Unconformity Trops'

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Abstract Accumulations of oil and gas are closely relaled to uncon lormlties in almost every oil region of the world. Except for c1asslfkalions and *early* ottempts to ulilize them in regional correlations, the local ion, origin, ond geometry of successive unconformities largely have been ignored.

Unconformities occur in every teclonic and depositional environment. They are most common on Ihe conlinental plolform, where disconformities oceur in close rhythmic successlen, In the cooslal areas between basin and plotform, frequent warping has resulted in intersecling *low*-angle unconformities. Basins have the fewest unconformities, but angular unconformities may occur associated with midbosln uplift and diapirism.

In the typical platform area, traps above disconformities are mainly in qucrtz sandstones and ore long and narrow; carbona le rocks are the principal reservoirs beneath disconformities. Traps in the hinge orea between the plaHorm ond Ihe bosin ore associated with low-angle unconformities; they are commonly very large and generally have orencceeus reservoir rocks. In basins not later deformed by leclanism, most unconfarmily traps are on the uplhrawn side of growth faulls and on and around mid basin ridges, where submarine erosion has produced local unconformities. Reservoir rocks are commonly thin and discontinuous, fine-grained lurbidites and residual sandstones.

INTRODUCTION

Surfaces of nonconformity between sequences of sedimentary rocks or between sedimentary rocks and crystalline rocks were recognized by James Hutton as features of considerable siznificance in geologic history (Hutton, 1788, quoted *by* Adams, 1954). Hutton, however, placed too much emphasis on their importance, for he regarded unconformities as records of "former worlds" which had been destroyed during episodes of violent upheaval. To Hutton and his followers, these revolutions represented the only reliable basis for correlation between widely separated areas. In fact, they were believed to be so important that all the major subdivisions of geologic time were established on the basis of unconjorrnities which were. in turn. regarded as being worldwide. By the beginning of the 20th century, diastrophism was thought to be the "ultimate basis of correlation" (Chamberlin. 1909).

The belief thnt all unconformities are significant punctuation marks in the geologic time scale was severely discredited when stratigraphic studies expanded into regions where no great breaks are present between systems and where major unconformities are present within previously established systems. As the Huttonian concept of great worldwide episodes of diastrophism collapsed under the weight of evidence accumulated in the first decades of this century, major unconformities were discovered to be common. Schuchert (1910), for example, had recognized 11 within the Paleozoic of North America which he regarded as sufficiently important to justify the establishment of new periods. Stratigraphers who sought important structural breaks to use as svsternic boundaries became increasingly aware of the local abundance of unconformities. For example, in the southern Mid-Continent the Pennsylvanian-*Permian* boundary is nowhere marked by an angular discordance, but many separate erosional breaks have at various times been selected as the contact (Branson, 1962).

Geologists are now aware that unconformities are exceedingly common in some geologic settings, less common in some, and virtually absent in others. Moreover, the relation of petroleum accumulations to unconformities has been demonstrated and documented. Levorsen (1934, p. 783) pointed out that:

> The majority of the oil fields and by far most of the oil production found in the Mid-Continent region show an intimate association between the producing formaiion and unconformities. This relationship seems to hold for production found in all ages from Cambro-Ordovician to Tertiary; for production from a sandstone, limestone, dolomite, arkose, or conglomeratic material; where the unconformity has the rank of nonconformity, disconforrnity, or diastem; Whether there has been post-unconformity folding or not; whether the production is oil, gas, or both; whether the time value of the unconformity is relatively long or short; whether the stratigraphic hiatus is great or small; and whether the pre-unconformity deformation was intense and local, gentle and regional, or absent entirely. We may safely conclude that unconformities have an important bearing on petroleum geology in this region.

Likewise, Miller *et al.* (1958, p. 601), in discussing the oil pools of the Maracaibo basin, commented: "Nearly three-fourths of the estimated ultimate reserve is found in . . . rocks associated with an unconformity and an Eocene hinge belt." Similar statements have been

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made regarding the oil accumulations in many parts of the world.

In view of this close association of petroleum with unconformities, one would assume that concentrated studies of unconformities would occupy much of the time and talents of explorationists. Paradoxically, this is not so, and the unconformity-an extremely common and admittedly important feature-remains imperfectly understood.

DEFINITION AND CLASSIFICATION

Generally, classification of unconformities is merely an academic exercise, for it tends to belabor the obvious and clog the literature with cumbersome and unneeded terms. On the other hand, the act of classifying tends to stimulate thought about the various factors responsible for producing the conditions which allow such classification. Unconformities change in character from place to place; the same one may be a high-angle unconformity at one locality and a surface of near-conformity at another. All unconformities mark a hiatus which is represenled elsewhere by a stratigraphic unit. Any classification thus becomes arbitrary and any particular name is applicable only locally. There have been numerous attempts to develop an elaborate classification to fit all the possible conditions, but most of these appear to bear little or no relation to the central problems of exploration. Dunbar and Rodgers' simple scheme 0957. p, 118-119) is the most useful:

Nonconiormltv is that erosion surface between plutonic igneous or metamorphic rocks below and stratified sedimentary rocks above.

Unconlorniiiy (usually modified with the adjective "angular") is that variety which separates strata of markedly different structure.

Disconjormltv has strata above and below essentially parallel yet shows some evidence of erosion between the iwo sets of strata.

Paraconjorniitv refers to the situation in which no apparent erosional break exists but a time hiatus is nevertheless present

An unconformity is an erosion surface or a surface of nondeposition overlain by layered rocks or unconsolidated sediments. According to this definition, the base of a lava flow which Was extruded upon a land surface is an unconformity. So also is the base of a Pleistocene till lying on Precambrian gneiss. and so is a paraconformity-a bedding plane between two units of disparate ages. Moreover, subaqueous as well as subaerial erosion may produce an unconformity. The magnitude of an unconformity may be expressed by the difl'ercnce in dip of the strata on opposite sid.es or by the length of time represented by the missing inte-vil. Thus, magnitude is also an arbitrary and meaningless measurement except for local descrmive purposes.

DISTRIBUTION OF UNCONFORMITIES

Unconformities of every type occur in nearly every geologic environment. In some environments, however, they are more common than. in others. On the continental platforn. for example, where beds are thin and altenately of shallow-water marine and nonmarire origin, disconformities occur in close rhythrnc succession. Many of these may be traced Izerally for long distances. In the coastal area berveen the basin and the platform, low-angle urconforrnities abound, commonly in a confusiru pattern (Chenoweth, 1967). In geosynclines md depositional basins, sedimentation and biologic evolution have proceeded with fewer interruptions. In the classic geosyncline, furrows an; tectonic welts develop which are interrnitterxv emergent (Kay, 1951, p. 15). The close c: the geosynclinal cycle produces many relatnely local and commonly highly angular uncoz'ormitles. In a sedimentary basin-whether the basin be on a continental margin, a low spot in a geosyncline, or on the craton-c-depositior is likely to be interrupted by structural growtr and submarine mass movements. Salt or shale intrusions or growth faulting may proccce local high areas on the sea floor. Marine currents plane the upper layers. frequently redszributing the sediments and producing local azruler unconformities.

OIL AND GAS TRAPS AT UNCONFORMITIES

It has been noted repeatedly that oil and gas traps occur both above and below izconf'ormity surfaces. Places are known where oil pools are present in both situations in the szne field. In fact, it is not unreasonable to ccnceive of many superimposed unconformity traps in a small area. Levorsen (1954) has panted out that repeated folding is a common preuomenon in many oil regions. Each structura' uplift results in a local unconformity: several rolded or tiltcd unconformities may be present, one above another. Residual tectonic forrrs such as the Central Kansas "uplift"—where zrovement was actually downward, but subsidenze was uneven and slower than that of surroinding elements-were subject to the same frequent development of erosion surfaces.

Marlin (1966) outlined many of rhe trapping conditions which appear both above and

below an erosion surface. A thorough understanding of the geomorphology is necessary for efficient exploration, especially in shelf areas such as Western Canada, from which Martin drew many examples.

Along the margins of the shelf, at the hinge between basin and platform, angular unconformities occur in bewildering array-particularly where warping of the surface has occurred (Chenoweth, 1967). In this area a knowledge of subsurface geology and the geometry of the sedimentary bodies is perhaps more important in exploration than is geomorphology.

Unconformities in the basin are less common than on either the shelf or the basin margin, but they may have a profound influence on the location of suitable reservoir rocks. As a consequence of basin downwarping on the surface of the sphere, a midbasin ridge commonly develops (Dallmus, 1958, p. 893) which may become the locus of submarine erosion. Also, the ridge is commonly the site of diapirism which, in a sense, increases the magnitude of uplift and henee enhances erosion. Certain basins subside along series of bordering growth faults. The upthrown side of such faults is subject to erosion by submarine currents. In some places, tilting of strata away from the fault occurs and truncated traps may develop.

UNCONFORMITY TRAPS ON SHELF

The shelf or platform, used in the stratigraphic sense, is that of Horberg *et al.* (1949): "--- the area of thinner sediments adjoining a geosynclinal wedge of thicker equivalent beds." On the shelf the sedimentary section is not only thin but contains numerous unconformities, most of which are disconformities-i.e., the strata above and below are nearly parallel. Some warping has occurred in places (on a typical platform), producing a slightly angular relation between the beds on either side of the erosion plane.

Most of central North America, the "hedreocraton" of Kay (1951), was a shelf throughout Paleozoic and Mesozoic time. Locally and at different times on this platform, moderate downwarping resulted in development of basins; the Williston, Michigan, Forest City. and Illinois basins are prime examples. Elsewhere, arching took place. forming the Transcontinental arch-the Chadron, Lasalle, and Cincinnati arches. Angular unconformities developed above and on the flanks of the uplifts and on other residual interbasin highs.

Levorscn (1960) portrayed the major regional unconformities of the Mid-Continent with a series of paleogeologic and subcrop maps. As he pointed out earlier (1934), virtually all the petroleum in this vast region is found to be associated with one or more unconformities, whether they be strictly disconformities, regional low-angular unconformities, or local high-angle unconformities. Even those large oil pools located on structures (Oklahoma City is a good example) are found, when studied in detail, to be closely related to surfaces of unconformity.

Traps in this region of low-angle unconformities and disconformities occur in almost every conceivable rock type below the erosion surfaces, where porosity has been enhanced by leaching, fracturing, and alteration. Above the unconformities, quartz sandstones form the principal reservoir rocks. Regressing seas exposed strata on a broad, flat land to erosion, lithification, and alteration. Stream-channel and deltaic traps are common in places beneath YDunger transgressive sediments. Generally, lithification due to exposure left little unconsolidated sediment to be reworked by transgressing seas; therefore, wide, blanket-type basal sandstones are relatively scarce. Local sandstone lenses-either reworked stream and residual deposits or beaches and bars-are the rule above the disconformities. Individual traps-such as those found in buttress sandstone bodies, sandstone lenses, and truncated units beneath unconformities-may be fairly large and entirely filled with oil and gas.

Locating traps in such an environment is a task requiring a thorough knowledge of stratigraphy and geomorphology, a maximum amount of subsurface data, a deep understanding of environments of sediment deposition (Busch, 1959), and a superior ability to visualize in three dimensions. That the application of all these related disciplines is effective is demonstrated by the high degree of success in exploration of the Morrow sandstone in western Oklahoma (Forgotson, 1969) and the nearly equal success in the Mesaverde in southwestern Wyoming (Weimer, 1966).

UNCONFORMITY TRAPS ON BASIN MARGIN

The basin margin-the coastal plain and shallow-water region on the side of the platform facing a more or less permanent seaway —is an area of frequent flexing and tilting. In a sense this is a hinge-but a hinge of greatly varied materials and thus subject to rather erratic movements each time it is flexed.

Each deepening of the sea results in the deposition of an overlapping sequence of sediments with a slightly different structural attitude from that of the strata previously laid down and eroded. Ultimately. a coastal pl.iin is produced.-characterized by the presence of shallow-marine, genlly dipping strata in which there are numerous, repeated, low-angle uiconformities. These unconformities commonly are difficult to detect, except through regional studies. They form a highly complex and confusing pattern.

Careful studv of basin-flank unconformities can be rewarding. Each unconformity may conceal one or more stratigraphic traps. In order to interpret these unconformities correctly. one must analyze the sequence of events which led to the present configuration and position. For effective exploitation, each must be considered in relation to the others. The subsurface strike, width, rare of thinning, and angle of dip of each potential reservoir are important factors to consider in a successful exploration program. The reconstruction of the history of the unconformity and the determination of the different patterns of outcrop and subcrop related to the unconformity should be studied. This procedure has been termed "unconformity analysis" (Chenoweth, 1967).

Unconformity analysis can be an effective prospecting method in areas which remain relativclv undisturbed, such as the inner margin of the Gulf and Atlantic coastal plains. Three conditions of complexity are recognized: where successive transgressions are at only slight angles to previous ones, where anticlinal warping has intervened, and where synclinal warping has occurred between successive transgressions.

Unconformity traps in regions of this type are commonly large. The East Texas and Pemhinu oil fields and the Clinton gas field are typical examples. A large quantity of the ultimate reserves of the world's major fields is located in this depositional setting (Halbouty *et al.,* 1970): much of that oil is enclosed in unconformit)' traps.

UNCONFORMITY TRAPS IN BASIN

As used in this report, the term "basin" refers to a somewhat restricted area with a thickened sedimentary section, either on the shel[or in low spots and sags in the geosyncline, All basins have one characteristic in common.: the sediment was deposited more or less co nllnuously with only minor localized and brier interruptions. In those basins which were not subject to later strong tectonic deformsnnr but which have had a history of slow and rezilar subsidence, probably the only place where uplift and subsequent erosion occurred, and consequently the development of unconformity traps, was above and on the flank of the middle sin ridge. Dal1mus (1958) showed that as a consequence of subsidence the basin floor is subject to compression; with continued compression, a ridge rises near the basin center. This compression may be partly responsible lzr the development of diapirism if sufficient plastIC rocks (shale and salt) are present. As the ridge (or salt or shale domes) rises. it pushes bottom sedimentary beds into an area *d:* stronger marine current and wave action where some erosion may occur. The unconformaer which develop on the flanks of such domes are commonly very angular; any porous stratum beneath the erosion surface, if truncated and overlapped by sufficiently impervious beds. csr form an efficient trap. Such traps are partly rr wholly circular in plan. Jntermittent and irregular uplift may take place: consequently, several local angular unconformities may be supernrposed.

A further consequence of uplift and dominr within the basin is the redistribution of porous material. In some basins, particularly in the part where water depth is greatest and which is farthest removed from bordering lands. sediment is brought in and spread on the botton; by turbidity currents. Commonly. the supply of coarse material is meager in the deep part zi: the basin. Currents sweep around topograpnc highs on the bottom and, therefore, the crests of such highs may be devoid of porous material. It has been noted frequently that the tops of structural highs formed deep in the basins have little or no porous material; whole provinces have been condemned as having little rr no reservoir rock simply because test wells drilled at the crest of anticlines have encountered mainly shale.

Faulting contemporaneous with subsidence and sedimentation is an important, if no; the primary, mechanism of basinal subsldeac; Shelton (] 968) showed that many basins, such as the Los Angeles basin of California, are bounded by positive features which have been affected by significant vertical uplift along faults. Faulting and sedimentation also occurred contemporaneously within the basin. Sursidence, to a large extent, was caused by movemerit along such growth faults. Durinz fault movement and basin subsidence, erosion of the

upthrown blocks and deposition on the downthrown blocks were common. Growth faulting commonly occurs intermittently, and an upthrown block may be buried for a brief period prior to renewed upward movement. In thi.. manner, unconformity traps are produced 011 the upthrown blocks if sutlicient porous material was deposited over them *prior* to upward movement.

Searching for unconformity traps in the type of basin described becomes a problem in reconstruction of basin history. It is particularly important to recognize the larger growth faults and the structural uplifts within the basin depths. Moreover, the area from which coarse material may have come and the route by which the currents may have distributed it in the basin should be known. In those basins where sand or other coarse material forms only a small part of the total sediment, it becomes particularly important to reconstruct the manner in which turbidity currents may have distributed this material. Since virtually all traps in such areas are, in some manner, unconformity traps, the least likely place to look for commercial accumulations of hydrocarbons is on structure.

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