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Relationship between petroleum and iodine in Southeastern Anatolia Basin

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Research Article

Keywords:
Southeastern Anatolia basin, Iodine, Petroleum hydrogeology, Oil and gas exploration, Oilfield waters, Formation waters.

ABSTRACT

This study was made for investigating the relationship between iodine and hydrocarbon accumulations and to determine iodine contents of formation waters in the Southeastern Anatolia basin oilfields where have been produced almost all of the Turkey oils (more than 95%). Formation water samples have taken from 234 production wells in 49 oilfields which have different geological structures where oil and gas production has performed by the Turkish Petroleum Company (TPAO). Also, the drilling mud samples from EBY-17 oilwell in Elbeyli (Adıyaman) field has collected, and their iodine analyses were carried out. Although the fields in the Southeastern Anatolia basin are old and some fields the secondary production methods are used, the high relationship between the oil and gas deposits and iodine were proved. As well as in other oil and gas fields in the world, not all reservoir waters in the Southeastern Anatolia basin are saline. However, all of them are rich in iodine. Therefore, the iodine-rich waters are a direct indicator for oil and gas producible reservoirs (containing mature hydrocarbon). Reservoir-targeted iodine geology and hydrogeology methods have simple sampling process, and laboratory analyses can result at a short time. The results are low cost, reliable and consistent. In the case when these data are utilized with other geological and geophysical methods, it is determined will be a practical and useful tool to reduce the hydrocarbon exploration risk to a minimum and to discover new deposits suitable for commercial production.

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1. Introduction

Russians suggested the iodine as a hydrogeochemical indicator for oil and gas. Kartsev et al. (1959) stated that a vast amount of iodine in waters is originating from petroleum, and, iodine is a direct hydrogeochemical indicator for petroleum. Kovda and Salvin (1951) determined in their studies that the iodine content in soil usually is 10-4 %. However, iodine content of soils covering oil and gas fields increase up to 10^3% or 10^2%. Iodine has been used to discover an oil and gasfield in the many studies (e.g. Ginis, 1966; Kudel'sky, 1977; Gallagher, 1984; Allexan et al., 1986; Singh et al., 1987; Tedesco et al., 1987; Gordon and Ikramuddin, 1988; Tedesco and Goudge, 1989; Leaver and Thomasson, 2002; Goudge, 2007, 2009; Mani et al., 2011; Hummel, 2011). Collins and Egleson (1967), Collins (1969, 1975), Bojarsky (1970), Schoeneich (1971), Kudel'sky (1977) and Levinson (1980), in these studies, have proved the relationship between petroleum and iodine-rich waters in hydrocarbon production basins. Current studies are showing that supporting geological and geophysical survey with iodine geochemistry increases the efficiency of hydrocarbon exploration. Use of iodine for the discovery of hydrocarbon fields has the advantage of both having reliable and consistent results and being simple and cost-effective. Besides, as anomaly results are controllable and repeatable, risks and costs of exploration are mitigated to a great extent (Leaver and Thomasson, 2002).

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2. Material and Method

All formation water samples, except for Mardin and Şırnak oilfields, were taken from the wellhead of the production well shown as figure 2. The samples from wells in Mardin (Çamurlu, İkiztepe, and Eastern Sınırtepe) and Şırnak (Güney Dinçer and Batı Kozluca) oilfields were taken from the separator due to finding gas together with the oil in wells. The samples taken from separator and wellhead have been performed tests in samples of oilfields belonging to the Adıyaman Regional Directorate of TPAO for detecting whether or not any difference between iodine values. According to the result of this study, it was seen that iodine values taken from separator were lower than the values taken from the wellhead. On formation water samples were carried out Iodine analyses using the titration technique based on the Hach (1992) method

Figure 1- Location map of oil and gas production fields in the Southeastern Anatolia basin of Turkish Petroleum Company (TPAO) in which the iodine analysis is carried out in the formation waters.

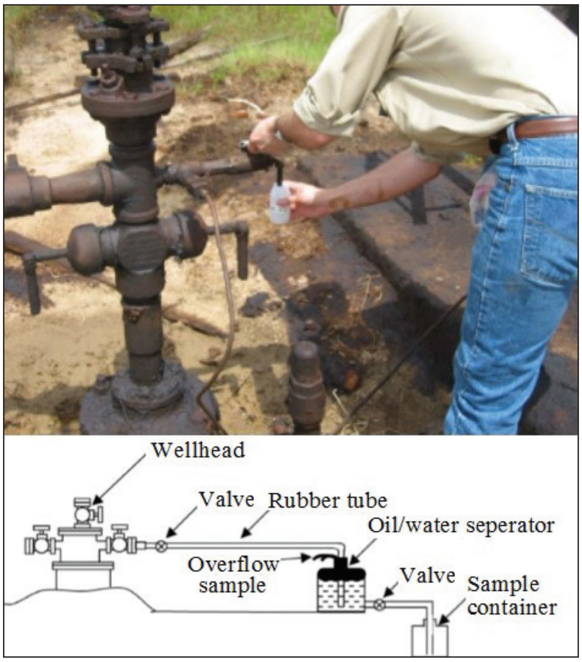


Figure 2- Schematical view of sample collection method from the oilwell formation water for iodine analysis.

and UV spectrophotometry device in TPAO Batman and Adıyaman Regional Directorates (Figure 3). The total iodine concentrations (mg/L) of the samples were detected by these analyses, and these concentrations were used directly in assessments.

Figure 3- An UV spectrophotometer device.

3. Relationship between Iodine and Petroleum

Iodine, which was discovered by Courtois in 1811 by extracting from seaweed ash, is scarcely found on Earth's crust. 99,6 % of Earth's crust is composed of 32 main elements. Remaining 0.4% shared among 64 trace elements. Ranking 61 among these 64 elements concerning abundance, iodine is one of scarcest non-metal elements within the composition of Earth's crust (Hora, 2016). It is a halogen with Symbol I, atomic number 53, atomic mass 126,92, density 4,93 gr/cm^3 and valency -1, +1, +3, +5, +7. In seawater, there is 0,05 ppm iodide ion concentration. The behaviors of iodine significantly differ from that of chlorine, since it has the most biophilic features among the halogens. The most significant reservoir of chlorine in the world is seawater (2,66x10^{16} tonnes, 72,2% of total chlorine), whereas the source of iodine is marine sediments (5,90x10^{12} tonnes, 68.2% of total iodine) (Muramatsu and Wedepohl, 1998). Thus, iodine enrichment is more related to the accumulation of iodine by marine phytoplankton, algae and organic matter deposition on the marine sediments rather than seawater (Tsunogai, 1971; Price and Calvert, 1977; Elderfield and Truesdale, 1980; Harvey, 1980; Lloyd et al. 1982; Tomaru et al., 2009a, b). Iodine distribution in seawaters and oceanic waters shows that sediments closer to the shore include more iodine than the deep sea sediments (Figure 4) (Shishkina and Pavlova, 1965).

Huang (1984) stated that most available geologically places for iodine accumulation of large and well covered, less deformed structures in areas where young and thick marine sediments are found (external neritic/bathyal reduction environment). Also, he defined the porous and permeable sandstones as the iodine reservoirs, the thick organic-rich shales as the source of iodine and the algae-rich organic matters as the accumulation regions of iodine. A vast amount of iodine (excluding potassium nitrate-caliche deposits in the Chile and seaweeds) find in the formation waters in oil and gas fields. Alvarez et al. (2015 and 2016) have determined that the source of the iodine in the Atacama (Chile), the most significant iodine deposit in the world, is the Jurassic, old organic-rich sedimentary basement. Some marine organism types like some seaweeds, planktonic algae, and corals take the iodine from the seawater and accumulate it in their bodies (Huang, 1984). Iodine accumulation mechanism in the mud of seafloor is as follows; 1) Accumulation in seaweeds, plankton diatoms, algae, and other marine organisms, 2) Accumulation of dead organisms on the seafloor. Iodine finds on the surface of organic sediments absorbed by colloid surfaces or bound to carbon components, and it is mostly immobile (Fuge, 1974). Marine organisms accumulate the iodine on external neritic seafloor together with inorganic

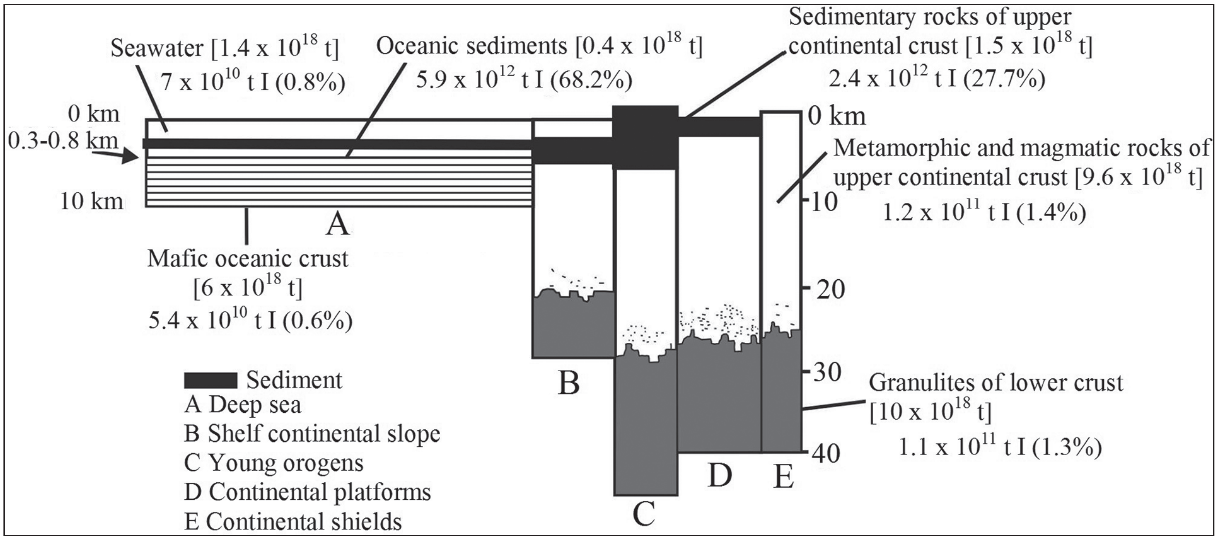


Figure 4- The distribution of iodine in the earth crust (Muramatsu and Wedepohl, 1998).

matters and in bathyal reduction environment, and also in clayed sediments which are primary sources of iodine in oil and gas reservoir waters. Iodine-rich waters have classified in two groups; (1) gaseous or petroliferous iodine-rich waters in oil and gas fields, (2) iodine-rich waters with the dry gas (dissolved natural gas) (Figure 5) (Huang, 1984).

The main reservoir of iodine in actual marine environments is organic matters. Organicrich sediments or their volatile derivatives (hydrocarbons) are primary sources of iodine in many sedimentary basins. Iodine enrichment in waters increases with proximity to petroleum reservoirs and depth of burial. Iodine increase in porewaters is faster than bromine (Warren, 2006; Martin et al., 1993). Salt lakes either contain a little iodine or no iodine at all (Warren, 2006).

The Organic-rich marine sediments and halite are primary sources for iodine in the terrestrial environment (Figure 6). These sources can be differentiated with I/Br ratios (Elderfield and Truesdale, 1980; Moran et al., 1995; Muramatsu and Wedepohl, 1998). Buried marine organic matter produces microbial/thermal methane and releases iodine. Meanwhile, iodine and

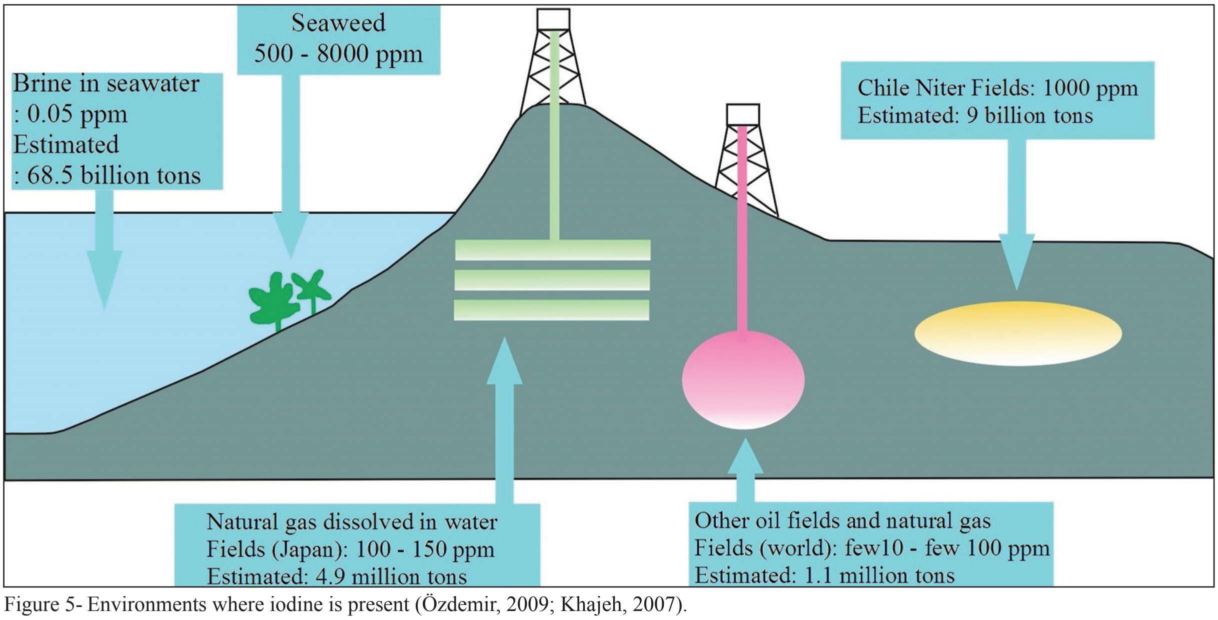


Figure 5- Environments where iodine is present (Özdemir, 2009; Khajeh, 2007).

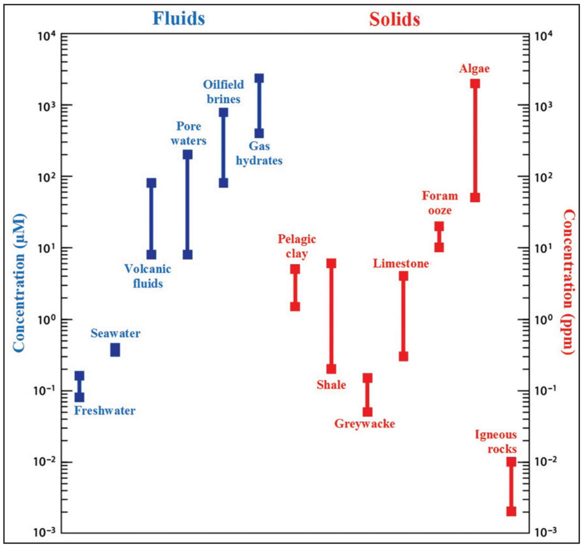


Figure 6- Iodine contents of different fluids and solid materials (Fehn, 2012).

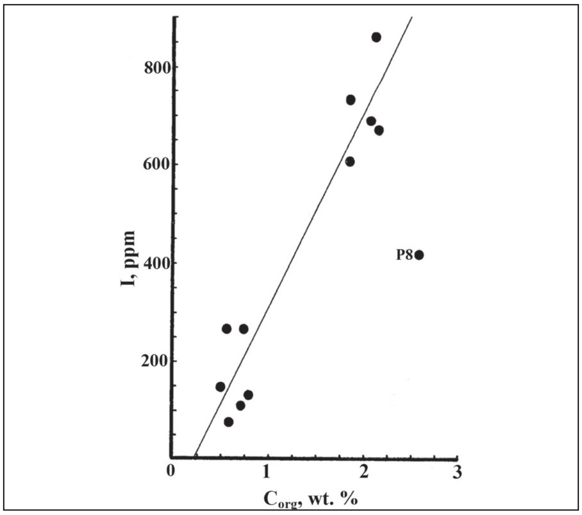


Figure 7- The relationship between salt-free iodine and organic carbon in Panama basin surface sediments. Sample P8 was omitted from the regression calculations since it deviates strongly from linearity. This deviation may be due to the presence of reworked, relatively refractory carbon in the core (Peterson, 1979).

methane (CH_4) which leave sediments accumulate in pore waters. These fluids which are rich in methane and iodine achieve to surface with leakages or trapped in sedimentary rocks in terrestrial environments. There is a vast amount of iodine in oil and gas field waters (Moran et al., 1995). The amount of decomposed organic matter during generating of hydrocarbon in the marine environment affects the amount of released iodine (Fuge and Johnson, 1986).

High concentration of iodine accumulation in near-coastal and continent margin sediments has reported in various studies (Vinogradov, 1939; Shishkina and Pavlova, 1965; Price et al., 1970; Pavlova and Shishkina, 1973; Price and Calvert, 1973). In sediments in the early stages of diagenesis are seen that the iodine and bromine contents generally decrease with the increasing burial depth (Shishkina and Pavlova, 1965; Pavlova and Shishkina, 1973; Price and Calvert, 1977). The loss of iodine in sediments is accompanied by the gradual decrease in organic carbon content and by iodine increase in pore waters (Pavlova and Shishkina, 1973). A similar increase can be expected in the content of bromine in pore waters. It is found that iodine increase in surface sediments is in direct proportion with organic carbon content (Figure 7; Peterson, 1979).

Iodine enrichment is a precise indicator of iodine-rich organic buried matter and is related to the rate of sedimentation (Figure 8). In zones with rapid sedimentation, iodine-rich organic matter buried rapidly, and most of the iodine trapped in pore waters. In slow sedimentation zones most of the iodine is also released into seawater (Martin et al., 1993).

The biological connection between iodine and carbon systems have well established. There is a strong relation between organic carbon and iodine concentrations in marine sediments. Iodine is found in low concentration in sedimentary rocks (for instance in carbonates <1 ppm, in marine evaporites <0.1 ppm). Shales generally contain high iodine concentrations like 1-20 ppm. The iodine amount found in sedimentary rocks cannot be found in any rock-forming mineral and cannot be absorbed in clay. It is more related to preserved organic carbon (Cosgrove, 1970; Collins et al., 1971). High amounts of iodine concentrations have measured in shales containing kerogen, the primary organic matter (Cosgrove, 1970). Wilke-Dörfurt (1927) and Cosgrove (1970) studies are shown close link between oil contents of shale ($r^2 = 0.98$) and organic carbon content ($r^2 = 0.76$), and iodine content of Lias (Posidonia) shales and Kimmeridge shales, the source rocks of North Sea (England) oil and gas fields. As iodine content is increasing in shales, oil and organic carbon contents are seen that increased (Figures 11 and 12). Greenhalgh (2016) stated that TOC (Total Organic Carbon) value of Kimmeridge shales is >10%, Hilger (2003) stated that carbon content of Lias shales is 9% and oil yield as 40-45 liter/tonnes.

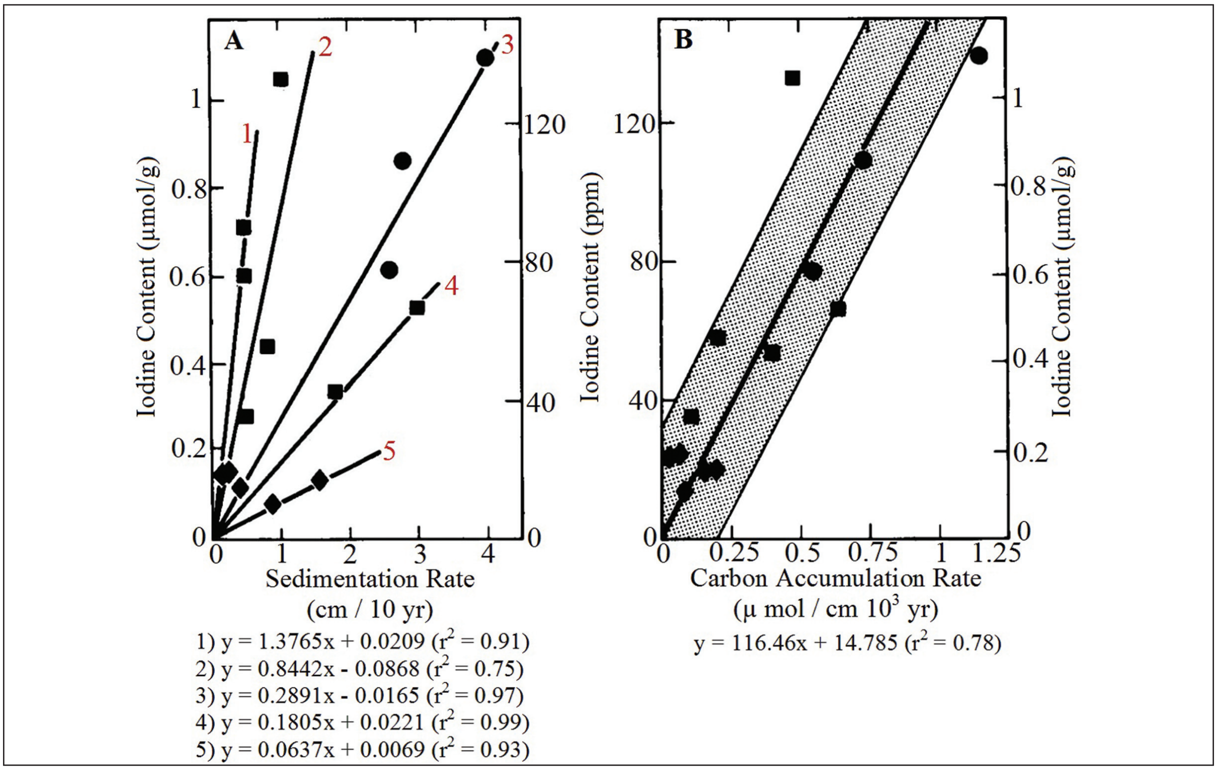


Figure 8- The relationship between iodine content, sedimentation rate, and carbon accumulation rate. The equations were determined from graphics by the author (from Kennedy and Elderfiel, 1987).

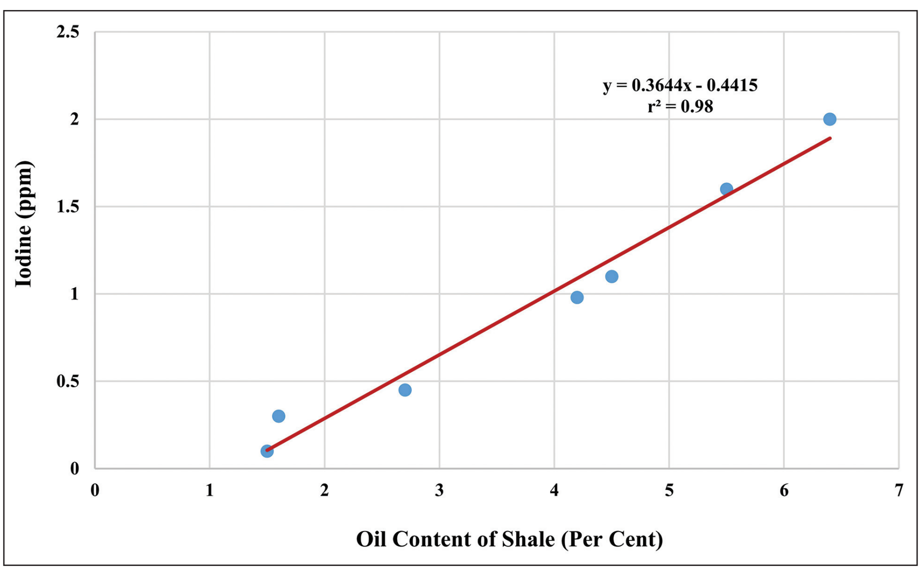


Figure 9- The relationship between oil and iodine contents of Lias shales (Data: Wilke-Dörfurt, 1927).

Compaction in deeply buried marine sediments pushes iodine-rich porewaters towards sands which are more conductive from clays and muds. Decomposition of organic matter releases iodine to porewaters, though slowly conditions of such process. Diagenesis of marine muds to shales causes a decline approximately 40% to 10% in the porosity from less and from 50 to 8 ppm in iodine content (solid phase). This process is a function of the pace of release, the age of sediment, depth and mineralogy, formation

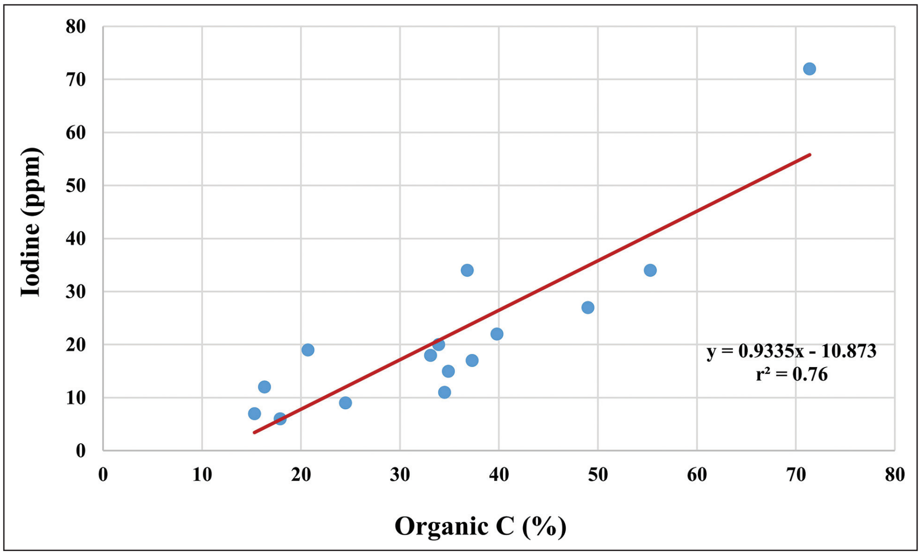


Figure 10- The relationship between organic carbon and iodine contents of Kimmeridge petroleum source rocks (Data: Cosgrove, 1970).

temperature and nature of bound iodine (Figures 11 and 12) (Fabryka-Martin, 1984). While organic matter turns into petroleum, most of the iodine is released to related waters (Fehn et al., 1990).

In halogen systematics of marine porewaters are seen that gas hydrates and most of the organic bromine are merged whereas maturing hydrocarbons, H_2S, CH_4, and iodine together are migrated from the basin

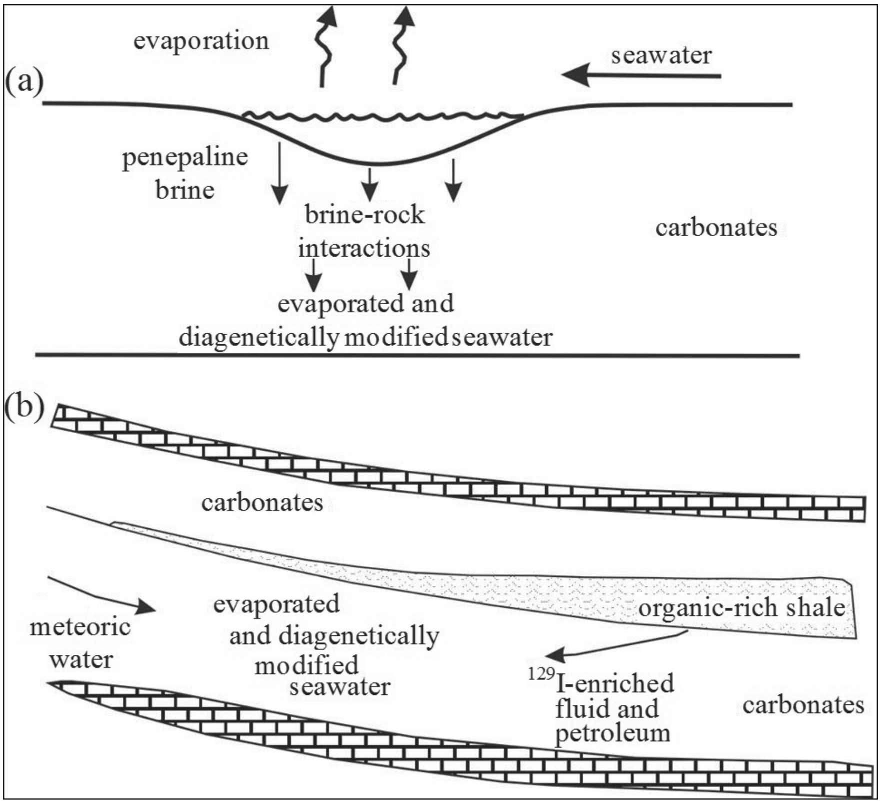


Figure 11- a) The schematic diagram showing subaerial evaporation of seawater, followed by chemical modification of penesaline brine in the subsurface. (b) Schematic diagram showing subsequent mixing of remnant brine with an I-enriched fluid from shales and with meteoric water from recharge areas (modified from Stueber and Walter, 1991).

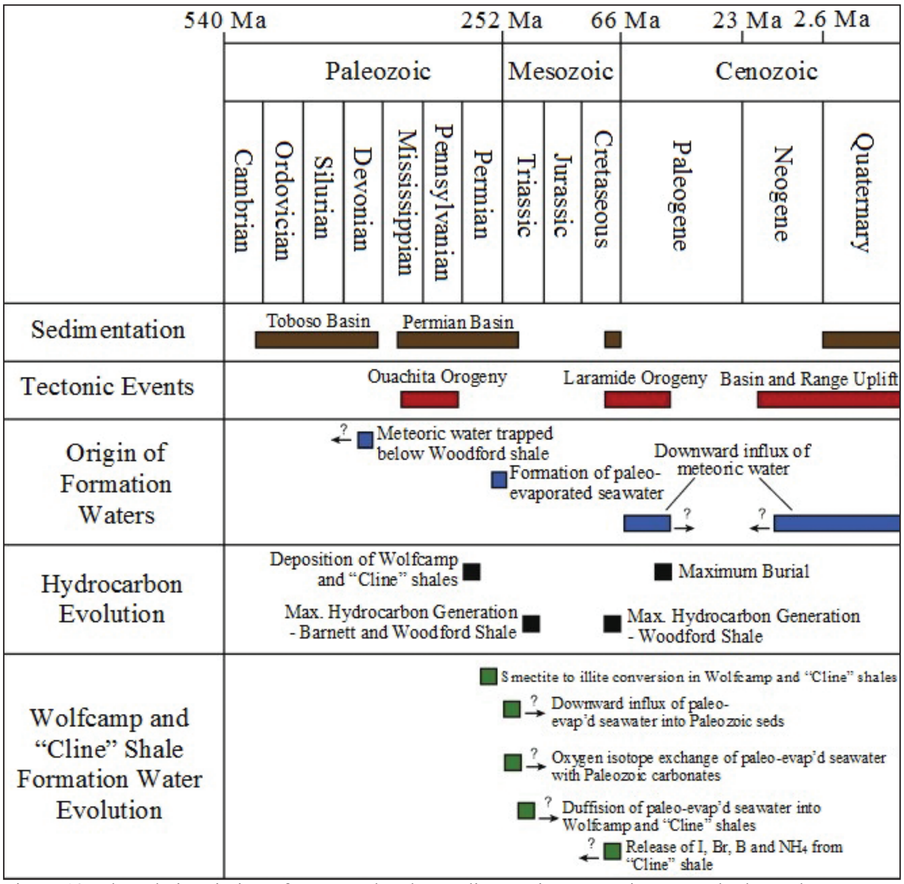


Figure 12- The relative timing of events related to sedimentation, tectonic events, hydrogeology, water-rock interaction, and hydrocarbon evolution in Permian Basin (Engle et al., 2016).

(Figure 13) (Kendrick et al., 2011; Fehn et al., 2003; Gieskes and Mahn, 2007; Muramatsu et al., 2007). Therefore, the potential of hydrocarbons to influence iodine and bromine contents of formation waters is high. High saline formation waters ensure organic Br contribution. Combined noble gas and halogen analyses provide an intriguing new method for investigating hydrocarbon-groundwater interactions because hydrocarbons have elevated Br and I contents and noble gases and halogens are both fractionated between hydrocarbons and groundwater (Kendrick et al., 2011).

Buried organic matter, which turn into petroleum after maturing and which cause to increase of iodine concentration in surrounding waters and which is the source of iodine in waters of sedimentary basins having vast amounts of hydrocarbon accumulation have dominant control over total iodine concentration. Chen et al. (2016) have stated that these iodine-rich waters mediate the hydrocarbon migration. Therefore, iodine concentrations of basin fluids can be used as a first approach to tracer the interaction between fluids and organic-rich sediments (Osborn et al., 2012).

Land (1991) and Stueber et al. (1993) studies have proved that to be a flow mechanism from depths towards Earth's surface of fluids in sedimentary basins. Harrison and Summa (1991) has calculated vertical velocities of fluids in sedimentary basins and suggested iodine releasing model from thermal alteration of organic matter in solution (Mani et al., 2011). Synder and Fabryka-Martin (2007) stated that formation water has same 129I/I age with on the environment it derives and organic matter it interacts. Moran et al. (1995) submitted long distance vertical migration model for hydrocarbons and waters related with iodine, in the study made on fluid movements in sedimentary basins and age of source. Problems in these models are whether or not the iodine is bound to organic molecules for millions of years. It is an important subject. Because, iodine concentration of crude oil is very low (<1 ppm) (Fehn et al., 1990; Tullai et al., 1987). Therefore, iodine has preserved

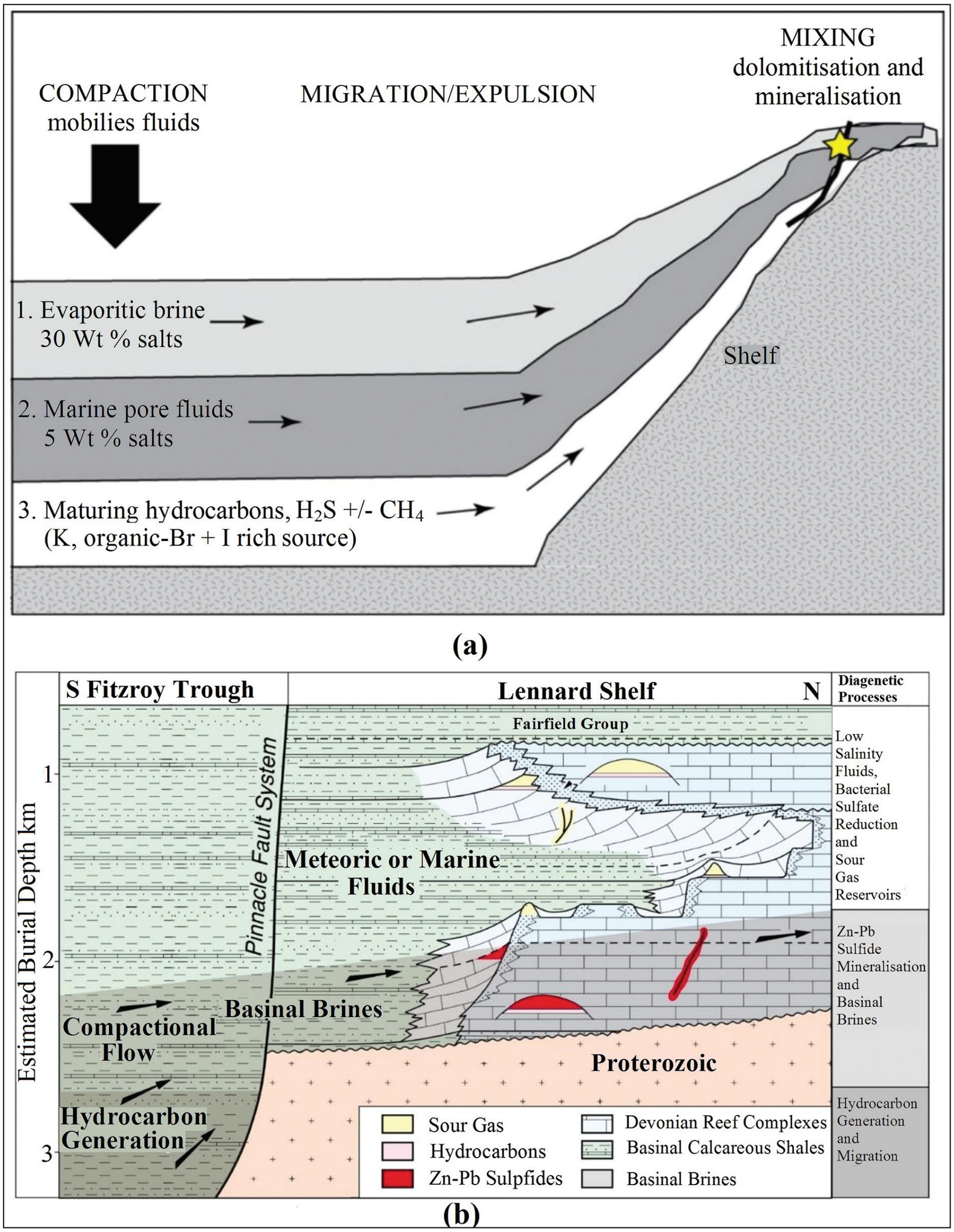


Figure 13- In the Lernard shelve of maturing hydrocarbons and iodine, (a) migration (from Kendrick et al., 2011), (b) trapping (Wallace et al., 2002) models.

its relation with organic C throughout decomposition of organic matter and sedimentation process and has released in water during thermal maturing. As iodine protects its close relation with organic C systems, the age of iodine will be the age of the organic matter with which iodine is in relation (Moran et al., 1998).

4. Discussion

Based on results of iodine analysis of water samples taken from oilwells of Southeastern Anatolia basin were evaluated iodine content of the formation waters in the wells and source of iodine in the basin. Also, the relationship between basin depth, oil (bbl)/ water (bbl) ratios in wells, water % in wells, reserves of oilfields with the iodine contents of formation waters were studied.

4.1. Source of Iodine in Waters and Iodine Contents of Waters Associated with Hydrocarbon Accumulations

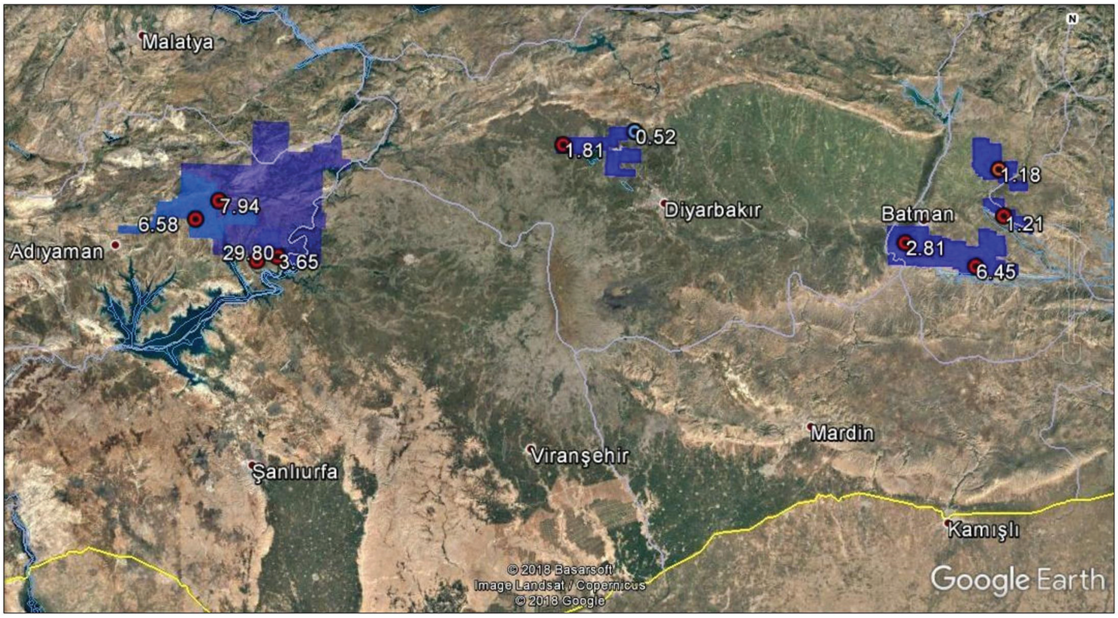
Iodine contents in the formation waters of the Southeastern Anatolia basin are consistent with the studies of Bojarski (1970) and Collins (1975). Iodine source in iodine-rich reservoir waters (iodine content >1 mg/L) of the Southeastern Anatolia basin, which is an oil and gas basin, is the organic-rich Silurian and Jurassic-Cretaceous petroleum source rocks. The results of iodine analysis of oilwells are given in figures 14-18 and Appendix-1.

In preliminary studies have been observed that formation waters of all oil and gas production basins in the world (including Southeastern Anatolia basin and Thrace basin) are contained >1 mg/L iodine (USGS Produced Water Database; Engle et al., 2016; Oppo et al., 2014; Oppo and Capozzi, 2015; Sudo, 1967; Kaiho, 2015; Kharaka et al., 1987; Dia et al., 1999; Dresel and Rose, 2010, Rowan et al., 2015; Mirnejad et al., 2011; Xun et al., 1997; Fisher and Kreitler, 1987; Dickey et al., 1972; Land, 1995; Birkle et al., 2002; Birkle et al., 2009; Franks and Uchytil, 2016; Hitchton et al., 1971; Machpherson, 1992; Kokh and Novikov, 2014; Novikov, 2013*a, b*; Novikov, 2012; Novikov and Shvartsev, 2009, Demir and Seyler, 1999, Kurchikov and Plavnik, 2009, Fu and Zhan, 2009, Kireeva, 2010, Bagheri et al., 2014). However, there are also production wells with formation waters containing iodine <1 mg/L in Southeastern Anatolia and Thrace basins (Appendix-1), Dörtyol (Hatay) gasfield, Cambay basin/India (Rebary et al., 2014) and in basins of other global oil and gas fields. Looking at the iodine contents of formation water samples of Southeastern Anatolia and Thrace basins, 60 of them >1 mg/L, 59 of them between 0,5-1 mg/L, 108 of them between 0,1-0,5 mg/L and 16 of them range between 0,01-0,08 mg/L (Figure 19). Formation waters with iodine content <1 mg/L in production wells, the oilfield waters are iodine content decreased waters as results of mixing with other water types (meteoric and reinjection waters) in the basin of oilfield waters with iodine content >1 mg/L. Çelik and Sarı (2002) detected meteoric water effect in the water sample produced from a well in the Karababa C formation which was one of the reservoir rocks of the Adıyaman oilfields. In another study (Çelik et al., 1998), has determined that formation waters in Adıyaman region could be trapped in marine units and they have been mixed with the meteoric water.

4.2. The Relationship between Depth and Iodine Content

Özdemir (2009) study carried out for iodine production from formation waters in the Gorgan (Iran) region it is seen that the iodine content increases in parallel with the increase in the depth. In this study, change of iodine content with depth was studied, and usability condition as an indicator of whether there is oil or gas in well during oilwell drilling of change of iodine content was evaluated. For this aim, iodine analyses have carried out by means of titration and UV spectrophotometer based on Hach (1992) method in laboratories of Adıyaman Regional Directorate of TPAO in drilling mud samples (well inlet and outlet) taken as parallel to penetration during drilling of EBY-17 oilwell drilled Elbeyli (Adıyaman) field and total iodine concentrations (mg/L) were detected.

According to the results of the analysis, the iodine content in the well increased in parallel with the increase in depth up to the oil zone. In the well which started with drilling mud containing 0,20 mg/L iodine at 100 m depth, when the well has reached 700 m depth, the content of iodine of drilling mud increased to over 1 mg/L. It was seen that the relation between the increase in iodine content of drilling mud up to 1900 m and depth increase was linear (iodine content at 1900 m is 4,07 mg/L). At a depth of 2000 m, the content of iodine of drilling mud suddenly increased to 10,72 mg/L. This zone was defined as water zone (containing gas + condensate?) above the oil zone. In oil zone, the content of iodine of drilling significantly decreased (average 0,55 mg/L), because, the content of iodine of crude oil is less than 1 mg/L (Fehn et al., 1987). At a depth of 2330 m, the lower water zone was entered leaving the oil zone (Figures 20 and 21). In this zone, the iodine content of drilling mud again increased (>1 mg/L). Oilwell was terminated at a depth of 2337 m. Production perforate zones of the wells in Elbeyli oilfield are at depths of 2050 - 2392 m. Reservoir units are Sayındere, Karaboğaz and Karababa C formations. As a result of the interpretation of geophysical log data obtained in EBY-17 oilwell was decided to perforate ranges between 2013 - 2115 m, 2138 - 2146 m, 2159 - 2168 m, 2177 - 2186 m, 2195 - 2203 m and 2234 - 2257 m of Sayındere formation; range between 2287 - 2294 m of Karaboğaz formation and range between 2308 - 2324 m of Karababa C formation. Zones to be perforated determined through geophysical logs and oil zones are compatible with oil zones determined by drilling mud iodine analysis.



No.	Oilfield	Average Depth (m)	API Gravity	Oil production percentage in southeast Anatolian basin (%)*	Maximum Iodine Content (mg/L)
1	Batı Raman	1300	13	22.30	2.81
2	Raman	1350	18	19.44	6.45
3	Beykan	1900	33.2	6.10	1.81
4	Karakuş	2700	30.1	4.66	6.58
5	Kurkan	1600	31.4	3.27	0.52
6	Beşikli	2100	25.6	3.06	3.65
7	Silivanka	2350	23.5	2.29	1.18
8	Garzan	1450	24	2.05	1.36
9	Cendere	2700	29	2.05	7.94
10	Elbeyi	2300	26.1	2.00	29.80
		Total (%)		**67.25**	**Average iodine content: 6.21 mg/L**

* Total oil production in the Southeastern Anatolia basin: 34917 bbl/day (September 2017 production data)

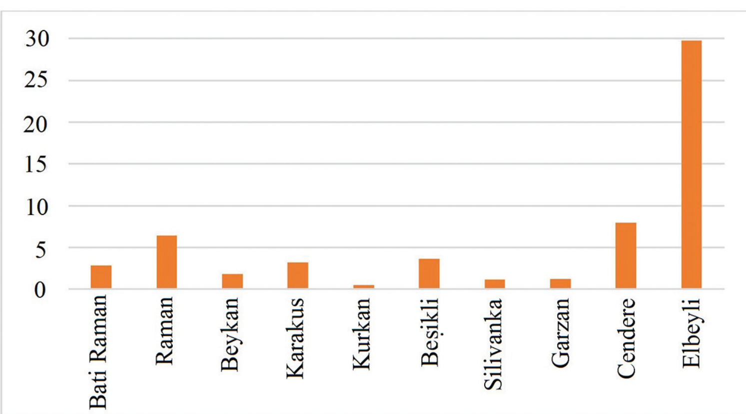
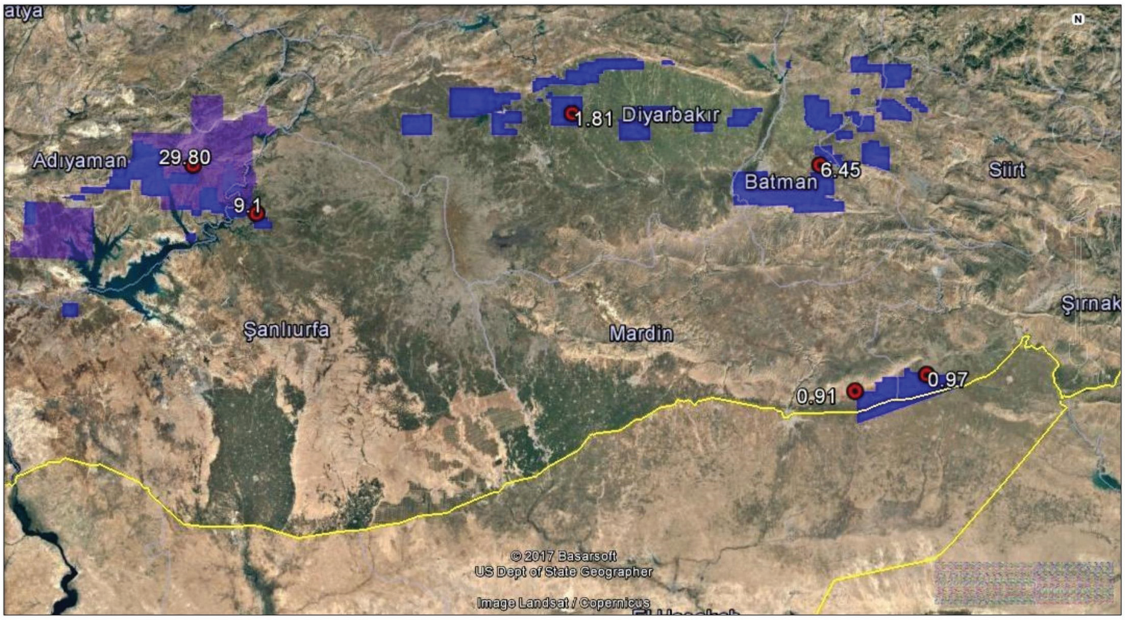


Figure 14- The highest iodine contents of formation waters in most productive 10 fields of the Southeastern Anatolia basin (blue polygons show the production fields).



City	Analyzed oilfield number	Analyzed well number	Oil production percentage in the Southeastern Anatolia basin (%)	Maximum Iodine Content (mg/L)
Batman	4	42	49.40	6.45
Diyarbakır	13	74	19.55	1.81
Mardin	4	17	2.14	0.91*
Şırnak	2	21	1.84	0.97*
Adıyaman	22	74	25.05	29.80
Şanlıurfa	4	6	2.01	9.10
Toplam	49	234	99.99	**Average iodine content: 8.17 mg/L**

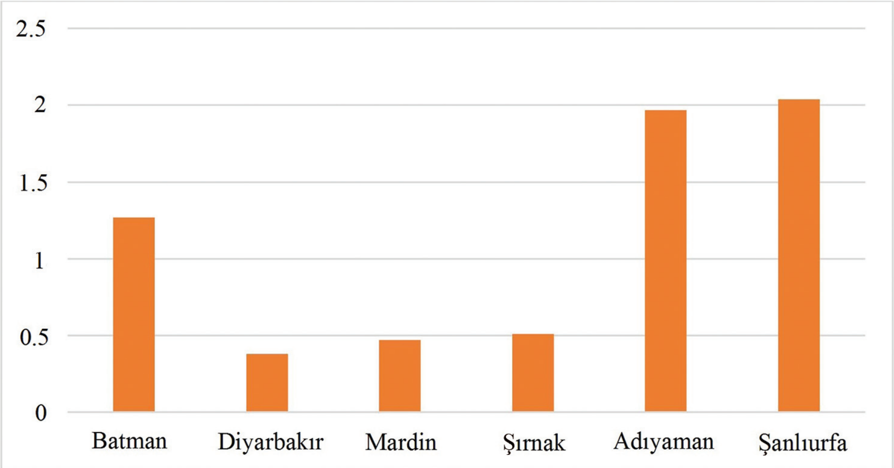


Figure 15- The highest iodine contents of formation waters in cities where oil and gas production in the Southeastern Anatolia region are made (blue polygons show production fields, *= water samples were taken from separator).

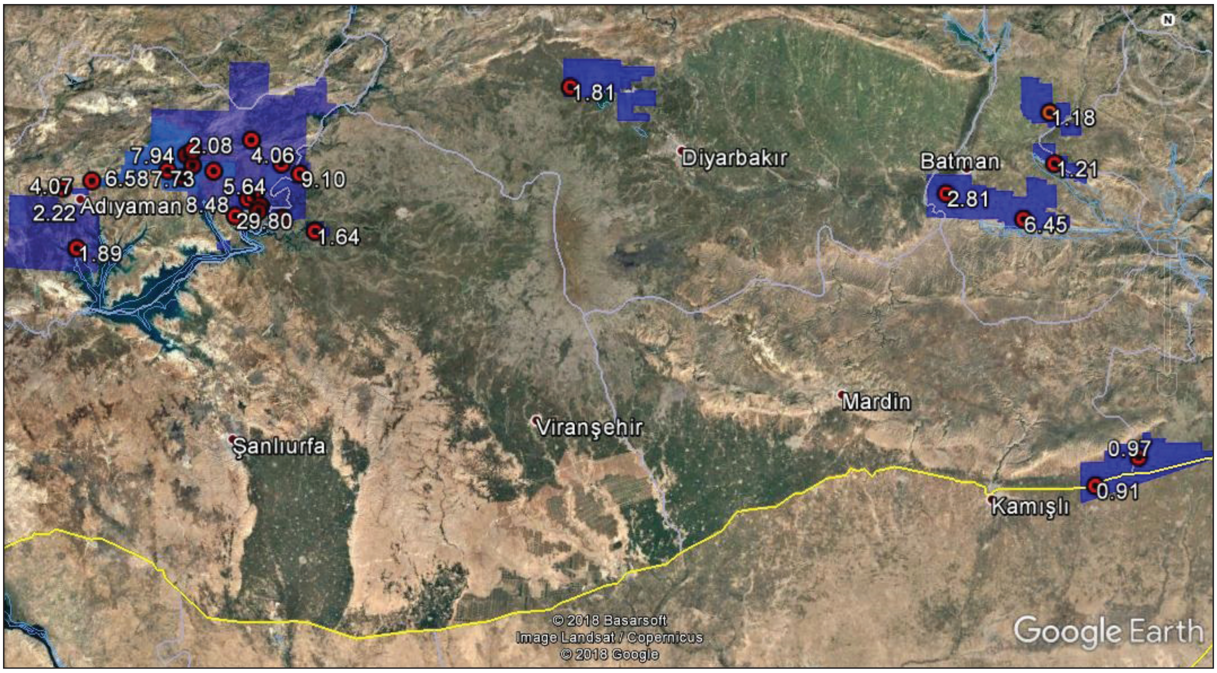


Figure 16- The highest iodine contents of formation waters in production wells of oil and gas fields in the Southeastern Anatolia basin (blue polygons show production fields and values are in mg/L. Mardin, and Şırnak water samples were taken from separator).

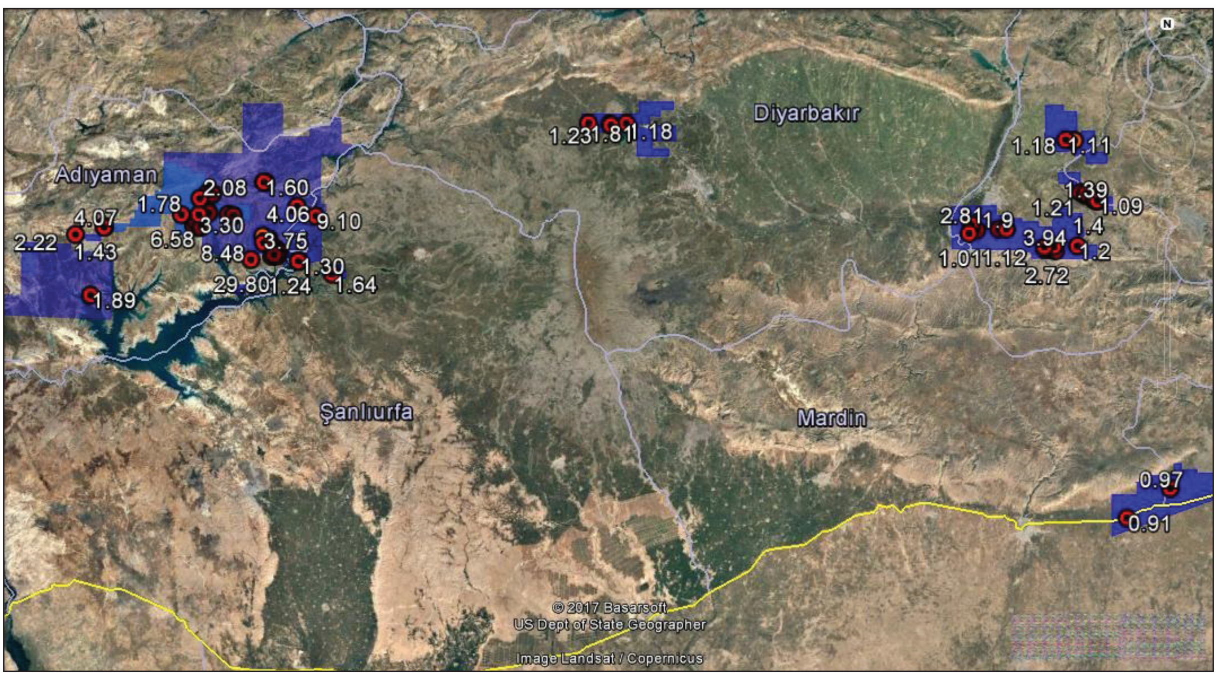
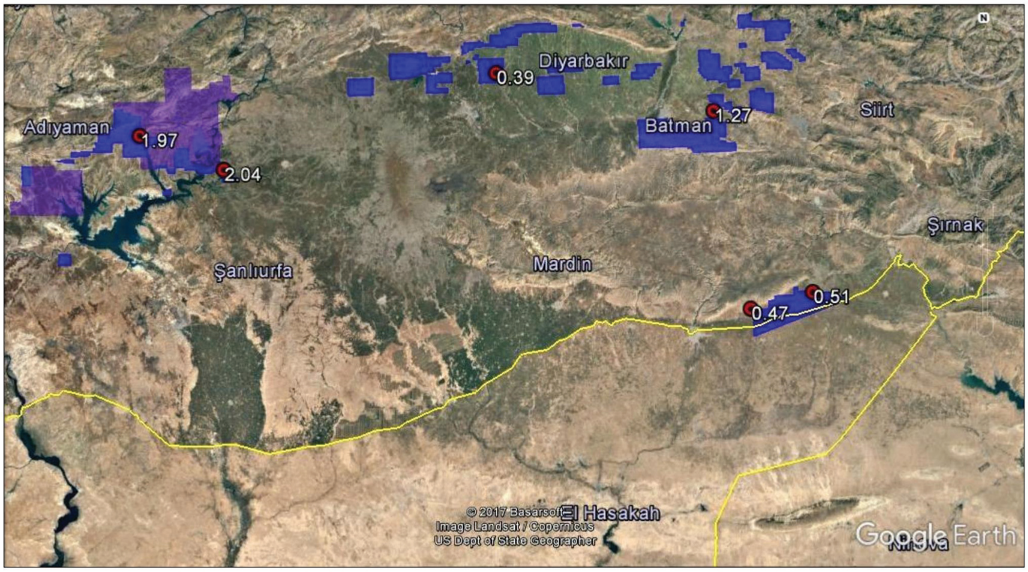


Figure 17- Distribution of oilwells with iodine content >1 mg/L in oil and gas production fields of the Southeastern Anatolia basin (blue polygons show production fields and values are in mg/L. Mardin and Şırnak water samples were taken from separator).

Net 512 barrels of oil is produced as daily from non-water EBY-17 oilwell. EBY-17 oilwell is highest net oil producing well of Southeastern Anatolia basin with this production. EBY-17 oilwell is highest net oil producing well of Southeastern Anatolia basin with this production. Water sample of the well as there was only oil in this well could not be taken so iodine analysis could not be performed. However, with a simple approach, it is thought that of iodine content of the well may be minimum two-fold of the iodine



City	Analyzed oilfield number	Analyzed well number	Oil production percentage in the Southeastern Anatolia basin (%)	Maximum Iodine Content (mg/L)	Average Iodine Content (mg/L)
Batman	4	42	49.40	6.45	1.27
Diyarbakır	13	74	19.55	1.81	0.39
Mardin	4	17	2.14	0.91*	0.47*
Şırnak	2	21	1.84	0.97*	0.51*
Adıyaman	22	74	25.05	29.8	1.97
Şanlıurfa	4	6	2.01	9.1	2.04
Total	49	234	99.99	**Maximum iodine content of oilfields in the Southeastern Anatolia basin : 29.80 mg/L**	**Average iodine content of oilfields in the Southeastern Anatolia basin : 1.11 mg/lt**

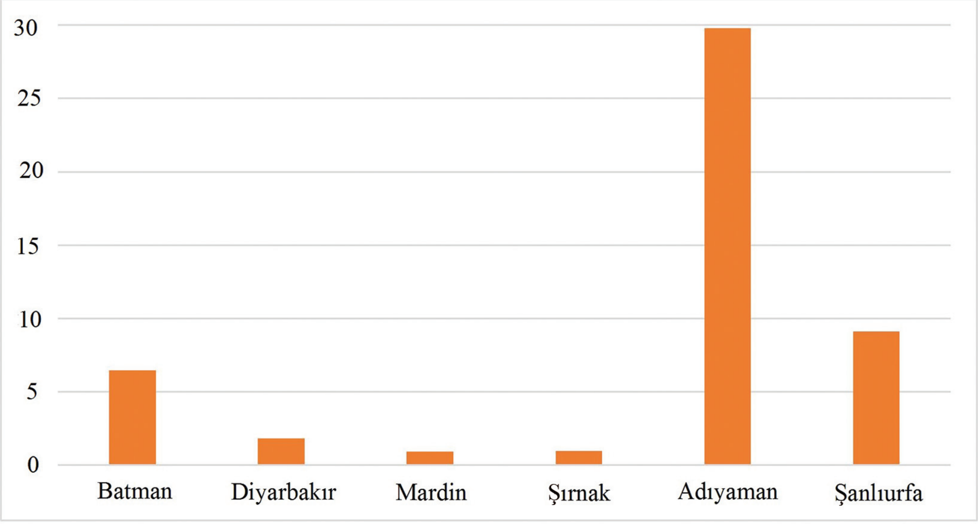


Figure 18- Average iodine contents of formation waters in cities where oil and gas production in the Southeastern Anatolia basin are made (blue areas show production fields, *= samples were taken from separator).

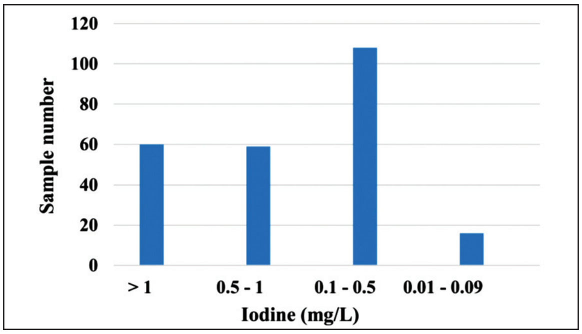


Figure 19- Iodine contents of formation waters in the Southeastern Anatolia and Thrace basins.

content of drilling mud. However, with a simple approach, it is thought that of iodine content of the well may be minimum two-fold of the iodine content of drilling mud. The highest iodine content in drilling mud was measured as 10,72 mg/L. This content is second highest iodine content measured in iodine analysis of oilwells (approximately 250 wells) in Southeastern Anatolia basin. In Southeastern Anatolia basin, the highest content of iodine is 29,80 mg/L in EBY-7 well in Elbeyli oilfield. From this well, 350 barrels of net oil is still produced daily.

According to Özdemir (2009) and results of this study, with iodine analysis to be performed on mud samples during drilling, are seen that it is possible that the prediction of oil volume to be produced from well and the detection whether there is oil or gas in the well (from increases/peaks in iodine contents of drilling mud both in entrance and exit of oil zone). Besides, these data from the EBY-17 oilwell is showed that iodine could be used as an excellent hydrocarbon accumulation indicator during both the exploration and drilling.

4.3. The Relationships between Oil (Bbl)/Water (Bbl) Ratios, Water% (Bbl) Ratios, and Iodine Contents of Formation Waters

Oil and gas reservoirs produced by primary methods have a natural water layer. These iodine-rich water constitute the most significant part of the volume of fluid produced during oil and gas production processes. Produced water amounts are different in oil and gas production fields. The amount of produced water depends on oil extraction technology and reservoir characteristics. Generally, gas wells contain less water than oil wells (Campos et al., 2002; Qiao et al., 2008). The average water/oil ratio in the world is 2/1 - 3/1, the 7/1 in the US. According to the produced

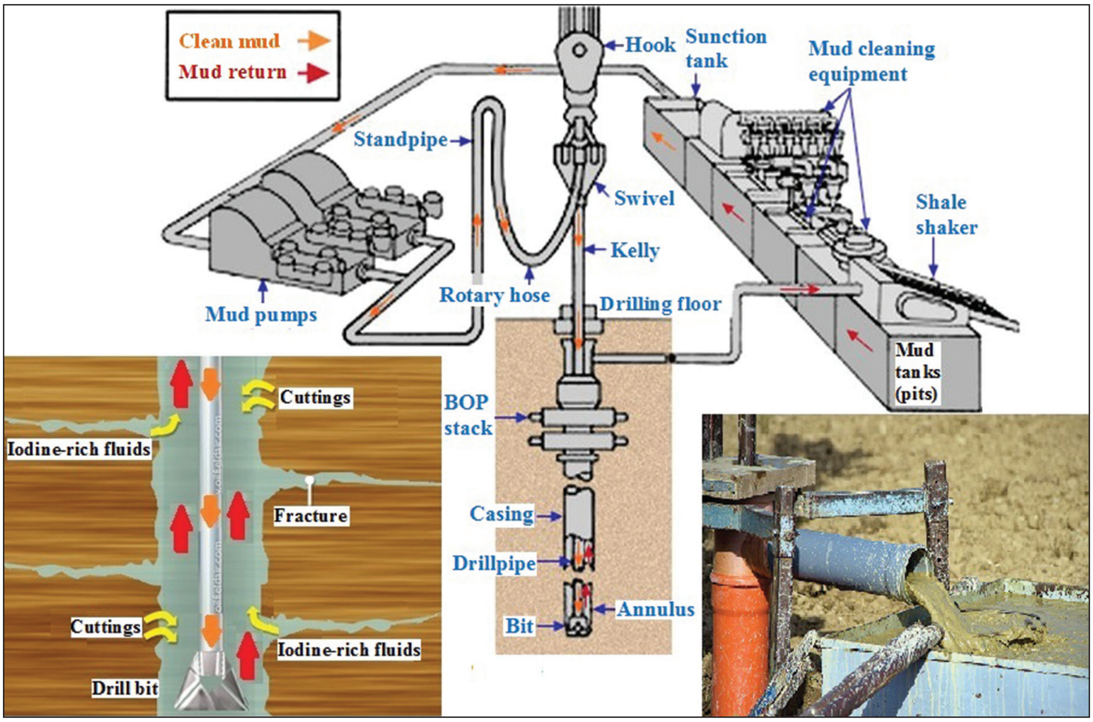


Figure 20- Schematic model for the investigation method of the relation between iodine content and depth in EBY-17 oilwell drilling mud.

Depth (m)	Sample location	Measured iodine (mg/L)	Iodine content (mg/L)
-100	Mud return	0.22	0.02
	Clear mud	0.20	
-200	Mud return	0.28	0.25
	Clear mud	0.03	
-300	Mud return	0.74	0.49
	Clear mud	0.25	
-400	Mud return	0.74	0.62
	Clear mud	0.12	
-500	Mud return	0.90	0.78
	Clear mud	0.12	
-600	Mud return	1.18	0.41
	Clear mud	0.77	
-700	Mud return	1.24	1.14
	Clear mud	0.10	
-800	Mud return	1.43	1.43
	Clear mud	0.00	
-900	Mud return	1.35	1.15
	Clear mud	0.20	
-1000	Mud return	1.22	1.13
	Clear mud	0.09	
-1150	Mud return	1.68	1.52
	Clear mud	0.16	
-1200	Mud return	0.59	1.46
	Clear mud	0.04	
-1300	Mud return	1.63	1.46
	Clear mud	0.17	
-1400	Mud return	3.19	3.19
	Clear mud	0.00	
-1500	Mud return	2.37	2.25
	Clear mud	0.12	
-1600	Mud return	2.73	2.73
	Clear mud	0.00	
-1700	Mud return	3.22	3.09
	Clear mud	0.13	
-1800	Mud return	3.31	3.26
	Clear mud	0.05	
-1900	Mud return	4.07	4.07
	Clear mud	0.00	
-2000	Mud return	10.72	10.65
	Clear mud	0.07	
-2100	Mud return	0.81	0.71
	Clear mud	0.10	
-2150	Mud return	0.77	0.67
	Clear mud	0.10	
-2200	Mud return	0.69	0.37
	Clear mud	0.32	
-2250	Mud return	0.74	0.69
	Clear mud	0.05	
-2300	Mud return	0.49	0.29
	Clear mud	0.20	
-2330	Mud return	1.08	1. 07
	Clear mud	0.01	
-2335	Mud return	1.82	1.74
	Clear mud	0.08	
-2340	Mud return	1.10	1.05
	Clear mud	0.05	

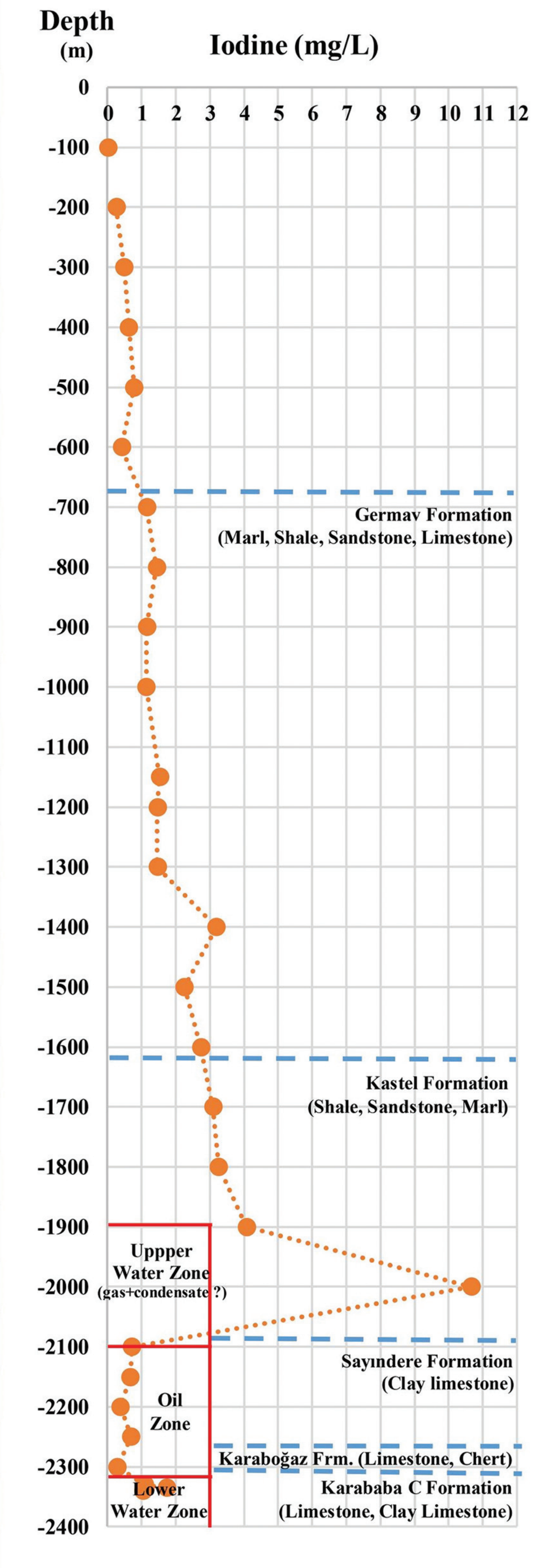
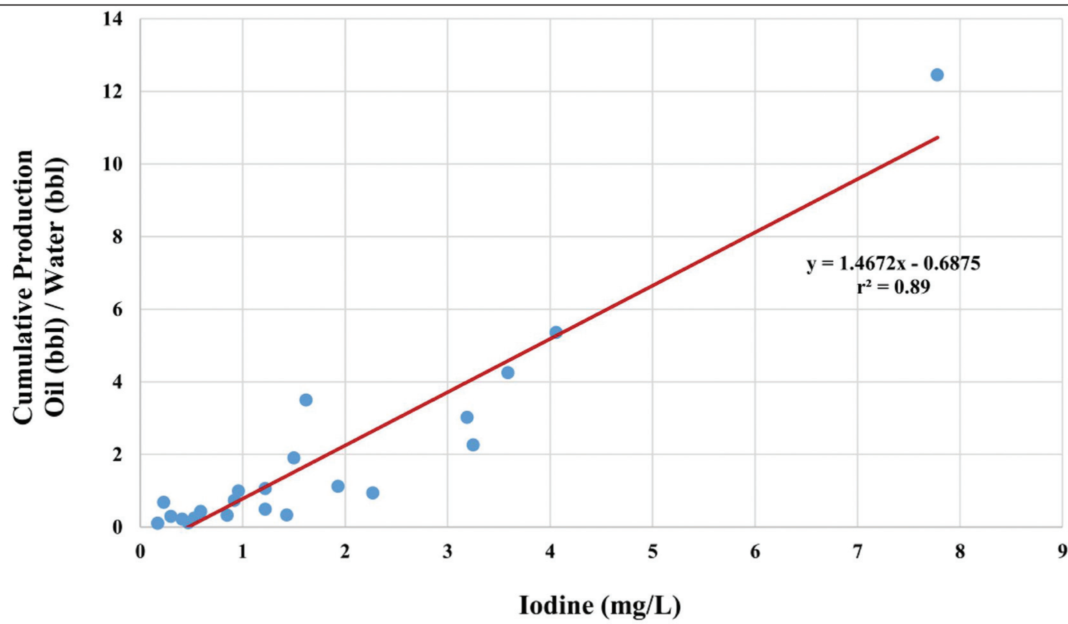


Figure 21- The graphics of depth and iodine content in EBY-17 oilwell.

water researches of the API (The American Petroleum Institute), the amount of produced water increase as a result of the age of oil production wells. In old wells in the US, this value is increased up to > 50/1 (Veil, 2006). In studies of API, the oil/water ratio has calculated as approximately 7,5 barrels of water per oil barrel. In oil wells which have reached the end of production life, the amount of water can be 10-20 barrels per of oil barrel. When water management cost starts to be very high, oilwell starts to none economic benefit (Lee et al., 2002; Veil, 2006).

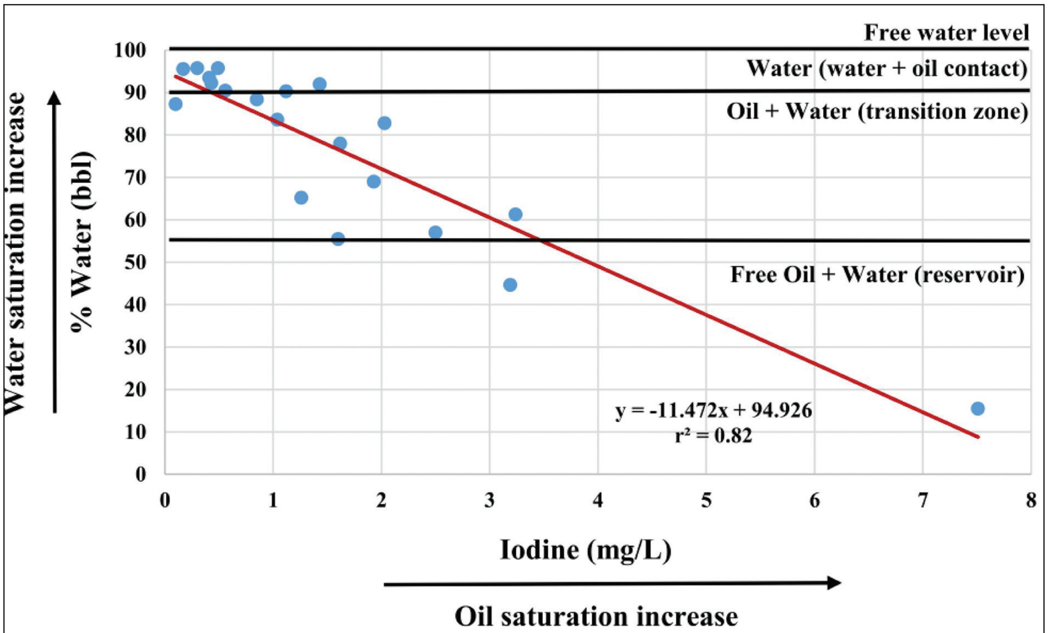
Water chemistry data in western Siberia (Russia) is used to estimate the amount and phase composition of hydrocarbons in reservoirs. Water chemistry data are useful indicators for migration processes as well as the formation of hydrocarbon accumulations and phase stages. Amount of total dissolved solids and content of salt ions (Na, Ca, Mg, Cl, HCO_3 and others), trace elements (I, B, Br) and dissolved gases have essential effects on the reservoir potential (Kurchikov and Plavnik, 2009; Plavnik et al., 2007; Pogodaeva et al., 2007; Borodkin et al., 2005; Shvartsev and Novikov, 2004; Surkov et al., 1999).

Results of iodine analysis in Southeastern Anatolia basin oil and gas fields and relations between oil (bbl)/water (bbl) ratios and water% (bbl) ratios were examined. A significant relationship was found between measured iodine contents and Cumulative Oil (bbl)/Water (bbl) ratios (r^2=0,89). As the iodine content increased, oil (bbl)/water (bbl) ratio also increased (Figure 22). There was also found a significant relationship between iodine contents and water% (bbl) ratio (r^2=0,82). As iodine content increased, water% (bbl) ratio decreased (Figure 23).



Oilfield	Cumulative Production Oil (bbl)/Water (bbl)	Average Iodine Content (mg/L)	Oilfield	Cumulative Production Oil (bbl)/Water (bbl)	Average Iodine Content (mg/L)
Adıyaman	0.53	0.25	Akgün	1.22	1.06
Çemberlitaş	1.22	0.49	Batı Raman	1.62	3.5
Karakuş	1.5	1.9	Raman	1.43	0.33
Kuzey Karakuş	0.47	0.12	Garzan	0.92	0.73
Cendere	2.27	0.94	Barbes	0.17	0.1
Beşikli	1.93	1.12	Beykan	0.85	0.32
Doğu Beşikli	0.96	0.99	Güney Kırtepe	0.59	0.43
Tokaris	3.25	2.26	Güney Sarıcak	0.23	0.68
İkizce	4.06	5.36	Güney Sahaban	0.11	0.3
Batı Gökce	3.19	3.02	Karacan	0.17	0.1
Gölgeli	3.59	4.25	Kurkan	0.3	0.29
Elbeyi	7.78	12.45	Yeniköy	0.41	0.22

Figure 22- The relationship between iodine content of formation waters and cumulative production Oil (bbl)/Water (bbl) ratios in oilfields of Southeastern Anatolia basin (Cumulative Production Oil/Water ratios of oilfields data are 2017 production data).



Field	Iodine Content (mg/L)	Water% (bbl)	Field	Iodine Content (mg/L)	Water% (bbl)
Adıyaman	0.49	95.75	Batı Raman	1.62	78
Batı Gökçe	3.19	44.67	Raman	1.43	92
Beşikli	1.93	69	Garzan	1.12	90.33
Cendere	2.03	82.81	Barbeş	0.17	95.56
Çemberlitaş	1.04	83.67	Beykan	0.85	88.38
Elbeyi	7.51	15.5	G. Kırtepe	0.43	92.25
Karakuş	1.24	66.2	G. Sarıcak	0.56	90.44
K. Karakuş	1.26	65.2	G. Şahaban	0.30	95.75
G. Karakuş	2.50	57	Karacan	0.10	87.33
Tokaris	3.24	61.3	Yeniköy	0.41	93.5

Figure 23- The relationship between iodine contents of formation waters and %water (bbl) ratios in oilfields of Southeastern Anatolia basin (Water% ratio data of oilfields are 2017 production data).

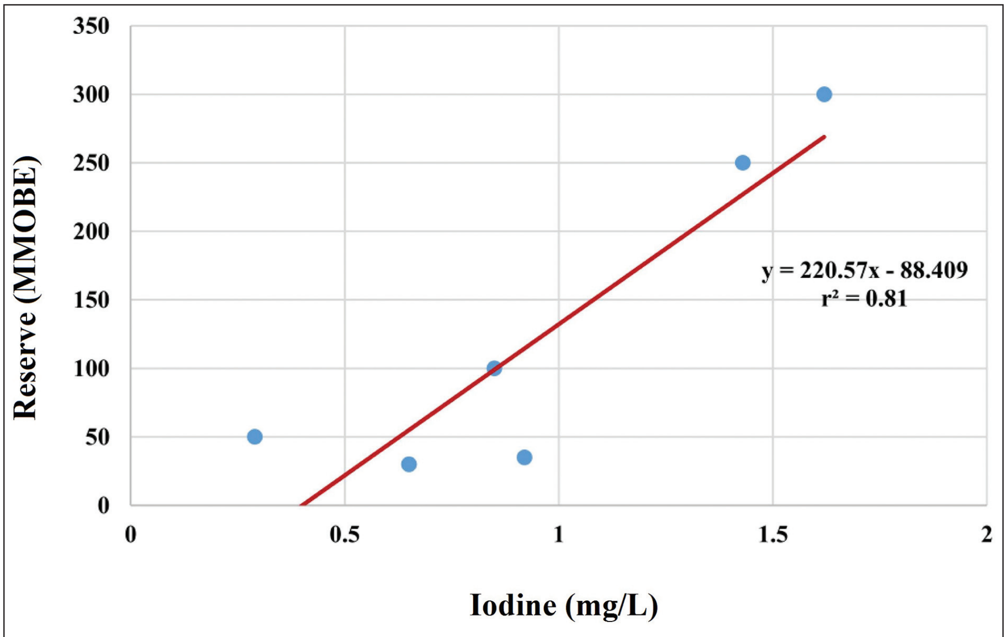
It is known that a vast amount of water is produced together with oil in Cambay basin (India) oilfields found formation waters with low iodine content (0,08-1,89 mg/L, the average value: 0,83 mg/L). Iodine contents of Ahmedabad oilfield formation waters: lowest 0,25 mg/L, highest 1,89 mg/L, average 1,06 mg/L; Ankleshwar oilfield: lowest 0,08 mg/L, highest 1,10 mg/L, average 0,48 mg/L and Mehsana oilfield: lowest 0,19 mg/L, highest 1,79 mg/L, average 0,96 mg/L (Rebary et al., 2014). The Ahmedabad oilfield, including 25 subfields, has discovered in 60's year and has been producing oil for more than 50 years. These are the fact that it has problems such as; multi-layer, heterogeneous, low permeable, low productive per well, and contains tight reservoirs. These difficulties bring various exploration and production challenges (water injection to the reservoir, etc.) to produce oil and gas from this area (Gupta et al., 2016). Similarly, iodine contents are low, and a vast amount of water is produced with oil in Southeastern Anatolia basin. Besides, there are also difficulties of exploration and production similar to Cambay basin.

The relationship between iodine and organic matter/organic carbon is linear (Figures 7, 8 and 10). Therefore, iodine contents of reservoir waters (petroleum saturation, oil/water ratio) are high in petroliferous basins found of source rocks containing high organic matter (kerogen). In the case, water saturation (water% ratio) of production wells will decrease because the abundance of iodine in formation waters is due to the release of most of the iodine in organic matter into related water during the transformation from organic matter to petroleum. This opinion is supported, the fact that these wells are highest net oil producing and least containing water wells (with highest iodine content) in Adıyaman region, EBY-17 well (512 barrels of net oil production, iodine content of drilling mud: 10,72 mg/L), EBY-7 well (350 barrels of net oil production, iodine content of formation water: 29,80 mg/L) and PYK-3 well (210 barrels of net oil production, iodine content of formation water: 9,1 mg/L).

4.4. The Relationship between Reserve and Iodine Content of the Formation Water

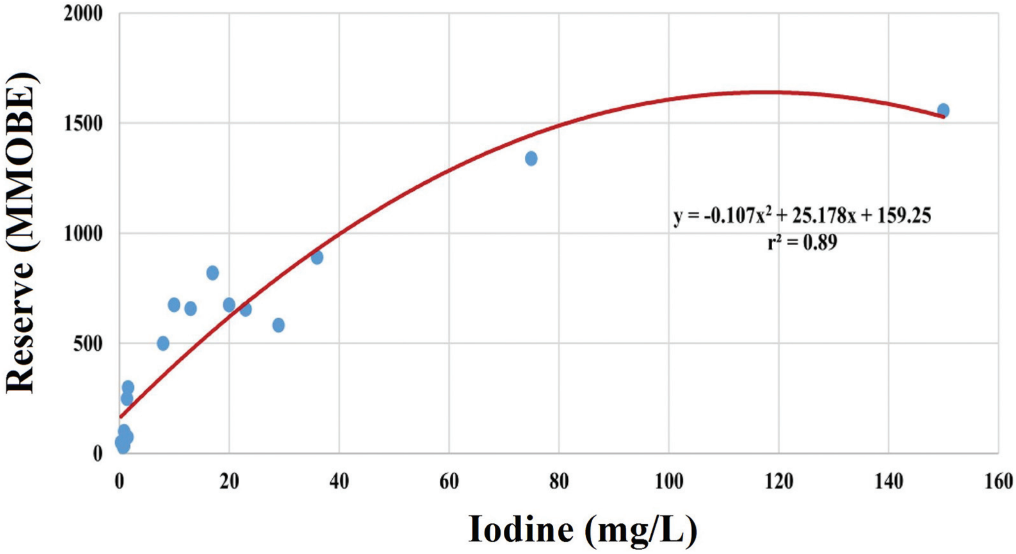
The relationship between the average iodine contents in formation waters and highest reserve oilfields in Southeastern Anatolia basin is given in figure 24. In the graph, it is seen that the reserves of oilfields are increase as the iodine content of formation waters increase (r^2=0,81). The reserves of Southeastern Anatolia basin fields with an average of 1,1 mg/L iodine content are similar to the fields in Cambay (India) basin with an average of 0,83 mg/L iodine content and total basin reserve of 170 million bbls (Figure 25).

The relationship between some basins containing giant oil and gas fields of USA and reserves of the oilfields in Southeastern Anatolia and Cambay (India) basins, and average iodine contents of formation waters are given in figure 25 (giant oilfield >500 million bbls of oil or oil equivalent gas reserve oilfield). The reserves of fields are increase as iodine contents of reservoir waters increase (r^2=0,89). It is seen that iodine contents of formation waters of basins containing giant oilfields are 8 mg/L or more. Besides, iodine contents of formation waters in giant oil and gas



Oilfield	Oil production percentage in the Southeastern Anatolia basin (%)		Iodine content (mg/L) Max.	Iodine content (mg/L) Min.	Reserve (MMOBE)
Batı Raman	22.30		2.81	1.62	300
Raman	19.44		6.45	1.43	250
Beykan	6.10		1.81	0.85	100
Kurkan	3.27		0.52	0.29	50
Garzan	2.05		1.43	0.92	35
Kuzey Karakuş	2.00		1.74	0.65	30
Total	55.16	**Average**	2.46	0.96	127.5

Figure 24- The relationship between oil reserves and iodine contents of formation waters in oilfields of Southeastern Anatolia basin. Iodine content data of formation waters in the oilfields: this study, reserve data of the oilfields: Özgür (2016) and 2017 production data of Turkish Petroleum Company (TPAO).



Basins Containing Giant Oil- and Gasfield				Major Oilfields			
Basin	Iodine Content (mg/L)		Reserve (MMOBE)	Field/Basin	Iodine Content (mg/L)		Reserve (MMOBE)
	Max.	Average			Max.	Average	
Anadarko	1480	150	1558	Batı Raman	2.8	1.6	300
Los Angelas	190	75	1340	Raman	6.5	1.4	250
Mississippi-Louisiana	106	36	892	Garzan	1.4	0.9	35
Sacramento	74	29	583	Beykan	1.8	0.9	100
Western Gulf	86	23	656	Cambay	1.9	0.8	60
Cherokee Platformu	188	20	623	Kuzey Karakuş	1.7	0.7	35
Powder River	54	20	676	Kurkan	0.5	0.3	50
Permian	320	17	820				
Appalachian	105	13	658				
Illinois	210	10	675				
Big Horn	23	8	500				

Figure 25- The relationship between reserves and iodine contents of formation waters of basins containing giant oil and gas fields of US, and main oilfields of Southeastern Anatolia (Turkey) and Cambay (India). (Iodine content data of US giant fields: USGS Produced Water Database, iodine content data in Southeastern Anatolian basin: this study, average iodine content data of Cambay basin: Rebar et al., 2014, Average reserve data of giant fields in US: Mann et al., (2003), reserve data of oilfields in Southeastern Anatolian basin: Özgür (2016) and 2017 production data of Turkish Petroleum Company (TPAO), reserve data of Cambay basin: www.selanoil.com

fields of US are quite higher than Southeastern Anatolia and Cambay basins (India). Therefore, reserves of fields will also be high in basins where found the high iodine contents waters because iodine enrichment is a sensitive indicator for the history of the buried iodine-rich organic matter. Thus, iodine contents of waters will be high due to fast sedimentation and high carbon deposition rate in basins where giant oil and gas fields are located. In basins where low reserve oil and gas fields, iodine contents of waters will be low due to slow sedimentation and low carbon deposition rate and release of iodine into the sea (Figure 8). The fact that there is not discovered any giant field in 1,1 mg/L iodine-containing Southeastern Anatolia basin which exploration and production have been made since 1930 and in 0,83 mg/L iodine-containing Cambay (India) basin which exploration and production have been made since 1950 is supported this result. Moran (1996) proved that the source of both very high iodine content of waters and hydrocarbons observed in Anadarko basin oil and gas fields are Woodford shales quite rich in organic matter using geochemical and hydrogeochemical methods.

4.5. The Relation between Salinity of Formation Water and Iodine

The Oilfield waters are fossil marine waters. Therefore, salinity ratios are expected close or higher than seawater. However, in addition to oil and gas fields containing saline water, there are containing brackish waters (Total dissolved solids, TDS: 1000 - 10000 mg/L) and freshwaters (Total dissolved solids, TDS: 1000 mg/L) many oilfields around worldwide (Table 1). The salinity of most oilfield waters in Southeastern Anatolia basin is also lower than seawater salinity (Table 2). However, distinguishing property among all oilfield waters and other water types (seawater, freshwater and saline waters derived from evaporates, etc.) is because the amount of iodine in oilfield waters is higher than other water resources. The ratio of I/Cl is a more remarkable distinctive (Figures 26 and 27) (Lemay and Konhauser, 2006; Whittemore et al., 1981; Lloyd et al., 1982). Iodine-rich waters are direct indicators for reservoirs in which the oil and gas can be produced (containing mature hydrocarbons). For this reason, it is more appropriate to use iodine-rich or iodized water definition instead of saline water for oilfield reservoir waters (Figure 28).

5. Conclusion and Suggestions

Pirson (1942) has defined success rates for different search methods as; random drilling 5,8%; geology + drilling 8,2%; geophysics + drilling 14,9% and geology + geochemistry + geophysics + drilling 57,8%. In the active tectonic (dynamically “excited” - “unbalanced”) and geologically complex basins of the Alpine mobile belts, the implementation of the standard exploration strategy and techniques rooted in the half-century-old exploration empirics within relatively simple, tectonically “quiescent” platform regions with the dominating old foursome of “source

Table 1- Salinity and I/IC ratios of low saline formation waters in some oil and gas production fields. Formation water data: Yang (2017), Fu and Zhan (2009), Kurchikov and Plavnik (2009), Novikov (2013*a, b*), Novikov (2012), Kokh and Novikov (2014); USGS Produced Water database, Seawater data: Oppo and Capozzi (2015). Giant field: > 500 million bbl oil or oil equivalent gas reserve field. Total salinity values of regions are average salinity values of oilwells in the region.

Oilfield field / region	Total Salinity (mg/L)	I (mg/L)	Cl (mg/L)	I/Cl (x 10^{-5})
Renqie (China, giant field)	178	-	43	-
Gudao, Shengli (China, giant field)	3228	-	1036	-
Shengli (China, giant oilfield)	17960	-	10402	-
Daqang (China, giant oilfield)	16316	-	7896	-
Furrial-Musipan (Venezuela, giant oilfield)	5643	-	1780	-
Prudhoe Bay (ABD, giant oilfield)	18863	16.5	9270	177.9
Yarudei region (Russian)	18400	7.20	10767	66.8
Severnyı Arch region (Russian)	21779	7.35	12325	59.6
Western Khatanga region (Russian)	8230	8.24	3877	212.5
Yamal Peninsula region (Russian)	15788	24.26	8345	290.7
Yenise-Khatanga region (Russian)	8936	8.47	4233	200.1
Seawater	35148	0.05	19500	0.26

Table 2- Salinity and I/Cl ratios of formation waters of some oil production wells in Adıyaman and Thrace oilfields. Chemical data: Çelik and Sarı (2002); Hoşhan et al. (2008), Okandan et al. (1994). Iodine data of formation waters: this study, seawater data: Oppo and Capozzi (2015).

Well	Total Salinity (mg/L)	I (mg/L)	Cl (mg/L)	I/Cl (x 10^{-5})
Adıyaman-7	13595	0.79	8250	9.5
Adıyaman-44	879	0.12	480	25
Batı Fırat 2	25104	4.06	15234	26.6
Beşikli 10	18161	0.11	9713	1.1
Çemberlitaş-44	9526	0.20	5024	4
Güney Karakuş-11	25112	3.20	13692	23.4
Vakıflar	10150	0.56	3601	15.55
Kuzey Osmancık	21695	0.37	12980	2.85
Seawater	35148	0.05	19500	0.26

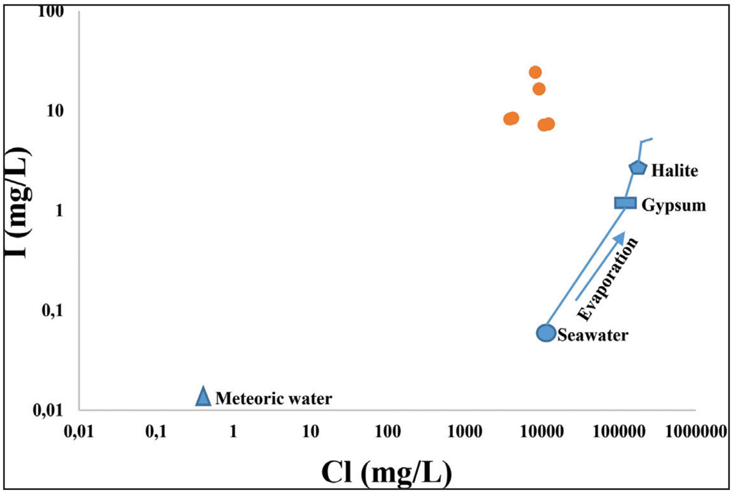


Figure 26- I/Cl ratios of low saline formation waters in some oil and gas production fields (data: Table 1). Seawater evaporation line was created using data of Chen et al. (2016), GERM (2004), Zherebtsova and Volkova (1966).

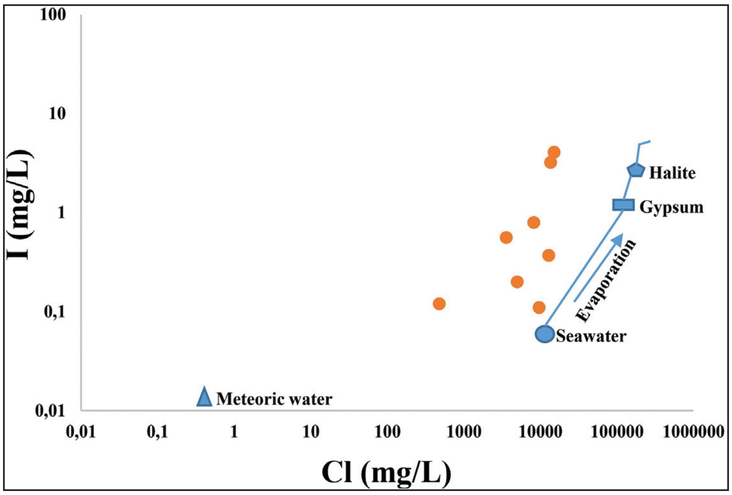


Figure 27- I/Cl ratios of formations waters of some oil production wells in Adıyaman and Thrace oilfields. Chemical data: Çelik and Sarı (2002); Hoşhan et al. (2008), Okandan et al. (1994). Iodine data: this study. Seawater evaporation line was created using data of Chen et al. (2016), GERM (2004), Zherebtsova and Volkova (1966).

rocks/traps/reservoir rocks/seals" turns out to be costly and often unsuccessful. A most telling example is the South-Caspian Basin (SCB). There, the largest western transnational companies and consortia, working under the PSA arrangements from 1995 through 2008, drilled 28 exploratory wells, up to 7301 m depth (almost 24,000 feet). The wells were spudded on the structures deemed highly potential and preliminarily subjected to high-resolution 3D seismic surveys. The effort cost about $1 billion and did not result in a single commercial discovery (Rachinsky and Kerimov, 2015).

Today, hydrogeochemical research is carried out primarily in regions where many water resources (cold and hot springs and wells) found and the petroleum potential not known in detail. This hydrogeochemical data are highly valuable the regions where the geology and the chemical composition of waters are well-known. Because hydrogeochemical research mainly based on the interpretation of existing water analysis and if necessary results of the new analyses. Since the reservoir characteristics of rocks do not take into consideration, it is not possible to estimate the commercial value of the areas, which have high

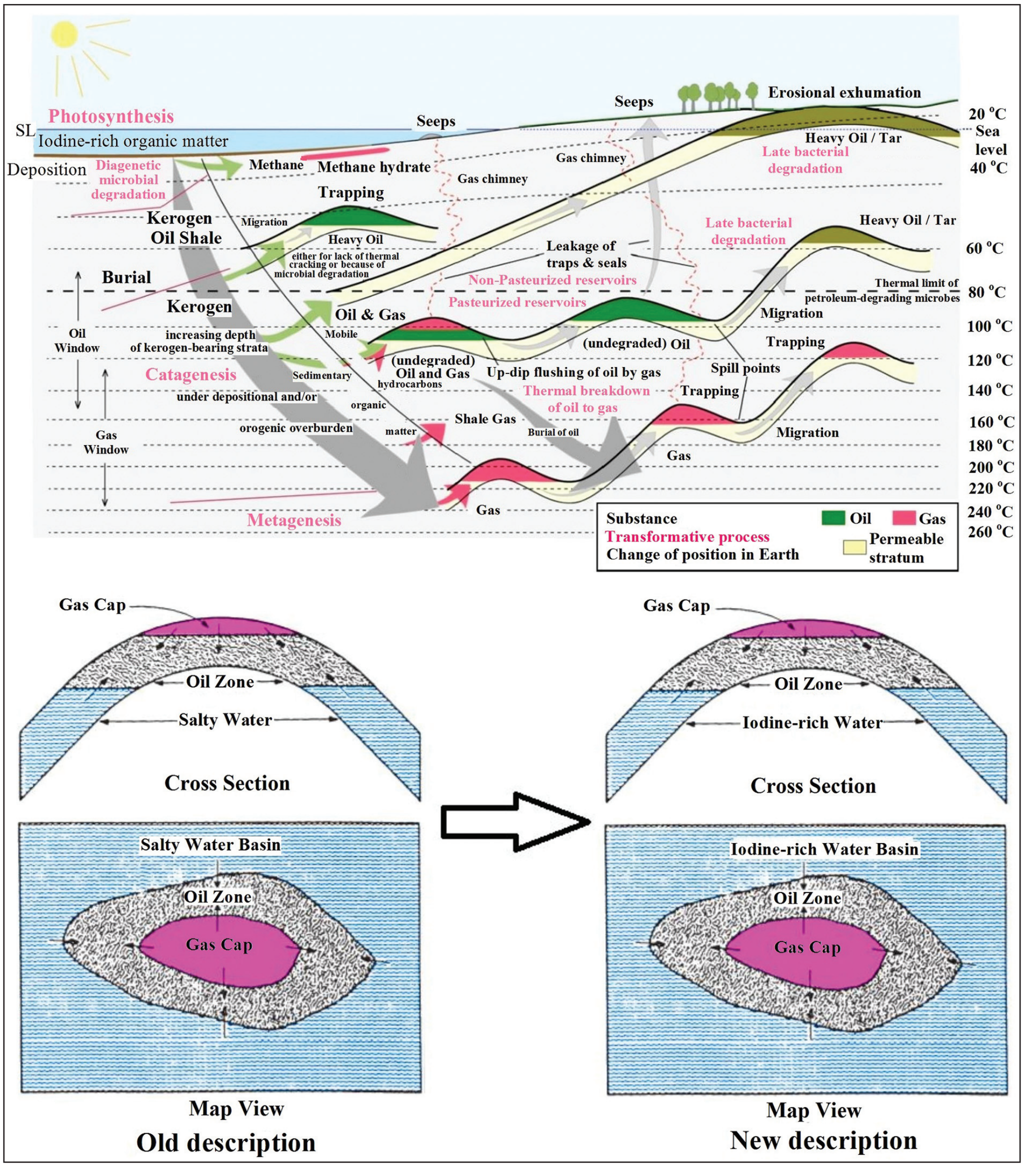


Figure 28- Transformation of iodine-rich organic matter to hydrocarbon and evolutionary process of occurrence of iodine-rich waters in Southeastern Anatolian basin.

oil and gas potential, based on the hydrogeochemical data. However, Sukharev (1948) has shown that in some cases hydrogeochemical data predict petroleum presence and commercial value in a given region, as well as even the estimation of the structure of deposits. While it is not entirely possible to estimate the cost of a groundwater based petroleum exploration model, this research method could reduce the cost of exploration on onshore by up to 50% (Tooth, 1987).

The hydrogeochemical and isotopic analysis as to make in all production wells of oilfields in the basin are critical to describe the unknown petroleum systems in the basin for future exploration and production activities in Southeastern Anatolia basin. Detailed chemical (TPHTotal Petroleum Hydrocarbons, TOC-Total Organic Carbon, CPI-Carbon Preference Index, BTEX-Benzene, toluene, ethylbenzene and xylene), isotopic (^{129}I and ^{127}I) analyses and mapping studies should be carried out in order to understand dominant factors controlling types and amounts of iodine in waters and soils of the Southeastern Anatolia basin. Iodine is a stable biophilic element and finds in highly enriched amounts in fluids associated with hydrocarbons such as oilfield waters. Due to this feature, iodine isotope (^{129}I) is used in recent years to determine hydrocarbon sources in various structures and the age of formation water associated with these hydrocarbon sources (since the age of the iodine in the formation waters is also the age of hydrocarbons in the basin) and migration processes (some studies: Fehn et al., 1987, 1990; Martin et al., 1993; Moran et al., 1995; Liu et al., 1997; Birkle, 2006; Fehn et al., 2007; Muramatsu et al., 2007; Lu et al., 2008; Tomaru et al., 2009*a, b*; Togo et al., 2014; Alvarez et al., 2015, 2016; Santschi et al., 2016; Chen et al., 2016). The occurrence of hydrocarbons, time of maturation and the starting of migration are critical questions in understanding the processes of formation of oil reservoirs. Liu et al. (1997) have used the 129I isotope system to find answers to these questions (Figure 29).

Chen et al. (2016) study, is seen that 129I isotope system can provide useful information in reducing the costs of petroleum exploration activities and increasing efficiency (Figure 30). This data can be beneficial for petroleum exploration because hydrocarbon migration is related to water movement.

Worden (1996) approach based on I/Br ratio of iodine-rich waters settled to the reservoir and migrated together with maturing hydrocarbons derived from source rock can be used to determine kerogen type generating the hydrocarbons (Figure 31).

Specifically, the determination of iodine type (iodate, iodide or organic iodine) and their proportion in production oilwells may explain why different quality oils produced in the basin is of different quality. General Directorate of Mineral Research and Exploration of Turkey has been preparing soil and rock geochemistry maps of all elements (except iodine) throughout the country for the mineral exploration. It should prepare anomaly maps with this data and should determine the isotopic properties (^{129}I,^{127}I) and iodine types (iodate, iodide or organic iodine) found in oil and gas well waters (case study; Voutchkova et al., 2014), and in the soils (case studies: Tedesco et al., 1987, 1995; Allexan et al., 1986; Xuejing and Binzhong,

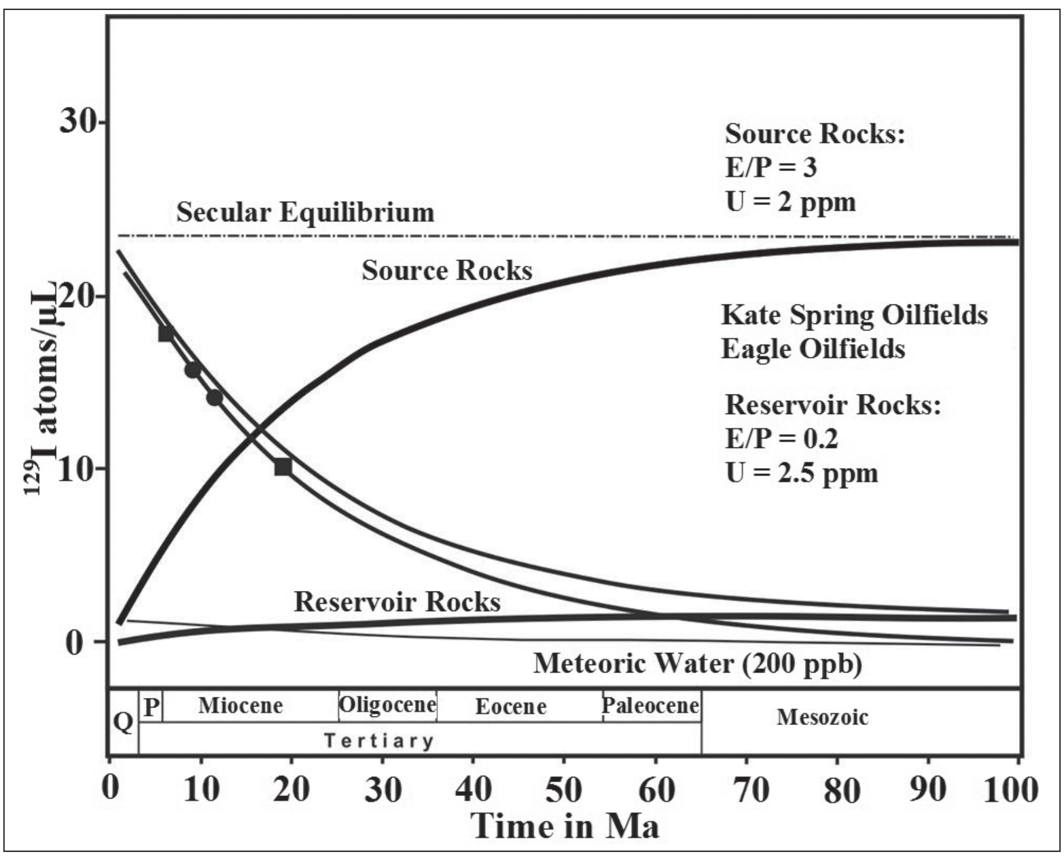


Figure 29- The evolution of ^{129}I concentrations in source rocks and reservoir rocks (heavy lines) and the decrease of ^{129}I concentrations after the separation from the source rocks (thin lines). The numerical time scale refers to residence times associated with the decay curves (thin lines), the geological times cale to the age of formations and the buildup curves (heavy lines). Data points are plotted on the uncorrected decay curve, the line above it indicates the decay corrected for the contribution from the production in the reservoir rock. Potential contribution from pre-anthropogenic meteoric water is also shown in the diagram (Liu et al., 1997).

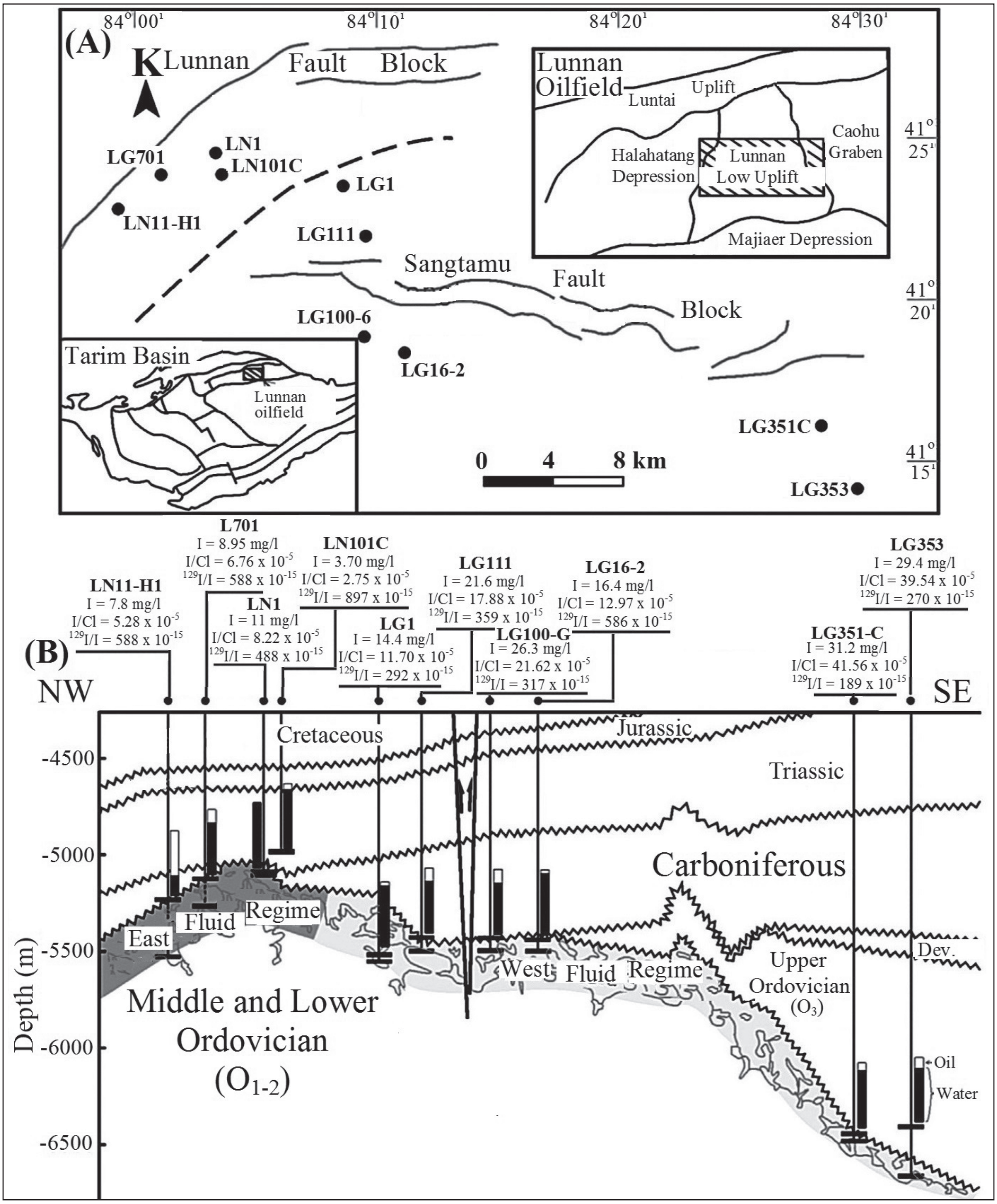


Figure 30- (A) The structural map of Tarim basin and the Lunnan oilfield (China). (B) the iodine contents of formation waters, and the water ratios, I/Cl and $^{129}I/I$ ratios of the oilwells (modified from Chen et al., 2016).

1989; Leaver and Thomasson, 2002; Mani et al., 2011) in the Southeastern Anatolia basin. Besides, the identification of oil and gas potential of the basin in detail and the determination of new exploration areas and the selection of new well locations will be drilled in existing licenses of these analyses are expected to provide significant contributions.

Iodine source in iodine-rich reservoir waters (iodine content >1 mg/L) of the Southeastern Anatolia basin, which is an oil and gas basin, is the organic-rich Silurian and JurassicCretaceous petroleum source rocks. It was seen that iodine contents of formation waters of oil and gas production fields in Southeastern Anatolia basin are >1 mg/L. However, there are also

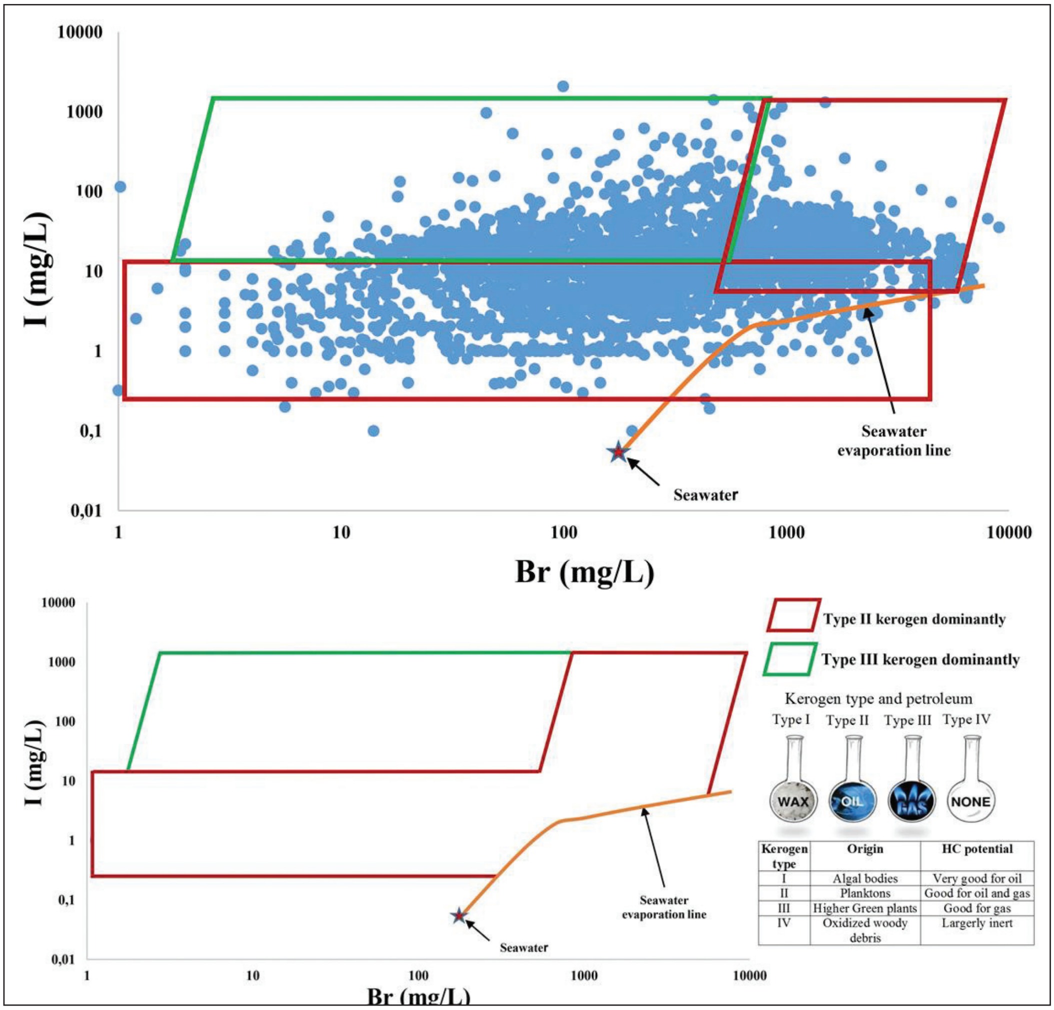


Figure 31- The relationship between kerogen type and I/Br ratios of formation waters. Worden (1996) model was taken as the basis in preparing the graph. The iodine data of formasyon waters of oil and gas fields: USGS Produced Water Database; Engle et al., 2016; Chen et al., 2016; Oppo et al., 2014; Oppo and Capozzi, 2015; Sudo, 1967; Kaiho, 2015; Kharaka et al., 1987; Dia et al., 1999; Dresel and Rose, 2010, Rowan et al., 2015; Mirnejad et al., 2011; Xun et al., 1997; Fisher and Kreitler, 1987; Dickey et al., 1972; Land, 1995; Birkle et al., 2002; Birkle et al., 2009; Franks and Uchytil, 2016; Hitchton et al., 1971; Machperson, 1992; Kokh and Novikov, 2014; Novikov, 2013*a, b*; Novikov, 2012; Novikov and Shvartsev, 2009; Demir and Seyler, 1999; Kurchikov and Plavnik, 2009; Fu and Zhan, 2009; Kireeva, 2010; Bagheri et al., 2014; this study, sample numbers: 3673).

production wells with formation waters containing iodine <1 mg/L. Total of 60 formation waters consist of 1 mg/L, 59 of them range between 0,5-1 mg/L, 108 of them range between 0,1-0,5 mg/L and 16 of them range between 0,01-0,08 mg/L iodine in the Southeastern Anatolian basin. Formation waters with iodine content <1 mg/L in production wells, the oilfield waters are iodine content decreased waters as results of mixing with other water types (meteoric and reinjection waters) in the basin of oilfield waters with iodine content >1 mg/L.

As result of this study, with iodine analysis to be performed on mud samples during drilling, are seen that it is possible that the prediction of oil volume to be produced from well and the detection whether there is oil or gas in the well (from increases/peaks in iodine contents of drilling mud both in entrance and exit of oil zone). Besides, these data from the EBY-17 oilwell is showed that iodine could be used as an excellent hydrocarbon accumulation indicator during both the exploration and drilling.

In the Southeastern Anatolia basin, the iodine ratios are considerably lower than that of basins containing giant oil and gas fields, and a large amount of water is produced with oil. The relationship between iodine and organic matter/organic carbon is linear. Therefore, iodine contents of reservoir waters (petroleum saturation, oil/water ratio) are high in petroliferous basins found of source rocks containing high organic matter (kerogen). In the case, water saturation (water% ratio) of production wells will decrease because the abundance of iodine in formation waters is due to the release of most of the iodine in organic matter into related water during the transformation from organic matter to petroleum. This opinion is supported, the fact that these wells are highest net oil producing and least containing-water wells (with highest iodine content) in Adıyaman region, EBY-17 well (512 barrels of net oil production, iodine content of drilling mud: 10,72 mg/L), EBY-7 well (350 barrels of net oil production, iodine content of formation water: 29,80 mg/L) and PYK-3 well (210 barrels of net oil production, iodine content of formation water: 9,1 mg/L). Therefore, reserves of fields will also be high in basins where found the high iodine contents waters because iodine enrichment is a sensitive indicator for the history of the buried iodine-rich organic matter. Thus, iodine contents of waters will be high due to fast sedimentation and high carbon deposition rate in basins where giant oil and gas fields are located. In basins where low reserve oil and gas fields, iodine contents of waters will be low due to slow sedimentation and low carbon deposition rate and release of iodine into the sea.

As well as in other oil and gas fields in the world, not all reservoir waters in the Southeastern Anatolia basin are saline. However, all of them are rich in iodine. Therefore, iodine-rich waters are a direct indicator for oil and gas producible reservoirs (containing mature hydrocarbons). For this reason, it is more appropriate to use iodine rich or iodized water definition instead of saline water for oilfield reservoir waters. Iodine-rich waters are direct indicators for reservoirs in which the oil and gas can be produced (containing mature hydrocarbons) in the Southeastern Anatolia basin.

Although the fields in the Southeastern Anatolia basin are old and some fields the secondary production methods are used, the high relationship between the oil and gas deposits and iodine were proved. This study also gives an idea about how iodine geology and hydrogeology data (formation water iodine content and I/Cl - Cl ratio) will affect the success of oil and gas exploration projects in the basin or field scale. The explorations in oil and gas industry are carried out as structure-targeted (trap) with seismic survey and source rock-targeted with the organic geochemical survey. The success ratio of commercial oil discovery is 10-20% with the data obtained through these methods. Reservoir-targeted iodine geology and hydrogeology methods have simple sampling process, and laboratory analyses can result at a short time. The results are low cost, reliable and consistent. In the case when these data are utilized with other geological and geophysical methods, it is determined will be a practical and useful tool to reduce the hydrocarbon exploration risk to a minimum and to discover new deposits suitable for commercial production. Due to the results can be controlled and easily repeated are thought that the method will reduce the exploratory risk and costs. It is also foreseen that iodine analyses (chemical and isotopic) that will be carried out in drilled wells in oilfields at the production stage will provide significant contributions in selecting new well locations and accordingly determining the direction of field development.

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APPENDIX: Results of Iodine Analysis of Oilfield Waters in Southeast Anatolian Basin

Results of Iodine Analysis of Oilfield Waters in Batman Region (Data: DPT, 2001 and this study)

Province	Field	Discovery year	Well number in oilfield	Producing formation	Average depth (m)	Oil production percentage in southeast Anatolian basin (%)	Average iodine (mg/L)	Max. iodine (mg/L)	Min. iodine (mg/L)	Water sampling method
Batman	**Batı Raman**	1961	327	Garzan	1300	22.30	**1.62**	**6.45**	0.08	wellhead
	Raman	1945	221	Garzan + Mardin	1360	19.44	**1.51**	**2.81**	0.2	wellhead
	Garzan	1951	42	Garzan	1435 - 1450	2.05	**0.92**	**1.36**	0.23	wellhead
	Silivanka	1962	21	Garzan + Beloka	2250 - 2500	2.29	**0.65**	**1.18**	0.12	wellhead
Sırnak	**Güney Dinçer**	1981	24	Beloka	1626	0.29	**0.4**	**0.97**	0.1	seperator
	Batı Kozluca	1984	29	Sinan	1515	1.43	**0.61**	**0.81**	0.44	seperator
Mardin	**Çamurlu**	1976	40	Sinan	1450	1.37	**0.45**	**0.71**	0.03	seperator
	İkiztepe	1976	15	Sinan	1490	0.23	**0.58**	**0.85**	0.39	seperator
	Doğu Sınırtepe		5			0.40	**0.5**	**0.91**	0.29	seperator
Diyarbakır	**Beykan**	1964	42	Mardin Group	1889	6.10	**0.85**	**1.81**	0.36	wellhead
	Güney Sarıcak	1973	21	Derdere	1600	1.30	**0.62**	**0.86**	0.03	wellhead
	Yeniköy	1973	20	Derdere + Sabunsuyu	1940 - 2100	1.21	**0.41**	**0.79**	0.12	wellhead
	Barbes	1972	14	Mardin Group	2272	1.83	**0.19**	**0.42**	0.03	wellhead
	Malatepe	1970	9	Mardin Group	1685	1.36	**0.055**	**0.11**	0.01	wellhead
	Güney Şahaban	1978	6	Derdere	1660	0.14	**0.3**	**0.41**	0.22	wellhead
	Kurkan	1963	37	Mardin Group	1621	3.27	**0.29**	**0.52**	0.12	wellhead
	Karacan		7			1.00	**0.1**	**0.12**	0.08	wellhead
	Güney Kırtepe		14			0.67	**0.43**	**0.6**	0.14	wellhead
	Mehmetdere	1982	5	Derdere	2000	0.14	**0.14**	**0.14**	0.14	wellhead
	Katin	1971	5	Mardin Group	2611	0.13	**0.09**	**0.12**	0.06	wellhead
	Doğu Yatır	1974	6	Mardin Group	1563	0.68	**0.075**	**0.09**	0.06	wellhead
	Güney Kayaköy	1976	6	Derdere	2620	0.43	**0.125**	**0.13**	0.12	wellhead

* Total oil production in the Southeastern Anatolia basin: 34917 bbl/day (September 2017 production data)

Results of Iodine Analysis of Oilfield Waters in Adıyaman Region (Data: DPT, 2001 and this study)

Province	Field Karakuş	Discovery year	Well number in oilfield	Producing formation	Average depth (m)	Oil production percentage in southeast Anatolian basin (%)	Average iodine (mg/L)	Max. iodine (mg/L)	Min. iodine (mg/L)	Water sampling method
	Karakus Beşikli	1988	27	Karabogaz + Karababa + Derdere + S.suyu	2700	4.66	1.51	6.58	0.13	wellhead
	Besikli	1990	28	Karabogaz + Karababa	1900	3.06	1.93	3.65	0.11	wellhead
	Cendere	1989	18	Karabogaz + Karababa + Derdere	2700	2.05	2.27	7.94	0.10	wellhead
	Elbeyli		13			2.00	14.97	29.8	0.13	wellhead
	Kuzey Karakuş	1990	18	Karababa + Derdere	2590	2.00	0.65	1.74	0.10	wellhead
	Güney Karakuş	1989	21	Karababa + Derdere	2370	1.40	2.10	4.05	0.60	wellhead
	Adıyaman	1971	23	Karababa	1750	1.20	0.49	2.22	0.12	wellhead
	Ikizce	1991	14	Karabogaz + Karababa	2285	1.00	3.39	5.64	0.78	wellhead
	Bozhüyük		5			0.89	1.89	1.89	1.89	Other
	Çemberlitaş	1983	11	Karababa + Derdere	3200	0.70	1.04	4.07	0.13	wellhead
Adıyaman	Tokaris	1991	10	Karabogaz + Karababa + Derdere	2410	0.69	4.58	8.48	0.67	wellhead
	Doğu Karakuş		6			0.42	3.19	3.65	2.72	wellhead
	Batı Gökçe		13			0.49	3.19	7.73	0.29	wellhead
	Batı Fırat	1985		Karababa + Derdere	2570	0.06	2.33	4.06	0.60	wellhead
	Yalankoz		1			0.19	0.72	0.72	0.72	wellhead
	Akgün	1998	4	Karababa	2130	0.32	1.73	3.36	0.10	wellhead
	Ozan Sungurlu	1991	2	Sayindere + Karabogaz + Karababa + Derdere	2800	0.07	1.84	2.08	1.60	wellhead
	B.Altıntop		1			0.15	0.17	0.17	0.17	wellhead
	Çaylarbaşı		8			0.31	0.99	1.64	0.34	wellhead
	Şambayat		12			0.77	0.19	0.37	0.11	wellhead
	Doğu Şambayat		2			0.27	0.14	0.16	0.12	wellhead
	Piyanko		1			0.43	9.10	9.10	9.10	wellhead
Şanlıurfa	Doğu Beşikli	1991	6	Karababa + Derdere	1860	0.82	0.96	1.30	0.34	wellhead
	Bozova		6			0.46	0.125	0.13	0.12	wellhead

* Total oil production in Southeastern Anatolia basin: 34917 bbl/day (September 2017 production data)

Results of Iodine Analysis of Oilfield Waters in Batman City

No.	Well	Iodine (mg/L)	No.	Well	Iodine (mg/L)
1	Batı Raman-71	0.84	22	Raman-268	0.75
2	Batı Raman-183	0.77	23	Raman-169	1
3	Batı Raman-210	0.2	24	Raman-188	1.12
4	Batı Raman-286	2.65	25	Raman-230	0.45
5	Batı Raman-336	1.9	26	Raman-289	1.2
6	Batı Raman-364	2.81	27	Garzan-8	0.23
7	Batı Raman-403	2.78	28	Garzan-9	1.4
8	Batı Raman-470	1.01	29	Garzan-20	1.14
9	Raman-22	6.45	30	Garzan-36	2.21
10	Raman-211	2.72	31	Garzan-58	1.05
11	Raman-232	4.33	32	Garzan-63	0.35
12	Raman-284	3.94	33	Garzan-69	1.21
13	Raman-88	0.22	34	Garzan-76	1.36
14	Raman-105	0.29	35	Garzan-79	1.09
15	Raman-144	0.23	36	Silivanka-32	0.46
16	Raman-174	0.8	37	Silivanka-33	1.18
17	Raman-180	0.08	38	Silivanka-34	1.11
18	Raman-187	0.32	39	Silivanka-41	0.54
19	Raman-235	0.33	40	Silivanka-19	0.12
20	Raman-245	0.94	41	Silivanka-25	0.41
21	Raman-264	0.57	42	Silivanka-28	0.74

Results of Iodine Analysis of Oilfield Waters in Adiyaman City

No.	Well	Iodine (mg/L)	No.	Well	Iodine (mg/L)
1	Adıyaman-4	2.22	38	Çemberlitaş-52	4.07
2	Adıyaman-7	0.79	39	Çemberlitaş-53	1.43
3	Adıyaman-8	0.14	40	Doğu Karakuş-2	3.65
4	Adıyaman-14	0.22	41	Doğu Karakuş-9	2.72
5	Adıyaman -24	0.12	42	Doğu Sambayat-1	0.12
6	Adıyaman-39	0.85	43	Doğu Sambayat-6	0.16
7	Adıyaman-44	0.12	44	Elbeyi-7	29.8
8	Adıyaman-48	0.13	45	Elbeyi-14	0.13
9	Adıyaman-56	0.15	46	Güney Karakuş-8	0.6
10	Akgün-2	0.1	47	Güney Karakuş-10	1.15
11	Akgün-3	3.36	48	Güney Karakuş-11	3.2
12	Batı Altıntop-1	0.17	49	Güney Karakuş-22	4.05
13	Batı Fırat-2	4.06	50	Güney Karakuş-29	1.5
14	Batı Fırat-13	0.6	51	İkizce-5	5.64
15	Batı Gökçe-1	7.73	52	İkizce-7	3.75
16	Batı Gökçe-4	1.55	53	İkizce-C1	0.78
17	Batı Gökçe-9	0.29	54	Karakuş-3	0.13
18	Beşikli-2	1.85	55	Karakuş-7	0.15
19	Beşikli-10	0.11	56	Karakuş-11	0.15
20	Beşikli-14	2.29	57	Karakuş-13	0.14
21	Beşikli-31	2.35	58	Karakuş-24	3.30
22	Beşikli-26	1.31	59	Karakuş-29	0.15
23	Beşikli-34	3.65	60	Karakuş-38	6.58
24	Bozhöyük (Avg.)	1.89	61	Kuzey Karakuş-5	0.11
25	Cendere-1	7.94	62	Kuzey Karakuş-21	0.1
26	Cendere-3	0.37	63	Kuzey Karakuş-24	1.74
27	Cendere-7	0.11	64	Ozan Sungurlu-1	2.08
28	Cendere-9	0.10	65	Ozan Sungurlu-4	1.6
29	Cendere-10	6.83	66	Paşaoğlu-2	0.58
30	Cendere-13	0.42	67	Sambayat-1	0.14
31	Cendere-23	0.14	68	Sambayat-7	0.37
32	Çaybaşı-1	1.64	69	Sambayat-17	0.11
33	Çaybaşı-5	0.34	70	Sambayat-20	0.13
34	Doğu Çemberlitaş-3	0.13	71	Tokaris-3	0.67
35	Çemberlitaş-5	0.24	72	Tokaris-12	8.48
36	Çemberlitaş-27	0.17	73	Tokaris-14	0.57
37	Çemberlitaş-44	0.20	74	Yalankoz-2	0.72

Results of Iodine Analysis of Oilfield Waters in Diyarbakir City

No.	Well	Iodine (mg/L)	No.	Well	Iodine (mg/L)
1	Barbes-5	0.11	38	Güney Sarıcak-25	0.60
2	Barbes-6	0.14	39	Güney Sarıcak-30	0.72
3	Barbes-12	0.12	40	Güney Sahaban-2	0.22
4	Barbes-13	0.08	41	Güney Sahaban-7	0.24
5	Barbes-14	0.14	42	Güney Sahaban-10	0.32
6	Barbes-16	0.23	43	Güney Sahaban-15	0.41
7	Barbes-19	0.25	44	Karacan-3	0.12
8	Barbes-20	0.08	45	Karacan-5	0.10
9	Barbes-23	0.42	46	Karacan-7	0.08
10	Beykan-1	1.12	47	Katin-2	0.12
11	Beykan-9	0.97	48	Katin-7	0.06
12	Beykan-14	1.18	49	Kurkan-5	0.18
13	Beykan-17	0.83	50	Kurkan-11	0.29
14	Beykan-22	0.58	51	Kurkan-12	0.12
15	Beykan-23	1.81	52	Kurkan-15	0.25
16	Beykan-27	0.65	53	Kurkan-23	0.30
17	Beykan-30	0.60	54	Kurkan-30	0.42
18	Beykan-33	0.46	55	Kurkan-39	0.52
19	Beykan-36	0.59	56	Kurkan-44	0.13
20	Beykan-37	1.23	57	Kurkan-52	0.37
21	Beykan-38	0.36	58	Malatepe-2	0.06
22	Beykan-58	0.61	59	Malatepe-6	0.01
23	Doğu Yatır-3	0.06	60	Malatepe-8	0.01
24	Doğu Yatır-4	0.09	61	Malatepe-13	0.05
25	Güney Kayaköy-7	0.12	62	Malatepe-30	0.11
26	Güney Kayaköy-8	0.13	63	Malatepe-32	0.09
27	Güney Kırtepe-2	0.60	64	Mehmetdere-9	0.14
28	Güney Kırtepe-3	0.14	65	Yenikoy-14	0.79
29	Güney Kırtepe-7	0.51	66	Yenikoy-18	0.41
30	Güney Kırtepe-11	0.47	67	Yenikoy-20	0.22
31	Güney Sarıcak-2	0.57	68	Yenikoy-26	0.51
32	Güney Sarıcak-5	0.35	69	Yenikoy-30	0.61
33	Güney Sarıcak-6	0.03	70	Yenikoy-33	0.27
34	Güney Sarıcak-7	0.72	71	Yenikoy-35	0.46
35	Güney Sarıcak-15	0.71	72	Yenikoy-36	0.56
36	Güney Sarıcak-18	0.86	73	Yenikoy-39	0.15
37	Güney Sarıcak-19	0.44	74	Yenikoy-40	0.12

Results of Iodine Analysis of Oilfield Waters in Mardin City

No.	Well	Iodine (mg/L)
1	Çamurlu-2	0.51
2	Çamurlu-10	0.59
3	Çamurlu-26	0.03
4	Çamurlu-28	0.03
5	Çamurlu-30	0.41
6	Çamurlu-31	0.62
7	Çamurlu-35	0.71
8	Çamurlu-39	0.53
9	Çamurlu-51	0.29
10	Doğu Sınırtepe-1	0.91
11	Doğu Sınırtepe-2	0.29
12	Doğu Sınırtepe-5	0.43
13	Doğu Sınırtepe-7	0.38
14	İkiztepe-1	0.39
15	İkiztepe-6	0.85
16	İkiztepe-CP2	0.44
17	İkiztepe-CP4	0.64

Results of Iodine Analysis of Oilfield Waters in Sirnak City

No.	Well	Iodine (mg/L)
1	Batı Kozluca-1	0.54
2	Batı Kozluca-5	0.49
3	Batı Kozluca-6	0.72
4	Batı Kozluca-9	0.68
5	Batı Kozluca-19	0.74
6	Batı Kozluca-22	0.6
7	Batı Kozluca-28	0.44
8	Batı Kozluca-29	0.51
9	Batı Kozluca-30	0.49
10	Batı Kozluca-31	0.81
11	Batı Kozluca-34	0.64
12	Güney Dinçer B1	0.21
13	Güney Dinçer 1	0.41
14	Güney Dinçer 6	0.46
15	Güney Dinçer 8	0.56
16	Güney Dinçer 13	0.37
17	Güney Dinçer 14	0.22
18	Güney Dinçer 15	0.32
19	Güney Dinçer 16	0.39
20	Güney Dinçer 23	0.97
21	Güney Dinçer 29	0.10

Results of Iodine Analysis of Oilfield Waters in Sanliurfa City Basin

No.	Well	Iodine (mg/L)
1	Doğu Beşikli-5	1.30
2	Doğu Beşikli -7	0.34
3	Doğu Beşikli -11	1.24
4	Bozova-1	0.13
5	Bozova-8	0.11
6	Piyanko-3	9.10

Results of Iodine Analysis of Oilfield Waters in Thrace

No.	Well	Iodine (mg/L)
1	Vakıflar-1	0.26
2	Vakıflar-4	0.21
3	Vakıflar-5	0.29
4	Vakıflar-7	0.80
5	Vakıflar-14	1.24
6	Kuzey Osmancık-2	0.08
7	Kuzey Osmancık-8	0.66
8	Deveçatağı-2	0.74
9	Deveçatağı-9	0.56