EVIDENCES FOR DISCOVERING SUBSURFACE STRUCTURES USING REMOTE SENSING DATA IN NINEVEH GOVERNORATE, NORTHWEST IRAQ

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ABSTRACT

Analysis of remotely sensed data and topographical maps with some field observations have helped in the identifications of fourteen morphostructural anomalies controlling the landscapes and the drainage networks in the strip border between Iraq and Syria, from Fiesh Khaboor to Wadi Al-Ajij. These data are representative of new local subsurface structures. Various geomorphic indications were used in the identifications of these anomalies like, radial drainage patterns, water divides, domelike structure, isolated homoclinal ridges, tonal variations and abrupt change in stream courses and fan surfaces.

Most anomalies detected are aligned Northwest – Southeast and East – West, suggesting the presence of morphostructural trends in this part of northwestern basin's of Iraq. A comparison between these anomalies and the available geological and geophysical data enables the definition of two distinct morphostructural domains in the study area.

These data were utilized to draw a regional morphotectonic map of the study area. The map can be used not only for assessing the adaptability of landforms and/ or the sensitivity of geomorphic conditions to the related neotectonic activity, but also for the studying of the relationship between morphotectonic zones and oil exploitation in this area.

دلائل الكشف عن بعض التراكيب تحت السطحية باستخدام معطيات التحسس النائي في محافظة نينوى شمال غرب العراق

حكمت صبحي الداغستاني و بسام محمد الديوة جي

المستخلص

إن تحليل معطيات التحسس النائي والخرائط الطبوغرافية مع بعض الملاحظات الحقلية ساعدت في اكتشاف أربعة عشر شاذة مورفوتركيبية، إذ سيطرت على مظاهر التضاريس الأرضية وشبكات التصريف السطحية في منطقة الشريط الحدودي بين العراق وسوريا، من فيش خابور إلى وادي العجيج، والتي أسهمت جميعها في تحديد هذه التراكيب تحت السطحية الموقعية الجديدة. استخدمت مجموعة من الدلائل الجيومورفولوجية لتمييز هذه الشواذ، مثل نظام التصريف ألشعاعي، خطوط تقسيم المياه، التراكيب القبابية، الحواجز التركيبية المتفرقة، التباين في شدة الدكانة، التغير المفاجئ في مجاري الوديان وسطوح المراوح الفيضية.

اتضح أيضاً من الدراسة الحالية بان معظم مواقع الشواذ هذه كانت مرتبة باتجاهين، الأول شمال غرب – جنوب شرق والثاني شرق – غرب، مما يدل على وجود محورين مورفوتركيبيين في الجزء الشمالي الغربي من الحوض الترسيبي الشمالي الغربي في العراق. أشارت المقارنة بين مناطق الشواذ هذه مع المعلومات الجيولوجية والجيوفيزيائية المتوفرة الى إمكانية تمييز هذين النطاقين الواضحين في منطقة الدراسة.

استخدمت هذه المعلومات في إعداد خريطة مورفوتكتونية إقليمية لمنطقة الدراسة. إن هذه الخريطة ساهمت ليس فقط في تحديد العلاقة بين أشكال سطح الأرض والعمليات الجيومورفولوجية نسبة الى النشاط التكتوني الحديث، بل إنها أعطت العلاقة المتبادلة بين الأنطقة المورفوتكتونية ومناطق الاستكشافات النفطية الواعدة في منطقة الدراسة.

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INTRODUCTION

One of the crucial elements in the geological orientation of exploration for petroleum, geothermal resources, and ore deposits is the use of maps of morphostructural anomalies that help in analyzing the tectonic evolution of crustal segments and its relationship to the origin, movement and accumulation of fluids. Analysis of Landsat imagery is useful for oil exploration, where the structures had influenced the morphological development of the area (Zwain, 1976; Goetz *et al*., 1983; Bocco *et al*., 2005 and Fernandes *et al*., 2005).

The study area, located in the northwestern part of Iraq (Fig.1), has attracted over the last few decades a number of researchers who investigated different aspects of the tectonic, stratigraphy, geophysics, hydrogeology and geomorphology (Perry, 1938; Nasr, 1960; Al-Rawi, 1973; Ma'ala, 1977; Tamr-Agha and Numan, 1979; Mustafa, 1980; Al-Azzawi, 1983; Zwain, 1984 and Al-Daghastani, 1989).

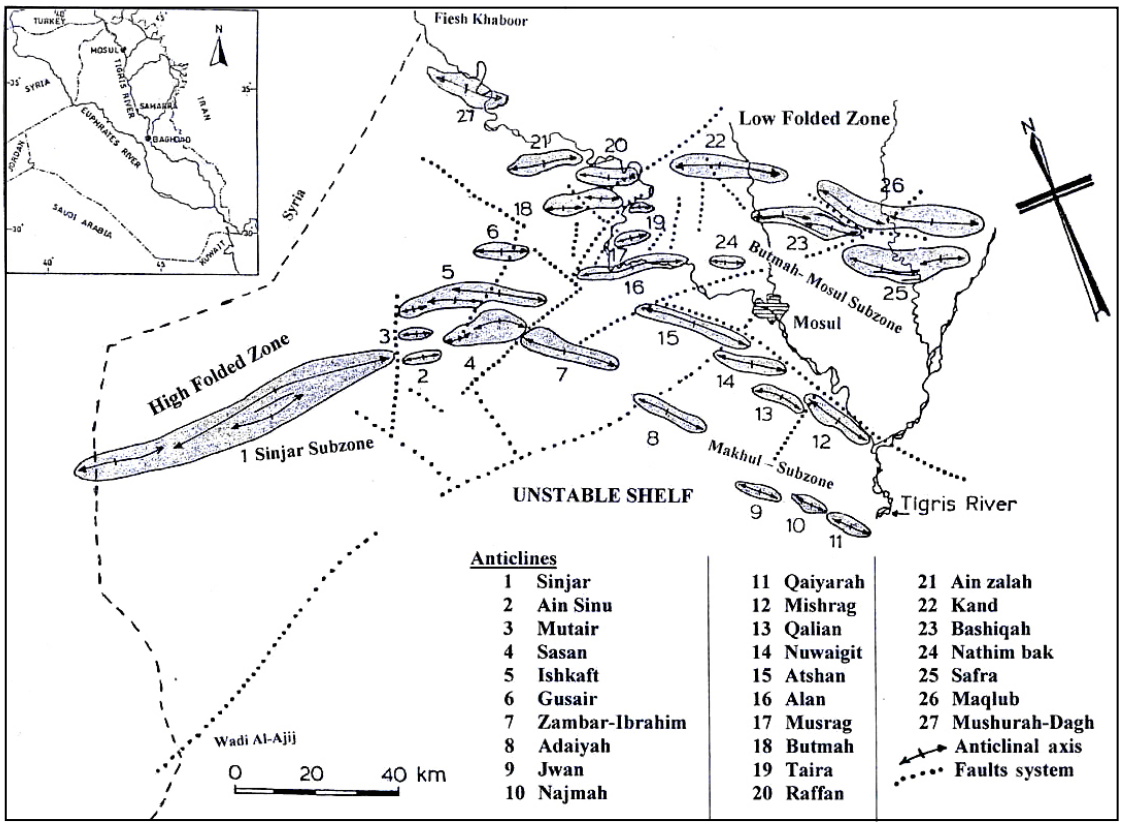

Fig.1: Morphostructural framework map of the study area
(modified after Al-Daghastani and Al-Daghastani, 1996)

The methodology used in this study follows the standard sequence of landforms, drainage and lineaments analysis and the integration of their results for geological and morphotectonic evolution. This approach was used successfully for many years with both satellite images and topographic maps, for the aforementioned tasks. These will be discussed in details in relating subsections of this study.

Complete coverage of the Nineveh Governorate by Landsat TM imagery has been analyzed for detecting unsuspected zones of tectonic origin, and for rationalizing the relationship between those deduced from topographic and field mapping. Morphostructural interpretation of remotely sensed images now plays an important role in exploration and terrain evaluation at the reconnaissance stage.

A morphostructural framework map has been compiled to show spatial morphotectonic zones distribution and distinctive morphotectonic anomalies in the strip border between Iraq and Syria, from Fiesh Khaboor to Wadi Al-Ajij (Fig.1). Morphotectonic zones help greatly to evaluate the relative effectiveness of fluvial and structural control, and in turn to analyze and interpret the main features response to the style of structural deformation.

This research represents an attempt to evaluate the ability of using remote sensing analysis for discovering subsurface structures and discriminate different morphotectonic zones of the study area.

METHODOLOGY

Over the years, scientists have developed some valuable approaches to interpret remotely sensed data, including the use of collateral information, convergence of evidence, and application of the multi concept of image analysis (Jensen, 2007). This investigation utilized both Landsat TM imagery and topographic maps. Determination of the morphostructural framework of the study area was carried out by first, using Landsat TM false color composite imagery, bands 1, 4, 7, digitally enhanced by GEOPIC (Earth Satellite Corporation, 1995), taken in 14 January 1992, Path 171, Row 34, at approximate scale of 1: 250 000. Image geocoded using spacecraft ephemeris.

Detailed analysis of this imagery was used to delineate and trace geomorphic units, fold axis, drainage anomaly, fan surfaces, dip slopes, lineaments and fault patterns in order to analyze and interpret the structural grain of the area under consideration. The visual interpretation of the Landsat TM imagery included observation and analysis of:

- Tonal and textural variations of different morphotectonic surfaces.
- Differential weathering, erosional and depositional features related to geomorphic process and bedrock lithology.
- Inferences from drainage patterns, indicating the probable types of parent materials and the morphotectonic evaluation.
- Landform associations and morphogenetic aspects and their relationships to adjacent features.

Secondly, a detailed descriptive analysis of drainage patterns was carried out using topographic maps at a scale of 1: 100 000 to prepare data base map of anomalies reaches. Each map was then corroborated and supplemented by field work.

Finally, mapping and representation of the present sheet is nearly similar to the scheme devised by the ITC textbook (Zuidam and Zuidam, 1979).

The optimum images selected for this study are those with the lowest angle of solar illumination, so that shadows most sharply express relief and geomorphic lineaments in the gently sloping planer surfaces surrounding anticlinal structures, this means that winter images are the most useful. However, most geomorphic features with NW – SE and E – W orientations contain minor irregularities, which do cast shadows and have associated tonal features related to differential erosion. Different morphotectonic zones including superficial deposits and morphostructural anomalies were discriminated according to their tone, shape and associated drainage patterns and textures. This image was also useful to show all previously mapped folds, faults and other geomorphic lineaments in many directions. Given these conditions, the basic principles of visual interpretation of images are all that is required of interpreter to implement them (Lillesand and Kiefer, 2000).

STRUCTURAL SETTING

The fundamental framework of the structure and stratigraphy of north Iraq is strongly influenced by the positioning of the country within the main tectonic units of the Middle East, the Arabian Plate and Eurasian Plate, since Miocene episode of continental collision (Sengor and Kidd, 1979; Daly, 1989; Numan, 2001 and Jassim and Buday in Jassim and Goff, 2006). The Zagros – Taurus Mountain Belt Area, related to post obduction shortening in the Neogene – Pleistocene, is one of the youngest and most active on earth.

The changes in the strike of the exposed Phanerozoic rocks in the northwest Iraq define several anticlinal structures such as Sinjar, Mushurah-Dagh, Ain Zalah, Raffan, Butmah, Gusair, Ishkaft and Sasan ...etc. (Fig.1). The oldest rocks that crop out in the core of Sinjar Anticline are of Late Cretaceous age (Shiranish Formation). The stratigraphic sequence exposed in the study area surrounding Sinjar and Mushurah-Dagh anticlinal structures is Miocene in age and represented by the Euphrates – Jerribe Formation (Early – Middle Miocene), Fat'ha Formation (Middle Miocene), Injana Formation (Late Miocene) and Quaternary sediments. Fat'ha Formation is fully exposed within the study area, whereas the others are partly exposed or denuded. Quaternary sediments are either related to the fluvial drainage system or the polygenetic synclinal filling (Buday and Jassim, 1987).

Structurally, the studied area is located within the northwestern margin of the Foothill Zone of the Unstable Shelf (Buday and Jassim, 1987). Al-Kadhimi *et al.,* 1996, in their tectonic subdivision of Iraq, considered the studied area in Butmah – Mosul Subzone (Foothill Zone) and Sinjar Subzone (High Folded Zone). The area is characterized by an en-echelon anticlinal system, which gives to a relief with a general orientation of NW – SE and E – W, respectively. Heights up to 1460 m (a.s.l.) are reached in Sinjar Anticline. Wider synclinal system occurs in this zone, which is strongly influenced by tectonic control. Average altitude is between (250 – 400) m (a.s.l.). Some major faults and lineaments trend parallel to the fold axes and other dissect diagonally across the axes, are also shown on this map. These faults are very significant in neotectonic movements activity throughout the study area.

According to Al-Jumaily and Domaci (1976); Mohi Ad-Din *et al*. (1977); Ma'ala (1977); Zwain (1984) and Buday and Jassim (1987), the study area is influenced by the block tectonics of the basement. Continuous faulting and vertical block movements have been occurring since the Paleozoic and continued intermittently up to Late Tertiary. The sediments that overlain the unequally disturbed basement blocks formed a sheet of heterogeneous sediments. They were folded primarily by the horizontal compressive stress and secondarily by vertically induced stress.

In the eastern side of the study area (Sasan, Ishkaft and Gusair anticlines), strike-slip fault, striking NE – SW and extending for 30 Km is observed from Landsat images and field data. It has brought about a remarkable swing in the fold axis and general outcrop pattern in the vicinity of the fault (Fig.1). This defines a zone of active sinistral shearing that shows signs of having been active during the Late Pleistocene (Al-Daghastani and Al-Daghastani, 1996).

Morphotectonically, the primary tectonic force involved appears to have been horizontal plate motion. The Alpine Orogenic force was translated into minor secondary tectonic movements between basement blocks. These were both vertical (as reflected by changes in sedimentary facies) and horizontal translational and rotational movements (reflected by changes in fold trend and geometry) (Buday and Jassim, 1987).

MORPHOTECTONIC LANDFORMS ANALYSIS

Based on observation of individual morphotectonic units and landforms from dynamic, tectonic and morphogenetic aspects, the study area was divided into four morphotectonic zones. These are characterized and described below as they appear in the map legend (Fig.2).

▪ High Structural Ridge Zone

The dominant and the highest structure in the study area is the Sinjar Anticline trending E – W. The anticline rises as a range of hills approximately 1000 m above the rolling plains on the south and the Sinjar basin on the north (±300 m, a.s.l.). Sinjar Anticline is a broad, open, doubly plunging asymmetric fold, approximately 75 Km long, more than 12 Km wide. The western 30 Km of the structures is in Syria (Ma'ala, 1977). Numerous faults, striking NW – SE, N – S and E – W seem to cut the well defined homoclinal ridges (Fig.2). Cretaceous and Tertiary sedimentary successions are exposed in the core and limbs of the Sinjar Anticline.

▪ Low Structural Ridge Zone

Within the eastern border of the study area, there are three large discrete NW – SE oriented anticlinal structures severely dissected by many dry valleys. The folds include Mushurah Dagh, Gusair and Ishkaft anticlinal structures, from north to south (Figs.2 and 3). The axial traces of these en'echelon folds are discontinuous, when traced through the whole fold system. The synclines occupy a broad topographic low plains covered with thick Quaternary sediments. The general elevation of the plains is ±400 m (a.s.l.); Jebel Mushurah Dagh, at 570 m is the highest point on the structure.

The present distribution of local morphostructural anomalies in the strip border between Iraq and Syria reflects the role of neotectonic activity. They are distinguished throughout the anomalously drainage networks and the isolated homoclinal ridges and domelike structure in an area of very low rolling plains.

Within the study area, hydrocarbon seepages are located in some of the drainage basins, usually at the core and flanks of these new local morphostructural anomalies, both in Iraq and Syria (Fig.3). Tonal variations may be used as indicator in the study area for oil exploration based on the spectral reflectance characteristics of hydrocarbon associated with hydrochemical alteration and mineral potential.

▪ Bajada Zone

In the study area, alluvial fan surfaces exist where a distinct boundary occurs between the anticlinal structure and the surrounding plains. The fans vary considerably in morphology and extent throughout the study area, because of varying characteristics of catchments areas and different local base levels (Selby, 1989).

In contrast to this phenomenon, tectonic control is one of the most important controlling factor in the evaluation of the alluvial fans belt system, which exist in the northern flank of Sinjar Anticline, stretching for more than 25 Km (Figs.2 and 3). The alluvial fans system in the area crosses many structural lineaments indicating that these fans respond to the neotectonic activity. These sequences of fans are related to different episodes of neotectonics, and to the fluctuation of base level in the area. Taking into account the existence of a major fault in the northern limb of Sinjar Anticline, oriented E – W and in a marked alignment with parallel sets of geomorphic lineaments further north, it is reasonable to assume that this alluvial fans system alignments developed during the Pleistocene neotectonic event, which occurred throughout the northwestern basin of Iraq.

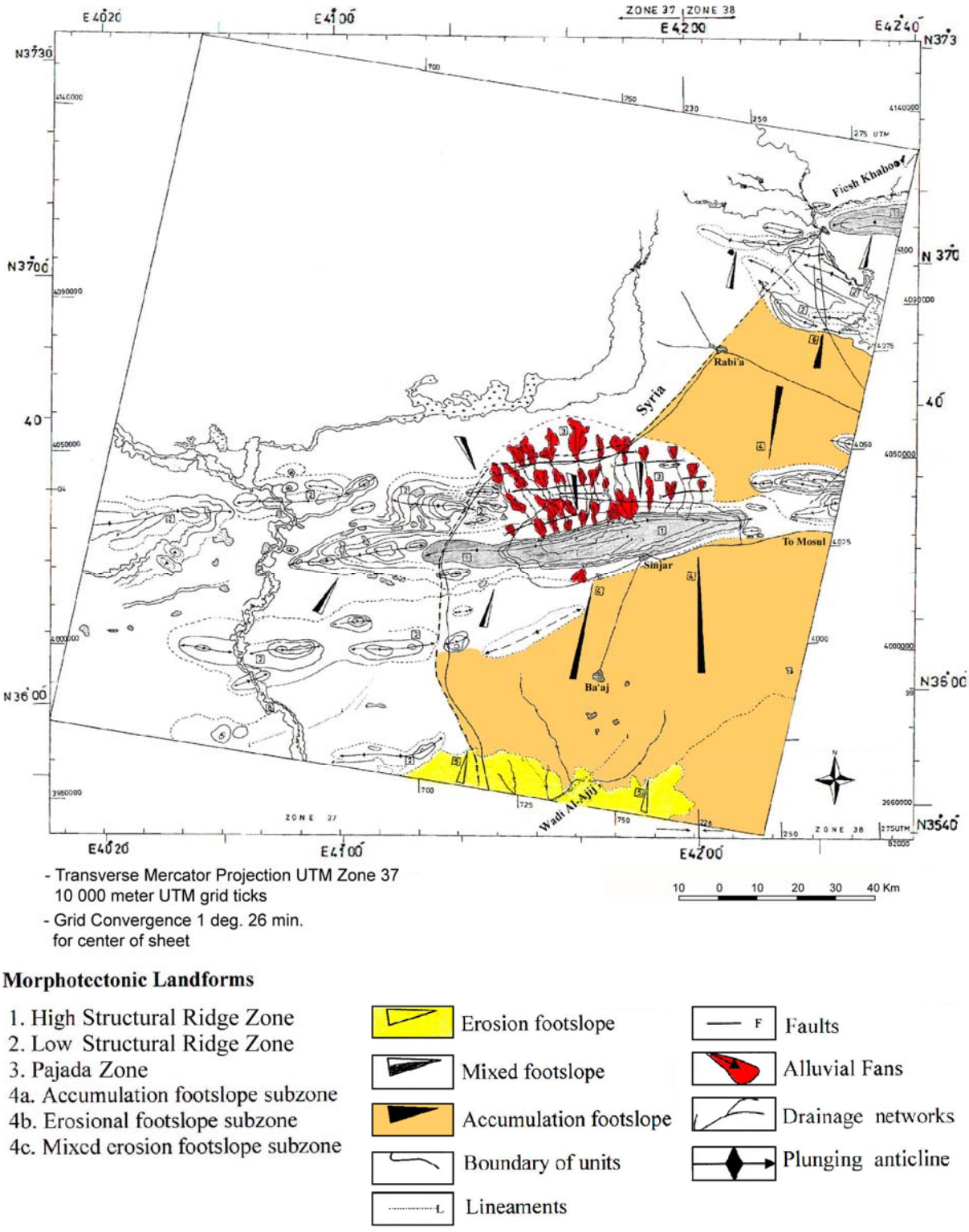

Fig.2: Morphotectonic Map of the study area as interpreted from Landsat TM imagery

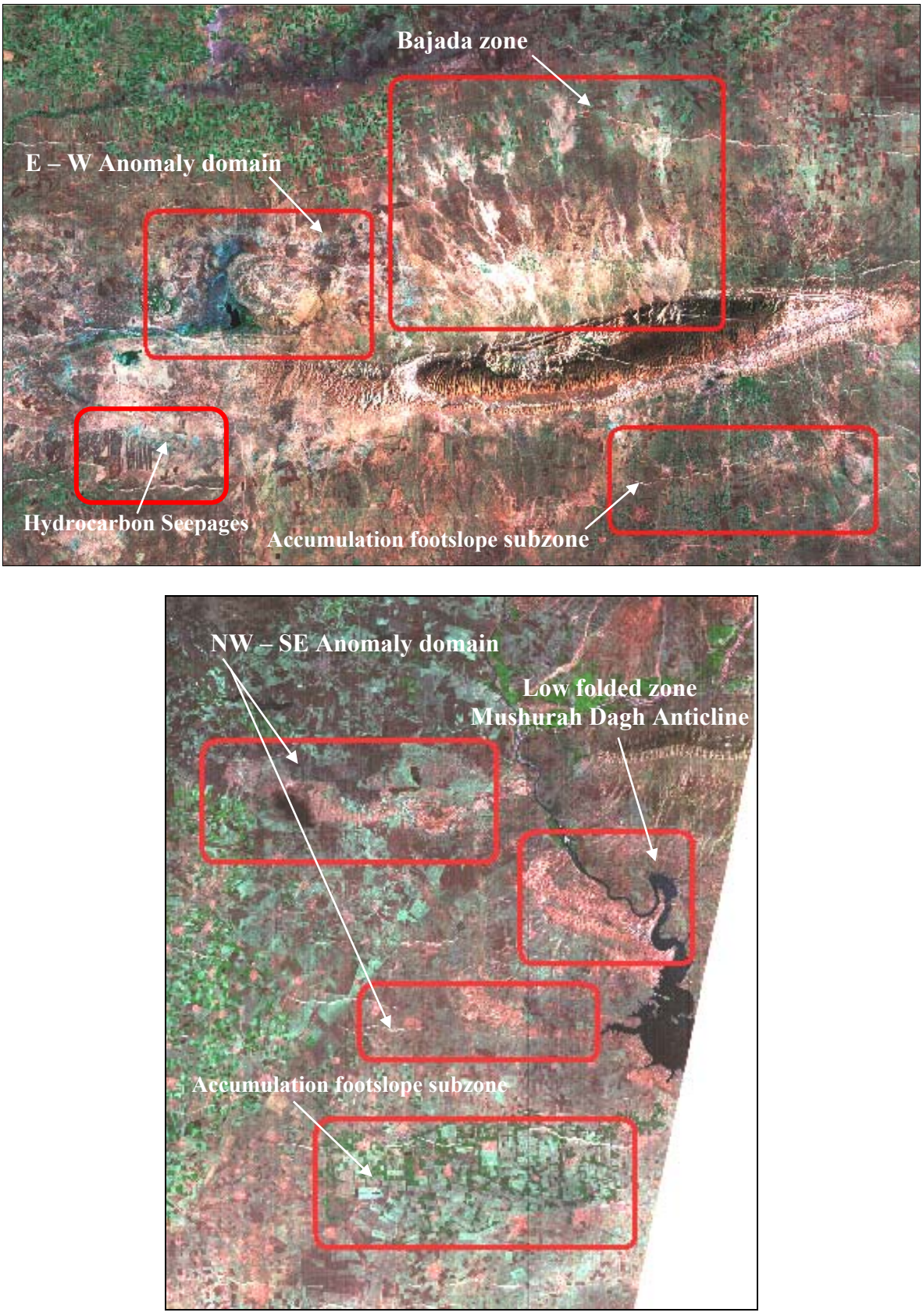

Fig.3: Landsat TM image (Bands 1, 4, 7), digitally enhanced by GEOPIC (1995), of the study area showing morphotectonic zones

▪ **Fluvial Aggradation – Degradation Footslope Zone**

The most obvious area in this map is the zone of pediment surfaces that surround the anticlinal structures. These surfaces surround the flanks of Sinjar, Ishkaft, Gusair, Ain Zalah and Mushurah Dagh anticlinal structures, and can be divided into three subzones, according to the degree of geomorphic processes and evolutions, these are (Fig.2).

– **Accumulation foot slope** is defined as a gently sloping planar surface, as a rule at a slope of (1 – 7)°, at the foot of a discrete local anticlinal structure, and descending to a local base level (Huggett, 2003). There are vast expanses of these accumulation surfaces in the study area. These foot slopes are planation surfaces developed by pedimentation (Figs.2 and 3).

– **Mixed erosional foot slopes** are characterized by bedding trace of alternating sequences of resistant and non-resistant lithologies, namely Fat'ha and Injana formations. However, the inclination of the erosional surfaces vary from (10 – 20)°. This variation could be attributed to fault orientation and to the asymmetry of the anticlines (Figs.2 and 3).

– **Erosional foot slope** is generally aligned along the pediment surface, at the northern border of Wadi Al-Ajij. Erosion surface tend to occupy topographically low and rather gently rolling terrain, severely dissected by drainage networks and underlain by Fat'ha Formation (Figs.2 and 3)

DRAINAGE NETWORK ANALYSIS

Drainage networks provide good examples of the nature of channel response to actively growing faults and folds and despite differences in size and erosive power, they all show features in common (Al-Sakini, 1975; Al-Daghastani and Campbell, 1995; Helen, 1997 and Al-Daghastani and Al-Banaa, 2006). The drainage pattern is strictly dependent on the slope, the nature and attitude of the bedrock and on the regional and local fault patterns.

A detailed drainage network map of the study area was prepared at a scale of 1: 100 000 and used as a base map (Fig.4). This was followed by earlier visual Landsat image analysis of the area, so that the lithology and structural control on the drainage network is well understood. Drainage is studied according to its pattern type and its texture (Selby, 1989). Whilst the first parameter is associated to the nature and structure of the substratum, the second is related to rock type and also to rock/ soil permeability. Four basic types of drainage patterns were identified, namely: dendritic, parallel, radial and rectangular (Fig.4). Frequent cases of radial drainage patterns were observed, were parallel channels flowing away from a central high point. It usually occurs on the domelike structure.

The morphological interpretation of the drainage networks carried out by means of topographic maps led to the detection of fourteen morphostructural anomalies, which are representative of probably local folds. Most anomalies are not randomly located. Rather, they seem to be aligned with NW – SE and E – W trends, suggesting the presence of two morphostructural trends in this part of the northwestern basin of Iraq. A comparison between these anomalies and the available geological and geophysical data enables the definition of two distinct morphostructural domains in the study area.

The first morphostructural domain is defined by a set of drainage anomalies with NW – SE orientation, located in a shallower portion of the basin (Fig.3). Seven en'echelon anticlinal axes can be traced in this area (Anomalies No. 1, 2, 3, 4, 5, 6 and 7, as shown in Fig.4). The first anomaly is located entirely in the Syrian territory. This group of en'echelon double plunging anticlinal folds follow the same trend of folds in the Butmah – Mosul Subzone. This domain consists of low rolling relief area, about ±400 m (a.s.l.) (Fig.4).

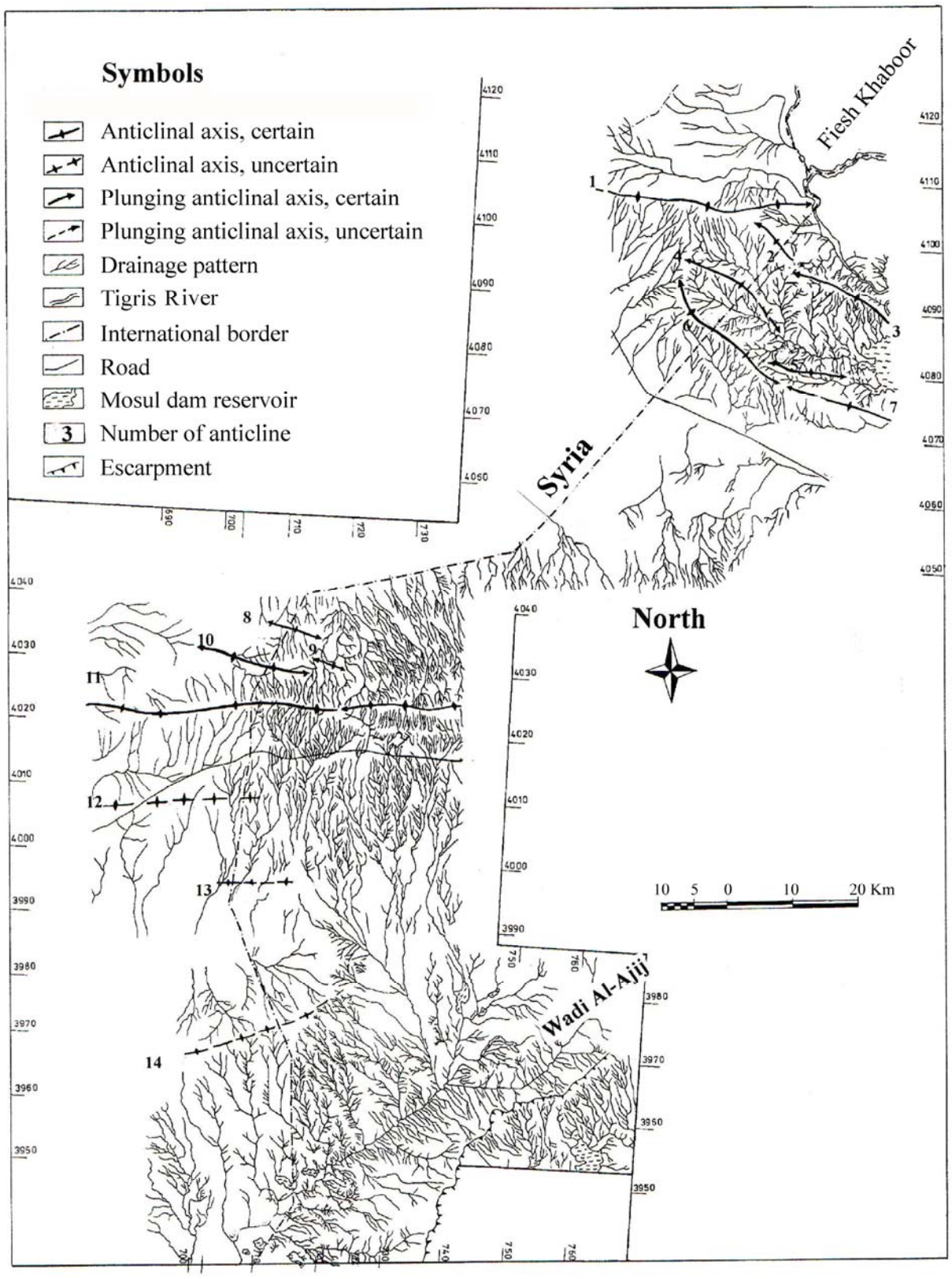

Fig.4: Drainage network map of the study area, as interpreted from topographic maps

The second morphostructural domain (Fig.3) embraces drainage anomalies situated where the sedimentary pile exceeds 1750 m. In this domain, many anomalies seem to be related to the Sinjar Subzone (Anomalies No. 8, 9, 10, 11, 12, and 13, as shown in Fig.4) mainly in E – W direction. The last anomaly (No. 14) follows the same trend, but located near Wadi Al-Ajij at the southern margin of the Unstable Shelf. A strong control by linear feature is observed in this wadi, which has part of its course clearly oriented along NE – SW geomorphic lineament (Fig.4).

DISCUSSION

A significant contribution of regional studies of the tectonic framework of northwest Iraq was achieved through the morphostructural analysis of Landsat TM imagery. The existence of many major and minor morphostructural features of different types and orientations indicate that the study area has been subjected to different episodes of tectonic activity. This activity seems to be continuous as its effects is clearly expressed by the different morphotectonic zones present in this area. This continuity could be strongly influenced by the positioning of the country within the main tectonic units of the Middle East, the Arabian Plate and Eurasian Plate since the Miocene on-world. The two dominant subsurface anticlinal structures, in the study area are mainly distributed in NW – SE and E – W directions, associated with the two main tectonic provinces of North Iraq.

Fourteen possible morphostructural anomalies were observed; seven around the western plunge of Mashurah Dagh Anticline, the others lie near the western plunge of Sinjar Anticline. All of them were considered as subsurface anticlines, according to the geomorphological expression and the behavior of drainage networks. In fact, a comparison between these new morphological detected anomalies and the available Bouguer anomaly map, showed many remarkable coincidences (Fig.5).

It should be stressed, however, that the identification of morphostructural trends is an important tool not only in the definition of the Northwestern Iraqi Basin's neotectonic framework, but also in the optimization of seismic survey planning in such a region of hostile oil field exploitation. The use of Landsat images and topographical maps thereby improves the cost-effectiveness of more traditional methods of exploration and evaluation. Many morphostructural features in the study area, especially the large ones may represent anticlines, which form suitable subsurface structural traps for petroleum.

CONCLUSIONS

- Techniques of remote sensing and topographic interpretations have been applied in an investigation of the influence of neotectonism on geomorphic development within the strip boarder between Iraq and Syria, from Fiesh Khaboor to wadi Al-Ajij. These data were utilized to draw a regional morphotectonic map of the study area at scale of 1: 250 000.
- Two distinct morphostructrual domains were recognized in the study area. The descriptive morphotectonic interpretations showed the presence of four regional morphotectonic zones and fourteen local morphostructural anomalies, having different characteristics and reflect the role of neotectonic activity.
- If these local anomalies are outlined as geomorphic forms, then from analysis of the aforementioned existing data, we may be able to pinpoint sites worthy of detailed field examination and mapping for oil exploration in this area.

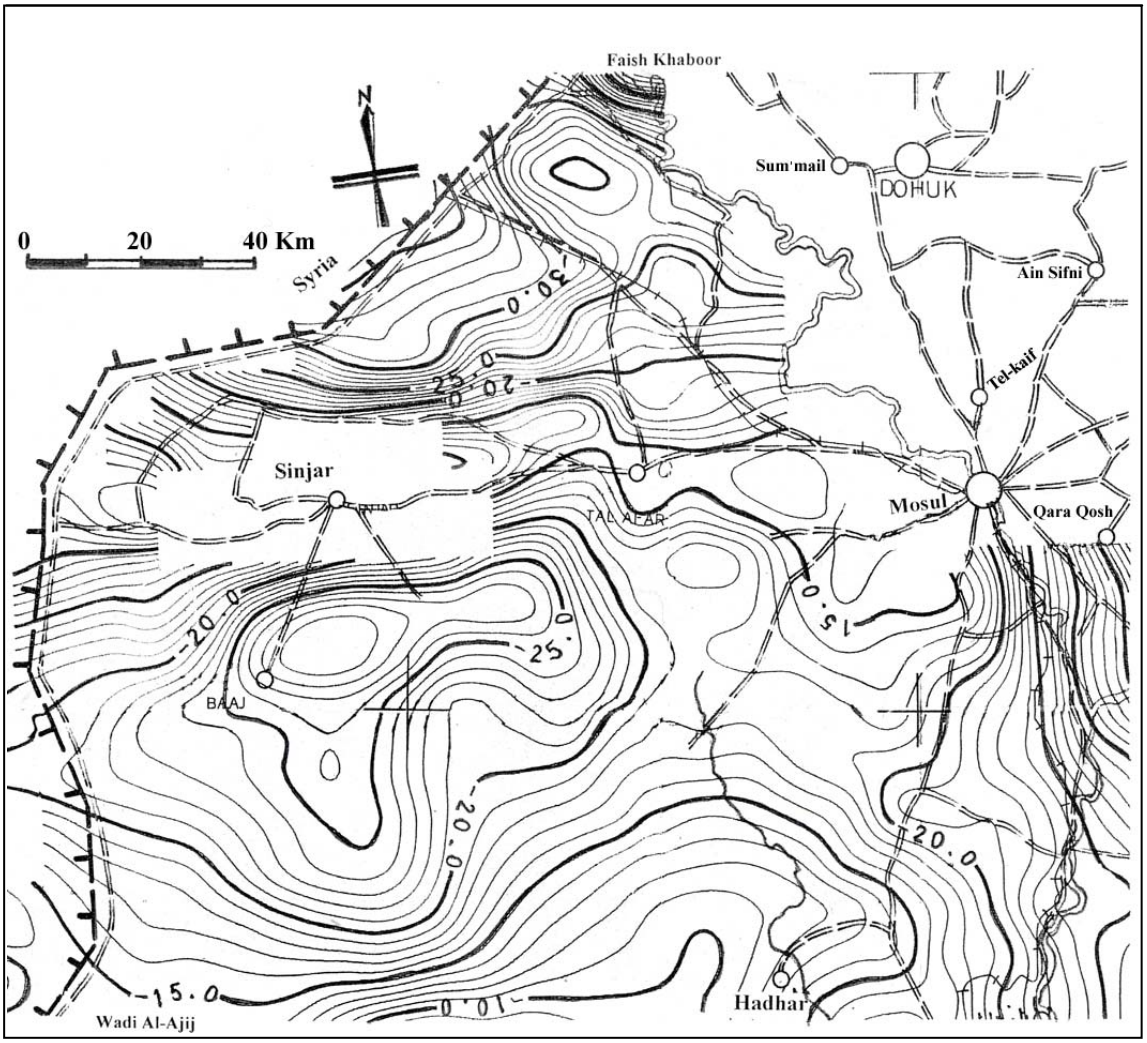

Fig.5: Bouguer anomaly map of the study area (after Al-Kadhimi and Fattah, 1994)

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