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Geomorphological and geochemical characteristics Mud volcanoes near Zendan fault, Iran

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ABSTRACT

Mud volcanism is a global phenomenon usually associated with compressional tectonics that favor extrusion of fluid- and clay mineral-rich sediment both on land and offshore. Iran's coastal, bordering the western Makran Coast, has more than 50prominent onshore MVs. In this research, after data collection, including topography and geology maps, IRS satellite data and aerial photos, remote sensing verifications were implemented. Then, mud volcanoes determination was completed by field work studies and checking. Their geomorphology characteristic such as area and height were measured. One sediment and one water samples were taken from each mud volcano in the field work, then analyses of major, minor and trace elements were carried out through ICP-OES. About 20 small or big mud volcanoes were determined in Hormozgan province that they have not been introduced before. In the meantime, hydrogeochemistry studies or determination of the percentage of available elements in water for all mud volcanoes were implemented. Since this geomorphological phenomenon indicates tectonic activity of a region, hence there is a possibility of mild earthquake and faulting occurrence. After determine correlation analysis cluster and factor analyiss determine between different factors from scoter plot map characterized that source of elements Al, Fe, Ni, V, Sc, Ti, Cr, Zn, Cu, Mn, Na, K, Li, Be is geogenic and source of elements Ca,Mn and S is biogenic.

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1. Introduction

The Makran accretionary complex has developed throughout the Cenozoic at the convergent margin between the Arabian and the Eurasian Plates (Fig. 1), stretches from Iran to central Pakistan and off the south coast of this area (Von Rad et al., 2000). Mud volcanoes are geological structures formed as a result of the emission of argillaceous material on the Earth's surface or the sea floor in areas of high sedimentation rates and compressional tectonics, commonly in convergent margin settings. They are natural phenomena that reflect regional geological processes. There are many global studies of mud volcanoes that reveal aspects of their origin, mechanism of formation and paleo-activity (Yusifov and Rabinowitz, 2004).

Mud volcanoes have been reported both onshore and offshore along the Makran accretionary wedge (Brown, 1990) in this research we briefly outline the geomorphology charactrestic of makran MV's. Finally, we report a large number of mud volcanoes that have not been reported and/or described before, which occur in the form of isolated conical volcanoes, fields/ clusters, or elongated ENE–WSW to E–W-oriented ridges. Mud volcanism commonly associated with compression tectonics at convergent margins (Mellors et al., 2007). Their abundance seems to correlate with (a) thick, rapidly deposited sediments comprising high clay mineral contents (Robertson, 1996) (b) sediment over-pressuring due to hydrocarbon formation (Kopf et al., 2009) (c) a structural association due to tectonic shortening dehydration (Dimitrov and Dimitrov, 2002) and/or earthquake activity, (e) fluid emission such as gas, brines, water from mineral dehydration and gas hydrate dissociation (Huguen et al, 2004) and (f) polymictic assemblages of the surrounding rock present in the ejected argillaceous matrix (Panahi, 2005). Hence, they are predominantly aligned around subduction zones and orogenic belts where rapidly buried sediment is thrust to deeper levels. Mud volcanoes are known in fewer than30 regions worldwide, and thorough assessments of their origins and tectonic significance are limited (Kopf et al, 2008). Iran's coastal, bordering the western Makran Coast, has more than 50 prominent onshore MVs. One of the most active examples is located 15 km far from the village of Gatan and less than 30 km far from the coastline of the Makran Sea (Fig. 2). In this paper we intent to introduce newly mud volcano complex. These mud volcanoes are in south east of Iran near the zendan fault. This complex includes more than 20 MVs. The relative heights that mud volcanoes reach vary from a few centimeters up to 40 m. In plain view, they are isometric or slightly elongated with craters up to 30 m in diameter, and 2-3 km across the base. Some of the MVs are spaced very close to each other, forming a common body and the flows of MV breccias cover areas of 30km² or more.

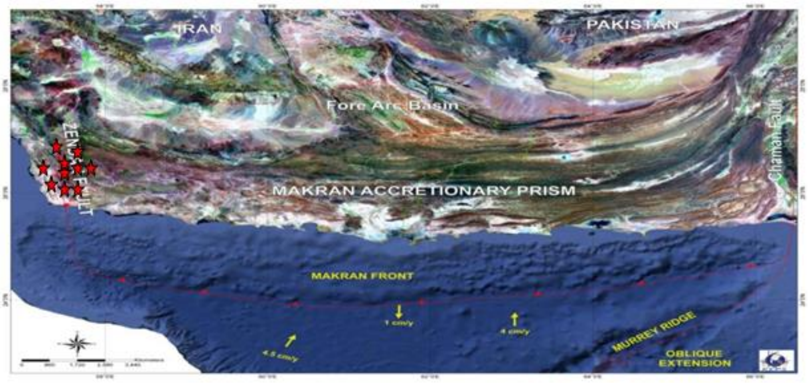

Fig. 1. ETM image of the Makran accretionary wedge and area showing positions of mud volcanoes.

1.1. Description

1.1.2. Geological Setting

The Makran convergent margin comprises a wide accretionary wedge (Fig. 1), It has been formed by the subduction under the Eurasian Plate and is built up of sediments scraped off the Arabian Plate. Subduction was probably initiated about the Paleocene (Kukowski et al., 2001) and accretion started about Eocene (Whitmarsh, 1979). The modern Makran accretionary prism developed since the Late Miocene (Quittmeyer and Kafka, 1984). Two features make this accretionary wedge especially interesting: firstly, the sediment thickness on the oceanic crust is extremely high, secondly the dip angle of subduction is extremely low. Accretion and underplating of the sediments caused uplift of the coastal belt and seaward migration of the coastline (Feyzullayev et al., 2005). Based on morphology, the Makran accretionary prism has been divided into three domains (Higgins and Saunders, 1974) the accretionary wedge, the trench, and the Murray Ridge system. Three main relationships have been identified between mud volcano development and geological environments (Harms et al., 1982) (1) the occurrence of a close relationship between mud volcanism and tectonics especially in compressional settings (Hutchinson et al., 1981) (2) the existence of deep potential source layers in the sedimentary succession (Snead, 1964) and (3) the location of mud volcanoes where hydrocarbons have been or are actively being generated and (Barber et al, 1986). The Makran accretionary wedge stretches from Iran to central Pakistan and off the south coast of this area (Fig. 1). It has been formed by the subduction of oceanic crust of the Arabian Plate under the Eurasian Plate and is built up of sediments scraped off the Arabian Plate. Subduction was probably initiated about the Paleocene (Yassir, 1989) and accretion started about Eocene (Bannert et al., 1992). The modern Makran accretionary prism developed since the Late Miocene [3]. Two features make this accretionary wedge especially interesting:

firstly, the sediment thickness on the oceanic crust is extremely high, secondly the dip angle of subduction is extremely low. The 3000 m deep Oman Abyssal Plain is part of the Arabian Plate and is bounded in the north by the Makran accretionary prism and subduction zone (Fig. 1). In the south and southwest the Oman Abyssal Plain is bounded by the Little Murray Ridge/Murray Ridge and by the Oman continental margin and the Owen Basin, respectively. To the east the abyssal plain narrows due to convergence of the Murray Ridge and the Makran accretionary wedge and disappears at about 65˚,30´E. Despite the northward subduction of the Arabian Plate below the Eurasian Plate at a convergence rate increasing eastward from 3.6 to 4.1 cm/yr (Harms et al., 1984), there is no expression of a deep sea trench. This presumably is due to high sedimentary input from the Pakistan and Oman coasts and due to the small dip of the subducting plate of about 2-3˚ (Guliyev and Feizullayev, 1997). Sediment accretion and underplating of sediments [39] caused the uplift of the Makran coast of about 1.5 mm/yr a seaward migration of the shoreline. The age of the 6 km thick oceanic crust below 7 km of sediments (Feyzullayev et al., 2005) of the Oman Abyssal Plain is unknown. A Jurassic (or older) crust is assumed by (White and Louden, 1982) a speculated Eocene crustal age seems more reasonable to (Mountain, and Prell, 1990) Based on heat flow measurements (Milkov, 2000) calculated a Cretaceous (70-100 Myr) age. No seafloor spreading magnetic lineations could be correlated in the Oman Abyssal Plain, indicating that the oceanic crust developed during a magnetic quiet period. The onshore Makran accretionary wedge forms an arcuate belt of deformed Tertiary terrigenous and mud sediments. Most of the 500 km broad accretionary wedge is exposed onshore Pakistan and Iran and has been investigated at its on and offshore parts (Kopf et al., 1998). The onshore wedge of the Makran ranges contains (Oligocene?) Lower to mid-Miocene thick-bedded turbidites (Panjgur Formation) overlain by up to 2 km of Middle to Upper Miocene mudstones passing upwards and laterally into Late Miocene to Pliocene (Parkini and Branguli Formation) shelf sandstones. The tightly folded and imbricated turbidites occur farther inland than the younger slope facies mudstones with broad synclines in the near shore areas. There is evidence from sequence stratigraphic interpretation of the Makran wedge and from the type of sediments in front of the wedge for two phases of imbrication [4] Convergence and the formation of an early wedge was probably initiated in the Paleogene, followed by a second phase of thrusting from mid-Miocene to Pliocene, leading to subsequent underthrusting of the older wedge and thickening and uplift of the accretionary complex. Since the Pliocene renewed frontal accretion and continuous underthrusting above a mid-level detachment occurred. The bedrock geology of the Makran coast consists of Middle Miocene flysch sequences associated with post-Middle Miocene marls and limestones overlain by Quaternary unconsolidated sediments comprising eolian sand dunes, mud flat and marine terrace deposits in the coastal areas.

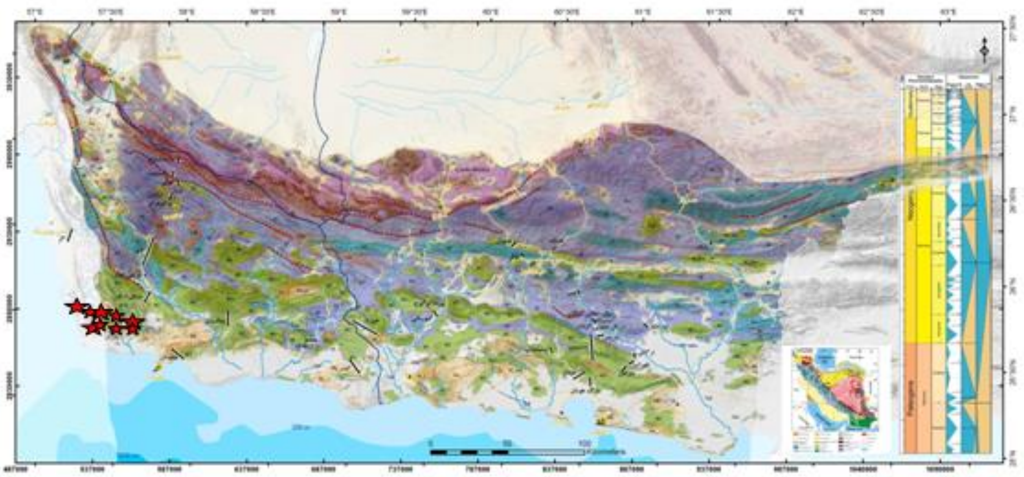

Fig. 2. Geological map of the coastal belt of Makran (modified after Hunting Survey Corporation, 2013)

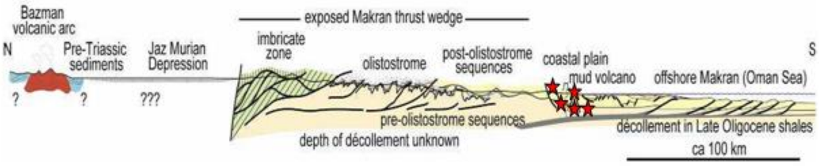

Fig. 3. Synthetic section across the Makran subduction system (extended from The northern part of the Jaz Murian depression was compiled from the Iranshahr and Jaz Murian geological maps (1:250,000 scale)

2. Material and Methods

This research is based on the use of remote sensing data (Landsat-5 ETM satellite images of the coastal belt of Makran), field observations (field observations during periods from 2010 to 2012), sediments sampling. GPS surveys (specifically in the coastal belt of Iran territory for determining exact location of mud volcanoes). A sediment sample was taken from each mud flow in the field work, then analysed for major, minor and trace elements in it through ICP-OES by Varian model in Research Center of Geological Survey of Iran laboratory. Area, length, width, height of all mud volcanoes were measured, also.

3. Results and discussion

3.1. Mud volcanoes Structure

There are no relationship between the mud volcano types and their distribution, the shapes and sizes of mud volcanoes depend of the degree to which mobilization has been initiated by pore-fluid pressures, the frequency and character of their activity, the viscosity of the out-flow mud and local lithology, tectonic framework of the host sediments. Although a variety of factors affects on relationship between them, the basic rules seem to be simple: the higher the pore-fluid pressure, the more violent the eruption; the more frequent the activity, the larger the structure; the lower the viscosity, the larger and flatter will be the body of mud volcano. The relative heights that mud volcanoes reach, vary from a few meters up to 300–400 m, and in some cases even more than 500 m. In plain view, they are isometric or slightly elongate with craters up to 500 m in diameter, and 3–4 km across the base. Some of the mud volcanoes are spaced very close to each other, forming a common body and the flows of mud volcano breccia can cover areas of 100 km2 or more (Williams et al., 1984). The peculiarities of the host formation and the evolution of the mud volcanoes can generally explain the variety in the morphology and activity of mud volcanoes. Most mud volcanoes consist of both active and inactive vents that formed during multiple eruptions, which we refer to as complexes. Historical accounts indicate that mud volcano eruptions involve fluidized mud, gas, and water; and they can be violent (Williams et al., 1984). Recent mud flows, hydrocarbon seeps, and vents filled with waters that bubble intermittently as a result of gas exsolution demonstrate that four out of the five mud volcanoes examined are currently active. There are many terms that describe the shape and seize of mud volcanoes (Milkov, 2000). Some terms are referred to as mud cones, mud pies, domes and craters. The distinctive type of mud volcano with a negative surface expression is called a mud pool (Gorgan mud volcanoes), when extruded material is so fluidized and gassy that it collapses into the crater and fills the depression. Simple rules appear to apply to the formation of different shapes of the mud volcanoes. The higher the pore-fluid pressure, the more violent the eruption; the more frequent the activity, the larger the structure; the lower the viscosity, the larger and flatter the body. Mud with low porosities form mud domes or ridges, more consistent mud with intermediate fluid content can give rise to mud volcanoes with large diameters, and high porosity mud creates mud pies with great areal extent. A number of papers describe the mud volcanoes as features closely related to so-called ‘‘clay or mud diapirs’’. Diapirs are domes or anterooms produced by the plastic deformations or flow of fine-grained sediments; they may deform or rupture overlying rocks. Indeed, many mud volcanoes are developed in the crests of such diapirs, but also, many of them are not connected with diapiric structures at all. However, clay diapirs most probably have the same mechanism of formation but they do not pierce totally the sediment cover, rising only to a level some way beneath the surface. If a diapir reaches the surface during its development, because of the plastic, even semi-liquid nature of the composed rocks, it has to form clay/mud outflows; consequently, it would be called a mud volcano.

3.2. Mud volcanoes Morphologic Features

Extrusive circular mud volcanoes are the most spectacular features of the Makran coastal range now. Mud volcanoes are geological structures formed as a result of the emission of argillaceous material on the Earth's surface. Sufficient water and gas is incorporated to make it semi-liquid and to force it up through long narrow openings or fissures in the crust to produce an out-flow mass of mud on the surface. The extruded material forms characteristic isometric to elongated morphological features largely varying both in shape and size (from very large structures-up to 10 km2 area, to small landforms- a few tens of square meters). They are evidences of a separate natural process [14]. In Iran most of the mud volcanoes appear in coastal plains of the Caspian and Oman Seas. Twenty mud volcanoes recently have been found during this research between Minab and Jask sites in Hormozgan province (Oman Sea). The mud structures may form more isolated conical volcanoes, fields of mud volcanoes or elongated. The occurrence of mud related features seems to be aligned along tectonic structures, along thrust anticlines. The amount and size of identified mud extrusions seem to decrease from the west to the east. Close to and along the Zendan fault, where the Makran accretionary prism bends towards WNW, the quantity of mud extrusions is higher and their distance from each other is smaller than further in the east. It seems reasonable to explain the dense occurrence of mud volcanoes in the west by the west ward increasing plate convergence associated with more frequent thrust anticlines, as well as with left-lateral strike-slip along the Zendan fault.

Table 1. Characters of various mud volcanoes

S. No.	Name of the MVs	No. of MVs	Morfology of MVs	Lithology	Range ocrater diameters (m)
1	Afzali MVs	20	Conical-Active	Silty clay	1-40
2	Gatan MVs	4	Conical and lake-Active	Sandy, silty clay	30-40

3.3. Afzali Site mud volcanoes

These complex includes more than 20 MVs. The relative heights that mud volcanoes reach vary from a few centimeters up to 40 meters. In plain view, they are isometric or slightly elongate with craters up to 30 m in diameter, and 2-3 km across the base. Some of the MVs are spaced very close to each other, forming a common body and the flows of MV breccias cover areas of 30km² or more. In the Afzali Site mud volcanoes are spread 25–30 km north of the coast and is considered as the largest active mud volcanoes area of the region (Figs. 4 a and b). It comprises 16 mud volcanoes, along with some dried-up vents, distributed in a line in east to west direction. A number of small mound-like features are also present. Covered areas of the mud volcano deposits range between 2 and 5 ha. Diameters of the craters range from 5cm to 20 m. Diameter of the craters have relationship with the size and covered area of the mud deposits. Most of the mud volcanoes (12 out of 20) are presently active, extruding fluidized mud and hydrocarbon gases; however, they show fluctuations in extrusion activity.

3.4. Composition and main elements

Result of ICP-OES analysis were show in the table (1, 2). Some elements such as Ag are less than detection limite of instrument.

Fig. 4. Iimages and field photographs showing mud volcanoes morphology

Table 2. Composition and main elements of the Afzali mud volcanoes

sample no.	Ag (ppm)	As (ppm)	Co (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Mo (ppm)	Nd (ppm)
AMC(1)	< 0.1	4.54	14.24	3.41	1.86	0.96	13.37	4.32	0.43	21.10
AMC(2)	< 0.1	4.82	11.54	3.62	1.70	0.89	9.38	3.45	0.54	17.16
AMC(3	< 0.1	4.79	12.02	3.46	1.67	0.86	9.92	3.27	0.33	18.73

Table 3. Composition and main elements of the Gatan mud volcanoes

sample no.	Ag (ppm)	As (ppm)	Co (ppm)	Dy (ppm)	Er (ppm)	Eu (ppm)	Ga (ppm)	Gd (ppm)	Mo (ppm)	Nd (ppm)
GM(1)	< 0.1	4.65	13.58	2.55	1.64	0.85	12.29	3.90	0.50	19.54
GM(2)	< 0.1	4.81	12.68	2.59	1.54	0.82	11.82	3.76	0.67	18.76
GM(D)	< 0.1	4.16	12.69	2.46	1.47	0.79	11.62	3.69	0.67	18.08
GM(k)	< 0.1	6.14	12.13	2.72	1.54	0.83	11.30	3.90	0.83	19.29

4. Conclusion

Mud volcanoes (MVs) are geological structures formed as a result of the emission of argillaceous material on the Earth’s surface or the sea beds. Iranian Mud volcanoes (MVs) are commonly found in east southern Iran. We are believing they are products related to the accretionary prism due to the ongoing subduction of the Oman oceanic lithosphere beneath the Iranian micro-plate. They are natural phenomena that reflect regional geological processes. Twenty mud volcanoes found between sites of Minab and Jask in Iranian Hormozgan province (Oman Sea) recently. The amount and size of identified mud extrusions seem to decrease from the west to the east, Close to and along the Zendan fault, where the Makran accretionary prism bends to the WNW, the quantity of mud extrusions is higher and their distance from each other is smaller than further in the east. It seems reasonable to explain the dense occurrence of mud volcanoes in the west by the west ward increasing plate convergence associated with more frequent thrust anticlines, as well as with left-lateral strike-slip along the Zendan fault.

Available geochemical data obtained from the mud volcanic areas,were compared. Data inter-comparison can help us a better understanding the genetic features of fluids expelled by mud volcanic areas. After determining correlation analysis, cluster analysis factor and determine between different factors from scoter plot map characterized that source of elements Al, Fe, Ni, V, Sc, Ti, Cr, Zn, Cu, Mn, Na, K, Li, Be are geogenic and source of elements Ca,Mn and S is biogenic.

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