for Ch. 1 of Basin Analysis

The American Association of Petroleum Geologists Bulletin
V. 67, No. 12 (December 1983), P. 2175-2193, 15 Figs.

Global Basin Classification System[1]

D. R. KINGSTON,[2] C. P. DISHROON,[2] and P. A. WILLIAMS[4]

ABSTRACT

A proposed system classifies sedimentary basins, worldwide, into specific as well as general categories. The geologic history of each basin may be subdivided into cycles using three parameters: basin-forming tectonics, depositional sequences, and basin-modifying tectonics. Sedimentary basins may be simple, with one or two tectonic/sedimentary cycles, or they may be complex polyhistory basins with many different cycles and events. There are eight simple cycle types in this classification, which cover continental, continental-margin, and oceanic areas. The eight basic cycle types, their depositional fills, and tectonic modifiers have been given letter and number symbols so that the specific geologic history of each basin may be written as a formula. These formulas may then be compared and similarities or differences between basins noted.

INTRODUCTION

The main purpose of sedimentary-basin classification is to create a system whereby basins may be compared with each other and similarities or differences noted. Various basin classification systems have been proposed in recent years, e.g., Weeks (1952), Knebel and Rodriguez-Eraso (1956), Uspenskaya (1967), Halbouty et al (1970a, b), Perrodon (1971), Klemme (1971a, b, 1975), Bally (1975), Huff (1978), Bally and Snelson (1980), and Bois et al (1982). The geologic history of two continental-margin basins or two cratonic basins may be similar in general aspects, but will show important differences in detail; consequently, in the past, two basins could be compared only in very general terms. An alternative system proposed herein compares basins in both general and specific terms.

This basin classification system is based primarily on the principles of plate tectonics that have been developed by numerous authors over the past 20 years. Morgan (1968), Le Pichon (1968), Isacks et al (1968), and others provided ideas for many of the basic elements of plate tectonics, such as divergence, convergence, and transform movements. Documentation for continental breakup and divergence has been supplied by Francheteau and Le Pichon (1972), Norton and Sclater (1979), and Rabinowitz and LaBreque (1979). Models for divergent continental margins and basins have been described by Sclater and Christie (1980) and Sawyer et al (1982). Convergent movements of plates have been investigated by many workers. Subduction and orogeny were described by Roeder (1973). Dewey and Bird (1970) and Atwater (1970) investigated convergence and mountain building. Dickinson (1973) and others described volcanism and convergence.

Esso Exploration began plate tectonic restorations on a global scale in the late 1960s. The purpose was to reconstruct movements in the earth's continental plates through geologic time, and to determine the effects of these movements on the structure, stratigraphy, and hydrocarbon occurrence of present-day basins both onshore and offshore. It was believed that by making these plate reconstructions we could recognize and predict oil potential by the development of analytical techniques for plate and continental margins. Finally, the writers wished to establish valid comparisons of tectonic style and therefore of basins: their sedimentary fills, oil plays, and potentials. The result of these global plate restoration studies was the development of a basin classification system, whereby all sedimentary basins, worldwide, could be classified according to their structural genesis and evolutionary history. Contributions from Exxon domestic and overseas affiliates provided data on approximately 600 identifiable sedimentary basins worldwide. We were able to classify all of these basins within the system, the accuracy depending on the quality of the data and our collective knowledge of the regional geology.

The basic unit in this classification is the cycle, which consists of the sediments deposited during one tectonic episode. Some basins have only one sedimentary or tectonic cycle. These are called simple basins. Most basins, however, contain more than one tectonic/sedimentary cycle, and are called polyhistory basins. Figure 1 is a chart for the classification of simple basins and the identification of cycles for polyhistory basins. It should be noted that the terms "basin" and "cycle" may be used interchangeably in this system as a unit formed by one structural mode of basin formation. Basins, both simple and complex, may be classified by analyzing their geologic history in the context of plate tectonics. The major elements of this history are (1) depositional cycles or sequences, (2) basin-forming tectonics, and (3) basin-modifying tectonics.

DEPOSITIONAL SEQUENCES

The first major elements used in the basin classification system are depositional cycles and stages. A cycle is defined as the sediments deposited during one tectonic period. The minimum stratigraphic unit that can be called

[1]Manuscript received, February 22, 1983; accepted, May 13, 1983.

[2]Esso Exploration Inc., Houston, Texas 77024.
[3]Esso Exploration Inc. (retired), 203 Pompano, Surfside, Texas 77541.

The writers thank the management of Esso Exploration Inc. for permission to publish this paper; T. A. Fitzgerald, H. M. Gehman, Jr., D. S. McPherron, T. H. Nelson, and J. B. Sangree, for comments and assistance in revisions; and B. E. St. John, J. D. Frick, J. R. Gealy, and D. H. Roeder, who along with the writers were members of the original global studies team.

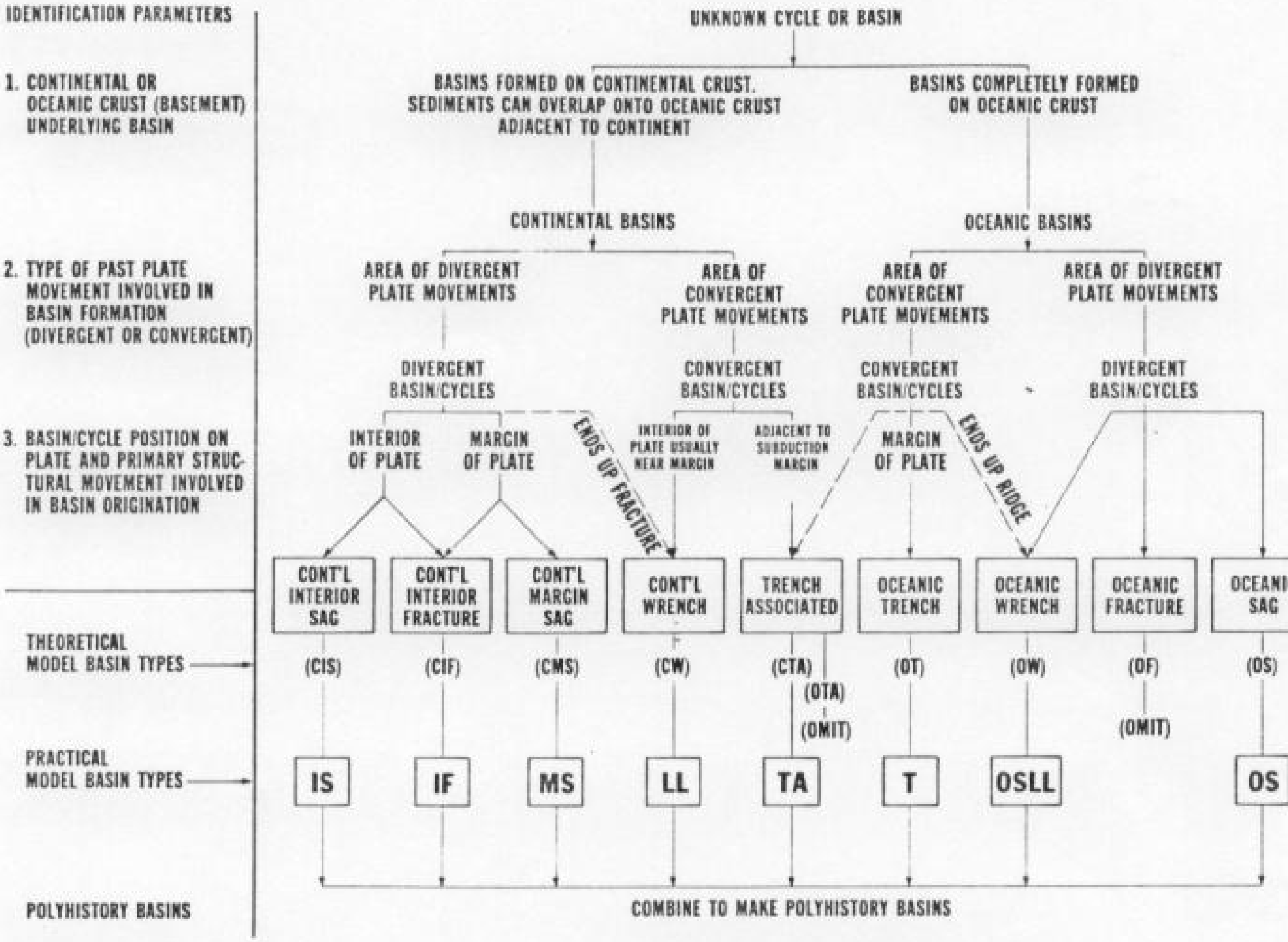


FIG. 1—Basin/cycle identification key for basin-forming tectonics. Two theoretical basin types (OTA and OF) are omitted from practical basin types.

a cycle must have significance in the development of a basin, either in thickness or span of geologic time. This allows us to lump thin units of high-shelf or wedge-edge deposits, which may form over long periods of time, into just a few cycles and to split thick prograding deposits into identifiable units.

Figure 2 shows the relation of the depositional stages to the tectonic cycle. One can think of the concept of wedge base, wedge middle, and wedge top as one sedimentary cycle with the three stages representing the three elements of one major transgressive-regressive wedge (White, 1980). Stage 1 of the cycle corresponds to a nonmarine wedge base. This includes primarily nonmarine flood-plain, lagoonal, and beach deposits, if they can be distinguished. Sedimentary types normally present are nonmarine conglomerates, sandstones, and shales. Other lithologic characteristics less commonly found are red beds, coals, volcanics, and fresh-water limestones. If the basal wedge of clastics in question is thick and over half nonmarine, it is classed as stage 1. Stage division is shown in Figure 2 at the 50% marine dashed line cutting the transition zone between wedge-edge sands and wedge-middle shales.

Stage 2 is the marine wedge middle. Lithologic types most commonly found here are marine shales, limestones, and sandstones. All massive salt is included here on the theory that thick evaporites generally indicate a marine connection or at least the drying of a marine-connected tongue. Also, massive evaporite deposition indicates enclosed depositional conditions and is generally found only in interior basins. Other less common lithologic characteristics found in stage 2 are volcanics, marine coals, flysch and other turbidites, and deep-water marls and pelagic deposits. Stage 2 may also contain the distal ends of nonmarine tongues provided these do not exceed 50% of the total.

Stage 3 is the nonmarine wedge top and the associated regional unconformity. Lithologically it typically resembles the wedge base with more than 50% nonmarine conglomerates, sandstones, shales, red beds, coals, fresh-water limestones, and minor evaporites. Post-wedge-top unconformities are included in stage 3.

The sedimentary stages should be described from the center of the depositional cycle in enclosed basins or from the thickest part of the wedge in a margin basin open to the sea on one side. Referring to a cross section of the wedge concept shown in Figure 2A, it is evident that if the portion of the basin studied is too far updip, past the pinch-out of

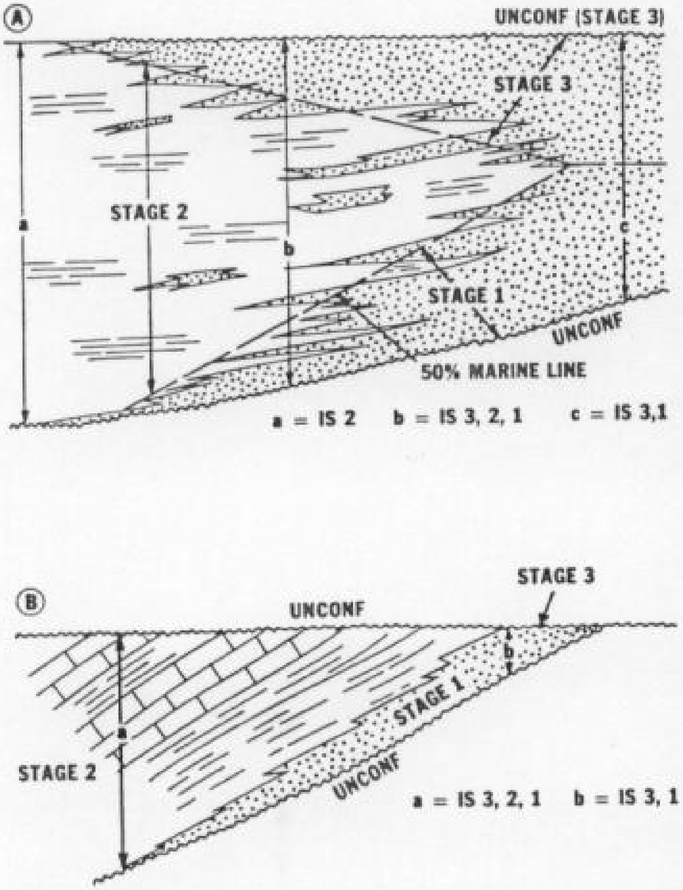


FIG. 2—Relation of stages to sedimentary wedges. (A) Sedimentary wedge showing transgressive wedge base (stage 1), wedge middle (stage 2), and regressive wedge top plus unconformity (stage 3). Dashed median line separates stages. (B) Sedimentary wedge where unconformity has cut out stage 3 and part of stage 2.

the marine wedge middle at c, only the nonmarine rocks of stages 3 and 1 will be described. Conversely, section a of Figure 2A shows that by going too far downdip, especially in continental-margin cycles, only the stage 2 marine wedge may be described.

BASIN-FORMING TECTONICS

Basin-forming tectonic style is the second major element used in classification. Figure 1 shows the identification key used in distinguishing the various basin- or cycle-forming tectonic styles. The three parameters used in the general identification of these cycle types are shown on the left in Figure 1. The composition of the crust underlying the basin is the first parameter necessary for identification. There should be no difficulty in determining crustal composition if dealing with true continental craton or true oceanic crust. Intermediate crustal composition may present a problem that can generally be resolved (Green, 1977). For the purpose of cycle identification, it need only be known whether the basin lies on continental or oceanic crust.

The type of past plate movement involved during the cycle or basin formation is the second parameter used in Figure 1. Fundamentally, there are two types of plate movements affecting cycle or basin formation: (1) divergence and (2) convergence. It has been argued that transform movements are a third type, but these rarely show perfect side-by-side motion and generally exhibit some divergence or convergence. Small angles of convergence show up as wrenching or foldbelts, and small angles of divergence appear as normal faulting or sagging. Consequently, transform movements are not specified in the basin classification.

Convergence normally affects the margins of actively colliding plates, particularly of overriding plates. Strong convergence may be transmitted into the interior of cratonic plates along major shear zones (episodic wrenches), deforming basins well into the interior and away from the convergent margins. Convergent and divergent margins are found on both continental and oceanic crustal plates.

The third parameter used in Figure 1 is basin position on the plate (continental interior or margin) and primary structural movement (sagging, normal faulting, or wrench faulting). These combinations give rise to the theoretical model of 10 simple basin or cycle types (shown in parentheses in Fig. 1). Two of these (OTA and OF) are not considered at this time to be prospective for hydrocarbons and are omitted from the practical model, which has eight simple basin types. These eight cycle or basin types are the ones used in this basin classification. A cycle, or simple basin, is normally referred to by its abbreviated letter, thus margin sag cycles are MS, wrench or shear are LL (lateral), oceanic sags are OS, and so forth.

From the standpoint of petroleum exploration, the greatest number of cycles fall into four major categories and the rest into four minor categories. The major categories are interior sag (IS), interior fracture (IF), margin sag (MS), and wrench (LL). The minor categories are trench (T), trench associated (TA), oceanic sag (OS), and oceanic wrench (OSLL).

Globally, most of the hydrocarbons discovered to date have been found in the four major cycle categories which are associated with continental crust. All the basins within this classification consist of one or more of these cycles, plus modifying structural events. For example, a foldbelt, which is complete folding of a basin or part of one, is not considered to be a basin or cycle type, but is treated as a tectonic event that affects preexisting basins. Some of these cycle types may be split into variations for play analysis and evaluation.

Divergent Cycle Types

Divergent plate movements are the underlying cause of several important basin types. These may be single cycle (simple) basins or multicycle polyhistory basins. Models for various types of divergent fracture basins have been discussed by Shatskii (1946a, b), Klemme (1971), Lowell and Genik (1972). Margin and interior sag basin types have been discussed by numerous writers including Shatskii and Bogdanoff (1960) and Klemme (1975).

Interior sag cycles/basins (IS).—These cycles or basins are defined as being located entirely on continental crust in areas of divergence. They are found in the interior of con-

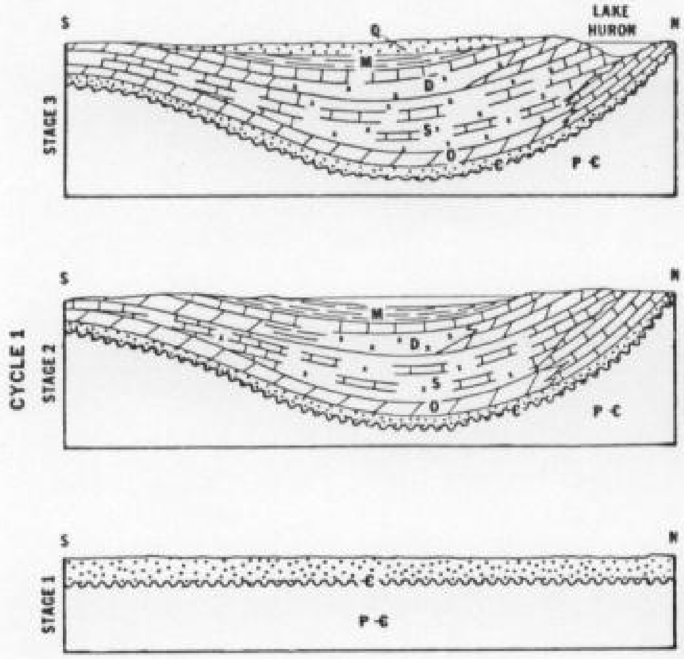


FIG. 3—Evolution of interior sag basin illustrated by restored cross sections in three stages. Example from Michigan basin.

tinental masses, not at the plate margin, and if near the edge their axes are generally at a significant angle to the margin. Interior sag basins (IS) are normally more or less circular or oval in shape and generally do not accumulate as great a thickness of sediments as continental margin basins. They are formed by simple sagging of the continental crust as shown in Figure 3. Many interior sag basins originated in the Paleozoic. Some are simple or single cycle basins, whereas others contain several repeated sag cycles. Figure 3 shows the evolution of a typical interior sag (IS) basin. The basin simply sags with minor or no faulting. Interior sag cycles are commonly found in polyhistory or multiple cycle basins.

Interior fracture cycles/basins (IF).—This basin/cycle type is defined as being found on continental crust, either in the interior of present plates or at the crustal margins of old continental plates. Interior fracture basins are caused by divergence and tension within the continental block. Vertical horst-and-graben faulting and subsidence are the dominant features.

Figure 4 is a series of restored cross sections showing the Gulf of Suez, a typical interior fracture basin. Cycle 1 shows basin formation in the Early Cretaceous, with tension block faulting, and subsidence. Stage 1 nonmarine sandstone and shales are deposited. During stage 2, marine rocks filled the Suez graben as block faulting, and subsidence continues. Reservoir sands and carbonates are deposited over the highs while shales fill the lows. Continued subsidence and compaction cause drape of beds over high-standing fault blocks. During the third or final stage of interior fracture the basin fills or is uplifted, allowing nonmarine wedge-top sediments to be deposited; unconformities may truncate the top of the section. If this cycle is repeated with additional faulting and deposition, the succeeding cycle still would be classified as an interior fracture basin. Should the structural style change to something else, it becomes a polyhistory or multiple-cycle basin.

Margin sag cycles/basins (MS).—Margin sag cycles/basins are located on the outer edges of continental crust blocks in areas of divergence. The basin axes lie parallel with the continental/oceanic crust boundary, and the sediments may overlap onto oceanic crust. Such basins are referred to as being located on "Atlantic-type" margins. All margin sag basins have at least two basin-forming tectonic origins and are polyhistory basins.

The evolution of a typical margin sag basin is shown in Figure 5. The basin begins with the cracking of a cratonic mass by divergence. This first phase (stage 1 of cycle 1) as previously outlined is called interior fracture, and may resemble the present-day rift valleys of Africa. These grabens generally are filled with nonmarine sediments. During graben formation, basal block fault structures are formed and buried by sediments. Probably no continental separation occurs at this time, though deeper fracture zones may have extended through the crust. There is generally no stage 2 in this cycle, inasmuch as the continents have not separated enough to allow a marine incursion.

The next phase of basin formation, stage 3 of cycle 1, is the end of interior fracture basin development. Continued continental divergence and graben subsidence by block faulting are typically accompanied by nonmarine deposition. One or more deep fracture zones may form as potential separation centers. These fracture zones may fill with basalt intrusions and dike swarms. Stage 3 of cycle 1 normally ends with a major unconformity. Basement block faults cease differential movement near the end of the interior fracture cycle, and overlying beds generally do not show any rejuvenated movement or structure. It may be that continental rifting freezes the basement block faults

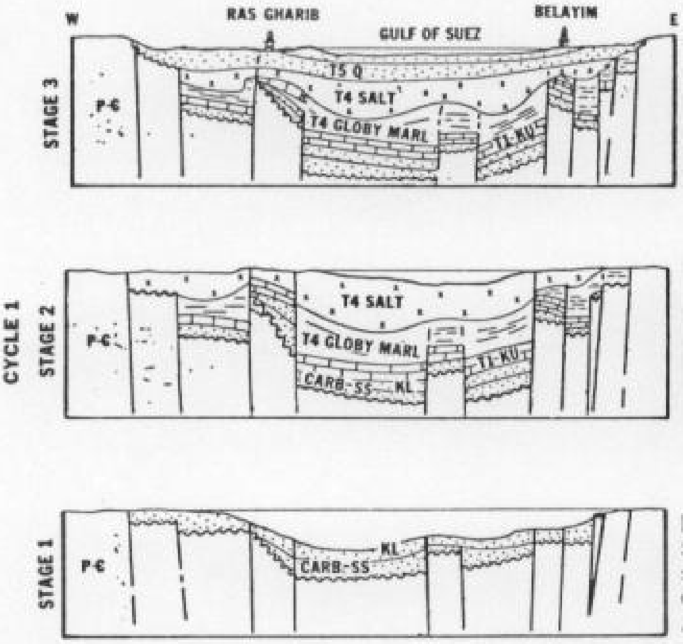


FIG. 4—Evolution of interior fracture basin illustrated by restored cross sections in three stages from Early Cretaceous to Holocene. Example from Gulf of Suez.

on either side; but whatever the cause, at this time the type of structural origin changes from interior fracture to margin sag.

Margin sag is initiated as the spreading center in the interior fracture grabens is activated and begins to grow. The continents separate and begin to move apart. Basement faults are no longer independently active, and basement begins to subside as one block. The entire edge of the continent sinks. Simultaneously, stage 1 of margin sag cycle 2 commonly begins with deposition of nonmarine beds and

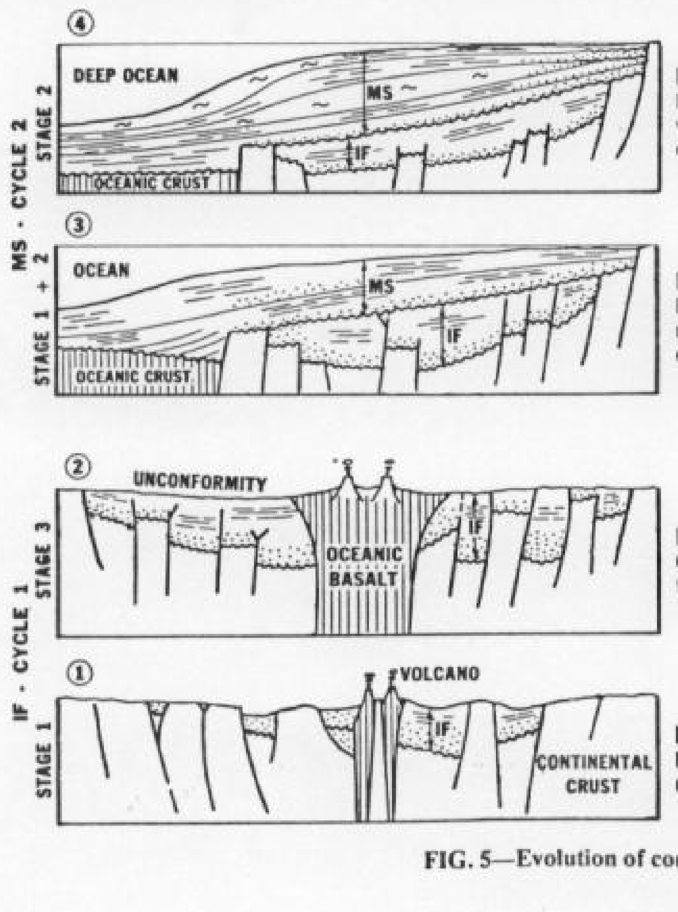


FIG. 5—Evolution of continental margin sag basin.

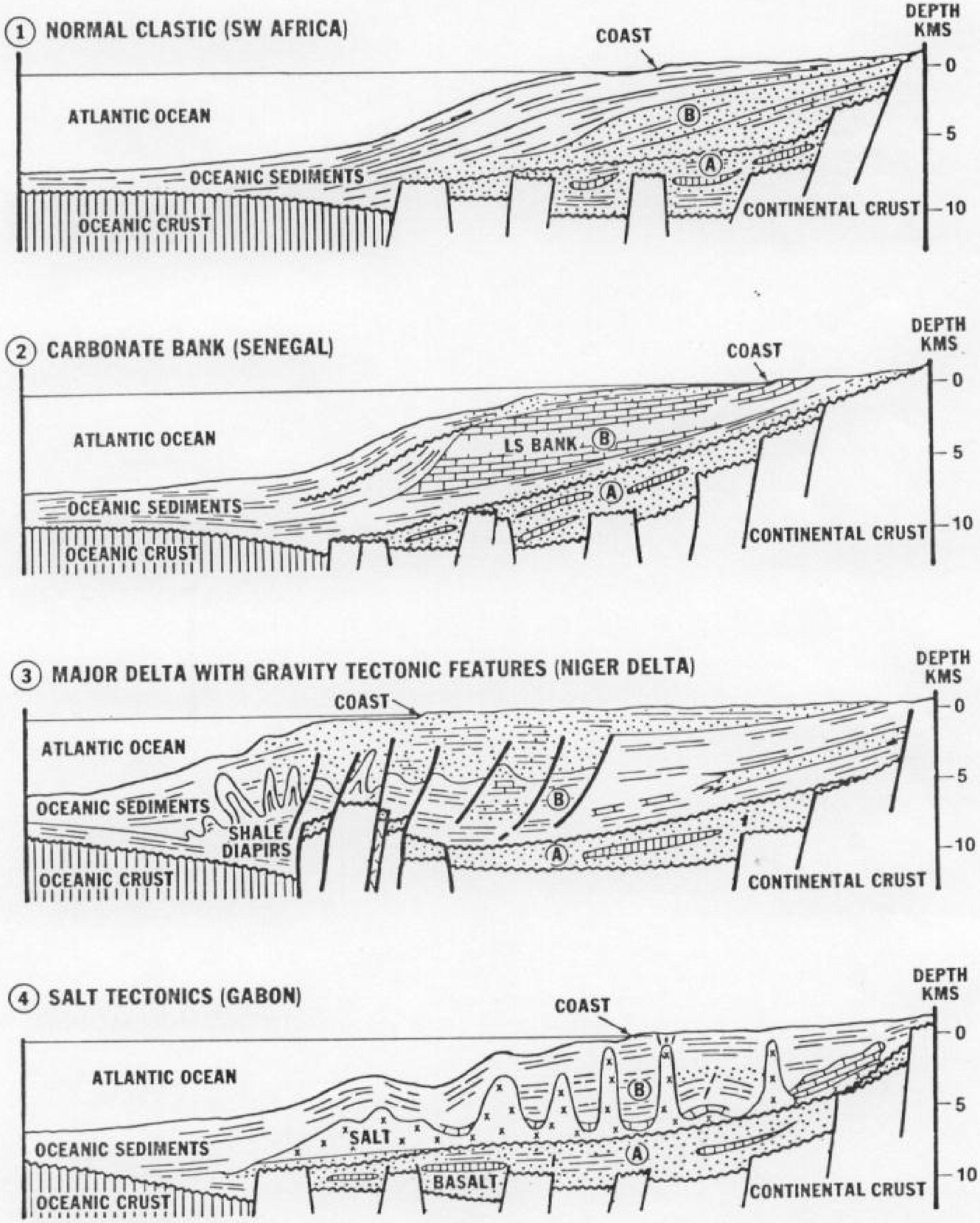
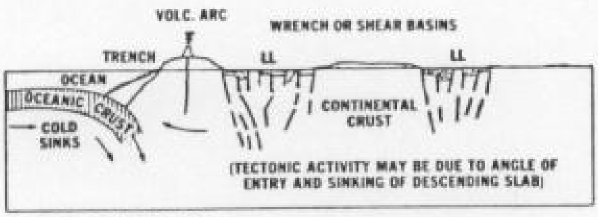
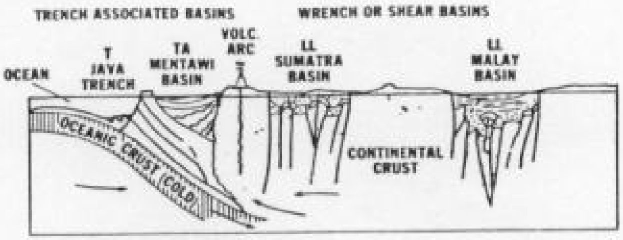


FIG. 6—Examples of four main types of continental margin sag basins classified according to cycle 2 marine fill: (1) normal clastic, (2) carbonate bank, (3) major delta, (4) salt tectonics. Most divergent basins are in one of these four categories or in combinations of two or more. For example, Tarfaya (Morocco) basin contains combination of Triassic salt (type 4), Jurassic carbonate bank (2), and Lower Cretaceous delta clastics (3). A = lower cycle 1 nonmarine series; B = upper cycle 2 marine rocks. Adapted from Beck and Lehner (1974).



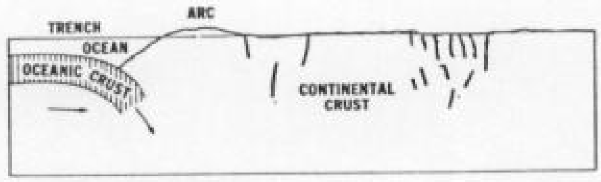
2. MIOCENE TIME

A. Arching of upper slab. Basin formation.
B. Trough collects deep-water sediments (some volcanic).
C. Volcanoes on inside arc.
D. Wrench or shear basins initiated by block faulting and differential plate movement.



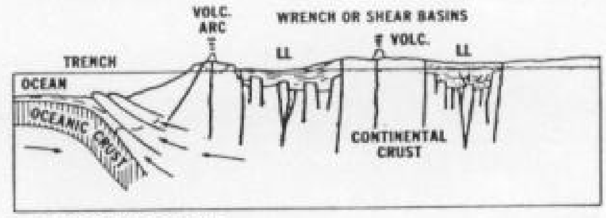
4. PRESENT DAY

A. Trench sediments deformed. Thrusting produces new nonvolcanic arc and associated basin.
B. Volcanoes inside arc.
C. Strike-slip basins continue to fill and deform by wrench-fault couplet.



1. MIDDLE TERTIARY

A. Convergence of 2 plates (oceanic + continental) subduction begins.
B. Trench and arc are formed (downbending of oceanic plate causes tension in overriding plate; or cold oceanic plate simply sinks under upper plate, and no compression results).



3. PLIOCENE TIME

A. Trough continues to collect sediments which are continuously folded and thrust faulted. This is only area of compression.
B. Volcanoes inside arc.
C. Strike-slip tension basins fill first with nonmarine clastics, later with marine sediments. Basins sporadically wrenched (structured) as they fill.

FIG. 7—Evolution of convergent basins (shear and trench). Example from Java-Sumatra.

occasional minor evaporites.

Stage 2 of margin sag includes continued subsidence and continental separation, and is identified by marine deposition. Marine waters invade the infilled graben system for the first time, depositing clastics, carbonates, or massive salt at the base of the series. As the oceanic spreading center expands, the continents separate. New layers of oceanic crust form, and the older ones cool.

On many present-day divergent continental margins, there is evidence of very rapid subsidence and oceanward tilting of the basins, beginning in the Early Cretaceous and accelerating in the Tertiary. Marine sediments on the open shelf mark periods of highstands of sea, and nonmarine sediments and paleoslope unconformities mark the lowstands. As the ocean basins become deeper, clinoform deposition into the deep water dominates all previous patterns. The continental crust margin may appear to have subsided more than the adjacent oceanic crust, probably because of sediment loading. If salt is present, salt diapirs may intrude during the later stages of the basin formation. Delta deposits may accumulate at the mouths of rivers, with attendant gravity features, shale diapirs, and growth faults.

Margin sag basins have been divided into various general types by Beck and Lehner (1974). These are normal clastic, carbonate bank, major delta, and salt tectonics; they are illustrated in Figure 6. Most of the more than 100 margin sag basins we have identified can be placed in one of these four groups. The four margin sag basin types, however, are not subdivided from the margin sag category; all are referred to as margin sag (MS) basins or cycles. The advantage of these groupings is in their oil-play association (see Kingston et al, 1983).

One variation of the margin sag cycle should be noted separately—it comprises "old" continental margin basins that, as suggested by depositional evidence, have been converted into interior basins by the subsequent formation of a foldbelt on the seaward side. They were margin sag cycles transformed into interior sag cycles by orogeny.

In many situations the evidence for margin sag origin is only partial, but we assume that these basins once were margins sags because any evidence to the contrary was destroyed by the formation of the foldbelt. The main reason for the separation and identification of margin sag–interior sag (MSIS) cycles is that they are the classic "asymmetrical basins" and, worldwide, many are prolific producers of hydrocarbons.

Margin sag–interior sag (MSIS) cycles were generally deposited on broad, gently dipping continental platforms with sheet sands and carbonate deposits more closely comparable to those of interior basins than those of present-day narrow continental margins. Sediments deposited in these old margin sag–interior sag (MSIS) cycles are marginal, i.e., they generally grade from coarse to fine in the paleosea direction, and show no structural or stratigraphic evidence for the existence of the other side of the basin. No clastics were being introduced from the seaward side; this indicates the existence of an "old ocean." After the foldbelt has transformed the cycle into an asymmetric interior sag basin, it is designated MSIS to differentiate it from cycles deposited as interior sags and also from modern margin sag basins.

Convergent Cycle Types

Basins classified in this category are those formed on margins or nearby interiors of two or more plates converging toward one another. Most basins on converging plates mainly exhibit tensional features. Figure 7 shows a simplified version of the relative positions and development of basins on convergent plate margins. Models for basin formation on convergent margins are well known. Seely et al (1974) have discussed trench, forearc, and backarc basins. Carey (1958), Freund (1965), Harding (1973), and Crowell (1974) have discussed various aspects of shear or wrench basins. Carey (1958) described small ocean basins.

Wrench or shear cycles/basins (LL).—These strike-slip, shear, or wrench basins are referred to here as double "L" cycles (LL), for lateral movement. These cycles are found on continental or intermediate crust. For this classification, hydrocarbon-prospective wrench basins are restricted to those found on or directly adjacent to continental crust. Wrench basins/cycles are found in areas of two or more converging plates. They are formed by a divergent wrench couplet with strike-slip faults along two or more sides, as shown in Figure 8.

Most wrench couplet or shear basins are found in the areas of present-day, or Tertiary, plate convergence. Typical areas where these basins occur are: (1) the periphery of the Pacific Ocean, including Antarctica; (2) southeast Asia; (3) the Himalayan-Alpine chain from the Solomon Islands to Spain; and (4) around the Caribbean (Antilles arc).

For most of these shear basins, stage 1 (basin initiation by divergent wrenching) appears similar to an interior fracture (IF) basin, with tensional block faulting and little or no evidence of wrenching. Nonmarine wedge-base sediments are deposited, unless the basin is initiated under water.

Sometime after the basin is initiated in stage 1 or 2, wrench deformation of the basin begins. Wrench structures may form along the flanks or within the basin. Major wrenches outline the basin, and minor wrenches form structures within the basin. If the basin is near enough to the ocean, marine sediments may be deposited; many wrench basins have no marine fill, being too far from the sea to have had invasions of marine waters.

In stage 3 of the wrench (LL) cycle, the basin is uplifted and eroded, and the continued shearing may begin to destroy the structures and parts of the basin. The term "L3FB" is used for the final stage of a basin completely wrenched to a foldbelt. Continued plate convergence may result in orogeny.

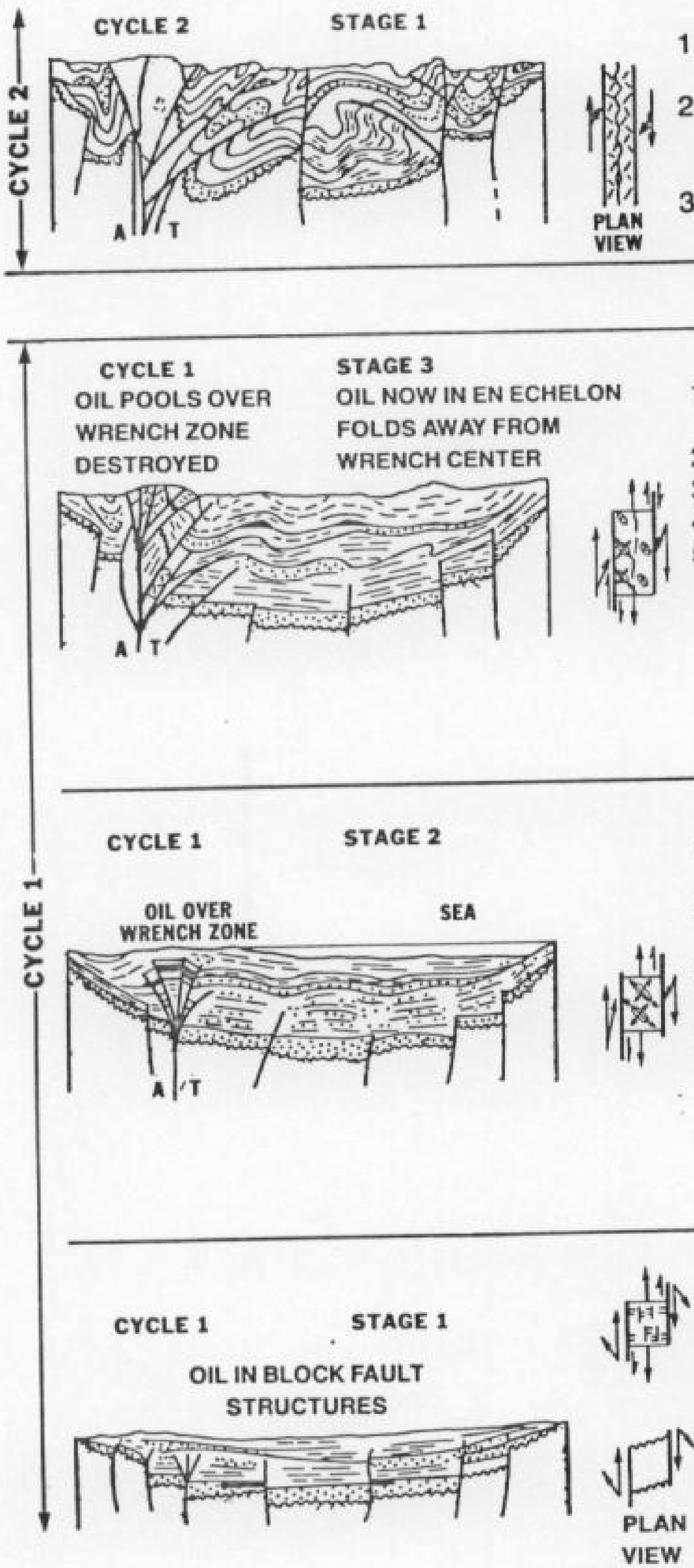
If the wrench-faulting process continues over a long enough period, it will eventually destroy the LL basin. As a result, few examples are found of preserved wrench basins older than Tertiary. Typically, pre-Tertiary wrench (LL) basins occur as wrenched foldbelts, with only fragments of the destroyed basins being recognized. However, if convergence between the two plates and, therefore, the engine driving the mechanism, has stopped at some intermediate interval, the basins existing at that time may be preserved. Some portions of the wrench basins of Oklahoma (Ardmore) are believed to represent different stages of arrested wrenching. Sedimentary fill in wrench (LL) basins is extremely varied. Marine clastics, carbonates and evaporites, nonmarine clastics, volcaniclastics, and flysch-chert-ophiolites are all found, depending on depositional conditions.

Trenches (T) and trench-associated (TA) basins.—These categories of the classification system are relatively minor from a hydrocarbon-prospect standpoint. Results from past exploration have been poor, and it appears these basins have very little future prospect of containing commercial hydrocarbons.

Trench-associated cycles/basins (TA), as shown in Figure 7, are located on convergent continental plate margins, landward of the trench or nonvolcanic arc, if one is present. The basins generally are built on folded trench sediments, not continental crust, and are formed by a simple sag, often deformed by contemporaneous wrenching. Trench-associated (TA) basins are likely to be filled with a high percentage of volcaniclastic sediments, though quartz or arkosic sands may be found, given the proper nearby sediment source area. Sediments in these basins generally are marine, though some have been found to contain nonmarine materials in the lower stage (Abukuma basin of Japan). Other trench-associated basins appear to have subsided rapidly and are filled with deep-water sediments in the lower stage. Thus, two basins of diverse origins are included in the trench-associated (TA) category because of their location. Trench-associated (TA) basins easily may be confused with wrench (LL) basins. Forearc basins (Seely et al, 1974) are included in this trench-associated category. In our global basin classification system, we find many "forearc basins" with no arc association (Sabah, Palawan, Philippines, etc). As a consequence, we prefer to use the term "trench-associated basins."

Trenches (T) are located (1) on oceanic crust, and (2) at the margins of two or more converging plates. A subduction zone is formed with the trench being the "bent" portion of the lower plate, as shown in Figure 7. Present-day trenches are relatively narrow downwarps located over subduction zones. Active trenches are areas of low heat flow and are Tertiary in age; older trenches have been converted into foldbelts.

We recognize two types of trenches. The first involves one oceanic plate overriding another, forming a mid-ocean trench such as the Mariana, Aleutian, and Philippine trenches. These features normally have little sediment fill, and the amount they do have primarily is volcanogenic and deep-water pelagic. The second type involves an oceanic plate overridden by a continental plate. This trench can receive oceanic pelagic sediments and volcanics, as well as land-derived fine clastics. These ocean-margin trenches accumulate very thick deep-water deposits. Continued convergence with its attendant compression and shearing, eventually results in a foldbelt. Most trenches and trench-associated basins end up as foldbelts, and such folded trench sediments are given the designation "FB3T."



L3FB

1. Wrenching continues through basin until wrench foldbelt results.
2. Too much tectonism breaks up big structures, reducing size of oil fields or destroying them.
3. Continued wrenching may result in metamorphism and orogeny.

LL-3

1. Uplift and erosion, general uplift of entire basin or local uplift by wrench faults.
2. Wrench structures continue to grow.
3. Nonmarine deposition in lows.
4. Usually 3rd stage ends in unconformity.
5. Oil prospects over main wrench zones may be destroyed; en echelon folds away from main wrench zones most prospective.

LL-2

1. Continued subsidence of basin by downfaulting or sag—possibly no visible wrenching.
2. Wrench fault structuring begins. It may be continuous or periodic.
3. Marine sedimentation, clastics, carbonates, major evaporites (salt), and volcaniclastics.
4. Oil prospects localized in folds developing over top of wrench zone.

LL-1

1. Basin initiated by wrench fault couplet or strike slip tension (looks like normal IF tension graben).
2. Tension block faulting and subsidence.
3. Commonly little or no evidence of wrenching movement at this stage.
4. Nonmarine sedimentation, clastics, coal, volcanics, minor evaporites, oil shales.
5. Oil prospects in block fault structures.

FIG. 8—Evolution of wrench or shear basins. LL = lateral. Development of convergent plate wrench in three stages (LL-3, 2, 1). L3FB shows final step in many wrench basins, that of foldbelt caused by wrenching. This is final step in process that creates basin and finally destroys it. After initiation of basin (LL-1), movement may cease in any succeeding stage. Basin may also stop strike-slip mode and change to polyhistory basin.

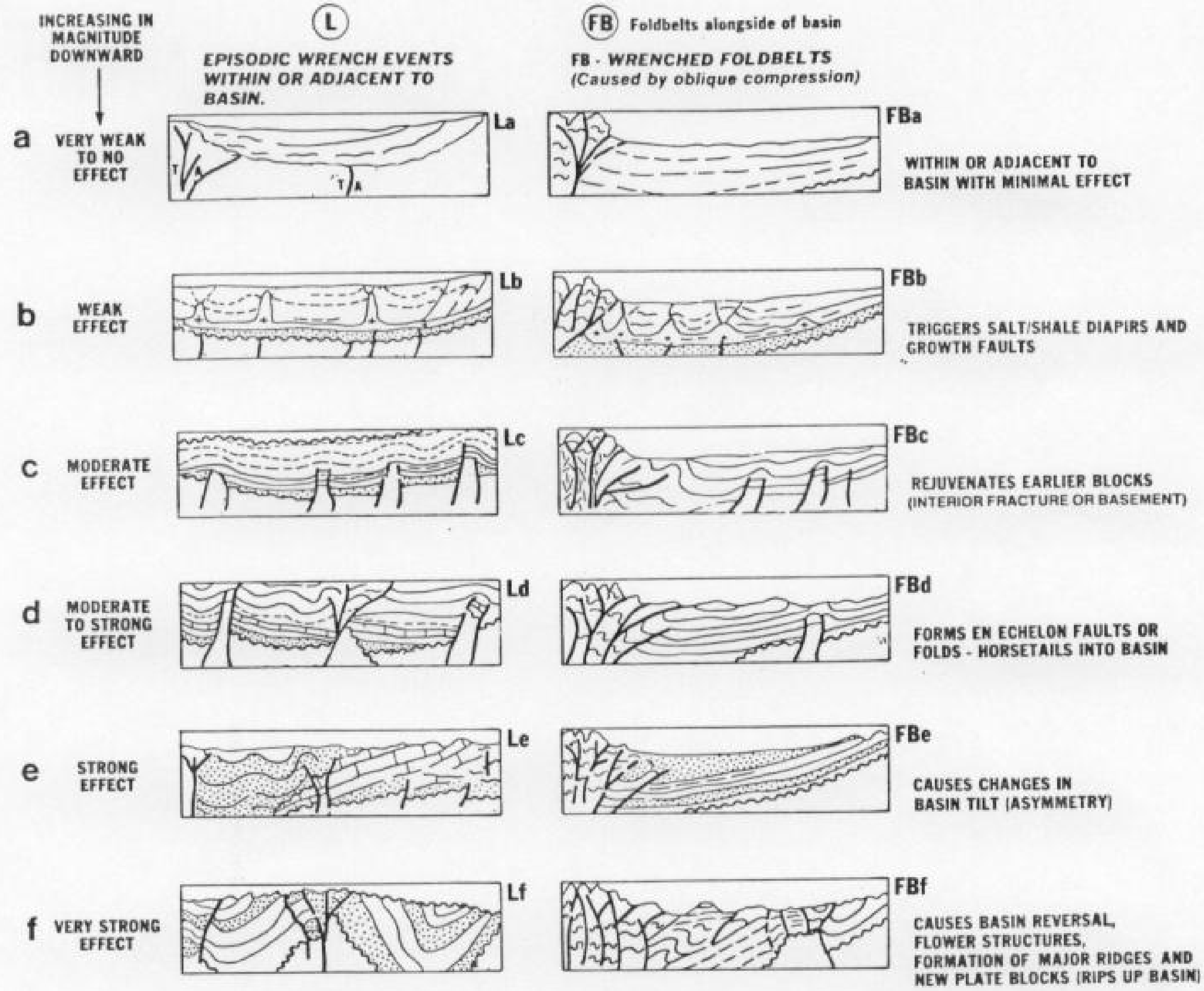


FIG. 9—Tectonic modifiers of primary basin types (L and FB).

Oceanic sags (OS).—Oceanic sags are areas where oceanic crust has been formed by continental separation and the formation of a spreading center. Subsequent cooling and subsidence of the oceanic crust have caused it to sink. The sag areas that have accumulated a significant thickness of sediments are called oceanic sag (OS) basins. Most of these thick sediment areas are near continental blocks or island arcs and may be associated with either convergence or divergence. The sediments consist of pelagic material, volcaniclastics, and distal turbidites. Like the trench and trench-associated basins, oceanic sags appear to have very limited hydrocarbon potential.

Oceanic sags–wrench couplet cycles/basins (OSLL).—These are the mini-oceans or small ocean basins, floored by oceanic or transitional crust. Such basins are believed to have been formed by a large divergent wrench couplet (rather than mantle upwelling and sea-floor spreading) that opened a mini-ocean through separation of the sialic layer. These basins may be filled with pelagic materials, volcaniclastics, or distal turbidites, as in oceanic sags (OS) basins.

BASIN-MODIFYING TECTONICS

The third major element used to classify basins is basin-modifying tectonics. Basins or cycles formed by one type of tectonic movement may be changed during their history by other structural events. There are three types of basin-modifying tectonics: episodic wrenches (L), adjacent foldbelts (FB), and complete folding of a basin area (FB3) which is foldbelt formation.

Definition of Episodic Wrenches and Foldbelts

Episodic wrenches are designated by the single letter "L," and represent a wide variety of lateral movements not connected with basin/cycle origin. Episodic wrenches modify basins formed by other means and are found in basins with all ages of basement rocks. It is believed that old zones of weakness in the basement, such as old sutures, interior fracture zones, plate boundaries, etc, move periodically or episodically in response to plate movements. These plate movements are manifested at the surface by plate collisions, rotations, fragmentation, and by subduction zones. Wrench faulting or rotational movements are prevalent in basin histories on all continents and react in different ways at different times. Crustal blocks floating on the asthenosphere may be similar to the jostling of ice flows on the polar seas.

Generally, the origin of an episodic wrenching or lateral L movement is fairly easy to ascertain, given good plate-tectonic reconstructions. In some places, however, one cannot directly trace the originating event for an L movement. The event which triggers isolated wrench movements may be on some other side of the plate in question, or even on some other part of the earth. The effect of varying intensities of L movements is shown in Figure 9.

Foldbelts are caused by convergence of two or more plates. Basin areas caught in this convergence may be completely or only partly folded. Basins not completely folded are not considered to be foldbelts and are said to have been episodically wrenched. Basins completely folded are called foldbelts (FB3). Foldbelt formulas are derived from the basin that was folded. If the edge of a large basin is folded, the formula for the foldbelt is the same as that of the basin except that the youngest event will be some type of folding. Completely folded rocks, or foldbelts (FB3) are commonly found adjacent to relatively unfolded basins and, in fact, may grade into basins. The expression used in the basin formula to denote an adjacent foldbelt is "FB." Foldbelts have varying effects on adjacent basins, as shown in Figure 9.

Tectonic Modifiers

Wrenches (L) and Adjacent Foldbelts (FB)

The tectonic modifiers of primary basin types are listed in Figure 9 in order of increasing magnitude, downward from "a" to "f." Each of these effects is found associated with both episodic wrenches (L) and adjacent foldbelts (FB). The very weak "a" effect is known to occur within or adjacent to a basin with minimal structural effect. La would mean that a wrench passed through or adjacent to a basin but caused no faulting or folding visible at the surface or on seismic reflection. Porosity and permeability, however, may be affected. FBa would mean that a foldbelt was formed on the side of a basin but had no effect, of faulting or folding, on the basin itself.

Lb and FBb illustrate the "b" effect—still very weak on the scale. The "b" effect triggers salt or shale diapirs and growth faults within the basin and can cause open folds in basins adjacent to FBb. We believe that without a tectonic event of "b" intensity or stronger, salt and shale may not be triggered to flow. The movement could be described best as "jiggling." There are numerous examples, worldwide, of basins with thick salt layers and plenty of load that have never flowed to produce domes (e.g., Yakutsk, Touggourt, Permian basins). Nor do they exhibit any other evidence of post-salt deposition structuring. It can be concluded that slight plate motions or jiggling are required to initiate or trigger salt and shale diapirs and growth-fault movements. Salt and shale diapirs, once triggered by an Lb event, could continue to grow by static load without further jiggling to keep them moving.

Lc and FBc illustrate the "c" effect which is rejuvenation of preexisting blocks, either interior fractures or basement. This jostling of older blocks can cause structural growth which may or may not reach the surface. Many of the world's giant fields owe their structural growth to "c" effects. It is important to note that the "a," "b," and "c" effects of domes or arches may not reach the top of the structured cycle, which was also the old ground surface. The first modifier to reach the old ground surface as wrench-generated faults and folds is the "d" effect, which is rated as a moderate to strong event. It is convenient to divide the list of modifiers into the ones causing "weak" effects (a, b, c) and the ones causing "strong" effects (d, e, and f).

Ld and FBd are examples of classic wrenching. Relative plate movement is enough to cause en echelon faults or folds to be well developed. Here are found the first flower structures recognizable on seismic records or visible on the surface. Horsetails (a series of en echelon faults or folds) may be seen as fanning out of foldbelts or wrench zones into basins. The Ld flower structures are fairly modest ones and do not bring basement to the surface, as they do in stronger wrench events. Le and FBe are strong plate tectonic effects which significantly alter basin tilt, causing marked basin asymmetry. Tilt in one direction, or change of tilt direction, is an "e" effect.

Lf and FBf effects are the strongest episodic wrench events we record in a basin. Basins are turned inside out or "reversed" with synclines becoming anticlines. Flower structures bring basement or very old rocks to the surface. These "f" effects also see the formation of major ridges or arches in a basin, the breakup of plates under basins, and consequent formation of new smaller basins out of the old megabasin. The basin can be ripped up extensively and still be called an "f" effect. However, if the basin is completely folded, destroyed, or altered by faulting, we would go one step further than "f" and call it a foldbelt (FB3).

It should be noted that any of the characteristic tectonics of the weaker modifiers may be found in any stronger one. For example, salt and shale diapirs and growth faults (Lb) may be found along with rejuvenated block movements (Lc). All of the tectonic parameters, salt domes, jostled blocks, flower structures, basin tilts, etc, may be found in Lf.

Several important points need to be emphasized concerning L and FB events. First, the tectonic modifiers affect, in varying degrees, basins already formed by other processes. Second, an episodic wrenching zone (L) can turn into a wrenched foldbelt (FB) along its length, as a matter of degree of wrenching. We believe that most foldbelts are caused by wrenching movements or convergence at some oblique angle (other than 180°). Third, the modifiers are described as to what effect they have on the basin, not on the wrench or foldbelt. For example, a wrench alongside a basin may be very disruptive locally but have little or no effect on the basin itself. Similarly, a foldbelt alongside a basin may be vaulted or highly deformed mountains but have little structural effect on the adjacent basin. It is the structural effect on the basin that is described in Figure 9. If the foldbelt is hydrocarbon-prospective, it will have its own description.

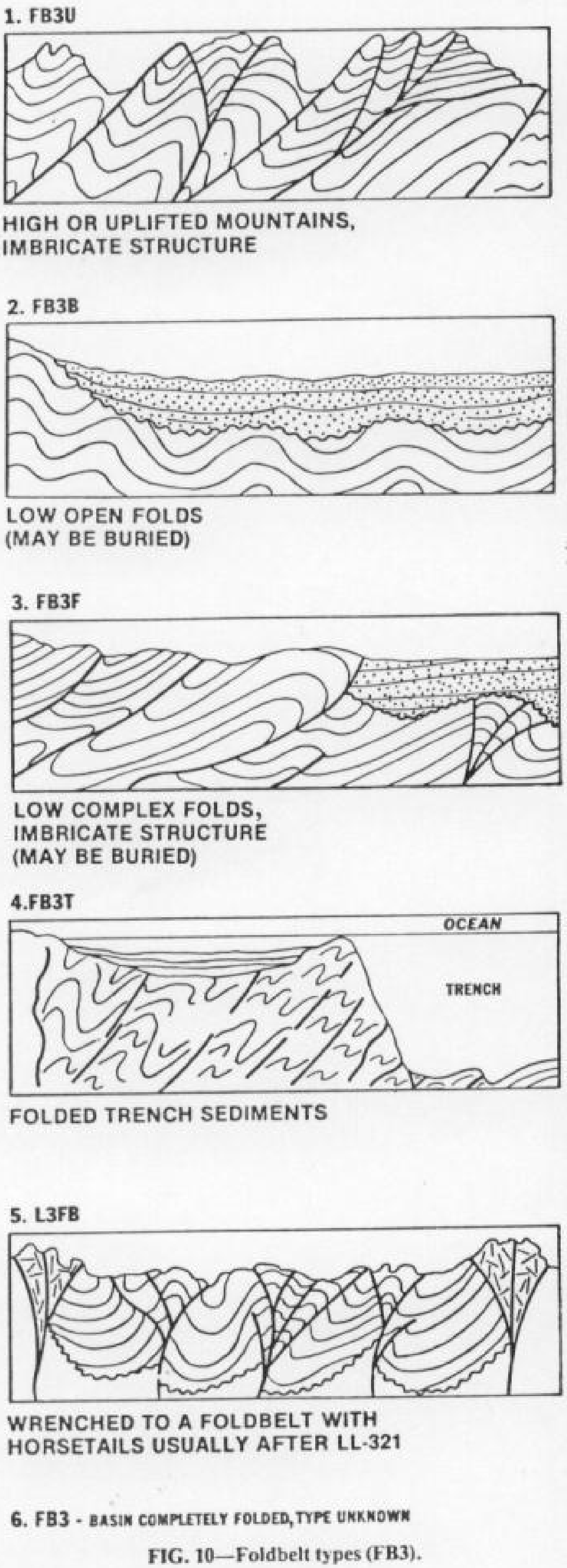


FIG. 10—Foldbelt types (FB3).

Foldbelts (FB3)

Foldbelts represent sutures where past plates have converged or are still converging. This convergence results in compression and shearing motions that cause the rocks to be wrenched and folded. If ultrabasic rocks, serpentine, chert, volcanic flysch, and other oceanic sediments are found in foldbelts, it is assumed that an old area of oceanic crust was destroyed by subduction or plate collision, and the foldbelt suture is all that remains of the vanished oceanic plate.

The six different types of foldbelts (FB3) are shown in Figure 10. They are: (1) FB3U, the uplifted foldbelts or high-mountain ranges, generally having imbricate structure, such as the Canadian Rockies; (2) FB3B, the topographically low, open folds, which may be partly or almost completely buried by younger sediments, as in part of the Iranian foldbelt; (3) FB3F, the topographically low but complex folds with imbricate structure, which may be partly or almost completely buried by younger sediments, as in the Vienna basin; (4) FB3T, folded trench sediments, found on convergent plate margins; (5) L3FB, wrenched to a foldbelt (can have horsetails), invariably a former LL basin; and (6) FB3, basin completely folded, specific type unknown. Of the six foldbelt types listed, only three—FB3B, FB3F, and L3FB—presently produce commercial hydrocarbons.

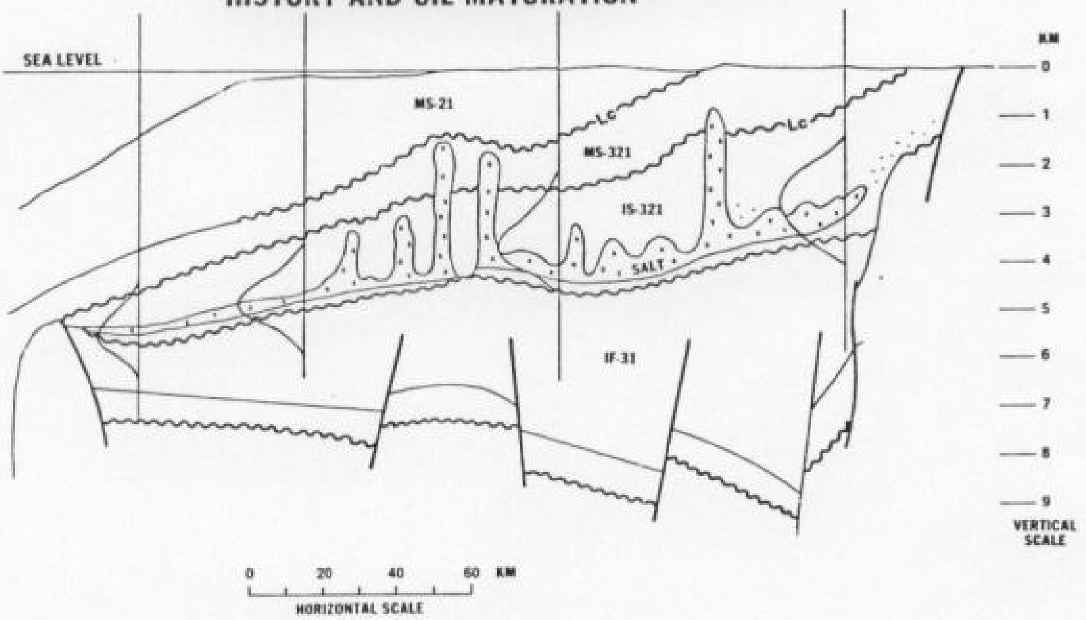
BASIN CLASSIFICATION

All basins, worldwide, may be classified by using the structural and stratigraphic elements previously discussed. It is possible to combine these elements to make a formula for each of the basins within the system. The formula is a general expression of the basin's structural and stratigraphic history. It does not describe unit thickness, rock color, source, reservoir, grain sizes, and many other factors necessary for basin analysis. Therefore, there is no magic formula which can separate sedimentary basins into oil- and gas-prone versus barren. Formulas are simply useful means for summarizing the important points in a basin's structural and depositional history. In classifying a basin and writing its formula, it is important to outline only the main events in the basin history, and not to attempt to describe all detail. Too much detail results in long and needlessly complicated formulas, which are difficult to use.

Basins may be classified by comparing basin parameters, as shown in Figure 11. The data needed are regional maps and cross sections, well logs or surface sections, and regional seismic lines, if available. From the maps and cross sections, the geologic and plate tectonic history of the basin may be deduced. Major unconformity breaks within the cross sections should be restored to the old paleosurface, and a series of historically restored cross sections should be made. From these, the basin history can be broken down into cycles, stages, and tectonic events. These may be compiled as shown in Figure 11 to derive the proper basin classification and formula.

Figure 11 shows how the (1) cycles, (2) stages, and (3) tectonic events of a polyhistory basin are combined to create

A. CROSS SECTION OF AN ATLANTIC MARGIN SAG BASIN SHOWING CYCLE POSITIONS, BURIAL HISTORY AND OIL MATURATION



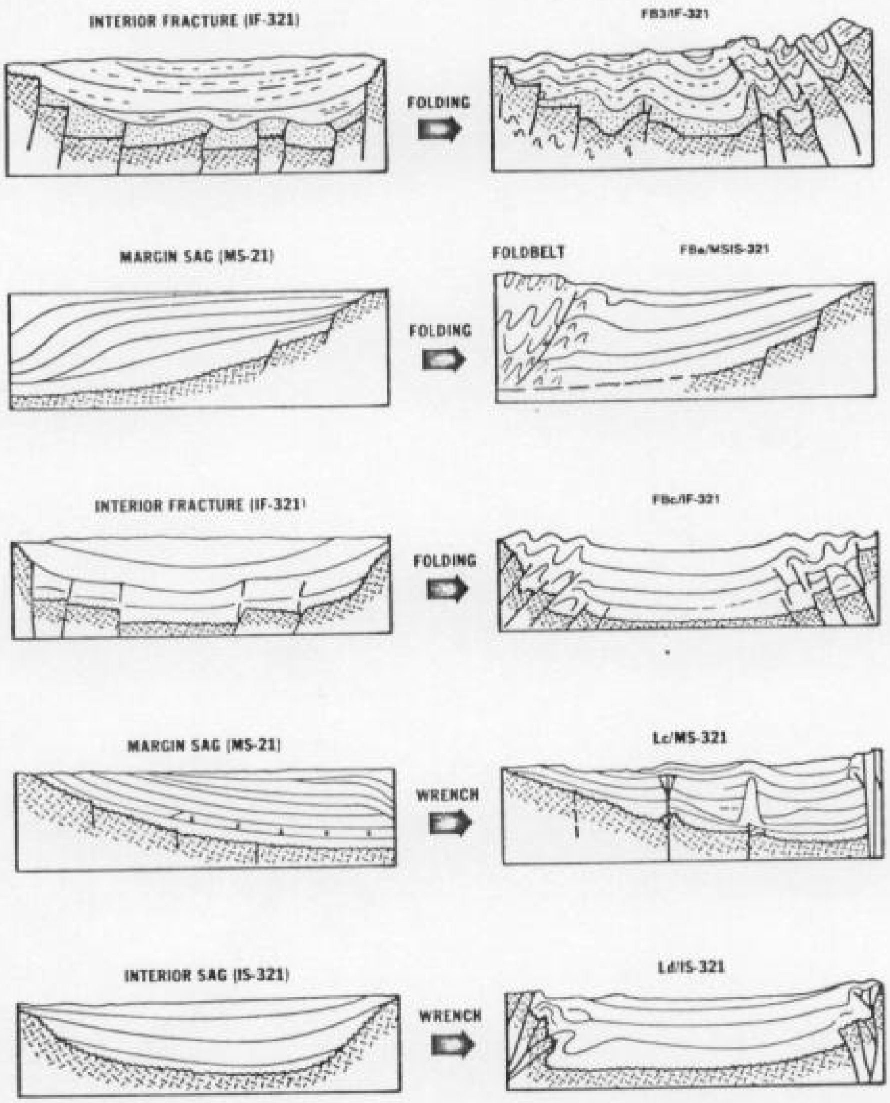
B. COMPARISON OF BASIN PARAMETERS

Q-Tm, Tm, Tm-Km, Km, Km-Kl, Kl-Ju

FORMULA: MS - 21/Lc/MS - 321/Lc/IS - 321/IF - 31

CYCLE NO.	SEQ.	AGE	BASIN/CYCLE TYPE	TECTONIC EVENTS		DEPOSITIONAL STAGE	PROD. PLAYS
4	A	QUAT. TO E. MIO.	MARGIN SAG MS		2	(MARINE, WEDGE MIDDLE)	
					1	(NONMARINE, TRANSGRESSIVE)	
				Lc			
3	B	E. MIO. TO M. CRET.	MARGIN SAG MS		3	(NONMARINE, REGRESSIVE)	SALT STRUCTURES CLASTIC RESERVOIRS
					2		
					1		
				Lc			
2	C	M. CRET. TO E. CRET.	INTERIOR SAG IS		3		DRAPE OVER BASEMENT FAULT BLOCK, CLASTIC RESERVOIR
					2	(SALT)	
					1		
1	D	E. CRET. TO L. JUR.	INTERIOR FRACTURE IF		3–1	ALL NONMARINE	SUB-UNCONFORMITY ON BASEMENT FAULT BLOCK STRUCTURE, CLASTIC RESERVOIR

FIG. 11—Comparison of basin parameters using example (A) from Atlantic margin. Formula for basin is given at top right of B. In left column, cycles are numbered in ascending order, oldest to youngest; this gives a system of identifying geologic events as they developed during history of basin. Second column, labeled "sequence," is inversion of column 1, using letters; this enables identification of cycles or events from youngest to oldest as they would be encountered in drilling a well. Third column ties cycles to geologic age. Fourth column (boxes) gives gross cycle type and abbreviation. Next column shows tectonic events affecting basins, their strength, and when they occurred in relation to other events. Sixth column shows depositional stages of wedge top (3), middle (2), and base (1), with or without unconformity. Right column shows hydrocarbon-producing plays.



A
1. Example of interior fracture basin (IF-321) completely structured by foldbelt. May also include some wrenching. Formula FB3/IF 321. (FB3 means entire basin folded.)

B
1. Example of margin sag basin (MS 321) affected on one side by a foldbelt. Foldbelt and remainder of original MS basin are now separate entities. The formula for remaining basin is FBa/MSIS-321 (FB/without a FB3 means foldbelt affecting only part of basin.)

C
1. This example is the same as B above except the folding is on two sides of basin instead of just one side. The entire basin is not affected. Therefore formula is FBc/IF-321.

D
Example of a margin sag basin affected by wrench faulting late in its development. Probably old Precambrian sutures reactivated. Linear wrenches cause ridges or arches to form in basin. May also activate salt ridges. Isolated ridges form within basin or along one side.

E
Example of interior sag basin that has been overprinted by wrench faulting late in its development. Wrenching runs around one or both sides of basin.

FIG. 12—Examples of polyhistory basins, showing simple divergent basins overprinted by foldbelt and wrenching tectonics.

the basin formula. Figure 11A is a cross section of the basin to be formulated. Figure 11B translates the cross section events into the formula. It should be noted that cycles are ended by any of four events: (1) a change in cycle type (basin-forming tectonics); (2) the occurrence of a significant wrench or folding event, such as L, FB, or FB3 (tectonics affecting basins); (3) a major sedimentary transgression and regression; or (4) a regional unconformity which may be caused by L, FB, or FB3 events but commonly occurs without them.

Viewing the events in the example shown on Figure 11, as they would become apparent in drilling a well, the youngest cycle is a margin sag (MS) which is still in stage 2 because the continental margin is under water. The marine wedge overlies a wedge base of early Miocene age and an unconformity; this unconformity corresponds to an episodic wrench which may have, in part, caused the unconformity. This Lc event reactivated the salt domes. The next older event is another margin sag (MS) cycle with wedge top, middle, and base (3,2,1) followed by another Lc event in the middle Cretaceous. This event initiated the salt dome movement in the basin and probably affected the unconformity. The next cycle down is an interior sag, IS-321, with thick salt in the stage 2 portion. The bottom cycle, an interior fracture, IF-31, has an unconformity at the top which is not related to L or FB events. The oldest cycle is entirely nonmarine. Combination of these cycles, stages, and events results in the formula being written youngest to oldest as follows: MS-21/Lc/MS-321/Lc/IS-321/IF-31. The abbreviated ages of each cycle may be written above the formula, as shown in Figure 11B.

Figure 12 shows examples of how single-cycle basins are affected by foldbelts and wrenching, and how the formulas are written.

Figure 13 is a series of cross sections showing the step by step development of the Persian Gulf basin, and its formula. The basin starts out in the early Paleozoic as an interior sag, as evidenced by the Hormuz Salt. The next cycle appears to be a margin sag, existing from the Permian through the Jurassic. An Lc event at the end of Jurassic was caused probably by convergence in the Tethyan zone and jostling collision of Turkish and Iranian microplates

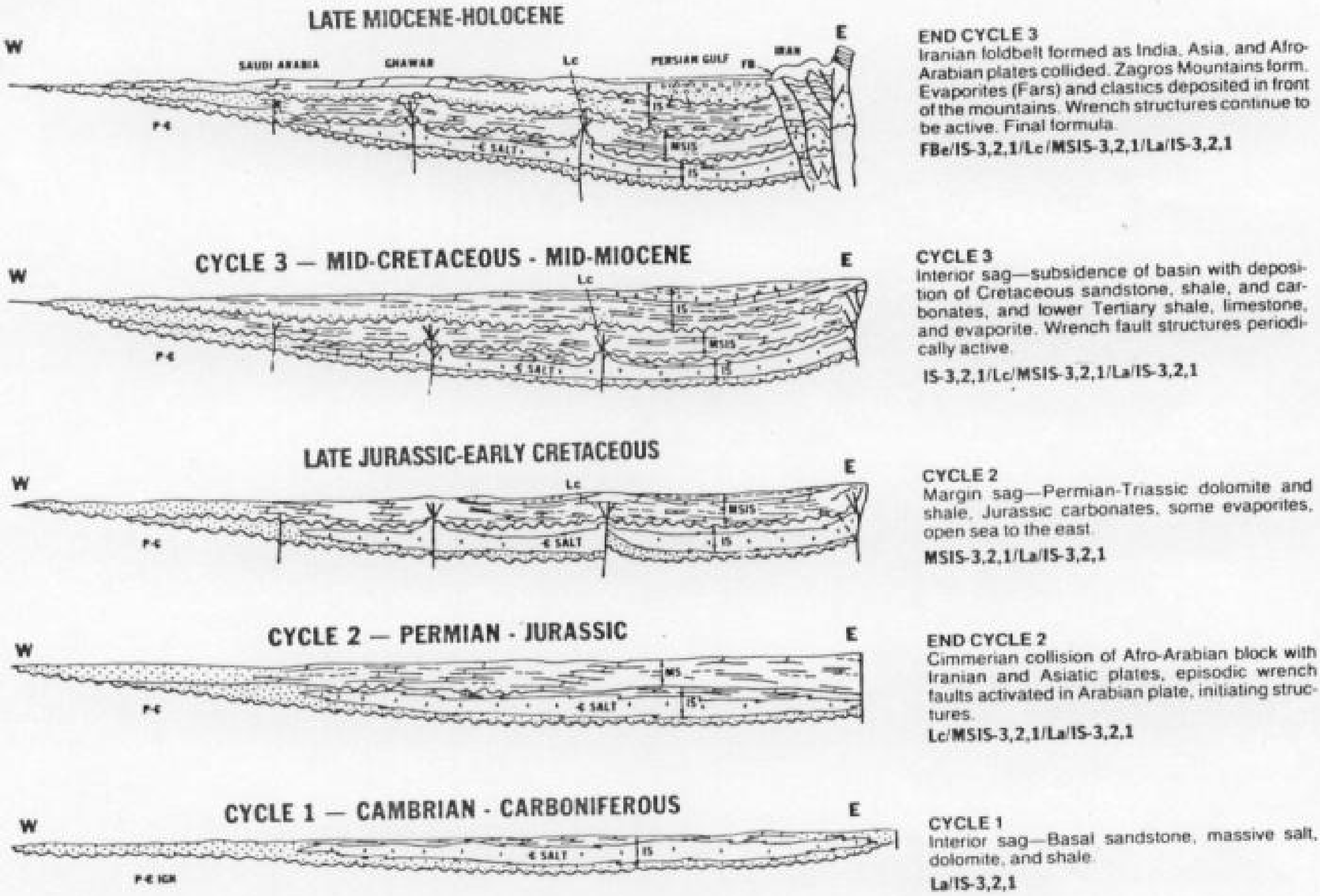


FIG. 13—Evolution of polyhistory basin showing successive stages and formula development. Example from Persian Gulf.

against the Afro-Arabian shield. This Lc event also closed off the eastern sea margin, and changed the previous margin sag cycle to an MSIS cycle. The Persian Gulf basin remained closed from that time to the present. The final events show late Mesozoic and Tertiary interior sags, here shown as a single cycle, and the final folding of the Zagros Mountains along the eastern margin of the basin.

Figure 14 shows a form we have found useful in summarizing key characteristics of basins for classification, analysis, and assessment. The form has been completed using the Persian Gulf basin as an example. The various parameters of basin classification and assessment are listed vertically on the left of the form, whereas the geologic ages are shown horizontally, from youngest to oldest, across the top. This permits us to locate, in time, the various key parameters within a basin such as cycles and stages, basin-forming or modifying tectonics, type of sediment fill, trap types, and hydrocarbon reserve information. This form may be used to describe either an individual basin or an oil field, for comparison with others.

St. John (1980) has published a map showing the location of world sedimentary basins. We have included approximately 600 of these basins in the global classification system. It is obviously too complicated to refer to each one by its specific formula; so another description must be available for more general use. The writers have found it convenient to use the following categories. On a global basis, about two-thirds of the basins in the system may be called simple or single-cycle basins. These have only one basin-forming tectonic cycle or, if they have other cycles and tectonic events, are dominated by one type. These basins are grouped under the name of this dominant cycle such as interior fracture basins, interior sags, margin sags, wrench or shear basins, oceanic sags, oceanic wrenches, trenches, and trench-associated basins. The more complex polyhistory basins that cannot be categorized with the eight basic cycle types, make up the remaining one-third of the basins classified globally. These are referred to simply as complex polyhistory basins, and further subdivision is not proposed at this time.

Regional Cross Sections

Six regional sections, drawn across a variety of polyhistory basins, are presented in Figure 15 to illustrate examples of how the more complex basins are classified. The formula for each basin is constructed using the information available on the section. In all cases, the cross sections will be described in their order of deposition—from the bottom up. The construction of these regional cross sections is both an aid to basin classification and a useful tool in rapidly explaining the tectonic history of a basin to others.

Cross Section AA′.—This is a section of a series of sags

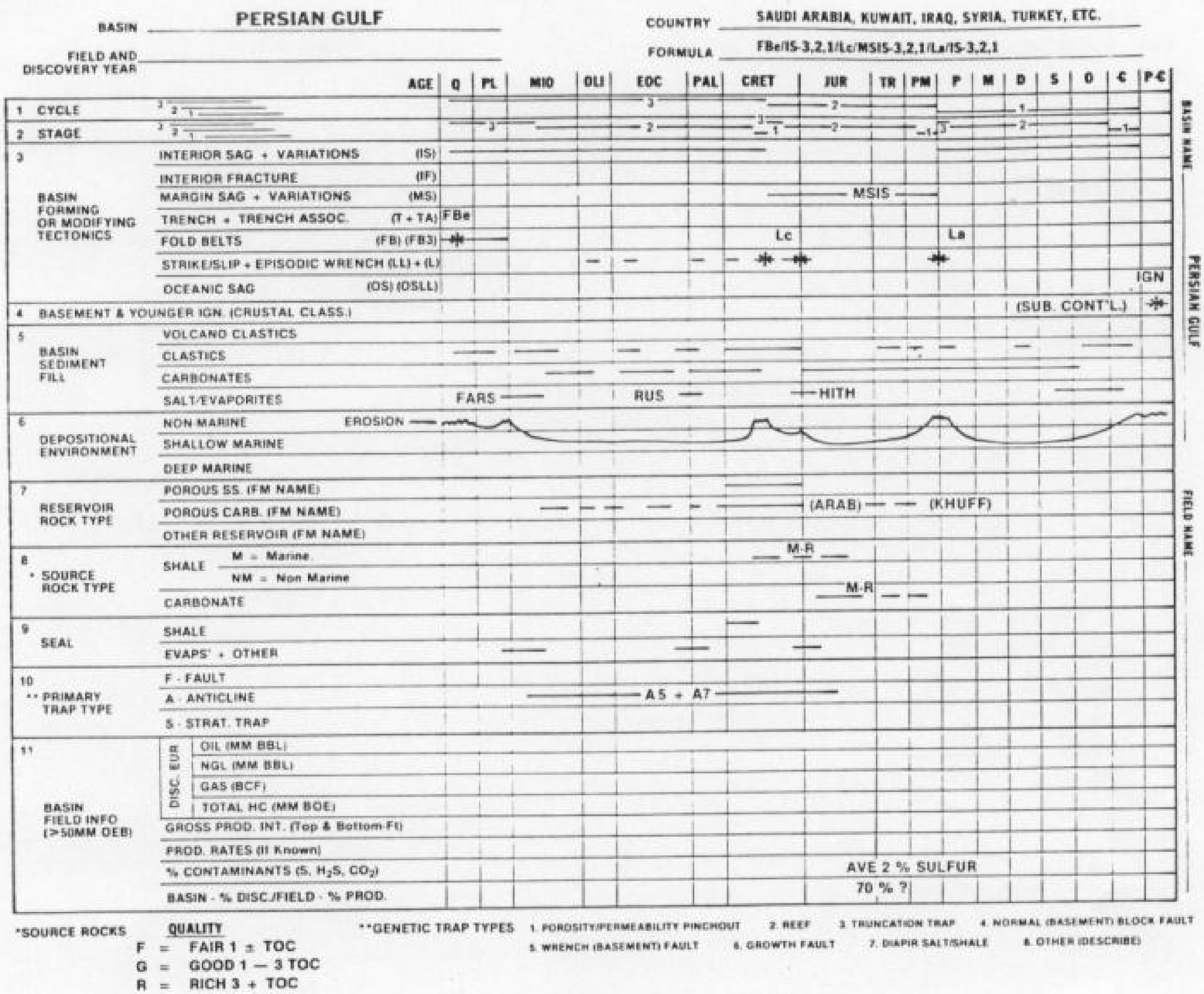


FIG. 14—Basin classification summary form.

with wrenching along one side. Three major unconformities in the section include the post-Precambrian, but exclude the present surface. The major tectonic events are associated with these unconformities so that cycles correspond to the intervals in between. The bottom cycle (1) lies on the Precambrian basement and shows no structure corresponding to the cycle. Sandstone appears to be coming into the basin from both sides with marine shale in the center. Cycle 1 appears to be an interior sag and would be written IS-321. The second cycle, which is late Paleozoic in age, also has sandstone coming in from the sides and limestone and shale in the center. This cycle appears to be another interior sag and should be written IS-321. Corresponding to the unconformity at the top of cycle 2 is an L event which affects both older cycles but not the Permian. This wrench appears to be an Ld event. The third or final cycle, of Permian age, is another interior sag, apparently with no marine stage 2, which would be written IS-31. The final formula for the cross section, written left to right, youngest to oldest, would be IS-31/Ld/IS-321/IS-321.

Cross Section BB'.—In section BB', there are three major unconformities, excluding the present surface, and the structuring is coincident with cycles or unconformities. Cycle 1 appears to be an interior fracture of Late Cretaceous age, containing sandstones for stages 1 and 3, marine shale for stage 2, and ending with an unconformity. Cycle 2, of Paleogene age, appears to be an interior sag with marine shale and limestone in stage 2 and sandstones being introduced from both sides. The cycle ends with an unconformity which coincides with wrenching activity along the right side of the cross section. The wrenching appears to be an Ld event. Cycle 3, the Neogene, is clearly another interior sag with sandstones coming in from the sides and limestone in the middle. The final formula can be written IS-321/Ld/IS-321/IF-321.

Cross Section CC'.—This cross section exhibits a reversal of tilt in the middle of its depositional history of three cycles. The bottom cycle is Late Cretaceous in age. It has a wedge base, carbonate platform with shales for stage 2, and an unconformity cutting off the wedge top for stage 3. There is no way of knowing from the cross section if this is an IS or MSIS cycle. Either would be correct. From rela-

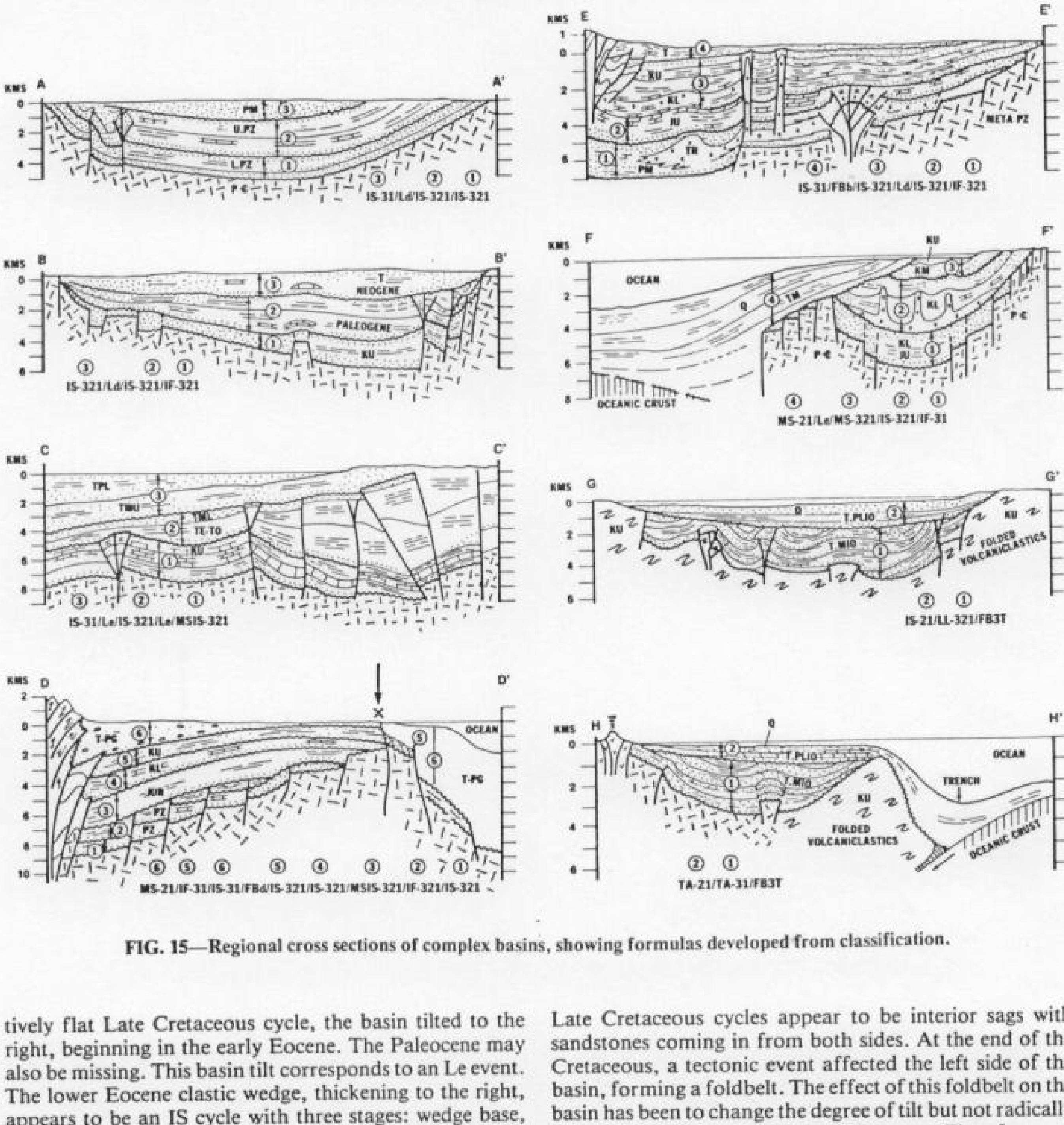


FIG. 15—Regional cross sections of complex basins, showing formulas developed from classification.

tively flat Late Cretaceous cycle, the basin tilted to the right, beginning in the early Eocene. The Paleocene may also be missing. This basin tilt corresponds to an Le event. The lower Eocene clastic wedge, thickening to the right, appears to be an IS cycle with three stages: wedge base, middle, and top plus unconformity. At the end of the early Miocene, there was another basin tilt reversing the direction to the left. This is considered to be another Le event. The last cycle of late Miocene-Pliocene would be nonmarine interior sag. The final formula for the basin would be IS-31/Le/IS-321/Le/MSIS-321.

Cross Section DD'.—Cross section DD' illustrates the complexity that may be caused when too many basin areas are included in the same formula. First, from the bottom up, there are two fairly thin Paleozoic cycles. The bottom cycle appears to be an interior sag cut by interior fractures of cycle 2. The Jurassic rocks appear to be directed into a deeper basin to the left, with no sign of the other side. We can designate this cycle MSIS-321. Both the Early and Late Cretaceous cycles appear to be interior sags with sandstones coming in from both sides. At the end of the Cretaceous, a tectonic event affected the left side of the basin, forming a foldbelt. The effect of this foldbelt on the basin has been to change the degree of tilt but not radically enough to call it an "e"-strength event. Therefore, we would probably designate it FBd. During Late Cretaceous to Paleogene, the mountains formed, the basin subsided, and clastics were shed off the rising mountains into the basin. This cycle is another IS cycle. The formula now reads: IS-31/FBd/IS-321/IS-321/MSIS-321/IF-321/IS-321. This should have been the end of the formula, but in this extended basin area a new ocean margin formed in the Tertiary at the right side of the cross section. If these geologic events were added, the formula would read MS-21/IF-31/IS-31/FBd/IS-321/IS-321/MSIS-321/IF-321/IS-321. This cumbersome geologic-history formula illustrates one of the pitfalls of including too large an area within the basin boundaries. The solution would have been to separate the area into two basins at point "X" on the section, and to give each basin a separate formula.

Cross Section EE'.—In this section, there are four major unconformities separating the cycles. At the bottom, is a Permian-Triassic interior fracture with a thick salt layer as a stage 2. No tectonic event is visible at the end of cycle 1. Cycle 2 looks like an interior sag with sandstone coming in from both sides of the basin and carbonates in the middle. At the end of cycle 2 (Jurassic), the large flower structure at the right of center was activated by wrenching (Ld) and then truncated. Possibly some salt movement was triggered at this time also, but the diapirs have younger movements which obscure the older evidence; therefore any old movements are unconfirmed. The Lower and Upper Cretaceous are lumped together into one cycle which appears to be an interior sag owing to the presence of Lower Cretaceous salt, because no evaporites are found in margin sag (MS) cycles. At the close of the third cycle is a tectonic event. A foldbelt formed on the left side that caused the salt to flow; but it does not appear to have jostled basement blocks. It probably should rate about an FBb. The final cycle is another interior sag, probably nonmarine. The final formula for the basin would be IS-31/FBb/IS-321/Ld/IS-321/IF-321.

Cross Section FF'.—In this section, a divergent continental-margin basin, four major unconformities outline basin cycles. The oldest cycle is an interior fracture with nonmarine sediments only. The second cycle is Lower Cretaceous and includes a thick salt bed. This means it must be an interior basin inasmuch as there is no salt deposition on open-ocean margins. Cycle 2 is called an interior sag, and may have ended with some L-event tectonic activity during middle Cretaceous time; however, there is no conclusive evidence on this cross section. Cycle 3, middle and Late Cretaceous, has been cut off on the left side by an unconformity. It is therefore impossible to determine, from the evidence on the cross section, if this cycle was an interior sag or a margin sag. However, because the basin is an opening continental margin, this cycle should be more marginal than the previous cycle. The best guess is that it is MS-321. The end of cycle 3 was accompanied by a strong uplift of the ridge in the basin center which changed the tilt of the basin, truncated the previous cycles, and caused salt domes to rise. This activity corresponds to an episodic wrench of Le intensity. The final cycle (4) is clearly a margin sag (MS) which occurred as the continental margin sank in the Tertiary. The final formula for this basin would read: MS-21/Le/MS-321/IS-321/IF-31.

Cross Section GG'.—The type of basin found on this cross section is commonly found around the margins of the Pacific Ocean. It is a wrench or shear LL basin overlain by an interior sag. The formula of this cross section would be IS-21/LL-321. The FB3T basement of folded trench sediments included in the formula is considered to be a key indicator of a convergent margin basin.

Cross Section HH'.—This cross section shows a convergent continental margin with volcanic arc, basin, and trench. The basin was initiated on folded volcaniclastic trench sediments in the Miocene. From the cross section, it is not possible to tell whether or not the trench-associated (TA) cycle contains a marine stage 2; because most TA cycles have marine rocks, we assume this one does also. The basin formula would be written TA-21/TA-321/FB3T.

CONCLUSIONS

This global basin classification system identifies and compares basins in specific as well as general terms. The system is based on the genesis and evolution of basins in the context of their geologic history. The main elements used to classify basins are basin-forming tectonics, depositional cycles, and basin-modifying tectonics. Basin-forming tectonics are deduced by knowledge of the type of underlying crust, past plate tectonic history, basin location on the plate, and type of primary structural movement involved in the basin formation—such as sagging or faulting. The result is eight single tectonic-cycle or simple basin types that are termed interior sag, margin sag, interior fracture, wrench, trench, trench associated, oceanic sag, and oceanic wrench.

Basin-modifying tectonics include episodic wrenches, basin-adjacent foldbelts, and completely folded basins. These have been identified and placed on a scale of increasing magnitude, from movements of slight to major structural effects. More complex basins may contain several different tectonic cycles, plus basin-modifying tectonic events. These are called polyhistory basins. The eight simple basin types, their depositional fills, and tectonic modifiers have been given letter and number symbols so that the specific geologic history of each basin may be written as a formula. These formulas may then be compared between basins, and similarities or differences noted.

The primary uses of the global basin classification are summarized as follows: (1) to locate and identify all basins of the world in one framework (the system can expand the explorationist's viewpoint to include all possible basin types, and not just those with which he or she has had personal experience—it is an aid to exploration thinking); (2) to permit the separation of complex basins into their simple component parts, for analysis as simple units; (3) to compare plays within one or two basins of the same type, or two or more basins classified as different types; (4) to provide a system for evaluating favorable plays and risks for each basin type, because risks should be understood before venture decision; (5) to predict what geologic events must be found in a basin to improve oil prospectiveness; (6) to enhance the prediction of oil potential in unknown or little known basins by referring to known basins of the same classified type; (7) to provide a system where the paleontology, seismic stratigraphy, geochemistry, and sedimentary history of like (and different) basins can be compared and evaluated; (8) to permit location and assessment of the best specific-play areas in a basin, not just total sediment volume; and (9) to act as a vehicle for comparative assessment of hydrocarbon basins, worldwide.

SELECTED REFERENCES

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: GSA Bulletin, v. 81, p. 3513-3536.

Bally, A. W., 1975, A geodynamic scenario for hydrocarbon occurrences: 9th World Petroleum Congress Proceedings, v. 2, p. 33-44.

——— and S. Snelson, 1980, Realms of subsidence, *in* A. D. Miall, ed.,

Facts and principles of world petroleum occurrence: Canadian Society of Petroleum Geologists Memoir 6, p. 9-75.
Beck, R. H., and P. Lehner, 1974, Oceans, new frontier in exploration: AAPG Bulletin, v. 58, p. 376-395.
Bois, C., P. Bouche, and R. Pelet, 1982, Global geologic history and distribution of hydrocarbon reserves: AAPG Bulletin, v. 66, p. 1248-1270.
Carey, S. W., 1958, The tectonic approach to continental drift, *in* S. W. Carey, ed., Continental drift: University of Tasmania, Geology Department Symposium, No. 2, p. 177-355.
Crowell, J. C., 1974, Origin of late Cenozoic basins in southern California, *in* Tectonics and sedimentation: SEPM Special Publication 22, p. 190-204.
Dewey, J. F., and J. M. Bird, 1970, Mountains belts and the new global tectonics: Journal of Geophysical Research, v. 75, p. 2625-2647.
Dickinson, W. R., 1973, Widths of modern arc-trench gaps proportional to past duration of igneous activity in associated magmatic arcs: Journal of Geophysical Research, v. 78, p. 3376-3389.
——— 1974, Plate tectonics and sedimentation, *in* Tectonics and sedimentation: SEPM Special Publication 22, p. 1-27.
Francheteau, J., and X. Le Pichon, 1972, Marginal fracture zones as structural framework of continental margins in South Atlantic Ocean: AAPG Bulletin, v. 56, p. 991-1007.
Freund, R., 1965, A model of the structural development of Israel and adjacent areas since upper Cretaceous times: Geological Magazine, v. 102, p. 189-205.
Green, A. R., 1977, The evolution of the earth's crust and sedimentary basin development: Offshore Technology Conference 2885, p. 67-72.
Halbouty, M. T., A. A. Meyerhoff, R. E. King, R. H. Dott, Sr., H. D. Klemme, and T. Shabad, 1970a, World's giant oil and gas fields, geologic factors affecting their formation, and basin classification, part I, giant oil and gas fields, *in* Geology of giant petroleum fields: AAPG Memoir 14, p. 502-528.
——— R. E. King, H. D. Klemme, R. H. Dott, Sr., and A. A. Meyerhoff, 1970b, World's giant oil and gas fields, geologic factors affecting their formation, and basin classification, part II, Factors affecting formation of giant oil and gas fields, and basin classification, *in* Geology of giant petroleum fields: AAPG Memoir 14, p. 528-555.
Harding, T. P., 1973, Newport-Inglewood trend, California—an example of wrenching style of deformation: AAPG Bulletin, v. 57, p. 97-116.
Huff, K. F., 1978, Frontiers of world oil exploration: Oil and Gas Journal, v. 76, n. 40, p. 214-220.
Isacks, B., J. Oliver, and L. R. Sykes, 1968, Seismology and the new global tectonics: Journal of Geophysical Research, v. 73, p. 5855-5899.
Kingston, D. R., C. P. Dishroon, and P. A. Williams, 1983, Hydrocarbon plays and global basin classification: AAPG Bulletin, v. 67 (follows this paper).
Klemme, H. D., 1971a, What giants and their basins have in common: Oil and Gas Journal, v. 69, n. 9, p. 85-90.
——— 1971b, To find a giant, find the right basin: Oil and Gas Journal, v. 69, n. 10, p. 103-110.
——— 1971c, Look in Permian reservoirs or younger to find supergiants: Oil and Gas Journal, v. 69, n. 11, p. 96-100.
——— 1971d, Trends in basin development: possible economic implications: World Petroleum, v. 42, n. 10, p. 47-51, 54-56.
——— 1975, Giant oil fields related to their geologic setting—a possible guide to exploration: Bulletin of Canadian Petroleum Geology, v. 23, p. 30-66.
Knebel, G. M., and G. Rodriguez-Eraso, 1956, Habitat of some oil: AAPG Bulletin, v. 40, p. 547-561.
Le Pichon, X., 1968, Sea-floor spreading and continental drift: Journal of Geophysical Research, v. 73, p. 3661-3705.
Lowell, J. D., and G. J. Genik, 1972, Sea-floor spreading and structural evolution of southern Red Sea: AAPG Bulletin, v. 56, p. 247-259.
Morgan, W. J., 1968, Rises, trenches, great faults and crustal blocks: Journal of Geophysical Research, v. 73, p. 1959-1982.
Nehring, R., 1978, Giant oil fields and world oil resources (prepared for the Central Intelligence Agency): Rand Corporation, R-2284-CIA, 162 p.
Norton, I. O., and J. G. Sclater, 1979, A model for the evolution of the Indian Ocean and the breakup of Gondwanaland: Journal of Geophysical Research, v. 84, p. 6803-6830.
Perrodon, A., 1971, Essai de classification des bassins sedementaires: Nancy, France, Sciences de la Terre, v. 16, p. 195-227.
Rabinowitz, P. D., and J. L. LaBreque, 1979, The Mesozoic South Atlantic Ocean and evolution of its continental margins: Journal of Geophysical Research, v. 84, p. 5973-6002.
Roeder, D. H., 1973, Subduction and orogeny: Journal of Geophysical Research, v. 78, p. 5005-5024.
Sawyer, D. S., B. A. Swift, and J. G. Sclater, 1982, Extensional model for the subsidence of the northern United States Atlantic continental margin: Geology, v. 10, p. 134-140.
Sclater, J. G., and P. A. F. Christie, 1980, Continental stretching—an explanation of the post-mid-Cretaceous subsidence of the central North Sea basin: Journal of Geophysical Research, v. 85, p. 3711-3739.
Seely, D. R., P. R. Vail, and G. G. Walton, 1974, Trench slope model, *in* C. A. Burk and C. L. Drake, eds., The geology of continental margins: New York, Springer-Verlag, p. 249-260.
Sengor, A. M. C., K. Burke, and J. F. Dewey, 1978, Rifts at high angles to orogenic belts: tests for their origin and the Upper Rhine graben as an example: American Journal of Science, v. 278, p. 24-40.
Shatskii, N., 1946a, Basic features of the structures and development of the east European platform: Akademiya Nauk SSSR Izvestiya, Seriya Geologicheskaya, n. 1, p. 5-62.
——— 1946b, The Great Donets basin and the Wichita system: comparative tectonics of ancient platforms: Akademiya Nauk SSSR Izvestiya, Seriya Geologicheskaya, n. 6, p. 57-90.
——— 1947, Structural correlations of platforms and geosynclinal folded regions: Akademiya Nauk SSSR Izvestiya, Seriya Geologicheskaya, n. 5, p. 37-56.
——— 1955, On the origin of the Pachelma Trough: Byulletin Moskovskogo Obshchestva Ispytapel'noi Prirody, Seriya Geologicheskaya, v. 5, p. 5-26.
——— and A. A. Bogdanoff, 1960, La carte tectonique internationale de l'Europe au 2,500,000°: Akademiya Nauk SSSR Izvestiya, Seriya Geologicheskaya, n. 4.
St. John, B., 1980, Sedimentary basins of the world and giant hydrocarbon accumulations: AAPG Special Publication, 23 p., 1 map.
Trümpy, R., 1960, Paleotectonic evolution of the central and western Alps: GSA Bulletin, v. 71, p. 843-908.
——— 1975, Penninic-Austroalpine boundary in the Swiss Alps—a presumed former continental margin and its problems: American Journal of Science, v. 275-A, p. 209-238.
Umbgrove, J. H. F., 1947, The pulse of the earth: The Hague, Martinus Nijhoff, 358 p.
Uspenskaya, N. Yu., 1967, Principles of oil and gas territories, subdivisions, and the classification of oil and gas accumulations: Amsterdam, Elsevier Publishing Co., 7th World Petroleum Congress, Proceedings, v. 2, p. 961-969.
Weber, M., 1921, Zum Problem der Grabenbildung: Deutsche Geologische Gesellshaft Zeitschrift, v. 73, p. 238-291.
——— 1923, Bermerkungen zur Brunchtektonik: Deutsche Geologische Gesellshaft Zeitschrift, v. 75, p. 184-192.
——— 1927, Faltengebirge und Vorlandbruche: Centralblatt Mineralogie, Geologie, Palaontologie, Abt. 5, p. 235-245.
Weeks, L. G., 1952, Factors of sedimentary basin development that control oil occurrence: AAPG Bulletin, v. 36, p. 2071-2124.
White, D. A., 1980, Assessing oil and gas plays in facies-cycle wedges: AAPG Bulletin, v. 64, p. 1158-1178.
Whiteman, A. J., G. Rees, D. Naylor, and R. M. Pegrum, 1975, North Sea troughs and plate tectonics: Norges Geologishe Undersøkelse, n. 316, p. 137-161.
Wilson, J. T., 1966a, Some rules for continental drift, *in* G. D. Gardland, ed., Continental drift: Royal Society of Canada Special Publication 9, p. 3-17.
——— 1966b, Did the Atlantic close and then re-open?: Nature, v. 211, n. 5050, p. 676-681.
Wilson, R. C. L., 1975, Atlantic opening and Mesozoic continental margin basins of Iberia: Earth and Planetary Science Letters, v. 25, p. 33-43.
Ziegler, P. A., 1975, North Sea basin history in the tectonic framework of north-western Europe, *in* A. W. Woodland, ed., Petroleum and the continental shelf of north-west Europe: New York, John Wiley and Sons, p. 131-149.
Ziegler, W., 1975, Outline of the geological history of the North Sea, *in* A. W. Woodland, ed., Petroleum and the continental shelf of north-west Europe: New York, John Wiley and Sons, p. 165-190.