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THE MAIN STAGES OF GEOLOGICAL DEVELOPMENT OF THE MESOPOTAMIAN FOREDEEP

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Abstract

The main tectonic elements within the territory of Iraq from northeast to southwest are: (1) the Alpine geosynclinal area of Zagros, characterized by mountainous relief; (2) the Mesopotamian Foredeep covering an intermediate structural position; and (3) the northeastern part of the African-Arabian pre-Cambrian platform characterised by almost horizontal dipping of strata and smooth relief.

Definition of the boundaries between various megastructures within these tectonic elements, although depends on similar principles, nevertheless, still remains to be questionable.

The main stages of the geological development within the territory are the platforms, the geosynclinal and the orogenic stages. Each of these stages corresponds to certain structural stages of specific characteristics. Pre-Paleozoic, Paleozoic, Upper Permian-Lower Eocene and Middle Eocene-Quaternary structural stages are identified.

The isolation of the geosyncline as a separate tectonic element has been indicated to start from Permian epoch. The first orogenic movements took place during Upper Cretaceous. The major uplifting of the geosyncline which culminated in the formation of the Zagros Mountain Ranges took place during Pliocene-Pleistocene times.

The structural development of the Mesopotamian Foredeep as a separate tectonic element should be assigned to Middle Eocene as the red-coloured sediments of the Gercus Red Beds belonging to this time unit are considered and distinguished to be the first orogenic milasse.

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Introduction

This article discusses the main stages of geological development of the Mesopotamian Foredeep. A brief account of the main tectonic structures within the territory of Iraq is also given. The various geological and geophysical data on which this work is based mainly consist of : a) regional reconnaissance geological surveys carried out by oil companies with semi-detailed and detailed mapping of few areas of interest; b) semi-detailed mapping of part of the Thrust zone and adjacent areas of a scale 1 :100,000 carried out by Site Investigation Company and more detailed mapping that has been carried out by relatively newly established national Iraqi administrations; c) regional subsurface control provided by exploration and appraisal wells which were drilled by oil companies in the area; d) regional reconnaissance seismic surveys, with semi-detailed operations over few localised areas of interest, carried out by subcontractors to the oil companies and by Iraq National Oil Company over an area of some 150,000 sq.kms; e) regional reconnaissance gravity and magnetic surveys carried out by subcontractors to the oil companies. The gravity surveys covered an area of some 320.000 sq.kms whereas the magnetic surveys covered some 272,500 sq.kms of Iraq territory.

Progressive interpretations of the available data led to the outlining of the general account presented. The present article represents an early stage in the development of a more complete understanding of the geological development history of the territory when the construction of paliotectonic and paleogeographic maps are carried out in detail.

Many excellent papers have been published dealing with various aspects of geological problems of the Middle East. Iraq has been treated well in the geological literature by Iraqi, European and American geologists but only few selected references are reported at the end of this paper.

Main Tectonic Elements

Many geologists, mainly from oil companies, have devoted part of their works to the determination of the peculiarities of the Mesopotamian Foredeep structure, the adjacent regions of the platform and the orogeosynclinal zone. Most of the investigators have tried to define the limits between different mega-structures with different degrees of detail. Although establishing such boundaries is based on the same principles, nevertheless it still remains to be questionable. This is attributed to the fact that a transition zone exist between the platform and the folded zone within which, the Mesopotamian Foredeep lies at the present day structural pattern. F.R.S. Henson, 1951, defined the limit between the pre-Cambrian platform and the Alpine folded area as to coincide with the axis of the Mesopotamian Foredeep. However, to be more precise one could state that this limit runs along the major faulting zone which separates the near-platform flank from the near-geosynclinal flank of the Mesopotamiaan Foredeep. In general this major faulting zone in some places is a graben type structure, and does not coincide with the foredeep axis as defined by F.R.S. Henson.

A brief view of the main conclusions drawn by some well known authors are shown below. The theoretical propositions of most of them depend on E. Zuess' ideas about concentric location of structural zones around the Arabian-Nubian shield.

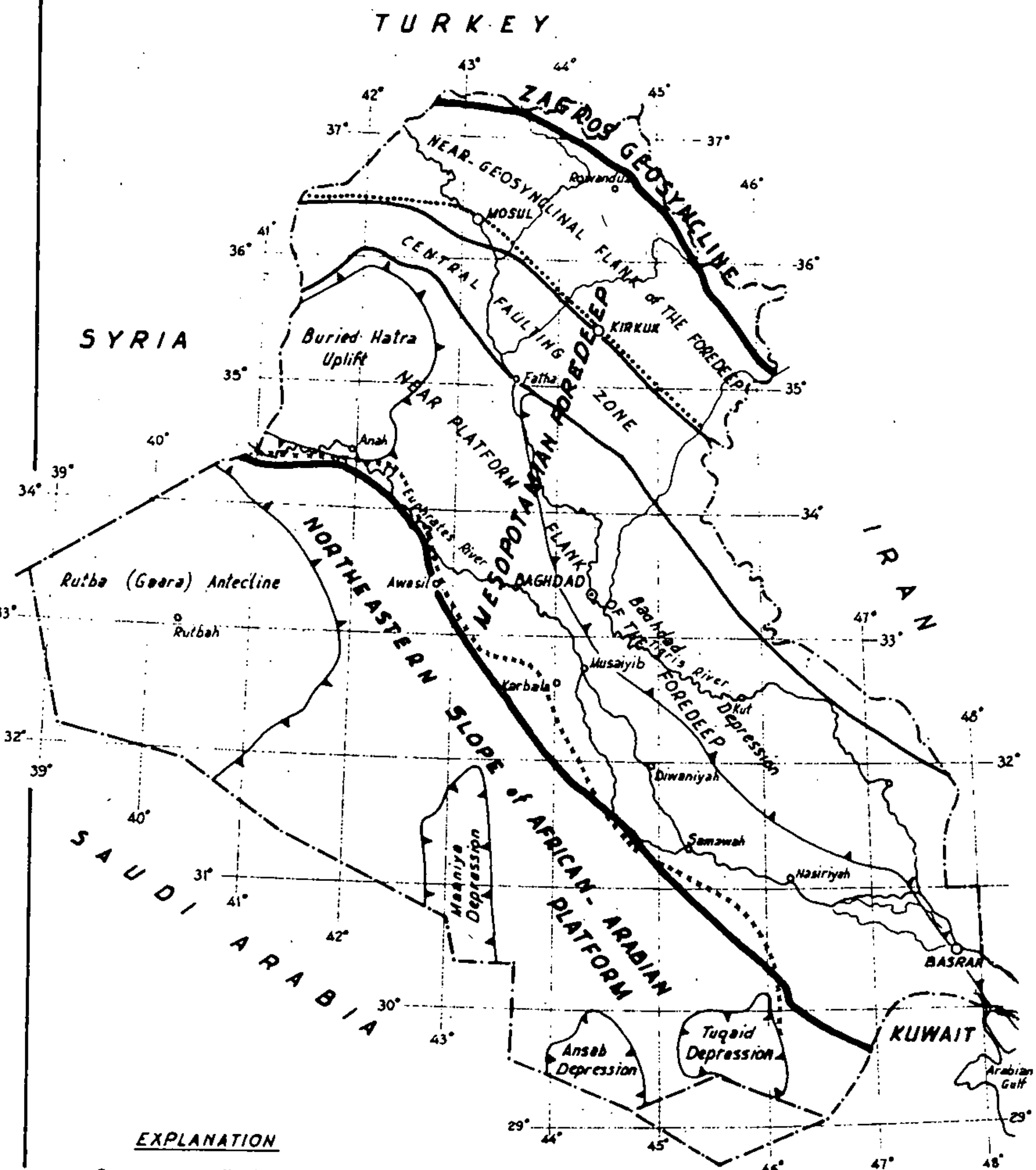
In this analysis of the tectonics of the whole of Middle East F.R.S. Henson considered the Arabian Nubian Massif of pre-Cambrian igneous and metamorphic rocks to be surrounded by subsequently changing zones: a) stable and unstable shelves; b) foredeeps filled with Eocene and Upper Cretaceous Flysch; c) foredeeps filled with Neogene molasse, d) a belt of autochthonous folds; e) thrust zone. He stressed the important role played by pre-Miocene vertical movements in the unfolded area and in the folded zone. Henson considered that folding due to late Tertiary compression was superimposed on and molded against an earlier deep-seated block-faulted framework, inherited from the pre-Miocene history of the region.

C.M. Lees (1952) described the general outlines of the peculiarities of folding in the foothills and concluded that the folding had resulted from crustal contraction and is not related to tangential stresses. He believes that the top part of sedimentary rocks should be considered an inert surface strata, which adjusts itself to the basement movements. He assigned anticlinal structures of Zagros foothills to a zone of simple anticlinal folding which is characterized by folds of extremely large dimensions.

R.C. Mitchell (1955, 1959) showed that a general concentric arrangement of the structural zones around the Arabian-Nubian shield is reflected in a gradual facies change. Structurally, he identified the following zones: a) stable shelf; b) mobile shelf of foothills; c) autochthonous marginal folds; d) Iranids of orthogeosyncline of southwestern Asia. According to him, folding within the shelves is mainly caused by vertical differential movements, though the role of tangential stresses should not be ignored.

J. Stocklin (1965) studied the geology of the Middle East for a long period of time. He defined the following structural zones: a) Shatt Al-Arab plain which is a part of the Mesopotamian plain and structurally is a part of the platform; b) Zagros folded belt with old cores composed of Paleozoic and Triassic rocks considered to be an integral and marginal mobile part of the platform; c) Zagros thrust zone, bounded by the main thrust line on the northeast. He considered this line to be a surface expression of the Northeastern limit of the pre-Cambrian African-Arabian platform.

H.V. Dunnigton (1958) and R.M. Al-Naqib (1960) divided the territory of Iraq tectonically into three major parts each of which is characterised by its own specific development history reflected in the present day structural pattern. From northeast to southwest these are: a) thrust belt; b) autochthonous folded belt; c) unfolded area. The boundary between the



EXPLANATION

.... Southwestern Limit of the Distribution of Flysch

xxxxx Southwestern Limit of the Distribution of Middle Miocene Molasse.

Figur. 1 _ MAP SHOWING The MAIN TECTONIC ELEMENTS OF IRAQ.

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1973

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thrust and the folded zones passes along the main Zagros thrust and that between the folded and unfolded zones passes along the Hamrin anticline and Jabal Sinjar.

Most recently a team of both Soviet and Iraqi geologists, among whom the author of this paper participated very actively, outlined the main tectonic elements (figure-1) within the territory of Iraq. From northeast to southwest the following tectonic elements were defined: 1) the southwestern part of the Alpine geosynclinal area of Zagros, characterized by mountainous relief; 2) the Mesopotamian Foredeep covering an intermediate structural position between the Alpine geosynclinal area of Zagros and the pre-Cambrian African-Arabian platform; 3) the northeastern part of the African-Arabian pre-Cambrian platform characterized by almost horizontal dipping of strata and smooth relief.

Alpine Geosynclinal Area of Zagros

The folded geosynclinal area of Zagros lies mainly on the adjacent territory of Iran and Turkey covering the marginal northeastern areas of Iraq. Taking into consideration the degree of folding and faulting of strata and metamorphism of rocks, their composition and thicknesses as well as eruptive manifestation, tectonically the geosynclinal area of Zagros falls into two zones: a)interior or eugeosynclinal (physiographically assigned to the Thrust Mountain province); b) exterior or miogeosynclinal (physiographically is defined as part of Mountain Fold province). The boundary between these two zones passes along the main Zagros thrust where the rocks of the eugeosynclinal zone are thrust over those of the miogeosynclinal one.

a- Eugeosynclinal or interior zone of Zagros

This zone attains a width of up to 50 kms inside the territory of Iraq and extends further into both Iran and Turkey. As a whole this zone has a very complicated thrust structure. Exposed cretaceous radiolarian series, Eocene metamorphic series of Qandil and Eocene-Oligocene shale series of Naupurdan are pierced by intrusions of basic and acid igneous rocks (basalts, spilites, andesites, dolerites and granites) are thrusted southwestwards over non-metamorphic Upper Miocene rocks. Within the interior parts of this zone, mainly outside Iraq much older formations are outcropped including Infra-Cambrian salt bearing Hermuz series of Iran. The presence of radiolarian series and ophiolite intrusions in the thrust zone serve as basic evidences of its attribution to eugeosynclinal zones.

b- Miogeosynclinal or exterior zone of Zagros

This zone immediately adjoins the main Thrust zone and covers a considerable part of the territory named "folded zone of Zagros". On the southwest its limit is defined along the line which delineate the distribution area of flysch deposits to Upper Cretaceous (Tangero formation) and of Paleocene-Lower Eocene (Kolosh formation). This line is seen to run along a system of major faults. This zone is a typical miogeosyncline according to the thicknesses and composition of its deposits, type of folding and absence of volcanic activities.

As far as the tectonic nature of the miogeosynclinal zone is concerned, the idea that this zone in paleotectonics of pre-Mesozoic times was an integral part of the pre-Cambrian African-Arabian platform is widely accepted by many authors. Hence this zone is developed on a deeply subsided marginal part of the platform. The Upper Cretaceous and Paleocene-Lower Eocene flysch deposits are overlain by thick deposits of orogenic molasse formation complexes. This signifies qualitatively a different stage of geological development, namely, the stage of initiation of the Mesopotamian Foredeep. Accordingly, this zone corresponds to the interior or near-geosynclinal flank of the Mesopotamian Foredeep in the present day structural pattern. As for the paleotectonics of Mesozoic-Lower Paleogene times, this folded belt is assigned to the exterior or miogeosynclinal zone of the Zagros geosyncline.

Mesopotamian Foredeep

Tectonically, the Mesopotamian Foredeep is in general a marginal synclinal structure, being formed on the marginal submerged part of the pre-Cambrian platform. Deposits of the foredeep start with the orogenic molass rocks, dated from Middle Eocene (Gercus Red Beds) and end with Recent deposits of alluvium. The maximum depth of subsidence of pre-Cambrian basement reaches some 16 kms and probably even more. This foredeep is one of the largest in the world; it runs southeastwards from southeast Turkey across Syria, Iraq, Iran, Kuwait, Saudi Arabia and the Arab principalities of Arabian Gulf. Within Iraw it is about 900 kms long and 270 kms wide.

The northeastern boundary between the foredeep and the Alpine folded mountain system of Zagros may be formally drawn along the outcrops of Upper Cretaceous and Lower Paleogene flysch deposits. However it should be noted that within areas of exposed Mesozoic deposits and in the immediate proximity of the Main Zagros Thrust, grey coloured coarse molasse deposits of Upper and Lower Bakhtiari formation are present especially in synclines. These deposits overlie the red-coloured molasse deposits of Upper Fars formation. Accordingly, the northeastern boundary of the Mesopotamian Foredeep is drawn immediately along the Main Thrust which completely delimits the area of orogenic complex of deposits on the northeast. Consequently on the tectonic map (figure-1) the miogeosynclinal (exterior) zone of Zagros geosyncline, corresponds to the near-geosynclinal or interior flank of the Mesopotamian Foredeep. Its southwestern boundary which separates it from the northeastern slope of the pre-Cambrian African-Arabian platform is defined to run along a system of major faults; Anah graben, Euphrates-Ramadi fault and Abu Jir zone of step faulting. Definition of this boundary is based on the absence of Middle Miocene molasse deposits of Lower Fars formation beyond the mentioned system of faults towards Rutba Anteclise. Within the Mesopotamian Foredeep as well as other foredeeps the near-geosynclinal or interior and the near-platform or exterior flanks are clearly defined, being separated by a Central Faulting zone.

Two major uplifts are identified within the foredeep, namely, the Mosul block uplift within the near-geosynclinal flank and the buried pre-Tertiary Hatra uplift within the near-platform flank. The Mosul uplift and to a considerable less degree the buried Hatra uplift divide the foredeep into two structurally separated troughs: the Mesopotamian trough proper in which the depth to the pre-Cambrian basement is calculated to reach some 16 kms. and the North Mesopotamian trough on the northwest in which the depth to the basement is calculated to reach some 7 kms within Iraq.

Mesopotamian Foredeep structures are characterized by the fact that they were developing simultaneously with the building of mountain folded Zagros. The Mosul block uplift was not paleogeographically a constant and continuous barrier that was dividing the northern and southern basins of Tertiary sedimentation. Structural linear zones, genetically connected with main Zagros folding that took place during Pliocene-Pleistocene times, are traced in both parts of the foredeep as well as within the Mosul uplift.

According to the pecularities of folding, tectonic intensity and morphology all the folds of the interior flank are grouped into two specific structural zones. In both zones the anticlinal folds are characterized by crest displacement in deeper horizons as compared with the crest in upper horizons. Both zones trend in the same direction as that of the Main Zagros thrust zone. The one directly to the southwest of the thrust zone is characterized by the development of box-type folds of asymmetric and often overturned nature with flat crests. In their cores Jurassic or Lower Cretaceous sediments, or even Triassic, are exposed. Usually their southwestern flanks are complicated by faults and sometimes the northeastern flanks are also of the same character. The other structural zone differs from the previous one by outcropping of younger deposits in the core of the anticlines and structurally by the fact that the folds included in this zone are narrower and rather long folds of an echelon type. Their crests and southwestern flanks are usually complicated by faults.

The northeastern limit of the central faulting zone runs along major faults to the northeast of which the geosynclinal flysch sediments are absent. Its southwestern boundary with the near-platform flank of the foredeep is drawn along major faults trending in a northwest direction along large linear anticlinal structures of South and North Hamrin, Makhul and Sadid. The width of this zone reaches 85 kms. The central faulting zone has a number of features which characterize both the near-platform and the near-geosynclinal flanks of the foredeep. This zone cannot be considered as a part of the near-geosynclinal flank of the foredeep due to the absence of geosynclinal flysch deposits. In general this zone is relatively sharply subsided and in some places has a well pronounced graben shaped structure. However within its limits especially along the southwestern boundary, the up-thrusting and thrusting of rocks, most clearly identified as long and narrow horst type anticlines are observed. The main peculiarity of structures within this zone lies in the fact that most of them have been produced due to differential movements of basement blocks.

In the present day structural respect, the near platform flank of the foredeep is generally characterized by a monocline which gently dips towards the axis of deeper parts in the northeast. This monocline is complicated by stepped-like faults starting from the basement and affecting the whole of Paleozoic and Mesozoic deposits. Some of these faults are associated with long lineally located buried zones of anticlinal structures. On the northwestern part of the buried Hatra uplift is shown on the tectonic map. This uplift has a complicated block structure; it is split by systems of intersecting faults trending northeast and northwest with which a number of northeast trending grabens are associated, namely, Anah, Tayarat and Khleisia grabens. Southwestwards from this uplift in Baghdad area, a large synclinal structure is defined by seismic reflectors within Middle Miocene sediments and called Baghdad depression.

Northeastern Slope of Pre-Cambrian African-Arabian Platform

The pre-Cambrian African-Arabian platform lies mainly outside the territory of Iraq. Only the marginal northeastern part of this platform covers a small area of Iraq adjacent to Jordan and Syria. It is characterized by almost horizontal bedding and smooth relief. Only occasionally long cuestas and low gently sloping hills, reflecting anticlinal folds, flexture type bends and other structural complications, are observed here. A large uplift (Rutba or Ga'ara anteclise) is recognizable within this part of the platform. Physiographically, it is assigned to Desert Plain province.

Regionally within the northeastern slope of the platform Rutba anteclise and three interplatform depressions, namely, Tuqaid, Ansab and Ma'aniya depressions are differentiated. The Rutba anteclise is well defined through outcrops of Middle and Upper Triassic, Jurassic and Cretaceous deposits. On the surface the slopes of this uplift are made up of Paleogene and Neogene deposits. On the slopes of Rutba anteclise which are gradational into the platform slope, the Mesozoic-Cenozoic deposits make up a number of gentle isometric and ellipsoid-like anticlinal and synclinal folds. The depth of the crystalline basement within the anteclise ranges from 1-4 kms. The interplatform depressions were differentiated according to geophysical (mainly gravity) data. The depth of the basement within these depressions ranges from 8.0 - 8.5 kms.

Geophysical Guidance

The interpretations of the available geophysical data have contributed a great deal to the understanding of the regional tectonics of the territory. The geophysical investigations within the foredeeps are very important. The great thickness of the sedimentary cover does not permit a thorough study of either the basement or the lower parts of the sedimentary section by traditional geological methods.

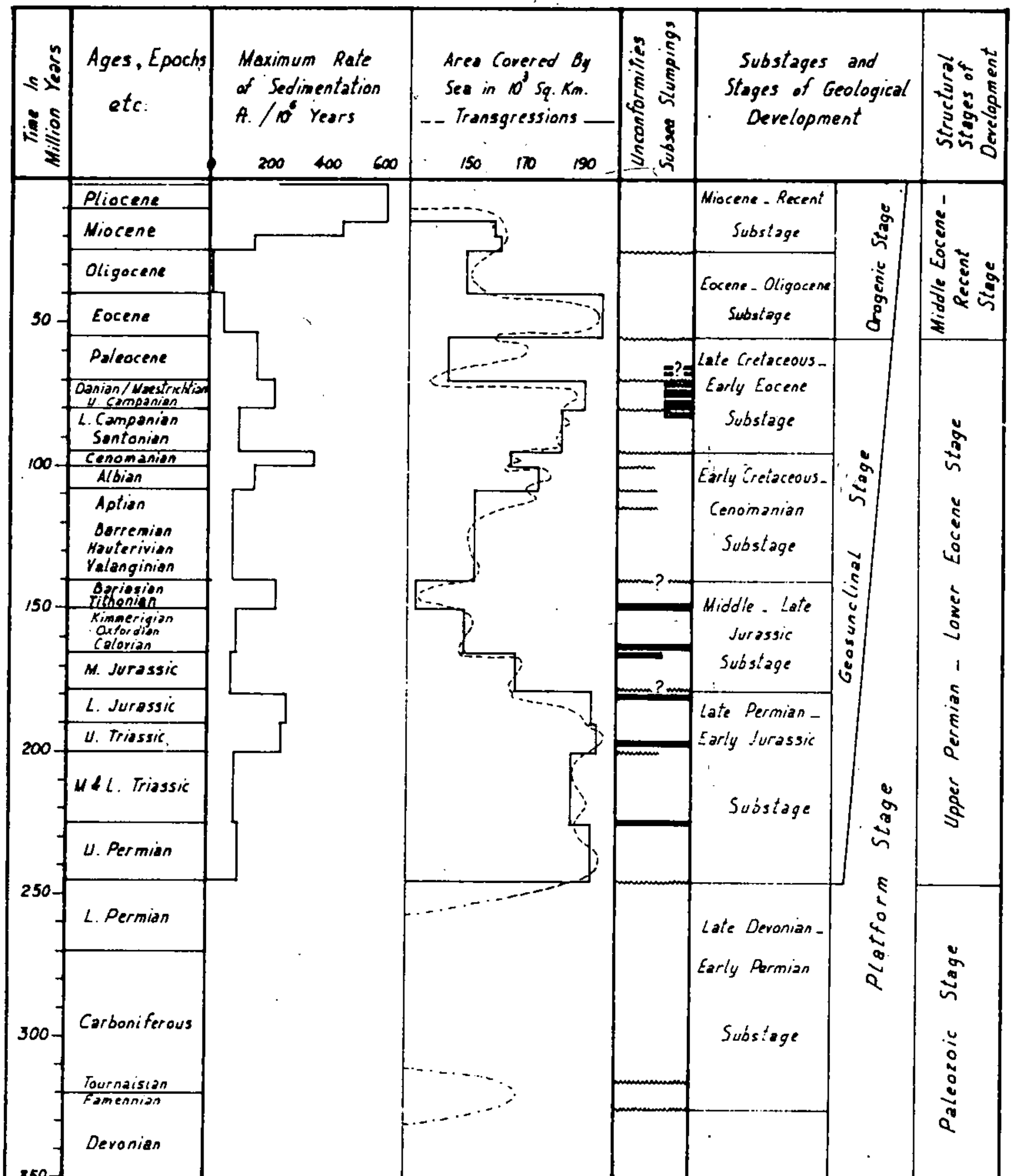

Figure 2. **CHARACTERISTICS of GEOLOGICAL DEVELOPMENT of The MESOPOTAMIAN FOREDEEP**

- 1973 -

IRAQ NATIONAL OIL COMPANY - Baghdad -

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Many dislocations have been identified from seismic data. According to the character of gravity and magnetic fields the territory could be divided into four parts which correspond respectively (from northeast to southwest) to near-geosynclinal flank, central faulting zone and near-platform flanks of the foredeep and to the slope of Afro-Arabian platform. Zagros geosyncline is not covered by surveys. Each tectonic element is characterised by its own picture of gravity and magnetic field distribution. The boundaries between the elements coincide usually with strips of high gravity gradients indicating in their turn the existence of buried faults.

Regional Development Stages

The main stages of the geological development of Iraq are the platform, the geosynclinal and the orogenic stages. Each of these stages is characterized by its own structural peculiarities of sedimentary basins and source areas and corresponds to certain structural stages of specific characteristic folding and faulting, metamorphism of rocks, combination of formation complexes and their mode of occurrence (figure-2).

During its development the Zagros geosyncline covered the subsiding northeastern margin of the pre-Cambrian African-Arabian platform and caused its considerable reworking. According to J. Stocklin, the first indications of Zagros initial stages of geosynclinal development were evident even during infra-Cambrian time. Subsequently the isolation of the geosyncline as a separate tectonic element and later on the more active development have been indicated starting from Permian till Jurassic inclusive. Typical geosynclinal development with the isolation of the eugeosynclinal and miogeosynclinal zones began at the end of Jurassic; at the beginning of the intrusion of ophiolite in the interior zone. The first orogenic movements took place during Upper Cretaceous. The major uplifting of the geosyncline which culminated in the formation of the Zagros Mountain Ranges took place during Pliocene-Pleistocene times. This cycle was closed by a period of regional uplift which is probably still in progress. According to the analysis of formation complexes, the structural development of the Mesopotamian Foredeep as a separate tectonic element should be assigned to Middle Eocene. This conclusion is based on: a) the presence of flysch deposits in the exterior southwestern zone of Zagros which were accumulating during Upper Cretaceous, Paleocene and Lower Eocene times; b) Middle Eocene red-coloured molasse of the Gercus Red Beds lies directly on the flysch. These red-coloured sediments are considered and distinguished as Lower Molasse signifying the beginning of the development of the Mesopotamian Foredeep. This foredeep gradually migrated to the southwest on the neighbouring marginal part of the African-Arabian pre-Cambrian platform.

Previously, in the scientific publications, the time of the initial stage of Mesopotamian Foredeep development was not clearly described. Late Cretaceous and Early Tertiary movements are usually mentioned which were responsible for the formation and accumulation of flysch. In addition, Late Tertiary (Pliocene-Pleistocene) movements are mentioned which have produced the present day Zagros Mountains. Lower and Upper Fars formations were identified as the Lower Molasse whereas the Upper Molasse was taken to be represented by lower and Upper Bakhtiari and hence concluding that the Mesopotamian Foredeep started to be formed not earlier than Middle Miocene time. This is considered not to be accurate as Middle Eocene is considered to be the time of the beginning of the development of the foredeep.

Pre-Paleozoic, Paleozoic, Upper Permian - Lower Eocene and Middle Eocene-Quaternary structural stages are identified and described below. These stages were separated by large regional unconformities and breaks in sedimentation. These are further divided into substages according to some specific characteristics such as presence of unconformities, transgressive and regressive rhythms etc.

Pre-Palezoic Development Stage

Very little is known about the geologic history of Iraq during pre-Paleozoic times as no pre-Paleozoic rocks are known to outcrop within this territory. The Lower Ordovician Khabour Quartzite-Shale is the oldest formation outcropping on the surface and the deepest reached by any well. However, the 2000 metres thick infra-Cambrian series of the neighbouring Iran which are mostly represented by micaceous shales, sandstones, cherty dolomites and stromatolitic limestone are found. The behaviour of these rocks and their distribution over a large area have led J. Stocklin (1955) to conclude that the pre-Paleozoic series over the whole territory of Iraq lie on a platform type basement which is, probably, the extension of the African-Arabian platform.

V.P. Ponikarov (1969) suggested that during the pre-Cambrian time a complex geosynclinal basin existed on the territory of Iraq and that the development of this basin was terminated by the beginning of the Cambrian period.

Paleozoic Development Stage

Two major regional unconformities are recognised within this development stage of the platform over the territory giving rise to the Cambrian-Middle Devonian and Late Devonian - Early Permain substages.

During the Cambrian period, conditions of sedimentation were similar to those of southern parts of Turkey and southwestern parts of Iran. A thick Cambrian series of red-coloured sandstones with intercalations of limestone, dolomite and argillaceous shales with beds of rock salt (Harmuz series) at the base crop out in the neighbouring territory of Iran.

Near shore environments existed in the considered territory during Early Ordovician epoch which caused the deposition of great thickness of more than one thousand metres of mainly terrigenous sediments evidencing the probable preservation of the tectonic regime of the Cambrian sedimentation.

Late Ordovician was closed by the deposition of red-coloured sediments of Prispiki formation and volcanic activity. The absence of Pirispiki formation in Khleisia-1 well may indicate the uplifting of Hatra area during Late-Ordovician epoch.

During Silurian and most of Devonian epochs land conditions existed over the territory. The deposition of sediments during Late Devonian marked the beginning of epicontinental transgression of sea over the territory and hence marking the onset of Late Devonian-Early Permain substage of development. During Early Carboniferous a greater part of the territory under consideration was covered by shallow sea. This was followed by regression during Visean age and the onset of a continental environment which continued till Late Permian Epoch.

Thus two major breaks in sedimentation are recognised:- a) the Silurian - Late Devonian; b) the Middle Carboniferous - Early Permian. The Orodivician, Famennian - Tournaisian and Late Permian sediments overlie each other transgressively without noticeable angular unconformities. This provides evidence of the comparative quietness of the tectonic activity in the area during this stage.

Late-Permian-Early Eocene Development Stage

During this stage epicontinental seas covered most parts of the territory depositing nearly continuous shallow marine and lagoonal type of sediments. These conditions of sedimentation were interrupted by minor sequences of transgression and regressions. According to the nature of the distribution of sediments and the relationship between the stratigraphic units overlying each other, the following geological development substages are recognised: a) Late Permian - Early Jurassic; b) Middle-Late Jurassic; c) Early Cretaceous-Cenomanian; d) Late Cretaceous - Early Eocene substages. These are separated by regional breaks in sedimentation and are characterized by specific tectonic activities.

The Late Permian-Early Jurassic development substage began with a wide transgression over almost the whole territory. It is more likely that the Zagros geosyncline started to form during this substage and was separated from the comparatively uplifted parts of Iran by deep-seated faults of northwest-southeast trend.

The Late Permian sea deposited shallow water Chia Zairi formation of detrital organic limestones with abundant various fauna (possibly reef facies). Normal sedimentation was interrupted for short durations by the deposition of dolomites and anhydrites (Satina evaporites) which were associated with either lagoonal conditions or reef development. The maximum rates of sedimentation ranged from 35 to 40 metres per million years. The presence of sand and chert concretions in the upper part of the formation may bear evidence of the manifestation of tectonic movements at the end of the epoch and of a partial sea regression. However, epeirogenic movements of this epoch are neither recognised in Iraq nor in the neighbouring territories of Iran, Turkey or Syria. Three linear depressions trending northwest-southeast were probably formed. The northern depression is characterized by prevalence of calcareous rocks whereas the central one according to the location and its section in Syria might have been filled with mixed calcareous and terrigenous rocks. This depression coincides with the present Baghdad depression and the Central Faulting zone. The southern depression is probably located within the main zone of terrigenous facies.

It is quite possible that the Late Permian basin of sedimentation generally differed very little from the Triassic sedimentary basin. However, the character of sedimentation was considerably changed in the Early Triassic epoch as gypsum, anhydrite and dolomites began to play a greater role. The Mirga Mir formation is characterized by the presence of Subsea slumping whereas volcanic activities took place during the deposition of shales and marls of Beduh formation. The nature of the Middle Triassic sediments of chemical lagoonal limestones with sandstone intercalations of Geli Hana formation provides evidence of the general shallowing of the sea. A pre-Late Triassic unconformity is strongly suggested from the hematization and silicification of the upper part of the formation. The sediments of neither Permian nor Lower Triassic epochs are found in Khleisial-1 well on the Hatra uplift.

The Late Triassic sedimentary basin differed from the Early Triassic basin by having more tectonic activity and, probably, by a transgressive nature of its development. The tectonic activity is evident from the great amount of terrigenous supply and from the increased rates of sedimentation which reached some 75 metres per million years. The appearance of beds with subsea slumping and slumping breccia in the Kurra Chine formation is another porrf of the tectonic activity.

The Rhaetic-Liassic sediments of the neighbouring Iran are characterized by continental environments of deposition and attain thicknesses from few hundred to several thousand meters. In few places large pre-Rhaetic angular unconformity is evident.

The sedimentary basin of the Early Jurassic covered the same area as that of the Late Triassic basin. Salt and anhydrite accumulation took place in the Central depression from time to time. In the northern depression mainly chemical calcareous rocks were accumulated. The rocks of this depression are often slightly folded, cavernous, brecciated and silicified as in Sarki formation. Perhaps, these peculiarities are related to tectonic activity rather than to gypsum solution as it was previously suggested. However, neither gypsum nor anhydrite are recognised in the stratigraphic section. Silicification may be related to some volcanic activity.

The Middle-Late Jurassic development substage was characterized by general regression and decreasing of the sedimentary basin area. Sea transgressions were of short duration and the rates of sedimentation were comparatively very small and reached some 25-30 meters per million years.

The Middle Jurassic basin accumulated calcareous-argillaceous sediments and later on led to the formation of thin laminated bituminous limestones and shales. This basin probably reached its maximum size at the time of the formation of Muhaiwir deposits. Chert beds were formed at the end of the Middle Jurassic epoch. The Late Jurassic sediments of the northern areas overlie bituminous limestones of Sargelu formation and are characterized by subsea slumping and phacoids in the lower part indicating considerable movement along fault planes. The development of the Late Jurassic deposits ended in the formation of thick anhydrite deposits of Gotnia and Barsarin formations. The tectonic movements led to the formation of linear uplifts and depressions which were associated with faults. The revival of tectonic activity during the Late Jurassic epoch in the area is supported by the fact that such movements took place in the central and southern neighbouring territory of Iran where they were accompanied by intrusive activity, poor metamorphism, regional uplifting and erosion (J. Stocklin, 1965). The regional unconformity between the Upper Jurassic and Lower Cretaceous series is well defined in Iran, and might have also extended over the territory of Iraq. The land area to the west of the territory attained its maximum size by the beginning of the Early Cretaceous epoch during the deposition of the Karimia and Chia Gara formations. During this time the areas of Rutbah, Hatra and Mosul uplifts were generally low land and covered by shallow sea. The gradual replacement of shallow water deposits by deep water sediments was indicative of sea regression during Tithonian-Berriasian ages.

Thus the Middle-Late Jurassic substage of development ended in the manifestation of relatively intensive phase of oscillatory tectonic movements that led to the general uplifting and the appearance of land over the neighbouring Syrian and Saudi Arabian territories as well as over the western and northwestern parts of Iraq. This uplifted land was the source of the clastic materials for Zubair, Nahr Umr and other formations of the Early Cretaceous - Cenomanian development substage during which sharp tectonic movements took place. The strong outflows of effusive rocks in Syria and the unconformity between Aptian and the underlying deposits in Iran are strong evidences of the above indicated tectonic movements. The rate of sedimentation was increased from some 35 metres to 100 meters per million years during this substage.

In the south and southwestern parts of the Early Cretaceous-Cenomanian sedimentary basin terrigenous sediments were mainly accumulated whereas in the area of buried Hatra and linear Dohuk-Kirkuk uplifts organic detrital and clastic limestone sediments were deposited. Away from the active source areas north and northeastwards marly deposits were accumulated. During Albian age lagoonal conditions prevailed in the area between Hatra and Mosul uplifts. These conditions led to the accumulation of anhydrite and gypsum of Jawan formation. Thus the Early Cretaceous-Cenomanian development substage was characterized by subsequent slow oscillatory tectonic movements. These tectonic movements affected the regional distribution of thicknesses and lithofacies of the various sediments. As a whole the Aptian to Maestrichtian ages were characterized by a general transgression with short durations of regressions. The greatest regression of the sea took place at the end of the Cenomanian-Early Turonian ages.

The Late Cretaceous-Early Eocene substage marked the start of a considerable change in the development history of the territory and was associated with the beginning of strong tectonic movements, mainly along the faults, which led to the formation of large uplifts within the Zagros geosyncline itself. These uplifts acted as the main source for most of the flysch deposits of the exterior geosynclinal zone. This substage began with wide sea transgression over most of the territory and ended in the deposition of thick flysch sediments. It terminated the Late Permian-Early Eocene geosynclinal stage.

The Late Cretaceous epoch was characterized by changes in the paleogeographical environments associated with the rejuvenation of tectonic movements and subsidence of the territory below sea level. Clastic deposits of this epoch are found in both Hatra uplift and Rutba anteclise. These clastics are indicative of the proximity of land. Open sea sediments were accumulated over a smaller area of the central basin whereas the greater part of the area was covered by shallow sea sediments. The variety of facies during Turonian to Early Campanian ages serves as an evidence for the existence of complicated tectonic conditions in the sedimentary basin. A noticeable revival of tectonic movements took place along the northeastern trending faults such as the Anah graben.

During the Late Companian and Maestrichtian ages further expansion of the sedimentary basin took place and covered even the western and southwestern parts of the territory, namely, Hatra and Ga'ara areas. The most striking feature of these two ages is the beginning of deposition of flysch sediments. The axis of the flysch trough runs parallel to the Zagros thrust. Northwestwards flysch deposits pass into reef limestones of Aqra/Bekhme formations. Another feature was the slumping of huge masses of sediments over large areas extending from the Mediterranean and Turkey on the northwest (M. Rigo De Righi & A. Cortesini, 1964) to Iran and Abu Dhabi on the southeast (H.H. Wilson 1969). Movements along the northeastern trending faults led to the sharpest downthrow of Anah graben and other grabens of the Hatra uplift.

During the transgression which took place after Danian regression flysch sediments of Paleocene age were deposited in a trough covering areas of Dohuk, Erbil and Kirkuk. As compared with the Cretaceous flysch basin, the Paleocene flysch trough was shifted further to the southwest. In other parts of the territory argillaceous, marly and reef langoonal sediments were accumulated. Probably a considerable part of the Paleocene-Early Eocene sediments were eroded from the Hatra and Rutba areas at the end of the Late Cretaceous-Early Eocene substage of development.

Middle Eocene - Quarterly Development Stage

Continuous tectonic movements of different intensities within the Zagros geosynclinal area characterized this development stage. The gentle uplifting of the Zagros geosyncline in Early Middle Eocene time resulted in the formation of the Mesopotamian Foredeep as an independent tectonic element which was filled with the first orogenic molasse (Lower Molasse) of red-coloured mainly terrigenous deposits of the Gercus Red Beds during the Middle Eocene times. The first phase of the upward movements was of short duration and was accompanied by some volcanic activities. During the transgression of Middle Eocene - Middle Miocene times, and under conditions of comparatively weak pulsating tectonic movements with some volcanic activities, shallow water, reef and lagoonal, calcareous and evaporitic sediments were accumulated. The salts accumulated in a number of semi-closed and closed gulfs and lagoons. The axis of the foredeep paralleled and passed near the margin of Zagros which was a broadly uplifted and gently folded area at that time. Outside the foredeep towards the platform calcareous sediments were deposited in open marine environments. To the northwest, the Hatra uplift was gradually submerged below sea level during the Late Oligocene time. This was followed by the accumulation of calcareous and evaporitic sediments during Early Miocene time.

Middle and Late Miocene times were characterized by new uplifting and folding within the Zagros geosynclinal area. At the same time, the migration of the foredeep further southwestwards with its axis running in the Central Faulting zone which was the deepest parts of the Mesopotamian Foredeep. The movements along the subparallel to Zagros Mountains trending faults led to the development of narrow and rather long asymmetrical anticlinal folds. The migration of the foredeep continuously influenced the platform margins and mainly Hatra uplift. The advance of the foredeep westwards and the sharp increase in the degree of dynamic forces caused further separation of the crystalline basement into comparatively narrow and long blocks and accordingly forming box and horst types anticlinal structures trending northwest-southeast and associated with major faults. The Hatra uplift, the most stable part of the platform flank of the foredeep, caused the folding zones to deviate from their general northwest - southeast trend and to take a near latitudinal direction. During Middle and Late Miocene times lagoonal and continental environments replaced the previously existed marine conditions. The Mesopotamian Foredeep was mainly filled with red-coloured upper orogenic molasse of evaporitic and terrigenous sediments.

The sharpest tectonic movements, that led to the major uplifting of Zagros geosyncline and culminated in the formation of the Zagros Mountain Ranges, took place during Pliocene - Quaternary times. Thick series of grey-coloured molasse sediments of the Lower and Upper Bakhtiari formations were accumulated within the foredeep. Rates of sedimentation reached their maximum (180 metres per million years) during Late Miocene and Pliocene times.

During Pleistocene-Halocene time tectonic activities relaxed and the cycle of Zagros Mountain building was closed by a regional uplift which is probably still in progress. At the same time within the interior and central zones of the foredeep the present linear structural pattern attained their final forms and were complicated by different types of faults among which thrusts were responsible for disharmonic folding. All the movements were closely related to the tectonic intensity within the folded Zagros Mountains.

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