Geological Field Trips

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Between history, work and passion: medieval castle, mud volcanoes and Ferrari

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Between history, work and passion: medieval castle, mud volcanoes and Ferrari

Goldschmidt Conference, Fiorano Modenese - 31 August - 1 September, 2013

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Riassunto

In questo lavoro viene presentata la guida geologica all'escursione organizzata per la Goldschmidt Conference 2013, tenutasi a Firenze dal 25 al 30 Agosto 2013.
L'escursione, della durata di due giorni, intende presentare alcune delle innumerevoli peculiarità geologiche, naturalistiche e culturali presenti nel territorio di Fiorano Modenese (Modena), in cui storia, geologia e passione per la Ferrari si fondono in un perfetto connubio.
Il primo giorno prevede la visita della Riserva Naturale delle Salse di Nirano, in cui è possibile osservare da vicino i vulcani di fango, prodotti dalla risalita in superficie di fango freddo, acqua salata ed idrocarburi.
Il secondo giorno è dedicato alla visita del Museo della Ferrari e prosegue al Castello di Spezzano. Il Castello ospita il museo della Ceramica, in cui viene mostrato come le argille della zona, definite "l'oro grigio" del distretto ceramico, vengono utilizzate per la produzione della ceramica. Nel Castello è inoltre presente un'acetaia comunale, dove poter degustare il tipico e famosissimo aceto balsamico di Modena. L'itinerario termina a Modena, con la visita della casa di Enzo Ferrari.

Parole chiave: *Vulcani di fango, Calanchi, Ferrari, Castello di Spezzano*

Abstract

This field trip guide organized in the framework of the Goldschmidt Conference 2013, held in Florence from August 25 to 30, 2013, is here presented.
The two-days field trip, shows some of the many geological, naturalistic and cultural features in the Fiorano area (Modena), in which history, geology and passion for Ferrari come together in a perfect marriage.
The first excursion day is dedicated to visit the Natural Reserve of Salse di Nirano, where the mud volcanoes, produced by the cold mud, salt water and hydrocarbons - mainly methane- can be observed.
The second day is devoted to visit the Ferrari Museum and goes on at the Spezzano Castle, hosting the Ceramics Museum. Clays are, in fact, abundant in the hilly margin, where they form badlands, characteristic narrow crests washed out by running waters. In the Castle there is also a Balsamic Vinegar producing Consortium, it's a peculiar and typical product of Modena province. The itinerary ends with the tour to Enzo Ferrari's Birthplace at Modena.

Keywords: *Mud volcanoes, badlands, Ferrari, Spezzano Castle*

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1.1 General and touristic details

The Regional Natural Reserve of Salse di Nirano is located in the low hill territory of the Modena Apennine, about 30 kilometers from Modena and 35 km from Reggio Emilia (Fig. 1). The Salse di Nirano, an important geological phenomenon of international relevance, represent a successful example of environmental and touristic valorization. Indeed, since 1982 the Natural Reserve of Salse di Nirano was established in the area by the Emilia-Romagna Region with the aim of safeguarding and preserving the natural and environmental characteristics of the site.

This area, belonging to the Fiorano Modenese municipality (Modena), in ancient times it was called "the beautiful place", due to its hilly landscapes forming the foothills of the Apennines. The plain, instead, is populated by more than sixteen thousand inhabitants and dotted by many productive companies, mainly for ceramic tiles production.

Scientists cite Fiorano for the Salse di Nirano, car fans know it for the Ferrari's circuit, archeologists are more familiar with the characteristic Neolithic ceramic culture named "Cultura di Fiorano". Therefore, not only the Salse di Nirano are worth of mention. In Fiorano, some more treasures are well worth a visit during the field trip, such as the Spezzano Castle and the Ferrari's World.

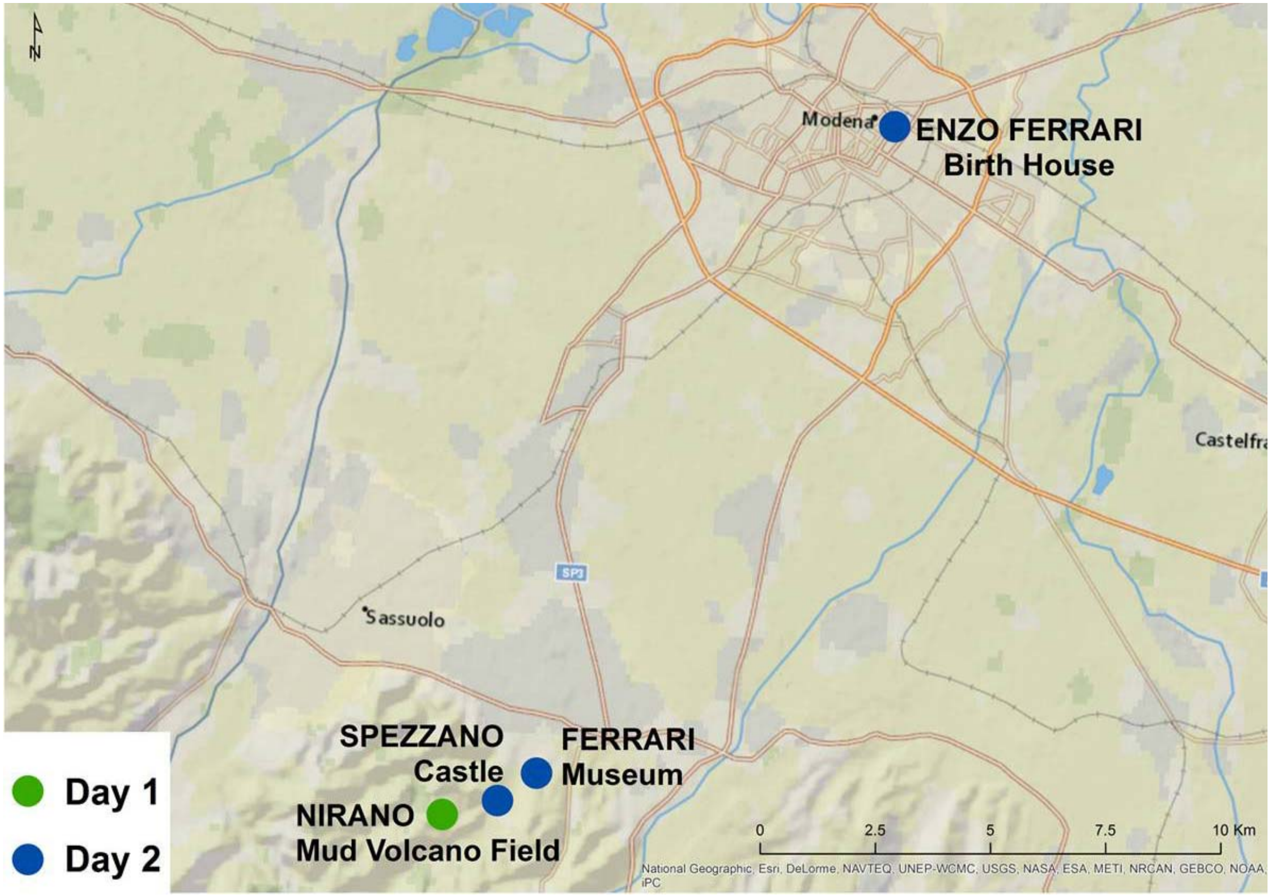

Fig. 1 - Map of the field trip location.

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During the first day of field trip, scientist will walk inside the Natural Reserve of Salse di Nirano. 9 Stops will be devoted to show the cone- and pond-shaped mud volcanoes, the outcropping rocks (marine clays), the badlands and landscape around the topographic depression containing the Nirano mud volcanoes field. The second day the participants will visit the Ferrari Museum in Maranello, the Spezzano Castle and the Enzo Ferrari's Birthplace Museum in Modena.

1.2 History of Salse di Nirano mud volcanoes

The Salse (mud volcanoes) are the product of mainly gaseous (methane) and partly liquid (oil) hydrocarbons cold deposits, ascending to the surface along faults and fractures. The name "Salsa" results from the high "salt" content of these muddy waters.
The field of Nirano, is one of the best developed mud-volcano phenomena of the entire Italian territory and among the largest in Europe. This have been known since ancient times and have been studied from historians, scientists and travelers (e.g. Stoppani, 1873; Coppi, 1875; Pantanelli & Santi, 1896; Biasutti, 1907; Barbieri, 1947; Mucchi, 1966, 1968; Bertolani, 1980; Ferrari & Vianello, 1985; Gorgoni et al., 1988; Bertacchini et al., 1999; Castaldini et al., 2003 and 2007; Gorgoni, 2003; Bonini 2008, 2009 and 2012; Carobene & Gasperi, 2008; Bertacchini, 2009; Castaldini et al., 2011), contributing to create an important documentation on its evolution.
Since the roman period, the Nirano area was a dwelling place of organized groups that worked with ceramics and bricks, as testified by many historical sources and proved by the discovery of an ancient crockery furnace. The first description of the Salse di Nirano is by Plinio il Vecchio in his "Naturalis Historia" (A.D. 50). He described the eruption of a mud volcano in the Modena district, with skyscraping flames and smoke, seen from a distance of ~10 km, during which the violent ejection of overpressured mud was accompanied by methane combustion. Similar correlations between large earthquakes and methane mud volcano eruptions have been documented for other mud volcanoes worldwide (Mellors et al., 2007).

From the 17th century, other scientists described the Salse with apocalyptic and spectacular attributes (e.g. Ramazzini, 1698; Spallanzani, 1792). At the end of the 19th century, the abbot Antonio Stoppani compared the Salse's phenomenon to molehills out of which noises similar to "retching" came out, giving them the epithet of "cesspool volcanoes" (Stoppani, 1873) (Fig. 2a).

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In the past, the mud from the Salse was applied for cosmetic use as mud masks and for mud-baths at the Terms of Salvarola, near Sassuolo. Also, natural oil of the Salse was much appreciated for its balsamic and purgative properties and sold by monks of San Peter in Modena. Nowadays, the cold mud is used only in veterinary science to blaze up articulations of horses.

Since the end of 19th century, investigations to find hydrocarbon deposits were undertaken without any luck. Then the area of Salse was cultivated, the volcanoes ploughed and covered in the vain attempt to limit their activity (Fig. 2c).

In March 1982, the Regione Emilia Romagna, instituted the Natural Reserve of the Salse di Nirano (Decree of the President of the Region Nr.178), to safeguard and preserve the natural and environmental characteristics of the site (Tosatti, 2002). The Salse di Nirano was the first Natural Reserve to be recognized by the Emilia Romagna Region and among the first protected areas identified in Italy.

In 2004, the European Commission identified the Reserve area and its surroundings as a Site of Communitarian Importance (SCI) (on the basis of the Directive CEE Nr. 43 of 1992). This declaration is mainly due to the presence of natural and semi-natural habitats, animal and vegetation species to be protected that are of primary importance at European level. Afterwards, the protected area has had the recognition of “Geosite” for the protection of the cultural heritage of our country. The Reserve is visited yearly by about 70,000 people.

Fig. 2 - Picture representing the Salse di Nirano in the XIX century from the book "Bel Paese" of Antonio Stoppani (from Stoppani A., 1847) **(a)**; engraving dating 1540 representing the oil extraction from superficial spills, near Nirano (from Gorgoni C., 2003) **(b)**; view of the Salse before the constitution of nature reserve **(c)**.

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1.3 Behavior rules for visitors within the Salse di Nirano Reserve

Being a protected area, visitors of the Reserve are invited to respect some simple behavior rules that are clearly visible in many places on specific panels.
It is suggested not to hike under wet-ground conditions since clay can be very slippery favoring falling.

Behaviour rules for visitors within the territory of the Reserve
In order to defend and preserve the natural, geomorphologic and landscape characteristics of the Reserve, with rules approved by the Province of Modena, the following behavior rules catalogue has been introduced. It lists all rules, which have to be respected by visitors within the territory of the Natural Reserve of Salse di Nirano.

IN THE INTEGRAL PROTECTION AREA OF THE RESERVE it **is strictly forbidden to**:

- damage mud volcanos;
- damage alophylous vegetation;
- remove mud from the Salse;
- put any kind of object into the Salse;
- camp overnight or remain longer than necessary for a complete visit;
- enter the area during rain events, or 24 hours afterwards;
- enter the area 1 hour before sunrise and 1 hour after sunset;
- leave the official excursion and educational trails.

IN THE WHOLE AREA OF THE RESERVE **it is strictly forbidden to**:

- leave any rubbish on the ground;
- make any kind of fire;
- damage, pick or take away any kind of vegetation, or parts of it;
- damage, take away or disturb animals;

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- pick or damage eggs, nests or lairs;
- damage or cut trees;
- use any kind of motor vehicle outside the usual street grid (in exceptional cases allowed);
- fly too low over the Reserve (with aeroplanes or gliders);
- park cars along Via Rio Salse and Via Nuova del Gazzolo (vehicles will be removed with costs);
- modify any geomorphological structure, dig holes, build buildings or roads;
- keep or rear any species of autochton or allochton wild animals;
- cultivate plots of ground which are not usually used for agriculture;
- let dogs walk free without leash;
- leave the official excursion and educational trails (in exceptional cases allowed);
- pick mushrooms and truffles;
- pasture sheeps;
- introduce allochton vegetal and animal species;
- spread sewage, fertilizers, weed killers or any toxic or pollutant substance;
- camp;
- bathe in any pond;
- fish (exception: "no kill" fishing is allowed);
- build any kind of shelters, even temporarily;
- hunt for animals or train dog, in any form.

Salse are a unique geosite, an unusual example of biodiversity. This delicate ecosystem has to be defended and preserved. Salse have been well known since ancient times: they represent a sort of natural door to deeper parts of our territory, normally very difficult to get in touch with, a door we have to try to keep open, so that also those who will come after us will have the opportunity to get fascinated by this beautiful phenomenon and maybe get a little more familiar with the history of our planet.

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2.1 Mud volcanoes of the Northern Apennine

Among fluid venting structures, mud volcanoes are the most important phenomena related to natural seepage from the earth's surface (Mazurenko & Soloviev, 2003). Mud volcanoes have variable geometry and size, from one to two meters to several hundred meters in height, and are formed as a result of the emission of argillaceous material and fluids (water, brine, gas, oil) (Milkov, 2000; Dimitrov, 2002; Kopf, 2002). They occur globally in terrestrial and submarine geological settings: most terrestrial mud volcanoes are located in convergent plate margin with thick sedimentary sequences within the Alpine-Himalayan, Carribean, and Pacific orogenic belts (Hovland et al., 1997; Kopf et al., 2000; Delisle et al., 2002; Etiope et al., 2002; Deville & Prinzhofer, 2003; Yassir, 2003; Shakirov et al., 2004; Stewart & Davies, 2006). Mud volcanoes and mud diapirs are responsible for the genesis of many chaotic deposits, such as mélanges, chaotic breccias and various deformed sediments (Barber et al., 1986; Barber & Brown, 1988; Orange, 1990; Brown & Orange, 1993).
The normal activity of mud volcanoes consists of gradual and progressive outflows of semi-liquid material called mud breccia or diapiric mélange. Explosive and paroxysmal activity are interpreted as responsible for ejecting mud, ash, and decimetric to metric clasts. Mud volcano breccias are composed of a mud matrix, which supports a variable quantity of chaotically distributed angular to rounded rock clasts, ranging in diameter from a few millimetres to several meters (Camerlenghi et al., 1992; Dimitrov, 2002; Deville & Prinzhofer, 2003). Clasts are of various lithologies and provenances, derived from the rocks through which the mud passed on its way to the surface or to the sea floor.
The occurrence of mud volcanoes is controlled by several factors, such as tectonic activity, sedimentary loading due to rapid sedimentation, the existence of thick, fine-grained plastic sediments and continuous hydrocarbon accumulation (Treves, 1985; Guliyev & Feizullayev, 1997; Ivanov et al., 1996; Limonov et al., 1996; Milkov, 2000; Dimitrov, 2002).

Mud volcanoes in Italy occur along the external compressive margin of the Apennine chain (Pellegrini et al., 1982; Capozzi et al., 1994; Martinelli, 1999; Martinelli & Judd, 2004). They were described far back into history (Spallanzani, 1792; Stoppani, 1908) and listed by Biasutti (1907), Scicli (1972) and Ferrari & Vianello (1985). Italian mud volcanoes are usually small and unspectacular, when compared to other world examples.

They rarely exhibit the periodic explosive activity (Capozzi & Picotti, 2002), which is often related to important seismic activity. Chaotic brecciated deposits associated with short "eruptive" periods of some Modena-Reggio mud volcanoes are debris flows made of polygenic breccias floating in a viscous mud. These deposits show a number of analogies with monogenic and polygenic brecciated lithofacies of the Miocene methane derived authigenic carbonates of the Northern Apennines. Similarities between the examined fossil seep carbonates and mud volcanoes include also the type of fluids which consist mainly of methane mixed with connate waters and clay mud.

The comparison between recent and fossil diapiric-related structures has been useful for constraining the nature of the fossil seepage pathway, understanding fluid expulsion processes and reconstructing models of chemoherm evolution. In particular, this investigation suggests that brecciated structures and exotic clasts in ancient chemoherms are due to the offscraping and chaotic mixing of sediments during the rapid rise of methanogenic fluids along diapiric conduits or fractures, following similar processes and mechanisms as in chaotic deposits associated with mud volcanoes.

The Nirano mud volcanoes represent one of the best examples of the Bulganaskshi category as reported in the Northern Apennines (Martinelli & Rabbi, 1998), even if the fluid pathways are still not well understood. An integrated geophysical and geological study of small mud volcanoes occurring along the external compressive margin of the chain in the Northern Apennines was carried out in order to investigate the fluid pathways and the mud reservoir. Results obtained by tomographic inversion of first arrivals of 3D seismic data, and models obtained by 2D geo-electrical data, made it possible to determine the geometry of the buried shallow structures, and the details of the fluid seepage down to 50m below the mud volcano surface.

A mud chamber was identified at a depth of 25 meters. This shallow reservoir could represent the last phase of mud accumulation before the final emission. Comparison with other mud volcanoes of the northern Apennines suggests a close relationship between extruded materials and substratum typology.

The Salse di Nirano are linked to a hydrocarbon reservoir located in the miocenic fractured rocks, some hundreds of meters deep. Low-permeability Pliocenic-Calabrian clays, cannot contain hydrocarbon deposits, but they allow the fluid migration through a fault system. The methane carries up the oil and waters which dissolves, along the way, the Pliocenic clays. The salt-rich mud flow, gradually builds a cone of a volcano-like appearance.

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Mud volcanoes are conic edifices constructed by surface extrusion of cold fluids, like mud, saline water, and gases expelled from a pressurized deep source layer up through structurally controlled conduits. Surface mud volcanoes, seeps of gas, and saline water unequivocally manifest fluid expulsion from depth and sediment mobilization in general. Inside the cones, mud seems to boil because of hydrocarbons bubbles, which are actually emitted at ambient temperature. Mud volcanoes are normally associated with gas hydrates, of which methane is commonly the most abundant gas emission, and indicate a fluidization of sediments operated by rapid flow of pore fluids up through a sedimentary mass.

Following the terminology in Planke et al. (2003) and Mazzini et al. (2008) the mud volcano features are referred to as (i) gryphons and (ii) mud cones for <3m and <10m high steep-sided cones, respectively, and (iii) salsas for water-dominated pools with gas seeps. The term mud volcano is used to indicate larger edifices or an area or field that contains a number of the above features.

Mud volcanoes are a classical example of "geomorphologic convergence", that is, similar forms but with different origins (Panizza, 1992). In fact, although cone-shaped cones and flows are being formed and, in the specific case of Salse di Nirano, a caldera-like depression contains all these emissions, mud volcanoes have nothing to do with actual volcanism, although many visitors still think they have.

2.2 Geological setting of the Modena Apennine margin

The Natural Reserve of Salse di Nirano is located in the western sector of the Modena Apennine margin, which belongs to the Northern Apennines (Fig. 3). The territory of the Natural Reserve covers a total area of about 200 ha with elevations ranging from 140 and 308 m a.s.l. The area where the mud volcanoes are found covers about 10 ha and is situated at the bottom of a wide sub-circular depression at an altitude of about 200 m.

The mud volcanoes are usually cone-shaped edifices of variable dimensions constructed by the extrusion of mud, rock fragments and fluids, such as saline water and gases (e.g., Higgins & Saunders, 1974). These features can be found in different tectonic settings, but they typically predominate at converging plate boundaries and are disseminated all along the Alpine–Himalayan collision zone. Methane is the most frequent gas, and is normally linked to the formation and accumulation of hydrocarbons at greater depths. It is commonly accepted that overpressure generated by methane-rich fluids is one of the main driving mechanisms triggering mud volcanism (Brown, 1990). Though mud volcanoes exhibit smaller dimensions than the magmatic relatives, they can

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occasionally give rise to impressive explosive eruptions, with violent ejection of mud and rock blocks often accompanied by flames produced by self-ignition of the methane contained in the mud.
From a geologic standpoint, the Nirano area is on an active thrust along the Pede-Apennine margin of the Northern Apennines (e.g., Benedetti et al., 2003; Bonini, 2008) (Fig. 3). The Modena Apennine margin is characterized by prevalently compressive structures which correspond to the so called Emilia Folds (Pieri & Groppi, 1981; Gasperi et al., 1989). Tectonic structures have been produced by northbound translational movements (occurring mainly during the Messinian and Pliocene) which affected both the Apennine Chain and the plain which lies in front of it. Clayey and sandy marine sediments ranging from the Lower Pliocene (about 5 m.y. B.P.) to the Lower Pleistocene (about 1 m.y. B.P.) outcrop almost continuously in this area. To the south, towards the mountains, these deposits usually covers rocks from Cretaceous to Miocene in age; to the north, towards the Po Plain, they are covered by alluvial deposits of the Middle-Upper Pleistocene.
The Nirano mud volcanoes field (NMVF) is located over the crest of a thrust anticline associated with the main Pede-Apennine thrust and represents a good example of an onshore relationship between a mud volcano caldera structure and active thrust deformation.

The NMVF is currently formed by four main vents composed of a number of individual active cones (or gryphons) defining structural alignments trending ~N55°E (Fig. 3a) (Bonini, 2008). Such cones are up to 3 m high, and emit mud breccias and mudflows spreading over an elliptical (~500 m long, 350 m wide, ≤60 m deep) depression with essentially planar morphology (Fig. 3a). This depression is bound by steep flanks shaped in marine claystones (Argille Azzurre Formation), and exhibits morphological and structural characteristics similar to those of igneous calderas, most notably an abrupt and circular rim enclosing vents and lava domes erecting from a topographically depressed area (Bonini, 2008) (Fig. 3b).
The study area is characterized by the presence of two systems of tectonic discontinuities (faults and/or fractures), NW-SE and SW-NE oriented, respectively. The main streams are the Rio Chianca (which marks the western and northern boundary of the park), Rio delle Salse and its tributary Rio Serra which, as previously stated, flow in the southern sector of the Reserve. In addition, some small reservoirs are also found: three ponds and four marshy areas. Another four relict ponds have been completely filled by palustrine deposits. Their origin is artificial as witnessed by the presence of artificial embankments downstream. The morphology of this area is, in fact, constantly evolving with the formation of new mud volcanoes whilst others cease their activity.

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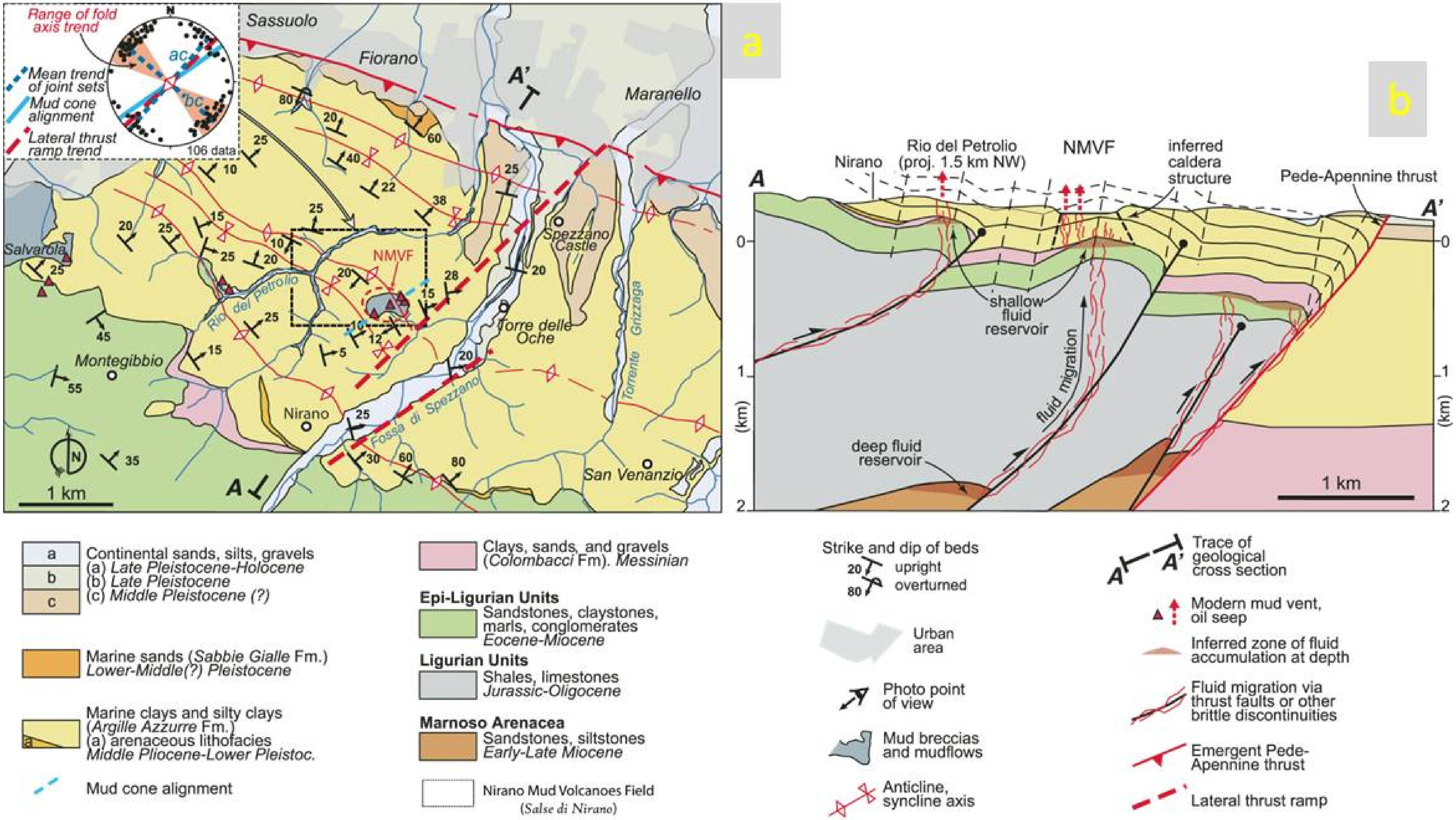

Fig. 3 - Geological-structural map of the Modena Apennine margin (from Bonini, 2008). Inset shows distribution of joints in relation to the direction of fold axes, lateral thrust ramps, and mud volcano alignments (black dots indicate the pole to joint planes; Schmidt net, lower hemisphere; modified from Bonini, 2007). Dashed box indicates area of joint collection (**a**); typical geological cross section. Note preferential localization of seepage over the crests of anticlines (**b**).

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2.3 Characteristics of discharged fluids

The fluids of the NMVF are characterized by mud, gas bubbles (methane represents the largest part of emitted gases), and muddy water, which may also contain a small fraction of liquid hydrocarbons (Martinelli & Rabbi, 1998). Analysis of the extruded mud has revealed the presence of sub-millimeter angular fragments of claystones and carbonates that are indicative of the source layer and wall rocks encountered by the rising of overpressured fluids (Bonini, 2008). The preferred geological model to explain this phenomena involves pressurized fluids moving up through discontinuities in the Ligurian units, and accumulating at shallower reservoirs controlled by the lithological boundary between the impermeable claystones (Argille Azzurre Formation) and the underlying, more permeable, epi-Ligurian units and Colombacci Formation (Fig. 3b).
The activity of a salsa is influenced by meteorologic factors. In summer, the activity may decrease due to the muds' de-hydration until the possible obstruction of the up-welling channel occurs. During wetter seasons, due to the terrain softening and to the increasing methane's pressure accumulating deeper down, the obstruction can be demolished and the activity may restart. During non-active periods, the mud volcanoes are subject to erosion by precipitation water and can be partially dismantled, until the following activity phases when they are rebuilt. The number of apparatuses can vary with time, as well as their location: in the case of Nirano, the mapping and photographic documents point to a considerable steadfastness during the past one hundred years (Gorgoni, 2003).

2.4 Earthquakes and mud volcanoes eruptions

The tectonic activity of the Apennine margin is testified by the numerous earthquakes that hit the Nirano area and surroundings, mostly concentrated along the plain-hill boundary. Among the most intense seismic events, the quakes of 1399 (Imax=7/8, Mw= 5.1), 1501 (Imax= 9, Mw= 6), 1671 (Imax= 7, Mw= 5.3), 1811 (Imax=6.5/7, Mw= 5.3), are mentioned (Gruppo di Lavoro CPTI, 1999; Mantovani et al., 2013; in bold in Table 1).
Recently (May, 2012), the Emilia area (about 60 km NE from Nirano) was affected by a very intense seismic sequence. The main destructive earthquakes occurred on 20th and 29th May, with local magnitude 5.9 and 5.8, respectively. The earthquakes caused a number of fatalities and significant damage as well as many ground effects such as mainly cracks, liquefaction-type phenomena, and hydrological anomalies.
In the following weeks other five earthquakes with local magnitude in the range 5-5.3 took place in the same area.

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Year	Mo	Da	Ax	Lat	Lon	Imx	Mw
1234	3	20	Ferrara	44.836	11.618	7	5.1
1285	12	13	Ferrara	44.836	11.618	7	5.1
1308	1	25	Rimini			7.50	5.4
1365	7	25	Bologna	44.498	11.340	7-ago	5.4
1399	**7**	**20**	**Modenese**	**44.441**	**10.925**	**8**	**5.1**
1409	11	15	Parma	44.801	10.329	7	5.1
1411	1	9	Ferrara	44.836	11.618	7	5.1
1438	**6**	**11**	**Parmense**	**44.844**	**10.239**	**8**	**5.6**
1501	**6**	**5**	**App. modenese**	**44.519**	**10.844**	**9**	**6.0**
1505	1	3	Bolognese	44.508	11.231	8	5.6
1536	8	17	App. tosco-emili.	44.364	10.933	6-lug	5.3
1547	**2**	**10**	**Reggio Emilia**	**44.697**	**10.631**	**8**	**5.1**
1570	11	17	Ferrara	44.824	11.632	8	5.5
1671	6	20	Modena-R. Emilia	44.674	10.866	7	5.3
1779	6	4	Bolognese	44.444	11.479	7	5.2
1780	2	6	Bolognese	44.568	11.309	6-lug	5.1
1796	10	22	Emilia orientale	44.615	11.670	7	5.6
1801	10	8	Bologna	44.468	11.420	6	5.1
1806	2	12	Novellara	44.862	10.671	7	5.2
1810	12	25	Novellara	44.898	10.712	7	5.3
1811	7	15	Sassuolo	44.572	10.728	7	5.3
1818	**12**	**9**	**Parmense**	**44.696**	**10.295**	**7-ago**	**5.3**
1831	9	11	Reggiano	44.752	10.544	7-ago	5.5
1832	3	13	Reggiano	44.765	10.494	7-ago	5.5
1857	2	1	Parmense	44.749	10.480	6-lug	5.1
1873	5	16	Reggiano	44.612	10.701	6-lug	5.1
1873	9	17	Liguria orient.	44.497	10.283	6-lug	5.4
1878	3	12	Bolognese	44.424	11.543	6	5.1
1881	1	24	Bolognese	44.401	11.348	7	5.2
1898	3	4	Valle del Parma	44.655	10.260	7-ago	5.4
1904	2	25	Reggiano	44.490	10.640	7	5.1
1909	1	13	Bassa Padana	44.579	11.688	6-lug	5.5
1915	10	10	Reggio Emilia	44.732	10.469	6-lug	5.0
1929	4	10	Bolognese	44.447	11.385	7	5.0
1929	4	11	Bolognese	44.500	11.333	4	5.0
1929	4	12	Bolognese	44.500	11.333	4	5.1
1929	4	20	Bolognese	44.481	11.150	7-ago	5.3
1931	4	11	Medicina	44.417	11.600		5.1
1940	5	1	Noceto	44.800	10.183		5.2
1971	**7**	**15**	**Parmense**	**44.814**	**10.345**	**8**	**5.6**
1983	11	9	Parmense	44.652	10.342	7	5.1
1987	7	11	Bassa bolognese	44.697	11.267		5.4
1996	10	15	Correggio	44.798	10.678	7	5.4
2003	9	14	App. Bolognese	44.26	11.38	6-lug	5.3
2008	12	23	Frignano	44.54	10.35	5	5.2
2012	**5**	**20**	**Finale emilia**	**44.89**	**11.23**	**7-ago**	**5.9**
2012	5	20	Bondeno	44.86	11.37		5.1
2012	5	20	Vigarano	44.83	11.49		5.1
2012	**5**	**29**	**Medolla**	**44.85**	**11.09**	**7-ago**	**5.8**
2012	5	29	San Possidonio	44.89	11.01		5.3
2012	5	29	Novi di Modena	44.88	10.95		5.2
2012	6	3	Novi di Modena	44.90	10.94		5.1

Table 1
List of earthquake with Mw >5 occurred in in the Modena Province and surrounding area after the year 1000 (from CPTI11 Catalouge, Rovida et al., 2011). In bold the most intense seismic events. The macroseismic intensity (Imx) is showed as Mercalli-Cancani-Sieberg Scale(MCS).

In the past, some Authors noted a correspondence between episodes of violent activity of the mud volcanoes and earthquakes (Stohr, 1869; Pantanelli &

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Santi, 1896; Pellegrini et al., 1982; Gorgoni et al., 1988). Other investigations (Gorgoni, 2003) have shown that the activity of the mud volcanoes is influenced by local seismicity, some days before the occurrence of rather strong earthquakes. Earthquakes have been considered to be a potentially important trigger for mud volcano eruptions (Martinelli et al., 1995; Martinelli & Panahi, 2005; Mazzini et al., 2008; Bonini, 2009 and 2012), but several mud volcanoes have also erupted independently of seismic activity (e.g., Mellors et al., 2007). Noteworthy is the occurrence of a giant mud volcano eruption in the area, associated with the contemporaneous destructive earthquake of 91 B.C. that struck the Pede-Apennine margin around Modena (Guidoboni, 1989). As reported by the Roman writer Plinius, skyscraping flames and smoke were seen from a distance of ~10 km, in all likelihood a phenomenon attributable to a typical mud volcano eruption, during which the violent ejection of overpressured mud was accompanied by methane combustion. In table 2 the correlation between mud volcanoes eruptions or anomalous activity and earthquakes is shown.

Table 2
Relationship between earthquakes and mud volcano eruption or anomalous activity for the Nirano area.
EP: qualitative parameterization of eruptions/anomalous activity; **A**: large explosive eruption with self-ignition of methane and sky-scraping fire/smoke-columns accompanied by strong ground shaking, bursts, extensive eruption of mud breccias and mud flows; **E**: post-seismic increase in fluid and gas discharge. **ED**: epicentral distance. **Coseismic triggering (i.e. eruption triggered immediately or within a few hours after the passage of the seismic waves). Modified from Bonini, 2009.

Mud volcano eruption anomalous activity			Triggering earthquake						
Earthquake date	Source	EP	Date	Lat.	Long.	Mw	Ms	Source	ED (km)
15.03.1988	Martinelli et al., (1989)	E?	15.03.1988	N44.788	E10.684	4.73		CPTI (2008)	32.4
51.873	Coppi (1875)	E	16.05.1873	N44.612	E10.701	5.13	4.74	CPTI (2004)	14.6
91 BC**	Guidoboni (1989)	A	91 BC	N44.650	E10.780	5.66	5.53	CPTI (2004)	14.5

Big changes in the emissions type are reported especially after seismic events, as documented also in the Apennines thrust zone (Heinicke et al., 2006). The compilation of a catalog of historical eruptions (with relative positioning) and paroxysmal activity of the mud volcanoes would be also important to maintain. The intersection with macroseismic

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analysis may also reveal interesting relations with historical earthquakes. New and interesting perspectives provided by these devices involve the use of such systems as measuring natural fluctuations of the field strain, the latter capable of greatly affecting the seismogenic processes (Albarello, 2005). This is based on the assumption that the reservoirs are confined systems, and being water incompressible, are sensitive to changes in volumetric strain and can record even small deformations of the Earth's crust that normally accompany the seismic events.

2.5 Geochemical characteristic of mud volcanoes

In the Earth Sciences field, the most important changes concern the contribution of gases emitted from mud volcanoes to the greenhouse effect and the resulting global warming (Etiope & Klusman, 2002; Kopf, 2002).
Moreover, the substantial variation in the gas emission rate, such as ^{222}Rn, can be used as potential earthquakes precursors (Martinelli & Judd, 2004). The possibility of bursts associated with mud volcanoes also leads to consider such structures as potential areas, albeit moderate, geological risk.
The mud volcanoes show the presence of permeable structures, tectonically active, and their study can provide useful "windows" on how fluids move through the upper crust and the sedimentary cover towards the surface.
Water analysis emitted by salse highlighted connate origin of such fluids dominated by sodium-chloride component (Gorgoni et al., 1988).
Extruded gas is chemically composed by 93% methane, 5% nitrogen, 2% oxygen, 1% carbon dioxide, and about 660 ppm of ethane (analysis carried out by the Authors at the mud volcano complex, Stop 1.6, in June 2013).
The sludge produced by salse derives primarily from the fluidization of pelites by fluids, such as water formation and methane (biogenic and/or thermogenic) from hydrocarbon traps, which uprising along preferential leakage pathways, as faults/fractures. Mud volcanoes are then originated by one or more reservoirs located at different depths in which accumulate fossil salty waters mixtures, clay, and mainly methane. The liquid portion and clay accumulates mostly in the more superficial reservoir then mixes with rainwater (Nanni & Zuppi, 1986; Capozzi & Picotti, 2002). In fact, temperature is around 15.5 °C, pH about 7.73, HCO_3^- is 488 mg/L, ^{222}Rn about 41 Bq/L, electrical conductivity and Eh are 14.24 mS/cm and -231 mV, respectively (Stop 1.6, June, 2013).
The development of mud volcanoes seems linked to the presence of impermeable layers that act as hydraulic barriers to the migration of fluids, favouring the development of overpressure and fluidization of the pelites. Most mud volcanoes are localized in the Emilia Apennine which is characterized by bleed of Ligurian Units, composed largely by shales that make this blanket essentially waterproof.

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Day 1

The Itinerary of the first day winds along a walking trail throughout the Regional Natural Reserve of Salse di Nirano. Six touristic paths with different duration and degree of difficulty and four educational path with explanatory notice boards have been set up inside the reserve.
The Salse di Nirano complex includes several mud volcanoes, between cone-shaped and pond-shaped mud volcanoes, but it is not possible to give the exact number of the mud-ejecting points, because the morphology of this area is constantly evolving with the formation of new craters whilst others cease their activity. As many authors described, the Salse can be composed of several cones, whose number can vary considerably over time so that the cones are so ephemeral structures, since they can become clogged, turn off and open new ones in a relatively short time. The number of apparatuses can vary with time, as well as their location: in the case of Nirano the mapping and photographic documents point to a considerable steadfastness during the past one hundred years. Stoppani (1883) counted over forty in the field of Nirano while Camerana (1926) counted about ten. The clayey materials ejected from the craters cover the surrounding ground with mudflows. Therefore, owing to the constant emission of mud over time, the floor of this depression is covered by fine-grained deposits up to a few meters in thickness.

Indeed, mud volcanoes have variable geometry and size, from one to two meters to several hundred meters in height, and are formed as a result of the emission of argillaceous material and fluids (water, brine, gas, oil). Although most mud volcanoes have a typical conical shape, they can assume a great variety of forms, referred to as “mud cones”, “mud lumps”, “mud diapirs”, “mud pies” etc., depending on their shape and size which, in turn, depend on the degree of mobilization initiated by pore-fluid pressures, frequency and characteristics of their activity, and viscosity of the out-flowing mud (e.g. Dimitrov, 2002 and references in it; Kopf, 2002). There is an inverse relationship between the amplitude of the cones and their height. Besides, the extent of pools is usually inversely proportional to the density of the liquid emitted. If the mud is dense and viscous, it forms an high cone with steep sides, on the contrary, the apparatus will be much lower, and with slightly inclined sides as much as the mud emitted are liquid and fluid. At present day, four main groups of cone-shaped mud volcanoes (Stops 1.1, 1.3, 1.5 and 1.6) and four main groups of pond-shaped ones (Stops 1.2 and 1.7) were found. The itinerary is organized in 9 Stops, allowing the phenomenon of mud volcanoes to be observed from both close up and from a panoramic viewpoint (Fig. 4). For safety reasons the mud volcanoes of Nirano are fenced.

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Fig. 4 - Geomorphological map of the Salse di Nirano (from Castaldini et al. 2007) and Day 1 itinerary with the location of the Stops (1.1-1.9).

BEDROCK LITHOLOGY

- Marine silty clays (greysh blue) with stratification from massive to thin fine sandy layersinterbedded Upper Pliocene-Lower Pleistocene (?)
- Marine marly clays rarely interbedded Lower Pliocene

STRUCTURAL DATA

- Lithologic boundary
- Assumed fault/fracture

HYDROGRAPHY

- Main stream
- Pound
- Marsh

POLYGENETIC FORMS

- Ridge, watershed

LANDFORMS AND DEPOSITS RESULTING FROM THE ENDOGENETIC ACTIVITY OF THE MUD VOLCANOES

- Cone-shape mud volcano or group of cone-shaped mud volcanoes
- Level-pool mud volcano or group of level-pool mud volcanoes
- Mud-flow deposits of mud volcanoes

SLOPE LANDFORMS AND DEPOSITS DUE TO GRAVITY

Active Dormant/Inactive

- Edge of degradational and/or landslide scarp
- Landslide (flow type)
- Slope affected by solifluction

SLOPE LANDFORMS AND DEPOSITS DUE TO RUNNING WATERS

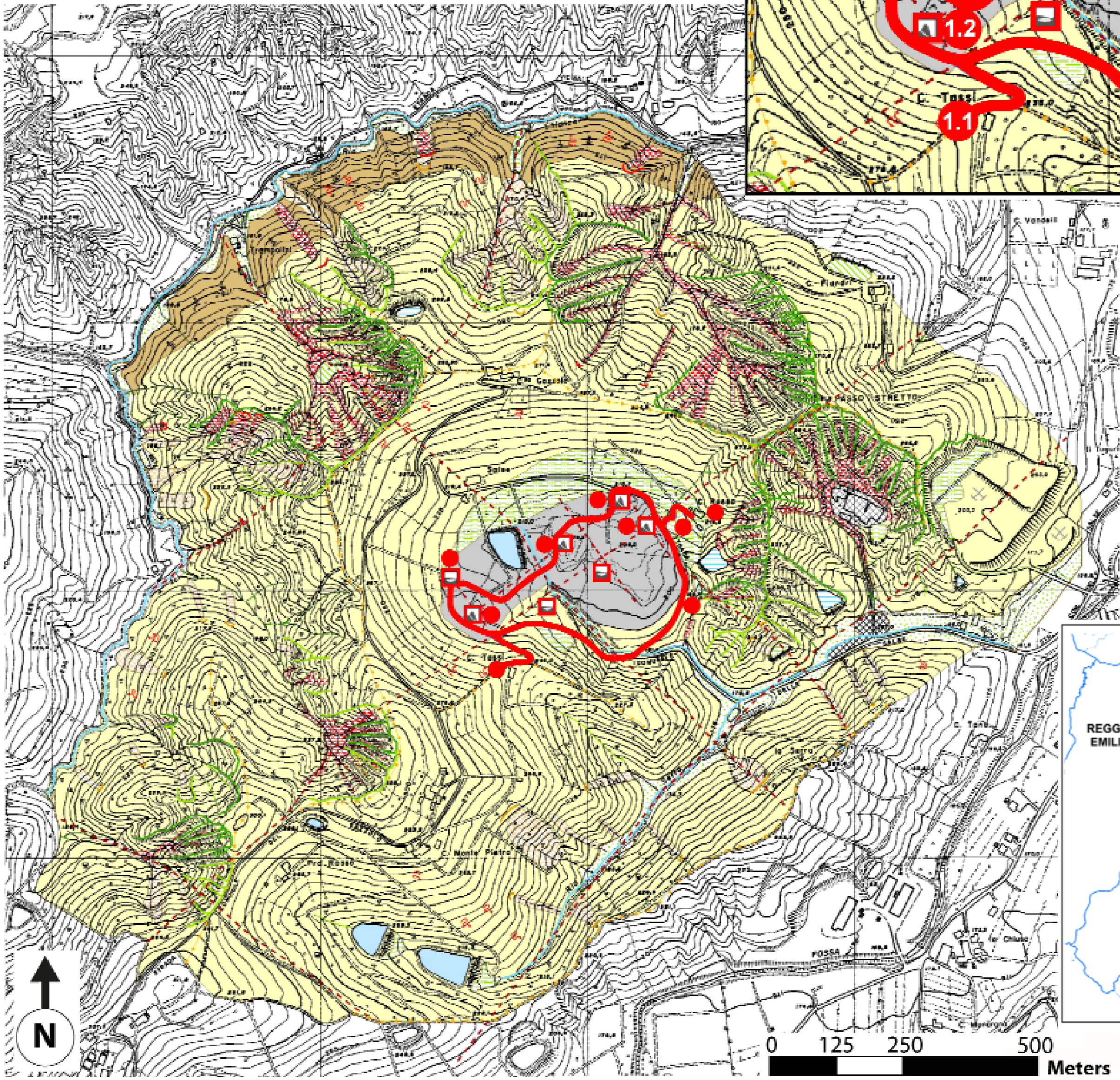
Active Dormant/Inactive

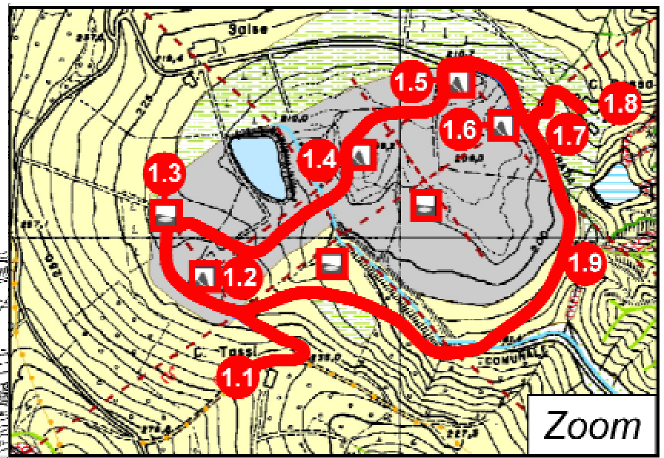
- Edge of badlands' scarp
- Gully
- Deposits of the main streams (texture from silt to clay, more than 1 m thick)
- Colluvial deposits (texture from silt to clay, more than 1 m thick)
- Palustrine deposits (texture mainly clayey, more than 1 thick)

ANTHROPOGENETIC LANDFORMS

Active Dormant/Inactive

- Heavely shaped area
- Quarring area
- Edge of artificial scarp
- Creep due to grazing
- Landfill
- Field trip itinerary
- Stop





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STOP 1.1: "Ca' Tassi" Visitor Centre

The "Ca' Tassi", literally the "badgers' house" is the starting point of the itinerary across the Salse di Nirano. This is the core of the services offered by the Reserve (Fig. 5). The building is constituted by an old rural complex, restored following bio-building techniques. The photovoltaic system, with its display showing instantaneously the energy produced and the amount of CO_2 saved, and the meteorological station allow to make simple, but significant considerations regarding the sustainability of the visitor centre and the micro-climate of the Salse's area.

Fig. 5 - Ca' Tassi: **(a)** Visitor Centre; **(b)** meteorological station; **(c)** natural and ornithological museum; **(d)** auditorium; **(e)** street view of Ca' Tassi.

The visitor Center hosts the natural and ornithological museum, the museum of fossils, the mineral museum and several multimedia educational devices, useful to understand the phenomenon of the Salse and to know the history of the Natural Reserve through panels, interactive games and educational boards. The Ca' Tassi has spaces dedicated to meetings with an auditorium and a conference room, a reception where it is possible to get information, to buy educational and explanatory aids, and a didactical laboratory for schools.

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STOP 1.2: The "High Salsa"

From the Ca' Tassi Visitor Centre, a walk of 150 m, leads to the western entrance to the integrated area. At the beginning of the complex, is located the oldest and the biggest salsa of the Mud Volcanoes Field, named the "High Salsa". This mud volcano consists of a complex of several smaller vents, some of them are actives, while others are exhausted.

The salse are the product of mainly gaseous (methane) and partly liquid (oil) hydrocarbons deposits. As they ascend to soil surface, they wash out silty-clay deposits of Plio-Pleistocene age. The erased fragments are referable to the Argille Azzurre Formation as well as to the underlying Eocene–Miocene epi-Ligurian and Cretaceous Ligurian units. This attribution is corroborated by the analysis of well-preserved microfossils (calcareous nannoplankton) contained in the mud.

This wide salsa is fenced, but during the visit with ecological guides it's possible to access on the mud volcano (Fig. 6a). The current activity of this cone is manifested by fresh mudflows and gas bubbling in the muddy water filling the crater. The volcanic complex is composed of more craters, characterized by the presence of single or multiple emissions but of smaller dimension. The crater has a unique appearance, unlike other similar craters of large cones, it is oval and not circular as well as very large (3 m high and 5-7 m wide). Around the apparatus, in various positions, there are pools while others are present on its flanks (Fig. 6b). A further peculiarity is represented by holes of few centimeters, located on the sides and the top of the apparatus. Here, in fact, besides the great oval crater there are other emission points. Depending on the density of the mud bursted, it is small pools or small adventitious cones. From the inside of the "High Salsa", looking in the direction N55°E is evident alignment of individual mud volcanoes, and the inverted L-shape forming with the last apparatus (Stop 1.6) (Fig. 6g).

The clayey materials ejected from the craters, often associated to fossils, cover the surrounding ground with mudflows. Therefore, owing to the constant emission of mud over time, the floor of this depression is covered by fine-grained deposits up to a few meters in thickness. The fossils are composed mainly by bivalves, such as *Anadara diluvii*, *Nucula piacentina*, *Venus* (*Ventricoloidea*) *nux*, *Aequipecten* (*Aequipecten*) *scabrella* and by gastropods, such as *Aporrhais uttingeriana uttingeriana*, *Heteropurpura polymorpha*, as well as *Natica* (*Naticarius*) *zigrina* and *Turritella* (*Haustator*) *vermicularis.*

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Fig. 6 - View of the High Salsa towards north **(a)**; the front slope (towards East) of large apparatus, wherever there are several small pools **(b)**; the oval crater very wide of the complex, with a thick mud and oily dark veils. In the pools at the base of the cone stretched in the north direction **(c)**; the summit of the cone in a southerly direction. In addition to the crater are also pools and small cones **(d)**; bubbles of mud (**e** and **f**); alignment of individual mud volcanoes, and the inverted L-shape forming with the last apparatus **(g)**.

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STOP 1.3: Pond-shaped mud volcanoes

Few meters WE from the "High Salsa", two pond-shaped mud volcanoes are presents. Although most mud volcanoes have a typical conical shape, they can assume a great variety of forms, depending on their shape and size which, in turn, depend on the degree of mobilization initiated by pore-fluid pressures, frequency and characteristics of their activity, and viscosity of the outflowing mud (Fig. 7). System of cones (single, double or multiple) of height ranging from a few decimeters to some meters may develop if dens mud is present. If the muddy mixture is liquid, ground level "pond-shaped" mud-volcanoes (diameters ranging from a few decimeters to some meters) are generally formed.

From a botanic point of view, the salse are a very selective habitat, because the salty mud and the physical characters of the clays are strongly conditioning the survival of plant species. So only the species that are well adapted to salt habitat can grow in the neighbouring of cones. Around the pond-shaped volcanoes, a graminaceous plant (*Puccinellia fasciculata)* has found the best adaptability to the worst conditions. The halophilic vegetation, is typical of Nirano mud volcanoes and is not found in the other salse of Emilia Region.

Fig. 7 - View of pond-shaped **(a)**, particular of pond-shaped mud volcano **(b)**, halophilic vegetation (**c** and **d**).

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STOP 1.4: The central cone-shaped mud volcano

The route from the Stop 1.3 to Stop 1.4 stretches directly on the ground, making a steep descent immersed in the greenery. All along the route were positioned illustrative panels on various environmental aspects of the Reserve written in Italian, in English and also in Braille.
The path crosses the Rio delle Salse, walking directly on muddy deposits of salsa at Stop 1.4. On the right side of the path two other pond-shaped mud volcanoes are presents.
This cone-shaped mud volcano is constituted by a single conic edifice, that is one of the most active of the Reserve. The current activity of this cone is manifested by fresh mudflows and gas bubbling in the muddy water filling the crater (Fig. 8a, b).
The fluids currently expelled at Nirano mostly consist of mud, gas bubbles (methane represents the largest part of emitted gases), and muddy water, which may also contain a small fraction of liquid hydrocarbons (Martinelli & Rabbi, 1998) (Fig. 8c, d and e).
Plants living near the mud ejecting points, are adapted to a persistent aridity, due to high clay content and salinity of the soil. These species, defined "xerophilous" (dry tolerant) and sometimes "alophilous" (salt tolerant), form populations ring-disposed around the salse, creating an excellent example, unique in Emilia Romagna, of typical vegetation (Fig. 8a).

Until a short time ago, methane emissions from this crater, were so high that the Ecological Guards of the Reserve, in occasion of particular events (such as this field trip), organized performances in which it was set fire to the gas emitted from the volcano. A tourist facility (Fig. 8f), located side to the volcanoes, allows to safely observe this spectacular event.
Along the flanks of the cones, it is also common to see animal footprints, that are attracted by humidity of mud constantly flowing out.

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Fig. 8 - View of cone-shaped mud volcano towards north **(a)**, particular of the salsa towards west **(b)**, bubbles of mud (**c**, **d** and **e**), tourist facilities to safely observe the mud volcano **(f)**.

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STOP 1.5: The border cone-shaped mud volcano

The way to Stop 1.5 continues on wooden walkway (Siti Aperti Itinerary), to allow the integral protection of the salse and to extent the accessibility to persons with disabilities.

The mud volcano at Stop 1.5 (Fig. 9a), likely the highest of the Reserve, is constituted by two distinct subgroups: the closer to the road composed by a main active cone and a minor one at a certain distance from the previous (towards SW) (Fig. 9b). During non-active periods, the mud volcanoes are subject to erosion by precipitation water and can be partially dismantled, until the following activity phases when they are rebuilt. Then, the number of gryphons varies with time, as well as their location.

“Xerophilous” and “alophilous” plants that grow around the mud ejecting points, forming a typical vegetation ring-disposed on the salse, are clearly evident in this Stop (Fig. 9a).

This apparatus is bordered by a variable number of satellites-pools, and in particular one located in the middle of the slope has maintained constant over time its position, its shape and its emission frequency. This little apparatus, has been used for about two decades as emission vent for scientific studies and research in this area (Fig. 9e).

Sometimes, in one of the level-pools happen to clearly identify the presence of hydrocarbons in the mud spilled, as evidenced by the pictures in Figure 9e.

The route stretches throughout the greenery of the reserve passing very close to a newly formed cone volcano, high about 1 m on the field, characterized by fast bubbling (Fig. 9f).

The wooden walkway ends directly on the municipal road. Following this to south, mud volcanoes of Stops 1.5 and 1.6 are clearly visible.

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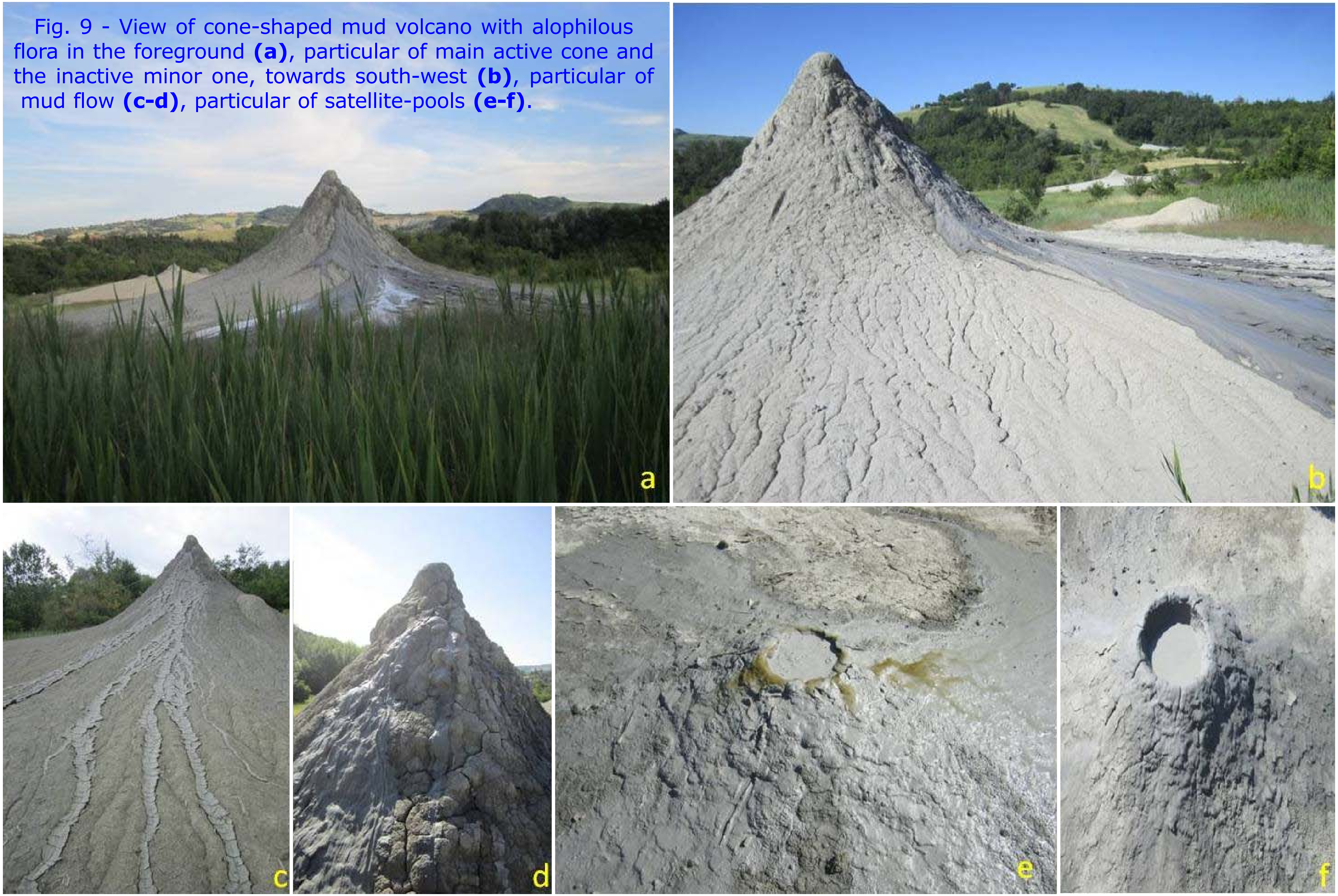

Fig. 9 - View of cone-shaped mud volcano with alophilous flora in the foreground **(a)**, particular of main active cone and the inactive minor one, towards south-west **(b)**, particular of mud flow **(c-d)**, particular of satellite-pools **(e-f)**.

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STOP 1.6: The eastern mud volcano complex

Continuing on the municipal road we arrive at the Stop 1.6. This mud volcano is constituted by more than six apparatus (Fig. 10a), among actives and not, and it is the most recently formed.
It is currently the largest and most dynamic of the whole field. From available cartographic documentation it seems to shift 30 metres toward South-East, with respect to the original position of beginning of 1900. This phenomenon could be due to the migration of emission pathways along faults that control the inverted L-alignment of mud volcanoes (Fig. 6g).
The activity of the mud volcanoes is not constant over time, show short eruptive periods alternated with long periods of dormancy with fluid emissions: meteorological factors, per example, can modify the bubble emissions and the mud flow. In summer, the muds' de-hydration due to high temperatures, can partially obstruct the up-welling channels, decreasing the activity at surface. During wetter seasons, the soft terrain and the increasing pressure of gas below the surface, allow the obstruction removal and the activity may restart. Also in this complex it's possible to note the populations ring-disposed around the salse of typical vegetation that living near the mud ejecting points.

Also seismic events may control the activity of Salse di Nirano. Indeed, episodes of intense activity of the mud volcanoes have been often correlated to local earthquakes (Stohr, 1869; Pantanelli & Santi, 1896; Pellegrini et al., 1982; Gorgoni et al., 1988) some days before the occurrence of these (Gorgoni, 2003). Per example, couple of days before of the strongest earthquakes of the Emilian seismic sequence of 2012 (May 20 and 29, M_L 5.9 and 5.8, respectively), an increased activity of Nirano mud volcanoes, that led to the morphology modification of the main volcanic apparatus, was visually recorded. On the other hand, such a direct earthquake-eruption connection has been determined only for a limited number of cases, as the great majority of mud volcano eruptions was not driven by regional seismicity.
In this Stop is clearly possible to note that methane can origin shallow trace on the mud flow. Indeed, besides the classic bubbling in the mud, can be highlights many small bubbles too. This event is especially marked when the mud emitted is dense and viscous. Little methane bubbles create many small circular holes with clearly evident marked edges.

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Fig. 10 - View of eastern mud volcano complex towards west **(a)**; peculiar small circular holes create by methane emission **(b)**; minor apparatus details **(c-g)**.

STOP 1.7: Newly formed pond-shaped mud volcanoes

After leaving the integral area, the itinerary carries on with the Ca' Rossa Ecomuseum. In the grove in front of the Ecomuseum two pond-shaped mud volcanoes, formed some days before the Garfagnana seismic event of January 25, 2013 (M_L 4.8), can be found (Fig. 11). The Garfagnana is an area at 35 km north of the Lucca city, wedged between the mountains of the Apuan Alps and the Tuscan - Emilian Apennines, not distant from Nirano (about 50 km as the crow flies).

Mud volcanoes are seemingly associated with more complicated plumbing systems (Mazzini et al., 2008), and are connected at depth to confined reservoirs that may record volumetric strain fluctuations induced by the seismogenic processes (Albarello, 2005).

These newly formed mud volcanoes are characterized by fine sediments likely related to the presence of colluvial deposits that in this sector overlie the clayey bedrock.

Fig. 11 - View of new pond-shaped mud volcanoes formed some days before the Garfagnana seismic event of January 25, 2013 (M_L 4.8).

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STOP 1.8: Ecomuseum Ca' Rossa

The itinerary inside the Nirano mud volcano field (NMVF) concludes to Ca' Rossa (literally "red house"; Fig. 12). This is a nineteenth-century rural building, owned by the Municipality, hosting the Ecomuseum. The building was recently restored using the latest green-construction and demotic techniques to limit energy consumptions. Ca' Rossa is a place of social participation that evokes the traditions through the exhibition of photographs, documents and tools. Inside the Ecomuseum an exhibition of peasant culture and agricultural heritage, is present. The predominant theme is the farmer in Nirano landscape, analyzed in all its possible nuances and especially with an emotional approach/experiential capable of stimulating the interest of a very diverse targets. A multisensory itinerary entitled "memorable tastes " promotes culinary products, especially oil, of which 3 panels illustrate the specific characteristics, the history throughout the ages and stages of production.


Fig. 12 - Ca' Rossa.

STOP 1.9: The badlands

From Ca' Rossa we retake the municipality road to south for Ca' Tassi. Nearly everywhere it is possible to observe badlands ("calanchi") in many cases stabilized by vegetation (Fig. 13). The badlands are one of the most spectacular forms of erosion of the Apennine margin.

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Badlands are characterized by a high-density hydrographic pattern with thin ridges that separate impluvium with debris on the bottom. In this context, landslides are widespread and largely active. Nowadays, the evolution of badlands occurs in many areas of the Reserve especially due to the landslides, that cause a fast retreating of the gullies. This process produces a thinning of the ridges separating badlands located on opposite sides and fills the valley with their clay deposits (Castaldini et al., 2007).

Fig. 13 - Several views of badlands surrounding the Salse di Nirano Reserve.

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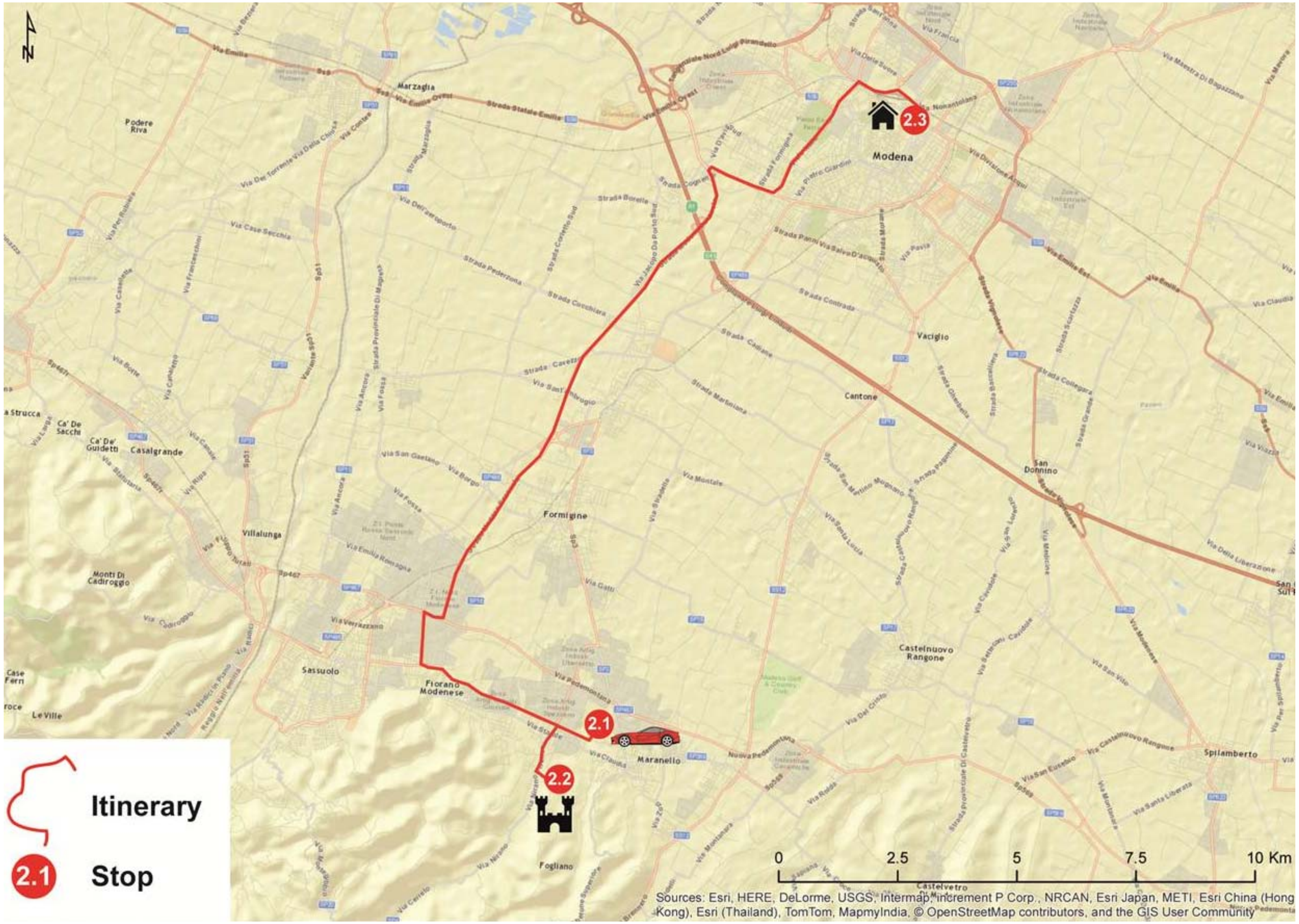
Day 2

The Itinerary of the second day brings the scientists inside a legendary world between history and passion, medieval castle and Ferrari.



Three touristic Stops (Fig. 14) will go throughout the Modena countryside allowing to test the typical balsamic vinegar and drive a Ferrari car along the historical roads of Maranello.

Fig. 14 - Day 2 itinerary with the location of the Stops (2.1-2.3).

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STOP 2.1: Ferrari Museum

Maranello, the kingdom of motors, awaits visitors at the Ferrari Museum where the birth and performance of a myth are narrated (Fig. 15). The Museum has a permanent section with the Victory Hall, where it is possible to find all the F1 cars World Championship the Scuderia Ferrari has won since 1999, the trophies and the World Champions history and the section dedicated to Formula 1 with the historical cars. Temporary exhibitions show all Ferrari models from the limited series which created the history of the Brand over the last 50 years and allow to discover the cars kept secret for experimentation and development. Many other attractions await visitors: a Screening Room where themed films are screened on a loop, Formula 1 simulators – a semi-professional one for adults and a junior one, based on an actual Formula 1 car; the opportunity of tackling a real tyre change, mega screens to view Grand Prix action, a large Ferrari Store and a welcoming cafeteria.

The museum is open all year round except for Christmas Day and New Year's Eve, from 09.30 – 18.00 (April/October 09.30 – 19.00). It is possible to purchase a combined ticket for the Museo in Maranello and the Museo Enzo Ferrari's Birthplace also online (http://museomaranello.ferrari.com/prices-and-tickets/).

Fig. 15 - Ferrari Museum in Maranello: Competitions Hall **(a)**; F2004 World Champion car of Schumacher M. **(b)**; Museum Enzo Ferrari's Birthplace in Modena **(c)**.

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Outside the Museum a private company allows to have a test drive with a "real Ferrari car" in Maranello. Turning towards Modena it is possible to reach the Fiorano Circuit, owned by Ferrari, hosting test sessions both for road and F1 Ferrari cars.

STOP 2.2: Spezzano Castle

The Castle of Spezzano dates back to medieval times to around the year 1200. The original fortification, traces of which can still be made out in the moat, the drawbridge and the battlemented walls, was transformed by the Pio Lords of Carpi into a noble palace surrounding an elegant portico and Renaissance courtyard (Fig. 16).

Fig. 16 - View of Spezzano Castle **(a)**; portico and courtyard **(b)**; entrance to the castle **(c)**; vinegar barrels **(d)**; fresco painting **(e)**; ancient ceramic product **(f)**.

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The main stairway opens onto the piano nobile of the large Galleria delle Battaglie, whose walls are decorated with frescoes telling of the deeds of Duke Alfonso I d'Este. The piano nobile is home to the sixteenth-century Pio di Savoia apartment, with the Sala delle Vedute, a majestic ceremonial room facing onto the courtyard. Still visitable and of great fascination are the prisons, displaced in the pentagonal tower, which conserve an ancient straw bed of wooden planks as well as hundreds of curious inscriptions left behind by the prisoners. The pentagonal tower is home to the Municipal Vinegar Works. Consisting of three batteries of Traditional Balsamic Vinegar from Modena, it features original furnishing and equipment: flasks, test tubes, barrels, kegs and buckets. The first floor of the building is home Fiorano's Museo della Ceramica (Ceramics Museum), which documents the techniques and production methods used for ceramics from the Neolithic to modern-day floor tiles. The castle is surrounded and hidden to visitors' eyes by a splendid historic park whose layout dates to the end of the nineteenth century.
The Castle is open from May to November from 3 p.m. to 7 p.m. with free entrance.
For information and booking guided tours contact the Cultural Office of Fiorano Modenese (http://www.castellidimodena.it/page.asp?IDCategoria=287&IDSezione=5850).

STOP 2.3: Museum Enzo Ferrari's Birthplace

The Museum Enzo Ferrari' Birthplace (MEF) in Modena, extends on about 6.000 m^2 and includes Enzo Ferrari's Birthplace and a futuristic automotive design gallery, painted in the yellow that Enzo Ferrari chose as the background for the Prancing horse on his famous logo (Fig. 15c). The interior features a multimedia display of pictures, unpublished films and precious mementoes of Enzo Ferrari's life as a man, driver and car-maker throughout the 20th century. Cars, protagonist of the mounting and exhibited like works of art on design platforms, are periodically changed according to the temporary exhibition organized, with a renewable exhibition method.

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References

Albarello D. (2005) - Mud volcanoes as natural strainmeters. A working hypothesis. In: Martinelli G. & Panahi B. (Eds.), Mud Volcanoes, Geodynamics and Seismicity. Springer, the Netherlands, 239-249.
Barber T. & Brown K. (1988) - Mud diapirism: The origin of mélanges in accretionary complexes? Geology Today, v. 4, p. 89–94.
Barber A., Tjokrosapoetro S. & Charlton T. (1986) - Mud volcanoes, shale diapirs, wrench faults, and melanges in accretionary complexes, eastern Indonesia. AAPG Bull., 70, 1729-1741.
Barbieri G. (1947) - Nuove osservazioni sulle salse emiliane. Riv. Geogr. It., 54, 172-185.
Benedetti L.C., Tapponnier P., Gaudemer Y., Manighetti I. & Van der Woerd J. (2003) - Geomorphic evidence for an emergent active thrust along the edge of the Po Plain: The Broni-Stradella fault. J. Geophys. Res., 108(B5), 2238, doi:10.1029/2001JB001546.
Bertacchini M. (2009) - GeoBenessere. La geologia tra salute e wellness. Artestampa Ed., Modena, p. 131.
Bertacchini M., Giusti C., Marchetti M., Panizza M. & Pellegrini M. (eds.) (1999) - I beni geologici della Provincia di Modena. Artioli Ed., Modena, 104 pp.
Bertolani M. (1980) - Fiorano e il suo territorio. Doc. e Ric. Comune di Fiorano Modenese, 1-24.
Biasutti R. (1907) - Le salse dell'Appennino settentrionale. Mem. Geogr. II, pp. 101-255.
Boccaletti M., Bonini M., Corti G., Gasperini P., Martelli L., Piccardi L., Tanini C. & Vannucci G. (2004) - Seismotectonic map of the Emilia-Romagna region, scale 1:250,000, with explanatory notes. S.EL.CA., Florence, Italy.
Bonini M. (2007) - Interrelations of mud volcanism, fluid venting, and thrust-anticline folding: Examples from the external northern Apennines (Emilia-Romagna, Italy). J. Geophys. Res., 112, B08413, doi:10.1029/2006JB004859.
Bonini M. (2008) - Elliptical mud volcano caldera as stress indicator in an active compressional setting (Nirano, Pede-Apennine margin, northern Italy). Geology, 36, 131-134.
Bonini M. (2009) - Mud volcano eruptions and earthquakes in the Northern Apennines and Sicily, Italy. Tectonophysics, 474, 723–735.
Bonini M. (2012) - Mud volcanoes: Indicators of stress orientation and tectonic controls. Earth-Science Reviews 115, 121-152.
Brown K.M. (1990) - The nature and hydrological significance of mud diapirism and diatremes for accretionary systems. J. Geophys. Res., 95, 8969–8982.
Brown K.M. & Orange D.L. (1993) - Structural aspects of diapiric mélange emplacement: The Duck Creek diapir. Journal of Structural Geology, 15(7), 831–847.
Camerlenghi A., Cita M. B., Hieke W. & Ricchiuto T. (1992) - Geological evidence for mud diapirism on the Mediterranean Ridge accretionary complex. Earth and Planetary Science Letters, 109, 493-504.
Capozzi R., Menato V. & Rabbi E. (1994) - Manifestazioni superficiali di fluidi ed evoluzione tettonica recente del margine Appenninico Emiliano-Romagnolo: indagine preliminare. Atti Ticinesi Sc. Terra, 1, 247-254.
Capozzi R. & Picotti V. (2002) - Fluid migration and origin of a mud volcano in the Northern Apennines (Italy). The role of deeply rooted normal faults. Terra Nova, 14, 363-370.

Carobene L. & Gasperi G. (2008) – Vulcanetti di fango a Nirano (Modena). GeoItalia, 25, 42-43.

Castaldini D., Chiriac C., Ilies D.C. & Barozzini E. (2003) - Documenti digitali per la conoscenza integrata dei Geositi: l'esempio della Riserva Naturale delle Salse di Nirano. In: S. Piacente & G. Poli (eds.), La Memoria della Terra. Regione Emilia Romagna. Ed. L'inchiostro blu. Bologna, 121-127.

Castaldini D., Conti S., Conventi M., Dallai D., Del Prete C., Fazzini M., Fontana D., Gorgoni C., Ghinoi A., Russo A., Sala L., Serventi P., Verri D. & Barbieri M. (2007) – Le Salse di Nirano. CD ROM. Enciclopedia Multimediale. Comune di Fiorano Modenese.

Castaldini D., Conventi M., Coratza P. & Liberatoscioli E. (2011) – La "Nuova" Carta Turistico - Ambientale della Riserva Naturale Regionale delle Salse di Nirano (Appennino Modenese, Italia Settentrionale). Bollettino A.I.C. nr.143/2011, I275-289.

Coppi F. (1875) - Brevi note sulle Salse Modenesi. Bollettino del R. Comitato Geologico, 7-8, 1-7.

Delisle G., Von Rad U., Andruleit H., Von Daniels C. H., Tabrez A. R. & Inam A. (2002) - Active mud volcanoes on- and offshore eastern Makran, Pakistan. International Journal of Earth Sciences, 91, 93-110.

Deville E. & Prinzhofer A. (2003) - Vulcani di fango. Le Scienze, 421, 84-90.

Dimitrov L.I. (2002) - Mud volcanoes – the most important pathway for degassing deeply buried sediments. Earth-Science Reviews, 59, 49-76.

Etiope G. & Klusman R.W. (2002) - Geologic emissions of methane to the atmosphere. Chemosphere, 49, 777-789.

Etiope G., Caracausi A., Favara R., Italiano F. & Baciu C. (2002) - Methane emission from the mud volcanoes of Sicily (Italy). Geophys. Res. Lett. 29, 1215. doi:10.1029/2001GL014340.

Ferrari C. & Vianello G. (1985) - Le Salse dell'Emilia-Romagna. Regione Emilia-Romagna, Collana Assessorato Ambiente, 116-118.

Gasperi G., Cremaschi M., Mantovani Uguzzoni M.P., Cardarelli A., Cattani M. & Labate D. (1989) - Evoluzione Plio-Quaternaria del margine appenninico modenese e dell'antistante pianura. Note illustrative alla Carta Geologica. Mem. Soc. Geol. It., 39, 431 pp.

Gorgoni C. (2003) - Le salse di Nirano e le altre salse emiliane - I segreti di un fenomeno tra mito e realtà - Comune di Fiorano Modenese. Tip. ABC, Sesto Fiorentino (Firenze), 128 pp.

Gorgoni C., Bonori O., Lombardi S., Martinelli G. & Sighinolfi G.P. (1988) - Radon and helium anomalies in mud volcanoes from northern Apennines (Italy) – a tool for earthquake prediction. Geochemical Journal, 22, 265-273.

Gruppo di Lavoro CPTI (1999) - Catalogo parametrico di terremoti italiani - ING-GNDT-SGA-SSN, Bologna, 88 pp. (version available on the web site).

Guidoboni E. (Ed.) (1989) - I terremoti prima del Mille in Italia e nell'area mediterranea: Storia, archeologia, sismologia. Istituto Nazionale di Geofisica-Storia Geofisica Ambiente, Bologna. 766 pp.

Guliyev I.S. & Feizullayev A.A. (1997) - All about mud volcanoes. Nafta Press, Baku, 52 pp.

Heinicke J., Braun T., Burgassi P., Italiano F. & Martinelli G. (2006) - Gas flow anomalies in seismogenic zones in the Upper Tiber Valley, Central Italy. Geophysical Journal International, 167, 794–806.

Higgins G. & Saunders J.B. (1974) - Mud volcanoes - their nature and origin. In: Contributions to the Geology and Paleobiology of the Caribbean and Adjacent Areas (Jung P. et al. Eds.). Verh. Aturforsch. Ges., 84(1), 101-152.

Hovland M., Gallagher J.W., Clennell M.B. & Lekvam K. (1997) - Gas hydrate and free gas volumes in marine sediments: Example from the Niger Delta front. Mar. Petr. Geol., 14(3), 245–255, doi:10.1016/S0264- 8172(97)00012-3.

Kopf A. (2002) - Significance of mud-volcanism. Review of Geophysics, 40 (2), 1-52.
Kopf A., Robertson A.H.F. & Volkmann N. (2000) - Origin of mud breccia from the Mediterranean Ridge accretionary complex based on evidence of the maturity of organic matter and related petrographic and regional tectonic evidence. Mar. Geol., 166, 65-82.
Ivanov M.K., Limonov A.F. & van Weering T.C.E. (1996) - Comparative characteristics of the Black Sea and Mediterranean Ridge mud volcanoes. Mar. Geol., 132, 253-271.
Limonov A.F., Woodside J., Cita M. & Ivanov M.K. (1996) - The Mediterranean Ridge and related mud diapirism, a background. Mar. Geol., 132, 7-19.
Mantovani E., Viti M., Babbucci N., Cenni N., Tamburelli C., Vannucchi A., Falciani F., Fianchisti G., Baglione M., D'Intinosante V., Fabbroni P., Martelli L., Baldi P. & Bacchetti M. (2013) – Assetto tettonico e potenzialità sismogenetica dell'Appennino Tosco-Emiliano-Romagnolo e Val Padana. Regione Emilia Romagna – Regione Toscana-Università di Siena, 168 pp.
Martinelli G. (1999) – Mud volcanoes of Italy: a review. Giornale di Geologia, ser. 3, 61, 107-113.
Martinelli G. & Rabbi E. (1998) - The Nirano mud volcanoes. In: in Vth International Conference on Gas in Marine Sediments. Abstracts and Guide Book, Bologna, Italy, September 1998, edited by P.V. Curzi & A. Judd, 202-206, Grafiche A & B, Bologna, Italy.
Martinelli G. & Judd A. (2004) - Mud volcanoes of Italy. Geol. J., 39, 49-61.
Martinelli G., Albarello D. & Mucciarelli M.(1995) - Radon emissions from mud volcanoes in northern Italy: possible connection with local seismicity. Geophys. Res. Lett., 22, 1989–1992.
Martinelli G., Bassignani A., Ferrari G. & Finazzi P.B. (1989) - Predicting earthquakes in Northern Apennines: recent developments in monitoring of Radon 222. Proceedings of the 4th International Symposium on The Analysis of Seismicity and Seismic Risk, Bechyne Castle, Czechoslovakia, 4–9 September 1989, 192–208.
Martinelli G. & Panahi B. (Eds.) (2005) - Mud volcanoes, geodynamics and seismicity. NATO Science Series IV. Earth and Environmental Sciences, 51, 288 pp.
Mazzini A., Svensen H., Planke S., Guliyev I., Akhmanov G.G., Fallik T. & Banks D. (2008) - When mud volcanoes sleep: Insight from seep geochemistry at the Dashgil mud volcano, Azerbaijan. Marine and Petroleum Geology, 26(9), 1704-1715, doi:10.1016/j.marpetgeo.2008.11.003.
Mazurenko L.L. & Soloviev V.A. (2003) - Worldwide distribution of deep-water fluid venting and potential occurrences of gas hydrate accumulations. Geo-Marine Letters, 23, 162-176.
Mellors R., Kilb D., Aliyev A., Gasanov A. & Yetirmishli G. (2007) - Correlations between earthquakes and large mud volcano eruptions. J. Geophys. Res., 112, B04304, doi:10.1029/2006JB004489.
Milkov A.V. (2000) - Worldwide distribution of submarine mud volcanoes and associated gas hydrates. Mar. Geol., 167, 29–42.
Mucchi A.M. (1966) - Il fenomeno delle salse e le manifestazioni del Modenese. Atti Soc. Nat. Mat. Modena, 97, 1-31.
Mucchi A.M. (1968) - Le salse del Modenese e del Reggiano. L'Universo, 48 (3), 421-436.
Nanni T. & Zuppi G.M. (1986) – Acque salate e circolazione profonda in relazione all'assetto strutturale del fronte adriatico e padano dell'Appennino. Mem. Soc. Geol. It., 35, 979-986.
Orange D.L. (1990) - Criteria helpful in recognizing shear zone and diapiric mélanges: Examples from the Hoh Accretionary Complex, Olympic Peninsula, Washington. Geological Society of America Bulletin, 102, 935–951.

DOI: 10.3301/GFT.2015.01

Panizza M. (1992) - Geomorfologia. Pitagora Ed., Bologna, 397 pp.
Pantanelli D. & Santi V. (1896) – L'Appennnino Modenese. Ed. Cappelli, Rocca San Casciano, Ristampa 1996, Ed. Iaccheri, Pavullo nel Frignano.
Pellegrini M., Brazzorotto C., Forti P., Francavilla F. & Rabbi E. (1982) - Idrogeologia del margine pedeappenninico emiliano-romagnolo, In: G. Cremonini & F. Ricci Lucchi (eds.) – Guida alla geologia del margine appenninico-padano. Guida Geol. Reg., Soc. Geol. It., Bologna, 183-189.
Pieri M. & Groppi G. (1981) - Subsurface geological structure of the Po Plain, Italy. C.N.R., pubbl. 414, P. F. Geodinamica, 13, 7, 13 pp.
Planke S., Svensen H., Hovland M., Banks D.A. & Jamtveit B. (2003) - Mud and fluid migration in active mud volcanoes in Azerbaijan. Geo-Marine Letters, 23, 258–268, doi: 10.1007/s00367–003–0152-z.
Ramazzini B. (1698) - De Petrolio Montis Zibinii. Modena.
Rovida A., Camassi R., Gasperini P. & Stucchi M. (eds) (2001) - CPTI11, the 2011 version of the parametric catalogue of Italian earthquakes. Milano, Bologna http://emidius.mi.ingv.it/CPTI, doi: 10.6092/INGV.IT-CPTI11.
Scicli A. (1972) - L'attività estrattiva e le risorse minerarie della Regione Emilia-Romagna. Artioli Modena, 626 pp.
Shakirov R., Obzhirov A., Sueze E., Aalyuk A. & Biebow N. (2004) - Mud volcanoes and gas vents in the Okhotsk Sea area. Geo-Marine Letters, 24, 140-149.
Spallanzani L. (1792) - Viaggi alle Due Sicilie e in alcune parti dell'Appennino, Pavia.
Stewart S.A. & Davies R.J. (2006) - Structure and emplacement of mud volcano systems in the South Caspian Basin. AAPG Bull., 90, 771–786.
Stoppani A. (1873) - Il Bel Paese. Milano, 651 pp.
Stoppani A. (1908) - Il Bel Paese: conversazioni sulle bellezze naturali: la geologia e la geografia fisica d'Italia, 662 p.
Stohr R. (1869) - Intorno agli strati terziari superiori di Montegibbio e vicinanze. Atti Soc. Nat. Mat. Modena, 4.
Tosatti G. (2002) - The Mud Volcanoes of Salse di Nirano. In: P. Coratza & M. Marchetti (eds.), Geomorphological Sites: Research, Assessment and Improvement, Workshop Proceedings, 19-22 June 2002, Modena, pp. 95-97.
Treves B. (1985) - Mud volcanoes and shale diapirs. Their implications in accretionary processes. A review. Acta Naturalia Ateneo Parmense 21, 31-37.
Yassir N. (2003) - The role of shear stress in mobilizing deep-seated mud volcanoes: geological and geomechanical evidence from Trinidad and Taiwan. Geol. Soc. Am. Spec. Publ., 216, 461-474.

DOI: 10.3301/GFT.2015.01