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Torpedo Jars of Iran: Context of Archaeological Discovery and Origin of the Bitumen Coating

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Abstract

One of the most important potteries used in Persian Gulf (Middle East) maritime trade with a large part of the ancient world, including the Persian Gulf, the Gulf of Oman, the Indian Ocean, Sri Lanka, and finally the country of Thailand. (Suriname ship cargo) earthenware jar called Torpedo-jar or storage jar. Although this type of pottery was dated by most researchers to Sassanian era, this type was used in trade and burial from the Parthian period to early Islamic era or 3rd century BC to 9th century AD (Kennet, 2004: 85). The most important feature of these types of jars is the coating of bitumen on its inner surface. So far, archaeologists have not succeeded in finding a kiln for the production of this type of pottery, so it is very important to know the place of pottery production and the bitumen mine used in them. In this article, using the method of geochemical laboratory studies and a comparative study, the bitumen samples taken from the torpedo jars from the south and southwest of Iran were investigated. In this research, 15 pieces of pottery with tar coating belonging to the archaeological excavations of Siraf and Mahruban ports on the coast of the Persian Gulf (south of Iran), related to the Sassanid and Islamic period, and samples from Shush and Shushtra region from the Parthian and Sassanid periods were selected.The sample of the Susa area is from the Iran National Museum and belongs to the archaeological excavations of Susa region, the sample of Ivan-i Karkheh is related to the Dezful region, and the sample of the Dastova area is also related to the Shushtar region in Khuzestan province, southwest of Iran. All bitumen samples were analyzed geochemically with the aim of determining the origin of bitumen in its specialized laboratories in Europe and America. The main result of the research shows the use of bitumen from the bitumen springs of Khuzestan, Lorestan, Ilam and Kermanshah provinces in the studied pottery (Fig. 1).

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1. Introduction

The present article is dedicated to the topic of geochemical analysis of bitumen from “torpedo jars” from Susa, Dastova, Ivan-i Karkheh, Mahruban and Siraf archaeological sites from Iran (Fig. 1).

Bitumen samples collected for laboratory studies in this research are categorized into two groups. The first group pertains to archaeological excavations in Siraf, Mahruban, and Susa in south and southwest Iran. The second group is associated with surface surveys conducted in Ivan-i Karkheh and the ancient site of Dastova (Elymais city in Khuzestan province), located in the southwest and south of Iran, respectively. The chronology of the selected samples indicates that the Shush (Susa) and Dastova samples are from the first millennium BC (Parthian and Elymais), while the Ivan-i Karkheh, Siraf, and Mahruban samples are from the first millennium AD (Sasanian period and early Islam). According to Esmaeili Jolodar’s chronology, the Siraf sample is categorized in the context of the early Islamic period(Esmaeili Jelodar, 2021:270-275). However, due to intentional accumulation of intact and fragmented pottery by Muslims to fill the previous architectural space and the comparison of this pottery with Sasanian period examples, these samples could be considered older, probably from the late Sassanid period. As this article focuses on Torpedo Pottery type, which is found across the entire Persian Gulf, the Indian Ocean, and recently in Thailand where the Suriname shipwreck was excavated (Choksy and Nematullahi, 2018: 144-151; Lischi *et al.,* 2020:1-14), it is important to have a deeper understanding of the archaeological background of the study samples.

The present article is dedicated to the topic of geochemical analysis of bitumen from « torpedo jars » from Susa, Dastova, Ivan-i Karkheh, Mahruban and Siraf archaeological sites from Iran (Fig. 1).

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1.2. Torpedo Jars: definition, study background and function

One of the most important potteries found in the Persian Gulf, the Gulf of Oman, and the Indian Ocean -including India and Sri Lanka- is the type known as Torpedo Jar. Adams (1970) introduces these containers as Torpedo Fuse Point. this type is also known as a

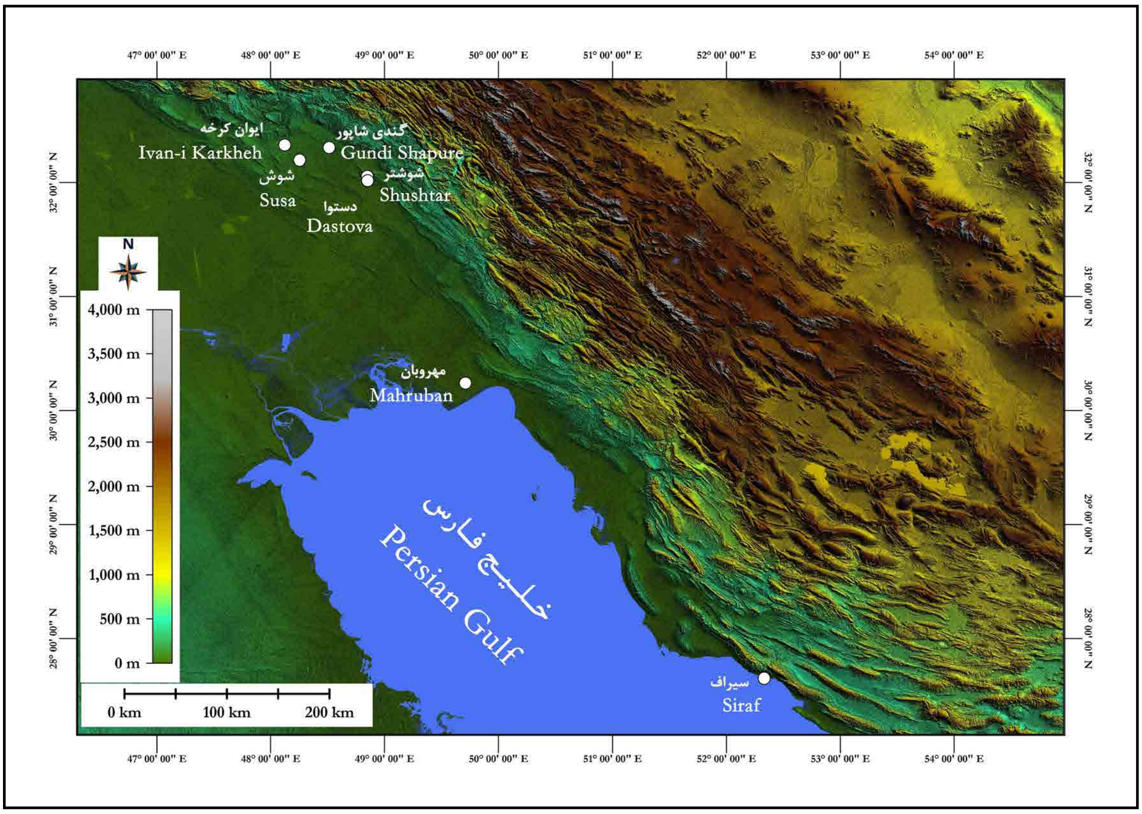


Fig. 1: Map location of the study areas (© Mohammad Reza Rokni).

'Spitzfuss' storage jars.1 The material used for both the interior and exterior coating is bitumen, as confirmed by tests. This coating is also referred to as "Glass Gum" in the Devnimory of India (Tomber, 2007: 976).

These jars typically stand about 100 cm tall and are approximately 35 cm wide. They feature sloping shoulders, thick rims, and either a rounded base or a flat bottom with a smooth, sharp, and well-rounded tip. Often known as Torpedo Jar Pottery or storage containers with ring-necked necks, these types have been discovered across the Persian Gulf and Mesopotamia from the Parthian period to the Abbasid era. The majority of examples date back to the Sassanid era, and were likely used for shipment of liquids. This type of pottery is fired at high temperatures, resulting in a reddish-yellow (7.5-6.8 YR) to pale yellow (2.5-4.8) color with a significant presence of sand and fine-grained particles measuring 0.1mm in thickness. The pottery's surface is smoothed with brushed salt and finished with wet hands, giving it a somewhat sandy texture. Its interior surface is predominantly coated with bitumen. Kennet (2004) believes that this type of pottery originates in Iraq (Kennet, 2004, p.85). The production centers of this pottery type have not yet been identified. However, the widespread presence of this pottery along the Persian Gulf coast, particularly in the major Sassanid cities like Ivan-i Karkheh near Andimshek, has been observed. It has been reported from the Mian Ab in Shushtar Plain (Khosrowzadeh and Aali, 2005: 240, Fig. 50), several ancient ports of Persian Gulf (from Mahruban to Siraf as noted by Esmaeili Jolodar, 2009) Gelalak in Shushtar and Shoghab in Bushehr (Rehbar, 1997; Sarfaraz, 1969). It has also been discovered in the Parthian and Sasanian layers of Susa.

There have been different opinions about the purpose of torpedo jars. The most significant ones include using this pottery to a) transport liquids like water, wine, or other beverages, b) store supplies, and c) bury the bones of the deceased. It is challenging to provide a definitive answer to this question, but the two purposes of transporting liquids and burying the dead align with archaeological evidence and written records (Table 1).

2.1. Archaeological sites

It is important to begin by providing the historical, spatial, and temporal context of the locations where the pottery samples were examined. Following this, the chronology of the chosen samples will be addressed.

2.1.1. Susa: Sample No.3430

Susa is an ancient site in Iran with a history of continuous settlement dating back millennia. As one of the world's oldest cities, Susa has long been a subject of fascination. Archaeological exploration in Susa has spanned 70 seasons from 1850 to 1987 (Mohammadifar, 2014: 65). British, French, Iranian, and international archaeologists have conducted excavations in this area and Stern and his colleagues have published an important article about bitumen's of Torpedo jar (Stern *et al.,* 2007).

The artifact selected from the National Museum of Iran pertains to the Parthian Susa period, bearing the registered number 5667-21233 and number 35. It stands at a height of 95 cm with an opening diameter of 17.5 cm (Fig. 2 and 4). This jar originates from the French archaeological excavations in Susa, although there is a lack of archaeological information regarding its context. Our research indicates that the jar was unquestionably acquired from Susa and was likely transported from Susa to the National Museum of Iran in recent years. Additionally, it is known that a similar specimen was discovered in the excavations conducted by Girshman2 in the cemeteries of Susa (Fig. 3) (Boucharlat and Haerinck, 2011:41, Fig. 19 b&c).

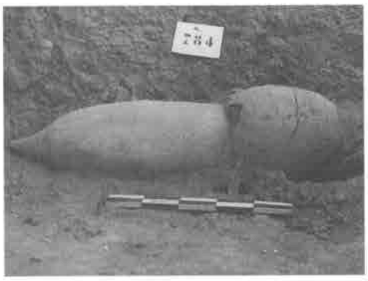


Fig. 2: (left)Torpedo jar from Susa (Boucharlat and Haerinck, 2011:41, fig.19a) Fig. 3) (center) cylindrical jar from Susa in National Museum. Fig. 4) image of inscription or a molded stamp on torpedo jar (right), (© Esmaeili Jelodar).

Boucharlat and Haerinck (2011) suggest that cylindrical jars from Susa coated with bitumen inside and having a round bottom, date back to approximately the first year AD to 225 A.D. (Parthian period). They believe that the other type of jars, namely the torpedo jars with a pointed or torpedo-shaped bottom, date back to the period between 225 BC and 110 BC. (Boucharlat and Haerinck, 2011:58, table1). The pottery of the National Museum closely resembles other similar examples of cylindrical jars discovered at Susa. As a result, its origin is estimated to be from the early first millennium AD to 225 AD., therefore, this pottery can also be dated to the Parthian period (for comparisons see: Fig. 2, 3 and 4 (Boucharlat and Haerinck, 2011:41; Fig. 19b and 19c; Boucharlat *et al.,* 1987, Fig. 69). Cylindrical jars and torpedo jars differ in the shape of the base. Cylindrical jars have a semi-round base.

The significant aspect of the jar selected from the National Museum is the presence of an inscription or a molded stamp on its body at the bottom of the rim. This feature indicates its commercial purpose. (Fig. 4a&b).

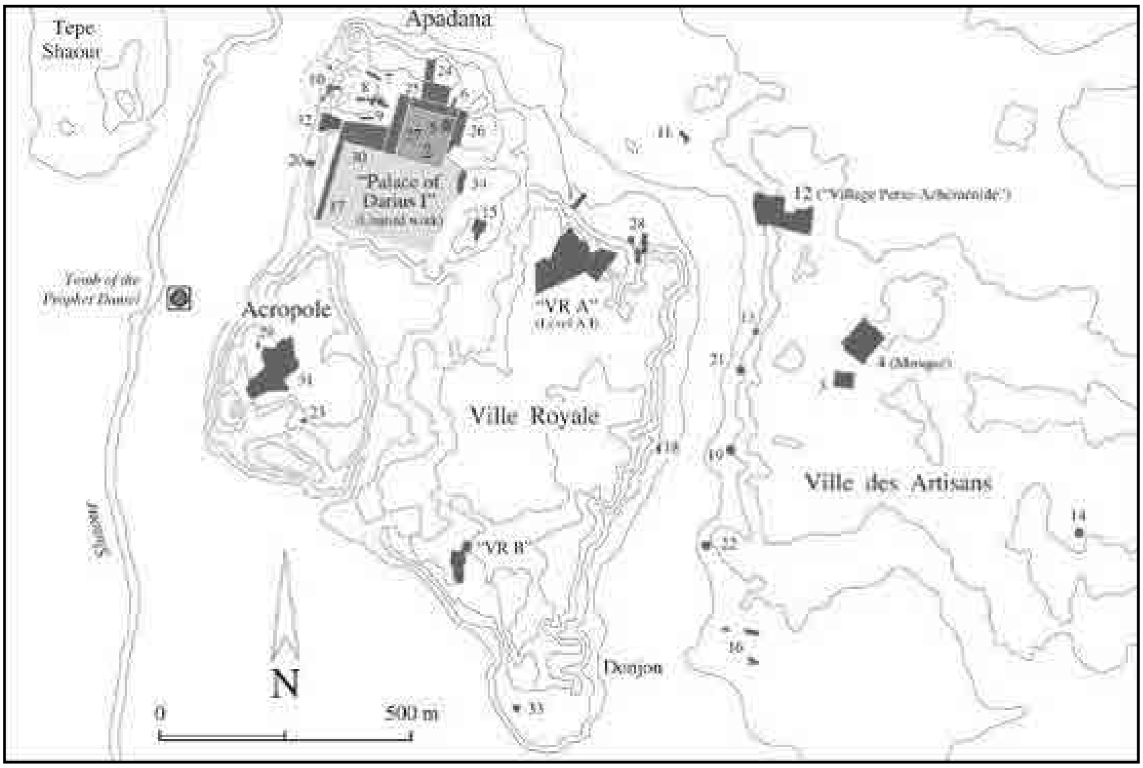


Fig. 5: The main sites (indicated by numerals) worked at Susa by Roman Ghirshman and Marie-Joseph Steve, 1946-68. (Gasche, 2009; Fig. 2).

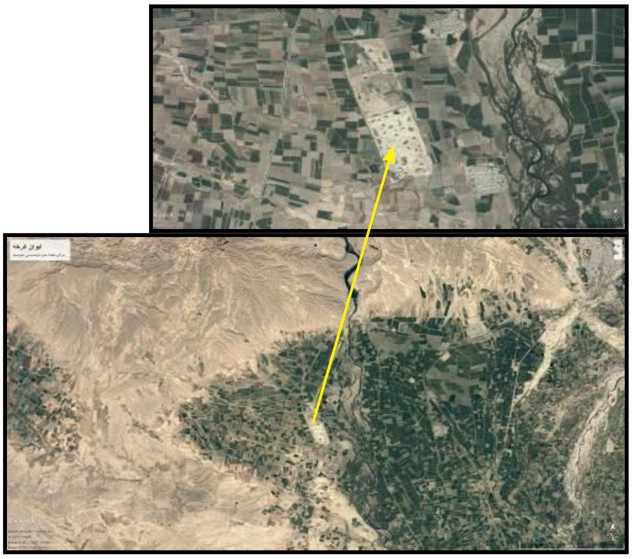


Fig .6: Arial map of Ivan-i Karkheh in Susiana plain near to Karkheh River (Google earth).

Table 1: Distribution of Torpedo jars in the Ancient Ports of the Persian Gulf, Indian Ocean, East of Africa, India and China.

Site name	location	Date	References
Siraf and Mahruban,	Iran	Sassanid and Early Islamic	Esmaeili Jelodar, 2010
Suriname shipwreck	Thiland	Sassanid and Early Islamic	Choksy and Nematullahi, 2018
Mian Ab e Shushtar	Iran	Parthian, Sassanid and Early Islamic	Khosrowzadeh and Aali, 2005: 240, fig. 50
Mleiha ,Al-Dur, Suhar phase III	UAE and Oman	pre-Islamic period	Kervran, & Hiebert, 1991: 341, fig. 6
Reyshahr	Iran	Sassanid	Khosrowzadeh, 2011: 180
Jazirat al-Ghanam	Kowait	Sassanid	De Cardi 1975, fig. 8: 15,36
Kush	UAE	5th and 6th centuries	Kennet, 2004: 69
Shoghab site in Bushehr	Iran	Sassanid era	Rahbar, 1997
Anuradhapura	Sri Lanka	200 AD to 600 AD) which dates back to about 200-600 AD.	Coningham and Batt, 1999; Coningham, 2006: 5, Table.1.1; Stern et al., 2007: 409-428
Gelalak of Shushtar	Iran	Parthian	Rahbar, 1997; Sarfaraz, 1969
Mantie port	Sri Lanka	Sassanid to the early Islamic	Wijayapala & Prickett 1986: 17
Kateshwar	India	6th century AD	Tomber, 2007: 979
Alagankulam Port	south of India	500 and 1200 AD	Tomber, 2007: 979
Tissamaharama	Sri Lanka	Parthian to the Islamic era	Tomber, 2007: 980
Nagara,Nevasa,Pattanam and Paunar	India	Sassanid layers	Tomber, 2007: 981
Ras Hafun	Somalia	the 3^{rd} to 5^{th} centuries	Smith & Wright 1988: Fig. 9ah

2.1.2. Ivan-i Karkheh: Sample No.3432

Ivan-i Karkheh is an ancient city from the Sassanid period, located 20 km northwest of the ruined city of Shush (Susa), and situated west of the Karkheh River. The city was fortified and had a rectangular shape, with a width of one kilometer and a length of 4 kilometers. The city was surrounded by a wall made of raw clay (Fig. 6). In their article, Gyselen and Gasche (1994) suggest that this city resembles Roman camps, with four nearly equal quarters and a sizable palace and gardens in the royal area. (Gyselen & Gasche, 1994; 30 -31; Vandenberghe, 2000: 680).

Through pottery analysis, Wenke (1976) suggests that Ivan-i Karkheh dates back to the third century AD and likely originated as a Parthian settlement prior to Ardeshir’s rule in 224 AD. He has not discovered any evidence of settlement from the Islamic era, indicating that this city was likely abandoned after the Sassanid period. (Wenke, 1976: 72-73). The sources of the early Islamic period also provide brief information about this city. For example, Istakhri *et al.,* (1994) only mentioned the name of this city.

The city of Dastova is situated 3 kilometers south of Shushtar, between two branches of the Karun River: the Gargar River (or Do Dangeh) to the east and the Shotait River (or Chahar dangeh) to the west (Fig. 1). The Gargar river is an artificial canal dating back to the Sassanid period. It was constructed in Shushtar along with the Shadorvan and the Mizan dams after the Achaemenid Darion canal was dried. The boundary between these two branches of the Karun River is referred to as MIĀN Āb (meaning "island" in Persian). Prior to the construction of the Gargar canal, the Achaemenid or post-Achaemenid Darion stream irrigated the agricultural lands of Miān Āb. This city was investigated in 1968 by Ali Akbar Sarfaraz from the General Directorate of Archeology and Popular Culture (Rahbar, 1997;175-176; Sarfaraz, 1969, 73-79). After him, Mehdi Rahbar excavated during three seasons in the years 2003, 2004 (Rahbar, 2003, 2004). In 2014, during Esmaeili Jelodar's field survey with his students from the Department of Archaeology, University of Tehran, sample No.3431 of the torpedo jar was collected from the surface of the area and selected for this laboratory study.

Mehdi Rahbar's excavation report states that torpedo jars were discovered in tomb 5, which was excavated in trench T12. Rahbar dated the tomb to the Seleucid-Parthian period based on the presence of 37 copper and lead coins featuring Parthian and Seleucid iconography. The discovery of Esmaeili team's sample in the same location supports the Parthian dating. (Fig. 7-10).

Fig. 7: Tomb of Gelalak in Shushtar, Khuzestan province (left,© Mehdi Rahbar).

2.1.4. Siraf: Samples No.3437-3444

Siraf or Bandar-I Taheri is located on the 250 km east of Port Bushehr and 35 km southeast of Port Kangan on the beach of the Persian Gulf. (Fig. 11)

Sirāf was one of the most important ports in the Persian Gulf, playing a key role in the region's maritime trade throughout its history. Early Islamic historians frequently

Fig. 8: Top: Sassanid coin. Down left: Parthian coin. Down right: Elemaeane coin. (Rahbar, 2004).

mentioned the name of Sirāf in their writings. (see e.g. Al-Jeyhani 1989: 55-60, 109-128; Muqaddasī 2006: 636-7; Yāghūt 1983: 60, 76; Ibn Faqih 1970: 374-5; Ibn Rusta 1986: 111; al-Masʿūdī: 1965: 143; Semsar, undated: 219, 220; Sūleymān and Abū Zayd-e Sirāfi 2002: 13, 14; Istakhri, 1994: 115, 116; Ibn Ḥawqal 1966: 55, 56; Anonymous 1983: 130, 131; Ibn Balkhi 1995: 328-332; Abul'l-Fidā 1970: 374, 375). Since the beginning of the 19th century, Siraf port has attracted the attention of political officials, history researchers, and foreign archaeologists. (Morier, 1812; Semsar, undated; 331/1; Wilson, 1942; Kempthorne, 1837, 1856; Pezard:2005; Ravaisse. 1914; Pezard, 2005: 133-129 and see also: Lamb, 1964; Stiffe, 1895; Stein, 1937).

The archaeological excavations at Siraf were carried out for seven seasons from 1966 to 1973 by a joint Iranian-British delegation led by Dr. Whitehouse. The results of these excavations were published in the form of numerous articles, particularly in the journal of Iran (Whitehouse, 1968, 1969, 1970, 1971, 1972, 1974, 2009).

After Whitehouse, H. Bakhtiari continued to excavate Siraf for a season in 1975 (Bakhtiari, 1974, 1976). Masoumi, Zarei, Sarfaraz, Sadraei, MirEskandari, Tofighian and Khakzad also conducted limited explorations and surveys in Siraf and its surrounding areas (Masoumi, 2004; Sarfaraz, 2004; Khakzad, 2012, 2015). In 2006-2007, the first and second seasons of the archaeological excavations in Siraf were carried out by Esmaeili Jelodar of the University of Tehran. (Esmaeili Jelodar, 2009). Later, the third season of excavations was also conducted by him in 2022 (Fig. 11).

The prospect of Siraf torpedo-jar pottery

The new phase of archaeological excavations in Siraf took place over two seasons, from 2008 to 2009. Torpedo-jar samples were uncovered during the second season. This phase of the excavations focused on establishing the chronology of Siraf. Two trenches, named A and B, were opened during this season. Seven potsherds selected for analysis were collected in 2009, with one piece originating from trench A and the remaining six from trench B. (Fig. 11). Sample No.3443 from Trench A (table 7), analyzed using C-14 dating, suggests a date range of 850-976 AD (Esmaeli Jelodar, 2021: 201-218). While this points

Fig. 11: Map of the location of the Siraf excavation trenches by Esmaieli Jelodar on the coast of the Persian Gulf on Google Earth map (Google Earth, 2015).
■ Tr. I, II & II excavated by Esmaeili Jelodar in the First Season .
● Tr. A & B excavated by Esmaeili Jelodar in the Second Season.

to its belonging to the early Islamic period, there is a strong possibility that this pottery was actually used in an earlier period, specifically the Sassanid era (Fig. 12, Table 2). The other six specimens were collected from locus 107 of Trench B, which is 80 cm thick. C-14 dated samples from the center of this layer yielded a date of 887 (95.4%)- 985 cal., indicating a date range from the late 10th century AD to the 12th century AD. The specific details about these samples can be found in Tables 3 and 7. Among them, four pieces are associated with the rim and body of the vessel, while three include the pointed base of the torpedo jar along with a part of its body (Figs.13-17, Table 4).

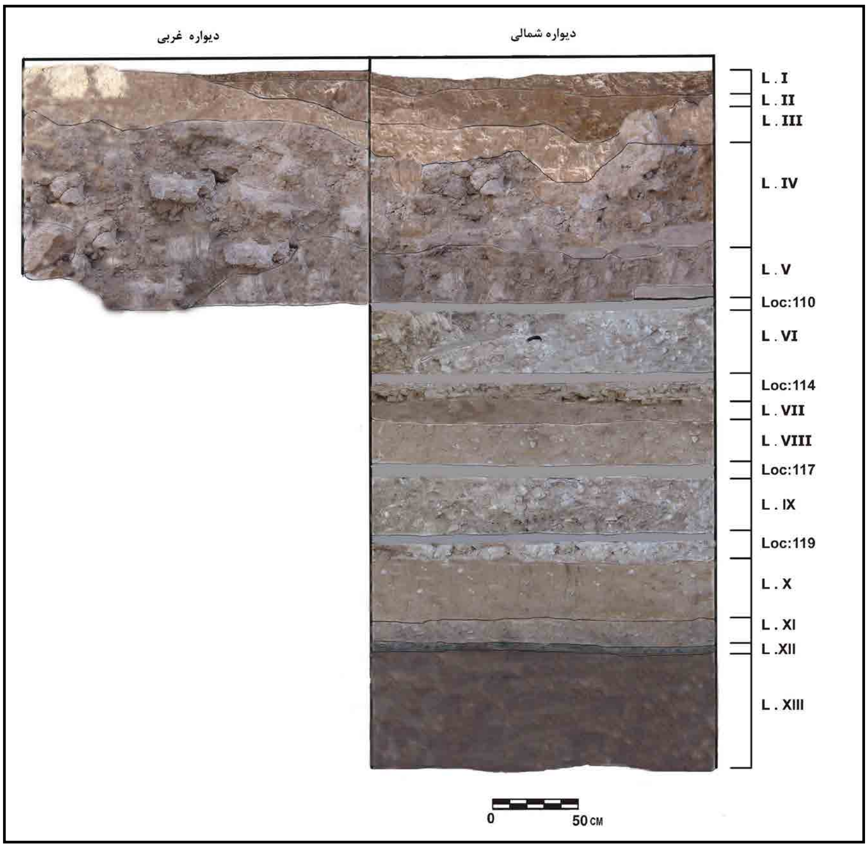


Fig. 12: Stratigraphy of Tr. A, Siraf 2009 (Left,Esmaeili Jelodar, 2021: 212).

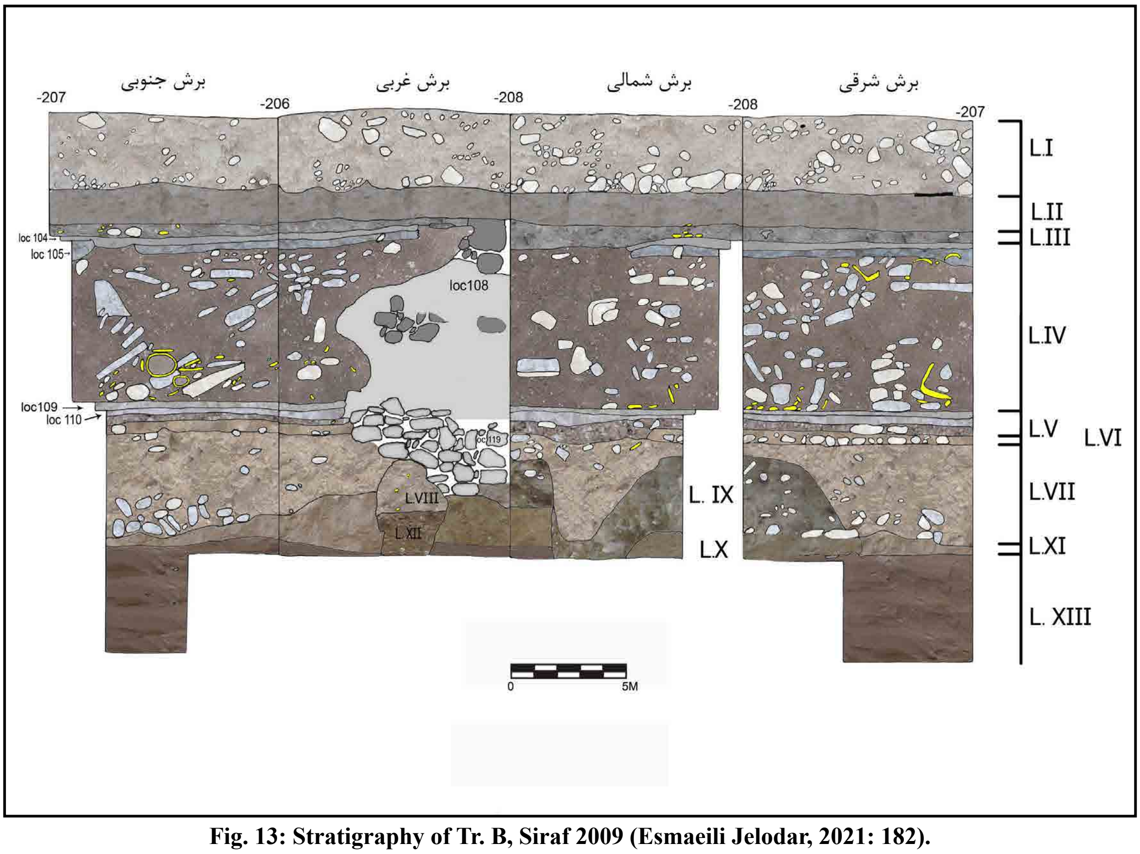


Fig. 13: Stratigraphy of Tr. B, Siraf 2009 (Esmaeili Jelodar, 2021: 182).


Fig. 14: East wall section of stratigraphy of Tr. B.(left). Fig. 15 &16: The deposit of the Early Islamic period, which is full of Sassanid cultural materials such as torpedo jar, blue- green glaze ware.

Fig. 17: Three torpedo jars from Siraf, Tr. B, loc.107, Layer Ic.

Table 2: Stratigraphy of Tr. A, Siraf 2009 (Esmaeili Jelodar, 2021: 218).

Locous	Layer	sous-phase	Phase	Period
-	XII, XIII	-	-	virgin soil
—	X, XI	-	Ia	I 800-1050 AD
119	IX	IbI	Ib	
117	VIII	IbII		
114 C14 Dating from Loc.114:850-976AD	IV, VII	-	Ic	
110	II, III, IV, V		Id	
-	I	-	-	Surface layer

Table 3: C14 dating result from Siraf,Tr. B, Oxford lab (Esmaeili Jelodar, 2021: 188).

No.	Oxf. No		Tr,	Loc.	Layer	Date
3	Oxa.22844	Bone	B	107	IV	887(95.4%)985 cal.AD

Table 4: Stratigraphy of Tr. B, Siraf 2009 (Jelodar, 2021: 189).

Locus of architectural structures	layer	Sub-phase	Phase	Period	
–	XIII, XII, XI, X	–	–	–	Virgin soil
–	IX, VIII, VII	IaI	Ia	Sassanid and Early Islamic era 400-800AD	I Late Sassanid and Early Islamic era
–	VI, V	IaII		800-985 AD C14 dating: layer IV, Locus 107; 887- 985 cal. AD (95.4%)	
108, 110, 119	–	IbI	Ib		
109	–	IbII			
–	IV	–	Ic		
105, 108	–	-	IIa	II 1000-1160 AD	II Islamic period (11-12 century)
104	–				
–	III	–	IIb		
–	II, I	–	–		Surface soil

Mahruban: Samples No. 3433, 3444, 3445, 3446

Mahruban was a significant port in the coastal Persian Gulf engaging in extensive trade with other ports such as Basra, Siniz and Genaveh as well as with inland centers like Arrajan in the Behbahan Area. Situated approximately 10 km north of Deylam near the village of Shah Abdollah, the remnants of this site now form a visible natural ridgeline stretching almost 1.5 km with a width exceeding 200 m. (Fig. 18).

Fig. 18: Left: Arial photo of Mahruban in west of Shah Abdullah village on Google Earth. Right: location of trenches A (top) and B (down) on the GIS map of the Mahruban port.

Mahruban was a thriving city from the late Sassanid era to the early Islamic era until the 10th century AD, as indicated by historical sources and archaeological research (Esmaeli Jelodar and Mortezae, 2013; Ibn Faqih 1970: 9, 114; Schwartz, 2003:164; Ibn Rusta, 1986: 111; Istakhri, 1994: 39-40, 115, 120-121, 127; Muqaddasi, 2006: 74, 631, 636; and 672-673; Ibn Ḥawqal, 1966:1, 7, 21 and 55; Al-Jeyhani, 1989: 55, 58, 110, 119; Anonymous, 1983:133; Qudama ibn Jafar 991:137; Qubaidiani Marvzi, 1984:160-163; Gaube, 1981a and b:77-78). In 2009, based on location and extent area of the Mahruban port, two trenches were opened: trench A and B (Fig. 19).

Fig. 19: General view from Trench B.

Fig. 20: Torpedo jar fragments from Locus 117, Tr. B.

Mahruban's Torpedo Shape Pottery Perspective

A Torpedo jar from Mahruban port was obtained for the first time from Locus 108, from a depth of -250 cm in the trench B, from layer IIc, with a chronology of 900-1300 AD. The C-14 dating for this layer is 943 to 1010 AD (Tables 5 and 6), and considering that the sample was chosen from the lowest level of this layer, it is logical to attribute it to the beginning of the 10th century AD (Esmaeili Jelodar and Mortezae, 2013; 343). The existence of early Sgraffito pottery along with Torquize glaze ware with barbotine decoration and their attribution to the Islamic period indicates the presence of this port in the international maritime trade of the Persian Gulf in the early Islamic centuries. However, most statistics related to the torpedo jar tipped pottery were obtained from the deposits of Locus 117 to Locus 122 in Trench B (Fig. 20)

The specimens chosen for laboratory analysis were gathered during a 2009 archaeological dig and consist of sample numbers No.3433, No.3435, and No.3436. These samples originate from a layer that, based on pottery typology for relative chronology and C-14 absolute dating, can be attributed to the late Sassanid and early Islamic Period. They were discovered in a stratum directly above a clearly Sassanid context, suggesting potential usage during the Sassanid era.

Table 5: C14 Dating of Port of Mahruban, Persian Gulf, Iran.1388, Tr. B (Oxford University Laboratory, UK, 2010).

No.	Oxf. No		Tr,	Loc.	Layer	Date
11	Oxa.22800	Tooth	B	108		897(17.8%)922 cal.AD 943(77.6%)1020. cal.AD
12	Oxa.22801	Bone	B	114		544(95.4%)633 cal.AD
13	Oxa.22669	Charcoal	B	114		878(95.4%)985 cal.AD

2.2. Samples analyzed

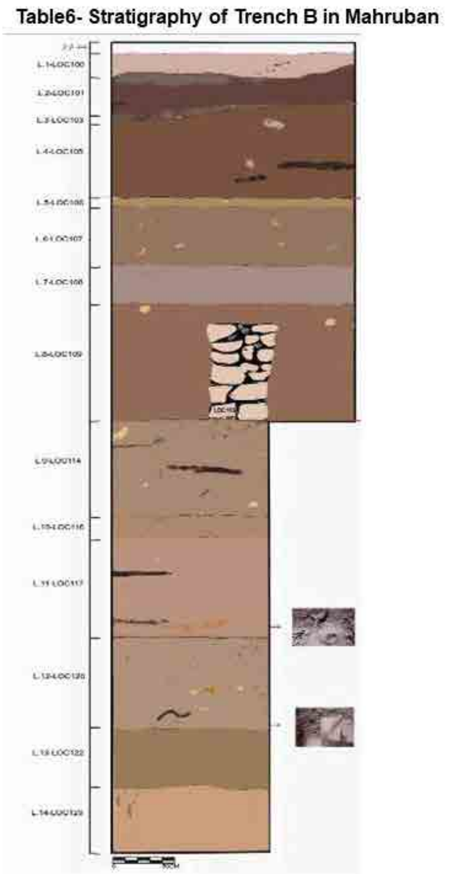
15 samples of bitumen (Table 7), coating the interior face of potsherds from torpedo jars, dated from the Late Sassanid to the Early Islamic period (6th-8th century AD), from one Parthian jar from Susa (247 BCE-224 AD) and from one sample of Dastova of Elimaei-Parthian period, were analyzed to collect molecular data on saturates and aromatics and isotopic data on chromatographic fractions: saturates, aromatics, resins (NSO compounds) and asphaltenes (Table 8). Photos of samples are reproduced in Figures 21 and 22.

2.3. Analytical procedures

Methods used in this study have been described in details in previous papers (Connan *et al.,* 2021, 2022).

Table 6: Stratigraphy of TR. B in Mahruban

LOC	LAYER	LEVEL	C14 DATING(OXF.L)
100	L1	IIC 900-1300AD 330-730AH	
101	L2		
102	L3		
103	L4		
104			
105	L5		
106	L6		
107	L7		
108	L8		897(17.8%)922 cal.AD 943(77.6%)1020. cal.AD
109	L9	IIB IIB 900-1150AD/ 330-480AH	
110	L10	IIA 630-850AD/ 30-240AH	
111			
112			
113			
114			878(95.4%)985 cal.AD 544(95.4%)633 cal.AD
115			
116	L11		
117			
118			
119	L12		
120	L13	I 200-600AD	
121			
122			
123	L14	O	
124			



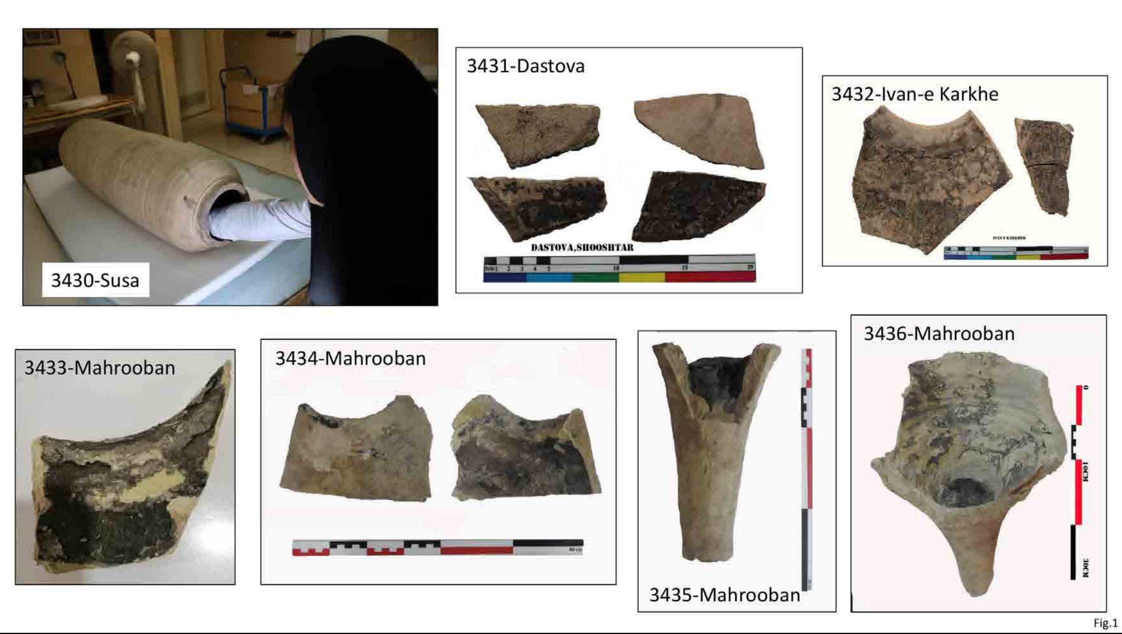


Fig. 21: Photographs of bitumen samples of Susa, Dastova, Ivan-i Karkheh and Maruban.

Fig. 22: Photographs of bitumen samples of Siraf.

3. Results and discussions

3.1. Gross composition

Gross composition data are compiled in Table 8. The scraped samples from potsherds are all rich in bitumen with a dichloromethane extract between 21 and 88 % / weight. Plot of % saturates vs. % aromatics vs. % polars (resins + asphaltenes) and % hydrocarbons (saturates + aromatics) vs. % resins (NSO) vs. % asphaltenes in Figs.23 and 24 shows that bitumens are all extremely rich in polar fractions and therefore are characteristic bitumens of archaeological sites, well documented in the literature (e.g. Connan *et al.,* 2021).

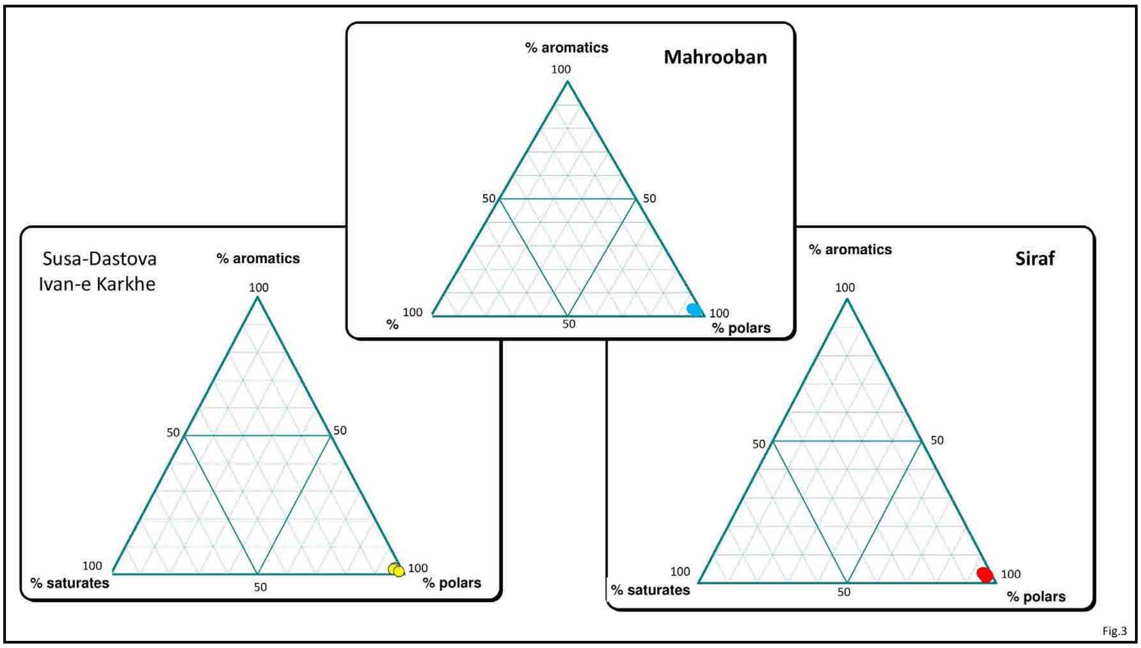


Fig. 23: Gross composition of the dichloromethane extract in ternary diagrams: %saturates vs. %aromatics vs. % polars (resins + asphaltenes) for Susa-Dastova-Ivan-iKarkheh, Mahruban and Siraf.

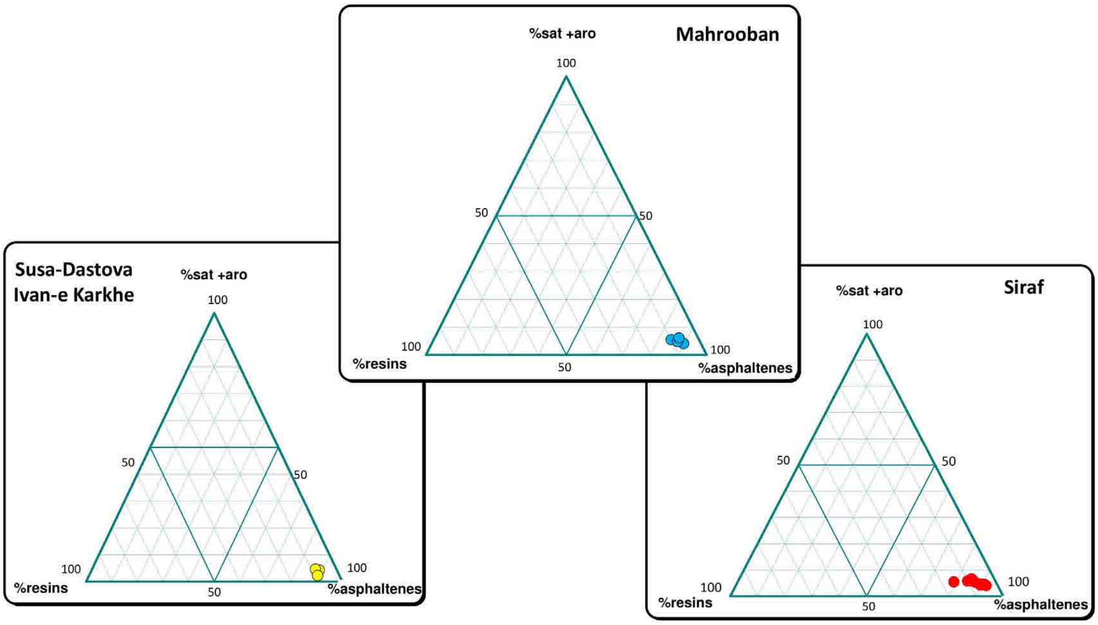


Fig. 24: Gross composition of the dichloromethane extract in ternary diagrams: %hydrocarbons (saturates + aromatics) vs. %resins vs. %asphaltenes for Susa-Dastova-Ivan-i Karkheh, Mahruban and Siraf.

3.2. Isotopic data

Isotopic data are listed in Table 2. Plot of $\delta^{13}C_{sat}$ (‰ /VPDB) vs. $\delta^{13}C_{aro}$ (‰ /VPDB) and $\delta^{13}C_{asp}$ (‰ /VPDB) vs. $\delta^{13}C_{NSO}$ (‰ /VPDB) in Fig. 25 shows a diversified situation among the samples and therefore different sources. By anticipating the rest of the study and taking into account the biomarker data and the presence of 18α(H)-oleanane, it follows that some samples cluster in a group (Fig. 25) where $\delta^{13}C_{asp}$ (‰ /VPDB) is ranging between -26.8 and -27.3 (‰ /VPDB). The occurrence of 18α(H)-oleanane is characteristic of bitumen originating from Iran. This feature is of course not surprising for samples of the Susa area but is informative for the bitumen of Siraf for it orientates the search of their bitumen sources towards Khuzestan, i.e the same area where the bitumen for the Susa samples where collected. Other samples came from other areas with $\delta^{13}C_{asp}$ (‰ /VPDB) ranging between -27.0 and -28.0 (‰ /VPDB).

Plot of δD_{asp} (‰/ SMOW) vs. dDNSO(‰/ SMOW) and δD_{asp}(‰/ SMOW) vs. $\delta^{13}C_{asp}$ (‰/ SMOW) in Figs.26 shows that bitumen from the potsherds of the Susa area seems to be more oxidized, i.e. more enriched in 2H, than bitumens from Siraf samples. Mahrooban samples display a diversified situation. No relation is recorded between δD_{asp} (‰/ SMOW) and $\delta^{13}C_{asp}$ (‰/ VPDB). δD_{asp} (‰/ SMOW) is not a source indicator but reflects either the stage of oxidation of the bitumen or a possible contribution of ingredients which were stored or processed in the potsherd and were therefore impregnating the bitumen. In the present case the δD_{asp} (‰/ SMOW), which ranges between -100 and -70 (‰/ SMOW), does not suggest any potential contribution of the contents stored in jars.

The data on the samples of this set were compared to data obtained on bitumens from archaeological sites used as proxis (Fig. 27) and oil seeps (Fig. 28) from Iran. Plot of δD_{asp} (‰/ SMOW) vs. $\delta^{13}C_{asp}$ (‰/ VPDB) of archaeological sites (Fig. 29) shows that many samples of Susa, Chogha Ahowan, Tepe Tula'i, are enriched in 2H as compared to what is recorded in this study. Some samples from Susa, Ali Kosh, Chogha Ahowan and Ali

Table 7: Gross composition and isotopic data on bitumens. Significance of abbreviations: EO% (% dichloromethane extract/ sample), sat% = % saturates / EO, aro% = % aromatics /EO, NSO% = % resins (NSO)/ EO, asp% = % asphaltenes /EO.

lab number	location	GeoMark number	Type of amphorae	EO%	sat%	aro%	sat +aro%	NSO%	asp%	pol%	δ^{13}Csat	δ^{13}Caro	$\delta^{13}C_{NSO}$	δ^{13}Casp	δD_{NSO} average	δDasp average
3430	Susa	UNK0872	MITCOV	29.3%	2.1	2.3	4.3	6.9	88.8	95.7	-27.6	-27.0	-26.69	-27.3	-95	-74
3431	Dastova	UNK0873	S?	55.4%	2.7	1.9	4.6	8.2	87.2	95.4	-27.2	-26.2	-26.5	-26.8	-92	-74
3432	Ivan-i Karkheh	UNK0874	C?	44.5%	1.3	1.1	2.3	8.5	89.1	97.7	-27.4	-26.6	-27.1	-27.0	-92	-73
3433	Mahruban	UNK0875	C	64.2%	1.9	2.2	4.1	6.2	89.7	95.9	-28.8	-28.0	-28.1	-28.0	-88	-69
3434	Mahruban	UNK0876	C	73.9%	2.4	3.1	5.5	9.9	84.6	94.5	-28.4	-27.0	-27.2	-27.2	-89	-76
3435	Mahruban	UNK0877	C	72.9%	1.9	2.9	4.8	8.0	87.3	95.2	-28.4	-27.2	-26.9	-27.0	-88	-85
3436	Mahruban	UNK0878	C	68.2%	2.9	3.2	6.1	6.8	87.1	93.9	-28.4	-27.0	-27.1	-27.5	-90	-97
3437	Siraf	UNK0879	C?	32.3%	2.1	3.7	5.9	9.6	84.6	94.1	-28.3	-27.0	-27.4	-27.5	-83	-91
3438	Siraf	UNK0880	S	88.5%	1.5	2.8	4.3	6.2	89.5	95.7	-29.1	-27.7	-27.9	-28.0	-86	-88
3439	Siraf	UNK0881	S?	63.4%	2.5	3.3	5.8	10.1	84.0	94.2	-27.9	-26.8	-26.6	-27.0	-96	-85
3439 bis	Siraf	UNK0882	S?	21.9%	2.1	3.4	5.5	15.3	79.2	94.5	-28.0	-27.3	-27.9	-27.6	-93	-95
3440	Siraf	UNK0883	C	65.0%	2.9	3.7	6.6	8.3	85.1	93.4	-27.7	-26.6	-26.9	-26.8	-96	-83
3441	Siraf	UNK0884	S	39.5%	1.7	2.4	4.1	4.2	91.8	95.9	-29.3	-27.4	-27.5	-27.9	-84	-84
3442	Siraf	UNK0885	S	74.7%	1.7	2.9	4.6	5.6	89.8	95.4	-28.7	-27.5	-27.9	-28.0	-90	-83
3443	Siraf	UNK0886	C	64.8%	2.5	2.0	4.5	4.6	90.9	95.5	-28.2	-27.1	-27.3	-27.3	-82	-87
3444	Siraf	UNK0887	C	35.1%	2.7	2.9	5.5	7.7	86.8	94.5	-27.6	-26.8	-26.6	-27.0	-89	-81
3444 bis	Siraf	UNK0888	C	68.9%	2.8	3.3	6.1	8.1	85.8	93.9	-27.8	-26.8	-26.9	-26.8	-92	-87

Table 8: Information about the samples: location, type of jar, date of samples.

lab number	Site	origin	Register number	photos	archaeological trench	Pottery No.	Locus	Layer/phase	campaign	latitude	longitude	type of torpedo jar (S or C?)	date of the potshed	date absolute dare (bone)	absolute date (tooth)	absolute date (charcoal)
3430	Susa	National Museum of Iran				56667				32°11'26"N	48°15'28"E	MITCOV	Parthian 247 BCE-224 AD			
3431	Dastova	Survey			archaeological survey 2012	1				32°0'22,31"N	48°50'22,80"E	S?	Parthian			
3432	Ivan-i Karkheh				archaeological survey 2012	2				32°19'15,84"N	48°7'35,36"E	C?	Sassanid or Early islamic era?			
3433	Mahruban port	Excavation project	M2/2020		Tr:B	10	117	L11/II or IIa		30°10'58,59"N	50°5'19,54"E	C	Late Sassanid	544(95,4)633 AD		
3434			M4/2020		Tr:B	26	109	L9/IIb		30°10'58,59"N	50°5'19,54"E	C	Early Islamic	670(93%)780 AD	943(77%)1020 AD	878(95,4%)985 AD
3435			M3/2020		Tr:B	3	117	L11/I? or IIa	2009	30°10'58,59"N	50°5'19,54"E	C	Late Sassanid	544(95,4)633 AD		
3436			M1/2020	259-260	Tr:B	32	117	L11/II or IIa		30°10'58,59"N	50°5'19,54"E	C	Late Sassanid	544(95,4)633 AD		
3437	Siraf	Excavation project	S7		Tr:B	828	TGF	Whitehouse Excavation 1968-1969-Great Mosque	1968-1969	27°40'4,03"N	52°20'7,05"E	C?	Late Sassanid? Early Islamic			
3438			S5		Tr:B	3	107	I.c	2009	27°40'4,03"N	52°20'7,05"E	S	Late Sassanid?Early Islamic	782(1,6%)789 cal AD 811(8,1%)847.cal AD 850 (85,5%)976.cal AD		
3439			S3	269-276	Tr:B	2/20;2	107	I.c	2009 code : 2	27°40'4,03"N	52°20'7,05"E	S?	Late Sassanid?Early Islamic	887(95,4%)985 cal.AD		
3440			S6		Tr: B	2/20;3	107		2009	27°40'4,03"N	52°20'7,05"E	C	Late Sassanid? Early Islamic			
3441			S2	278-295	Tr:B	2/21	107	I.c	2009	27°40'4,03"N	52°20'7,05"E	S	Late Sassanid?Early Islamic			
3442			S4		Tr:B	1	107	I.c	2009	27°40'4,03"N	52°20'7,05"E	S	Late Sassanid?Early Islamic			
3443			S8		Tr:A	32	118	I.b1	2009	27°40'4,03"N	52°20'7,05"E	C	Early Islamic			
3444			S1	269-276	Tr:B	2/20;1	107	I.c	2009 code :2	27°40'4,03"N	52°20'7,05"E	C	Late Sassanid? Early Islamic			

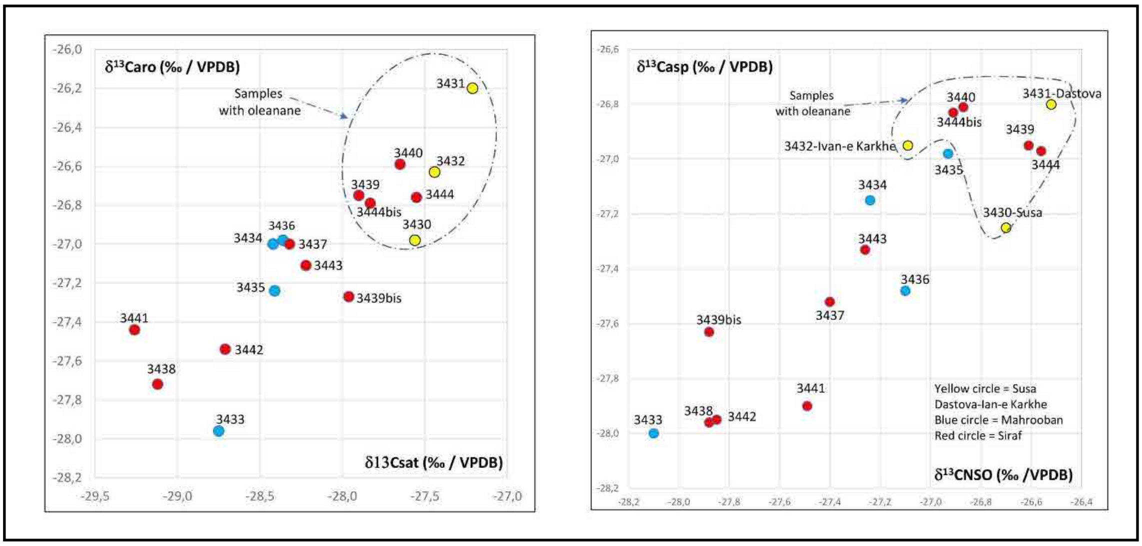


Fig. 25: Plot of δD_{asp} (‰ / SMOW) vs. δD_{NSO} (‰ / SMOW) and δD_{asp} (‰ / SMOW) vs. $\delta^{13}C_{asp}$ (‰ / VPDB). Significance of colours in Fig. 25.

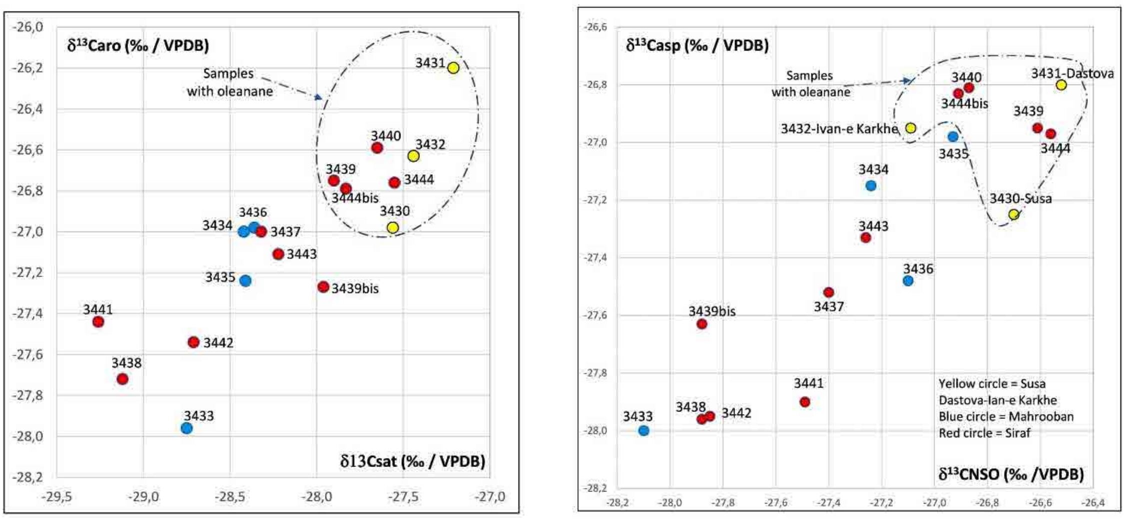


Fig. 26: Plot of δD_{asp} (‰ / SMOW) vs. δD_{NSO} (‰ / SMOW) and δD_{asp} (‰ / SMOW) vs. $\delta^{13}C_{asp}$ (‰ / VPDB). Significance of colours in Fig. 25.

Abad integrate the area defined by the samples of this study. One should notice that the Susa sample is in agreement with a Susa sample from the rim of a Parthian amphorae, previously analyzed. The record of δD_{asp} (‰/ SMOW) as a function of date (Fig. 29) did not show any tend despite the fact that oxidation of bitumen may have been enhanced with age. Plot of δD_{asp} (‰/ SMOW) vs. $\delta^{13}C_{asp}$ (‰/ VPDB) of oil seeps (Fig. 30) point that samples are matching with area of samples defined by Dehluran-Siah Kuh, Sultan/ Pol Doktar and Gilsonites, i.e. samples from Illam, Lorestan and Kermanshah provinces.

3.3. Biomarkers: steranes and terpanes (Table 9)

Mass fragmentograms of steranes (*m/z* 217) and terpanes (*m/z* 191) are reproduced in Fig. 31 and 32.

The sample of Susa (No.3430) exhibits a rather well preserved distribution of terpanes with a moderate Tm/Ts and gammacerane, a low amount of tricycloploprenanes and a well

Fig. 27: Map of bitumens from archaeological sites of Iran used as proxis in this study.

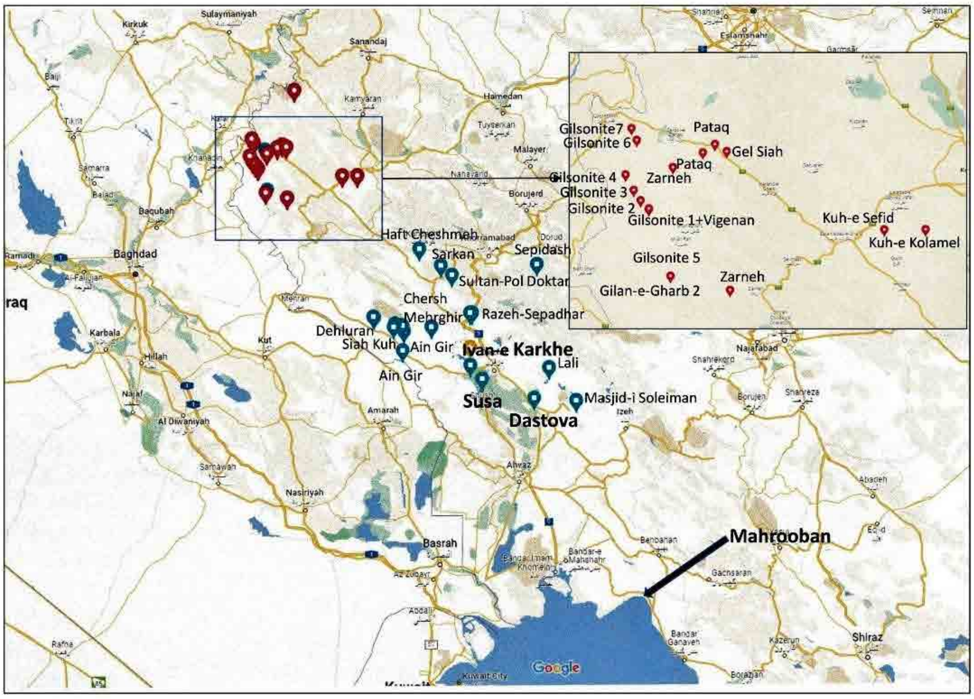


Fig. 28: Map of oil seeps used as references in this study.

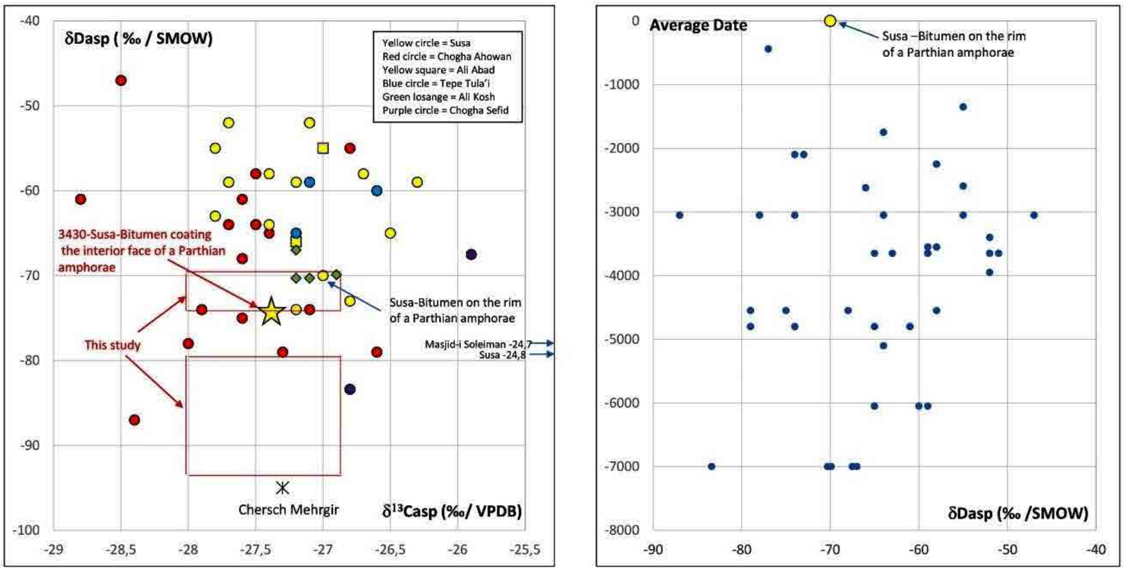


Fig. 29: Plot of δD_{asp} (‰ / SMOW) vs. δ$^{13}C_{asp}$ (‰ / VPDB) of bitumens from archaeological sites used as proxis. Plot of of δD_{asp} (‰ / SMOW) as a function of date of samples from archaeological sites.

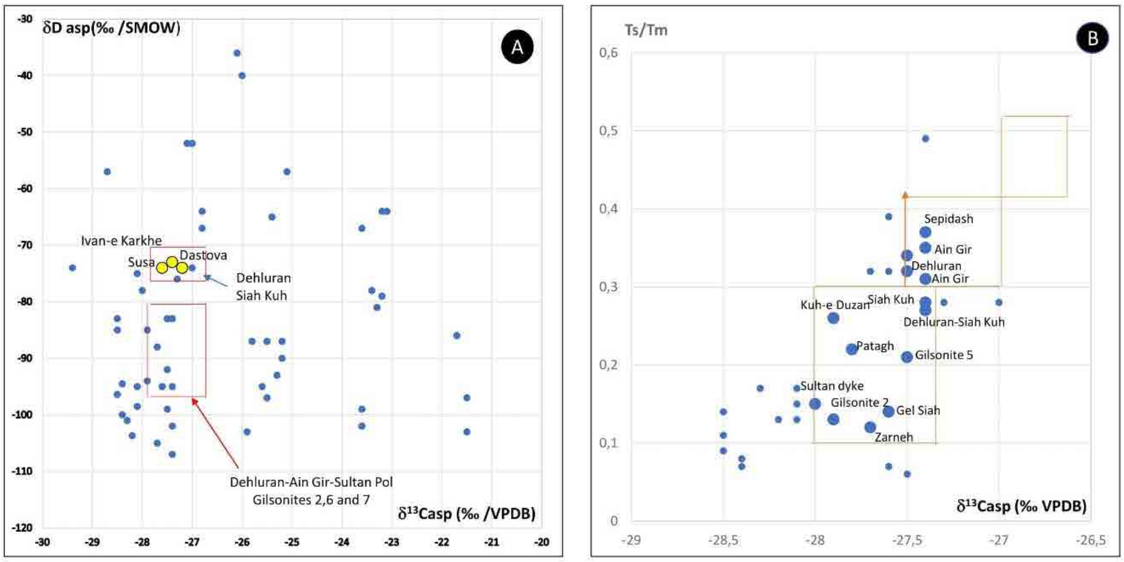


Fig. 30: Plot of δD_{asp} (‰ / SMOW) vs. δ$^{13}C_{asp}$ (‰ / VPDB) and Ts/Tm vs. δ$^{13}C_{asp}$ (‰ / VPDB).

present 18α(H)-oleanane. Steranes are biodegraded according to the well-documented sequence: C_{27} steranes are preferentially removed (Seifert and Moldowan, 1979, McKirdy *et al.,* 1983, Sandstrom and Philip, 1984, Seifert *et al.,* 1984, Chosson *et al.,* 1991, Connan *et al.,* 2022). In this set the C_{29}αααR sterane which have the biological configuration, is not selectively degraded as seen in the Dead Sea asphalt of Tell Yarmuth (Connan *et al.,* 2022).C_{21} and C_{22} pregnanes have been almost removed.

The sample of Mahrooban (No.3435) shows also a well preserved fingerprint of terpanes with a moderate Tm/Ts and gammacerane. 18α(H)-oleanane is questionable and may occur as traces. Steranes are again biodegraded but present a well identified occurrence of C_{27}diasteranes. C_{21} and C_{22} steranes are present and the biological configuration of C_{29}steranes namely the C_{29}αααR sterane has not been selectively degraded.

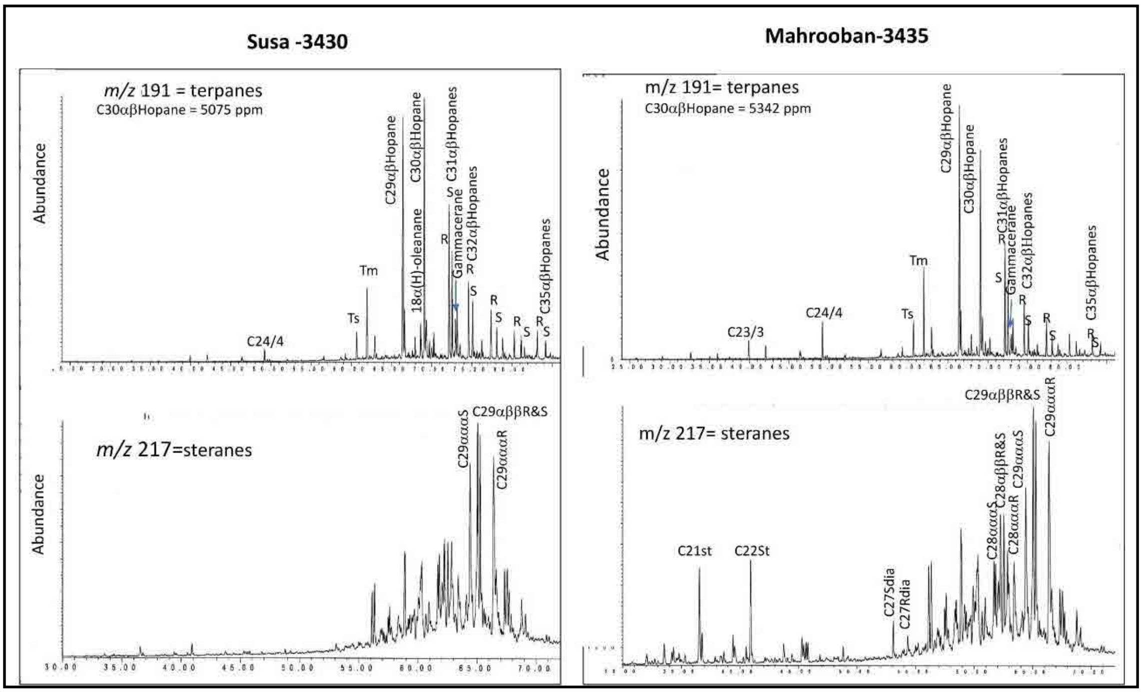


Fig. 31: Mass fragmentograms of steranes (*m/z* 217) and terpanes (*m/z* 191) from Susa (No.3430) and Mahruban (No. 3435).

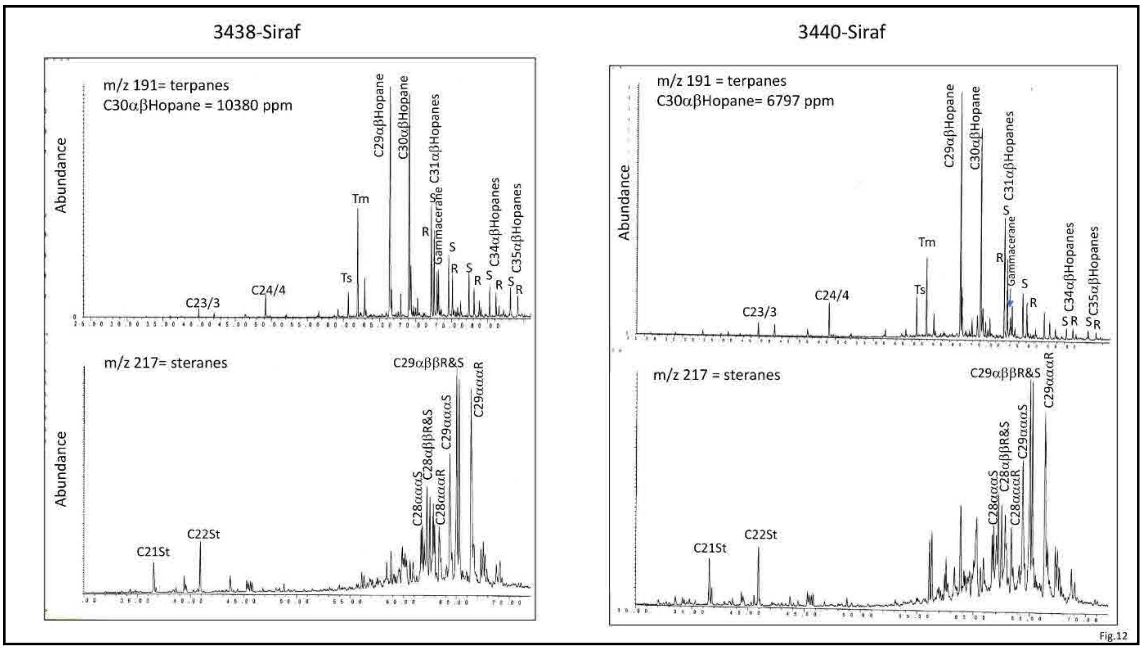


Fig. 32: Mass fragmentograms of steranes and terpanes (*m/z* 191) from Siraf (No.3438 and 3440).

The sample of Siraf N°3440 ressembles the Susa sample with the occurrence of 18α (H)-oleanane , a moderate Tm/Ts and gammacerane and biodegraded steranes in which the biological configuration of C_{29}steranes is not preferentially affected. C_{21} and C_{22} steranes are present. The sample of Siraf N°3438 is contrasted with a high Tm/Ts , more gammacerane , no oleanane and also biodegraded steranes with no C_{27}steranes. C_{21} and C_{22} steranes are present.

A plot of 18α(H)-oleanane vs. $\delta^{13}C_{asp}$ (‰ / VPDB) in Fig. 33a documents three main groups of samples : samples from the Susa area and 4 samples from Siraf (No.3439, 3440, 3444 and 3444bis) which contains 18α(H)-oleanane, samples from Siraf and Mahrooban with traces of 18α(H)-oleanane and samples from Mahrooban (No.3433) and Siraf without 18α(H)-oleanane. No oil seeps analyzed yet are corresponding to samples with 18α(H)-oleanane or traces of 18α(H)-oleanane (Fig. 33b). Obviously their sources are in the Zagros mountains, east or southeast of Susa, in the Khuzestan province. The third group without 18α(H)-oleanane matches a list of gilsonite and oil seeps from Illam, Lorestan and Kermanshah (Fig. 33b). Fig. 34 complete the comparison by referring to archaeological sites. Examples of bitumen with traces of 18α(H)-oleanane are also recorded in Susa and Tepe Senjar. Bitumen from Mahrooban may be originating from the same source, likeley in Khuzestan. Bitumen without 18α(H)-oleanane are matching with bitumens excavated from Chogha Ahowan, Susa, Tall-e Geser (Fig. 34)

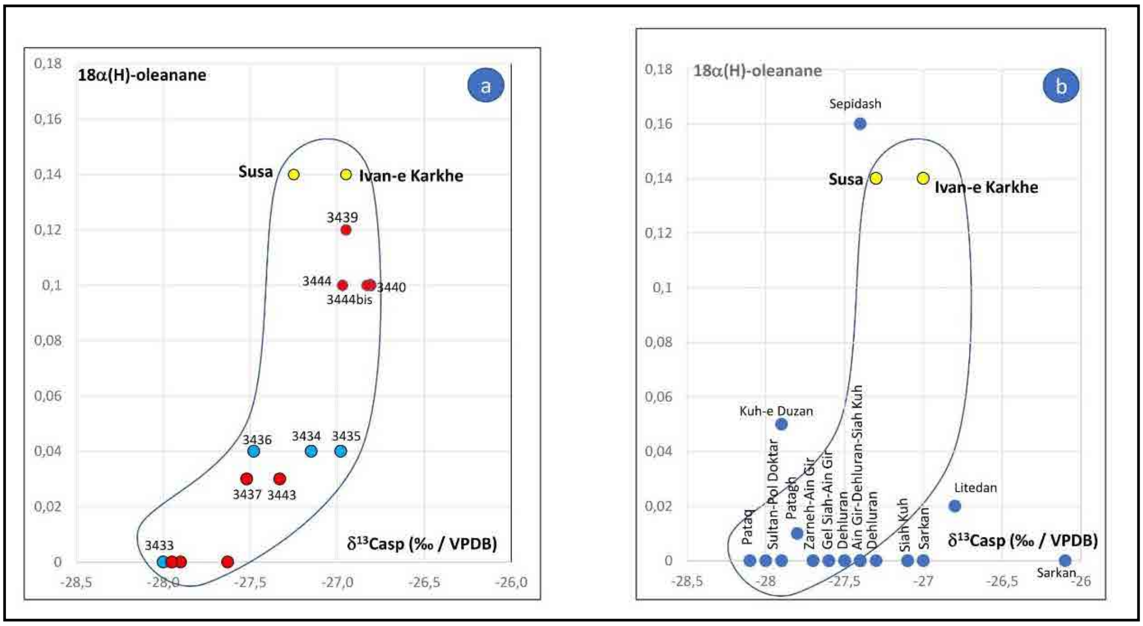


Fig. 33: Plot of 18α(H)-oleanane vs. $\delta^{13}C_{asp}$ (‰ / VPDB). a) samples of this study. b) samples of oil seeps.

A plot Ts/Tm vs. $\delta^{13}C_{asp}$ (‰ / VPDB) is another diagram currently used for correlation purposes. Fig. 35 and 36 gave the results in reference to data collected on oil seeps and archaeological sites. Many samples of both natural oil seeps and archaeological bitumen show properties that match those of bitumens from this study.

Report of results on maps of oil seeps (Fig. 37) and archaeological sites (Fig. 38) provides a synthesis of the potential sources. More gilsonites may be concerned if their $\delta^{13}C_{asp}$ (‰ / VPDB) are enriched of 0.4-0.5 (‰ / VPDB) though alteration and are consequently shifted from -28.3 to -27.9 (‰ / VPDB).

3.4. Aromatics

Mass fragmentograms of triaromatic steroids (*m/z* 231), phenanthrenes (*m/z* 178+192) and dibenzothiophenes (*m/z* 184 + 198) from Susa (No.3430), Mahruban (No.3433) and Siraf (Nos.3440 and 3438) are shown in Fig. 39. Phenanthrenes, dibenzothiophenes

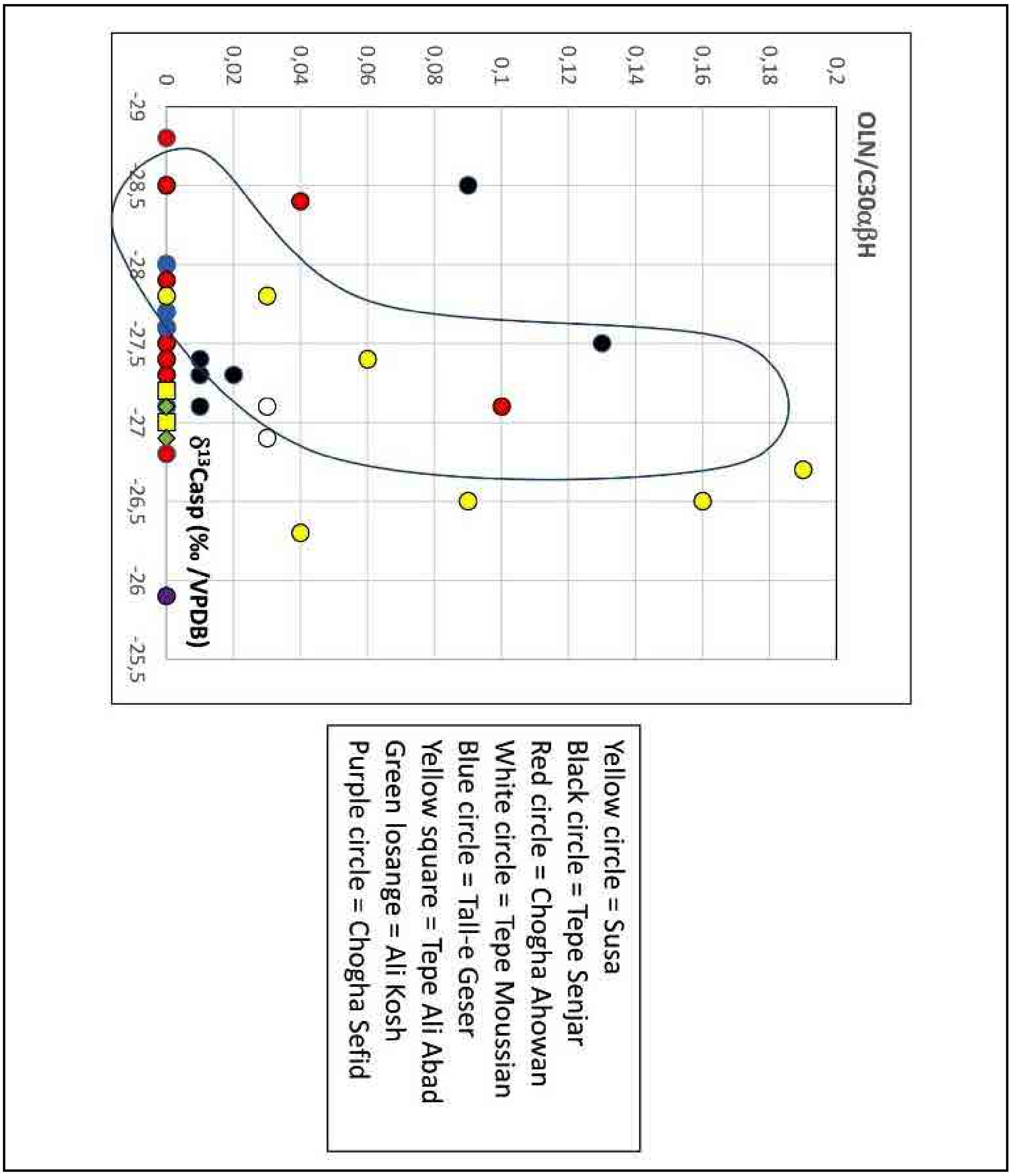


Fig. 34: Plot of 18α(H)-oleanane vs. $\delta^{13}C_{asp}$ (‰ / VPDB) : samples of archaeological sites.

and triaromatic steroids are all present. Triaromatic steroids show a very low amount of $C_{26}S$. Patterns of methylphenanthrenes and dibenzothiophenes are consistent with what is observed in Pataq oil seeps and some gilsonites but obviously aromatics of archaeological samples are more altered. Plot of some molecular ratios (4MDBT vs. P/DBT and $C_{27}R/C_{28}R$ vs $C_{26}S/C_{2}8S$, Table 10) of archaeological samples by comparison to those of five gilsonites used as unaltered references confirm that aromatics of archaeological samples are altered. The changes seen in the parameters of Fig. 40 are identical to what has been recorded in the Dead Sea bitumen (Connan *et al.,* 2022).

Table 9: Steranes and terpanes ratios and comment on their fingerprints. Significance of abbreviations: C30 Hopane ppm = C30$\alpha\beta$Hopane in ppm. Tet/C_{23} = C_{24} tetracyclic terpane / C_{23} tricyclic terpane, C_{29}/H = norhopane/ hopane, OL/H = 18α(H)-oleanane / hopane, C31R/H= 17α, 21β, 22R-30-homohopane/ hopane, GA/C31R= Gammacerane/ 17α ,21β,22R-30-homohopane, GA/C30$\alpha\beta$H = gammacerane/ hopane, C35S/C34S=17a,21b-C35 extended hopane (22S)/ 17a, 21b-C34 extended hopane (22S), ster/terp = steranes / terpanes, Dia /Reg = diasteranes / regular steranes, %C_{27}= 5α,14β,17β-20R+20S-cholestane,%C_{28}=5α,14β,17β-20R+20S-24-methylcholestane, %C_{29}=5α,14β,17β-20R+20S-24ethyl-cholestane, C_{29} 20S/R= $C_{29}\alpha\alpha\alpha$S/ $C_{29}\alpha\alpha\alpha$R, $C_{29}\beta\beta$S/$\alpha\alpha$R= $C_{29}\alpha\beta\beta$S/ $C_{29}\alpha\alpha\alpha$R, Ts/Tm = 18α-22,29, 30-trisnorneohopane / 17α-22,29,30-trisnorhopane.

Ref	Lab number	Geomark reference	location	C30 Hopane ppm	Tet/C23	C29/H	Ol/H	C31R/H	GA/C31 R	GA/C30αβH	C35S/C34S	ster/terp	Dia/Reg	%C27	%C28	%C29	C29 20S/R	C2ββ S/αR	Ts/Tm	tricyclic	terpanes	steranes	C27 diasteranes	C29ββ steranes R
1	**3430**	UNK0872	**Susa**	5075	2.09	0.92	0.14	0.41	0.36	0.14	0.96	0.16	0.31	1.3	29.4	69.3	0.81	1.03	0.39	almost absent	preserved	biodegraded	absent	R>S
2	**3431**	UNK0873	**Dastova**	281	0.47	1.25	1.64	0.42	0.29	0.12	1.45	0.45	2.71	11	34.5	54.5	2.29	1.69	0.8	present low	biodegraded	biodegraded	present low	R<S biodegraded
3	**3432**	UNK0874	**Ivan-i Karkheh**	3948	2.47	1.15	0.14	0.44	0.28	0.12	1.1	0.13	1.05	12.5	29.3	58.2	1.16	1.17	0.49	low	preserved	biodegraded	present low	R<S biodegraded
4	**3433**	UNK0875	**Mahruban**	22314	3.63	1	0	0.3	0.55	0.16	0.83	0.1	0.04	1.4	17	81.6	0.68	1.28	0.12	low	preserved	biodegraded	absent	R>S
5	**3434**	UNK0876	**Mahruban**	6789	2.39	1.54	0.04	0.36	0.26	0.1	0.92	0.17	0.46	2.2	30.2	67.6	0.57	0.96	0.39	present low	preserved	biodegraded	absent	R>>S
6	**3435**	UNK0877	**Mahruban**	5342	2.02	1.25	0.04	0.37	0.27	0.1	0.92	0.2	0.64	7.6	31.9	60.5	0.66	0.98	0.42	present low	preserved	biodegraded	present	R>>S
7	**3436**	UNK0878	**Mahruban**	6707	2.12	1.44	0.04	0.36	0.26	0.09	0.96	0.18	0.59	5.5	29.5	65	0.58	0.95	0.41	present low	preserved	biodegraded	present low	R>>S
8	**3437**	UNK0879	**Siraf**	8248	2.39	1.02	0.03	0.34	0.5	0.17	0.71	0.16	0.1	0.6	25.5	73.9	0.67	1.2	0.25	present low	preserved	biodegraded	absent	R>>S
9	**3438**	UNK0880	**Siraf**	10380	2.94	1.05	0	0.39	0.51	0.2	0.93	0.13	0.09	3.4	28.1	68.6	0.64	1.03	0.23	present low	preserved	biodegraded	absent	R>>S
10	**3439**	UNK0881	**Siraf**	5796	2.42	1.11	0.12	0.4	0.25	0.1	0.74	0.23	0.1	1.3	25.1	73.6	0.64	0.98	0.52	presnt	preserved	biodegraded	absent	R>>S
11	**3439bis**	UNK0882	**Siraf**	7707	3.01	1.05	0	0.38	0.52	0.2	1	0.12	0.15	9.7	26.6	63.7	0.69	1.12	0.24	low	preserved	biodegraded	absent	R>>S
12	**3440**	UNK0883	**Siraf**	6797	2.58	1.19	0.1	0.37	0.25	0.09	0.86	0.23	0.25	1.1	26.8	72	0.62	1.1	0.52	present low	preserved	biodegraded	absent	R>>S
13	**3441**	UNK0884	**Siraf**	10492	2.72	1.22	0	0.31	0.47	0.14	0.98	0.12	0.09	0.8	24.4	74.8	0.62	1.11	0.2	present low	preserved	biodegraded	absent	R>>S
14	**3442**	UNK0885	**Siraf**	9988	6.06	1.03	0	0.33	0.55	0.18	0.94	0.12	0.07	2.3	18.4	79.3	0.69	1.12	0.22	low	preserved	biodegraded	absent	R>>S
15	**3443**	UNK0886	**Siraf**	8036	3.12	1.43	0.03	0.34	0.27	0.09	0.88	0.14	0.31	3.1	29.2	67.7	0.61	0.95	0.34	low	preserved	biodegraded	absent	R>>S
16	**3444**	UNK0887	**Siraf**	7459	2.37	1.16	0.1	0.35	0.25	0.09	0.87	0.22	0.3	1.5	27.5	71	0.63	0.99	0.5	low	preserved	biodegraded	absent	R>>S
17	**3444bis**	UNK0888	**Siraf**	7007	2.61	1.25	0.1	0.37	0.25	0.09	0.8	0.22	0.27	1.3	26.6	72.1	0.63	0.99	0.51	low	preserved	biodegraded	absent	R>>S

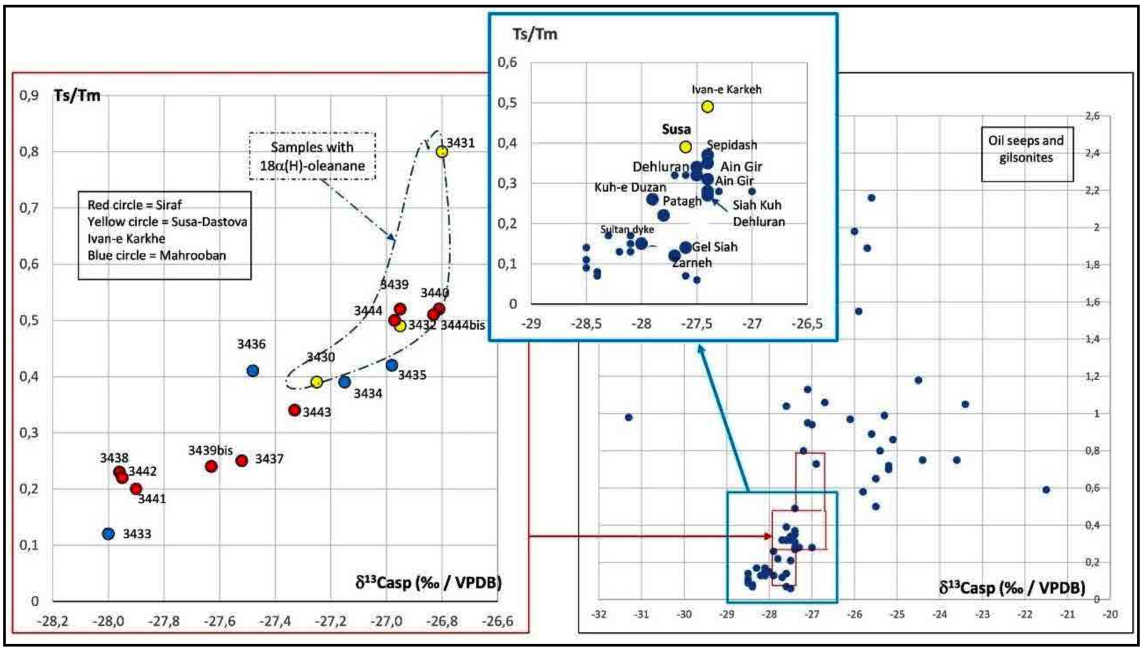


Fig. 35: Plot of Ts/Tm vs. δ13 13C$_{asp}$ (‰ / VPDB): samples of this study comp ared to samples of oil seeps and gilsonites

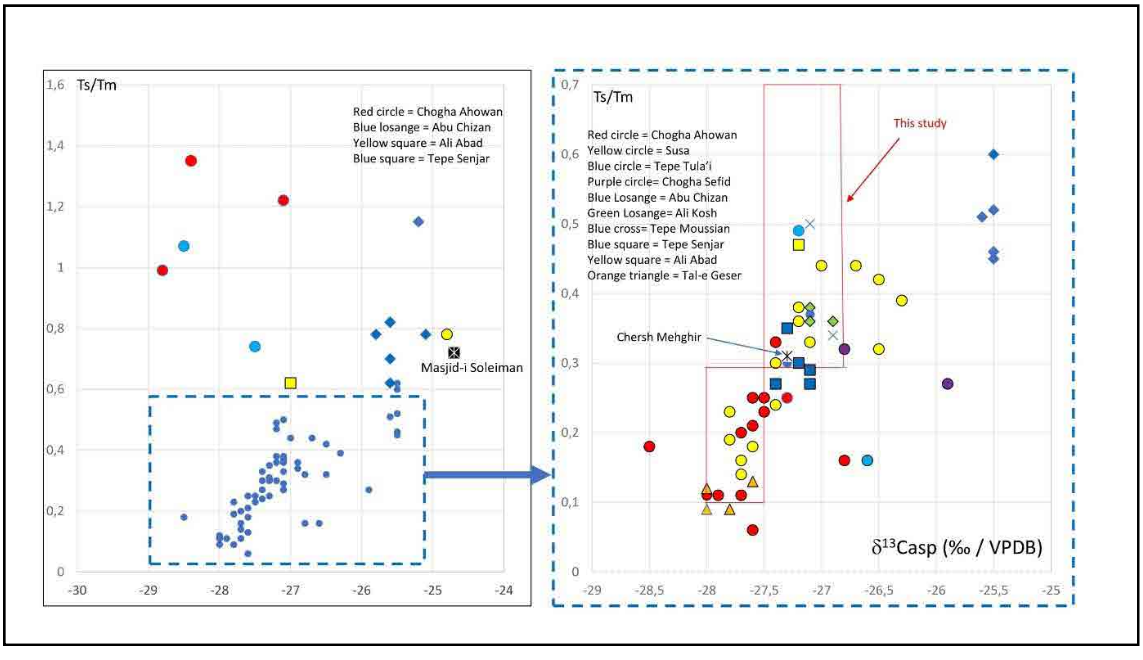


Fig. 36: Plot of Ts/Tm vs. δ13 13C$_{asp}$ (‰ / VPDB): samples of this study compared to samples of archaeological sites.

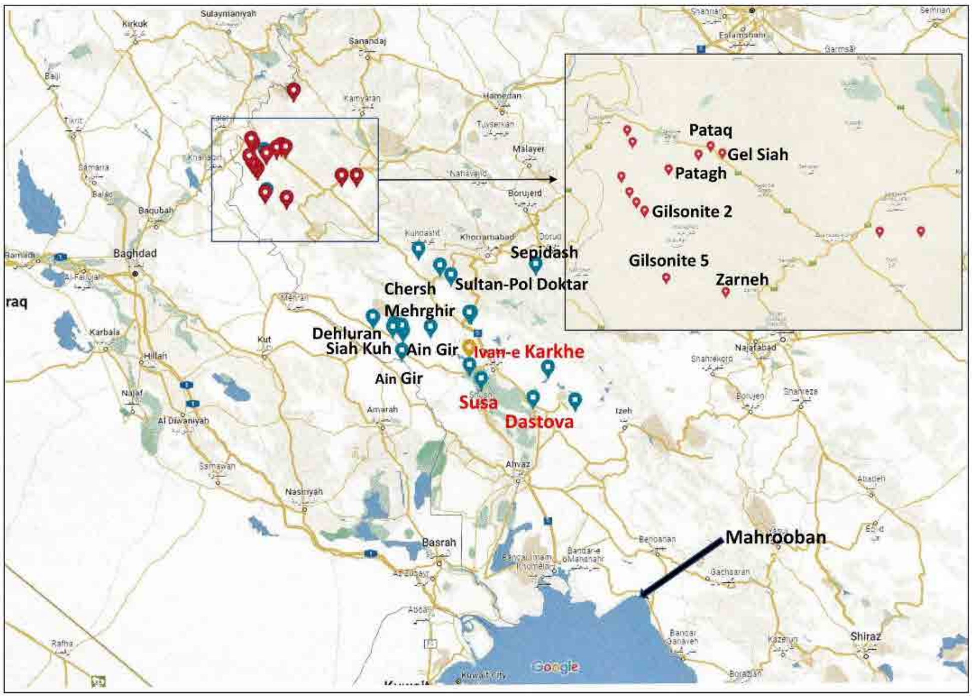


Fig. 37: Map of selected oil seeps identified as potential sources of archaeological bitumens of this study.

Fig. 38: Map of bitumens form archaeological sites which are matching bitumens of this study.

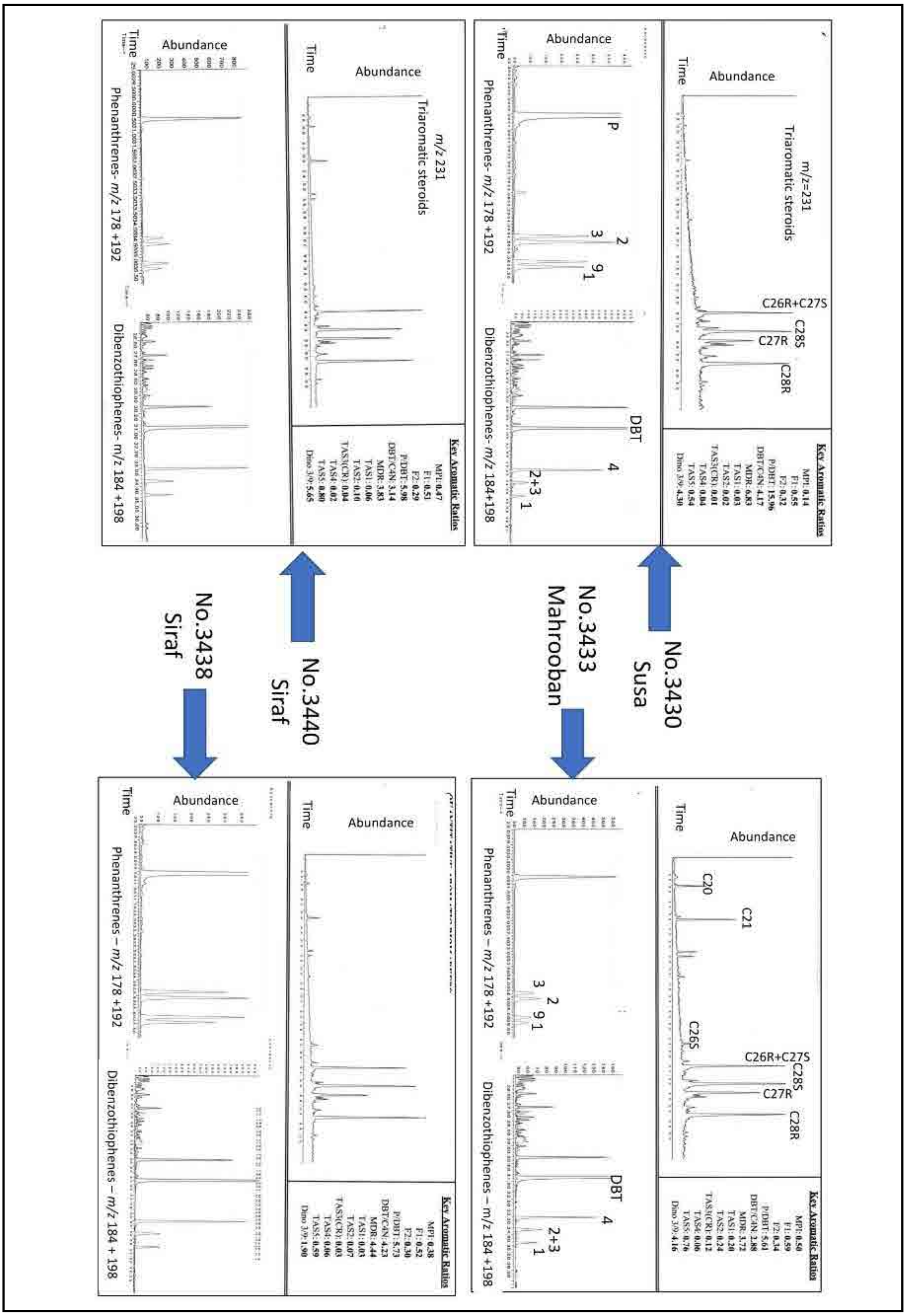


Fig. 39: Mass fragmentograms (*m/z* 231 =Triaromatic steroids, *m/z* 178 +192= Phenanthrenes), *m/z* 184 +198= Dibenzothiophenes) of aromatics of four samples : No.3430 (Susa), No.3433 (Mahruban), Nos.3440 and 3438 (Siraf).

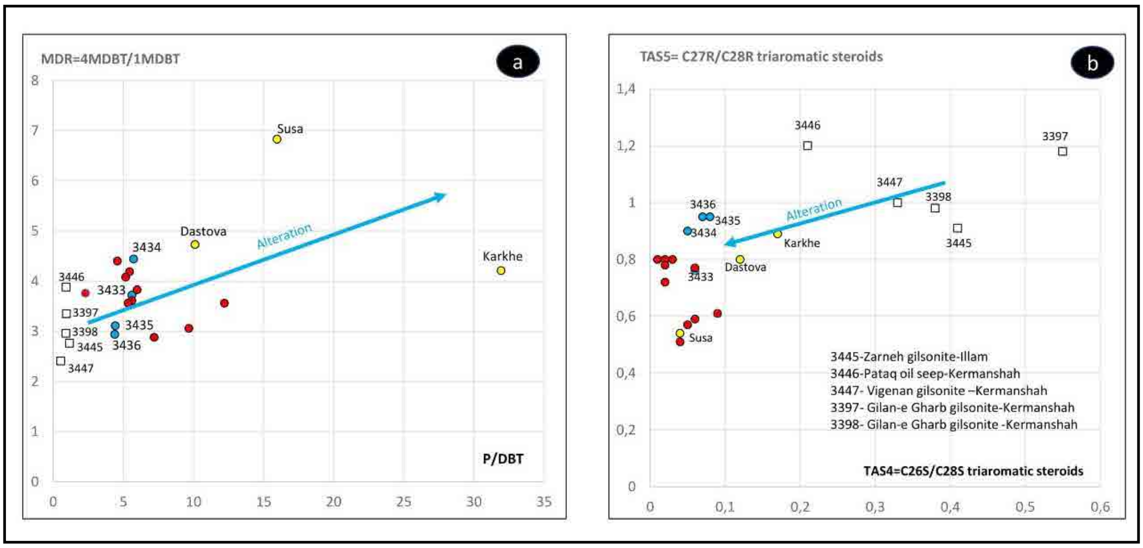


Fig. 40: Plot of some characteristic ratios of aromatics. a) 4MDBT vs. P/DBT. b) TAS5 vs. TAS4.

Table 10: Characteristic aromatic ratios on samples of this study and five representative gilsonites from the Kermanshah province. Significance of abbreviations: MPI = Methylphenanthrene Index = 1.5x[3MP+2MP] / [P + 9MP +1MP], F1= [3MP +2MP] / [3MP +2MP +9MP +1MP], F2= 2MP / [3MP +2MP +9MP + 1MP], P/DBT =phenanthrene/dibenzothiophene, DBT/C4N=dibenzothiophene/C4naphthalene, MDR = 4MDBT/ 1MDBT, TAS1= C20/ [C20+C27] triaromatic sterane, TAS2= C21/ [C21+C28] triaromatic sterane, TAS3 (cracking ratio) = [C20 + C21] / [C20-C28] triaromatic sterane, TAS4= C26S/C28S triaromatic sterane, TAS5= C27R / C28R triaromatic sterane.

lab number	Location	GeoMark reference	C30H ppm	MPI	F1	F2	P/DBT	DBT/C4N	MDR	TAS1	TAS2	TAS3	TAS4	TAS5	Dino3/9
3445	Zarneh Gilsonite	UNK0889	1782	0.73	0.47	0.27	1.16	3.05	2.76	0.36	0.33	0.16	0.41	0.91	3.22
3446	Pataq oil seep	UNK0890	1295	0.61	0.47	0.25	0.92	3.26	3.88	0.24	0.24	0.1	0.21	1.2	3.68
3447	Vigenan Gilsonite	UNK0891	1840	0.67	0.43	0.25	0.53	4.18	2.41	0.44	0.39	0.23	0.33	1	2.33
3397	Gilan-e Gharb Gilsonite	UNK0809	1009	0.69	0.42	0.24	0.94	2.02	3.35	0.64	0.6	0.38	0.55	1.18	3.4
3398	Gilan-e Gharb	UNK0810	1001	0.7	0.43	0.25	0.91	1.55	2.96	0.55	0.49	0.3	0.38	0.98	3.05
3430	Susa	UNK0872	5007	0.14	0.55	0.32	15.96	4.17	6.83	0.03	0.02	0.01	0.04	0.54	4.3
3431	Dastova	UNK0873	281	0.37	0.54	0.3	10.11	1.36	4.73	0.03	0.06	0.02	0.12	0.8	1.99
3432	Kharkheh	UNK0874	3948	0.44	0.54	0.31	31.93	0.73	4.21	0.07	0.07	0.03	0.17	0.89	3.16
3433	Mahruban	UNK0875	22314	0.5	0.59	0.34	5.61	2.88	3.72	0.2	0.24	0.12	0.06	0.76	4.16
3434	Mahruban	UNK0876	6789	0.46	0.62	0.36	4.58	3.08	4.4	0.06	0.12	0.05	0.05	0.9	3.55
3435	Mahruban	UNK0877	5342	0.42	0.53	0.3	4.42	2.18	3.11	0.09	0.16	0.06	0.08	0.95	2.24
3436	Mahruban	UNK0878	6707	0.41	0.54	0.31	4.39	2.26	2.94	0.07	0.15	0.06	0.07	0.95	2.21
3437	Siraf	UNK0879	8248	0.23	0.56	0.32	9.67	2	3.06	0.01	0.07	0.02	0.02	0.72	5.58
3438	Siraf	UNK0880	10380	0.38	0.52	0.3	5.73	4.23	4.44	0.03	0.07	0.03	0.06	0.59	1.9
3439	Siraf	UNK0881	5796	0.44	0.52	0.3	5.61	3.23	3.61	0.05	0.1	0.04	0.01	0.8	4.17
3439 bis	Siraf	UNK0882	7707	0.61	0.53	0.31	12.21	2.28	3.56	0.06	0.09	0.04	0.09	0.61	1.68
3440	Siraf	UNK0883	6797	0.47	0.51	0.29	5.98	3.14	3.83	0.06	0.1	0.04	0.02	0.8	5.65
3441	Siraf	UNK0884	10492	0.36	0.53	0.3	5.44	3.63	4.19	0.05	0.1	0.04	0.05	0.57	2.1
3442	Siraf	UNK0885	9988	0.59	0.47	0.27	7.2	3.31	2.88	0.03	0.07	0.03	0.04	0.51	2.86
3443	Siraf	UNK0886	8036	0.27	0.53	0.3	5.34	2.92	3.56	0.03	0.06	0.02	0.06	0.77	3
3444	Siraf	UNK0887	7459	0.45	0.51	0.3	2.29	3.54	3.76	0.05	0.09	0.04	0.03	0.8	4.87
3444bis	Siraf	UNK0888	7007	0.47	0.52	0.3	5.17	3.28	4.08	0.05	0.1	0.04	0.02	0.78	4.53

4. Conclusion

The method of using bitumen inside pottery jars for insulation or waterproofing has been employed in two types of jars: cylindrical and torpedo-shaped. Archaeological studies presented in this article demonstrate the continuity and utilization of these jar types from the Parthian (including Elymais) and Sassanian periods, persisting through the early Islamic era until the 10th century A.D. The first type is less common compared to the second type, with samples found exclusively in Susa during the Parthian period, and in the same context during the Elymaeans period in Khuzestan.

In their study of Girshman's excavations in Susa, Rémy Boucharlat and Ernie Haerinck (2011) note that both the cylindrical vessel and the torpedo jar tip were found in an archaeological site primarily used for human burial, especially child burial. The act of breaking these jars to place the body inside suggests that their use in burial should be considered a secondary function. The torpedo jar, which was the focus of this research, appears to have been primarily used for carrying liquids. It has been found in various locations in the Persian Gulf. Its presence is also evident in the Oman Sea, East Africa, and the Indian Ocean, with the farthest discovery being the Phanom Surin ship in Thailand (Choksy and Nematollahi, 2018). The use of torpedo jars for burying human bones has only been reported in archaeological excavations in Iran, specifically in the Persian Gulf and Khuzestan Plain. Outside of the Persian Gulf, in locations such as the Indian Ocean, East Africa, and the Oman Sea, there are no reports of torpedo jars being used for burial. Excavations in Susa, Shushtar's Gelalak Tomb, Bushehr port on the Persian Gulf, and the Shoghab cemetery from the Sassanid period have revealed burial samples of these jar graves (Figs.41 to 43). Archaeological studies have indicated that the Gelalak tomb samples in Shushtar and Susa are from the Elimaean and Parthian periods, while examples from Ivan-i Karkheh and Mahruban (with the exception of one piece) are related to the Sassanid period. The samples from Siraf can be dated to both the Sassanid and early Islamic periods.

Fig. 41: Left: General photo of Shoghab graveyard in Bushehr Peninsula, near the coast of the Persian Gulf. Right: Torpedo jar vessels with human bone burials inside, Shoghab graveyard.

The cylindrical vessel and torpedo jar serve the dual purpose of burial and transporting liquids.More recently, Lambourn believes that torpedo jars were used to carry water, but we think that used to store other liquids than water. (Lambourn , 2022). However, further laboratory studies are needed to analyze the remnants of their contents. Additionally, the origin of this pottery and its associated kilns remains undiscovered, necessitating extensive targeted archaeological research, particularly in the southern and southwestern

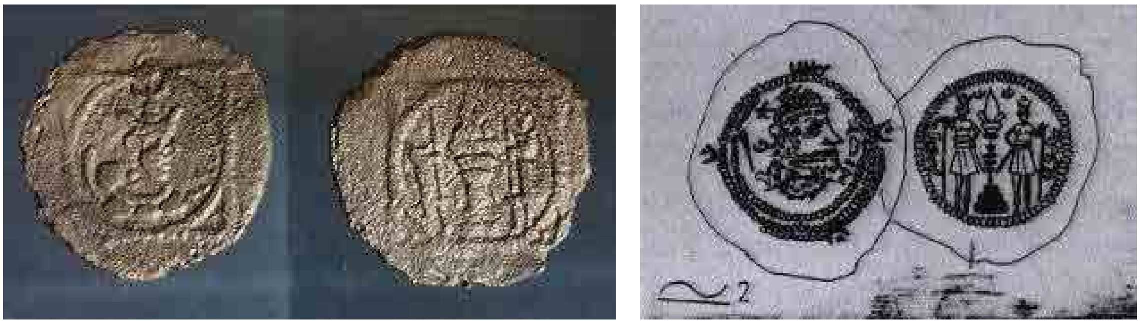


Fig. 42: Sassanian coin from Shoghab Graveyard in Bushehr Peninsula (Rahbar, 2004: fig. 51)

Fig. 43: Aerial photo of Gelalak Tomb, , Torpedo jar vessels with human bone burials inside (Google Earth).

regions of Iran (Khuzestan, Fars, Ilam, and the Persian Gulf coast).

Lab studies show that the origin of the bitumen used for coat the interior face of torpedo jars came from several areas of Iran. Bitumen from the samples of Susa and from some samples of Siraf which contain 18α (H) oleanane, originates from Khuzistan whereas bitumen from other samples of Siraf and Mahruban came for Illam, Lorestan and Kermanshah provinces.

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چکیده

یکی از مهم‌ترین سفال‌های مورداستفاده در تجارت دریایی خلیج‌فارس (خاورمیانه) با بخش بزرگی از جهانِ باستان، ازجمله خلیج‌فارس، دریای عمان، اقیانوس هند، سریلانکا و درنهایت کشور تایلند (محمولهٔ کشتی سورینام)، کوزهٔ سفالی به‌نام سفالِ نوک اژدری‌شکل یا کوزهٔ ذخیرهٔ آذوقه است. اگرچه قدمت این نوع سفال را بیشتر محققین به دورهٔ ساسانی منتسب می‌دانند، اما از دورهٔ اشکانی تا صدر اسلام از این نوع خمره در تجارت دریایی و تدفین استفاده می‌شده است. مهم‌ترین ویژگی این نوع کوزه‌ها، پوشش قیر روی سطح داخلی آن است. تاکنون باستان‌شناسان موفق به یافتن کوره‌ای برای تولید این نوع سفال نشده‌اند؛ بنابراین اطلاع از محل تولید سفال و معدن قیر به‌کار رفته در آن‌ها بسیار حائز اهمیت است. در این پژوهش با استفاده از روش مطالعات آزمایشگاهی ژئوشیمیایی و مطالعهٔ تطبیقی، نمونه‌های قیر برداشت‌شده از سفال نوک‌اژدری شکلِ جنوب و جنوب‌غرب ایران موردمطالعه و آزمایش قرار گرفت. در این تحقیق ۱۵ قطعه سفال با پوشش قیر متعلق به کاوش‌های باستان‌شناسی بنادر سیراف و ماهروبان در سواحل خلیج‌فارس (جنوب ایران) مربوط به دورهٔ ساسانی و اسلامی و نمونه‌هایی از منطقهٔ شوش و شوشتر از دوران اشکانی و ساسانی برای برداشت قیر انتخاب شد. نمونهٔ محوطهٔ شوش از موزهٔ ملی ایران و متعلق به کاوش‌های باستان‌شناسی منطقهٔ شوش، نمونهٔ ایوان‌کرخه مربوط به منطقهٔ دزفول و نمونهٔ منطقهٔ دستوا نیز از منطقهٔ شوشتر است. تمامی نمونه‌های قیر با هدف تعیین منشأ قیر در آزمایشگاه‌های تخصصی آن در اروپا و آمریکا مورد تجزیه و تحلیل ژئوشیمیایی قرار گرفت. نتیجهٔ اصلی تحقیق استفاده از قیر چشمه‌های قیر استان‌های خوزستان، لرستان، ایلام و کرمانشاه را در سفال‌های موردمطالعه نشان می‌دهد. همچنین گاهنگاری نمونه‌ها با تکیه‌بر مستندات کاوش و بررسی باستان‌شناسی و مطالعات تطبیقی انجام و بازهٔ زمانی شناسایی شده دورهٔ الیمائی‌ها، اشکانیان، ساسانیان و صدر اسلام را نشان‌داد.

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