that these terms should be included in the description where appropriate. Because most deltaic and nondeltaic coastal stratigraphic traps will probably be in deposits near the land-ocean interface, it is proposed that this be inferred and that no prefix be used.

Explanations of some of the terms used in the facies-change category in Table 2 are given below.

A6a. *Tidal bar*—Present-day examples described and illustrated by Off (1963).

A6b. *Tidal-bar belt*—Separated from other tidal bars by formation at a major slope break where tidal currents are concentrated by embayments (Ball, 1967).

A6c. *Sand belt*—Controlled by a major slope break, but without concentration of tidal currents (Ball, 1967). Differs in position from shelf-edge sands by being built up on the platform edge rather than accumulating at or below the break in slope. At Cat Cay, the example cited in the Bahamas by Ball, the carbonate sand is of local origin.

A6d. *Washover deposit*—Composed of debris washed over and accumulated behind barriers, reefs, or low islands. Composed commonly of carbonate sand or coarser debris.

A6e. *Shelf-edge deposit*—A sand-body type postulated by Rich (1951). Probably caused by relative lowering of sea level and transport of preexisting sand-sized shelf sediments seaward to and over the shelf edge (Fig. 3). Lehner (1969, p. 2469) used the terms "foreset beds" and "spillover beds" for sediments of Wisconsin age on the Texas shelf edge.

A6f, A7c. *Winnowed-crestal deposit*—Would result from winnowing of the fines from a coarse-fine particle admixture on the crest of a growing dome or anticline (Fig. 4).

A6g, A7d. *Winnowed-flank deposit*—Would be due to similar winnowing, but by stronger currents that would remove the sand or shell debris from the crest

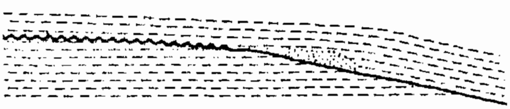


FIG. 3—Sand body formed at edge of shelf owing to relative lowering of sea level.

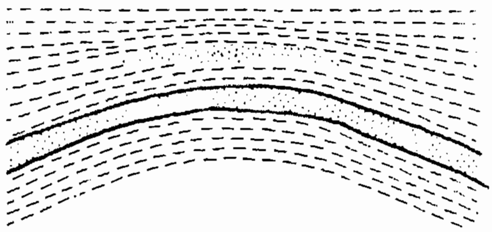


FIG. 4—Accumulation of sand over growing structure, as result of winnowing.

and deposit it on one or more flanks (Fig. 5). It is possible that winnowed deposits might occur also in other environments. If so, that environment may be used as a prefix.

A6h, A7b. *Shallow and deep turbidites*—Types separated at 600-ft (100 fm) water depth, shallow turbidites being on the shelf (or in lakes or bays) and deep turbidites at greater depths.

A7a, A7b. *Marine fan and deep turbidite*—Types separated on the basis of position, the marine fans being at a break in slope where velocities are reduced (thus being submarine equivalents of alluvial fans; Nelson *et al.*, 1970), and the deep turbidites filling depressions on the slope (Lehner, 1969) or covering basin or ocean floors.

B1a. *Slump deposit*—Would result from mass movement of sand bodies, usually shelf-edge and associated sands, down submarine slopes (Lehner, 1969). Talus adjacent to a carbonate buildup also would be a slump accumulation, but, because of the close association with other facies in such buildups, such talus is included with the buildup rather than being designated a type of slump.

B2. *Biogenic carbonate deposit*—Non-current-transported carbonate rocks that originally had commercial porosity and permeability and have retained it. Some diagenetic enhancement may have occurred, but it is not critical to making the rock a reservoir. Actually, there may be few traps in this category, because most traps in carbonate rocks owe a critical part of their porosity and permeability to diagenetic processes.

Although some excellent ideas on carbonate-rock and porosity classification have been advanced in the past decade (Ham, 1962· Choquette and Pray, 1970), they do not appear to provide a suitable basis for classification of

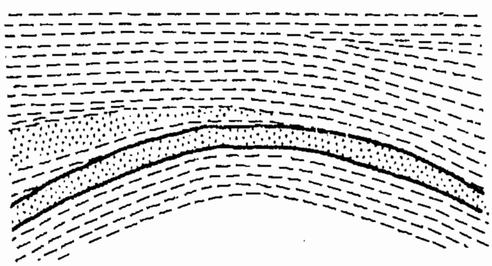


FIG. 5—Accumulation of sand over flank of growing structure as result of winnowing and lateral transport of sand.

stratigraphic traps. I propose that non–current-transported carbonate rocks in which traps occur be considered as either "stratigraphic reefs" as defined by Dunham (1970) or "blankets" (buildups vs. sheets), and that stratigraphic reefs be subdivided into "shelf margins" and "mounds." The shelf margins would be elongate or arcuate and would separate facies of different types on the two sides; mounds would tend to be equidimensional, usually would be surrounded on all sides by the same facies (whether all lagoonal or all open marine), and might or might not have marginal and interior facies of the same type. This facies differentiation is a modification of that suggested by Heckel (1970), and I believe it can be useful in exploration.

The position of shelf margins may be inherited from preexisting topography or structure, or it may result from the buildup itself. Although such large carbonate buildups as the Central Basin platform or the Bahama Banks might be considered oversized mounds or be placed in a separate category, I suggest classifying their edges as shelf margins.

Stratigraphic reefs large enough to contain commercial accumulations of hydrocarbons will almost everywhere be combinations (complexes) of carbonate types, both laterally and vertically. The proportion of organisms having the potential to build wave-resistant structures may vary widely. In initial exploration for, and attempts to find extensions of, shelf-margin accumulations, the type of carbonate and its wave resistance normally will be of less importance than determining the position of the margin and the location of highs on it. Even where diagenetic processes have formed the porosity, the conditions that allow these processes to operate probably will be more important than the carbonate types. For example, whether exposure permitted vadose leaching may be more significant than whether the carbonate was a boundstone or an early-cemented packstone. In contrast, in exploring for mounds, and particularly in searching for other mounds after the first has been discovered, the type of sediment or organisms may be relatively more important. For these reasons, I suggest that some modifying terms be used for mounds but have no suggestions at this time for meaningful subdivisions of shelf margins.

The term "blanket" is suggested for sheetlike non–current-transported carbonate deposits.[4] Blankets may have no close association with a buildup or may be associated with one. For example, a landward traverse across an elongate buildup might show the shelf margin flanked seaward by a blanket and landward by a continuous or discontinuous band of washover or other current-transported carbonate sediment. These bodies might grade landward into blankets of lagoonal and tidal-flat deposits. To distinguish different kinds of blankets, subdivision is suggested on the basis of dominant environment (tidal flat, lagoonal, *etc.*) and/or components (crinoidal, pelletal, *etc.*).

[4] Biostrome, a widely used term, is a type of blanket deposit with a large skeletal component.

II. Diagenetic Traps

Diagenetic traps not associated with unconformities may be formed during or soon after deposition or after considerable burial and perhaps after extensive lithification. They may occur either (A) where a nonreservoir rock has been changed to a reservoir rock and the unaltered or less extensively altered nonreservoir rock serves as an upper and/or a lateral barrier, or (B) where a reservoir rock has been changed partly to a nonreservoir rock and the altered part forms all or part of the barrier.

At least four processes—replacement, leaching, brecciation, and fracturing—can produce a reservoir rock from a nonreservoir rock. Replacement and leaching both require movement of water, but the effects differ. Both may operate concurrently. In replacement, the moving water brings with it dissolved matter which, under the prevailing surface or subsurface temperature and pressure, reacts with the preexisting rock. If new minerals of greater density and lesser volume are formed, new pore space may be created. Actually, rearrangement of existing pore space may be more important than creation of new pores because of volume decrease. For example, replacement in a porous but slightly permeable calcareous mud may result in larger pores and larger connections between them. Leaching that occurs concurrently with the replacement may further enhance porosity and permeability. Local, and in some places regional, dolomitization of limestones forms most such "replacement" traps.[5]

[5] The diagenetic changes during dolomitization may be complex. Dolomitization of a calcareous mud or wackestone first might selectively change a nonreservoir rock to a reservoir rock; continued dolomitization might reduce the porosity and change part of that reservoir rock to nonreservoir rock. Where this has happened, it may be difficult to determine whether the remaining reservoir rock should be classified under replacement or cementation, or whether a combination of both is involved.

In contrast, the major effect of the moving water may be as a solvent—to dissolve and carry away the rock or certain parts of it. Where the solution involves selective removal of some constituents of the nonreservoir rock, intergranular, oomoldic, or other types of fabric-selective porosity may result (Choquette and Pray, 1970). However, where the solution of the nonreservoir rock is nonselective, vugular, channel, or cavern porosity may form. Unaltered or less altered rocks above, lateral to, and in places stratigraphically below the reservoir prevent updip hydrocarbon migration. Where solution is at or near an unconformity and the seal is at least partially post-unconformity in age, the trap would be unconformity-related. In contrast, where the seal is not associated with the unconformity surface, the trap would be in the diagenetic category even though water that formed it may have moved downward or laterally from an erosion surface.

It is not meant to imply that the nonreservoir rock is completely devoid of porosity or permeability before replacement or leaching. In carbonate rocks particularly, fractures, differences in facies, and/or differential cementation may control the transmissibility of the rock to waters or the effectiveness of these waters in producing diagenetic changes.

Brecciated reservoirs also may result from solution, where such solution removes carbonate, anhydrite, or salt from large enough areas to permit collapse and brecciation of interbedded or overlying rocks. Mounds or other topographic features that penetrate upward into the solution zones may accentuate the brecciation.

Fractured reservoirs, in contrast, would be tectonic in origin but would not be the result of local structural deformation. The lateral termination of the fracturing may be due to change in subregional stresses or to change in rock ductility to a less easily fractured rock—*i.e.*, from dolomite to limestone, or from cherty to less cherty rock. The overlying barrier also would be a less easily fractured rock.

Diagenetic changes of a reservoir-type rock to a barrier may result from compaction or cementation, or a combination of both. Compaction may be either physical—as where relatively ductile, usually lithic grains are plastically deformed and squeezed into the adjacent pore space by the weight of overburden—or chemical—as where part of the rock is removed by solution. Such solution may occur at points of contact between quartz, chert, or other hard grains, or along stylolitic seams. Local redeposition of material so dissolved may reduce the amount of pore space still more. Some lateral variation in original grain size or composition usually would be required to allow formation of such barriers. They would be formed at depth, and, consequently, any relation to unconformities would be coincidental.

Cementation may reduce the pore space selectively in some parts of a reservoir rock but not in others. This cementation may be penecontemporaneous, or it may occur at depth where compaction waters moving upward or meteoric waters moving downward reach a critical temperature and/or pressure.

III. Traps Below Unconformities

Impermeable beds above unconformities form part or all of the barrier to vertical or lateral migration of hydrocarbons from many stratigraphic traps that occur below unconformities. However, for some traps below unconformities, part or all of the barrier is formed by diagenetic processes that are unconformity-dependent. Some barriers of this latter type, such as tar seals, may be just below the unconformity surface; others, such as those resulting from pore filling by mineral cements, may extend a considerable distance downdip. Because of its importance in exploration, differentiation of post-unconformity (depositional) seals from unconformity-related (diagenetic) seals seems desirable.

I suggest that the nondiagenetic traps below unconformities be differentiated on the basis of maturity of the unconformity surface, *i.e.*, whether the erosional surface was in a young, mature, or old stage when buried. Exploration methods for the different types will differ.

In the young stage, narrow, steep-sided valleys are eroded into flat or gently dipping strata, some of which could be reservoirs. If these valleys are filled or partially filled later with relatively impermeable sediments, and some tilting occurs, the impermeable valley deposits could become a barrier to updip hydrocarbon migration. If the reservoir rock abuts only against the valley side, the impermeable bed above it will form part of the barrier, and only later deposition of relatively impermeable beds in the valley adjacent to the reservoir rock is needed to prevent updip migration. Such "valley-flank" traps (Fig. 6) may be differentiated from "valley-shoulder" traps, where the reservoir rock formed part of the surface of low relief into which the valley was trenched and where nonreservoir beds were deposited

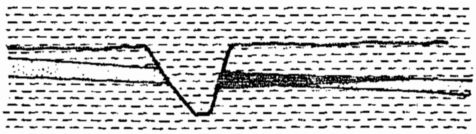


FIG. 6—Valley-flank accumulation against impermeable sediments filling youthful valley.

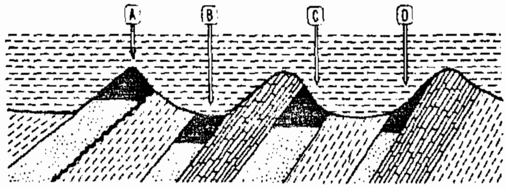


FIG. 8—Accumulations in crestal (A), valley (B), escarpment (C), and dip-slope (D) positions below mature erosion surface.

both laterally in the valley and on the low-relief surface above (Fig. 7).

If the unconformity surface is mature, the reservoir rocks may occupy topographically high, intermediate, or low positions, as shown in Figure 8. Those topographically high—including hills, cuestas, and mesas—may be termed "crestal." Those that are intermediate—*i.e.*, having less resistance to erosion than nonreservoir rocks that form the topographic highs—may be termed "dip-slope" or "escarpment" deposits. Those topographically low may be designated "valley" deposits. It seems probable that many stratigraphic traps in fractured and/or weathered igneous rocks would be in the "crestal" class.

For traps below old-age surfaces of slight topographic relief, the term "beveled" is suggested, because dipping beds have been truncated by an erosion surface of lesser slope. In exploration for the "young" and "mature" classes of traps, the application of geomorphic concepts as advocated by Martin (1966) and others may be very useful; however, for "beveled" traps below unconformities, other exploration methods are required.

In classification of stratigraphic traps, what role should lithology or the primary or secondary origin of the porosity or permeability play when the seal is above the unconformity—*i.e.*, "post-unconformity"? It ordinarily will be known from downdip penetrations of the section whether the porosity and permeability are primary. (Stratigraphic reefs may be an exception to this generalization.) The existence of widespread secondary porosity, as from dolomitization, generally will be known also. In these cases, the location of the subcrop and the topographic expression of the porous and permeable beds should be determined.

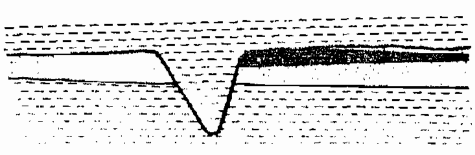


FIG. 7—Valley-shoulder accumulation against impermeable sediments both in valley and on low-relief surface to right.

In contrast, diagenetic processes related to the unconformity which produce or enhance porosity and/or permeability at and near the unconformity may be significant in exploration. Also, fracture belts of subregional extent (not associated with local structure) which traverse the areas of interest may be of exploratory significance, particularly if rocks of different lithologies fracture to different extents. It seems desirable, therefore, to prefix a diagenetic or lithologic-diagenetic descriptive term where local secondary porosity and/or permeability development is important. Thus, for example, we might have "fractured igneous–crestal," "leached oolite–valley," or "leached subgraywacke–dip-slope" traps. In my opinion, such word descriptions are far better than a combined numerical-alphabetical or decimal system that would require frequent reference to a master code, though such a system might be more desirable for computer usage. Even so, this compound-word terminology may prove too cumbersome and, if so, may have to be abandoned in favor of written supplementary descriptions.

Other unconformity-dependent diagenetic processes may decrease rather than increase porosity and/or permeability; thus, the permeability of what was once a reservoir rock may be reduced sufficiently to make it a barrier to hydrocarbon migration. This change may occur in three ways: (1) by introduction and localized deposition of mineral cements such as anhydrite, carbonate, or silica; (2) by conversion of oil to tar; and (3) by weathering of feldspar or other materials to clay minerals. Recognition of such diagenetic barriers may be important in exploration because (1) accumulations may be downdip from the more obvious post-unconformity barrier, and (2) accumulations may be present where sandstones or other reservoir-type beds overlie the unconformity. Thus, traps with diagenetic seals are separated from traps

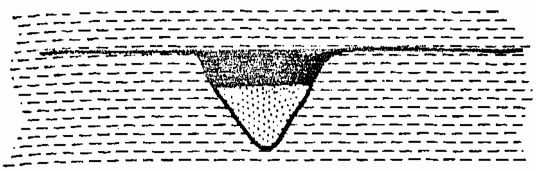


FIG. 9—Valley-fill (or canyon-fill) accumulation.

with seals above the unconformity. Those traps in which the seal is formed by deposition of mineral cements may be designated by the pore-filling minerals, of which the more common is probably anhydrite; those by degradation of oil, as tar seals; and those by weathering, by the original mineral or rock name—such as "weathered feldspar," "weathered lithic sandstone," or "weathered tuff."

IV. Traps Above Unconformities

Unconformity surfaces with considerable local relief may control the distribution of potential reservoir rocks. In contrast, unconformities with slight local relief may exert little, if any, control on the distribution of potential reservoir beds above them. Factors controlling sea level or regional subsidence may be much more important. This control or lack of it is suggested as a basis for classifying stratigraphic traps above unconformities. Exploration methods used to locate traps of the two kinds would differ.

The unconformity-controlled traps may be subdivided further on the basis of *extent* of control of the reservoir by the unconformity. In youthful valleys or submarine canyons, the potential reservoir rock may extend without interruption from one side of the valley or canyon to the other—*i.e.*, the reservoir is limited on two sides (and commonly its base) by relatively impermeable rocks below the unconformity surface. For such traps the terms "valley-fill" and "canyon-fill" (Fig. 9) are suggested. Although no examples are known, "blowout-fill" traps (Fig. 10), formed by sand deposition in wind-eroded depressions, should be included in this category.

Other unconformity-controlled reservoirs are limited on only one side by the unconformity,

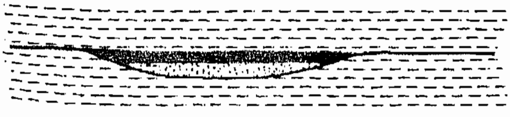
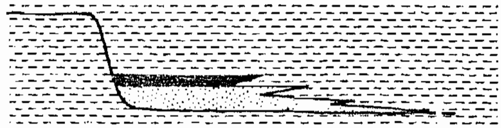


FIG. 10—Blowout-fill accumulation.

FIG. 11—Lake-cliff or coastal-cliff accumulation.



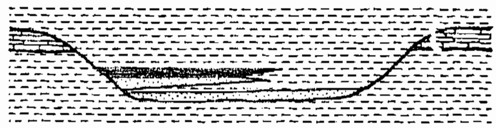


FIG. 12—Valley-side accumulation.

and the other boundary is a facies-related rock of low permeability. This category of traps includes what Levorsen (1954) and others have called "buttress sands," as well as some low-relief organic buildups. The unconformity surface against which the reservoir terminates may be a lake or coastal cliff, the side of a valley, an isolated hill, or an eroded structural uplift. The suggested designations for such traps are "lake-cliff," "coastal-cliff" (Fig. 11), "valley-side" (Fig. 12), "hill-flank" (Fig. 13), and "structure-flank" (Fig. 14) traps. McCubbin (1969) showed good examples of coastal-cliff traps.

If the reservoir rock is not current-transported, an appropriate modifying term can be used in conjunction with the unconformity term. Such accumulations are probably restricted to "hill-flank" and "structure-flank" positions and might be fringing reefs, mounds, or blankets. The crinoidal mound on the flank of an eroded Ordovician fold in the Todd field (Levorsen, 1954, Fig. 6–26, p. 215) is a good illustration of a carbonate reservoir rock in which the unconformity is an important trapping factor. Most stratigraphic reefs, although initiated in hill-flank or structure-flank or other

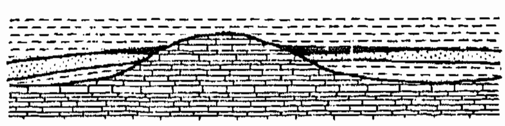


FIG. 13—Hill-flank accumulations.

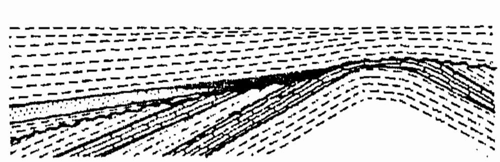


FIG. 14—Structure-flank accumulation.

positions on unconformity surfaces, normally would grow so high that the part abutting the unconformity would form only a minor part of the trap, even if tilting occurred later. Therefore, most stratigraphic-reef traps would not be included in this category.

It is possible that fault scarps may control *post-fault* distribution of reservoir rocks and also form one boundary of some traps. How should such traps be classified?

The scarps may be inland and, if so, may control, or partially control, the drainage system and be modified by river erosion; they may be at the coastline and may control the location of the land-water interface and be modified by wave erosion; or they may be submarine and not modified. The inland and coastal fault scarps are associated with unconformities; thus, they might be considered special types of "valley-side" or "coastal-cliff" unconformity traps to which the prefix "fault" would be added. Although the submarine fault scarps might not be associated with unconformities, I suggest that they be included here rather than be put in a separate class that would have only one representative. The suggested designation is "submarine fault-flank trap."

Actually, there may be so few traps in these fault categories that including them in a stratigraphic-trap classification may be academic. Usually, continued growth or later reactivation of the faults would control the location of the hydrocarbon accumulations or create new barrier-to-reservoir relations. Therefore, the trap would be structural rather than stratigraphic. Only if the hydrocarbons migrated into the trap before reactivation of the fault, and if the location of the accumulation in the trap were not modified substantially, could the trap be considered stratigraphic.

Nearly all traps above unconformity surfaces with essentially no relief result from transgression, and the distribution of reservoir rocks is controlled by factors other than the relief on the unconformity surface. It seems likely that such traps will be mainly of coastal or shallow-marine origin. The alluvial, deltaic, and deep-marine types commonly will not be adjacent to such low-relief unconformities. Except for some carbonate rocks, reservoir beds deposited during regression normally will be separated from the unconformity surface by nonreservoir rocks.

What we are really concerned with here is a kind of facies trap in which the reservoir body is deposited directly on a surface of unconformity rather than on sediments of nearly the same age. Theoretically, if the reservoirs are bars or other deposits with considerable relief, it may make no difference whether the rock below the unconformity is permeable or impermeable to hydrocarbons, because the hydrocarbons would have no contact with it (Fig. 2A). The unconformity is unimportant. Exploration methods used for locating such traps would be the same as those used in searching for facies traps.

In contrast, for low-relief deposits such as beach sands, or for those higher relief deposits which have been tilted, the permeability of the rocks underlying the unconformity may be critical in determining whether a trap exists and/or how large it is. Location of such traps requires exploration methods used for facies traps combined with other methods that will provide the required information on the permeability and attitude of the rocks below the unconformity.

What terminology should be used for traps above unconformities of essentially no relief? Should a distinction be made, and a different terminology be used, for traps where the unconformity does or does not form a part of the barrier to updip or sideways migration? To answer the second question first, I suggest that a distinction be made where possible but, for practical reasons, no complicating separate terminology be used. It seems probable that there will be few traps where the unconformity is unimportant, and that those which do exist will have limited capacity. Regional tilting of even half a degree in the right direction would make the permeability of rocks below the unconformity significant for bars or other deposits a mile or more in length. Of equal or greater importance, however, is the fact that, in searching for traps above unconformities of essentially no relief, one would wish to know in advance whether the unconformity might be a limiting factor. Consequently, exploration methods used for facies traps would have to be supplemented with others that would provide the required information on the permeability and attitude of the rocks below the unconformity.

For traps above unconformity surfaces of essentially no relief, it is suggested that the appropriate facies-trap term be followed by "unconformity" in parentheses. If the permeability of the rocks below the unconformity is, or may be, critical to the existence or size of the trap, the word "unconformity" would be underlined or italicized; if demonstrably not critical, "unconformity" would not be underlined or italicized. Thus, the designation might be "barrier-bar *(unconformity)*" or "barrier-bar (unconformity)."

V. Traps Below and Above Unconformities

Where a connection exists between reservoir rocks that overlie and underlie an unconformity, the hydrocarbon column may bridge that unconformity. Although both the seal and the reservoir may be in part above the unconformity, a major part of the accumulation may be below it. For such pools, a dual terminology that describes both reservoirs seems desirable. Thus, in a valley-side–plus–escarpment trap, most of the hydrocarbon is below the unconformity. The order would be determined by the relative volume of hydrocarbons in each type of reservoir—that with the lesser volume being first.

Combination Stratigraphic Traps

Most stratigraphic traps above unconformities involve a combination of facies and unconformities, and thus might be considered combination stratigraphic traps. Facies also may control the lateral extent of some diagenetic traps and traps below unconformities. In the diagenetic traps, however, this facies control is usually closely related to the operation of the diagenetic process that changes nonreservoir to reservoir rock or reservoir to nonreservoir rock. Replacement, solution, fracturing, or compaction that result in traps occur preferentially in some facies. Therefore, a combination terminology does not seem necessary for diagenetic traps. In contrast, where solution, fracturing, and possibly replacement have produced or enhanced porosity and/or permeability below unconformities, a diagenetic or diagenetic-lithologic terminology seems desirable, as proposed in the preceding section of this paper.

For traps below unconformities, a combined term may be desirable where facies control the lateral extent of the trap. The appropriate facies term might be added in parentheses. Thus, where a barrier bar has been truncated, the designation might be "beveled (barrier-bar) trap."

Should traps occurring at the updip intersection of two unconformities be considered as combinations? The dual-unconformity relations may be of two kinds—one in which the reservoir lies below both unconformities and one in which it is between them. In the first type, exemplified by the West Edmond pool, Oklahoma (Levorsen, 1954, p. 243, 623), a different direction of regional tilting between the earlier and later periods of erosion resulted in the reservoir extending farther updip at the intersection. No separate terminology for traps of this type seems necessary.

In the second type, the lower unconformity will be significant only if it controls the location of reservoir rocks deposited on it. Where the location of reservoir rocks is controlled by the older unconformity, truncation of these beds and later deposition of an impermeable bed above would form the trap and determine its location. The original unconformity-controlled distribution is modified by the later erosion. It is suggested that, for this relation, "truncated" be prefixed to the appropriate term for the trap above an unconformity; "truncated" rather than "beveled" is suggested, because the upper unconformity surface may have more relief than is implied by beveling.

Discussion

The classification of stratigraphic traps suggested here appears to eliminate some of the inconsistencies in systems used previously. The number of factors involved in stratigraphic trapping is large, however, and their relative importance may vary in different traps. Consequently, no classification method can be completely definitive without having a very large number of subclasses—a number approaching, if not equal to, the total number of stratigraphic traps. Therefore, a compromise is necessary. As a result, some traps will fit neatly into classification pigeonholes and others will not.

The suggested classification represents such a compromise, proposing few enough subdivisions to be acceptable. Furthermore, because the purpose of a stratigraphic-trap classification is economic—to help in finding (and developing) hydrocarbon accumulations—those factors that I believe will help in searching for such accumulations have been emphasized. Others may disagree with my emphasis. If, however, this paper stimulates thought about trapping factors, their relative importance, and their implications regarding exploration methods, it will have served a useful purpose.

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