LUSI Research Summary Report

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Russian Institute of Geological Studies

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« OOO RINeftGaz »

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Introduction

The LUSI research is the study of the sudden eruption of 100 °C mud and gas in NE Java in Sidoarjo. This event on 29th of May 2006 was named LUSI for Lumpur-Sidoarjo. This is located along the major Watukosek strike-slip fault zone.

There have been various studies done to identify the cause of the eruptions of LUSI. Some studies focused on the events surrounding the drilling operations while others have tried to link the eruption to an earthquake that occurred 2 days before the eruption.

Almost all studies till now only have not actually gone into the eruption zone and tried to "see" inside the zone. There may be several reasons not to have done that. However, a look into the subsurface will ultimately proof or disprove the various theories that have been floating around.

Firstly those who consider the drilling activity as the cause of eruption are assuming that there is a benign mud layer that sits quietly under the LUSI and that the drilling activity created an opening into that channel for the mud to escape and thus cause the disaster. However this theory has not been accepted by other scientist. A 3D seismic view and tracing of the mud formations under the LUSI zone will provide a conclusive answer to the question.

Secondly, some studies have also falsely indicated that mud volcanoes normally last a few days, whereas the LUSI eruption surprisingly continued and escalated. This study will provide data that will clarify characteristics of mud volcanoes around the world. For example there are many giant mud volcanoes which are 400-450 meters in height and some have craters 1000m^2. Emissions have also been about 2400 million m^3.

Historical geological information shows that such mud volcanoes are formed by transformation of smectite into illites which release water which is estimated at 17 to 20 Kg per cubic meter. These are in some ways similar to Oil & Gas formation which is in line with the fact that locations of mud volcanoes are also usually found near repository of Oil and Gas. Such water formation at LUSI would explain the lack of magmatic fluid as observed by fluid geochemistry even though LUSI is located close to the volcanic arc.

The objective of this LUSI Research and the development of 3D GIS are to construct the sub surface with information related to mud structures and enable viewing it.

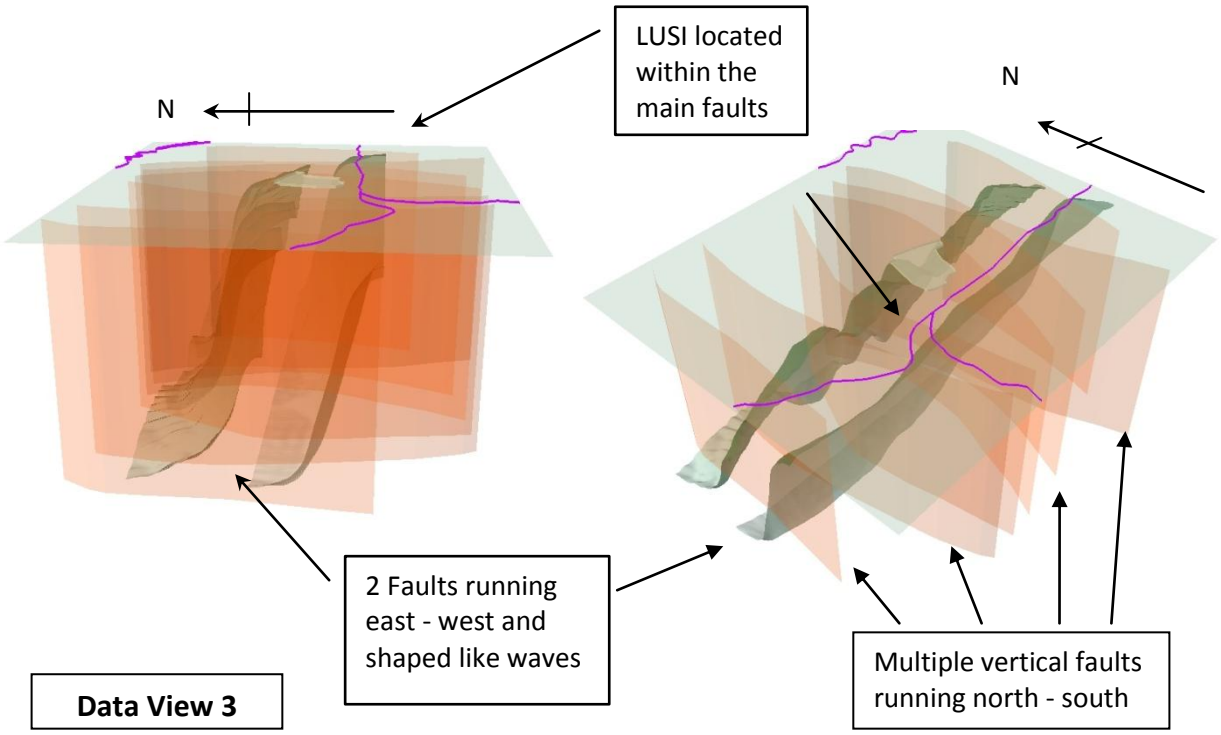
To achieve the objective our LUSI Research Team needed seismic profiles. Thus seismic profiles were consolidated from various agencies and those that were available over general publications, such as "*Triggering and dynamic evolution of the LUSI mud volcano, Indonesia*" by A. Mazzini. The consolidated seismic profiles were 2D images as digital seismic data were not available. The data consolidated, allowed for development of sub surface view around LUSI within a 20 X 16 km square zone.

The seismic profiles were then reconfigured using high speed data processing systems in Odessa National University with support of Ukrainian Ministry of Environment using specialized computer applications developed by USSR scientist with main contribution from works of Shnyukov Evgeny Fedorovich, the Geologist and Academician from Ukraine.

The sub surface 3D GIS developed had the following revealed:

1. Faults around LUSI.
2. Earthquakes epicenter information.
3. Multiple layers with mud structures detected.

The 3D GIS views of the Faults are shown below in Data View 3.

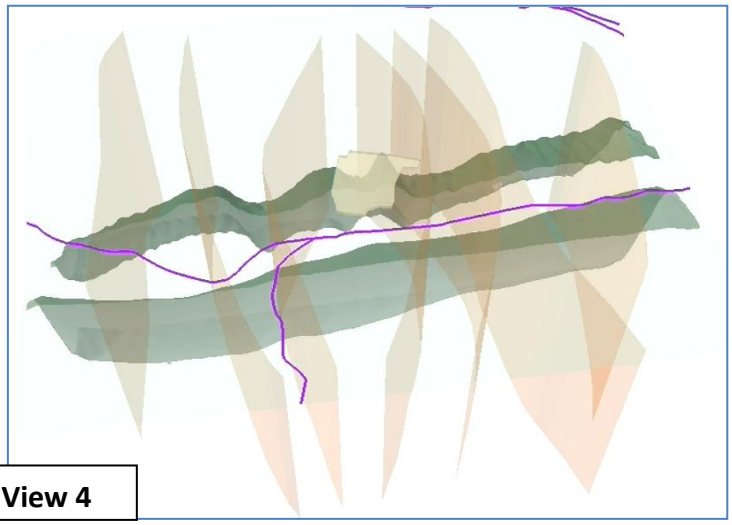


We observe multiple vertical faults in longitude running north to south. There are two wave-like faults running in latitude east to west. The LUSI mud lake position is within these faults.

The view shows very unstable zone. The zone is very likely to provide escape routes to any formation of water from mineralization as described earlier. It is likely to happen slowly over long period such as that happening in other parts of the world and also in Java Island.

Or it may consolidate to build up pressure which will explode when it overcomes over pressure and finds a route out to surface.

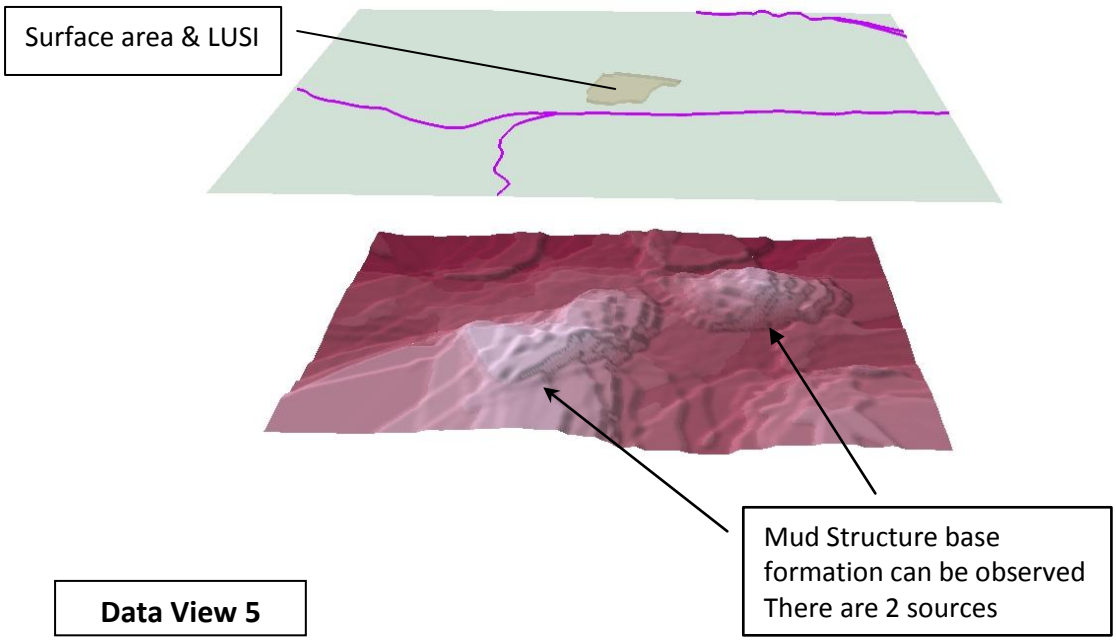
Shown below is location of LUSI viewed from top.



Data View 4

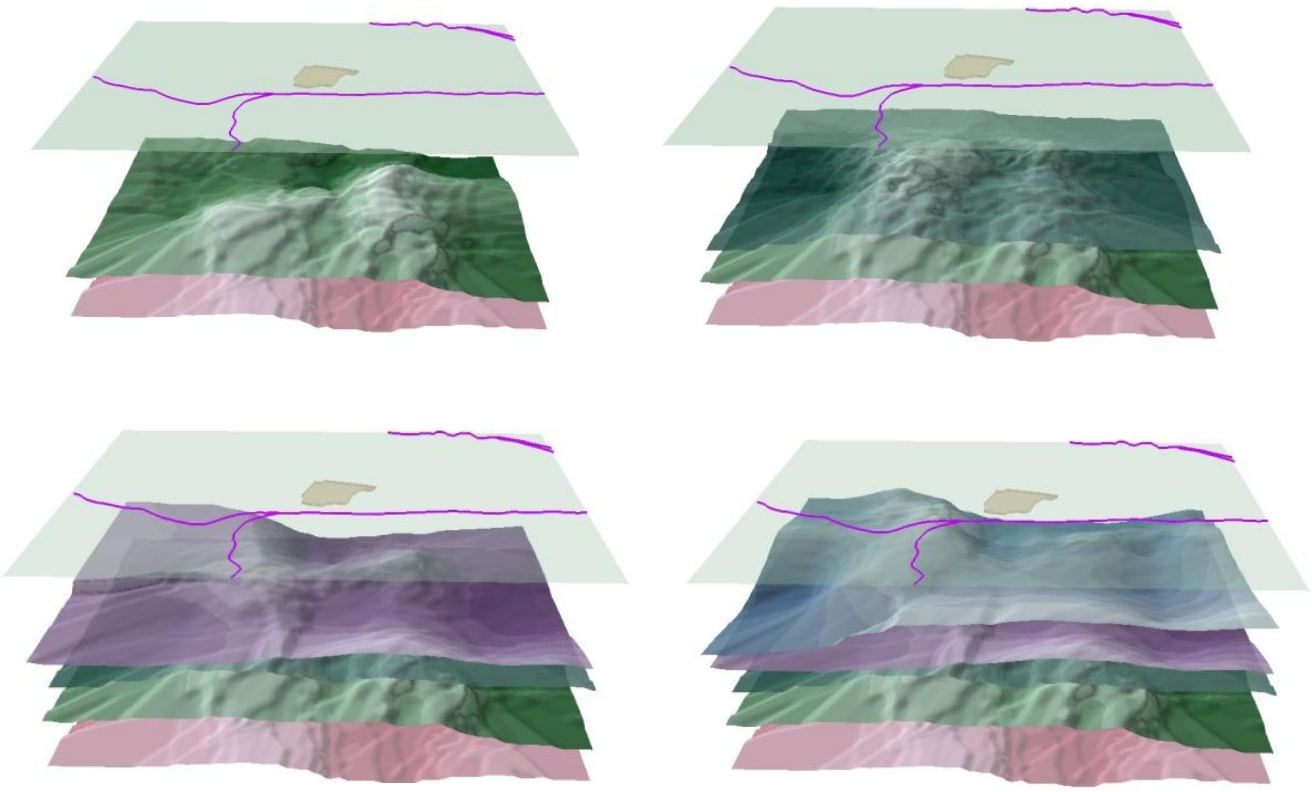
Next we processed the seismic profile images to identify and construct the mud structures. Layers were constructed between surface and up to a depth of 3000m.

The deepest layer at around 3000m shows two main mud structures.

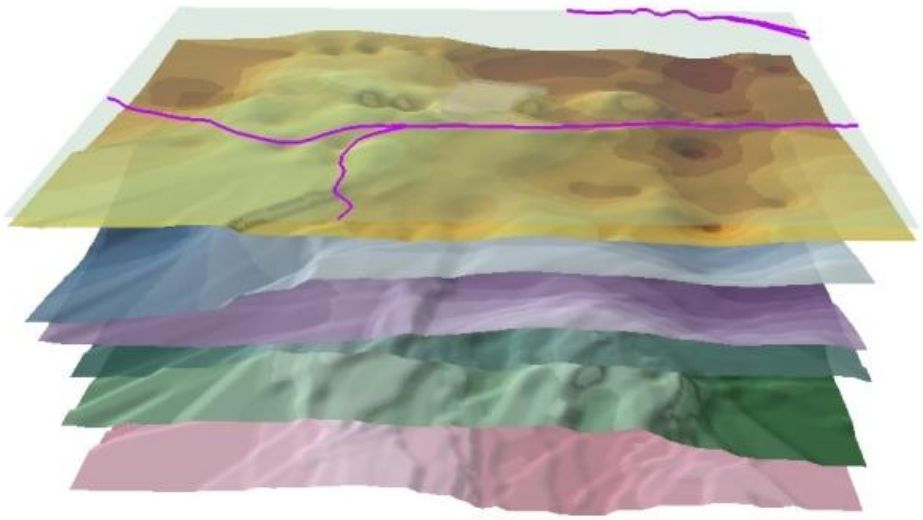


Data View 5

Further six more layers were constructed within the depth.

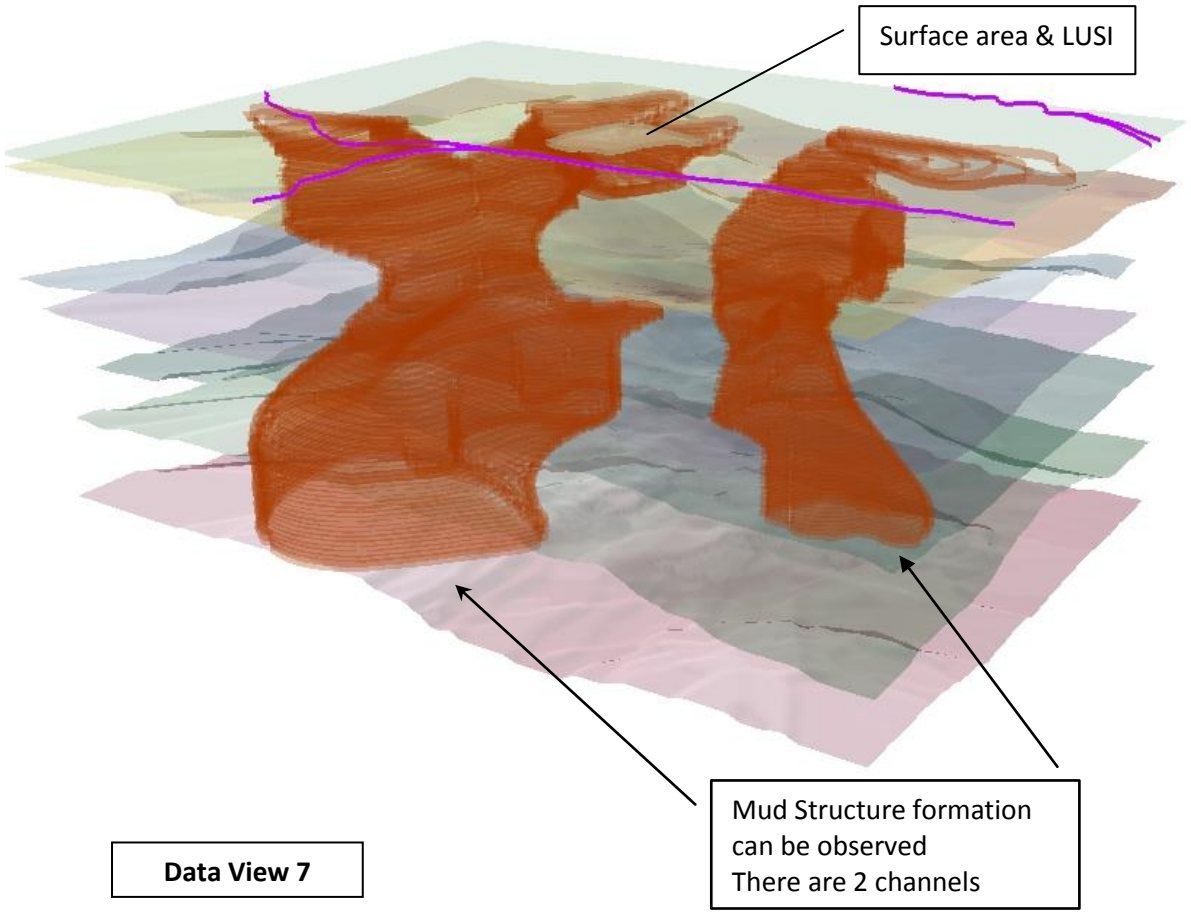


Once all six layers were constructed the layers were traced vertically using advanced data processors to produce the final 3D GIS.



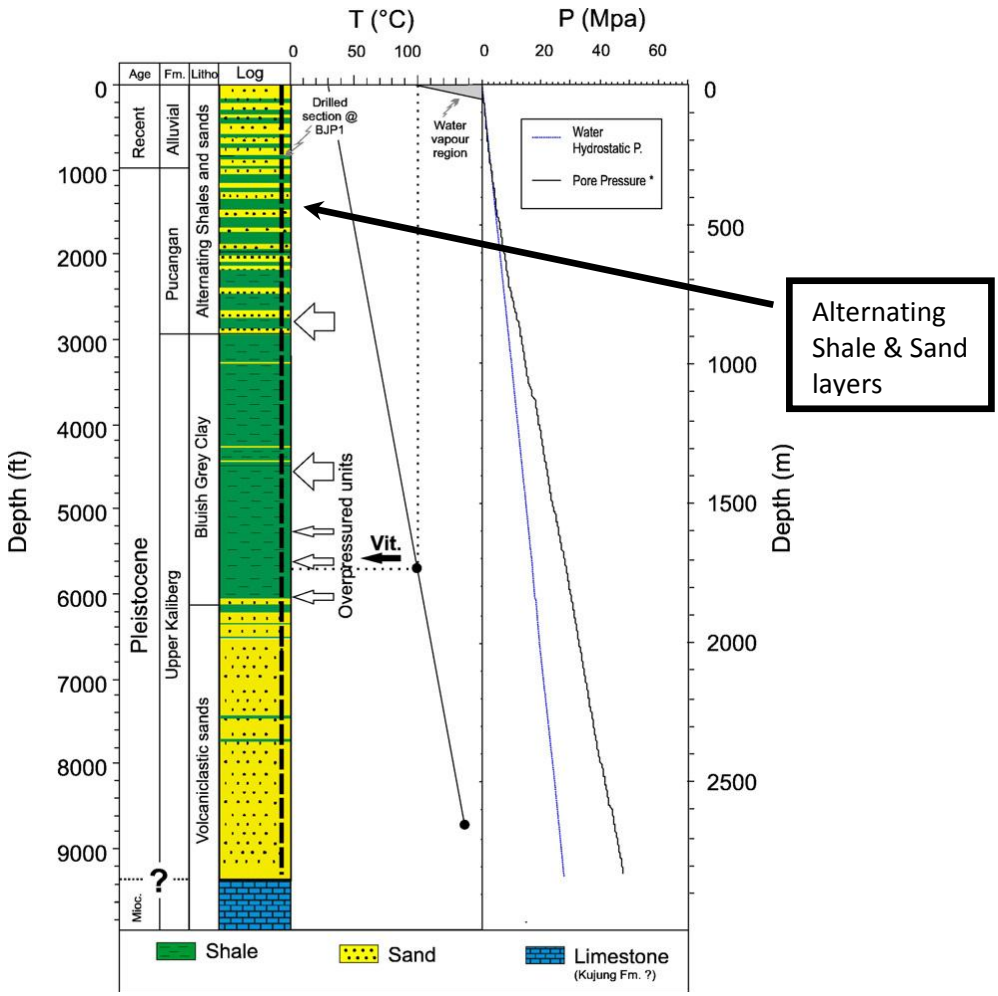
Data View 6

Based on the 3D Geo-Information System image we can see the formation of mud structure finally as follows: where the traced mud structures are shown in red color.



The merged layers clearly show a link between them and the final image clearly shows an old mud structure channel through which the new mud eruption LUSI has occurred. This is a view of sub surface in year 2005 as per the age of seismic profile used.

The 3D GIS shows that there is a huge mud structures running from deep down up to the LUSI region and also two other nearby areas. The structures existed long ago and indicate multiple eruptions over those years. This can be further observed from the statigraphic information as has been published in various articles as below.



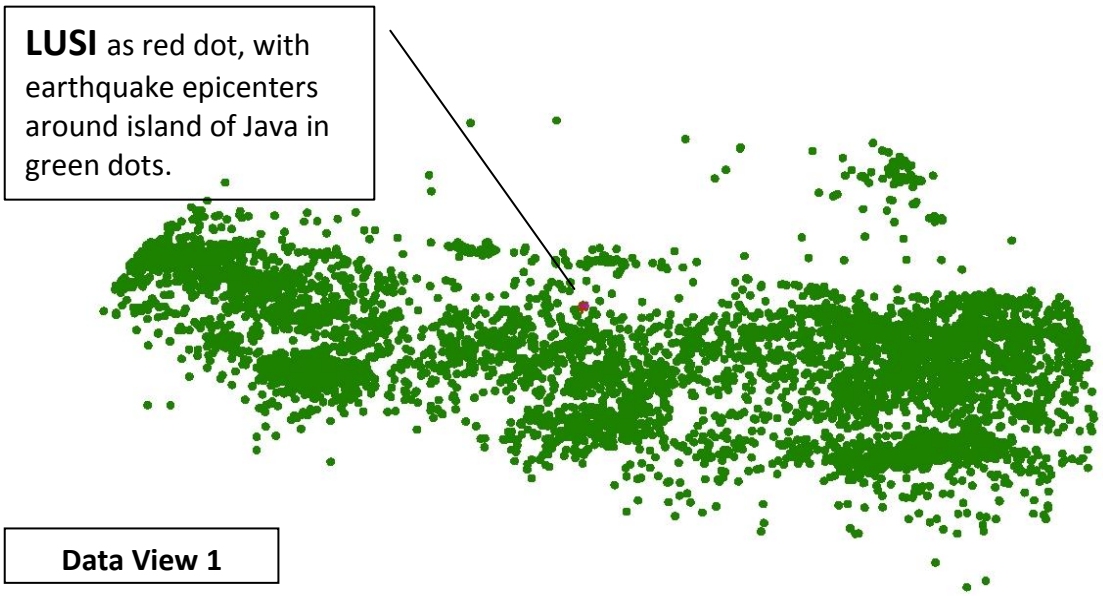
The multiple alternating shale and sand layers are indicative of the old mud eruptions estimated to be at around 100 to 150 years ago and occurred in similar intervals. The detailed grain size frequency study of samples taken at each of these intervals will reveal the age of each of the eruptions and also predict future eruptions.

Similar to waters that run along the same path of rivers that run dry, these mud structures are most likely ways in which each new eruption will occur. The fact that current mud eruption is over the same area above this mud structures and that fact that mud outflow is reducing rapidly implies that our LUSI Research conclusions are much closer to the truth. This can be further verified by Geo-Dynamic survey conducted over the area to detect movements within the sub surface using non-intrusive technologies.

This **LUSI Research Report** also provides in depth view of the zone within the LUSI regions with earthquake epicenter information.

Earthquakes around LUSI

LUSI is in the middle of a large unstable zone with history of earthquakes and also volcanic blow outs and also many mud volcanoes. All these are related.



Shnyukov Evgeny Fedorovich, the geologist and Academician from Ukraine, had done major works in this regards since 1953 to 1977 under the Institute of Geochemistry and Mineral Physics, Academy of Sciences of the Ukraine where he was the director.

During his Research dedicated to the study of iron ore of Krivoy Rog type of sedimentary iron and manganese ores, marine geology, he developed a new hydrodynamic hypothesis formation and placement of sedimentary deposits.

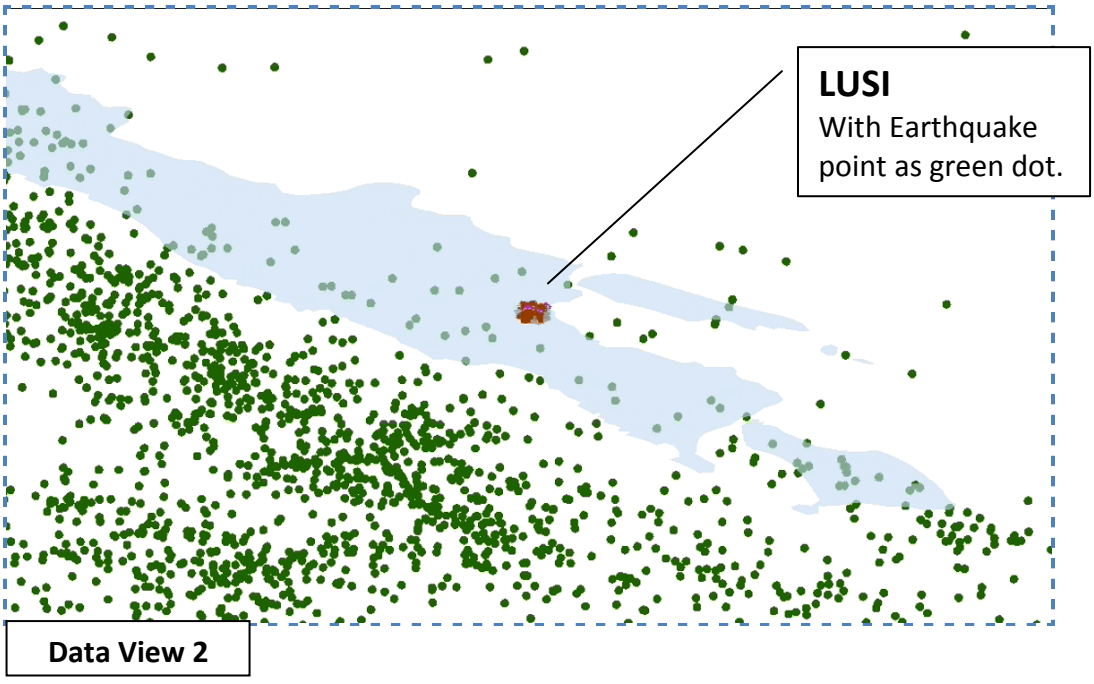
On the basis of its development and recommendations was started exploration of a new type of Kerch iron-ore deposits - deposits of mud volcanic structures. Comprehensive study of geology, lithology and mineral resources of the Azov and Black Seas and the Atlantic and Indian oceans were started on that basis.

And together with other USSR scientists developed the first scientific conclusions of mineral resources of the oceans.

This LUSI Research report is based on these works which include "Iron oxides Ukrainian Shield" (authored in 1961), "Zinc-iron ore of the Kerch basin" (1961), "Mud volcanoes and ore formation" (1971), "Geology of the Azov Sea" (co-authored , 1974).

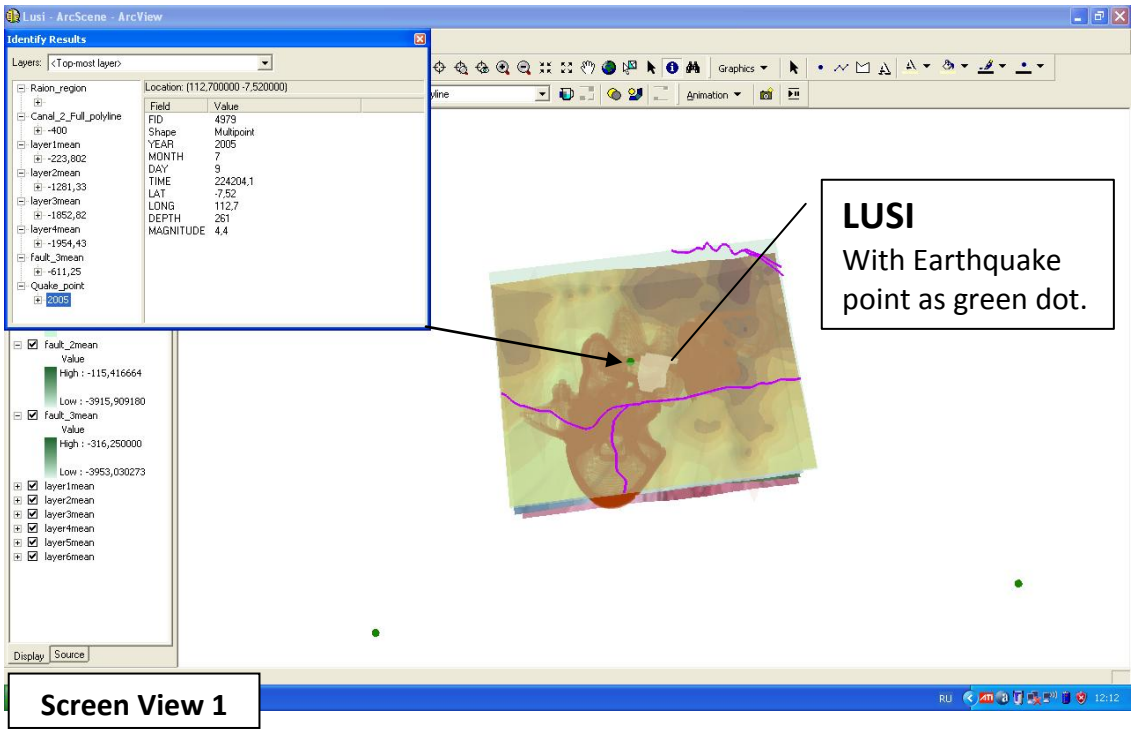
The above shows all the earthquake epicenters around island of Java within the last 10 years. You may observe the level of instability in Java.

The more closer look shows earthquake epicenters around East Java. The detailed study of earthquake points has shown that LUSI had several forceful events to accelerate the channeling of the mud formation through the existing mud structures and between the fault structures.



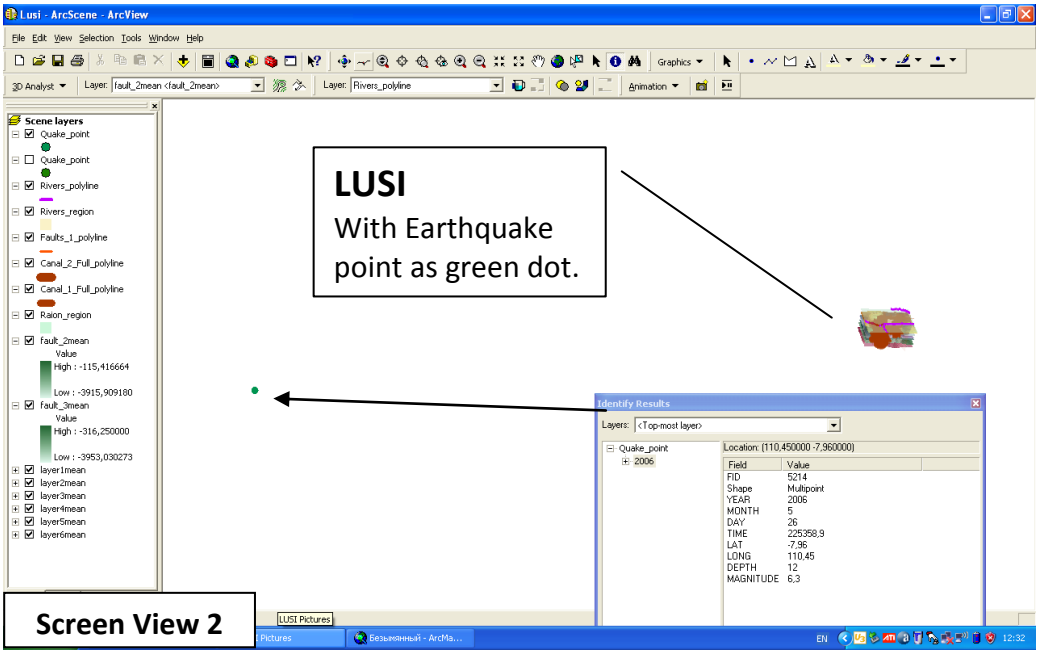
In 2005 July 9th there was an earthquake of 4.4 magnitude right below the LUSI mud eruption zone.

The screen view 1 of GIS software shows the epicenter data of an earthquake in the year 2005 July 9th with magnitude of 4.4 Richter. This is about 10 months before LUSI eruption.



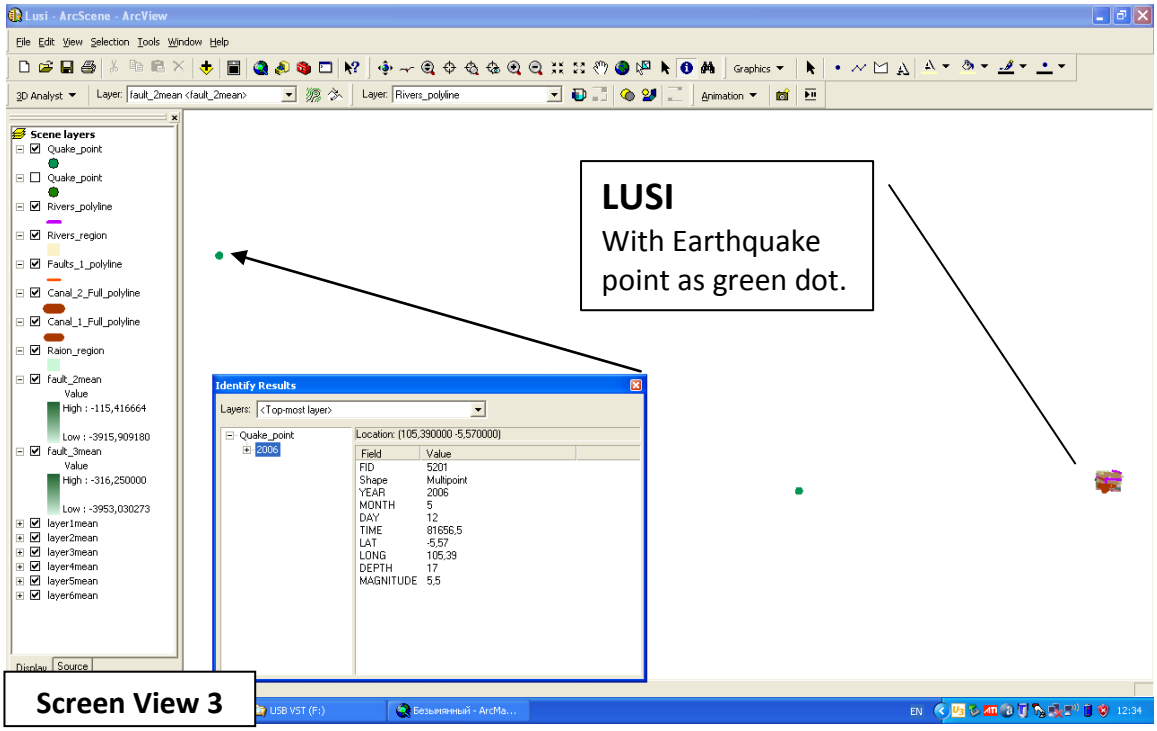
Screen View 1

The next important event is this is of course about 10 months before the actual eruption but indicates the geological nature of the location and fragility of the faults crisscrossing the region. (See the 3D view of Faults for more details of the faults).



Screen View 2

As already commonly known in May 2006, 2 days before LUSI eruption there was an earth quake of 6.3 magnitude about 185 km from LUSI locale and also another earthquake 16 days before about 450 km away with magnitude of 5.5 Richter.



Screen View 3

The earthquake exactly 1 year before the LUSI eruption would have been one of the geological events assisting the opening of the mud channels. The continuous Watukosek fault movement could be further assisting this process. And the earthquake 2 days before the eruption would be the final kick off.

By superimposing the faults data with mud channel formation we can see that the mud volcanoes have used the faults and avenues available to push its way out to wards the surface assisted by various earthquake events. It could not have been one single earthquake or drilling activity that can create such mud volcanoes and cause such eruption.

It may be arguable that geologically, the magnitude of such earthquake is not sufficient to trigger a mud volcano eruption. However it should be appreciated from all this data, that there exist

unstable faults, continuous earthquakes in and around the region and mud structures that indicate multiple previous eruptions over the same zone.

It would be very helpful to compare the LUSI Research Report 3D GIS Image [Fig 1] to the theoretical model provided in the article "*Subsidence and uplift of Sidoarjo*" by H. Z. Abidin et al. from works of Stewart and Davies (2006). It was said to be of a mud volcano from South Caspian Sea. [Fig 2]

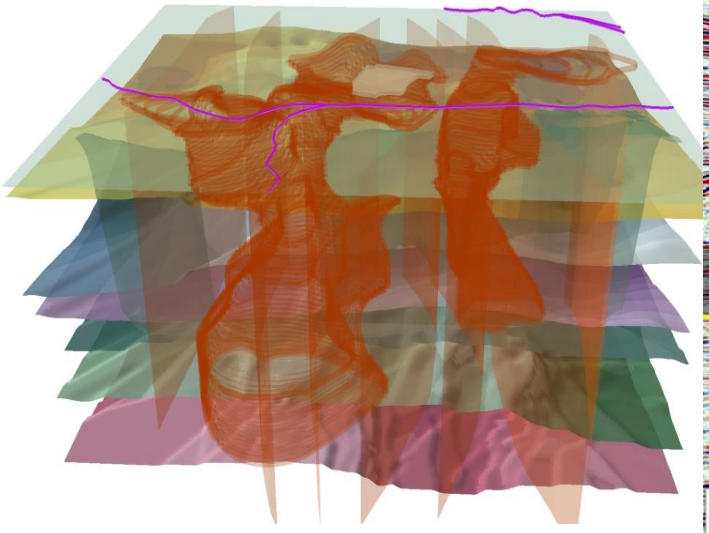


Fig 1

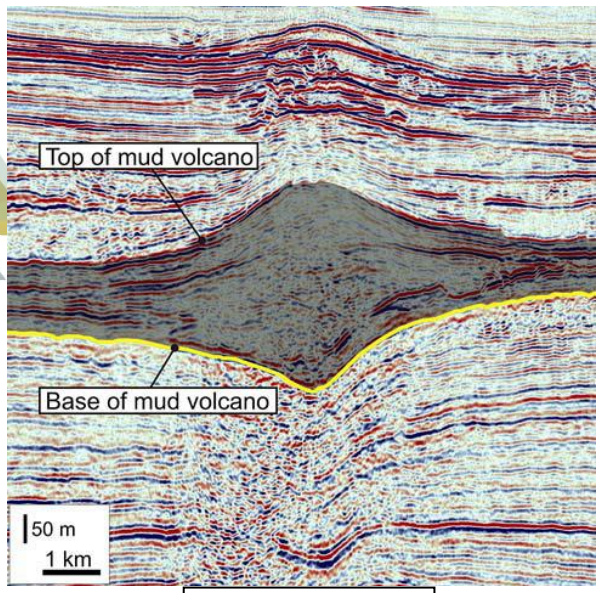


Fig 2

If the mud structure below LUSI is as in Fig. 2 then a drilling into the layer may indeed be cause of a mud volcano eruption. There is no other indication of previous eruptions. A drilling into that area will be a bad idea.

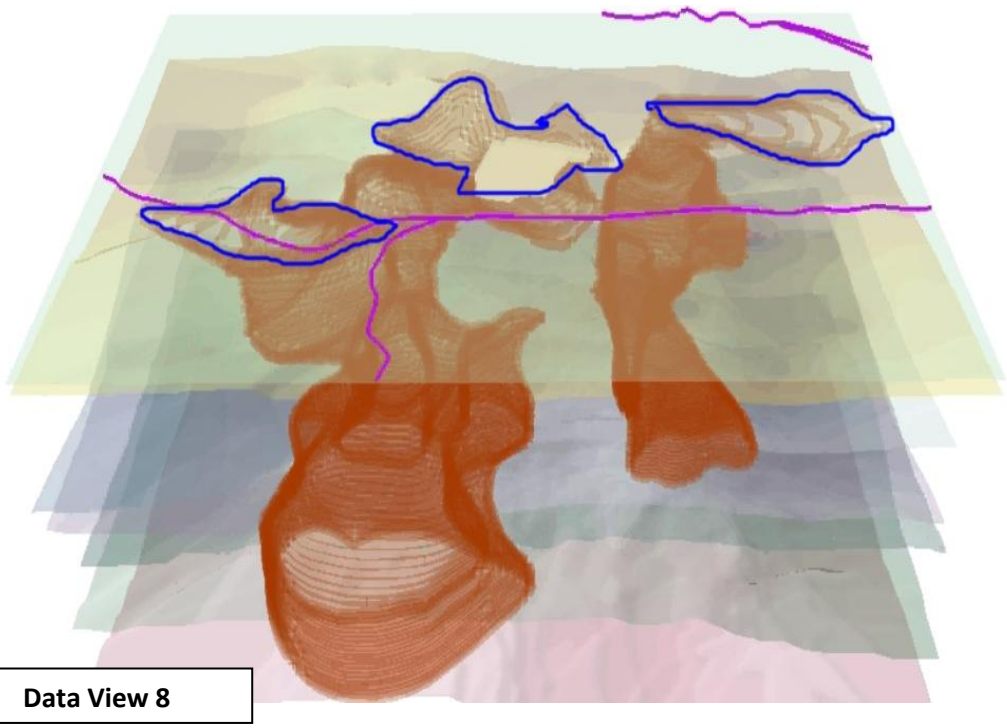
However, our LUSI Research Report has found the mud structure below LUSI actually to be as in Fig 1 which shows indication of many previous mud eruptions over many ages ago. The eruption is not triggered but is an eventuality of the mud formation escaping through already existing faults and geological events.

The countless fruitless arguments to the cause of mud eruptions are due to use of hypothesis and not real sub surface information. The reason is due to lack of an organization for detection and study of mud volcano formations.

There exist special departments which study mud formations in Russia and Ukraine other CIS countries where indications of possible mud volcano eruptions were exhibited. Indonesia should consider similar formation and allocation of resources to adopt methods which already exist in Russia and Ukraine. It should be noted that, there are plenty of indications around East Java of looming mud eruptions which are bubbling every day in various locations.

By conducting continuous sub surface monitoring using suitable technology will provide early warning of any eruptions and also prevent such complications that has happened in LUSI.

Further to LUSI event, our sub surface seismic 3D GIS data shows there are nearby areas within a 10 Km radius that shows possible signs of future mud eruptions. There is one region in the south west of LUSI while another in north east from LUSI location.



Data View 8

The 3D GIS shows conclusive evidence that, the whole region is in very high danger of further eruptions.

By wrongly assuming that the drilling caused the mud eruption the authorities are in danger of neglecting the upcoming disasters and may fail to take appropriate anticipatory actions. One serious option to consider is to evacuate the affected areas and reserve the areas as conservation zones without households. The other is to install seismic monitoring systems

Conclusion

We have concluded that based on seismic data collected years before the LUSI eruption, there already exist 2 mud channels rising towards the surface. The eruption is inevitable and there is enough reason to expect further eruptions within the region. Such mud structures are common in regions with geological features such as Sidoarjo, and are known to be commonly caused by mineralization process where smectite converts to illite releasing high volume of water forming mud volcanoes.

Constrains and Suggested future Studies

As mentioned above, the 3D model prepared is a *static* view of geological structures in the vicinity of the volcano «LUSI». It was based on results of geophysical observations made years before the eruption of mud volcanic activity. Therefore, the image of sub surface of LUSI region today may have changed quite a bit. To develop the Geo-*Dynamic* view, we should, within a selected area, use high resolution geophysical surveys to assess the current state of geological environment. To get this we need to directly conduct field geological and geophysical work as follows:

1. To assess the dynamics of the process of mud volcanism, we should systematically monitor not only the eruptions and the number of ejected material, but also the geodynamic state of the adjacent territory. This requires the installation of a monitoring network of observation points with sensors to observe natural seismic vibrations. The result of these observations should be developed to extra layers, reflecting the geodynamic state of the region eruption «LUSI». In the first place, fixing the value of pressure.

2. A detailed study of the stratigraphic section of the existing wells to determine the moments of previous eruptions of mud in time and space. Determining the exact timing of previous events can help predict the frequency of mud volcanic activity on the item under the underwater channel, as well as its duration. We would need to do X-Ray studies of samples from various depths to do more accurate mapping of seismic data.

3. In addition, a detailed stratification of reference wells, along with data on rates of passage of seismic waves in stratified sequences allow to build not only the geophysical (temporary) cut, but the geological (deep) incision.