MUD VOLCANO MONITORING AND SEISMIC EVENTS

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Abstract : Mud volcanic activity have been sometimes connected to seismicity but mud-volcanic gases and clayey waters have been poorly monitored. The lack of long-term monitoring data is due to the semi-erratic nature of mud volcanic emissions and to geological and technical constraint factors. A review of geophysical and geochemical available data has been carried out. Data confirm that mud volcanoes are confined fluids accumulations capable to work, in principle, as natural strain-meters. The absence of reliable long-term data sets hampers any definitive conclusions on the sensitivity of mud volcanoes to seismic events and evidence the need for reliable ground-based and satellite-based measuring techniques.

Key words: earthquake precursors, automatic monitoring, confined fluids, mud volcanism.

1. INTRODUCTION

Various methods have been used to explore natural fluid emissions. Geophysical and geochemical parameters have been used to describe the quantity and the chemical features of the fluids expelled from volcanoes, geysers, soil gases, cold and thermal springs, water wells, hydrocarbon wells, and so on. The experiences undertaken in many geological environments have allowed us to state that every natural fluid emission can be characterized by the description of mass flow rate, temperature and chemical composition. Repeated measurements of the flow rate, the temperature and the chemical composition have allowed for the collection of records or data sets. Sampling rate, precision and accuracy adopted in the measurement techniques have revealed unsuspected details concerning natural fluids. Their space distribution, origin and evolution have been explained and every day a large amount of data are collected and stored for exploration purposes, environmental control and other research activities.

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Mud volcano fluids are connected to deep-seated reservoirs and are not fed by surface fluids. Thus, they can work as natural strain-meters in poroelastic media (Bodvarsson, 1970) and can make a major contribution to a better understanding of seismogenesis. The idea that mud volcanoes could be sensitive to crustal deformations was first proposed by Tamrazyan (1972), who observed eruptive changes linked to moon-induced tides.

Unfortunately, among the natural fluids mud-volcanic gases and clayey waters are the least monitored.

Only a few mud volcanic waters or gases have been geochemically characterized. A review of the available geochemical data has been proposed by Martinelli and Dadomo (this book). Flow rate and temperature have often been inferred and sometimes measured. A review of the available gas-flow rate data has been proposed by Judd in this book. Liquid phase flow-rate data have been measured in only some mud volcanic areas (Brown, 1990) and reviewed by Kopf (2002). Clay dominating flow rates have been estimated in Azerbaijan and reviewed by Aliyev et al. (2002) and commented on by Panahi (this book).

There is a lack of long-term monitoring data but significant efforts have made done in developing technologies applied to monitoring mud volcanic areas by Mellors et al. (this book) and Delisle et al. (this book).

The lack of long-term automatic monitoring data is due to the semi-erratic nature of mud volcanic emissions, to the continuous morphological evolution and to the scarcity of sensors suited to extreme environments, so a significant amount of the available data have been recorded by manual sampling. To better understand the physical and chemical time-behaviour of mud volcanoes a review of the available data sets has been prepared.

2. FINDINGS FROM AVAILABLE GEOPHYSICAL DATA SETS

Many authors have for a long time attributed the flow-rate variations in the total fluid emissions of mud volcanoes to seismic activities. In particular, Guliyev and Feizullayev (1997) have reported in Fig.1 the number of seismic events per month in the period 1669-1982 in line 1, and in line 2 the

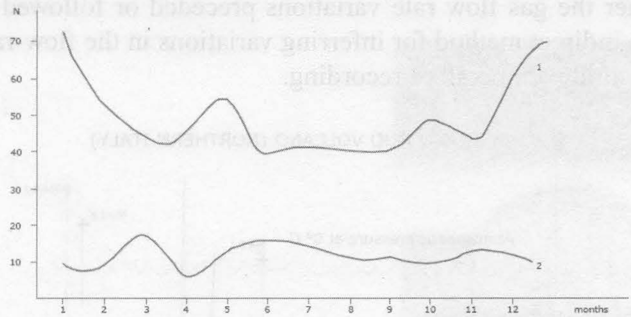

Figure 1. Number of seismic events per month registered in a selected area of Azerbaijan (line 1) and number of eruptions per month (line 2). After Guliyev and Feizullayev, 1997, modified.

monthly number of eruptions recorded in the period 1972-1987. The Authors have concluded that an increasing number of shocks is responsible for an increase in eruptive activity. Although the published graphs do not allow for definitive assessments, a variation in the eruptive activities during the year appear to be confirmed. Meteorological data have not been reported but a relationship with seismic events appears to be partially confirmed. Fig.2 was drawn by Aliyev et al., (2002) and shows that the clayey mud-flow rate varied over time in the period 1887-2001.

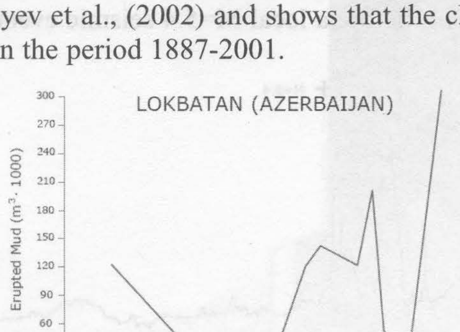

Figure 2. Variation of the erupted mud in the period 1887 – 2001 in the Lokbatan mud volcano (Aliyev et al., 2002).

The authors concluded that a strong eruptive period observed also in other mud volcanoes was triggered by strong local seismic events. Strong variations in the gaseous flow rate were detected by Caneva (1958) with an automatic recorder on the Regnano mud volcano located in Northern Italy (Fig.3). The monitoring period lasted six months and strongest variations were retrospectively attributed by Martinelli and Ferrari (1991) to an increase in the local seismic activity. The recorded data do not allow us to definitively state whether the gas flow rate variations preceded or followed the seismic activity. An indirect method for inferring variations in the flow-rate emission involves accurate temperature recording.

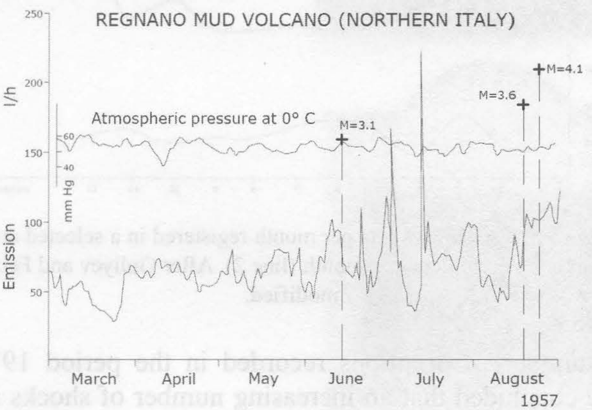

Figure 3. Methane flow-rate, atmospheric pressure and local seismic events recorded at the Regnano mud volcano, North Italy (Caneva, 1958; Martinelli and Ferrari, 1991).

Hasiotis et al.(1996) detected a sharp temperature variation in a pockmark field in the Patras Gulf before a local M=5.4 seismic event (Fig.4).

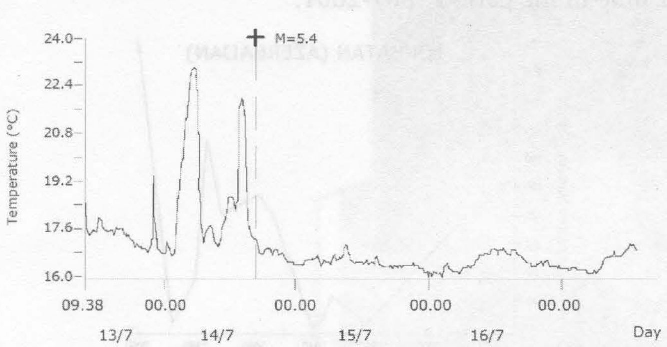

Figure 4. Temperature variation before a M=5.4 seismic event in fluids expelled from a pockmark field in the Patras Gulf, Greece (Hasiotis et al., 1996).

The pockmark cannot be strictly considered to be a mud volcanic structure but some geological features are common to both fluid emissions and suggest that similar phenomena could occur in mud volcanic areas. Foucher et al. (1992) monitored fluid temperature in accretionary wedges located in the Nankai complex. (Fig.5 and Fig.6).

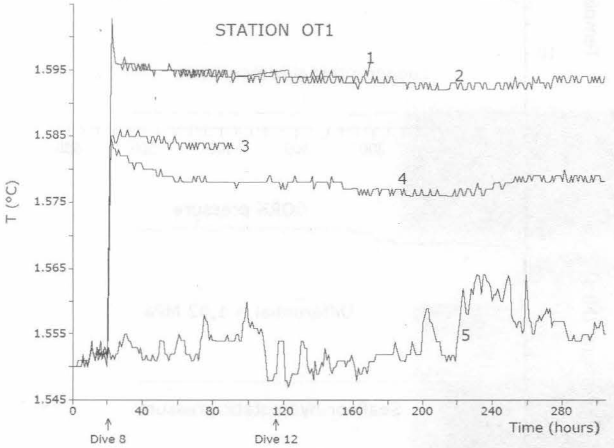

Figure 5. Graph shows temperature data collected at the Nankai accretionary complex. Record 1, 2, 3, 4 were collected at 64 cm depth (1 and 2), 44 cm depth (3) and 34 cm depth (4). Probe 5 was in sea water (Foucher et al., 1992).

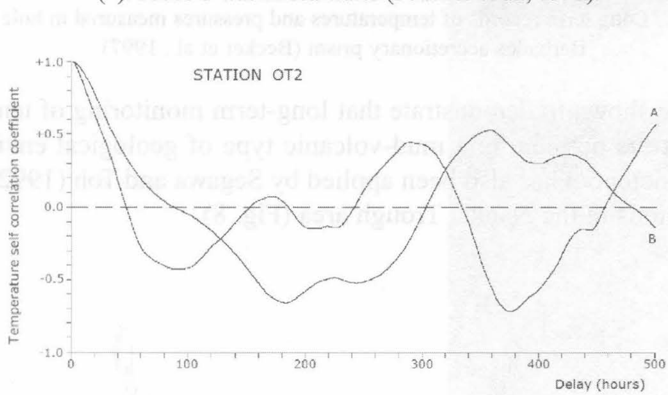

Figure 6. Variation with delay T of the self correlation coefficient for both sea water temperature (line A) and temperature at 34 cm depht in Nankai accretionary complex (line B). Sea water temperature is non periodic while sediment temperature may be affected by a periodicity of about 350 hours (Foucher et al., 1992).

Raw and processed temperature data demonstrated that fluid expulsion variations occurred for reasons independent of the sea currents. Becker et al. (1997) reached similar conclusions after monitoring pressure and temperature in the Barbados accretionary prism (Fig.7).

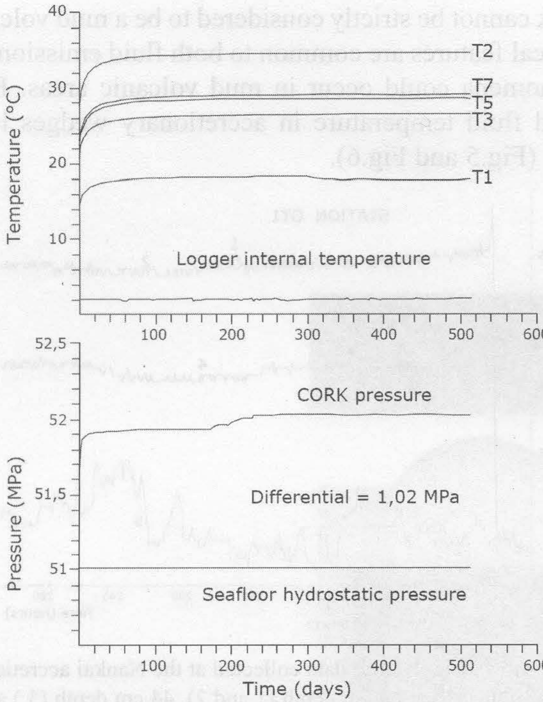

Figure 7. Long term records of temperatures and pressures measured in hole 949 C in Barbados accretionary prism (Becker et al., 1997)

Data are shown to demonstrate that long-term monitoring of temperature and pressure is possible in a mud-volcanic type of geological environment. Streaming potential has also been applied by Segawa and Toh (1992) to track fluid emissions in the Nankai Trough area (Fig. 8).

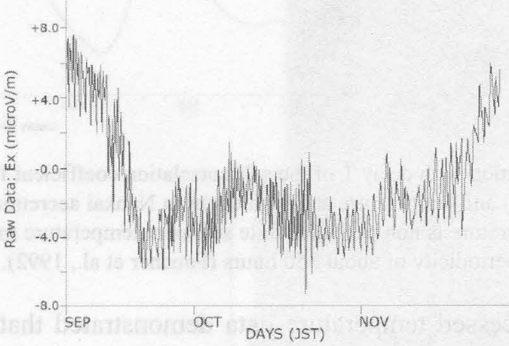

Figure 8. Electric field variations observed at the Nankai Trough in 1989 (Segawa and Toh, 1992).

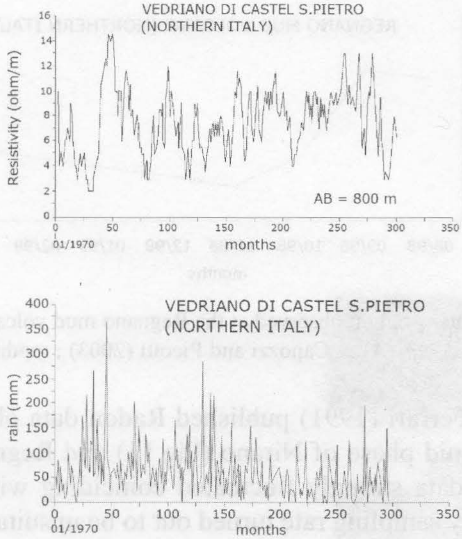

Figure 9. Resistivity values (top) and rains registered close to a small mud volcanic area in North Italy (Albarello et al., 1999).

Long-term monitoring has evidenced variations in the flow-rate not attributable to sea dynamics. A long-term monitoring program was carried out close to a small mud volcanic area of Northern Italy (Fig.9) by Parenti (1999, personal communication). Apparent resistivity was measured in the period 1970-1996 at a monthly sampling rate. Albarello et al. (1999) processed the data and reached the conclusion that strong fluctuations observed in resistivity values were mostly attributable to rain and other meteorological factors.

No further conclusions can be drawn since within a 50 km radius of. the measurement point no seismic events characterized by M> 3.5 occurred during the whole monitoring period. Furthermore, apparent resistivity measurements turned out to be unsuitable in the mud volcanic environment due to the very low electric resistivity of soils impregnated by highly conductive brackish waters. Geophysical records do not allow for a complete understanding of the possible link between seismicity and eruptive activity.

3. FINDINGS FROM THE AVAILABLE GEOCHEMICAL DATA SETS

Geochemical data obtained by manual sampling have been recorded by Capozzi and Picotti (2003) from the Regnano mud volcano located in North Italy. The data evidence a strong variation in the cation ratio during an 8-months time-period (Fig.10).

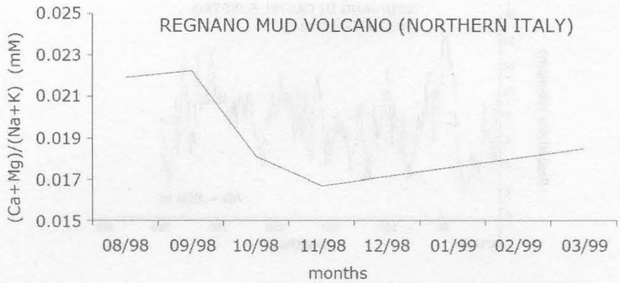

Figure 10. Cations variation observed at the Regnano mud volcano (North Italy) in 1998- 1999 . After Capozzi and Picotti (2003) , modified.

Martinelli and Ferrari (1991) published Radon data obtained by manual sampling in the liquid phase of Nirano (Fig.11) and Regnano (Fig.12) mud volcanoes. Radon data strongly fluctuated coinciding with a local seismic swarm, but a weekly sampling rate turned out to be unsuitable for evidencing possible earthquake precursors.

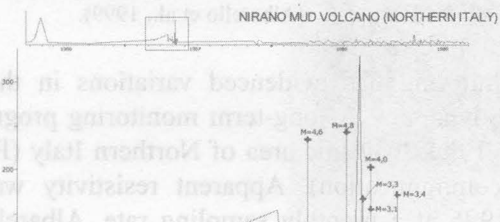

Figure 11. Radon fluctuations observed in Nirano mud volcano (North Italy) in 1986 – 1987 and local seismic events. After Martinelli and Ferrari (1991), modified.

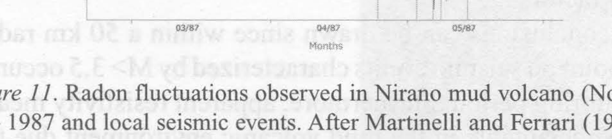

Figure 12. Radon fluctuations observed in Regnano mud volcano (North Italy) in 1987 – 1989 (Martinelli and Ferrari, 1991).

Hence, automatic Radon monitoring was attempted in the gas phase of the Regnano and Pujanello (Fig.13) mud volcanoes. A contemporaneous gas flow rate monitor evidenced a correlation between the gas flow rate and Radon anomalies. Possible relations between the gas flow rate increase and the local seismicity was also observed, although strong dependencies upon meteorological and other unidentified parameters was also identified by Albarello et al. (2003).

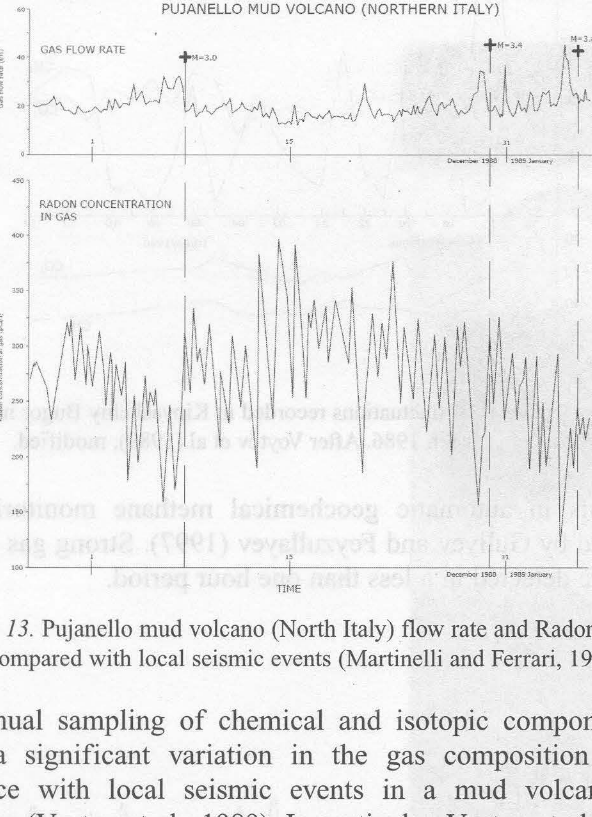

Figure 13. Pujanello mud volcano (North Italy) flow rate and Radon fluctuations compared with local seismic events (Martinelli and Ferrari, 1991).

The manual sampling of chemical and isotopic components of gases evidenced a significant variation in the gas composition (Fig. 14) in concomitance with local seismic events in a mud volcano located in Turkmenistan (Voytov et al., 1989). In particular, Voytov et al.(1989) started the geochemical monitoring after observing an increased eruptive activity following increased local seismicity.

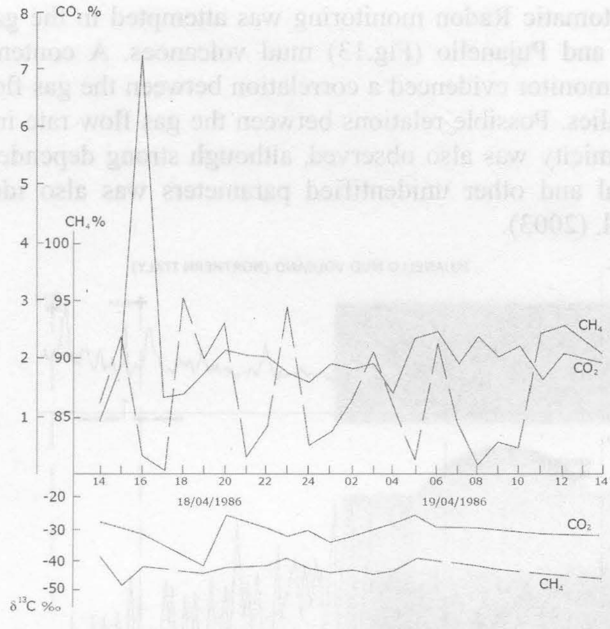

Figure 14. Geochemical fluctuations recorded in Kipyashchiy Bugor mud volcano (Turkmenistan) in 1986. After Voytov et al.(1989), modified.

Experiments in automatic geochemical methane monitoring (Fig.15) were attempted by Guliyev and Feyzullayev (1997). Strong gas composition variations were detected in a less than one hour period.

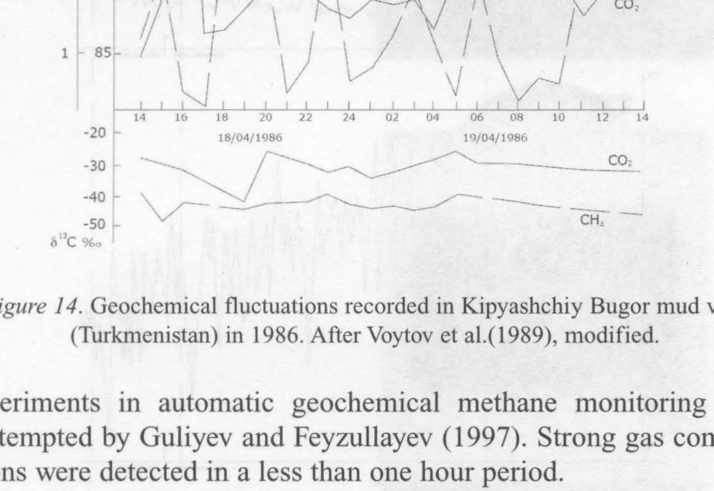

Figure 15. Methane fluctuations automatically registered at the Astrakhanka mud volcano, Azerbaijan (Guliyev and Feyzullayev, 1997).

Fission track Radon passive sensors were also utilized by Nevinsky et al. (2001) in monitoring a mud volcano in the Taman area (Fig.16). A positive relation Radon- flow rate was evidenced while further isotopic data were also reported for a better knowledge of the area.

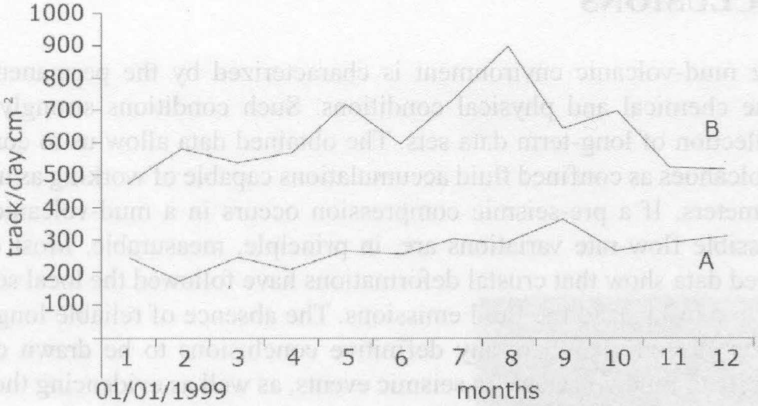

Figure 16. Radon fluctuations in the gas phase recorded in a mud volcano of the Taman area (Russia) in 1999 (Nevinsky et al., 2001).

All the available geochemical data sets show data compatible with the models proposed by Kopf (this book) and by Albarello (this book). Although important attempts have been made by many researchers no definitive conclusions can be drawn from the processing geochemical data sets in order to make out the possible links between fluid emissions and seismicity.

4. FINDINGS FROM THE AVAILABLE GEOCHEMICAL DATA SETS

The review of the available data sets recorded during geophysical and geochemical monitoring has evidenced that not all sensors are suitable in extreme environments. Data is often missed by the complex equipment utilized in mud volcanic monitoring. Temperature and pressure transducers are probably the most reliable devices (see also Khavroshkin et al., in this book). Advanced technology robots, rather like those used in space missions, have also been proposed (Delisle, in this book) for monitoring geochemical and geophysical parameters. Local seismic networks and geophones have also been proposed for long-term monitoring by Panahi (this book) and Albarello (this book). Mellors has proposed some new, satellite-based techniques that have produced promising results (Mellors et al., in this book).

Tramutoli et al. (2001) has used satellite techniques to monitor methane gas emissions expelled by mud volcanoes or carbon dioxide-dominated gas vents.

CONCLUSIONS

The mud-volcanic environment is characterized by the permanence of extreme chemical and physical conditions. Such conditions strongly limit the collection of long-term data sets. The obtained data allow us to consider mud volcanoes as confined fluid accumulations capable of working as natural strain-meters. If a pre-seismic compression occurs in a mud-volcanic area the possible flow-rate variations are, in principle, measurable. Most of the observed data show that crustal deformations have followed the local seismic events and influenced the fluid emissions. The absence of reliable long-term data sets strongly hampers any definitive conclusions to be drawn on the sensitivity of mud volcanoes to seismic events, as well as evidencing the need for reliable ground-based or satellite-based measuring techniques.

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