Deep-sourced fluids and recharge mechanism with surface aquifers: the Trinidad mud volcanoes case

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Mud volcanoes have been widely described along convergent margins. Although their general surface characteristics are well documented, the nature of expelled fluids as well as the mechanism of advection of mud along fault are poorly constrained It has be established that:

(1) mud volcanoes do contain mud and over-pressured multiphase pore fluids (water and dissolved gases, mainly methane),

(2) the sediment is fluidized by rapid advection of pore fluids up through the sedimentary mass along a conduit fault,

(3) mud volcanoes are located mostly above strike-slip faults,

(4) when located in subduction zone, mud volcanoes genesis, location and temporal evolution seem closely linked to the volume and the rate of fluid circulation in the subduction zone.

Even if chemical data are essential to determine the origin of the expelled fluids. Chemical and isotopic studies of these fluids are very few. Such information would also provide an insight into the deep circulation of fluids feeding mud reservoirs and their geodynamic context. In order to establish the origin of fluids expelled from mud volcanoes in Trinidad, we analysed their major-, trace-element and their isotopic compositions (H, O, Sr and Be). The mineralogical, chemical and Sr and Be isotope compositions of associated expelled muds were also determined.

Geologic setting and sample location

The island of Trinidad is situated on a seaward extension of the South American continent. It consists of two basins separated by the Central Range thrust complex. The oldest formations, low-grade metamorphosed phyllites, quartzites and recrystallized upper Jurassic limestones are located in the Northern Range. The Northern Basin is filled by a thick sequence of upper Miocene and younger age shallow-water sediments.

Some samples were collected in the Southern basin filled by Tertiary deposits where clay and sand layers alternate. Older formations and the E-W trending Siparia- Ortoire syncline dip steeply into this basin whose margins are locally complicated by folding and faulting.

South of Brighton structure, the Forest-Fyzabad anticline located within middle to lower Miocene sediments, is affected along its margin by a series of westward-pitching folds. These folds host significant oil deposits. The southern margin of Trinidad (Southern Range) is also folded into small, generally anticlinal structures that are separated by numerous faults. This zone contains most of the greatest number of active mud volcanoes found both in the past and during the present field campaign. These mud volcanoes are hosted by several different lower Miocene formations. A major right lateral wrench fault - the Los Bajos fault - which runs across the south-western part of the island in an east-south-easterly direction, is cutting and displacing all pre-existing structures in a right lateral sense.

Data and conclusions

(1) On the basis of their chemical compositions and their position relative to the Los Bajos fault, the mud volcanoes of Trinidad can be divided into two groups ; the NE and the SW group. The SW group is aligned along the southern anticline.

(2) The mud volcano fluids result from a complex mixing between two fluids from two deep reservoirs with fluids from surface aquifers.

(3) The major components of the fluids are Na^+, Cl^- and HCO_3. Na^+ and Cl^- concentrations depend on diagenetic processes and chemical interaction with silicates.

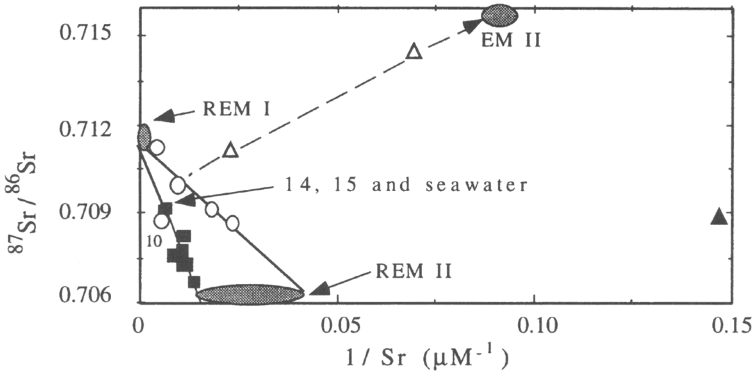

FIG. 1. $^{87}Sr/^{86}Sr$ ratios of fluid samples *vs* 1/Sr. the SW samples data are represented by full square symbols and the NE samples data by open circles. Karamat samples are represented by open triangles and the river water sample by a full triangle. The seawater value is also reported. The two deep-seated reservoirs REM I and REM II are reported as patterned areas. The meteoric end-member EM II corresponds with mixing represented by the dashed line. The two solid lines correspond with mixing between the two deep-seated reservoirs REM I and II.

(4) The chemical characteristics of mud volcano fluids located close to the sea are influenced by seawater. A detailed appraisal indicates, however, that this involved seawater is not recent but has been modified by diagenesis.

(5) The fluid Sr isotope data confirm the existence of two groups separated by Los Bajos fault. Although an isotopic "seawater" influence is evidenced in the SW group, anomalously high Sr contents indicate interaction with sediment before mixing with deep fluids. Data from the NE group are more scattered, but systematically more radiogenic. This cannot be due to a difference in the Sr isotope compositions of associated mud, since mud samples from both sides of the fault have comparable $^{87}Sr/^{86}Sr$ ratios, as well as identical mineralogical compositions. Both groups yield to separate mixing lines between a radiogenic end-member (0.71135) and a nonradiogenic one (0.70671). The nonradiogenic source possibly feeding the northeast group has a lower Sr concentration than the one involved in the southwest group (See Fig. 1.).

(6) The stable isotope (H and O) data indicate that the deep fluids become enriched in $\delta^{18}O$ through fluid-rock interaction. The most likely originally oceanic characteristics of the fluids have been strongly modified by extensive diagenesis at temperature high enough to lead to large $\delta^{18}O$ shifts. The fluid composition can be explained by the mixing of two deep components. However, secondary mixing with seawater and/or rainwater (occuring near the outcrops or in surface conditions), is also shown by these data.

(7) The gas phase is mostly composed of methane. The contents are not related to the location towards the Los Bajos fault, but most likely to the gas sampling method used.

(8) The almost unique methane content of the gas phase and the large positive $\delta^{18}O$ shifts as well as, the B, Li and Ba contents of the fluids record high-temperature fluid-rock interactions. The temperatures of the deep reservoirs are estimated using the Na-K-Ca geothermometer and range from 70°C to 150°C.

(9) To acquire the estimated higher temperatures, the mud volcanoes must have been fed by a reservoir deeper than 3 km. This corresponds to Lower Miocene sediments already proposed as the deep-seated reservoir of the fluids by previous geologic investigation. However, the original fluids mixed with a less deep-seated reservoir and with meteoric waters before reaching the surface on the ascending path owing to the fault network surrounding the mud volcanoes. This mixing implies recharge mechanism and contributes, with the local tectonic, to the dynamic of the expulsion. Since the expelled mud still does contain ^{10}Be (which is surprising considering the Miocene age of the mud and the ^{10}Be half life - 1.5 My), the recharge mechanism is confirmed and ^{10}Be must have been carried by meteoric waters.