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The Geomorphic and Morphometrics of Napag Mud Volcano In the South Eastern Area of Iran

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Abstract:

The Napag mud volcano, a cone-shaped hill in the coastal plain of Oman sea and lying west to the port of Chabahar and to the right of "Kahir-Tang road", is one of the most attractive geomorphological phenomena in Sistan and Baluchestan province. It is famous for being the most prominent mud volcano in Iran whose height amounts to 36 meters above the sea level. Because of methane (CH4) gas eruption and the formation of huge bubbles, it seems to be a unique one amongst other mud volcanoes in Iran. The eruption of mud from this volcano usually occurs smoothly, but the outpourings occasionally become severe with eruption of viscous mud in great quantity.

In this paper, attempts have been made to compensate for the absence of library sources by utilizing field work, laboratory experiments along with years of experience of and study on mud volcanoes.

Key words: Napag mud volcano, mud streams, mire, geomorphic, morphometric

Introduction:

Mud volcanoes are geological structures formed as a result of the emission of argillaceous material on the Earth's surface or the sea floor. These features reflect regional geological processes. Despite their name, the only characteristics of mud volcanoes that link them with normal (magmatic) volcanism are the surface morphology and the vague resemblance in the activity. (Lyobomir and Dimitrov, 2002)Indeed, sometimes they erupt violently, shooting mud and ash up to a height of a few kilometers. The emitted gases may burn to produce enormous flames. But most of the time of their life, mud volcanoes appear to be gentle, growing and expanding by massive, gradual and progressive outflows of semi-liquid material called mud volcano breccia (Barber et al., 1986). Usually, mud volcano breccia erupted from one major funnel called central or feeder channel (Fig.1).

The study of mud volcanoes generally makes available to mankind useful and valuable information on sediment from the depth of the ground where drilling operations are not possible (Negaresh, 2007: 687). Mud volcanoes are mainly concentrated in systems of accretionary prisms where compressed settings and active fluid dynamics prevail. Thus, they are an important source of information about subsurface sediments and conditions (Yusifov, and Rabinowitz, 2004) Basically, most of the mud volcanoes are located on the coasts, coastal plains, and also on the sea-beds. More than 50% of the total number of mud volcanoes is situated along the Alpine Himalayas Active Belt. (Lyobomir and Dimitrov, 2002) The largest and best cone-shaped mud volcanoes occur here, as well as the most active terrestrial mud volcano area with the greatest number of mud volcanoes in the world—the Baku region of the Caspian Coast, Eastern Azerbaijan. Starting from Mediterranean Ridge (Limonov et al., 1996) and adjacent land areas Sicily, Albania and Southern, Central and Northern Italy (Martinelli, 1998), passing the forelands of Eastern Carpathians in Romania, Kerch and Taman Peninsulas (Arhangelski, 1932; Gubkin and Feodorov, 1940) and Great Caucasus (Gubkin and Feodorov, 1940) through the Black Sea (Ivanov et al., 1996), the belt turns to the south in the area of Southern Caspian Sea (Azerbaijan and Turkmenistan) (Jakubov et al., 1971; Guliyiev and Feizullayev, 1997), South Caspian Basin (Ginsburg and Soloviev, 1994); and Gorgon Plain in Iran and passing the Makran coast of Pakistan and Iran (Higgins and Saunders, 1973) and Southern Himalayas (India and China), ending in Burma. Furthermore, the Alpine– Himalayas mud volcano belt continues to the south in the most NE part of Indian Ocean on and around numerous forearc islands situated along the Indonesia and Banda Arcs (Barber et al., 1986), Indonesia– Australia accretion and collision complexes (Williams et al., 1984), as well as within the Banda accretionary complex offshore (Barber et al., 1986). The greatest number of mud volcanoes seems to be known on Timor Island at the southeast end of this belt.(Lyobomir and Dimitrov, 2002) More than 30% of the world's known mud volcanoes are concentrated in the South Caspian Basin (Guliyev & Feizullayev, 1995).

The number of mud- volcanoes that are on the land and away from seas and oceans is virtually meagre and as such the mud volcano under discussion is not an exception, and is eighteen to twenty kilometers away from "Tang" port and from the coast of Oman Sea. This mud volcano manifests itself as a conical-shaped hill and inselberg on the coastal plain.

According to Rodman Snead, certain attributes of the mud volcanoes in Iranian Baluchestan look quite analogous to those mud volcanoes situated in Pakistani Baluchestan, like Chandragup, Ormara, and Kandawari (Snead, 1964: 547).

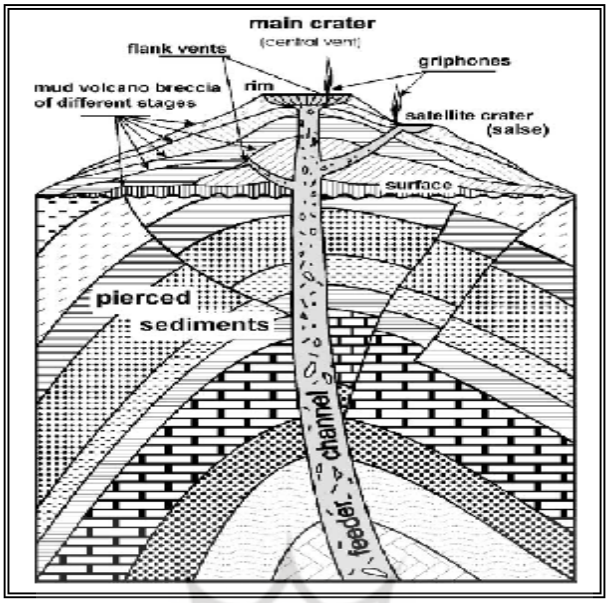


Fig.1: Basic structure and main elements of a conical mud volcano. (Lyobomir and Dimitrov.,2002)

Materials and Methods:

As mentioned earlier , one of the main and rudimentary hurdles in the study process of Iran mud volcanoes is the paucity of library-related sources in this area. Therefore, to overcome this shortcoming, endeavor would be made to make best use of the 14_ years_ field experience gained in the study of mud volcanoes of the province. Consequently, despite the fact that the mud volcano under discussion has been subjected to field survey and investigations by the writer for dozens of times during various seasons and years since 1990; however, during the last exploration-visit on the 5th of February 2004, concerning the field work on the mentioned mud volcano, a survey was conducted therein. Initially, the geographical location was determined with the help of GPS equipment; then geomorphic and morphometric investigations on the mud volcano were conducted in the area. Therefore, taking into account the aforementioned explanation, it can be said that the method of investigation of this article is based on the make-up of field investigation as well as laboratory research work , whereas the part played by the library-based study-is quite scanty because of want of library-reference resources.

Background:

There are many global studies of mud volcanoes that reveal aspects of their origin, mechanism of formation and paleo-activity (Brown, 1990; Guliyev & Feizullayev, 1995;

Jakubov, Ali-Zade, & Zeynalov, 1971; Kopf, 2002; Milkov, 2000).Some of the most important mud volcanoes studies, can be summarized in the following cases:

Makran accretionary wedge off Pakistan (von Rad et al., 2000), the Cascadian margin (Suess et al., 1999), the Aleutian subduction zone (Suess et al., 1998), the Costa Rica forearc (Schmidt et al., 2005), the Okhotsk Sea (Gaedicke et al., 1997; Shakirov et al., 2004; Obzhirov et al., 2004) and within passive margins where high sediment rates occur, such as in the Gulf of Mexico (Sassen et al., 1999), the Niger delta (Hovland et al., 1997, Mastalerz et al., 2007), the Eel River Basin (Burger et al., 2001). In the eastern Mediterranean, mud expulsion structures occur at the Mediterranean Ridge due to the collision between the African and Eurasian tectonic plates (Camerlenghi et al., 1995; Cita et al., 1996; Kopf and Behrmann, 2000), in the Anaximander area (Woodside et al., 1998; Zitter, 2004) and were recently documented in the Nile deep-sea fan (Mascle et al., 2001; Loncke, 2002;Loncke et al., 2004). Some studies emphasized mud volcanoes with plutonic origins including; Yellowstone (Sheppard et al., 1992), California and Nevada (White, 1955), and Italy (Chiodini et al., 1996), and those from hydrocarbon alteration in Central and South America (Arnoldand Macready, 1956; Humphrey, 1963;Aslan et al., 2001), Azerbaijan (Hovland et al.,1997; Yusifov et al.,2004), New Zealand (Ridd, 1970),Alaska(Patrick et al.,2004) and Japan (Chigiraand Tanaka, 1997).

In Iran some researchers have studied mud volcanoes. We can mention the important cases like Farifteh (Farifteh, 1988), Pourkermani and Zomorrodian (Pourkermani and Zomorrodian,1987), Falcon (Falcon, 1974), Ghorashi (Ghorashi, 1985), Little (Little,1970), Stocklin (Stocklin,1968) .

Reason for the nomenclature of the mud volcano:

The people of 'Dashtyarie' plain and eastern Baluchestan call the 'Gelfeshan'—a Persian term for mud volcano— "Bootten " in their local dialect, but the people on the western part-of Chabahar port , 'Kahir' and 'Zarabad' call "Gelfeshan", "Gelpashan"[1], whereas the native people of the area call this mud volcano "Napag"[2] which in Persian means "Naf" i.e. the navel of the earth or the Sea(Negaresh,1997:10) .

It is worth mentioning that though "Napag" is a proper name for this mud-volcano, the Baluch people sometimes use it as a general word and all other mud volcanoes are named after this generalized word.

1) - This term in fact , is "Gelfeshan", but, since the Baluch people of that region pronounce the "F" sound as the "P" sound , therefore, the word "Gelfeshan" has been termed as "Gelpashan" .

2) - The correct pronunciation of this word has been "Nafak", but, as the Baluch people of the area pronounce "F" with a sound of "P", therefore, "Nafak" has been replaced by the word "Napag".

Geographical location and geological conditions of the mud volcano:

This mud volcano lies on the coastal plain of Oman Sea , south of Makran heights , west of Chabahar port and on the southeastern village of 'Kahir'(fig.2). This mud volcano lies at a distance of 17kilometers from 'Kahir' village, 18-20 kilometers from 'Tang' port lying to the south western of it, 5km from 'Borborok' mud volcano, (direct and aerial distance) and from11km "Ain" mud- volcano (NGO, Pibeshk topographical map 1:250000, 1984).

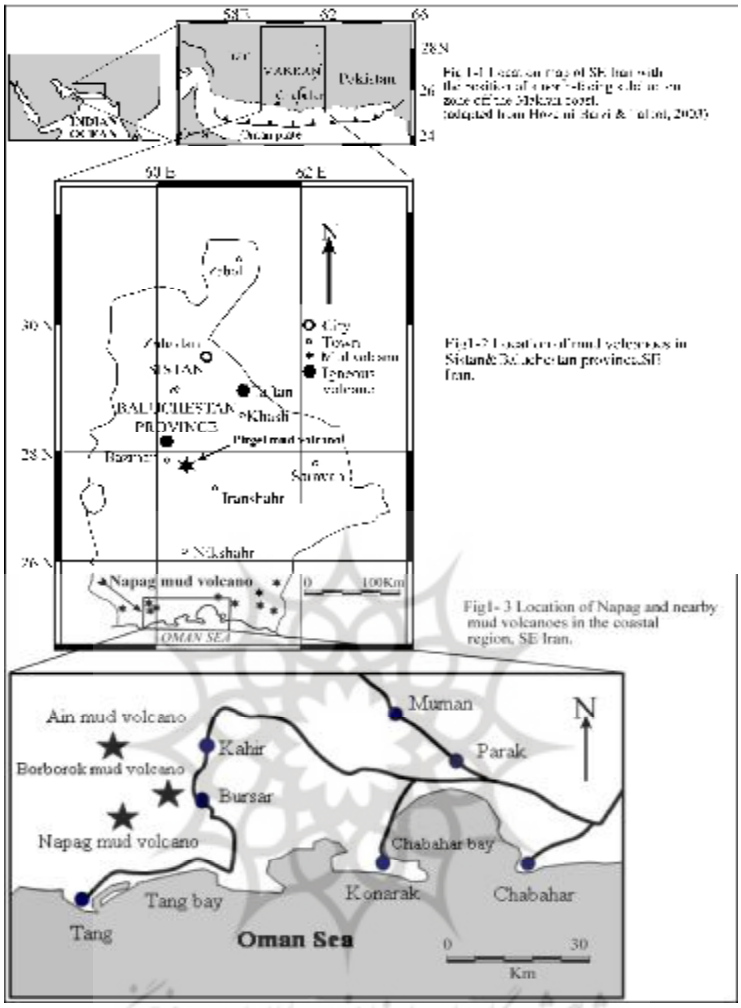
The area under consideration almost resembles other parts of the coastal plain of Oman Sea and the coasts of Makran in characteristics of geological, tectonic, lithological and stratigraphic characteristics, whereas situational and local disparities are not strikingly prominent in them. There are usually clay and mudstones under the ground in the region. They have comparatively a greater thickness and are almost gray in color. Their upper level is covered with a dark stratum 2 to 10 meters thick. There seems to be almost no stratification in the covered marls and mudstones. On the whole, most of the sedimentation in this region relates to tertiary and quaternary periods. The tectonic forces have left immense effects on them (Geological map 1:1000000 of Iran, 1977, South eastern sheet).

With regard to geomorphology, the location of the mud volcano is the vast coast plain where there are seemingly no particular geomorphologic features. The mud volcano in the form of a small inselberg has disturbed, to some extent, the leveling of this part of the coastal plain. This coastal plain in this region is completely clear and flat. Due to the presence of microlithic clay, marls, lime and salt materials, the coastal plain has taken on a white-color outlook with such an intensity that, during the summer season, looking at the coastal plain causes eye fatigue because of the white color and the mirage it bears.

Basically, most of the mud volcanoes of the world are of the type of cold and tectonic, and have no connection with the volcanoes within their perimeter. All the mud volcanoes in Iran including those of the coastal plain of Oman Sea are of the same category. Their being cold and tectonic means that the pressure of the tectonic forces and the subduction activity are the causes of their existence. Therefore, the subduction of the oceanic crust bed of Oman Sea beneath the continental crust of Iran in the vicinity of Makran heights and Looth plate have caused the formation of these mud volcanoes.

Sea and the remaining mud volcanoes on its perimeter. Geographical location of the mud volcano determined

By GPS instrument at 11: am .on the 5th of February 2004 reads as: 59° 55' 56" E longitude and 25° 28'17" N latitude.

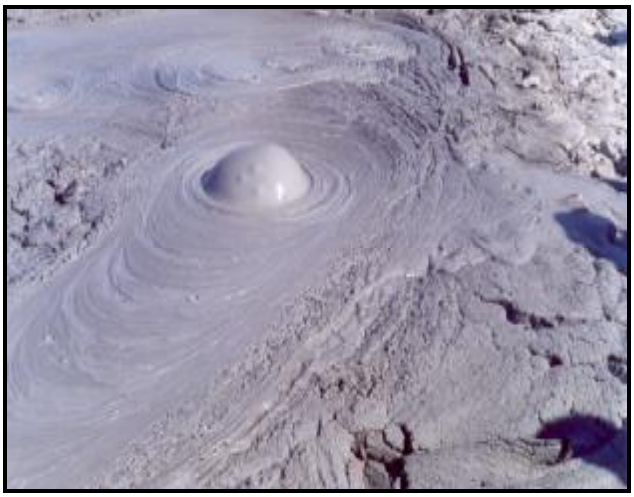


(Fig.2): The local and geographical location of 'Napag' mud volcano as compared to the coast of Oman

The formation mechanism of this mud volcano is similar to that of other mud-volcanoes in the province in the sense that the existing gas, formed in the depths of the earth, in the mud volcano, while coming out of the saturated strata passes through water and mud and as a result pushes them up to the surface of the earth. This mechanism mostly relates to the type of mud volcanoes that are tectonic or are of the same features of the volcanoes. The style of mud extrusion forms their shapes and morphology. The originating point of the gas and mud-water might be at a depth of 3 to 12kms from the earth surface (Negaresh 2003, p5). If the extruding mud is thick, the elevated cone for the mud volcano is gradually formed; otherwise the thin mud in the perimeter causes the formation of a flattened mud volcano and a shapeless mass resulting in a mud volcano with no specific and typical cone.

The system of mud outpouring from this mud volcano is nearly an exceptional case and is quite different from the rest of the mud volcanoes in the province. This is because the

exudation of Methane gas accompanied by mud has caused the formation of the most beautiful bubbles in this mud volcano. Sometimes, the outpouring of the mud takes place in such a manner that, besides formation of bubbles, mud steams start flowing downward on to the foot of the mud- volcano.



(Fig.3): Exudation of mud along with bubbles and streaming down to the foot of the range.

However, the exudation of mud is not always accompanied with the formation of bubbles. Sometimes, it has been observed that the outpouring of mud is carried in a hurling form, and in each discharge several liters of mud are hurled out with din and hullabaloo. In rare cases, it hurls out the mud into the air with certain thunder and boom and whirls the mud on the back of the cone. (fig.3)

Generally, it can be said that outpouring of the mud from this mud- volcano is usually accompanied by bubbles and rarely any other activity can be noticed. The outpouring mud is mostly cold and carries no vapors, but at times the mud comes out with a rumbling sound of a gun shot (Pourkermani & Zomorrodian, 1987, P162). However, during the last study-visit to this mud-volcano at 11:00 A.M on the 5th February, 2004 it was observed that its mouth was almost completely blocked by thick mud as a result of which bubble formation and its functioning had diminished to the minimum extent . There was a time when the writer of this article had witnessed an activity of this mud -volcano while pouring out thousands of cubic meters of mud either dispatching it to the foot or hurling it with a bang on the back of the mud volcano (for example, at 3:00 pm on 19th April 1992, at 10: A .M on 23rd February 1997 and at 9: A .M on the 19th February 2001).

The difference between, Napag mud-volcano and the rest of mud volcanoes of the region:

i.The bubble formation in the mud-volcano takes place in a best manner and, in fact, the bubbles of this mud volcano are unique in Iran.(fig.5)

ii.This mud volcano contains methane gas, whereas the rest of the mud volcanoes in the province contain carbon dioxide and or other gases.

iii.It is the only mud volcano in the province that has formed a crater at its opening. The crater is about 2 to 3 meters deep. No other mud volcano can be seen with such a crater.

iv.This is the only mud volcano that the subsidence process has taken its shape in the form of a semi-circle in the periphery of the mud volcano, whereas all other mud volcanoes in the province are short of such a phenomenon (Negaresh, 2001, p 250).

v.The badlandic vista of the fringes and the less-steep slopes of this mud volcano is nearly unique and has no identical mud volcano among the rest of the mud volcanoes in the province.

vi.The erupted mud-streams of this mud volcano are in the form of layers and are like onion skin. No other mud-volcano in the province bears such a panoramic view.(fig.4)

vii.No trace and no evidence of Salinity and puffed desert lands can be seen in any part of this mud-volcano as against other mud-volcanoes of the province.

viii.This is the only mud volcano in the province that brings forth small and large pieces of rocks along with mud from the depths to the surface of the earth, which makes it unique among others, and sometimes hurls them into the air.

Discussion and Results:

One of the peculiar features of this mud-volcano is that it has formed one of the most outstanding instances of cone for itself. Its real cone is a single and independent one, while there are four other small peripheral cones in its perimeter. One of them is nearly 3 meters high, while the others are 1 to 2 meters high.

(Fig.4): The main cone and the peripheral cones of the mud volcano.

They are all dormant and it is worth mentioning that the peripheral cones had had greater heights in the past, but, due to erosion caused by rainstorms of the region, their heights have gradually decreased in the course of time.

It seems as if the mentioned mud volcano, during its past lifetime, had formed a cone, with a lower height and with a diameter of nearly 800 meters, by the process of flaccid and watery mud-eruption. The exterior of the earlier cone is quite visible on the perimeter of the exterior parapet of the present one. Later, on this basis, thicker and stiffer mud flowed down and formed the central steep cone.

Rodman Snead has, in his book, mentioned the height of this mud volcano above the ground level as 72 meters while the

height above the sea level reads to 102 meters (Snead, 1970:509) which seems to be incorrect since the height of the mud volcano at the time of Mr. Snead's measurement recording, might have been greater, but must have been shortened due to the erosion, which, again, taking all the available facts and figures into account, seems to be a far-fetched conception. Anyhow, the height of the main cone of this mud volcano was 39 meters above the sea level and 24 meters above the ground level when recorded by a GPS instrument at 11:00A .M. on the 5th of February 2004. The height of the coastal plain, where the mud volcano stands, has been worked out at 150 meters above the sea level.

The strewing and extension of mud-streams around the Original cone have not been uniform and equal; and this process has been more prominent in the north and west as opposed to east and south. However, the extension of mud streams has been greater. The cone base-level diameter of this mud volcano on average has been estimated to be nearly 800 meters. Therefore, the approximate area of the base level circular shape of this mud volcano is equal to: $A = R \times R \times л \rightarrow A = 400 \times 400 \times 3/14 = 502400\ m^2$ or $\rightarrow$ (50.24 h)

Therefore, as far as the vastness and extension is concerned, this mud volcano is considered to be the vastest coastal mud volcano in Iran.

Bearing in mind that the cone-base level diameter of this mud volcano has been estimated as about 800 meters, therefore, the approximate circumference is equal to:

$P = 2R л \rightarrow P = 2 \times 400 \times 3/14 = 2512\ m$

This mud volcano has two craters: one being old and the other one being the present and the new and present one; both the craters lie right on the main cone of the mud volcano the old crater has, in the form of a precipice, engulfed the present crater, while the present crater lies within the old one. Its diameter, at different points, has been measured at 21 to 24 meters.

(Fig.5): A portion of old crater of the mud volcano, in the form of precipice with a 2 to 3 meters diameter, has enveloped the present crater; the present crater forming bubbles internally is quite visible.

However, with the passage of time, a portion of the parapet, nearly to the south of the original and old crater of the mud volcano, has been devastated, and the mudflows currently stream down from this flank. Perhaps, one of the reasons for retarded growth of the northern range, as compared to other ranges, must have been this phenomenon since the northern parapet of the main crater of the cone is completely intact and the mudflows stream down mostly from the southern flank and then extend to the east and west.

But the present crater, being 2 to 3 meters shorter in height then the old crater, constantly changes its shape and site. If the outpouring mud is dense, it would pile up, and there is no streaming down with the result that the difference between the heights of the old and new crater decreases (on 5th February, 2004, the height difference had been 1 to 1½ meters); and if the mud is thin, the downward movement to the south takes place and covers the earlier pile of mud to a distance.

The slope of different flanks of this mud volcano is not uniform; in the sense that the slope of the eastern and southern flanks is apparently greater than the others. By and large, the medium slope of the mud volcano flanks is comparatively greater and has been measured between 35 to 50 degrees.

The outpouring radius of the old mudflows ranging between 300 to 500 meters, have spread and extended onto many directions. These streams, numbering 6 to 7, have been estimated to have scaly-shape layers with a rough thickness of half to two meters being similar just like onion skins deposited one upon the other. But new-mud streams, in view of density fluctuating between 100 meters and at the most 250 meters, originated from the present crater of the mud volcano. New mud-streams with a heavy dark gray color can clearly be observed on the dry and white colored mud. Therefore, their flow radius can easily be inferred or worked out during every survey.

As has already been mentioned, the bubble formation in this mud volcano is unique in Iran and really rare in the world. Harrison, who surveyed this mud volcano in 1941, has explained that greenish and bold bubbles are formed from mud, which every few minutes burst out and again other bubbles replace the previous ones (Harrison, 1941:13). But the writer, who has seen this mud volcano very closely dozens of times since 1989, has witnessed small and big bubbles in different shapes; the following photo is an example:

However, the cause of bubble formation in this mud volcano is the extrusion of methane gas which on average takes shape in every 2 to 5 minutes' time and after a few seconds, it vanishes and instead another bubble appears; nevertheless, the bubble-formation site during the year or different years does not remain constant. Although the mud outpouring from this mud volcano is not always accompanied by bubbles, the outpouring shape of the mud and gas from this mud volcano is simultaneous with the bubble formation. (Fig.6)

(Fig.6): the formation of beautiful big bubbles in the crater of the mud volcano, in the winter of 1997.

The outpouring mud debit is quite different from the mentioned mud volcano, and undergoes great variations during the year or during various months. Many a times it has been observed that hundreds or thousands of cubic meters of mud come out of the mud volcano in a short period of time , but at times no mud at all comes out of the mud volcano for weeks or months and its function falls to the minimum . However, the average outpouring of the mud can be estimated at 2 to 7 liters per activity during the year.

Basically, certain mud volcanoes such as "Napag" mud volcano at the climax of their activity bring out pieces of stones along with mud from the depth of the earth to its surface or hurl it out with mud. These pieces of stone might measure to several meters (Guliyev, 2001: 2). Plenty of stone-pieces can be seen in outpouring mud of the Napag mud volcano. Although during the mudflow these pieces are invisible, with the erosion of mud, the stone-pieces are prominent and visible. Most of the stone pieces are of marls or limestone-sand and usually measure maximally 2 to 7 centimeters. Certain pieces measure nearly 12 to 15 centimeters which are quite rare.

The outpouring mud, which streams down to the foot of the volcano and becomes dry after a while, is usually unsmooth and malice. Rather, due to the local precipitation and rainstorms during different years and with the coming up of rill and gully valleys the perimeters of the mud volcano develop a badland outlook which is, however, not common amongst all mud volcanoes. The existence of columns and small but craggy and vertical ridges of 10 to 15 centimeters on the surface of mud-streams cause great hindrance to walking on them. The formation of badlands and the blind-valleys on the mud-streams of this mud volcano, confirms the mud-streams being of clay and marls and their erosion caused by local downpours and flowing water (Zomorrodian, 2002, p 181).

(Fig.7): Small and big stone-pieces that have been hurled out with the outpouring mud.

Mud-streams coming out of the mud volcano crater, are at first, slack and pasty but with the increase in quantity, they flow down to the foot and later in the hot and searing weather of the region, gradually lose humidity resulting in the development of immense and lengthy fissures in the form of polyhedrons. With the passage of time immensity and depth grows greater. It appears as if the cause of these fissures relate to the loss of humidity and the reduction of the mud volcano since as long as the mud is hydrous and humid, the volume is greater, but as soon as they lose humidity, the volume of the mud decreases and the fissures in them look prominent. With the growth of the age, the mud becomes so hard that the breaking of old mud is not possible.

On the northern and eastern foot of the mud volcano and between the fifth and sixth layers, which have covered each other in a scaly form, there is a crag of 1 to 3 meters. This crag has enveloped the northern and eastern peripheries of the mentioned mud volcano. The genuine cause of the formation of this crag is not yet determined thoroughly, but it is taken for granted that the process of subsidence for discharging the mud from the depth of the earth and also the difference of weight of the fresh mud, which heavier, and the old mud, which is lighter, have caused the instability and subsidence of this portion of the mud volcano. The sharp declivity of this precipice falls on the west of the cone mud volcano, while comparatively the mild declivity lies on its east and after the pouring down this precipice, the mud-streams extend to more than 100 meters towards east across the Kahir-Thang road; therefore, it can be gathered that the subsidence process has occurred at a later stage and thus is relatively a new one.

Contrary to certain mud volcanoes in the province, such as Ain, Kaashie, Pirgel mud volcanoes, having complete saline and alkaline water and mud, there observed no indications of salinity in the outpouring water and mud in this mud volcano.

The color of the outpouring water and mud is dark and gray and are quite distinguishable from the previous mud-streams which were totally dry, fissured and white.

The temperature of the exuding mud at 11:00 A .M. on the 4th of February,2004 was recorded at 30 degrees centigrade, while the environment temperature was worked out at 31/5 degrees centigrade, whereas the temperature of both the environment and the mud usually remain equal.

The available signs and evidences reveal that the mud from this mud volcano had been more diluted in the past, but due to unknown reasons, the viscosity of the mud has increased with the passage of time and this process has caused gradual rise in the height of the mud volcano; but there has not been any increase in its extent.

Apparently, it seems that the viscosity of the exuding mud has presently increased as compared to the past. The viscosity, most of the time, has a higher rate. But sometimes it has been noticed that the outpouring mud had been dilute and had been flowing, in the form of mud-streams hundreds of meters down to the foot. However, this is not a permanent feature; it takes place only very rarely.

Conclusion

Despite the fact that the mud volcanoes are considered exclusively to be geomorphologic and display most beautiful and spectacular scenes, but their study encounters countless hardships and obstacles including absence of library reference books, lack of approaching routes to them, their vast sparseness, etc. Nevertheless, the importance and necessity of studying them because of their multifarious applications to various fields is quite obvious and indisputable.

Although ample potentialities and abundant capabilities lying latent in the 'Napag' mud volcano which is considered to be the largest, most immense, and most beautiful mud volcano in Iran, it should be said that regretfully it has not been subjected to review and investigation to the degree it deserves and its mysterious and bewildering world is still abounding in ambiguities and obscurities.

As such, it is hoped that the geologists, Geomorphologists, Chemists and the specialists of the related fields, through the study of different aspects of this superbly attractive and immensely spectacular phenomenon, introduce this unique mud-volcano at least by attracting the domestic and foreign tourists and hence turn this place into a lucrative source of income.

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