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RESEARCH ARTICLE

RESERVOIR-TARGETED OIL and GAS EXPLORATION in METAMORPHIC and MAGMATIC ROCKS of the NİĞDE MASSIF (CENTRAL ANATOLIA, TURKEY)

Adil OZDEMIR[1,*], Alperen ŞAHİNOĞLU[2], Yildiray PALABIYIK[3], Atilla KARATAŞ[4]

[1] Ataturk University, Division of Geological Engineering, Erzurum, adilozdemir2000@yahoo.com,
ORCID: 0000-0002-3975-2846
[2] Istanbul Esenyurt University, Institute of Science and Technology, İstanbul, alperensahinoglu@esenyurt.edu.tr,
ORCID: 0000-0002-1930-6574
[3] Istanbul Technical University, Department of Petroleum and Natural Gas Engineering, İstanbul, palabiyiky@itu.edu.tr,
ORCID: 0000-0002-6452-2858
[4] Marmara University, Department of Geography, İstanbul, atilla.karatas@marmara.edu.tr,
ORCID: 0000-0001-9159-6804

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ABSTRACT

Basement rock reservoirs are a special type of oil and/or gas reservoir, which has been usually neglected until recently as a target for exploration. In this study, it is aimed to investigate the hydrocarbon potential of Niğde Massif. The n-alkane hydrocarbons found in the water samples collected are the mature petroleum hydrocarbons, which are the geochemical evidence for a working petroleum system in the study area. The dom structures in which they are suitable to be entrapped and protected for hydrocarbons in a predominantly SW-NE orientation, where metamorphic rocks in which granite has been located in its center have formed, is the possible hydrocarbon reservoir in the study area. The geochemical exploration methodology used in this study may be a new method that can eliminate the discovery of hydrocarbons in the metamorphic massif and granitic rocks by chance.

Keywords: *Basement rock, Metamorphic rock, Granite, Reservoir-targeted oil and gas exploration, Hydrocarbon-rich water*

1. INTRODUCTION

There are many metamorphic and granitic oil and gas production fields in the world including giant reservoirs [1-9]. Nelson [5] presented a list of 370 fields where substantial amounts of hydrocarbons are produced from basement rocks. It is estimated that only BP Amoco has produced 21 billion barrels of oil to date. Moreover, oil discoveries have been performed in fractured granitic and metamorphic rocks in the Masila basin (Yemen) [10]. So far, 100 million barrels of oil have been produced from basement rocks in Venezuela, California (USA), Kansas (USA), and Morocco. Initial productions are as high as 17,000 barrels per day and most of the reservoirs are fractured metamorphic and magmatic rocks. The trapping mechanism has been caused by an anticline or a formation structure with heterogeneous permeability. All the known base rock hydrocarbon accumulations are located at higher elevations than those of the sediments around the basement rock. The sedimentary cover on the basement rock may or may not contain petroleum reservoirs. Oil and gas reservoirs in most basement rocks were found by chance [2,3]. Parnell [11] examined granitic plutons containing biogenic hydrocarbons in the onshore UK and the migration of those hydrocarbons to these plutons while McNaughton [1], P'an [3], and Harrelson [4] investigated the migration and accumulation conditions of hydrocarbons in magmatic and metamorphic rocks in terms of geological perspective. In Mesozoic-Cenozoic rift basins in Eastern China [12-14], Southeast Asia [15-18], and North-South America [6,19,20], the fractured basement reservoirs were discovered. Hydrocarbons are produced from fractured Precambrian crystalline basement rocks in North Africa, in the Sirte basin of Libya [21,22], and in the Suez Gulf [23,24]. Most of these reservoirs were discovered by chance because the basement rocks are not primary targets in petroleum exploration. Historically, hydrocarbon accumulations in the basement rocks were generally discovered 10 to 30 years later after a certain amount of petroleum had been produced from the sedimentary rocks overlying them. For instance, the La Paz-Mara field in the Maracaibo basin in Venezuela [19] can be given as a good example for such a discovery. However, the Lancaster, 205 West in West of Shetland [25,26], and the Jinzhou 25-1S site in the Bohai basin [14,27] are some basement rock reservoirs that were discovered by a consequence of consciously basement-targeted explorations. To sum up, it has been revealed that the only way to discover oil and gas reservoirs in basement rocks does not have to be a coincidence.

The standard definition of crystalline basement rock was made by petroleum geologists as any metamorphic or magmatic rock having unconformity with a sedimentary sequence. However, it is not necessary that crystalline rocks were not subject to significant metamorphism or older ones than sedimentary covers [28]. A more suitable definition for the crystalline basement was performed by Landes et al. [2]. According to this definition, oil-generating formation (source rock) is not located below the basement rock reservoir. In basement rock reservoirs, the generally accepted theory for oil migration is “upward orientation” [1]. The examples of hydrocarbons that form a basement rock reservoir by migrating to older porous metamorphic or magmatic rocks are the Japanese volcanic reservoirs, oilfields of the Mexico and the Maracaibo basin in Venezuela [29]. Excessively and long-term regional erosion of basement uplifted and the presence of younger sediments that serve as a source of hydrocarbons on faulted limbs fallen down or directly situated on the fractured basement and provide an opportunity for trapping of petroleum in the basement rock are suitable conditions for exploration of basement rock reservoirs [4,10]. Basement rock reservoirs are a special type of oil and/or gas reservoir, which have been usually neglected until recently as a target for exploration. Most of the basement rock reservoirs are formed either in platforms or in intermontane basins whereas they are rare in foredeep basins. They always occur at high elevations within a basin or subsequent uplifts and are exposed as a consequence of long-time erosion and weathering phenomena. Petroleum can accumulate in sandstones and carbonate rocks containing secondary cracks, caves, or primary porosity, or in any magmatic, metamorphic, or sedimentary rock. Carbonates are the best basement rock reservoirs among the formations mentioned above because they are hard and brittle and do not only tend to develop secondary cracks, but also easily dissolve in groundwater. Thus, primary pores can expand and new porosity can be formed. Basement reservoirs are characterized by thick formations and porosity and permeability of the rock exhibit heterogeneous distributions. Production obtained from those types of reservoirs is generally high and the reserves are large [2,3,28]. Fractured basement reservoirs in areas near the active faults have a high potential of hydrocarbon production [30].

Ozdemir and Palabiyik [31-34] stated that accumulations, which are capable of occurring operable-size metallic ore deposits, have a shallow and reliable indicator for hydrocarbon deposits. There are Gümüşler mercury deposit in the Niğde Massif that were operated in the past [35]. All major mercury deposits in Turkey are epithermal and was occurred in the depth varying from 1 to 600 m by the upwelling of hot fluids (50°C to 200°C). The ore is located in veins or disseminated in sandstones and schists [35,36]. Oil or bitumen was found in the mercury deposits [37-40]. Bailey [41] and Shabo et al. [42] suggested that cinnabar (HgS) and bitumen precipitated by a common fluid. The presence of bitumens with mercury ores together has led to the assumption that mercury is precipitated by organic matter. However, in many cases, mercury appears along with oil rather than solid bitumen [43]. Chakhmakchev et al. [44] reported that mercury is enriched in light oil while many other metals are in heavy oil. Mueller [37] suggested that near-surface and low-pressure conditions prevalent during mercury mineralization are appropriate for the accumulation of a series of organic deposits specific to this mineralization. The maximum concentrations of bitumen in organic matter have been determined to be associated with the highest mercury content mineralization. Mercury is abundant in oil and gas fields and an important data used for hydrocarbon exploration [43,45,46]. In particular, formation waters of gasfields contain high amounts of mercury [45].

Until now, no research hasn't been conducted on the oil and gas potential of massifs and granitic plutons in different ages which cover expansive areas in Turkey. It was reported by Erentöz and Ternek [47] that there was an oil seep in the southeast of the Niğde Massif. Therefore, in this study, it is aimed to investigate the oil and gas potential of Niğde Massif by conducting TPH (total petroleum hydrocarbon) analyses on the samples taken from massif and the natural cold-water resources surrounding it (Fig. 1). As a result of analyses, mature petroleum hydrocarbons, which are evidence for the working petroleum system in the study area.

2. GEOLOGICAL SETTING

The Anatolian region is a part of the Alpine-Himalayan orogenic belt and today the outcropping rocks in regions contain the geological records of the closure history of the Neotethys ocean as a result of the convergence of the African-Eurasian continents during the Late Mesozoic-Cenozoic period. The location of the ophiolite mélange which outcrops along the Izmir-Ankara-Erzincan Suture Zone (IAESZ) indicates the location of the northern branch of the Neotethys. The Central Anatolian Crystalline Complex (CACC) consisting of metamorphic rocks, magmatic intrusions, and ophiolites located in the south of the IAESZ are the largest metamorphic complex which outcropped in Turkey. This crystalline complex has been subjected to complex tectonic events such as the local Barrovian metamorphism and magmatic intrusion, in which the ophiolite nappes has settled on Paleozoic-Mesozoic sedimentary units in the Late Cretaceous. However, in the previous metamorphic, magmatic and structural studies in the Central Anatolia Region, no consensus has been reached on the geodynamic evolution of the CACC in the Cretaceous [48].

The Niğde Massif, which is the study area, forms the southern end of the CACC under the influences of the Tuz Gölü Fault (TGF) Zone, the Ecemiş Fault Zone (CAFZ), and the Niğde Fault Zone (Fig. 1). The Niğde Massif is located on the southern boundary between the Anatolides and the Taurides in terms of its geotectonic position. It is the common opinion of all the geologists who studied in the massif that the Alpine orogenesis completed its development during the Laramian phase. During granite intrusion into the massif, dome structures and important fracture systems developed [49]. The Niğde Fault is an NW-SE trending fault zone consisting of at least three possible segments parallel to each other. The northwestern margin of the Niğde Massif is the fault escarpmentness that regressed in the SE direction during the Middle Miocene - Lower Pliocene [50]. Tuz Gölü and Ecemiş Faults are strike-slip and Niğde Fault is dip-slip. The presence of thick slope debris on the northwest of the massif supports this opinion. The massive limited by the Ecemiş Fault (CAFZ) from the east and the Tuz Gölü Fault (TGF) from the west have been subjected to large tectonic effects. The Ulukışla Sedimentary Basin is located in the south of the massif (Fig. 1).

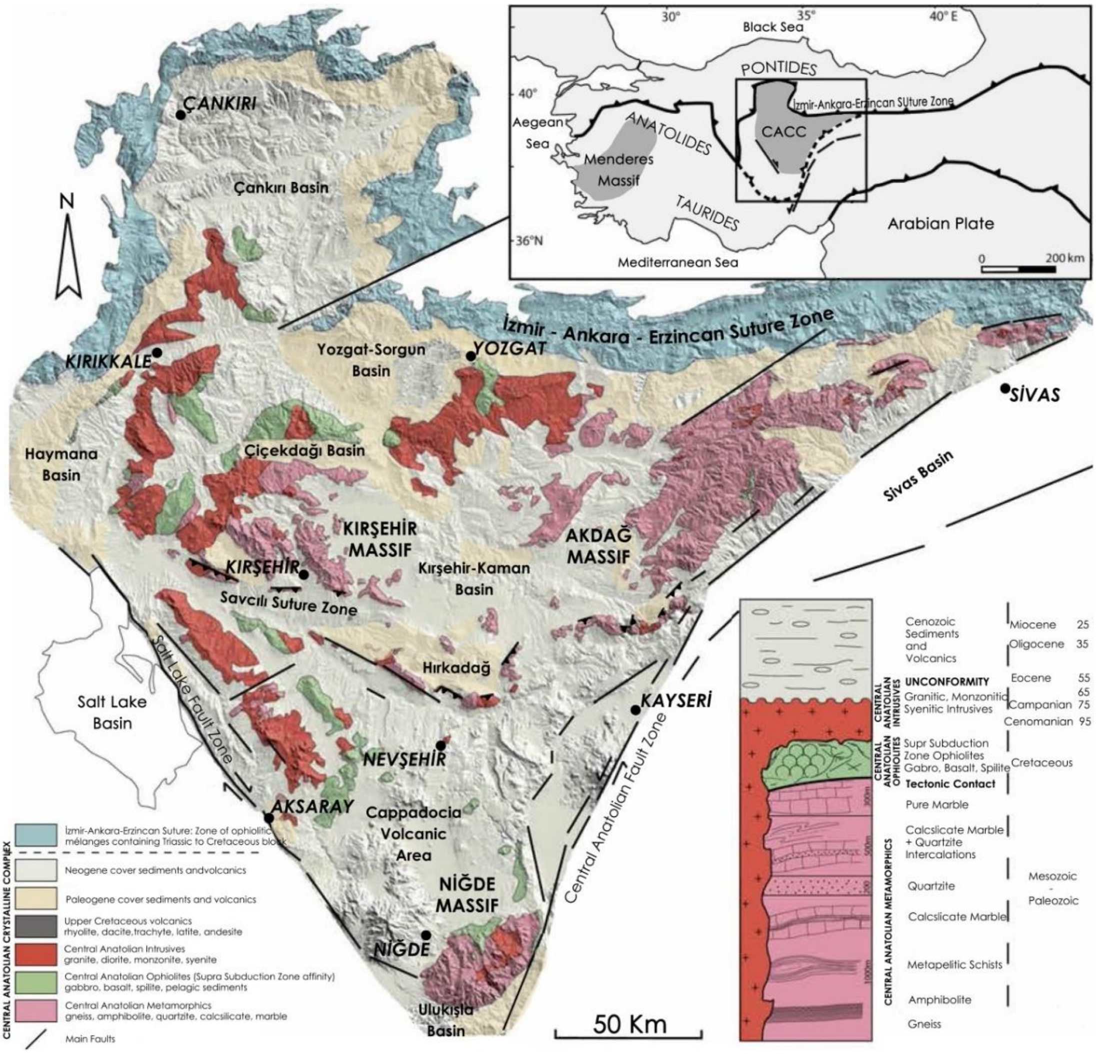

Figure 1. Geological map of the study area and its surroundings (modified from [48]).

The metamorphic rocks constituting the Niğde Massif have formed a largely irregular dome defined by slightly inclined foliation surfaces. The dom center is in the northwestern part of the region. The lower part of the metamorphic series consists mostly of paragneisses and mica schists subjected to partial melting in varying degrees. In the higher parts of the series, recrystallized quartzites and marbles are commonly dominant. In the massif, granitoids are abundant and show various degrees of deformation. The main intrusion is represented by Üçkapılı Granite and its associated dyke flock. In addition to these units, there are ophiolitic rocks. The ophiolites in the southern part of the massif are located as thin slices at higher levels of the high-grade metamorphic unit [51]. Low-grade metamorphic rocks form the autochthonous cover of the massif. These units are tectonically covered by flyschoid sediments and island arc rocks. The youngest units of the region are continental and volcanic rocks. The Niğde Massif metamorphics have undergone ductile deformation and folding at least in four stages. In the first stage, the rocks of the massif were folded as flat-isoclinal and foliated structure parallel to the axis planes. Due to the isoclinal and severe folding of the layer planes of the rocks, layer transposition developed and plain folding structures were formed. In the second stage, NE-SW oriented and both northeast and southwest dipped folds were developed by deformation. As a result of the interference of the folds, mushroom-like folds were formed in the region. The mesoscopic folds in the second stage are congested-isoclinal geometry and offer asymmetric and curved folds. As a consequence of the folding in the 3rd stage, a large dom structure has been developed in the region. The folds in the 4th stage have formed sinform and antiform structures, which are approximately perpendicular to the 2nd stage, and NW-SE trending and dipping to the southeast. The deformation has occurred in the 4th stage and the basement and cover rocks have been jointly deformed. Microscopic analysis shows that the Cretaceous-Eocene rocks were metamorphosed at low-grade greenschist facies by deformation at this stage. The geometry of the end-stage folds reflects the folding pattern specific to the regions where the basement and cover rocks are deformed together [52].

3. HYDROCARBON SHOWS IN THE REGION

In the adjacent basins of the study area, Ulukışla and Tuz Lake Basins (Fig. 1), there have been studies for petroleum geology purposes, and many hydrocarbon shows are available (Fig. 2). The units of the Ulukışla Basin are continuous from Upper Cretaceous to Miocene, although they exhibit local unconformities. In these sequences, the units with the characteristics of petroleum source rock, reservoir rock, and cover rock exist [53-55]. The data obtained from the wells drilled in the Ereğli-Bor Basin [56], which is a sub-basin of the Tuz Gölü Basin, are the most important signs of the oil generation in the region. As a result of the surveys initiated by MTA in 2006, 15 wells were drilled totally in the region. In 10 wells, petroleum shows were encountered and thick oil shale levels were drilled. Within the scope of the project, in 2007, a deep exploration well (NBK-07/02) of 1168.4 meters in depth, which was drilled to the north of Badak Village (Bor province), liquid crude oil was found between 1035.0 and 1168.4 meters (Fig. 2). The crude oil was occasionally observed in the drilling mud as well. In addition, in 2008, liquid crude oil and oil shale were observed in 8 wells drilled around Yeniköy and Acıkuyu Villages (Ereğli). In KEY-08/02 core drilling in Yeniköy Village (from 437.8 meters) and in KEY-08/04 core drilling in Acikuyu Village (from 350 meters), oil shale levels and liquid crude oil shows emerged (Fig. 2). Crude oil is in the liquid form and dense, and is located in the cracks and pores between the foliations of dolomites, siltstones, and oil shales in Upper Miocene lacustrine deposits in the basin (Fig. 3). Crude oil and oil shales are in a 171-meter zone between 437.8-608.7 meters. While the oil shales reach a total thickness of 85 meters in the Yeniköy well, it has 55 meters thick in the Acıkuyu Village well. In the other drillings in the basin, the average oil shale levels of 40 meters thick have been met. The fact that oil shales were drilled in all the wells in the basin and that the oil shales are observed at an average thickness of 40 meters indicate that this basin has significant oil shale reserve. The potential reserve is reported as 8 billion tons [57]. Oil shales in the basin spread over a large area of approximately 100 km^2 [58]. The effect of increasing temperature and pressure with the burial of oil shales which is suitable for oil generation depending on the types of kerogen, and the circulation of hydrothermal solutions caused by young volcanic activities in the basin have caused significant oil generation and primary migration [59].

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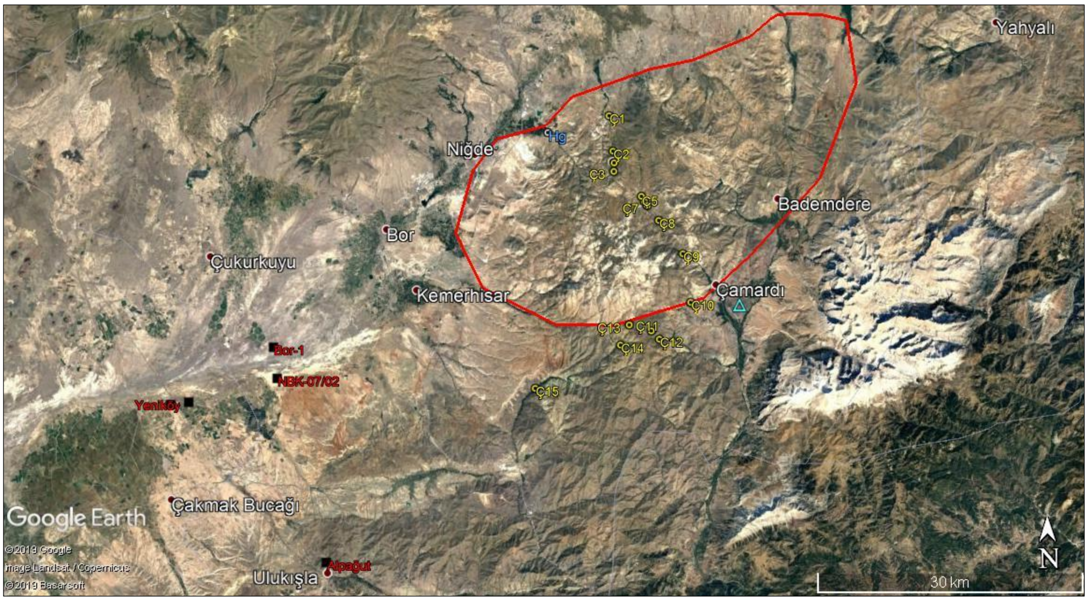

Figure 2. The hydrocarbon shows in the study area and its surroundings. Red polygon: Niğde Massif, yellow circles: the water samples, turquoise triangle: hydrocarbon show indicated by Erentöz and Ternek [47], black squares: shallow and deep wells also indicating hydrocarbon shows in the region, Hg: formerly operated Gümüşler mercury mine.

Figure 3. Views of oil shales and crude oil encountered in mineral exploration drilling in Ereğli-Bor Basin [59].

Sağlam [58] expressed that according to the average TOC amount of 4.72% and oil potential values obtained from the analysis results of 5 oil shale core samples taken during the drilling studies performed in the Ulukışla Basin, those formations have excellent hydrocarbon source rock potential. Besides, as the burial depth and TOC amount of oil shales in Acıkuyu (Ereğli) Village increase, oil and gas yield increase, the gas yield is higher than oil yield, and this result is thought to be caused by the kerogen types (Type II-III) (Fig. 2). Another finding of the same study indicates that oil and gas loss may be up to 0.5% if oil shale samples are kept in the open air for more than one week, and in some cases, this loss may be even greater. It has also considered that the samples had been waiting for 3 months in the open air before the experiment and the results obtained from the analyses might have been adversely affected under these conditions. In this case, it has been stated that the analysis results (oil and gas yield) obtained from the original samples taken from the subsurface should be higher than the determined values. Pusat [55], Sonel and Sarı [54], and Sonel et al. [53] expressed that various

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units in Ulukışla Basin have hydrocarbon source rock and reservoir rock potential. Besides, the map of gas outflow locations given by Sağlam [58] contains important data for the presence of a petroleum system in the region. TG-9 well having the depth of 1770 m drilled in 1979 and TG-10 well having the depth of 2075 m drilled in 1979 and 1980 for stratigraphic purposes in Eregli-Bor Basin by Turkey Petroleum Corporation (TPAO) were completed as dry wells [60]. Seismic, gravity, and magnetic studies were carried out by TPAO in the basin after the determination of significant petroliferous levels in core drillings in Badak (Bor), Yeniköy, and Acıkuyu (Ereğli) villages. In 2008, exploration well (Bor-1) was drilled at a depth of 2500 meters (Fig. 2); however, no economic oil was discovered [57]. In Bor-1 well, Paleocene-Lower Eocene sandstone, shale, sandstone, and limestone units were passed through from the depths of 1750 m to 2500 m. These units are overlain by 250 m thick lithological units characterized by Oligocene sandstone, shale, and evaporite. At the top of them, Middle-Upper Miocene, Pliocene oil shale, dolomite, siltstone, sandstone, mudstone, anhydrite, salt, and shale units with a thickness of 1500 m are located [58,61].

Oil shales observed in the Ulukışla Formation were deposited in a shallow lake environment towards the Altay Village (Ulukışla) in the south of the basin. In the vicinity of the Altay Village, rather than oil shale, the transition to limestones containing dense crude oil-smelling freshwater fossils is observed. Therefore, the depth of the lake environment that deposited lacustrine Paleocene-Eocene units in the Bor-Ulukışla Basin increase from south to north and west to east. The levels containing crude oil which was encountered in the drilled wells firstly observed in Badak village (Bor) by MTA and then TPAO exist in oil shales (Fig. 2). Hence, the source rock in which the crude oil has been formed in the region is Miocene oil shale levels [58]. Sonel and Sarı [54] claimed that the rock samples taken from the Çiftehan (Upper Cretaceous), Halkapınar (Lower Paleocene-Lower Eocene), and Hasangazi (Middle-Upper Eocene) Formations have generated inconsiderable amount of gas and moderate amount of oil along with gas content at medium level and certain amount of oil and oil/gas and that the suitable conditions are available for hydrocarbon occurrence in Ereğli-Ulukışla Basin. The most important indicator for hydrocarbons in the Ulukışla Basin is the gas outflow in the water well in the Alpağut region (Ulukışla) (Figs. 2 and 4). Turkish Petroleum (TPAO) conducted TPH (Total Petroleum Hydrocarbons) analyses on the water samples taken from the water well containing a high amount of flammable gas in the depth of 130 m in Alpağut region and another water well which is located about 300 meters away from this well without gas outflow. According to the results of the analyses, the presence of n-alkane hydrocarbons in the C13-C40 carbon range has been detected in both water samples. The TPH values (4.50 and 7.49) of the water samples in the Ulukışla Basin are considerably higher than the recommended limit values for groundwaters. The water samples on which TPH analysis are conducted and gas sample taken from the same water well in Ulukışla have been compared with gas sample taken from Bor-1 well and correlations have been developed depending on those comparisons. According to bulk components and isotope analysis results, the sample taken from Ulukışla gas outflow and the gas sample taken from the Bor-1 oil well are located into the same area, which indicates that both samples are the products of a working petroleum system and have been featured by the thermogenic origin (Fig. 5). Besides, it was determined that the sample from Ulukışla gas seep was generated from the source rock containing highly mature Type-II kerogen, which shows that it is highly oil-prone. It has been evaluated that the Ulukışla gas sample could be generated from a source rock of about 1.50% V Ro maturity. This situation is supported by the fact that the Ulukışla gas sample was generated from Type-II kerogen characterized by the high-maturation level. In addition, it was observed that Ulukışla gas sample had a 5% biogenic gas mixture and this has been considered as a possible contribution for such a gas sample taken at a shallow depth of 130 m. The results of TPH analysis in regions as well as those of the organic geochemical analysis of the gas samples in the region from where the water samples have been taken are compatible with each other [62].

Figure 4. The image of gas outflow in the water well in the Alpağut region (Ulukışla) and the locations of the wells from where the gas and water samples taken.

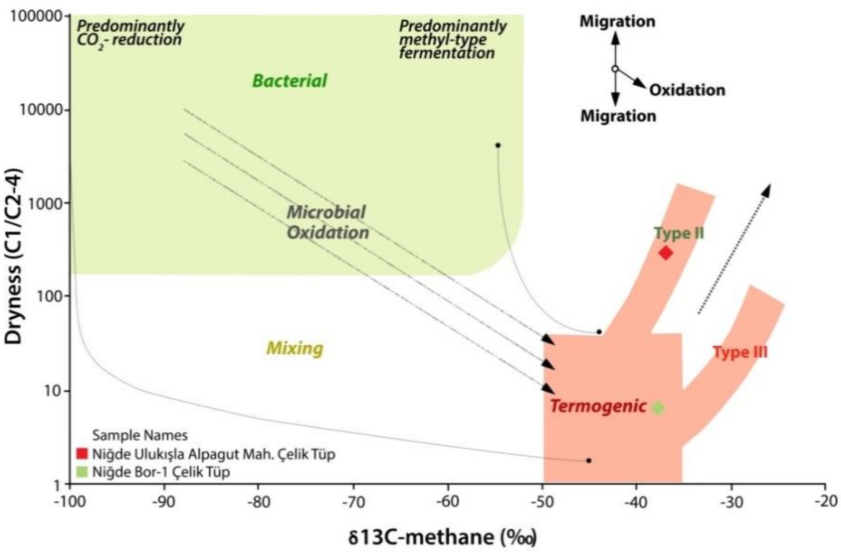

Figure 5. The origin of the gas samples taken from Ulukışla (Niğde) waterwell and Bor-1 (Niğde) oilwell [62].

4. FINDINGS AND DISCUSSION

4.1. Geochemical Findings

The study was based on the methods used and applied in the previous studies [63-66] as the material and the applied method. These studies contain detailed information. Hydrocarbon contents (Total Petroleum Hydrocarbons/TPH value) of water samples are extremely higher than the limit values that should be found in surface and groundwater (Table 1) [63-66]. According to Carbon Preference Index (CPI), hydrocarbons sign the high-mature organic matter derived from terrestrial plants (Fig. 6). According to the NAR (Natural n-alkane Ratio) parameter (Table 1), the n-alkanes show natural petroleum hydrocarbons. Ph/n-C18 values of all the water samples are less than 1 and therefore, the hydrocarbons are non-biodegraded.

Table 2. Analysis results.

Sample No	Water Resources	Coordinates X	Coordinates Y	TPH (mg/L)	CPI	NAR	TAR	n-C17/n-C31	Waxiness İndex	Pr/Ph	Pr/n-C17	Ph/n-C18	n-alkane maximum
1	Natural flowing water	4208407	662593	0.73	1.67	0.19	-	0.12	-	3.23	0.26	0.16	C29
2	Natural flowing water	4204364	663056	0.49	1.64	0.06	-	0.11	-	13.30	0.32	0.06	C29
3	Natural flowing water	4202047	663171	0.43	1.61	0.04	-	0.11	-	24.50	0.35	0.03	C29
4	Natural flowing water	4203024	663201	0.68	1.63	0.04	6.42	0.32	4.32	9.18	0.19	0.07	C29
5	Natural flowing water	4199235	666321	0.60	1.58	0.02	6.64	0.33	5.14	13.84	0.26	0.06	C28
6	Natural flowing water	4198613	666693	0.47	1.62	0.03	-	0.12	-	9.04	0.29	0.06	C29
7	Natural flowing water	4198190	666984	0.48	1.62	0.01	10.10	0.15	3.87	10.64	0.28	0.05	C29
8	Natural flowing water	4196513	668288	0.75	1.62	0.05	10.10	0.19	3.94	7.83	0.23	0.08	C29
9	Natural flowing water	4192745	671044	0.53	1.63	0.08	-	0.13	-	8.23	0.31	0.08	C29
10	Natural flowing water	4187250	671945	0.54	1.62	0.08	10.61	0.15	3.04	10.55	0.38	0.07	C29
11	Natural flowing water	4183998	667497	0.42	1.63	0.03	-	0.10	-	8.30	1.00	0.09	C31
12	Natural flowing water	4183058	668410	< 0.40	1.59	0.01	-	0.11	-	-	0.41	-	C31
13	Natural flowing water	4184657	664998	0.60	1.68	0.01	11.47	0.14	3.88	10.94	0.29	0.06	C31
14	Natural flowing water	4182373	664010	0.41	1.65	0.09	-	0.13	-	10.70	0.38	0.09	C31
15	Natural flowing water	4177442	654394	0.41	1.57	0.07	10.22	0.16	4.54	7.86	0.37	0.12	C31

CPI = {[(C23+C25+C27) + (C25+C27+C29)] / [2 *(C24+C26+C28)]} [67,68], TAR = (C27+C29+C31)/(C15+C17+C19) [69], NAR = [Σn-alk (C_{19-32}) - 2Σ even n-alk (C_{20-32})] / Σ n-alk (C_{19-32}) [70], Waxiness Index = ∑ (n-C21-n-C31)/∑ (n-C15-n-C20) [71], - : Could not be calculated.

The parameter TAR (Terrestrial/aquatic hydrocarbon ratio) reflects the ratio of the n-alkanes derived from terrestrial organic matter to the n-alkanes derived from aquatic algae [69,72-74]. High TAR values (> 1) sign terrestrial plant source whereas its low values (< 1) refer to marine algae source [75]. They have been calculated as very high for the tested water samples (> 1) (Table 1) indicating that the n-alkanes with high carbon numbers representing terrestrial organic matter are dominant in the water samples in the study area.

Waxiness index can be used to determine the amount of terrestrial organic matter based on the assumption that regional terrestrial organic matter contributes to extracts with high molecular weight n-alkane components [71]. It is seen that the water samples in the investigation area show high Waxiness values reflecting high amounts of biomarkers derived from terrestrial plant (Table 1). This finding is also supported by the fact that the analyzed water samples exhibit high TAR values.

The n-C17/n-C31 ratio indicates the source of the organic matter-derived hydrocarbons in the environment. Its high values (> 2) show marine algae while its low values (< 2) indicate land plant sources [76]. The ratio of n-C17/n-C31 of the water samples ranged from 0.10 to 0.33, indicating the terrestrial organic matter. This result is also consistent with TAR and Waxiness values.

The source rocks which derived the hydrocarbons are deposited in the oxic terrestrial environment (Type-III kerogen) and are high mature level (Figs. 7-10). Sonel et al. [77] determined that the kerogen types of Halkapınar and Hasangazi formations containing turbiditic sequences of Ulukışla basin are predominantly Type-III (gas-prone). The results of this study are compatible with the results of the Sonel et al. [77] study, and hydrocarbons should be derived from highly mature parts of those formations mentioned above (Fig. 7).

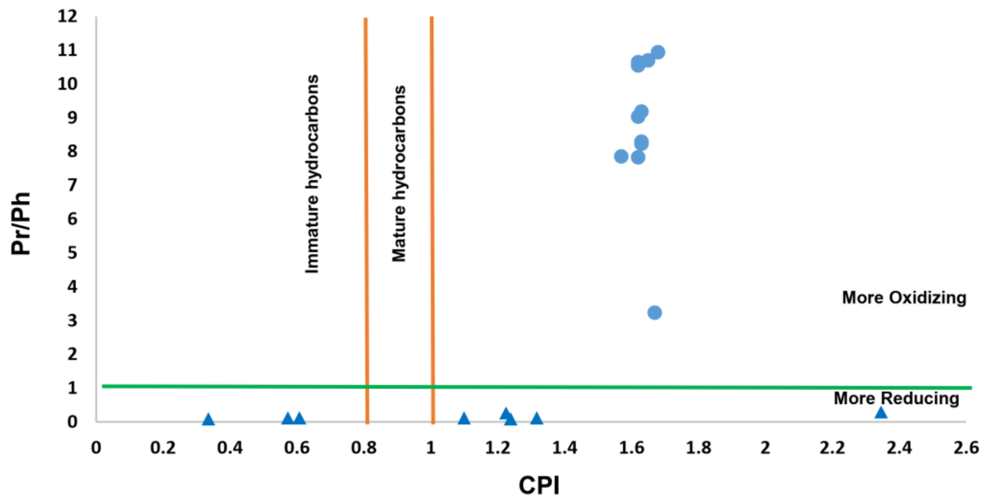

Figure 6. Pr/Ph vs CPI plot (the plot: from [78]). Blue circles: the water samples (this study), blue triangles: oil shales and crude oil samples obtained from Yeşilköy drillings [79].

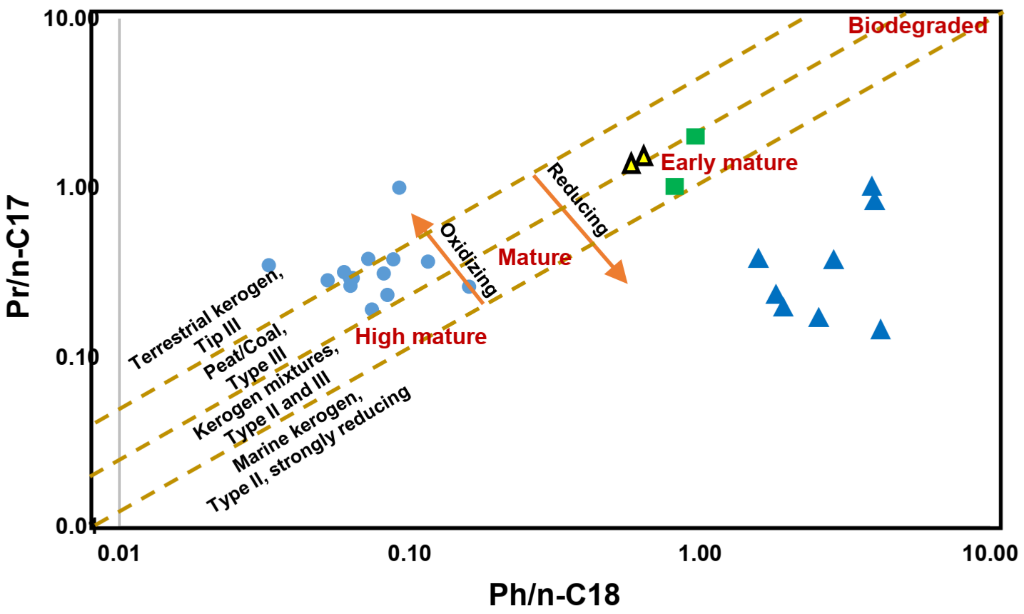

Figure 7. Pr/n-C17 vs Ph/n-C18 plot (the plot: from [80]). Blue circles: the water samples (this study), yellow triangles: source rock samples of Hasangazi formation [81], green rectangles: source rock samples of Halkapınar formation [81], blue triangles: oil shales and crude oil samples obtained from Yeşilköy drillings [79].

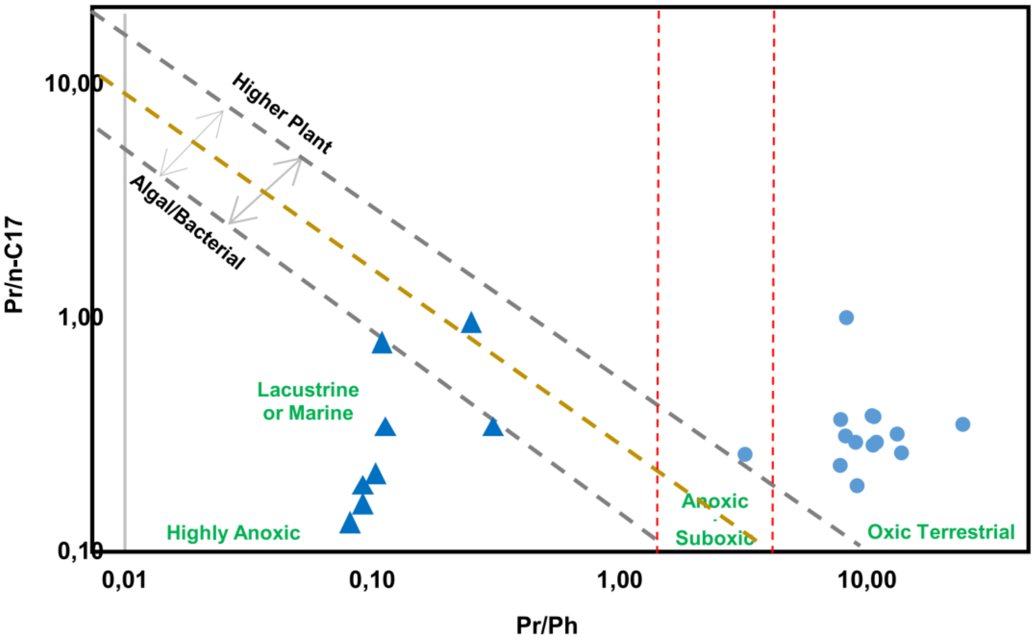

Figure 8. Pr/n-C17 vs Pr/Ph plot (the plot: from [82-84]). Blue circles: the water samples (this study), blue triangles: oil shales and crude oil samples obtained from Yeşilköy drillings [79].

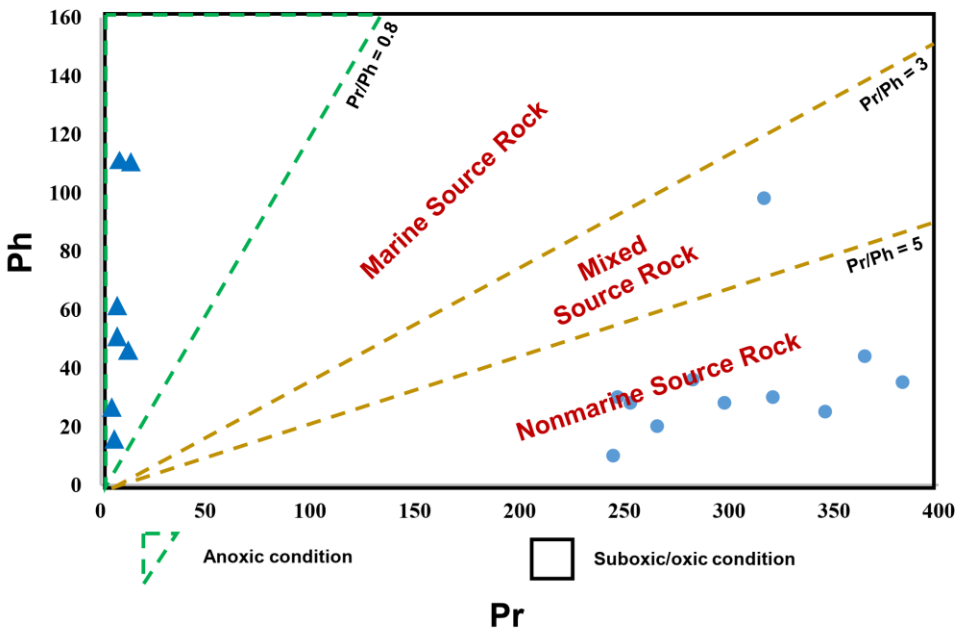

Figure 9. Ph vs Pr plot (the plot: from [85]). Blue circles: the water samples (this study), blue triangles: oil shales and crude oil samples of Yeşilköy drillings [79].

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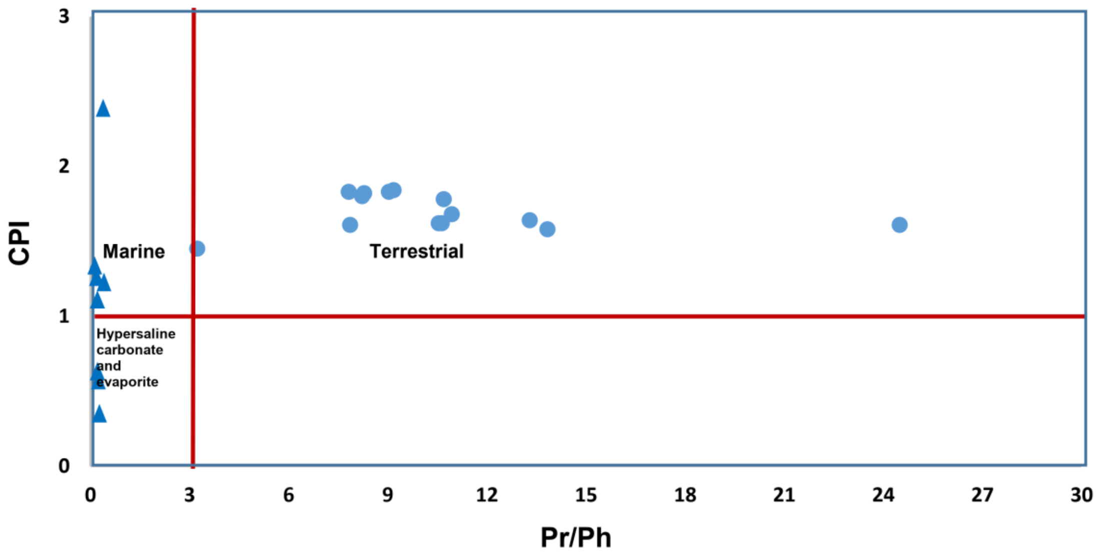

Figure 10. CPI vs Pr/Ph plot (the plot: from [86]). Blue circles: the water samples (this study), blue triangles: oil shales and crude oil samples obtained from Yeşilköy drillings [79].

4.2. Geophysical Findings

The Niğde Massif has a large dome structure (Fig. 11). Within this main structure, there are two distinct and small domes, one in the northwest and another one in the southeast. These structures are clearly seen in the images taken by utilizing the Landsat satellite (Fig. 12) [49]. These domes constitute the most important structures of the massif both geologically and economically. It is also possible that other dom structures else may exist in the massif. The settlement process of granite intrusion was effective in the formation of domes. The Gümüşler Dome, located in the northwest of the massif, is situated in the southeast of Gümüşler village [87]. An anticline extending in the NE-SW direction and dipping its axis to the southwest has formed the main structure of this dome. The granite intrusion, which causes the formation of the dome, cuts all the units and outcrops in the southern part of the dome [88]. The deformation phases during the tectonic development of the massif were explained in detail by Kleyn [89]. In the first stage, sedimentary units were metamorphosed and folded. Towards the end of this period, block faults occurred. The second stage took place when the rocks were no longer plastic. At the beginning of this stage, granite intrusion was settled into metamorphic rocks. The third stage was in conformity with the main phases of the occurrence of the Taurus mountains and the massif was significantly influenced by this mountain occurrence. These impacts are also observed in Tertiary units and the massive has gained the dome structure at this stage [89]. The Ören Dome is located in the southeast of the massif and in the north of Ören village. In the center of the dome, Üçkapılı granite exposes. The anticline, which forms the main structure of Ören Domu, extends in NW-SE direction and its axis is dipped to the southeast [87]. The Niğde Massif is bounded by the Ecemiş Fault (CAFZ) in the NNE-SSW orientation from the east (Figs 1 and 11). The Tuz Gölü Fault (TGF) in the west extends to the massif. The Niğde Massif is compressed by these two active fault systems (Fig 1).

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In the literature, there are many studies using gravity and magnetic methods for petroleum exploration [63-66,90-100]. In this study, gravity and magnetic data and maps were used to determine the areas where possible oil and/or gas traps are located (Figs, 13 and 14).

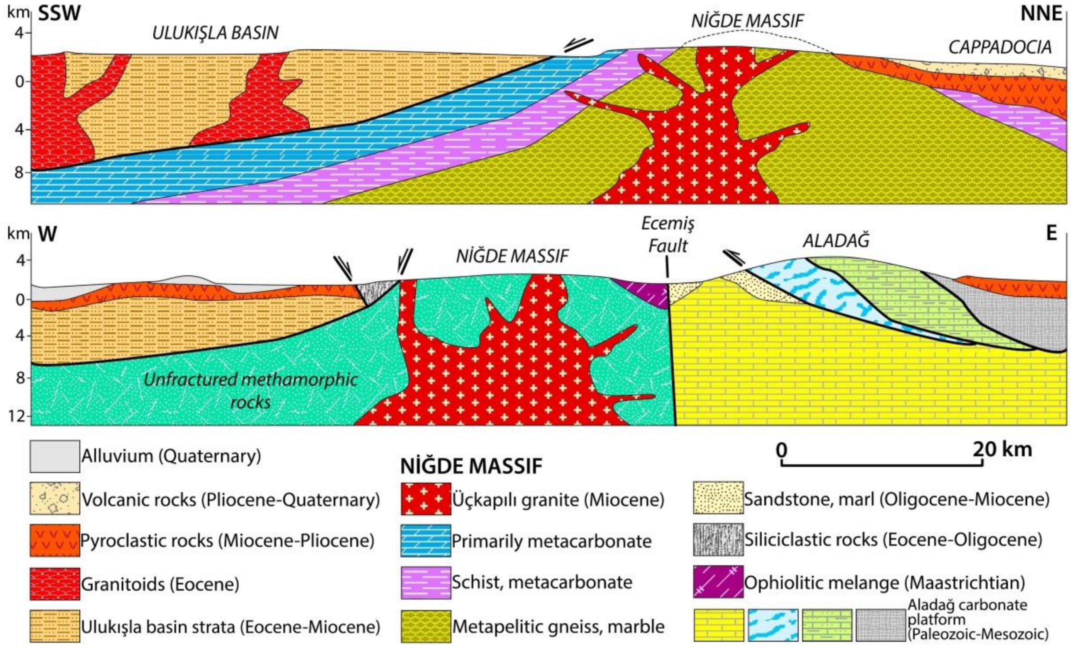

Figure 11. Geological cross-section of the study area (modified from [101]) (also see Figure 1).

As stated by Henden [49], Viljoen and Ileri [87], and Dennis [88], the dome structures (Fig. 12) extending in NE-SW orientation have been determined in the gravity map prepared for the study area (Fig. 13). Oil and gas accumulations in West Siberia have been observed in the areas where gravity and magnetic values caused by decrease in density and magnetism of the basement rocks are both low. It is also widely met that the gravity and magnetic values of the basement rocks exposed to the secondary alteration effects are less than their average values. The oil and gas fields above basement rocks with low magnetic and gravity are primarily located in the negative gravity and magnetic anomaly contours, i.e, in low gravity and magnetism areas. The revealed negative anomalies are in good agreement with the theory that epigenetic processes play an important role in the generation of hydrocarbon accumulations [102]. In the investigation area, both gravity and magnetism values of granites and metamorphic rocks, which are expected to be normally high gravity and magnetism, are very low (Figs. 13 and 14).

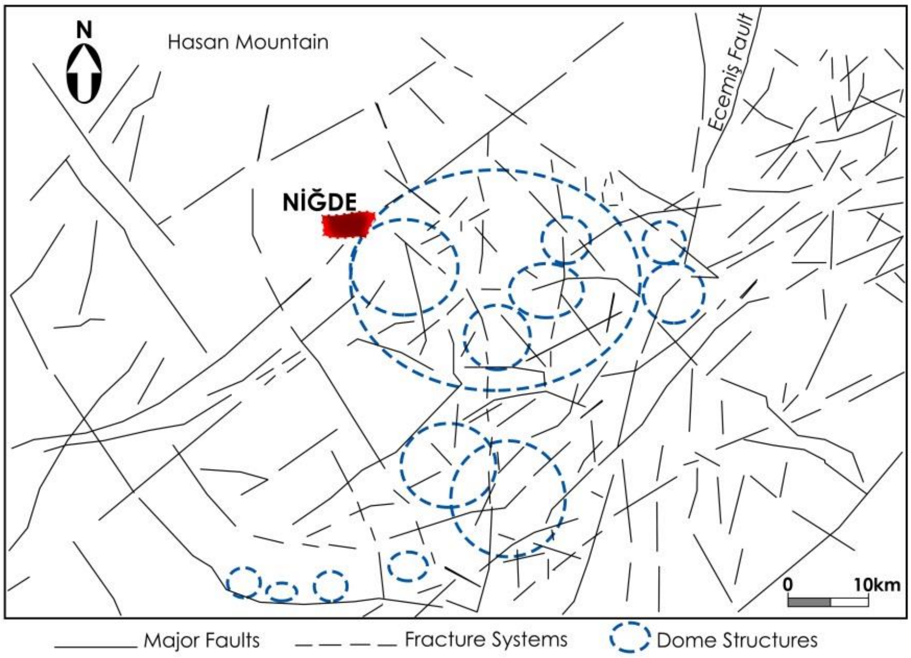

Figure 12. The fracture and fault systems in the Niğde Region obtained from Landsat satellite image (modified from [49]).

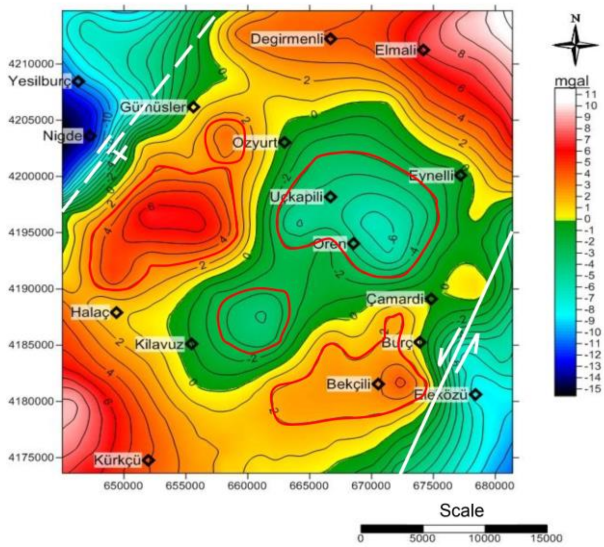

Figure 13. Colored contour map of gravity anomalies of the study area. Red polygons: Dom structures, white solid line: Ecemiş Fault, white dashed line: Niğde Fault.

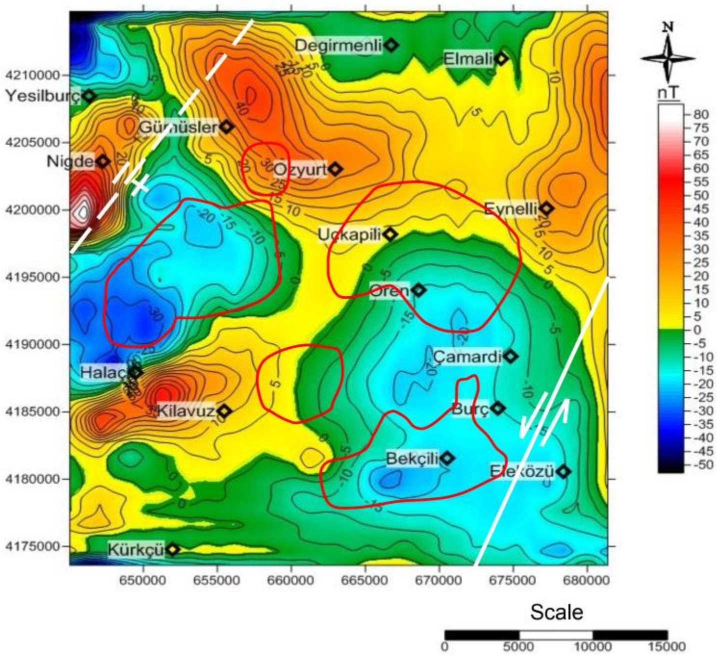

Figure 14. Colored contour map of aeromagnetic anomalies of the study area. Red polygons: Dom structures, white solid line: Ecemiş Fault, white dashed line: Niğde Fault.

4.3. Conceptual Model of Occurrence, Migration and Accumulation of Hydrocarbons

The understanding of the occurrence of petroleum source rocks is critical in oil and gas exploration. The factors controlling the occurrence and accumulation of the petroleum source rocks are related to the events and changes such as dynamics, chemistry, biology, etc. of an ocean system that take place through geological time. On the sedimentation in the Tethys Region, there is a great control of the paleogeographic location and the tectonic past, which have led to the formation, migration, and trapping of hydrocarbons in the region. Ozdemir and Palabiyik [103,104] have expressed that source rocks were formed in the mid-ocean ridges and in the continental rifts (spreading centers). Therefore, the source rocks which generated the hydrocarbons in the study area should have formed in the geological periods that involved the rifting process.

The water samples containing the mature hydrocarbons are evidence for a working petroleum system in the study area. Thus, high contents of mature hydrocarbons according to geochemical analysis results, and gravity and magnetic data indicate the presence of an oil and/or gas reservoir in the study area. The predominantly SW-NE orientation dome structures that can be trapped and protected of the hydrocarbons, formed by metamorphic rocks with granite in the center, are possible gas reservoir(s) in the study area. The fact that the structures are located between two fault zones and contain intense fracture zones increases the possibility of being accumulated in these dome structures of the hydrocarbons. In the formations, highly developed secondary permeability and porosity is expected thanks to the fractures and cracks caused by tectonic impacts (Figs, 14-16).

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Parnell [11] examined the granitic plutons containing biogenic petroleum hydrocarbons in the onshore UK and the migration of hydrocarbons to these plutons and proposed the mechanisms for interrelations of granitic plutons with biogenic hydrocarbons (Fig. 15). It is also stated that the presence of hydrocarbons in granitic plutons and other basic rocks is not evidence that these hydrocarbons are of abiogenic origin and that they host for the fluids migrating from peripheral environments to plutons, owing to being intensely fractured and heat center of plutons, including waters and biogenic hydrocarbons. Thus, it is suggested that hydrocarbons in plutons and other basement rocks are related to biogenic sedimentary source rocks in all conditions. The generated hydrocarbons maturing from the source rocks in the adjacent basin (Ulukışla basin) of the study area (Figs. 1 and 11) should have migrated to Niğde Massif units which uplifted during the settlement of Üçkapılı granite and accumulated in cracked and fractured zones and dome structures of the massif (Fig. 15). A and D mechanisms (Fig. 15) proposed by Parnell [11] are consistent with the geological units and their histories in and around the investigation area. According to the mechanism A, the intrusion of a pluton into an organic-rich sedimentary source rock causes a thermal change in organic matter in the source rock. A kilometer-scale pluton will have a extensively peripheral zone where the thermal maturation will occur (Fig. 15). The maturation of the organic matter in the source rock close to the hot intrusion causes the formation of liquid hydrocarbons and source rock generates a large number of hydrocarbons. According to the mechanism D, the granites around and in sedimentary basins help basin boundaries form. The reason for that higher topographic position of granites is generally caused by erosion and sediment accumulation. The boundary between granite and basin may be an unconformity and/or a fault. The upwelling migration of hydrocarbons from source rocks within a basin bounded by a granite can be realized through the fractures and cracks in granite and surrounding rocks. This process reveals the existence of biogenic petroleum hydrocarbons in the fractured granitic and other basement rocks. The hydrocarbons in the water samples should have migrated from the possible metamorphic-granitic reservoirs and mixed with shallow groundwaters (Fig. 16).

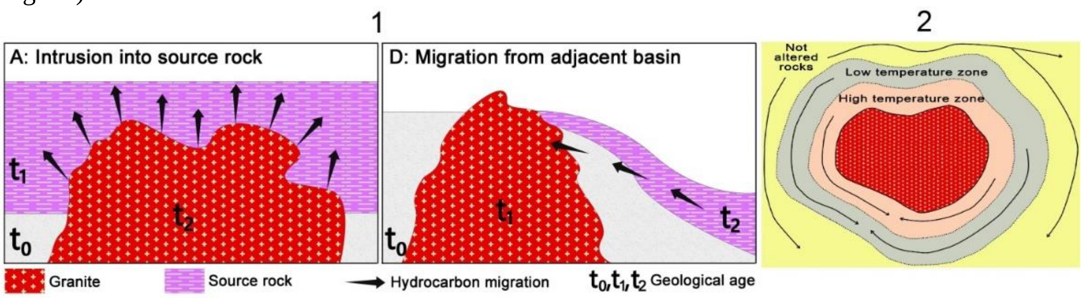

Figure 15. 1). The mechanisms which biogenic hydrocarbons are associated with granitic plutons (modified from Parnell [11]). 2) The metamorphic belt around the Üçkapılı granite.

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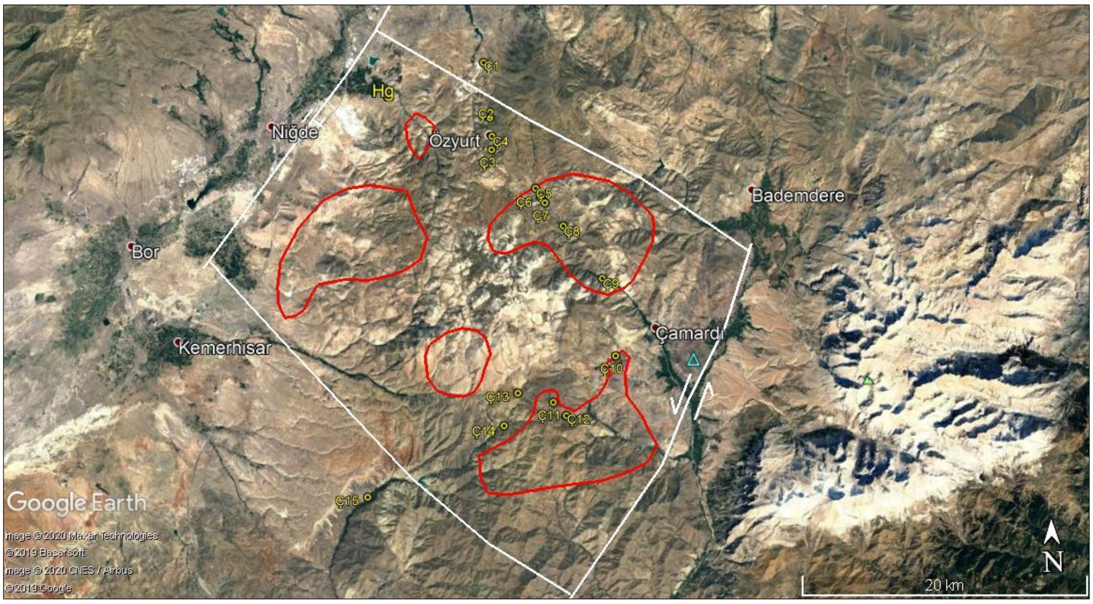

Figure 16. The possible hydrocarbon traps in the study area (red polygons). Yellow circles: the water samples containing mature petroleum hydrocarbons, turquoise triangle: hydrocarbon show indicated by Erentöz and Ternek [47], Hg: formerly operated Gümüşler mercury mine.

5. CONCLUSIONS

In the samples, the n-alkane hydrocarbons with high carbon number representing terrestrial organic matter seem to be dominant. The hydrocarbons are non-biodegraded. The source rocks generated the hydrocarbons are deposited in suboxic-oxic terrestrial environment (Type-III kerogen) and have a high level of maturity.

The mature hydrocarbon-rich waters are geochemical evidence for a working petroleum systems in the area where both gravity and magnetism values of granites and metamorphic rocks, which are expected to be normally high gravity and magnetism, are significantly low. It is also frequently encountered that the gravity and magnetic values of the basement rocks exposed to the secondary alteration effect are lower than their average values. The oil and gas fields above the basement rocks with low magnetic and gravity are primarily situated in the negative gravity and magnetic anomaly contours, i.e, in low gravity and magnetism areas. Hence, geochemical analysis results sign the presence of gas reservoir(s) in the area. The dome structures that can be trapped and protected of the hydrocarbons, formed by metamorphic rocks with granite in the center where predominantly SW-NE orientation, determined by gravity and magnetic maps, are the possible gas reservoirs in the study area.

The fact that the structure is located between two fault zones and contains intense fracture zones increase the possibility of hydrocarbons being accumulated in those structures because the locations of hydrocarbon-containing water samples are near and above these dome structures. In the units, it is expected that high degrees of secondary permeability and porosity due to the fractures and cracks caused by tectonic effects. The generated hydrocarbons maturing from the source rocks in the adjacent basin (Ulukışla basin) of the study area should have migrated to Niğde Massif units which uplifted during the settlement of Üçkapılı granite and accumulated in cracked-fractured zones and dome structures of the massif. The hydrocarbons in the study area should have migrated from the possible metamorphic-granitic reservoirs and mixed with shallow groundwaters.

Isotope analyzes (oxygen, Re-Os, etc.) should be performed to investigate the deep hydrocarbon system sources of the hydrocarbons in the water samples in the study area and to determine their geological ages. It is also important to determine the permeability and porosity of the crystalline rocks (metamorphic and granitic) in the study area.

Determining the hydrocarbon potential of the metamorphic massifs and granitic plutons is often impossible or long-term and very expensive by classic exploration methods. The method used in this study is thought that can be to change the framework of oil and gas exploration in the metamorphic massif and granitic rocks.

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