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Investigations of Natural Bitumen mineralization in Gilan-e-Gharb exploration block, Iran

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ABSTRACT
The Gilan-e-Gharb exploration block is structurally located in the Zagros fold-thrust belt, the eastern parts of which are part of the Lurestan sedimentary basin and the western part of the northern Dezful sedimentary basin. This area has been considered as a high prospective area for hydrocarbon resources, due to its deep potential in form of oil and gas, and natural bitumen on surface. Many of the known hydrocarbon sources of Gilan-e-Gharb block are related to anticline structures. The most important factor of controlling natural bitumen placement is the dominant geological structures of Gilan-e-Gharb block. Regarding the frequency of faults and fractures in this area, mineral deposits are controlled by structures of fold. Folding as a container of hydrocarbon material, fracture and fault are responsible for its distribution of the area. Based on this, primarily, after identifying stratigraphy units of mineralization hosts including Gachsaran, Asmari, Pabdeh and Gurpi formations, the main and minor anticlines of Gilan-e-Gharb block were investigated and analyzed. At this stage, monitoring of fractures and faults based on trending were done, then, positioning of these structures relative to folding axis and their stratigraphic sett was prepared as well as placement and distribution of natural bitumen in form of a three-dimensional Structural-Mineralization Modeling. The model is presented in this paper for the first time that could be a new approach to exploration of natural bitumen or gilsonite according to the exact study of the Gilan-e-Gharb exploration block.
KEYWORDS: *Natural Bitumen Mineralization, Structural Geology, Stratigraphy, Zagros fold-thrust belt, Gilan-e-Gharb area.*

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I. INTRODUCTION

Escaping crude oil from the depths of the earth over time and evaporates when exposing to atmosphere, the black mineral known as gilsonite or Natural bitumen remained [1-2-12] (Figure 1). In fact, natural bitumen is a heavy hydrocarbon material that has been classified according to its formation, physical properties, solubility in carbon tetra chloride and chemical composition into various groups such as asphaltic pyro bitumen, non-asphaltic pyro bitumen, asphaltites, etc., which these groups also, divided into different subgroups [1-2-12]. Asphaltites can be used in this regard that dividing into three groups of Gilsonite, Grahamite and Glance pitch [1-2]. Gilsonite (natural bitumen) is one of the highest quality and desirable bitumen which observed in terms of liquid, semi-solid and solid according to its purity and life span [1-2-12]. It is interesting to know that there is some kind of valuable elements such as rare earth and trace elements as a by-product in natural bitumen and oil sand deposits all over the world [7-23-47].

Figure 1. A hand sample of high quality gilsonite.

Natural bitumen mines are respectively the largest reserves in the United States, Canada, Iran, Iraq, Russia, Venezuela, China, Australia, Mexico and Philippines [3-4-12]. The largest natural bitumen reserves in the world are located in Utah and Colorado states that have been estimated to contain the reserve of 45 million tons, according to the US Geological Survey [3-4-5]. Generally, 65 percent of natural bitumen reserves are located in North American continent consist of the United States and Canada, and Iran stands for about 15 percent of these reserves as the third largest natural bitumen reserve in the world [3-4-6-12]. Areas with the potential for natural bitumen in Iran are mainly located in provinces of Kermanshah (Gilan-e-Gharb, Ghasr-e Shirin, Sumar villages), Ilam (Ivan and Dehloran), Khorramabad and Khuzestan [3-4-5-8].
The Gilan-e-Gharb block is structurally located in Zagros fold-thrust belt, the eastern part of which contains the Lurestan sedimentary basin and the western part in the sedimentary basin of northern Dezful[9]. This block of an area of 1277 square kilometers in the province of Kermanshah is located between Qasr-e Shirin and Gilan-e-Gharb towns, and to the city of Sumar southward near to the border of Ilam province [10-11-12]. This exploration zone contains surface and deep anomalies in terms of hydrocarbon potential, which superficial potential mainly consisted of natural bitumen, Natural bitumen in particular [9-13]. This paper presents the investigation results of geo-structural role that have made this zone as the most susceptible area for natural bitumen mineralization especially in Middle East.

II. GEOLOGY SETTING

Geology

The study of folding occurrences, faults, fractures, and mechanism of formation is of particular importance in exploration of natural bitumen surface potential or gilsonite [14-15]. The Zagros fold-thrust belt, which contains 8.6 percent of oil reservoirs and 15 percent of proven gas reservoirs globally [17-18], is located in the middle of the Alpine orogenic belt and considered to be the youngest Cenozoic orogeny [16]. Deformations in Zagros fold belt were caused by convergence collision of Arabian and Iranian plates from middle to the late Cretaceous (Figure 2) [18-19-20-21-22]. This convergence collision led to subduction of the northeastern edge of Neo-tethys Ocean under the central Iran [23-24]. It is believed after the occurrences of early Miocene, nearly about the time of continental-continental collision of Arabian and Central Iran plates, this Zagros fold-thrust belt has been formed while the main Zagros orogeny phase from the Upper Miocene to the present-day [25-26-27-28-29].

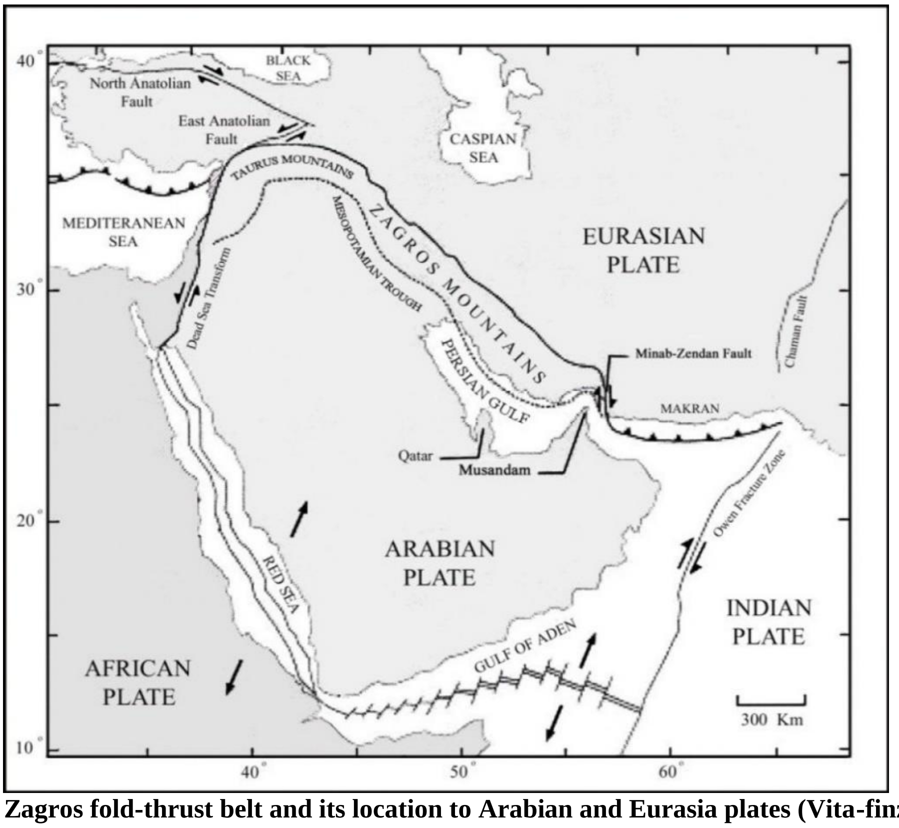

Figure 2. Zagros fold-thrust belt and its location to Arabian and Eurasia plates (Vita-finzi, 2001).

The Zagros fold-thrust belt from north-east to south-west was classified into five tectonic fault zones based on topography and structural morphology, deformation, evidence, geostructural data and regional seismology [30-31-32]. These five tectonic zones are separated by deep and discontinuous thrusts including: high-zagros thrust belt, folded belt, Dezful embayment, Zagros coastal plain, Persian Gulf low land and Mesopotamian [33-34-35]. The only possibility of exposing hydrocarbon minerals to surface has been provided with folded belt of these five tectonic zones [33-35-36-37-38]. Fault severity of high Zagros deteriorated formation of reservoir and buried these oil reservoirs of a thick covering with buried sediments in Dezful embayment, the Zagros coastal plain, the Persian Gulf low land and Mesopotamian that impeded hydrocarbon minerals to be outcropped on surface, especially natural bitumen [39]. Zagros fold-thrust belt is also divided into various geological regions from the north-west to south-east: Lurestan, Dezful embayment and Fars region (Figure 3, 4) [40]. The stratigraphic and structural properties in these three geologic regions are different from each other and created distinct folding and structural type [40].

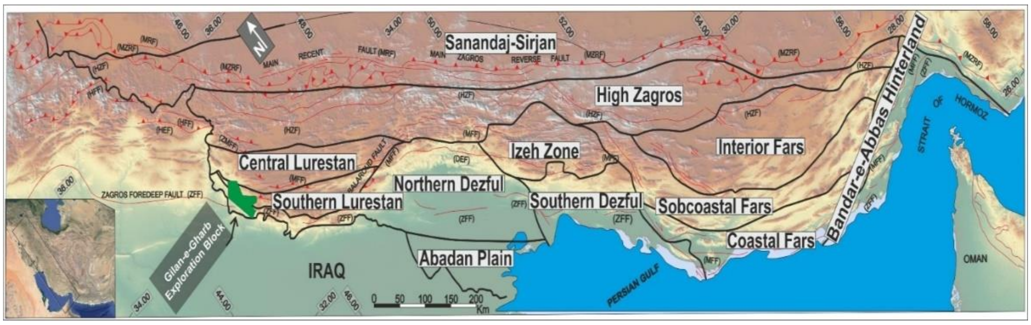

Figure 3. Geological classification of Zagros fold-thrust belt, which indicating Zagros fold-thrust belt is dividing to three regions of Lurestan, Dezful and Fard. Gilan-e-Gharb exploration block is showed in green.

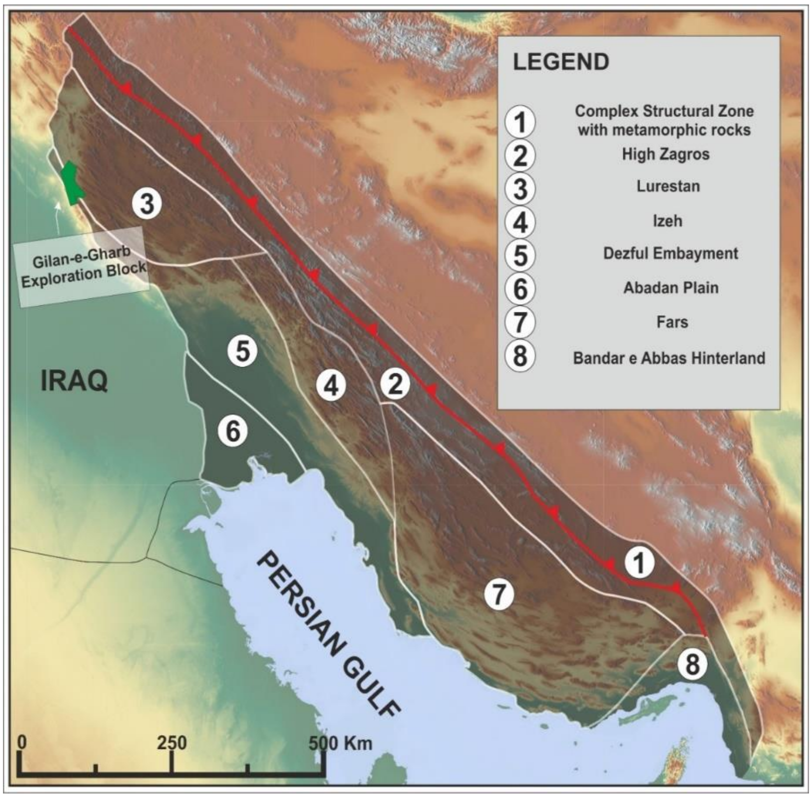

Figure 4. Structural division of Zagros fold-thrust belt (modified by Motiei, 1995), location of Gilan-e-Gharb block is identified in green.

Stratigraphic and structural properties of Gilan-e-Gharb block

The stratigraphy of Zagros plays an important role in morphology and main development of Zagros structures; moreover, the thickness of sedimentary sequences presents the complexity of tectonic history [41]. Major changed can be seen from the sideways in the belt area which indicates mechanical stratigraphy is not the same throughout the Zagros (Jackson, 1980). Hereupon, physical properties of sedimentary rock coverage laterally changed that resulted to different substructures in Zagros belt and reveal different structural types (Lurestan, Dezful and Fars) [38]. Several horizons of active detachment in sedimentary rock coverage including Cambrian saline formation (Hormoz Formation), Triassic evaporate sedimentary (Dashtak Formation), Cretaceous shale (Kazhdomi Formation) and Miocene evaporate sedimentary (Gachsaran Formation) play a significant role in geometry and structural formation of Zagros [33-37] (Figure 5). The oldest rock units in Gilan-e-Gharb block belong to the upper Cretaceous of the Gurpi Formation, which been outcropped along with rock units include Pabdeh, Asmari, Gachsaran, Aghajari and Quaternary sediments [39-41-42-43] (Figure 6).

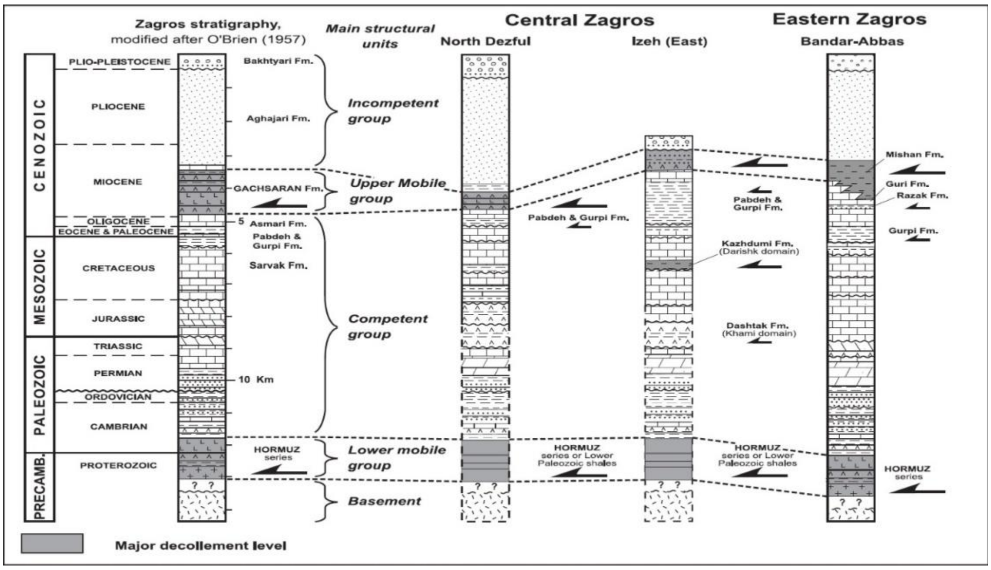

Figure 5. The division of Zagros sediments based on petrology classification of Sherkati and Letouzey, 2004.

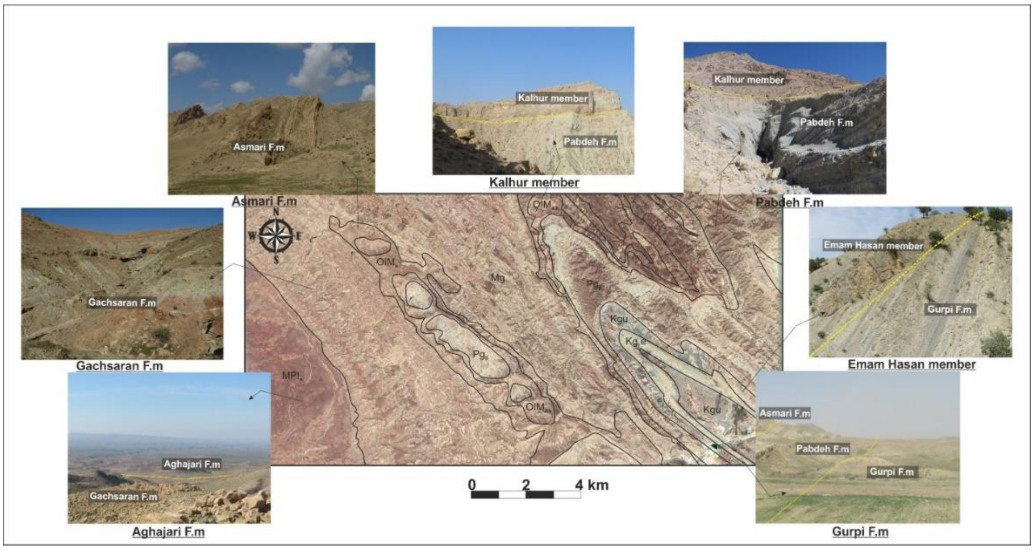

Figure 6. The exposed rock units in Gilan-e-Gharb exploration block based on field observation

Folds are the dominant structures of Gilan-e-Gharb block which observed in the sequences of anticline and syncline on surface [9]. In some parts of the area where the proper outcrops of the Pabdeh and Gachsaran formations are observed, this sequence of folds were intensified and seen as minor folds as subsidiary of the main and large folds of the region [31-36]. These anticlines as a host of mineralization of natural bitumen had a principal role in this area. Faults of the study area are mostly small scale and include faults with different trends and mechanisms [23-37]. The thrust and inverse faults in this region are following the general trend of anticlines, and transverse faults were acted as strike-slip faults with trend of north-east to south-west [40]. In parts of the area where formations of Pabdeh and Gurpi are considerably expanded, the characteristics of flexibility in these formations from one aspect and the other, the extensive outcrops of the Gachsaran formation in the area, resulted in minimizing of rapture on the surface, and consequently faults observed with short length and low-depth that could not exceed the thickness of Aghajari and Gachsaran formations [32].

According to stratigraphic sequences of the region, folding of the area can be divided into major and minor folds [31-37]. The core of major folds formed by Gurpi and Pabdeh formations, and the edges consist of Asmari and Gachsaran formations which formed the highlands of the region [32-37-38-42].The distance between anticline structures of major faults has been filled by Gachsaran Formation [9]. Minor faults are normally formed into Gachsaran formation that stratigraphically is only part of this formation, and lithologically, sequence of green marl, red marl and anhydrites have been observed [33].

The main anticlines of Gilan-e-Gharb block from northeast to southwest consist of Imam Hassan, Vijenan, Shotoran, Darvana and Siah-Kouh. According to the existence of natural bitumen mines and outcrops on the edges of these anticlines, especially the southwest, these structures had a high preference in terms of exploration tracks [10-12].

More than 90 percent of oil accumulations are in Asmari (early Miocene) and Bangestan (Sarvak formation with Cenomanian-Turonian age and Ilam formation with age of Santonin) (Bordenave, 2008). The reservoir and cap rock of oil system are based on the source rock in Zagros (Bordenave and Hegre, 2010). The source rock is completely mature in all parts of Lurestan and Asmari formation which has been covered by Gachsaran formation as a suitable cap rock for oil accumulation originated from Pabdeh formation [44] (Figure 7). These source rock, reservoir and cap rock are the most expanded rock units in Gilan-e-Gharb block [9]. This factor has caused Gilan-e-Gharb block to be known as the most prospective area in terms of characteristics for shallow reservoirs, near the surface and the outcrop of hydrocarbon minerals such as gilsonite in Middle East, in addition to other sediments and reservoirs of the Zagros belt [45].

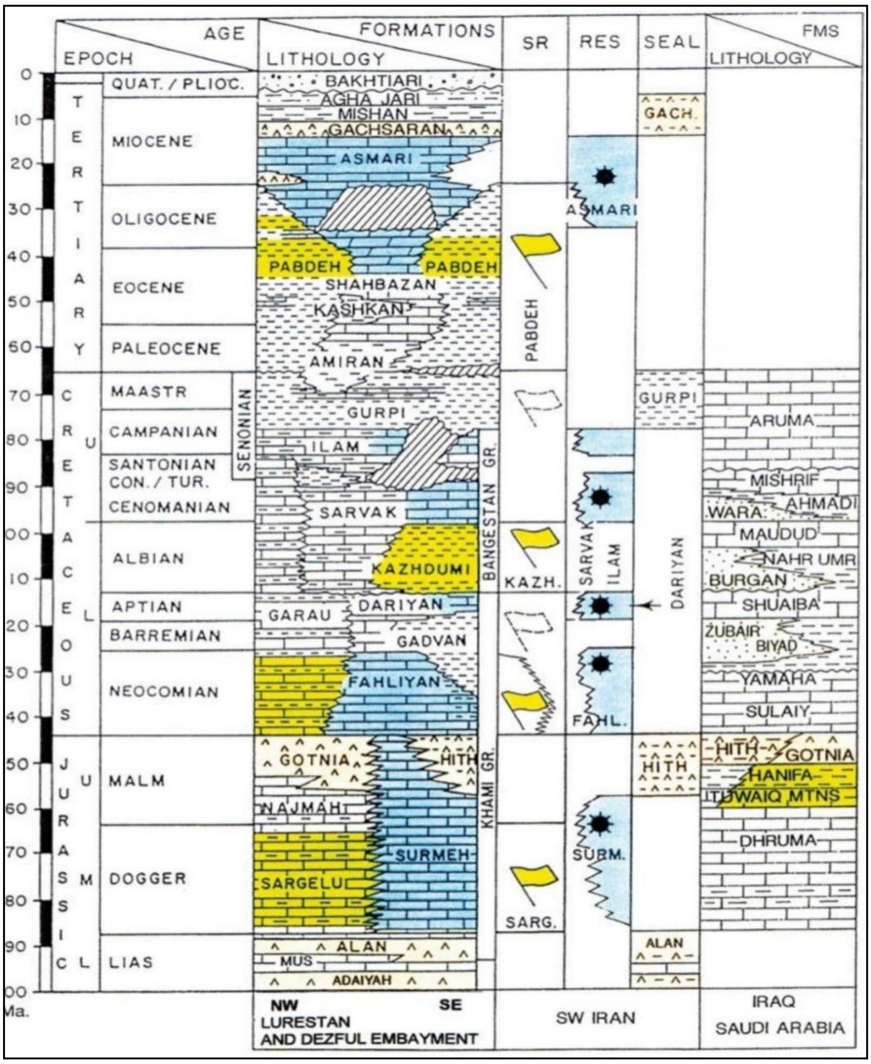

Figure 7. The relationship between source rock, reservoir and cap rock of Zagros stratigraphic units based on Bordenave and Herge, 2010.

Natural Bitumen Mineralization

Structural geology plays a critical rule in various mineralization especially natural bitumen [23]. Kermanshah Province has been known as a rich region for natural bitumen resources in Iran [2-3-6-9]. The most important host of natural bitumen mineralization (in terms of reserve and quality) in Gilan-e-Gharb exploration block is Gachsaran [6-9-46]. Moreover, the Kalhor anhydrite member of Asmari and Pabdeh formation, and in some cases the Gurpi formation, are also significant in some potential sites [44-46]. Location of several important natural bitumen mines is displayed on a satellite image of Figure 8. With regard to anhydrite member of Kalhor in Asmari formation, in some places there is a good space for accumulation of natural bitumen. In these areas, a low quality natural bitumen is largely involved in anhydrite, and mines in these areas are mostly currently abandoned [10-12]. On the contrary, active mines in Gachsaran formation have a good quality and considerable reserve due to presence of suitable space and mineralogical rock units [9]. Marjani and Kalkin-Sumar mines could be mentioned among large mines in the region. The significant feature of mine occurrences of this formation is that they are mainly observed with north-west to south-east trends and parallel with layering [11]. Mineralization of natural bitumen in Pabdeh formation is mainly observed with low reserves but high quality and along the transverse fractures. The Babre-soukhteh mine could be named among mines where found in Pabdeh formation [10-11-12].

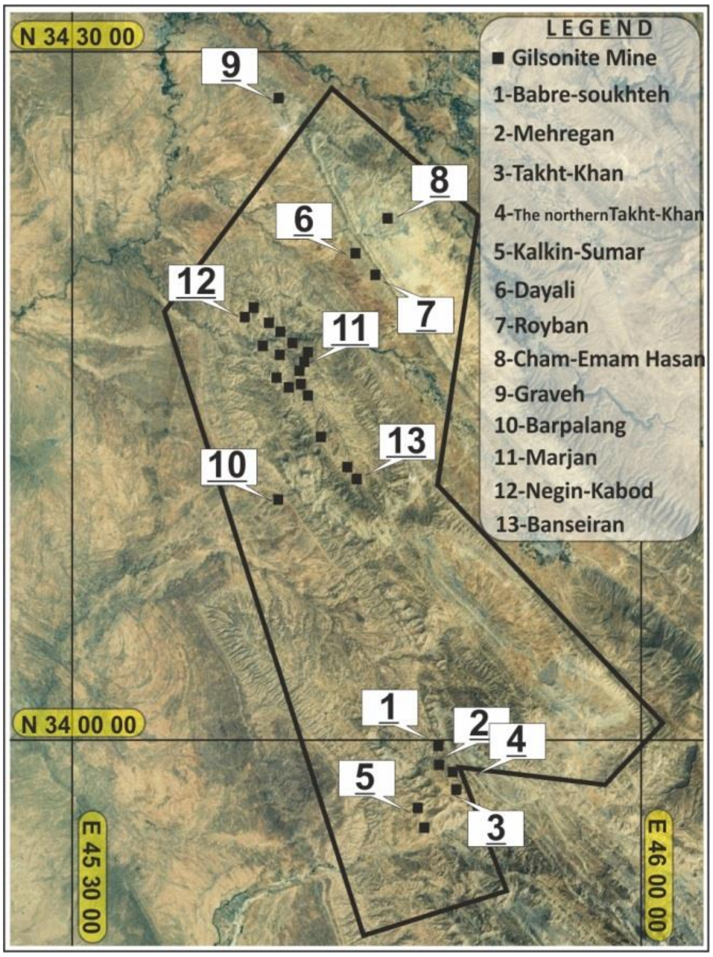

Figure 8. Location of abandoned and active gilsonite mines in Gilan-e-Gharb exploration block on Landsat satellite image (Mrsid format). Despite of numerous mines in the area, according to their size, quality and key units of mineralization, mines are selected to be presented in this picture as have been mentioned in the above description.

Babre-soukhteh Mine

Babre-soukhteh mine is located in 18 kilometers north-east of Sumar city, and geologically, situated in Pabdeh rock unit at the north of Siyah-Kouh anticline with N130 axial trend (Figure 9.a). Fracture trends in this range are mainly north-east to south-west and north-west to south-east. The characteristic of most important fault structure of this area is 270/80 and with a normal mechanism that influenced on rock units of Pabdeh, Asmari and Gachsaran (Figure 9.b, c). In the direction of this fault, natural bitumen injection is observed in different thickness and lens. In the other trends of fractures, an injection of natural bitumen is also observed which has a modest quality.

Mehregan Mine

Mehregan area is located in 1.2 kms southwest of Babre-soukhte mine, on the southwest edges of the Siyah-Kouh anticline and in the Asmari formation of Kalhor anhydrite member (Figure 9.d). Natural bitumen mineralization is mainly involved in anhydrite and somewhere in lenses by fractures. Faults with north-west to south-east trends are the main controllers of mineralization in this area. Also, mineralization of sulfur crystals in this area is abundant which resulted in the loss of quality of natural bitumen mineralization (Figure 9.e).

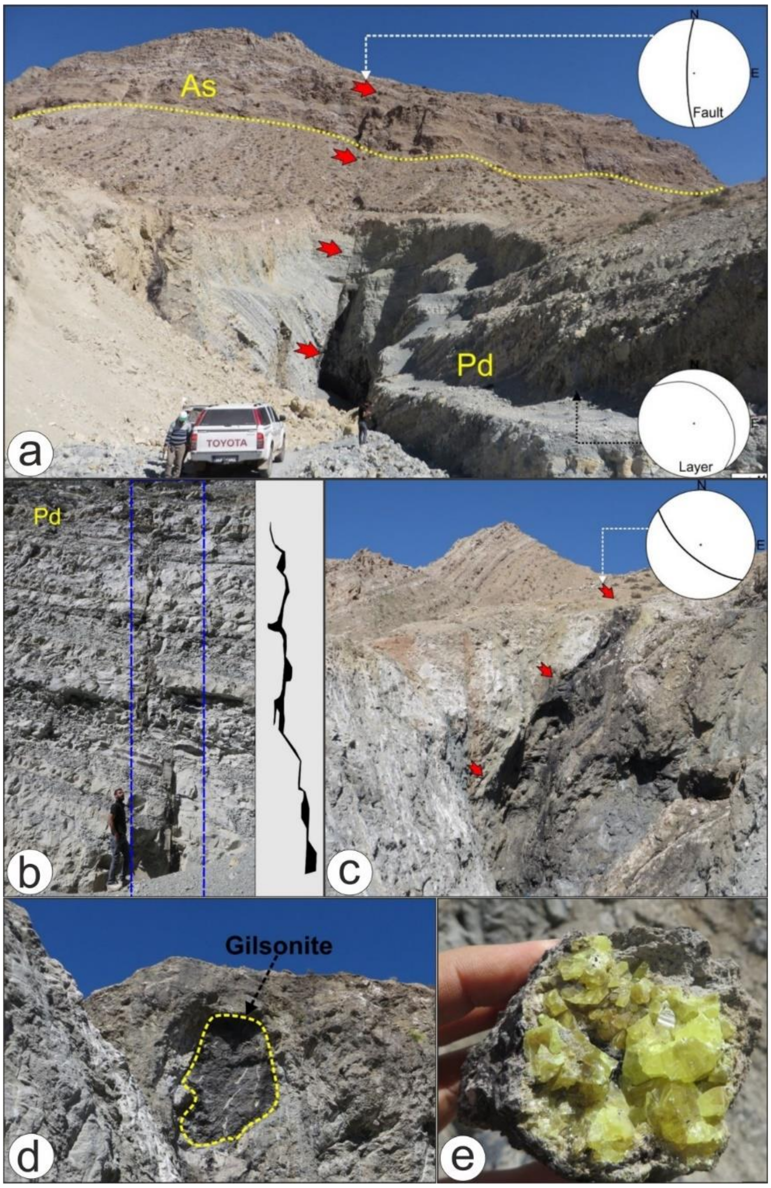

Figure 9. a: Babre-soukhteh mine is situated in Pabdeh rock unit. b, c: Faults trending from north-east to south-west and north-west to south-east. d, e: Gilsonite mineralization in Mehregan area with abundant sulfur mineralization.

Takht-Khan Mine

Takht-Khan area is located in 21 km north-easts of Sumar and the north-east edges of the Siyah-Kouh anticline (Figure 10.a). Natural bitumen mineralization occurred in Gachsaran formation. Faults with a north-west to south-east trends are the main mineralization controllers. The existent sulfur in both parts is much abundance that sulfur crystals are frequently found in natural bitumen, which led to decrease the quality of natural bitumen in this area (Figure 10.b, c).

Northern Takht-Khan Mine

The northern Takht-Khan area is located in 21 kilometers north-east of Sumar and south-west of the Shotoran anticline in anhydrite-marl rocks of Gachsaran formation (Figure 10.d). Reverse fault is the most important structure of the area with a specification of 040/65. Natural bitumen mineralization is observed along this fault and in the footwall. The trend of mineralization can be observed along the north-west fault (Figure 10.e).

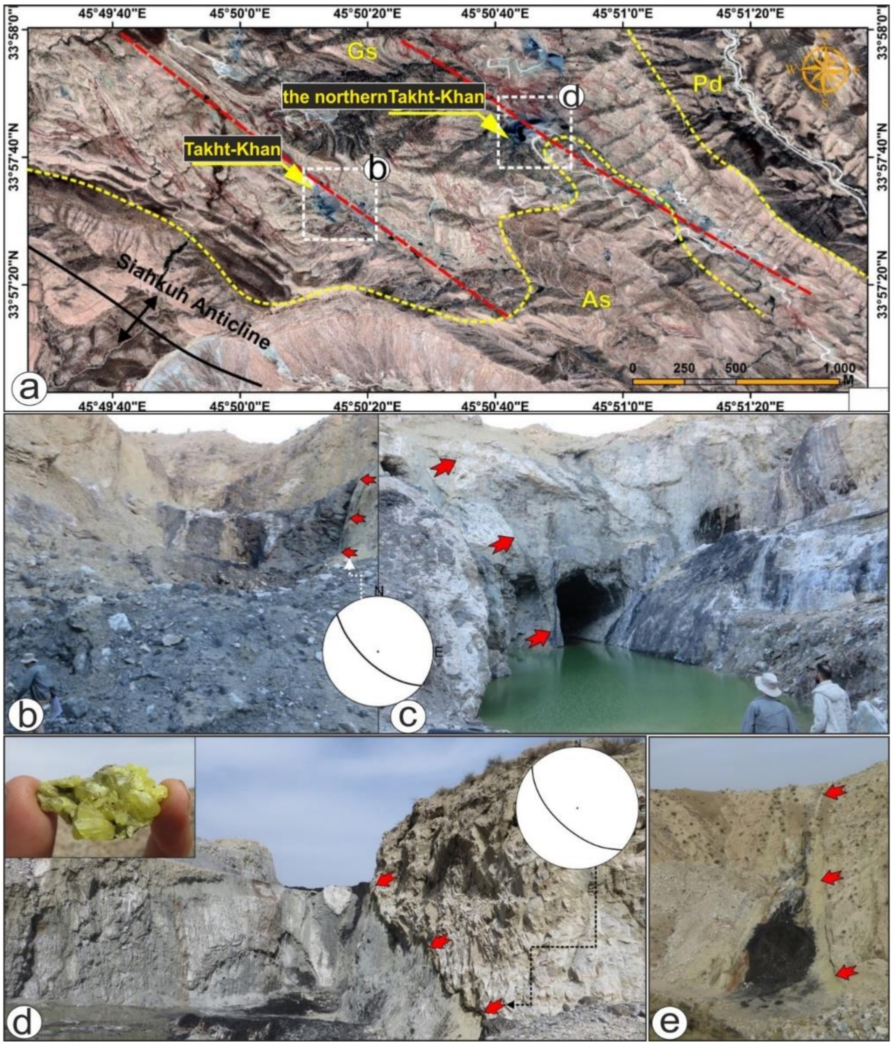

Figure 10. a: the location of Takht-Khan and northern Takht-Khan areas. b, c: Faults as the main mineralization controllers with a north-west to south-east trend caused gilsonite mineralization occurred in Gachsaran formation. d, e: The northern Takht-Khan with fault specification of 040/65 and gilsonite outcrop

Kalkin-Sumar Mine

Kalkin-Sumar area is located in 17 kilometers northeast of the Sumar city (Figure 11.a). Natural bitumen mineralization is presented on the Southwest of Siyah-Kouh anticline and in the Gachsaran formation that is parallel to layering with specification of 215/35 (Figure 11.b). The thickness of mineralization is 2-3 meters with a high quality.

Dayali Mine

Dayali area is located in 1 km north-east of the Big Royban Village which is structurally in the south-west edge of Imam Hassan anticline with a N146 pivotal trend (Figure 11.c). Natural bitumen mineralization occurred in Gachsaran formation. The most important structure of Dayali area is the sinistral fault with a specification of 330/85 that affected calcite-marl sections of Gachsaran formation (Figure 11.d). Natural bitumen Injection is observed in the direction of this fault and also in green marl and anhydrite.

Royban Mine

Royban is located in 1.7 kms east of the small Royban village. Similar to Dayali, this area is also located on the southwest of Imam Hassan anticline (Figure 11.e,f). Natural bitumen mineralization is also occurred in Gachsaran formation. Structural controller of mineralization in this area is transverse faults with east-west trends and with a sinistral mechanism. The evidence of rock unit displacements can be seen on satellite image.

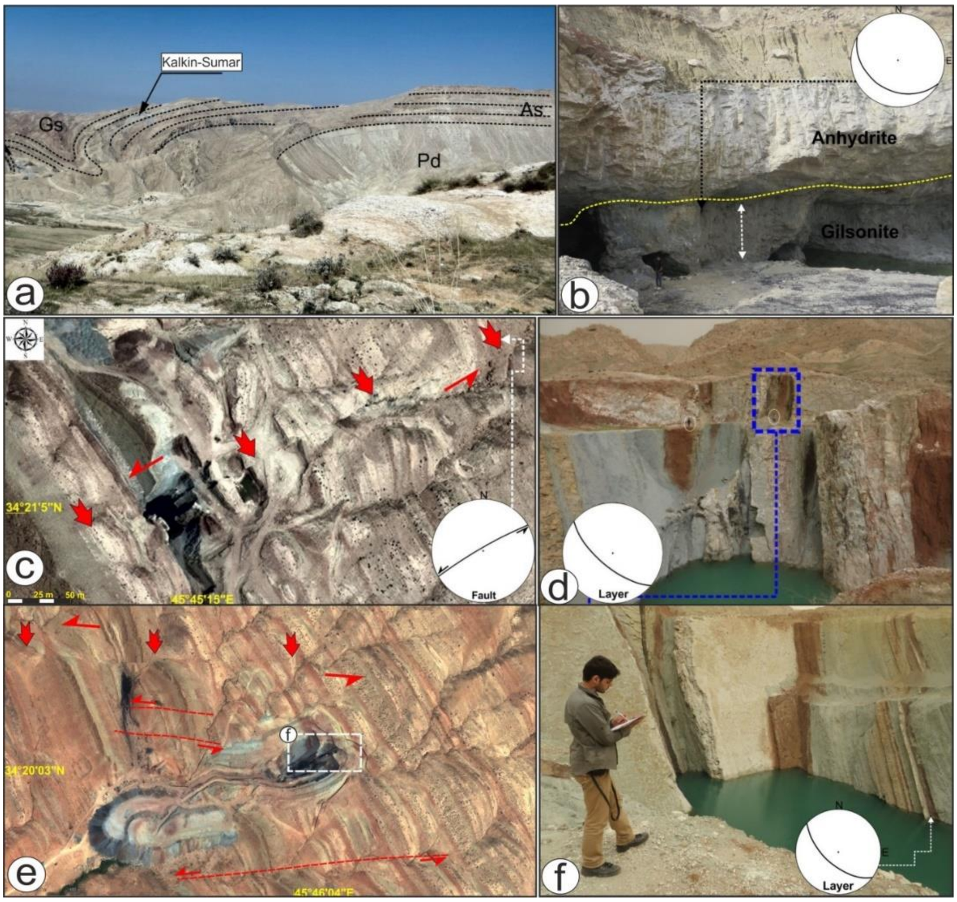

Figure 11. a, b: Gilsonite mineralization in Kalkin-Sumar area is occurred in Gachsaranformation parallel to layering. c, d: Similarly, gilsonite mineralization is occurred in Gachsaran formation in Dayali area as well as, e, f: Royban area.

Cham-Imam Hasan Mine

The area of Cham-Imam Hasan mine is located in 5 kms east of Imam-Hasan village and in the core of Imam-Hasan anticline. Mineralization in this area is liquid in Gurpi Formation (Figure 12.a, b). Gurpi formation is an outcrop of marl stone unit, gray shale, and lime-interlayers of Imam Hassan. Solid evidence of natural bitumen mineralization is also visible to/from some places. Extraction in this mine is carried out by wells have been drilled at a depth of approximately 100 meters and pumping liquid natural bitumen into reservoirs (Figure 12.c, d).

Graveh Mine

Graveh Mining Area is located in 11 kms south-west of Qasr-e-Shirin city. This area is structurally located near the top of Imam Hasan anticline and in Gachsaran formation (Figure 12.e, f). The layering of Gachsaran units with north-west to south-east trends has a slope to south-west. Mineralization observed with specification of 230/50 parallel to layering.

Barpalang Mine

Barpalang mine is located in the south-west edge of Vijenan anticline and under debris deposits of Aghajari formation. Natural bitumen mineralization in this area is in line with fractures and faults with north-east to south-west trends, which is evaluated in brittle and good quality (Figure 12.g, h).

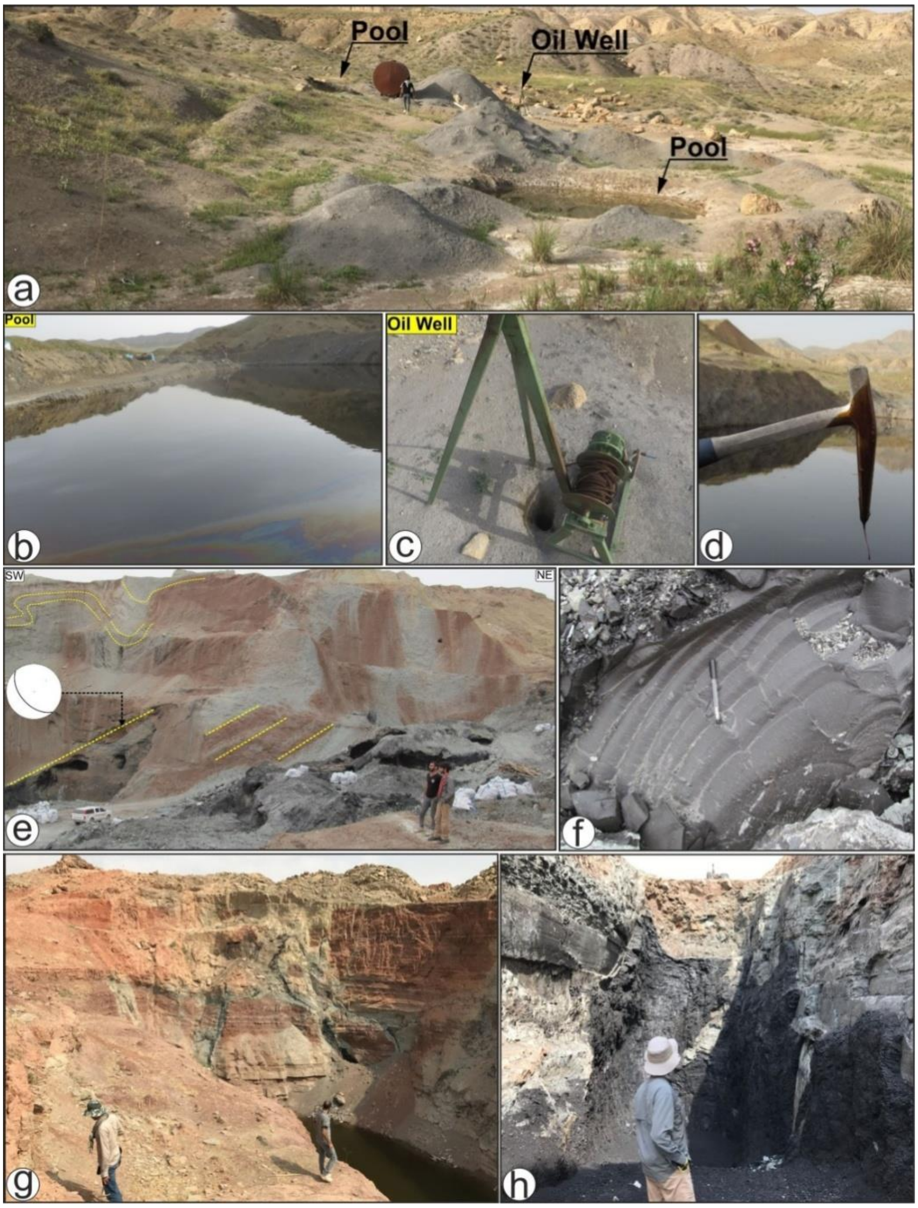

Figure 12. a, b: Cham-Imam Hasan mine in Gurpi formation. c, d: liquid mineralization extracted by wells. e, f: Gilsonite mineralization in Graveh Mining Area occurred in Gachsaran formation.

Marjan Mine

Marjan mine is located in the north-east edges of Vijenan anticline and in the marl stone and anhydrite parts of Gachsaran formation. In mineralization area, Gachsaran units are exposed to north-west to south-east and with layering characteristics of 055/70 (Figure 13.a,b). Natural bitumen mineralization is found in parallel with layering in a thickness of 10 to 17 meters and a length of 210 meters. Evidences of natural bitumen penetration are observed along the axial plane of anticline, which is faulted. In addition, mineralogical events in the south-west part of the area are located in north-west to south-east direction and on the boundary of Gachsaran and Asmari formation. The quality of natural bitumen in this mine is medium grade.

Negin-Kabod Mine

Negin-Kabod mine is located in southwest edges of the anticline with north-west to south-east trends in Kalhor anhydrite parts of Asmari formation. Mineralization in this mine is aligned with a fault trending from east to west and specification of 350/65 having a width of approximately 2 to 3 meters (Figure 13.c). This mineralization extends over the north-south fault with a 45° slope eastward. The thickness of mineralization veins is between 2 to 3 meters, with a low to moderate quality and in some places affected by anhydrite.

Banseiran Mine

Banseiran natural bitumen mine is located on local syncline, trending north-west to south-east axes and in the Gachsaran formation. Massive mineralization in the direction of local syncline axes and below the green marl units has been outcropped (Figure 13.d). Several faults with different trends have led to displacement of anhydrite and marl stones. The pressure resulted from massive natural bitumen has led to penetration of natural bitumen along faults of the ground that observed to a considerable reserve with a high quality.

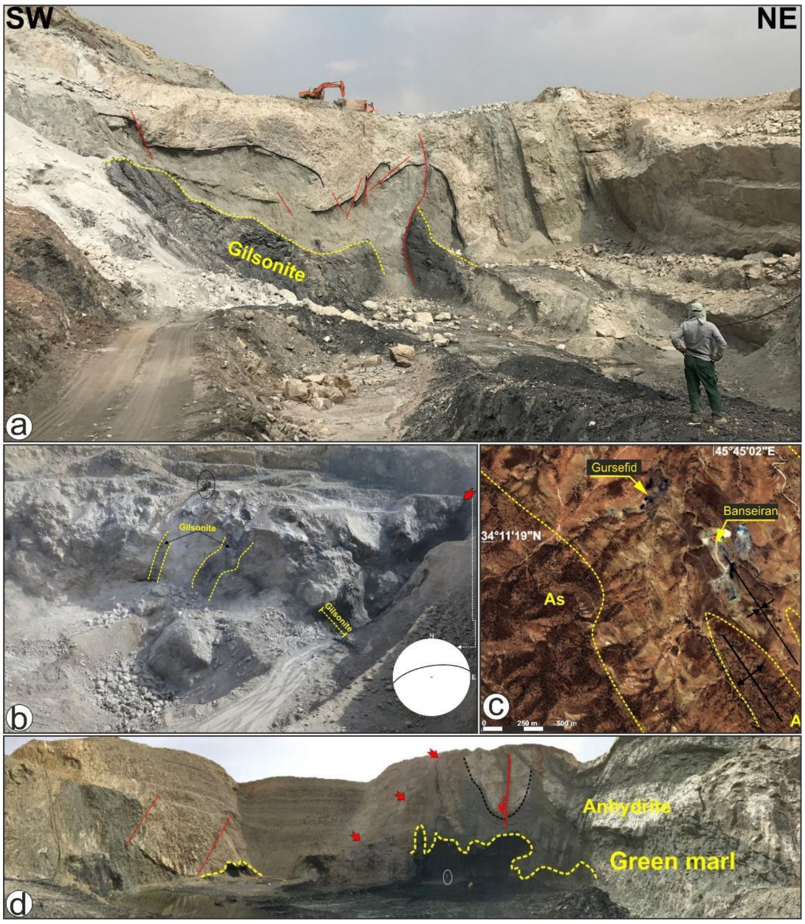

Figure 13. a: gilsonite mineralization parallel to layering occurred in Marjan mine. b: Negin-Kabod and c, d: Banseiran mines.

III. RESULT VIEW

The situation of oil reservoirs of Gilan-e-Gharb exploration block has been provided by stratigraphic units and structural sett. Being fractured of reservoir and hydrocarbon penetration to the surface is the first prerequisite for exposing natural bitumen, especially natural bitumen. The existence of anticline structures in different depths of a stratigraphic sequence has provided suitable containers for accumulation of hydrocarbon materials from the main reservoir. The extensive expansion of Gachsaran formation of this area prevents the spread of deep faults with the surface, and fractures and faults associated with folding on surface is the only major hydrocarbon penetration cores. Each anticline controls distribution of regular outcrops in different qualities, depending on their location in the sequence of folding, volume and expansion, rock units of core formation, edges and arrangement of fractures and faults, which controls outcrop distribution of natural bitumen in different qualities. These factors also affected in physical characteristics of natural bitumen. For example, in Cham-Bavand mine located on the core of anticline, natural bitumen is liquid and pumped out of a low depth to the earth surface, while moving forward the edges and make distance from the anticline core, the physical state of natural bitumen is changed to solid and outcrops are seen as gillsonite on surface. The relationship between distance from anticline cores and natural bitumen characteristic associated with the time of losing volatile in hydrocarbon materials. Structural-mineralization model prepared for Gilan-e-Gharb exploration block based on transverse sections of structures, excavations carried out on the anticlines by National Iranian Oil Company, local trenches and wells made by mining and field prospecting evidences that indicated the positive effect and correlation of achieved results related to tectonic and structural factors in Gilan-e-Gharb exploration block (Figure 14).

The profound origination and anticlines forming charges the sequence of folding which caused to vastly distribution and dispersion of natural bitumen outcrops in Gilan-e-Gharb exploration block with respect to the depth of the anticline closing, various dimensions and capacities, as well as the formation units of the edges and core of anticline. The outcrops vary according to the arrangement of fault and fractures associated with folding of each anticline and follow the pattern of the same structures.

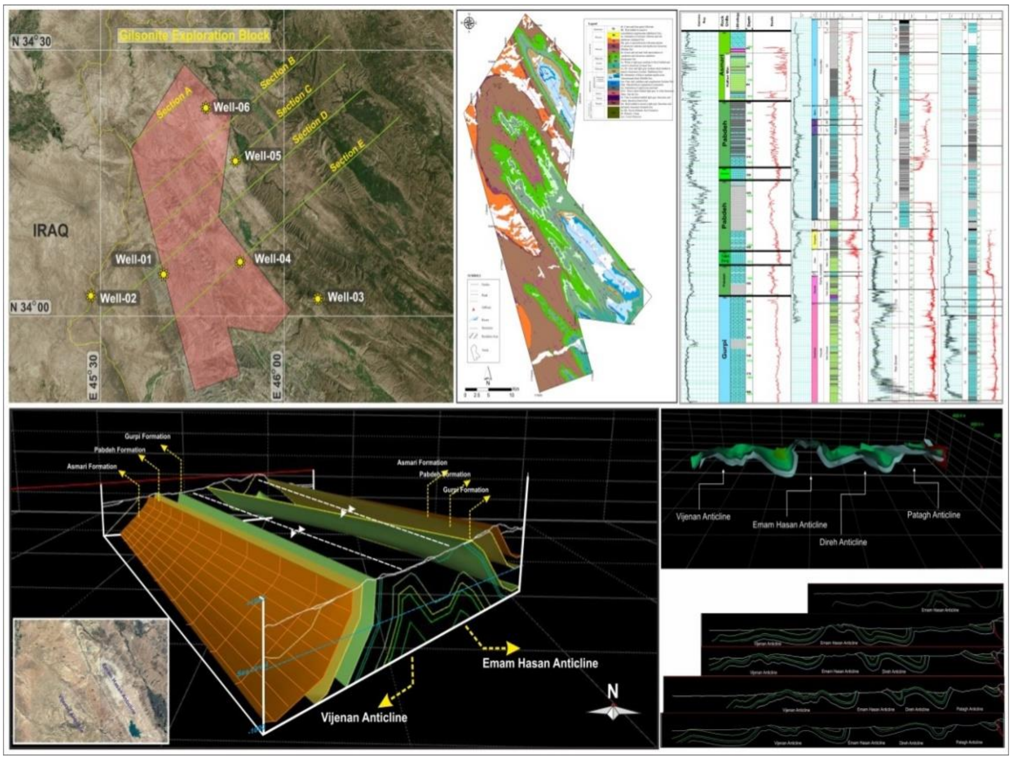

Figure 14. Three-dimensional structural-mineralization modeling of gilsonite in Gilan-e-Gharb exploration block.

IV. CONCLUSION

In this paper, in order to clarify natural bitumen mineralization, different investigations such as economic geology, structuralgeology, field work survey, etc. from different mines and index in the Gilan-e-Garb exploration block were done.The proper geo-structural location, ideal stratigraphic units for oil accumulation system, tectonic performance for being outcropped on the surface, and presence of large mines with high reserves are of significant parameters for natural bitumen mineralization in this block.Potential of rock units for natural bitumen mineralization from the oldest to recent ones consist of Gurpi rocky formation (Cham-e-Imam Hassan mine), Pabdeh formation (Babr-e-Soukhte mine), Asmari formation in Kalhor section (West Shakmeidan mine, Negin-Kabood, etc.) and Gachsaran formation (KalkinSumar mine, Marjani and ...) are hosts for natural bitumen in Gilan-e-Gharb exploration block. Also,distribution of natural bitumen mines in the mentioned block indicates that mineralization is occurred in all threePabdeh, Asmari (Kalhor member) and Gachsaran formations, but different from each other in volume of reservoir and quality observed in all three formations. For instance, natural bitumen mineralization in Pabdeh formation occurred mostly in transverse fractures with trends of northeast to southeast. In Asmari formation (Kalhor section), mineralization of natural bitumen is more involved in anhydrites, which is of low quality, but in Gachsaran formation, it is more prospective than the remaining ones in terms of reserve and quality. It should be mentioned that natural bitumen in the form of solid outcrops in abundant mines is found to locate on the edges of anticline, and liquid in the core of these structures in the block. Gurpistratiform formation is the only host of liquid natural bitumen which is the distinction between this formation and other bituminous hosts. Natural bituminous layer hosts have been increasing in terms of improving both qualitative and quantitative factors, respectively, from Gurpi, Pabdeh, Kalhor and Gachsaran, such that in Ban-Seiran mine is observed natural bitumen ash content less than 10 percent.Faults with northwest to southeast trend are the main controllers of mineralization in Gilan-e-Gharb block. Fractures are observed in the folded edges and variable depending on the type of rock unit, length, distribution and density of them. Based on fracture trends, they can be divided into three groups of longitudinal, transverse, and conjugate fractures. In Gurpi and Pabdeh formations, the frequency of conjugate fractures is greater than the longitudinal and transverse fractures, however, the frequency of longitudinal and transverse fractures is higher in Asmari and Gachsaran formations, which mineral deposition is more affected by these fracture forms. The transverse fractures in most cases are followed by sinistralfaults. Also, in the southern part of the Gilan-e-Gharb block, fractures are dominantly longitudinal on the edges of Darvana and Siyah-Kouh anticlines, which are parallel to the axis of the major and minor anticlines and occurrenceof natural bitumen is also followed by this trend. The Imam Hassan anticline, in terms of the mineral deposit quality, is more prospective than Darvana anticline while its reserve is lower. In Imam Hassan anticline, natural bitumen has two types of solid and liquid, although, in Darvana anticline, it is only solid and mostly involved in anhydrite. The Vijenan anticline hosts for the largest natural bitumen mine in Middle East. It seems that the structural and stratigraphical conditions have created this difference between these anticlines.

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