LUSI Research Report

August 2010

Russian Institute of Geological Studies

With

Institute of Electro Physics [Geo-Research Services]

« OOO RINeftGaz »

Chief Author: Dr. Sergey V. Kadurin

Igor Aleksandrovich Losev

Lubov Yurievna Eremina

Maxim Belmesov

Igor K. Nikolaevich

Content.

Introduction.

Increased mud volcanic activity usually effects significant changes in environmental conditions throughout the area adjacent to the eruption. These changes are felt especially strongly in heavily populated areas. In addition to potentially causing considerable material damage, mud volcanism, being a different, but equally powerful manifestation of commonly perceived magmatic volcanism, also has the capability to threaten the lives of people living in proximity to the eruption. The emergence of the powerful and long-enduring mud volcano «LUSI» in the eastern part of the island of Java, near the city of Surabaya (Indonesia), is certainly a significant manifestation of dangerous geological processes in a particularly vulnerable area.

The study of mud volcanoes has already been well established and reliable knowledge about the causes and conditions of their occurrence, as well as the dynamics of their development, has been well documented. However, the appearance and intensification of new mud volcanic centers always attracts considerable attention, particularly in the case of LUSI, which is situated in a densely populated area of one of the world's most densely populated islands- - Java.. Therefore, the high degree of interest in «LUSI» is due not only to the intensity of the eruptions, which have been very dramatic, but also to the havoc it has created amongst the local population and the potential for further disastrous effects in the future.

Thus, the purpose of this work was to study the geological structures in the area adjacent to LUSI and to construct a 3D geographic information system (GIS) which could be utilized to create a realistic model of the factors and conditions that contributed to the eruption of LUSI. Ongoing research through the use of the created GIS will have to address the questions regarding the existence of natural geological prerequisites for the development of this mud volcanism and, if possible, to determine the role, if any, the "human factor" played in the process of the reactivation of LUSI. The success in achieving these goals will lead to the solution of a number of problems that have plagued the LUSI eruption since May, 2006. In general, the three main goals of this research were:

1. To study the geological structure of the island of Java and the adjacent territory.
2. To study the causes, nature and dynamics of mud volcanism.
3. To construct, using modern computer technology, a 3D geographic information system that reflects the structure of the rocks in the immediate vicinity of the mud volcano «LUSI».

Initial data for the construction of a GIS came from seismic information kindly provided to us by the Indonesian Government, which had exclusive access to data resulting from seismic operations conducted in the area of the current development of mud volcano LUSI. This work was carried out between 2003 to 2006 and constitutes a set of 36 seismic profiles with a total length of slightly more than 600 km. Our own research also included field expeditions to study the geological conditions in the East Java area and the geological-geophysical conditions unique to LUSI.

It is our intent that the GIS and field operations we have conducted in relation to LUSI will open the door to a better understanding of the causes and long-term effects of this mud volcano, and encourage future researchers to carry on this quest in order to avert further potential disasters in the area adjacent to LUSI.

Geological characteristics of the Indonesian archipelago.

Physico-geographical outline.

Java is an elongated island extending in a latitudinal direction for nearly 1000 km, with a width of from 100 to 150 km. Its surface is mountainous, with the highest peaks rising to 3500 m above sea level. Throughout the entire island chain there are stretches of volcanoes and plateaus, composed of the products of their eruptions. There are a total number of 136 volcanoes, 28 of them active, with the highest of them being Semeru (3,676 m).

The mountain range stretching along the southern coast of the island is located on the southern flank geo-anticline, with width of the belt being about 50 km and characterized by a steep fall to the Indian Ocean. The axial part of the geo-anticline has subsided on major faults, and formed a zone of intermontane basins. The Neogene and Quaternary volcanoes (Semeru, Merapi, and Ungaran) ranges are bounded from the north and south of those basins. Tectonic depressions between the ranges are filled with thick strata of volcanic products and modern alluvium. Among them appear ridges of Paleogene and Neogene deposits.

To the north is a zone of tectonic depressions located on the anticline which are folded strongly between Neogene volcanic neck, dykes and stocks. In this area are located the Bukitungul and Tamponas volcanoes, among others.

Along the northern coast of the island the band width of the plains, at some points, is up to 40 km. The lowland is traversed by numerous rivers, flowing from the Central Range. The largest of them, the Bengawan Solo and Brantas, cross the mountain system and flow into the Java Sea near Surabaya. Along the southern coast also extends a narrow strip of lowlands, in large part composed of uplifted coral reefs.

The geological structure of Java involves rock of the Neogene and post-neogene ages. Crystal slates allegedly of pre-Neogene origin are known only in the eastern part of the island.

In the Baturangung ridge there appear more ancient, and pre-Neogene and lower Neogene deposits, represented by diorites, porphyries and basalts. At the base of the section lie Cretaceous phyllites and slates, which are unconformably overlapped with Eocene limestone and sandstone with intrusions of micro-diorit and diorite-porphyries.

The Lower Myocene is represented by marine sediments - shales, tuffs and conglomerates, with flows of basalt and andesite lavas. Their thickness exceeds 4000 meters and they overlap tuff-sandstone, tuffs, clays and conglomerates of the Middle Miocene. Above are marls of limestones and reef limestones of the upper Neogene, with a total thickness of 500-800 m.

The thick products of volcanic eruptions fill the tectonic depressions and compose the volcanic cones of numerous volcanoes. The time of their formation is defined as the Middle and Upper Pleistocene. Power volcanic formations reach 3000m or more in height.

Stratigraphic characteristics.

Over 90% of the surface of the core of Java contains upper Neogene and Quaternary rocks.

Despite the fact that the southern part of the island is represented by Geoanticline, Pre-Neogene deposits are confined to a very small area. This is partly due to the fact that the Neogene and Quaternary volcanic formations to a greater extent cover the major anticline, and partly to the fact that the subsequent uplift and erosion has been far weaker. [1, 2, 4]

Upper Neogene and Quaternary volcanic rocks of Java have blocked marine Neogene rocks.

Volcanic strata in Java often occur in the base of plastic marine species, and this causes tectonic deformation brought about only by its own weight of precipitation.

The Javanese geoanticline was separated from the continental Sunda geosyncline, with a broader and deeper part of the latter is located in the eastern part of the island.

Neogene deposits on the northern coast of West Java are mainly represented by marine sediments, the exception being only the tops of the cut. (see Annex 1)

In East Java the geosyncline is divided into the northern branch, which extends through the area of Rembanga to the islands of Madura and Kang, and the south, which extends along the Kandengskogo Ridge and the Straits of Madura.

Here, according to the outcrop and existing oil wells, it was found that the thickness of the rocks composing the geosyncline is 3100 - 3700 m, but in all probability, the total thickness is even greater, since the island of Madura Miocene and Oligocene boreholes reach 7000 m. (see Annex 2)

Table 1.

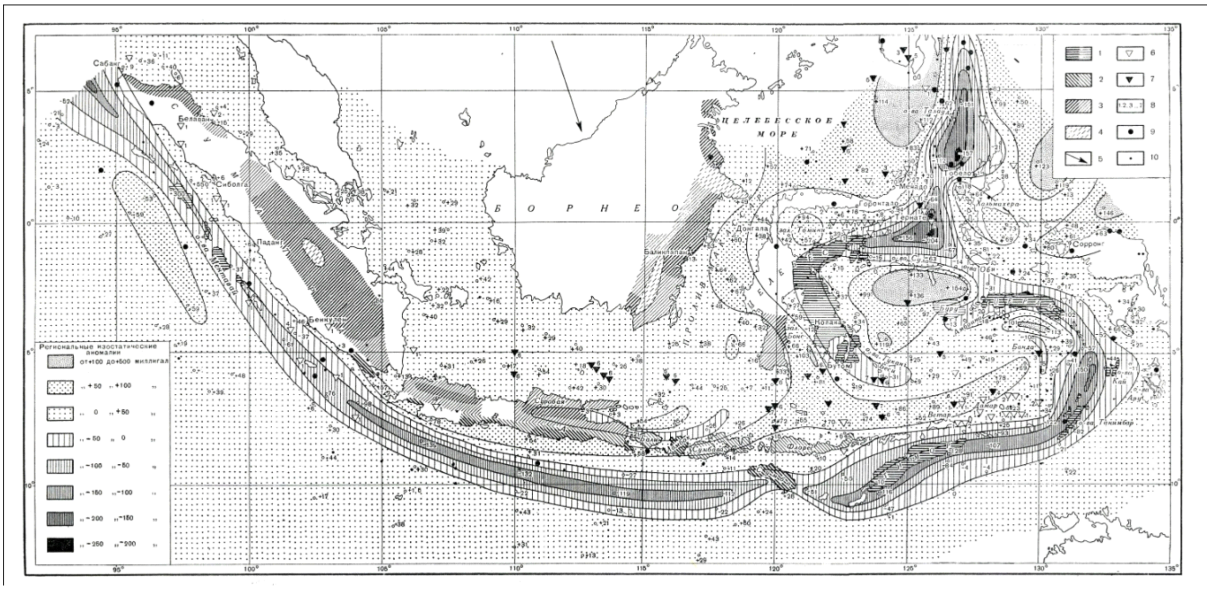
Summary Stratigraphic table of eastern part of Java Island

Stratigraphic division	Glacial division	Duration years	Sedimento-eustatism movement of the sea	Morphology and stratigraphy
Modern	Last congelation	25 000	Regress	Adjournment of accumulative terraces. Volcano and a raising of layers. Small modern cuts in terraces
Holocene			Transgression	Accumulation of adjournment of terraces
Pleistocene	Wiirm regress	100 000	Regress	Washout. Volcano and tectonic movements. Cutting of terraces. Formation of wide valleys.
	The third interglacial transgression	155 000	Transgression	Accumulation of adjournment of terraces. Volcano.
Mountain building				
	Riss regress	160 000	Regress	Washout and raising. A partition of terraces. Performance syncline.
	The second interglacial transgression	185 000	Transgression	Accumulation of adjournment fluvial terraces.
	Mindel regress	255 000	Regress	Partition fluvial terraces and adjournment estuary.

	The first interglacial transgression	360 000	Transgression	Accumulation of adjournment estuary and fluvial terraces containing a volcanic material.
	Gunc regress	460 000	Regress	Partition of terraces sea globigerina and coral limestones.

Tectonic structure

The Indonesian orogenic region (process of mountain formation, especially by a folding and faulting of the earth's crust) is located at the crossroads of the Mediterranean and Western Pacific geosynclinal belts. The main period of its geosynclinal development came at a time when the Tethys was a direct continuation of the eastern Pacific, experiencing expansion along the east-west strike. The future Indonesian archipelago, except the archipelagos Halmahera, Obi and Bangali Sula, was formed along the northern edge of the active transition from Tethys to the Pacific Ocean region.

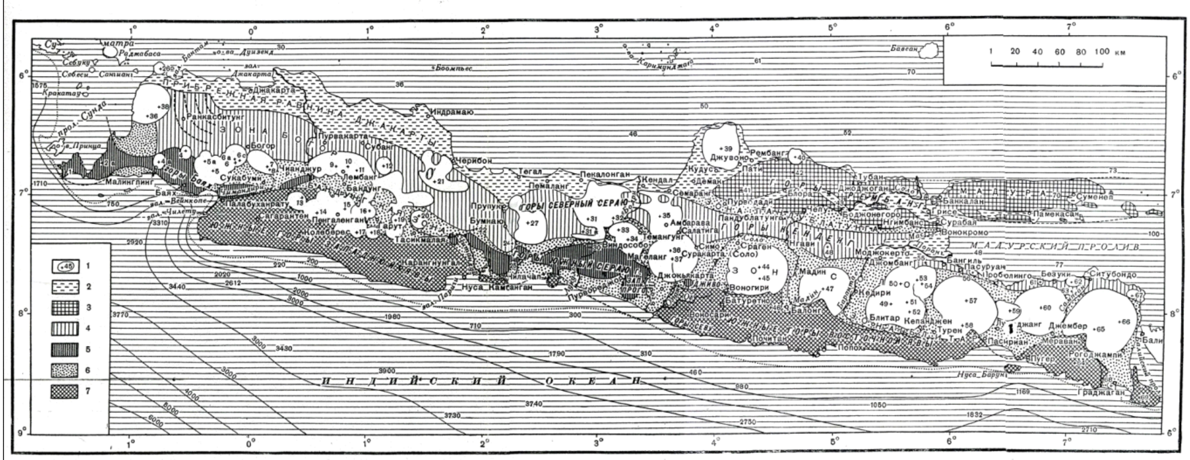


Geo Data showing gravitational anomalous regions

Structurally, the Indonesian orogen can be divided into two major areas - or systems. One of them forms an orogenic belt system, known in the west as the East Sunda Arc, and in the east by the name of the Banda Arc. This Sunda - Banda system can be described as the South Indonesian Belt. The present structure of this system is a direct continuation of the Birman - Sunda system, including Sumatra and Mentawais island, and extends from Java to the east by an almost continuous chain of volcanic islands, first east-west, then east-northeast strike, together with a strip of southern islands of non-volcanic origin - Sumba, Timor, Tanimbar, Kai, then abruptly envelope the Banda Sea to the east and north, where it includes the islands of Seram and Buru.

Another orogen system, located to the north, which could be called the North Indonesian Belt, consists of several orogen zones of general northeast strike with deviations from the meridian to the latitude that extends from Java to the Philippines. It includes a deep-water basin of the Sulu and Celebes Seas.

Our focus areas are in the Sunda - Banda geosynclinal system. [1, 2]



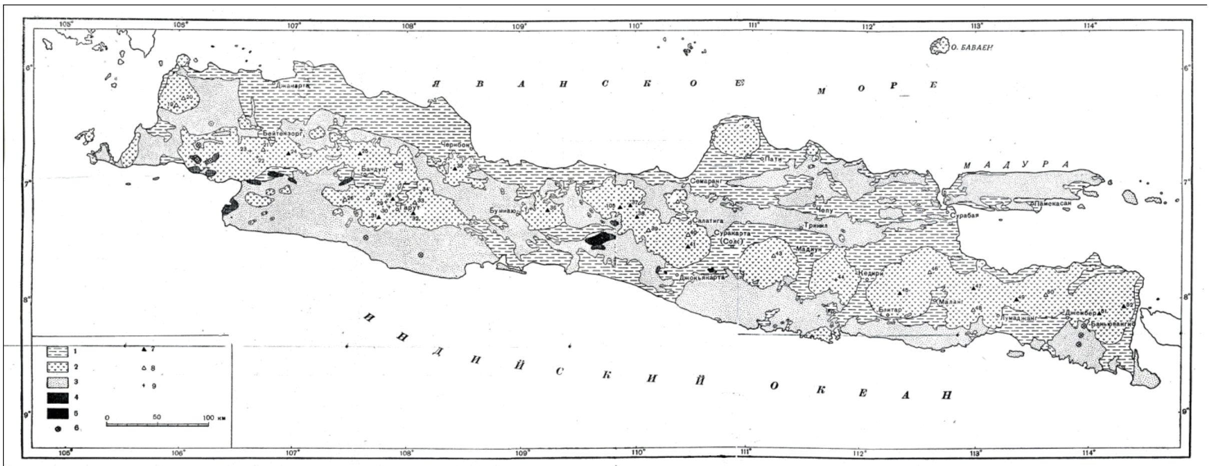
Фиг. 8а. Схематическая геоморфологическая карта Явы и Мадуры.

1 — четвертичные вулканы; 2 — аллювиальные равнины северной Явы; 3 — антиклинорий Рембанг—Мадура; 4 — антиклинорий Богор—Северный Серайю—Кенденг; 5 — купола и горы центральной депрессионной зоны; 6 — центральная депрессионная зона Явы и зона Рандублатунг; 7 — Южные горы.

The total length of the arc group of Java to the island of Buru is about 4000km. The longitudinal direction of the arc can be divided into two segments: a relatively straightforward west to east Sunda Arc and the Banda Arc itself, which forms a steep arc around the eastern Banda Sea,. The boundary between them can be conventionally defined at the east meridian of longitude 122^0. The western segment borders the Indian Ocean, while the eastern segment borders the underwater slope of the Australian platform and continues to New Guinea, that is, respectively, with the oceanic and continental crust.

The following structural zones can be divided into cross section from south to north:

1. The Deep Java Trench runs eastward to longitude 122^0. Beyond that longitude there is a fall to shallower trenches: Timorese, Aru and Seram;
2. An external, non-volcanic arc is expressed in the Javanese underwater ridge to the south of Java and next to it from the eastern part of the island, and in the eastern segment of the arc of islands, Roti, Timor, Babar, Tanimbar, Kai, Seram and Buru, as well as some smaller ones;
3. An outward arc deflection seen in the western segment of the Javanese and Lombok hollows is filled with thick sediments, and in the eastern segment - Irova and Weber depressions;
4. In the interior, a volcanic arc in the western segment consists of several major islands, from Bali to Flores, and in the east - the smaller islands, including individual volcanic islands and submarine volcanoes;
5. A backward arc depression - Bali Sea, Flores and Banda.



VII. Схематическая геологическая карта Явы и Мадуры, в основном по Руттену Rutten, 1935).
1—четвертичные отложения; 2—четвертичные вулканические породы и третичные базальты и андезиты; 3—неоген; 4—палеоген; 5—дотретичные породы; 6—миоценовые гранодиориты; 7—действующие вулканы; 8—вулканы сольфатарной стадии; 9—сольфатарные поля (7—9—по данным Вулканологической службы Индонезии).

The studied area belongs to the inner volcanic arc. The inner volcanic arc can be traced from Java to the area south of Buru, and makes a continuation of Barizan Irova-plutonic complex of Sumatra. However, on Java, the crystalline base is located at great depth and the most ancient rocks are of the Cretaceous and Paleocene periods. They are represented in the melange, unconformably covered by Eocene shallow sea water and continental deposits. The melange is represented by ophiolite association with clay minerals, quartz conglomerate, quartz porphyr. The melange is covered by Eocene-Oligocene (plus the lower strata of Miocene) deposits which are represented by conglomerates, sandstone, clays, lignite, alternating with shallow-water limestone in the lower part, marls in the middle, and limestone, partly reef on top.

Starting from the Upper to the Lower or Middle Miocene, the sediments appear as volcanogenic material, indicating the beginning of terrestrial volcanism, the maxima of which occured in the late Miocene and late Pliocene - Quarter. The products of volcanism are mainly high aluminate basalts and pyroxene andesites, with lesser production of dolerites

In the north of Java, several known recently extinct volcanoes are composed of alkaline rocks (leucitic basalts).

In the northern part of Java extends a band of depressions which is the continuation of an adjacent depression toward the north-east to Madura.

Sedimentary execution depressions include transgressive Oligocene, early Miocene deep-sea and younger regressive to the continental series. To the north the sediment moved into offshore facies, with the reef to the south consisting of volcanic material. Axis deflections consistently shifted to the north, to the extent of coverage of the southern part of the fold-thrust deformation that began in the Miocene, and passing cosedimentation. Quarternary deposits have tectonic deformations, as well. There are manifestations of clay diapirism. All these strains are associated with the intrusion of the volcanic belt and the resulting violation of gravitational equilibrium.

The offshore shelf of the Java Sea to the north of Java and Madura reveals the structure of the north-eastern strike, connecting the northern coast of Java to Kalimantan and, thus, belonged to the North - Indonesian folded system. This fact, together with other features, indicates the nature of the structure of Java and Madura and the conventionality of their assignment to the Sunda-Banda system. The volcanic arc end -point starts with another neighboring arc to the east of Java and Bali. Unlike the Java arc, the volcanic arc from Bali does not contain ancient rocks of the Miocene. And there are no ancient rocks of Upper Miocene to the east of the island of Flores

On the islands of Alor, Vetar and Roma to the north and north-east of Timor there are no active volcanoes and volcanic rocks are from the Upper Pliocene age. But further to the north-east and north, in the area of maximum bending of the Banda Arc there appears a chain of small islands.
These are isolated volcanoes, among which are, judging by the bottom topography, underwater volcanoes. To the extreme north of this chain is the island of Banda Api, south of Seram, but the bathymetry shows that the volcanic arc continues for another 400 km to the west of the island. In addition, the Pliocene-Quaternary calc-alkaline volcanoes compose the island of Ambon and several smaller islands to the south-west of Seram and south-east of Buru.

The larger islands are composed of volcanic basalt, andesite and dacite with the predominance of andesites, a characteristic increase K_2O is found to the north with increasing depth to the Benioff zone. There are small Irova of the same calc-alkaline composition. Small islands (single volcanoes) are formed by pyroxene andesites. The relatively high ratio of radiogenic to Sc non-radiogenic (0,704 - 0,795) is interpreted by a number of researchers as a result of subduction of sedimentary material.

In Java and Bali, these ratios are 0,704 - 0,705, increasing from east to west because of the increasing assimilation of crustal material.

Volcanic Formations.

Java is a part of the inner volcanic Sunda Arc - Banda orogen system. [4]

In the Mesozoic period, this belt was still a geosynclinal foredeep zone located to the north. Within this basin erupted ophiolites, which are currently in pre-Neogene precipitation (at least part of the Cretaceous) in Loch Ulo in Central Java and in the bay area of Ciletu in western Java.

The pre-Neogen rocks of Loch Ulo contain serpentinites (peridotites), gabbro and diabase.

The Pre-Neogene rocks at Ciletu Bay also consist of metamorphosed basic and ultrabasic rocks (gabbros, peridotites, serpentinites) and chlorite schists and phyllites.

The Lower Neogene was again a period of subsidence. Non-volcanic Eocene sediments formed in a transgressive pre-Neogene complex basement. By the end of the Palaeogene period magma reached the earth's surface and began a period of very strong volcanic activity that took part of the underwater nature, There were ancient andesites, the first cycle of the Pacific volcanism.

A volcanic belt south of Java was raised In the Middle Miocene period and granodiorite and granite batholiths rose to the base of andezite volcanos.

Intra-Miocene intrusions and their accompanying paroxysmal eruption of acid magma (dacites and dacite tuffs, developed south of Tendzholauta) completed the first cycle of the Pacific volcanism.

In the Upper Neogene period volcanic activity started the second cycle, with the second stage of volcanic uplift. In the Quaternary period, the third volcanic cycle started, and continuies until the present day.

A characteristic feature of the second and third volcanic cycle is that the intrusion and extrusion of the northern edge of geo-anticline southern Java tend to differentiate with the formation of alkaline rocks.

In the Quaternary period in the north-east of Java, on the inner side of the volcanic geo-anticline, appear several volcanoes with leucit containing loose products (Muriah, Irova). These are, thus, Mediterranean-type volcanoes.

Mud Volcanoes

Mud volcanoes are a fairly widespread geological phenomenon. At present, our planet has more than 1700 surface and submarine mud volcanic structures. [8, 10] Some mud volcanoes are giants, especially common in the territory of Azerbaijan, and have a height of 400-450 meters, a crater surface area of 900-1000 m^2 and a total amount of solid emissions in them at the time of eruption of more than 2400 million m^3. [11] The usual mud volcanic activity clearly falls into two periods. Eruptions begin with the explosion of gases in the crater, the destruction of the crater caps and flows to the surface as semi liquid mud. At the same time, solid blocks and fragments of rocks are ejected from the crater of the volcano, often accompanied by spontaneous combustion of hydrocarbon gases, with burning flames appearing in the crater. The height of these flames can reach several hundred meters. Masses of “mud-bressia” type minerals containing large quantities of water, oil, hydrogen sulphide and disseminated sulphides, spread over the area and build the old cone. The volume of solid emissions is enormous.

Volcanic eruption usually lasts several days, accompanied by an earthquake or a powerful underground tremor and is sometimes divided into separate phases, during which it is dominated by different kinds of mud volcanic activity products.

Then, generally, the volcano becomes tranquil for a long period of time. Numerous salze and springs appear at the crater site, continuously supplying the surface with mud, gas, water, and sometimes oil. Here, each source, as it breaks through the surface, deposits a mass of dense clay-rich crusts, which, as they buildi up, turn into a miniature likeness of the volcano. Such salze (small mud hills) generally have a height of no more than 2-3 m and are found in the craters in large numbers. At the same time, on the slopes of volcanic cones, there begins an oxidation process and an erosion of mud volcanic structures. Gray and greenish-gray clay containing scattered sulfides oxidize and turn into brown, reddish-brown rock rich in iron and manganese. Slopes become covered with a network of deep ravines (barranco), radially arrange in relation to the crater floor, as the deep waters of volcanoes coming from griffins and salz (small mud hills) and precipitation temporarily accumulate in uneven terrain. [6, 9]

Thus, mud volcanoes alternate from periods of eruption to periods of relative tranquility.

In explaining the mechanism of the formation of legitimate mud volcanoes in the beginning of the 20th century, three main areas have been identified.

Some researchers, staying on traditional ideas, continue to assert the endogenous genesis of mud volcanism similar magmatic eruptions, but they cannot always clearly explaine features of this phenomenon.

Other geologists suggest tectonic solutions to the problem and maintain that the main factor determining the appearance of mud volcanoes is geodynamics - the development of diapir folds, shallow thrusts or deep faults.

Finally, the most popular explanation was submitted by Petroleum Geologists, who linked the formation of mud volcanoes with the formation and destruction of oil and gas. In this case, the excess pressure arising in the oil fields creates the breakthrough of mud-bressia to the surface through volcanoes erupting through channels, with many researchers attributing the eruptions to the excessive pressure of hydrocarbon gases concentrated in the subsurface.

Patterns of distribution of mud volcanoes.

Both surface and submarine mud volcanoes are very rarely solitary; more often they are grouped into mud volcanic clusters of different sizes. The largest clusters of mud volcanoes are concentrated in the southeastern and northwestern parts of the Caucasus, in Azerbaijan (Absheron peninsula, south-west Gobustan and the Kura basin) where more than 220 mud volcanic structures have been mapped. Usually they are associated with anticlinal uplifts, partly controlled by tectonic fractures and sometimes spatially coincide with large oil and gas fields.

In the north-western part of the West Kuban basin, on the Taman Peninsula, as well as within the Kerch Peninsula there exists a large mud volcanic cluster. It has recorded more than 100 mud volcanic manifestations. [8, 9, 10]

Smaller mud volcanic clusters, which usually include a few dozen mud volcanoes, are located in Italy (Po River Valley, Sicily), in Albania, Romania, in western Turkmenistan, within the Gorganskoy plains of Iran, on the Makran coast of Iran and Pakistan, in the northern Beludzhane Pakistan, in Dzungaria (PRC), in western Burma, the islands of Malaysia and Indonesiaand on the island of New Guinea. Characteristic wide distribution of mud volcanoes on the island of Sakhalin, on the islands of Honshu and Hokkaido (Japan), as well as in New Zealand.

In the western hemisphere, mud volcanoes are known to exist on the island of Trinidad (Trinidad Tobago), in Venezuela and northern Colombia, and they have also been established on the Gulf Coast, in California, Greenland and Iceland.

Local names of mud volcanoes vary within very wide limits; they are called salzami, makalubami, glodurami, bolborosami, pyklyami (varietet-baked), griffins, potossami, Morne, Irova, yards, erviderosami, namarami, porsugelyami.

Submarine mud volcanoes are quite common on the shelves of the oceans and outer seas, as well as cold flow of hydrocarbons ("seeps") are existent within the western and eastern Pacific coasts, on the shelves of the Atlantic Ocean, Norwegian, Black and Barents Seas.

In general, examining the patterns of distribution of mud volcanoes on the continents of the world, as well as in the seas and oceans, we can easily conclude that most of the mud volcanic clusters are clearly gravitating to the alpine zone of folding. Their distribution confirms the conclusion - that modern mud volcanism is controlled by the location of the Alpine mountains.

Typically, the dissemination of mud volcanoes coincide with the largest oil and gas basins and their corresponding relationship with elizion systems.

Finally, it should be emphasized that in mud volcanic clusters, there are usually found very well developed high thick clay strata and zones of Ultrahigh-Pressure Reservoir Fluids (UPRF). Their expression is established in the Gulf of Mexico and the island of Trinidad in the West Kuban basin and in the Absheron Peninsula, the

West Basin of the Turkmen in the region of Elbrus, the Makran coast of Iran and Pakistan, Dzungarian basin in western Burma and the island of Java.

Morphogenetic typing of mud volcanoes.

If we use the data describing the 500 or more terrestrial and submarine mud volcanoes Crimea-Caucasus and South Caspian region, we can distinguish among them a number of morphogenetic types. [9, 10]

The first type of mud volcanic structures are diapir formation. Usually, these large mud volcanoes, in which mud volcanic breccia differs in viscous texture, and squeezed out of the crater channel, forming collumn-like Nekks. Essentially collumn-like bodies in the crater of a mud volcano sand silting, became petrified and turned into sandstone as a result of degassing and the pressure drop of CO_2. The formation of such systems, sand tubes, can most likely be associated with the repeated push for a liquid slurry through the porous sand or sandy clay plug in the crater of the volcano. The formation of tubes is undoubtedly a consequence of the rapid pressure drop in gas fluid containing an abundance of dissolved carbonates. This is evidenced by the presence of thin channels that capture the movement of gases in the central parts of the tubes, and frequent passages of pipes in concretions, fantastic forms and bodies.

The second type of mud volcanoes develop due to periodic influx to the surface of semi-liquid mass mud-bressia in the time they were conveyed over the next eruption from the crater to the periphery of the volcano, formed volcanic edifices, and thus increasing the volume of a concentric cone formation. The size of such mud volcanoes varies from 30-40 m in height and up to 0.5 km^2 at the base, but in some cases reaching 400-420 m in height and 20-25 km^2 in the area of the base. The crater area of mud volcanoes of the second type is usually complicated by numerous salzami and gryphons - miniature likenesses of maternal mud volcanic structures. They constantly give off water, mud, gas bubbles and a film of oil. The general appearance of these formations is very exotic, and, when grouped, they resemble a lunar landscape.

The third type of mud volcanoes are those in which, instead of mud volcanic structures, salt marshes, wetlands were formed, with mud puddles occupying large areas and are virtually free of any towering presence above the surrounding terrain. Such mud bogs are usually complicated by small salzes or griffins, whose dimensions do not exceed several meters in height, which constantly exude liquid mud, water, and small amounts of oil. During the eruptions of this group, streams of liquid mud are often formed, resembling sat (Sealy). Fragments of solid, mainly sedimentary rocks are usually included in volcanic mud. Characteristically, there is usually subsidence of individual sections of mud volcanic fields. Often within the development of mud breccia shallow lakes and ponds are formed and concentrated in the surface water.

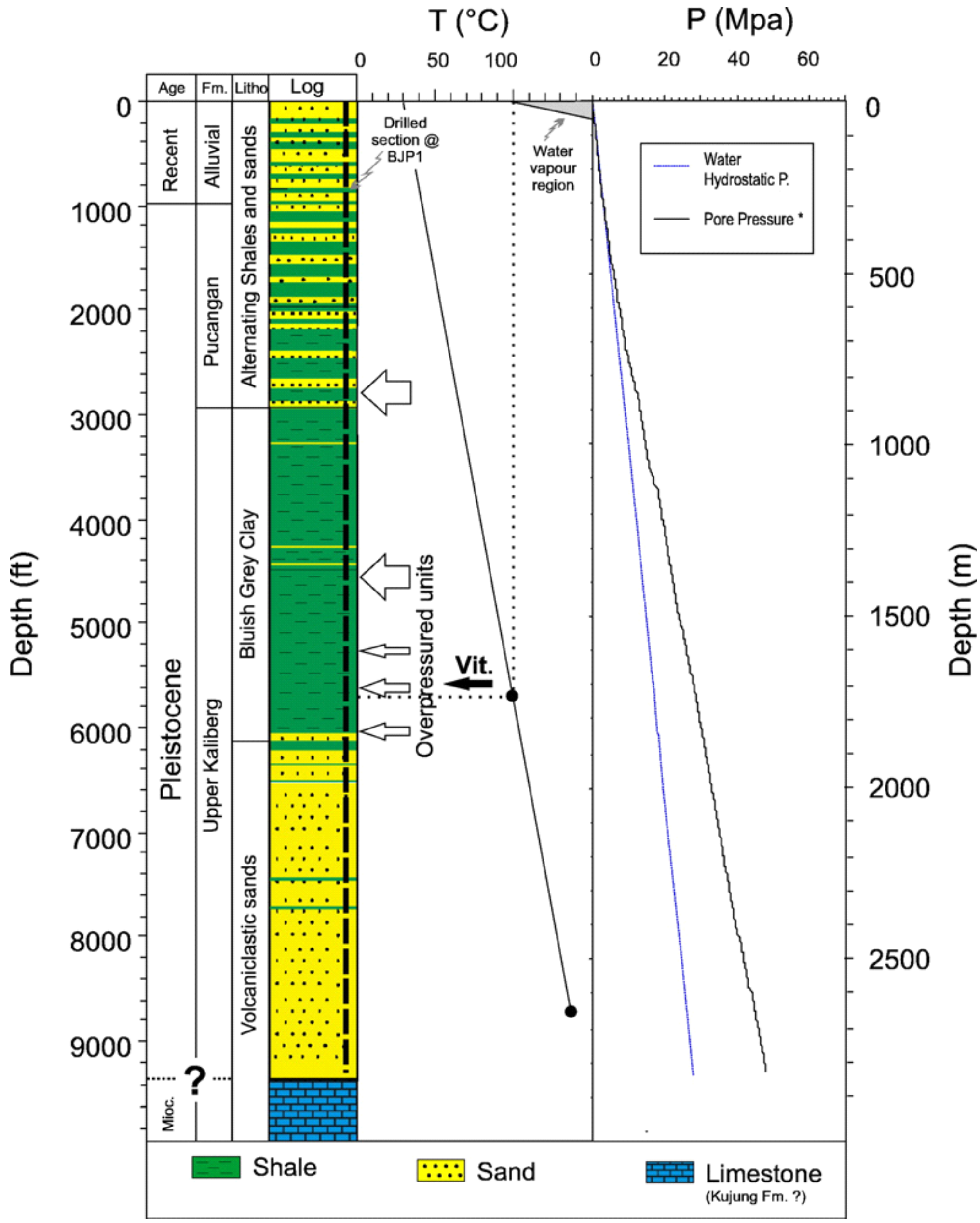
The fourth type of mud volcanoes are the pressed in syncline. Pressed in synclines are mud volcanic structures of the second type, usually with complicated central part of the anticline. Here along the faults limiting vent, part of mud volcanic structure fall down, and falling plase filled by mud breccia and normal sediments. In the 19th century, Golovkinsky suggested that such secondary structures of subsidence areas were associated with the eruption of a large mass mud-bressia and the corresponding diminution of the volume of rocks at depth. At present, after studying the work of Prokopov, Lychagin and Shnyukov, it is assumed that mud volcanism provides excess weight mud-bressia on the surface and the lack of depth, as a result of this situation, begins forming ring faults and grabens that are involved in the process of lowering the fragments normally overlying sediments, mud-bressia and landslides.

The above types of mud volcanoes can at the same time be regarded as different stages of a single process, as often as a result of the next mud volcanic eruption on the site of a large mud volcanic construction, where a lake can be formed, but instead of a large lake - become a new mud volcanic cone structure.

Without dwelling on the numerous examples of such metamorphoses, it should be emphasized that the proposed morphogenetic typing of mud volcanoes suggests that, on the whole, mud volcanic processes are realized not only through an excess of pressure in the interior, but also by a deficit in pressure. This conclusion significantly limits understanding of the mechanism of formation of mud volcanoes, and raises serious questions about the location, structure, condition and transformation of mud volcanic fire, feeding the volcano.

It can therefore be concluded that LUSI displays the above characteristics as shown by its Stratigraphy column and the temperature-pressure gradient in BJP1. The graph below shows clearly the shale layers which are typical of mud volcanoes. The layers' depth and thickness can be used to extrapolate and even predict the possible next eruption.

The sedimentary regressive sequence consists of clay and sandy sediments. Over-pressured units logged during the drilling are present in the intervals 762–914, 1323–1457, 1579–1594, 1670–1740, 1822–1871 m. T=100 °C is reached at about 1700 m.



Structure and mechanism of formation of mud volcanic centers.

The systems of vertical and inclined channels, which bring to the surface mass mud-bressia of different consistency- - water, liquid and gaseous hydrocarbons, gases and other components- - are, in geological literature, referred to as mud volcanoes. Depths to which the roots penetrate, were determined by several independent methods. [6]

Using seismic profiling, it was discovered that the depth of penetration of the roots of mud volcanoes and the root system of volcanoes does not extend beyond the lithosphere - the sedimentary and volcanic-sedimentary shell of the Earth. Indirect, but very interesting data about the origin of mud volcanoes can be obtained by studying the composition of gases involved in the process of eruption or coming to the surface as a result of salz-griffons activities. The results of numerous tests on volcanic gases in the Caucasus, Turkmenistan, and Sakhalin Island allow us to conclude that, as a rule, the predominance of methane, nitrogen and heavy hydrocarbon gases is very low, and that inert argon, xenon and krypton are present only in fractions of a percent. [It is significant that the LUSI mud volcano emits a great amount of methane.]

In contrast to mud volcanoes, true, or magmatogene volcanoes, emit virtually no methane. In their gaseous phase they usually accumulate chloride, carbon dioxide, nitrogen, hydrogen sulfide, sulfur dioxide, and even fluorides, but methane is usually absent.

In general, it is obvious that the composition of gases in the majority of mud volcanoes, delivered both during eruptions and in salze-griffone stage, suggests their genetic relationship to sedimentary strata of mud volcanic clusters.

In the assessment of the location of the roots of mud volcanoes, many researchers have tried to understend on the stratigraphic position of solid emissions in a given quantity, is always present among mud-bressia. In this case, it was assumed that the age of the oldest inclusions must correspond to the maximum depth of penetration of the roots of volcanoes in the sedimentary cover.

In general, the data for binding of solid inclusions mud-bressia to stratigraphic scale of the region are in good agreement with the materials of geophysics and geochemistry, considered the beginning of this section. Typically, clusters of mud volcanoes tend to be oil and gas basins of the alpine zone of folding, in which are accumulated terrigenous-clayey sediments and forming thick strata of clay with ultra-high-pressure fluids (UPRF). Most likely, that excess fluid pressure in the thick strata of clay formed mainly by the phase transformation of clay minerals at high temperatures (and pressure) and, primarily, by illite-forming on smectite.

In the scheme of this process can be represented as follows: a powerful layer of predominantly smectite clay is lowered into the depths of the sedimentary-rock elizione basin before the formation of the zone thinning and ultra-high pore pressure (UPRF) in clays. Here, successive layer occupies the position in relation to the zone of critical temperature and pressure, below which the smectite phase can not exist.

In the microscale process looks like that the blocks of smectite clay when immersed become illite, decreasing in volume and allocating water of crystallisation in the area of critical temperatures and pressures. As a result of this process, near the border zone thinning illite laid clay - layer, which illite blocks suspended in the separated, water of crystallization.
Below the newly formed illite blocks converge with each other under the effect of increased geostatic pressure, and all the pore water pressed up into a zone of decompression. As a result illite compacted clay, and above it increases the pore fluid pressure - in the zone of thinning of clay, a region UPRF.

Power zone thinning of clay and the quantity of reservoir pressures in it are highly dependent on the power of the transformed clay formation and on its position relative to the boundary of the critical temperatures and pressures. Originally zone thinning and UPRF relatively small. But as the go back into deep lithosphere, clay formation is increasingly covered illitizatsiey, region thinning becomes more powerful and UPRF - increases. Study of structural and geochemical clay suggests that the thickness of the zone thinning may reach 400-500 m and more.

In the wild elizion systems offered by our idealized scheme of phase transformations of clay minerals is more complex:

1. Number of smectite clays in the transforming, not necessarily strongly prevail over all other clay minerals. Calculations show that when the original content of 25-30% smectite illite-forming 1m^3 of clay is accompanied by 17-20 kg H_20. It is easy to understand that the clay stratum with a capacity of 1.5 - 2.0 km can create a very large area of flooding in the sedimentary cover.
2. Formation of subsurface clay silt dramatically increases the permeability of individual sections of clay formation and stimulates the strengthening of the reactions of thermolysis and termokatalize scattered organic matter, hydrolysis of carbonate and silicate dissolution - all the processes that occur in the main phase of oil and gas formation.
3. Reservoir pressure in the mud volcanic hearth grows at the expense of moving into his gas and petroleum hydrocarbons, made an intensive integration of the partial pressures and the relative homogenization of all components included in the system. In zones of decompression are not formed of water, and complex composition hydro-gaz fluids.
4. In the zone of thinning clay is intensive ordering orientation of clay particles (and terrigenous) of minerals and redistribution of chemical elements, changing their mode of occurrence. Here are born new association of authigenic minerals, reflecting features of the new physical-chemical environment.
5. During dives deep into the clay formation of the sedimentary basin and illite-forming smectite increased pore pressures stops when the region gets UPRF

fracture, vertical fracture zone or a sand reservoir bed. Then the pore fluids accumulated in the zone of thinning, rush into the pore space of sand or go on a plane faults, and pore pressure in clays drops to normal for these depths.

When a significant difference of pore pressure in clays and reservoirs may seem, conflicts arise, significantly alter the texture and character of occurrence not only clay, but other sedimentary rocks in the section. For example, when a layer of sand is in the area of thinning and UPRF, he turns into quicksand, the plasticity of sandstone and clay is flattened, and they both are deformed as a very plastic and similar education.

Sometimes the difference of pore pressure in clays and sands is so great that they encounter leads to a brighter fracturing; under enormous pressure liquefied sand is injected into the cracks, fill them and after decompression hardened components dissolved in the pulp.

This is formed of sand dikes, horizons with inclusions, diapir apophyses and others consequential body, we have described in some previous works. They often associate it with the mud volcanoes, and this leads to the idea that the focus of such formations in addition to diluted fluids clays may include thinning the sand-silt. Their manifestations are particularly typical of the mud volcanoes of Turkmenistan, where mud-bressia often contain the body of sandstone most bizarre.

Thus, the center of mud volcano is a body, composed of clay, at least - the sands, often containing a large quantity of solid debris, the surrounding rocks and diluted homogenized hydro-gaz fluids (water, oil, gases of different composition). It is formed at great depths due to self elizione systems and can, under favorable circumstances, "feed" the roots of mud volcanic structures. The potential of such mud volcanic centers is well disclosed in the investigation of accidents of oil wells.

Structures of Baku Archipelago are typical case, connected with ultra-high-pressure. There was the capture of the chisel tool, sometimes emissions of clay have appeared here in drilling of several wells. For example, drilling of well 42 at the mud volcano Dashgil concluded that the slaughter has been thrown out of the entire drill string length of 2500 meters, which force the release was a ring around the Legislative derrick. Significantly more of the bottom-hole drilling tool ousted plastic clay mass, resembling gryazebrekchii, and then these clusters of mud is squeezed out of the barrel like a diapir. [11]

Another case is associated with the emergence of so-called "violent wells”, widespread in the U.S. (Texas and Louisiana), as well as in the Baku area. Accidents in this case are characterized by the sudden release of large quantities of water and gas, failure of the drilling and formation rounded crater with a diameter of 200-250 m. For a long period of time after the accident (8-10 years) the surface water creates a large quantity of clay material.

Differences between these two extremes lie in the composition and structure of the mud volcanic source, as well as in his opening holes. In the first case, the mud volcanic center responds to the introduction of the bottom-hole as a single body, striving to occupy a larger volume; in the second – water and gas is evacuated, the pressure drops, and the source structure is formed in the depths of the earth, which is then reflected at the wellhead by forming the caldera subsidence and collapse of layers .

One might think that these two different cases of hearth mud volcano wells to some extent is similar to the formation of extreme morphogenetic types of mud volcanoes in our proposed typing. The first case is similar to the formation of diapir volcanoes and volcanic mud volcanic with strong buildings, and the second - with "pressed syncline" and porsugelyami is always similar in form to the collapsed caldera.

Obviously, the analogy in the behavior of wells and mud volcanoes indirectly confirms our understanding of the conditions and mechanism of formation of mud volcanic centers.

From a geological point of view, pockets of mud volcanic activity can be regarded as attenuated and lenticular layers, waveguides, lying roughly in accordance with the stratification of layers, but sometimes they cross stratigraphic boundaries. In those places where they intersect the system of cracks and faults, the consequent ramifications are actually the roots of mud volcanoes. Above, these formations (branches) are replaced by vent mud-bressia, and already on the surface - fields of the crater and Sopochnyj mud-bressia, often forming volcanic structures.

The dynamics of mud volcanoes.

The development of the vast majority of mud volcanoes can clearly be distinguished in three stages:

1) the stage of formation of mud volcanic fire, due to the peculiarities of development elizione system;
2) the stage of the eruption of mud volcano, largely reflecting the composition and terms of occurrence of mud volcanic hearth;
3) the stage of passive griffon-salze activities that disrupt the effects of the eruption of mud volcano and prepare for its next eruption.

The first stage takes place against the backdrop of the accumulation of terrigenous-clayey sediments, deepening depressions and income flyuid-formed clays in the field of high temperatures and pressures. In this case the primary properties of clay dumped determine those ratios of components in the fluids of mud volcanic fire, which play an important role in determining the type of eruption, and even morphogenetic type of mud volcano, and in this respect, mud volcanism is very similar to lava. In which, as we know, acidity - alkalinity of the magma and the rate of explosive characteristics determine the nature of volcanic eruptions and buildings.

The total value of UPRF arising in the hearth is very important in the activities of mud volcanoes. It, as well as the component structure flyuide largely depends on the primary, paleogeographic, sedimentation-diagenetic, facial and tectonic conditions of occurrence of argillaceous rocks composing elizione system.

In general, the formation of mud volcanic focus is towards integration and homogenization of solid, liquid and gaseous components in a closed physical-chemical system creates different from the surrounding deposits of potentially active and mobile environment, the waveguide layer.
The second stage of mud volcano begins with the opening of a mud volcanic center of the system of faults and fissures, which connects the passage closed physico-chemical system in the open. This process is accompanied by phase differentiation of matter and the simultaneous movement of the masses from the source to the surface.

The main factor governing the eruption is the pressure drop associated with the movement of mud volcanic masses through the channel from the source to the surface. Reduction in the pressure has an intense effect on the plasticity of diluted clay, as it is known. Pressure reduction creates a semi-liquid mass in the dense clay body.

A very important factor during the volcanic eruption is the loss of the gas component, which changes the properties of the residual solution and often leads to the formation of authigenic minerals, kolmatiruyuschih channel volcano. For example, the loss of gaseous CO_2 near the ground surface shifts the carbonate equilibrium toward precipitation of solid phase carbonates. Last cement before moving sands, quicksands and form a cork-colmatation, overlying mud volcanic channel. Multiple repetition of the deposition of carbonates and bursting through the sand and carbonate formed tube gas-water sandy silt can create a whole system of calcareous sand pipes, known under the name "Shaitansky” gardens.

Loss of methane contributes to the concentration of heavy hydrocarbons and the formation of Irova and asphalt formations cemented sands. Trudnoszhimaemoy water is very important during the eruption of a mud volcano and affects the volcano’s behavior. Its sudden release from mud-bressia and passage to the surface can cause what are known as "mad wells, promote the formation of the mass deficit at depth and the emergence of the caldera subsidence around the crater.

In some cases, the sealing of the channels of the volcano is a purely mechanical action. Lumps of solid rock and debris from the surrounding rocks, their size sometimes reaching 5 - 10 m3, may become trapped in the mud flow.

Very often the volume of crater- clogging mud-bressia is unusually high. The estimated mass of mud-bressia thrown to the surface as a result of the 220 volcanoes in Azerbaijan amounts to 100-110 million m^3.

Whatever the situation, the process of eruption of a mud volcano, in general, aims at the separation of components, integrated into the mud-volcanic hearth. It causes a significant drop in UPRF nutrition system, completed before sealing a vibrant channel and the transition to the next, relatively calm ethane development.

Third salze-griffons stage of mud volcanoes, on the one hand, can be seen as the end of the eruption, but on the other, as preparation for the next disaster. During this period, at a depth of focus of the volcano, regenerated UPRF, since developing elizionnye processes in a closed physical-chemical systems are able to restore their original settings (RT). At the same time there is a decrease in the permeability of the cork that seals the mud volcanic channel.

It should be emphasized that mud-bressia overlapping channels and the forming of a volcano crater area are rarely completely impervious systems; they often contain cracks, zones of increased permeability and the channels through which the discharged gases first move. In the history of many mud flames, which burn for a considerable period of time after the completion of the active volcano, and the decoration of the crater area. They certainly are a result of the migration of gaseous hydrocarbons, burning as it exits to the surface.

In salze stage of mud volcanoes development, water goes up following the gas. The water brings a lot of fine clay material to the eruptive volcano channel and finds the ways of unloading. At the same time water captures and partially dissolves in itself, a large number of clay material, which turns into a real clay solution is artificially created for the needs of the oil drilling. Hydro-gas mixture, bearing masses of pelitic clay material, gradually destroy the continuity of mud volcanic plugs, which closed the eruptive volcano channel. On the other hand, their path to the surface is accompanied by the deposition of clay aggregates from all sides surrounding the discharge channel and gradually form a cone-shaped building resembling a miniature mud volcano.

Salze-springs of water in mud volcanoes have a composition very similar to the stratified water in oil and gas fields in the region. It is also curious that within the same crater field each salza creates water of a different class and type.

Thus, the period of enhanced salze-griffons activity violates the monolithic mud-bressia clusters sealing mud volcano crater, making them loose permeated with numerous vertical channels and cavities. As a result of this, the loosening of mass mud-bressia is unable to withstand the pressure of mud volcanic fire, and when the first earthquake, seismic shocks, tectonic shifts, or other violation of the equilibrium occurs, there is a new eruption.

The region surrounding LUSI is clearly prone to mud volcanoes as seen above in red circles within East Java island. (With LUSI shown in yellow circle)

Geographic Information Systems

Principles of GIS in geology.

Modern priorities of geology allow us to approach an understanding of GIS (Geographic Information Systems) as a means of accumulating, storing, displaying geodata for factual and analytical background service or as a means of processing data to generate new knowledge, in which the accumulation, storage, display play a supporting role. In the first case, a repository of results of completed studies - maps, past edition. In this set of methods and means of working with data determined almost independently from the needs of their future use, and adapts technology originally not designed for geological purposes. In the second case, GIS is seen as a means for solving regulated geological instructional and procedural documents. Such funds shall be located directly in organizations geological studies, and the establishment of a geodatabase is solved, primarily from the standpoint of future treatment.

Both points of view exist and give rise to the complexity of coordination and interaction. Interaction is necessary because, on the one hand, launched a lot of work to create a bank of digital geological information, mainly aimed at the first interpretation, on the other hand, the normative and methodological documents already established an understanding of GIS as a tool for integrated office processing of materials and their analysis in order to obtain new knowledge and practical recommendations [3, 5, 7]. From this perspective, the requirements to GIS technology: to provide input, control, storage and display of geological data transformation, synthesis, analysis and interpretation of coordinate-referenced data, modeling and recognition of natural objects; forecast of mapping situations and minerals. In this initial information cards are all qualitative and quantitative characteristics of the territory of decoding schemes, and interpretation of geophysical data, digital data sets of geophysical and geochemical surveys, aerial and satellite imagery, photographs and textual descriptions of objects. Thus, we are talking about software systems, which, possessing the usual tools for GIS spatial data, the possibility of operating, are also a means of solving the actual geological problems on complex heterogeneous data. Proven practices to the inclusion of intelligent subsystems in the structure of the GIS gives it a new quality - the ability to interpret spatial data, ie, the transition from one conceptual system into another system of concepts, expressed in terms of the trust property (lithological and petrographic composition of rocks, the coordinates of promising sites, expected mineral resources, etc.). Thus, the inclusion of GIS intelligent subsystems provides a multi-dimensional zoning, forecasting and mapping situations, planning and optimization of field observations. This raises the question of the relationship between GIS and systems, specialized by type of data being processed.

Obviously, in a specialized package processing is performed more efficiently. At the same time, the output of such systems could and should serve as input to GIS, which not only provides the infrastructure, means of displaying and manipulating data, but is a tool for integrated interpretation of different types of qualitative and quantitative data. Thus, the place and the main role of GIS in geological studies are defined as the integration, analysis and comprehensive interpretation of different types of data, forecasting, modeling and planning future action, presentation of results in terms of target geological properties and in chart form. In this approach, GIS in geology is not only a means of transforming the presentation of information and reference and analytical services, and primarily a means to achieve the ultimate goals of geological research.

Requirements for GIS in geology.

The above stated definition and conditions give rise to specific requirements to the functions of GIS. A common requirement is to provide a coherent framework of technology from design to reporting materials to the task. This standard functions of GIS (storage, editing, measurement, sampling, combining and displaying data, etc.) must be supplemented by:

- special analytic functions (spatial statistics, taxonomy, search combinations of diagnostic features of objects, the study of relationships and dependencies, Verification of the homogeneity of samples, etc.);

- functions for constructing derivatives of maps that include algebraic, trigonometric, logical and other operations on the set of maps arbitrarily set by formula pointwise and in the processing of sliding windows, interpolation and contouring in the light barriers (surface disruption), the calculation of potentials and others;
- means of a multidimensional zoning, including the use of peer review;
- identification of functions - automatic recognition and mapping of objects and situations in their indirect qualitative and quantitative characteristics;
- functions of the optimization solutions for the recruitment of quality criteria for forecasting and mapping situations, and evaluation strategies of field work, the proposed user-geologist;
- built-in media development.

All these functions should be implemented in the form and terminology, easily perceived by geologists, and applied to the dataset, regulated by the instructions and collectively provide a comprehensive interpretation of qualitative and quantitative data.

Obviously, a system that meets the above requirements, can be created only by a team of developers which is comprised of professional geologists, analysts, programmers and highly skilled with experience developing systems for data interpretation.

It is also clear that such a set of requirements can be satisfied only within the vector-scanning system. The bulk of the processing will be on the raster data. Vector shapes are mainly used at the input and output, as well as for the measurements (area, distance, perimeter) and the establishment of topological relations (neighborhood, nesting, connectivity). The solution of meaningful tasks related to the study of variability of properties within the objects, spatial relations characteristics of objects and interpretations can be effectively implemented only on raster data.

The most common model of data organization is the layer model. Its essence lies in the division made of objects into thematic layers, and objects are then assigned to a particular layer. For example, they are placed in a single file or in a single directory and have a single and separate identity from other sections of the system of identifiers that can be treated as a certain set. So, you can place in a single layer of hydrography all objects, or all highways, or all references to vegetation. Most often, this division is organized as a thematic layer horizontally - by analogy with individual governmental data sheets. This is done primarily for the convenience for administration of Niya databases and avoids working with extremely large files. Within the layered model, there are specific implementations.

There are some additional limites for Vector-topological data model: in one sheet of one of the thematic layers you can place only one type of geometric objects. Thus, in the ARC / INFO, in a cover (physical unit corresponding to one sheet of one tematic layer) can be placed just point, or only linear or only areal objects, or a combination of linear and point, or linear and area. But can not pocible put together point and areal or all three types of objects. There are no problems for practice of this limitation, but it is typical for vector-topological data model.

In the Vector nontopological data model there is much more flexibility, however, often only objects of the same geometric type. are placed in one layer The number of layers in the layered organization of data can be very large and depends on the specific implementation.When layered organizations of data conveniently manipulate large groups of objects, pre- finance tools presented layers as a single entity, for example, switch on and off layers to visualize, identify transactions based on the interaction between layers.

Development of geographic information system

In developing the GIS usually distinguish the following stages:

1. analysis of the requirements for the system;
2. definition of specifications;
3. design;

4. operation and maintenance.

In the first phase, an analysis of the requirements for time is developing a system that is focused on the appearance and content of the system, as well as the principles of dialogue between this system and people who will use it. Requirements analysis can contribute to a better understanding of the proper solved problems and compromised situations, which helps select the best solution. It should identify the spatial-temporal but the restrictions imposed on the system, as well as tools used in its various versions for different applications. When you create a geographic information systems to a team of developers immediately raises a lot of problems as the technological and conceptual. It is necessary to define the concept of directories, facilities and information processing procedures that will underpin the GIS.

The analysis phase is for deciding whether to develop the system, then comes the stage of defining the specifications for the exact description of the given function of the structure of input and output data, to solve the complex issues related to the structure of files, organizing data access and updating. Specifications determine those functions that the system must perform, however during this phase there are no details as to how that is to be achieved.

At the design stage, detailed algorithms are developed and implemented from which the specifications are derived and the overall structure of the computerized Geo system is formed.

Once developed the system is divided into small parts so that it would be responsible for implementing each of these parts by either a developer or a group of programmers. Moreover, for each specific module the requirements shall be framed and implemented as functions of action modules, runtime, and so on.

Operation and maintenance of GIS demands the creation of a set of information layers, each of which stores specific information about the geological, tectonic, geomorphological and other structure of the object, as well as methods for their comparison and superposition. It creates a single set of information layers with a specific sequence of their location relative to each other, as well as view their graphical representation (colors, transparency, sharpness).

Ultimately, the client must receive the support of GIS formed within the specified spatial and temporal framework, which includes a set of information layers of interest to the customer information that reflects the decision set of geological problems.

Building GIS «LUSI»

The building of the GIS for «LUSI» was carried out in the above mentioned stages. The main requirement was to study the modeling of the deep structure of sedimentary cover rocks in the mud volcano LUSI. Of course, the most interesting and promising function would be in terms of developing the ability for forecasting future eruptions of the volcano and determining its causes, through the building of a full three-dimensional geodynamic model. However, to achieve such an objective requires the collection and compilation of an entirely different kind of background information, as well as staging polygon constantly monitor the geological phenomenon.

The network of geophysical profiles that is established at the moment allows us to study the structure of sedimentary cover within the mud volcano formation, as well as specify the location of underwater channels for receipt of mud volcanic breccia on the surface and show the location of major faults in the area in question. Creation of the GIS accomplished through gathering and analyzing information in three-dimensional form with the possibility of layer-viewing and post-processing results constructions. The model is based on the time preceding the start of the eruption of the mud volcano and shows the geological situation, anticipating the subsequent eruption. Unfortunately, the available information on the geophysical profiles makes it impossible to determine accurately the values of geodynamic stresses. As a result, the constructed model is a static picture of the main geological structures in the territory under consideration, but their very position in space, as well as relative to each other makes it possible to tell much about the causes activation of mud volcanic activity and the dynamics of its flow.

Specification of the information gathered can provide formation of the following list of GIS information layers:

- Layers of the location of the main. There are six reflecting horizons detected for this territory. Given the characteristic lithology of the sediments, forming a section of the investigated area, we can say that most clearly reflects the border creates alternating clay and sand layers. However, the absence in our disposal the results of parametric well logging operations and the values of the speed characteristics of each layer does not allow to recalculate the model of the time sections to depth. Nevertheless, the shape and position of the considered horizons suggest the processes occurring here mud volcanism.
- Layers of the location of submarine channels. They show the position and shape of the channels for mud volcanic material to rise to the surface of the earth. In the territory under consideration, as a result of the interpretation of seismic profiles, we have identified two of the most powerful channels. They stretch across all considered layers reflecting horizons and involve areas of their greatest distortion.
- Layers of the location of faults. Within the territory under consideration there are several major faults which are sublatitudinal as well as submeridianal. System submeridianal located faults, extends from located on the north bank of the

volcanic edifices of the Java Sea. The Series of sublatitudinal faults, apparently appears with changes, occurring in rocks as a result of compression in the direction from south to north. This system of faults is different in that has a mirror inclined position shift.

The design of the GIS itself begins with the selection of spatial frames and borders modeling. Since all the constructions were carried out for the area bounded by coordinates of longitude 112 ° 37 'to 112 ° 48' east longitude and the latitude of 7 ° 36 'to 7 ° 27' south latitude.Thus, the size of the simulated area of 20 kilometers from east to west and 16 kilometers from south to north.

The method of constructing information layers consisted of a series of successive actions. Thus, the first phase was carried out on the territory of the interpretation of seismic profiles. They stood out most clearly defined position reflecting horizons, faults, as well as the position of channels proceeds mud volcanic material to the surface of the earth.

Each reflector was formed by a layer of points with spatial gridding and temporal characteristics of the depth of its occurrence. Verification of the results the temporal characteristics of the depth of the reflecting horizons was conducted by the intersections of profiles. At these points the depth of the horizon on the two profiles should be the same, the difference is in the position of the reflecting boundary indicates the presence of errors in the values of one of the profiles and needs further verification by the neighboring profiles. Result of this work was the formation of tables of values of the temporal characteristics of occurrence of the reflecting horizons.

The next stage of information processing on the horizon was an interpolation within a given area of work. Interpolation was carried out by plots (area) with a choice of the size of the unit 100 * 100 meters. The choice of this method of interpolation was nonrandom. The fact that the original network determine the depth of the reflecting horizons were not uniform. Such a network was the result of the processing system profiles, which, although located on a certain regularity, but does not cover some parts of the modeled area. Thus, to obtain a complete picture of the interpolation was proposed by this method. The result was the construction of the interpolation maps of the spatial position of each reflector.
In addition to reflecting horizons in the interpretation of seismic profiles have been identified the location of submarine channels on which comes to the surface mud volcanic material. These structures are well traced on seismic lines as a rather broad, sometimes up to 1 km across the zone of loss of correlation of the seismic signal.Within the territory under study revealed two main channels. At the top of one of them has a modern mud volcano "Lucy". Determination of the channels was carried out as to the interpretation of seismic profiles and maps, reflecting on the

analysis horizon. Situation horizons in close proximity to the channel due to the sharp change in their shape.

The same layers were formed with the position of faults. Separate layers were formed displaying vertically arranged faults, and faults with an inclined position, the complexity of their situation in a mass of rocks depicted in separate layers. Identification of faults was accomplished by way of interpretation of seismic profiles. Faults are precisely defined as interrupting the continuity of the reflecting horizons. The same position of faults is associated with the provision of submarine channels.

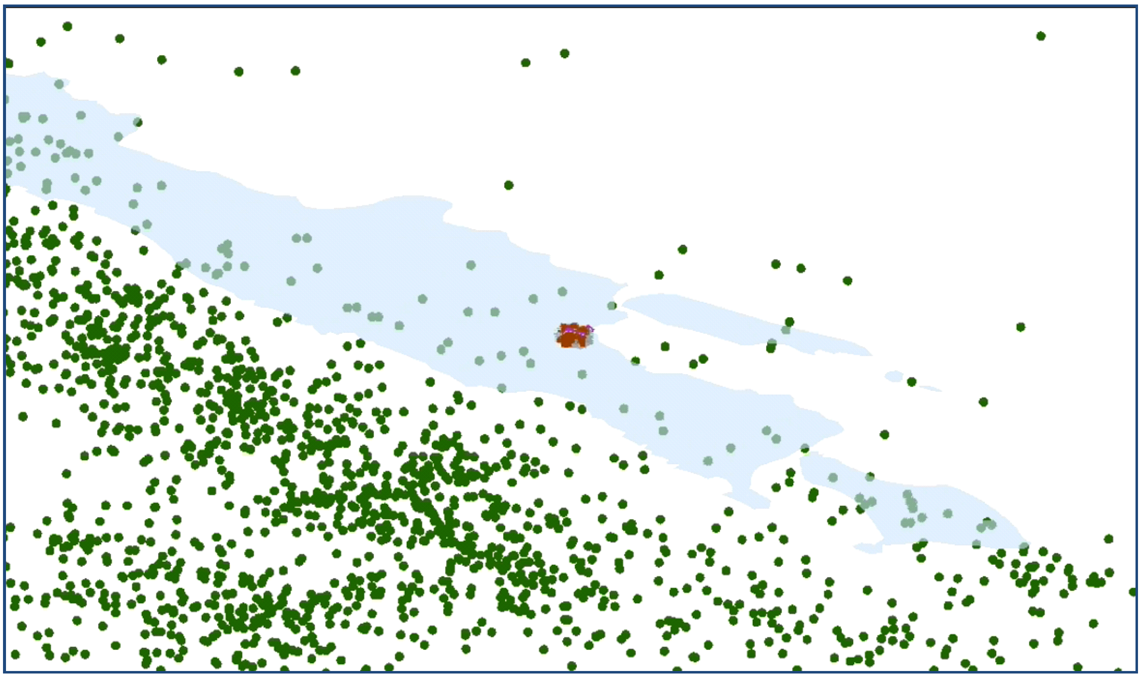
In addition, the geo-information system is complemented by a set of layers which show the hydrographic network of the area and physical-geographical features, the position of seismic profiles and so on.

The operation and maintenance of GIS was built based on the fact that the entire set of thematic layers of information is gathered together in one folder and saved as one set. Due to the fact that the GIS, on the condition of the client, is visualized in three-dimensional form, each layer has been assigned a unique and high-contrast color scale so that all information was available for perusal, and layers do not overlap. The established GIS makes it possible to disect a number of layers, focusing attention on the more interesting details. Line open GIS allows the future complementation of any interesting information, which can then be used to make new information layers.

Analysis of «LUSI».

Any analysis of a geographic information system for LUSI must be correlated with the characteristics of the geological structure of the surrounding territory of East Java. The fact is that the area under consideration, the island of Java, is an area where it is now understood that a number of active geological processes are taking place. The mere appearance of the island of Java involved a global process exploits of plates referred to as subduction.

Thus, Java is within the Sunda subduction zone where the oceanic plate is moving under the Indian Ocean region includes Indochina and the island of Sumatra, Java, Borneo, and others. That is, the island itself is located on the raised wing of a global geological structure. Moreover, the movement of plates is still ongoing, with recorded speeds of movement of up to 10 millimeters per year. The result of such active tectonic processes is the occurrence of strong and frequent earthquakes.



Green points indicating earthquake events within Jawa island.

In fact, almost all the geological processes taking place are, whether superficial or deep, are directly or indirectly related to and the result from the tectonic environment.

Thus, a chain of active volcanoes of sufficiently great height, located along the southern coast of the island, is the result of the global tectonic processes associated with the remelting of the descending oceanic plate and show up the faults of the system formed by magmatic material erupting to the surface. The processes of modern and ancient sediment as related to the general tectonic structure, however, is more indirect in nature. The deed zone plates and a strip of active volcanism was typically formed by the deflection of a large accumulation of sedimentary material of different genesis. In this region the deflection occupies the northern waters of Java and the Java Sea. Here, in the Quaternary strata, there is an accumulated capacity of up to 3,5 - 4,5 kilometers. So within the north-eastern tip of Java island the Quaternary sedimentary strata were formed, representing the alternation of clay and sand deposits with capacity of 3 km. [12] Such a lithological uniformity of the cut is not just accidental - it is caused by periodic sea flooding of the territory under consideration in the past and subsequently raised to the surface. These fluctuations are related both to eustatic changes in the level of the ocean, and the stages of the increased tectonic activity. Moreover, the periodic activation of magmatic activity in the vicinity of the territory under consideration resulted in the geological history of the repeated appearance of a section of volcanic ash that mixed with sea water and bottom sediments formed layers of clay rocks.

The presence near the active tectonic zone, as well as the extensive development of volcanic formations, could not but affect the conditions of occurrence of sedimentary cover. First, the fractures formed in connection with a break at the surface of magmatic rocks, stretched far beyond the volcanic ridge, breaking the rocks of sedimentary cover. As a rule, these breaks stretch from south to north, the mirrors are positioned vertically shift to shift and rocks of sedimentary cover are small. Secondly, the constant current contraction in the direction from south to north, directly related to the subduction of the two plates causes significant stress in all the rocks formed. As a result, the sedimentary rocks of the upper part of the section, have the lowest strength characteristics, subject to development as a disjunctive plicated and violations. Plicated violations are expressed in the form of folding. Folding in the rocks of the Quaternary in this region is manifest in the form of weakly expressed brachymorphic, sometimes isometric anticlines and synclines. Faults dislocations caused by the compression led to the formation of a series of thrusts, where the north wing tipped to the south. Angle thrust surface varies from 80 ° to 45 °.

As a result, the geological environment formed in the north-east of Java, is characterized by high velosity of modern sedimentation that existed there for the whole of the Quaternary period and lead to the accumulation of large strata of sand and clay composition. All young sediments stay in active tectonic zone, which leads to extrymely high pressure, especially in the lower layers. If you just take into account the theory of the excess of pressure in the clay strata associated with recrystallized smectite and release of water, it should be recognized that the pressure increases many times.

Thus, the area under consideration has all the necessary geological conditions for the development of mud volcanism. In reality, this fact is confirmed - within the north-east of Java does indeed exist a large number of seats manifestations of mud volcanism. However, the main practical issue is the question of the role of drilling a borehole in the BJP-1 in the activation of mud volcanic activity and the formation of «LUSI». At the moment the construction of the geographic information system is designed to answer questions concerning the geological structure of the area immediately adjacent to the «LUSI» and identification of natural geological prerequisites for the development of mud volcanism in the area.

Creation of the GIS has allowed to establish the existence of at least two underwater channels, which carry to the surface mud volcanic material. Form reflecting horizons suggests that these rocks have undergone considerable distortion. For example, the three lower horizons have pronounced anticlinal folds, locks which are confined to the provision of submarine channels. Such a configuration of layers and the position of channels suggests that it is here that the dome formed in the extrusion of clay strata and from here comes the material for subsequent eruptions on the surface. Above the underlying layers in the region of the channels also have disrupted bedding. This is reflected in the formation of a series of small folds in the background of general subsidence of the channel. Apparently, the faults were the main mode of transport to the surface of the earth.

Thus, through conducting research and modeling of the geological environment in the mud volcano «LUSI, one can see a number of key findings:

1. The geological structure of the north-eastern part of the island of Java has all the prerequisites for the formation of mud volcanoes.
2. Mud volcano «LUSI» is the continuation of a natural underwater channel, traced on seismic sections and expressed in the position of the reflecting horizons.

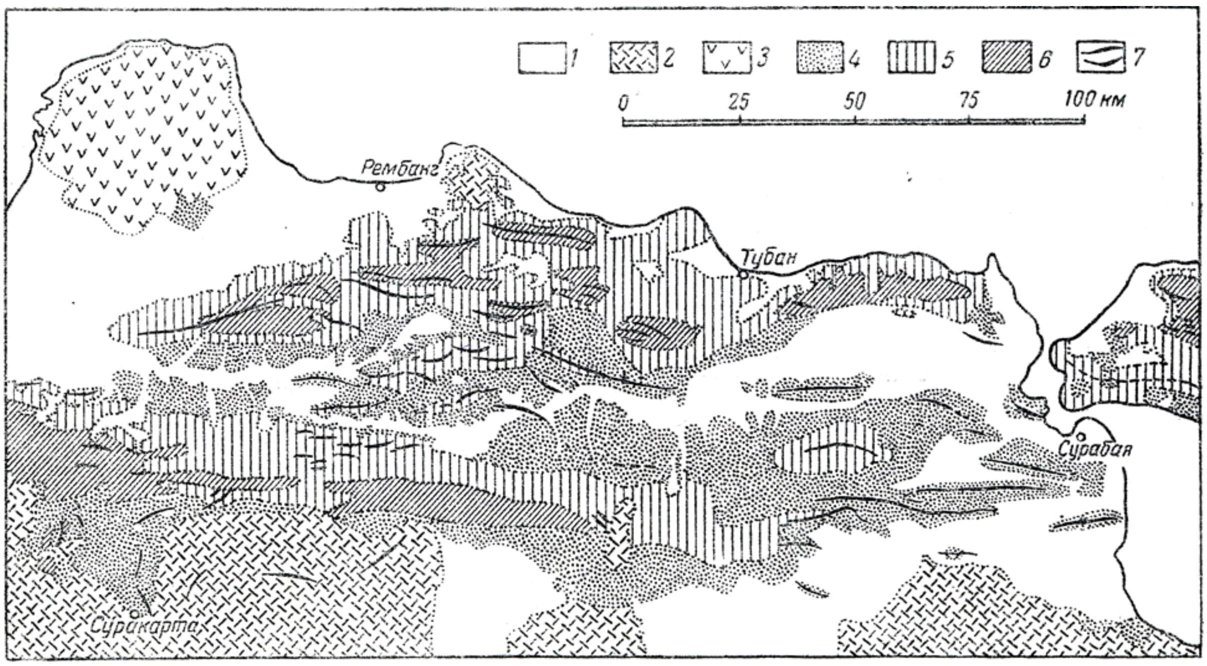
3. Analysis of the upper part of the well section BJP-1 shows the presence of a large number of relatively thin layers of clay material, which would be the result of previous mud volcanic eruptions occurred on the detected channels. That is, the current intensification of mud volcanic activity, apparently, is not the first or only instance in which these events occurred in the past in that region.

4. It can be concluded as Indisputable fact that in the case of the mud volcano «LUSI» the mud channel existed long before the drilling of wells. In fact there are 2 main channels with 3 potential eruption points as can be observed from the 3D view of the sub terrain.

Analysis of oil prospectives

On Java the petroliferous zone is stretched along the eastern part of the northern coast, within Neogene geosincline. Productive oil fields are existent between Rembangon and Surabaya.

In oil fields powerful thickness Neogene and Paleogene rocks are developed, their general thickness reaching 7000 m. In the Neogene basis the retinue high thickness marls lies down. Oolitic limestones, retinue alternating marls, limestones and sandstones lie above in places which contain oil. The thickness varies from 900 to 1500 m. On it rests a retinue of greenish high Miocene marls, with prolayers of the sandstones containing glauconite. In this retinue some layers of petroliferous sand are noted. Their thickness is 350-900 m, and in some places reaches 2000 m. That layer is the main petroliferous horizon around Surabaya. On it bluish-grey clay with sea fauna and above – rest volcanic sediments of lower Pleistocene.



Schematic geological map of oil fields in Surabaya area

1. Alluvial deposits.
2. Quaternary volcanic rocks.
3. Leicityc volcanic rocks.
4. Pleistocene deposits.
5. Pliocene deposits.
6. Miocene deposits.
7. Axes of anticlinal folds.

The tectonic structure of the eastern part of the island of Java leads to the formation of considerable prodeleting and an amplitude of folded formations. Industrial fields of oil hydrocarbons are dated for latitudial anticlines. Within analyzed territory such anticlinal structures are revealed to some degree. However, positive prospects of structures with the presence of oil hydrocarbons is determined not only by shape, but also by a number of of other characteristics such as:

• Characteristics of collector and tyre cover – it means that the underlaying would be capable to filter and accumulate within itself oil hydrocarbons – the collector, and layer above should be water resistant for prevention of the dispersement of the oil – a tyre cover.

• Positions of the basic tectonic faults. Presence of the large tectonic faults especially leading to considerable amplitudes of shift, can create a structure of accumulation of oil hydrocarbons. However, on the other hand, the break zone can be the drainage area of oil hydrocarbons from already generated and filled structure.

• The deposits Petrosaturation – means that even if all necessary conditions will be met and will be generated approaching for accumulation of oil in structure, the oil hydrocarbons must come and file the perspective structures.

This is not the complete list of geological characteristics for the prospects of finding oil- filled structures. A more detailed and exact definition of the possible presence oil in a structure can be executed as a result of geological and geophysical complexes including seismoprofiling, electrophysics and geochemical researches. At present, proceeding from the available data allows us to make a number of conclusions only about preliminary prospects for hydrocarbons in those or other structures located in the area of our three-dimensional LUSI mud volcano model.

However, one of the basic problems in the interpretation of the available data can be that the chosen anticlinal structures can be generated by mud. So, for example, for the area of our three-dimensional model, some anticlinal structures for deeply layers can be interpetated as mud diapires. Most likely, some of them are a source of receipt of a mud to the earth's surface via channels.

The position of prospective structures within the modeled territory.

Thus, within the studied territory, some structures which can be analysed from the point of view of their prospects for the possible accumulation of oil hydrocarbons have been revealed. The analysis of their prospectiveness is based on interpretation of the available information on a graphic representation of seismic profiles and includes the description above the stated characteristics.

So, the structure designated on illustration №1 is located in northern part of considered territory. It is rather small and its area reaches 1,9 km^2, and has an extended shape. The structure is located in the raised wing and limited from the east by a fault. Most likely the fault represented is like a limiting element and creates an anticline for possible accumulation of hydrocarbons. On seismic profiles the structure is presented in high resolution reflexions from a prospective tyre cover. Under type cover located collector deposits are characterised by low values of reflecting ability. To our regret, based on available seismic profiles, it is impossible to speak with a high degree of reliability about litology of a tyre cover and a collector, however, by analogy of close located wells it is reasonable to assume that the tyre cover is presented by Pleistocene and Pliocene clays, and the collector is presented by Miocene sands and limestones.

The structure №2 is located in a northwest part of considered territory. It is slightly extended in a latitudinal direction and the area is 3,16 km^2. The structure is dated to a large latitudinal fault limiting it from the south. Within the considered territory, the latitudinal faults are the general tectonic elements, and its direction is a realization of the basic tectonic movements. Thus, structure №2 is located within the lifted and pulled wing and that raises its prospects for discovery of oil. However, the structure is crossed by one more fault which can lead to a drainage of oil hydrocarbons in overlying layers.

Structure №3 is located in the central part of the studied area and occupies an area of 8,75 km^2. The structure's position is defined by the intersecting of two large faults. The latitudinal fault is one of large faults which crosses the entire area from the east to the west. Longitudinal faults divide the territory into a number of blocks. Thus, structure №3 is located on the block limited by several large faults. This structure is a regional part of a larger anticlinal structure located to the south. On the diagram it is shown under №5, however this structure represents the beginning of the mud channel crossing all overlying layers and which transmits mud volcano material to the surface. Finally, structure №3 can be considered as positive enough in terms of prospects for discovery of oil, although the proximity to the existing mud channel raises cause for concern.

Structure №4 occupies a southeast part of the territory and is the largest, occupying an area of 18,35 km^2. Most likely, it is part of a larger anticlinal formation which is stretched throughout the modeled area. The structure represents part of a dome, with some longitudinal faults crossing the structure in its highest part. The form, the sizes and amplitude of the structure and position of the faults allows us to assume that there is a possible mud diapire rising from depths to the surface. However quality of the image on seismic profiles does not allow to make unequivocal conclusions. Nevertheless, from the point of view of exploring for oil hydrocarbons that structure can be considered as a positive sign.

Two more structures- - numbers 5 and 6-- represent mud dapires. Mud channels are traced from those structures to the surface. They are located in areas with the highest number of faults. Most likely, these broken zones are the location of mud channel formation. Formation of the mud channel and the rising to the surface of fragments of underlaying horizons allow us to make conclusions about the lithology of deep layers, and to confirm the oil existing in collectors based upon the quantity of oil hydrocarbons in the mud.

Thus, the studied area certainly has positive prospects for discovery of oil. The greatest interest from our point of view, lies in the northwest and southeast parts of territory or area of №1, 2 and 4 structures. The area of structure №3 raises considerable fear related to the close proximity to the system of mud channels.

These conclusions can be used as the basis for future planning of more detailed and specialized studies.

References:

1. Antipov AA Structure tectonosphere Sunda subduction zone on the basis of geophysical data. Abstract of dissertation for Ph.D. degree in geology and mineralogy. M. 2006.
2. Antipov AA, Gaynanov AG, Gilod DA, Bulychev AA Geophysical Research tectonosphere Indonesian transition zone. Russia Geophysical Journal, NN 43 - 44, St. Petersburg: FGU NPP Exploration, 2006, pp. 40 - 44.
3. Bulgakov BS, Garkusha JH, Seredinin ES, Gaevenko AY Toolkit geographic information systems (manual). Kiev, GDI "WB". 2000.

4. Van Bemmelen RV Geology of Indonesia. M.: IL. 1957. 394 pp.

5. Interim requirements for databases of primary and derived data on the geological GSR - 200 (the content and selection criteria). Ed.Starchenko VV, Bourdais AI VSEGEI. St. Petersburg, 1998.

6. Limonov AF Mud volcanoes. / / Soros Educational Journal, Volume 8, № 1, 2004, p. 63-69

7. Reporting requirements in the LDCs and GBTSGI digital models of sheets of the State geological map of Russia in scale 1:200 000 of the second edition. Ed. Davidan GI, Moskalenko Z.D and other St. Petersburg. GlavNIVTs. 1999.

8. Kholodov VN Mud volcanoes: patterns of distribution and genesis / / Lithology and Mineral Resources, 2002, N 3, s.227-241; N 4, s.339-358.

9. Shnyukov EF, Gnatenko GI, Nesterovsky VA, Gnatenko OV Mud volcanism of the Kerch-Taman region. Kiev: Nauk. Dumka, 1992.200.

10. Shnyukov EF, Naumenko, PI, Lebedev YS etc. Mud volcanism and ore formation. Kiev, 1971, 329 pp.

11. Yakubov AA, Alizadeh AA, Zeynalov MM Mud volcanoes of Azerbaijan SSR: Atlas. Baku, 1971. 257.

12. A. Mazzini, H. Svensen, G.G. Akhmanov, G. Aloisi, S. Planke, A. Malthe-Sørenssen, B. Istadi Triggering and dynamic evolution of the LUSI mud volcano, Indonesia / / Earth and Planetary Science Letters. 261. 2007. P 375-388.