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Geological and Geochemical Setting of Natural Hydrocarbon Emissions in Italy

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1. Introduction

Hydrocarbons are hosted in underground geological formations and they can slowly migrate under the action of the lithostatic load and tectonic activity. Spontaneous hydrocarbon emissions can be detected on the earth surface and have historically drawn man's attention, and have even been the subject of health or religious cults. The natural hydrocarbon emissions were already well known in the ancient world, in particular during the classical age. Aristotle recalled the kitcgchen of the persian Kings fed by natural fossil fuel seeps (Montesauro Veronesi 1585). Lucretius described flammable gaseous emissions in his *DeRerum Naturae*. Pliny (23 A.D.-79 A.D.) wrote in his *Historia Naturalis* said that in the Syrian city of Commagene a pond existed expelling a burning loam called "malta" (Bianconi, 1840). In about the whole of Italy the various levels of interest paid to hydrocarbons by local inhabitants and in economic and industrial structure are recognizable in the historical and archeological documentation. During the Renaissance the mud volcano cluster of Sassuolo (meaning "*Boulder of the Oil*") near Modena, the largest in Italy, was particularly famous due to the possible medical properties of the their brackish waters (Scicli 1972) . That area was thus the first to be explored and exploited in the second half of the 19th century. The first database compilers acquired field information from the knowledge of salutiferous and religious cults widely known in the ancient specialized literature (Bacci 1571). Local detailed maps and lists of hydrocarbon seepages were compiled in the period 1850-1950 with the purpose of addressing the drilling strategies. The modern studies in Italy begun with the description of many hydrocarbon emissions recorded by Camerana and Galdi (1911; Biasutti 1907) in Emilia Region . Successively the recognition was extended to the whole of Italy (e.g. Camerana et al., 1926). This study phase lasted up to the end of the 1940s (Zuber 1938; Idem 1940) and the last traces of this approach to the research can be found up to 1969 (Martinis 1969; Reeves 1953). The advent of modern geophysical prospection methods (e.g. Accademia Nazionale dei Lincei and Ente Nazionale Idrocarburi 1948) and the growth of new study trends such as the isotopes geochemistry in the two last decades of the past century (Mattavelli et al. 1983; Lindquist 1999; Casero 2004, Bertello et al. 2010) lowered the importance of those former empirical methodologies. Thus no traces of interest can be found in the last modern handbooks dedicated to the petroleum

sciences (ENI 2009). Furthermore, the growing of the anthropogenic impact on the landscape (eg. roads and towns building) erased a great deal of natural evidence of hydrocarbon occurrences. The scientific literature has only recently has renewed its attention to the databases of gas or oil natural emissions and a possible loss of knowledge of sites related to hydrocarbon occurrence. In recent years Martinelli and Judd (2004), Etiope et al. (2009, and references therein) etc. recovered information on the occurrence and chemical composition of gaseous hydrocarbons bubbling in mud volcanoes. Furthermore current scientific literature has devoted attention to some spontaneous gaseous non mud-volcanic emissions as well but a large part of the small or low flow rate methane and oil emissions has been not listed. Since the recovery of the old geographical information and modern geochemical data set can help to achieve a better understanding of the geological phenomena related to deep fluid accumulation and migration (Minissale et al. 2000; Capozzi and Picotti 2010), faulting linked to the crustal stress field , natural greenhouse emissions (Etiope et al. 2009), etc., the present paper is devoted to a first recovery attempt of the available historical as well as recent information on the natural hydrocarbon emissions and to its comparison with the updated findings on Italy's geological features. A map of hydrocarbon gas seepages has been made and commented together with available analytical data on natural hydrocarbon emissions (see below). Hydrocarbon seepages drove the hydrocarbon exploration strategies and allowed for the discovery of important gas and oil rock sources. Most of the hydrocarbon accumulations are found in the foreland and in foothill areas whereas they are less frequent in mountain chain areas because of tectonic activity or of high heat flow areas. By moving in a subduction zone from the back arc tensive area, through the main thrust area, to the foredeep-foreland area, compression became dominant and newly formed sedimentary sequences were subjected to strong subsidence and compaction. In this kind of ambient the abundant organic matter and its chemical alteration produced hydrocarbons that tend to be squeezed towards the surface, mostly along fault systems. The main gas accumulations are located along a strip parallel to the Apenninic chain (Fig. 1). In particular, in the foredeep main biogenic gas accumulations occur due to high subsidence, sinsedimentary tectonics and turbidite sedimentation. In the Apennine chain gas of thermogenic origin is prevalent due to intense tectonic activity (Mattavelli and Novelli, 1988). Most of the Adriatic and Sicilian oils are high density while the northern Apennine oils are lighter, probably because of a more effective thermal differentiation. Heavy oils originated from Mesozoic rocks while those in the chain have a more diverse origin (Pieri and Mattavelli, 1986). A comparison with the available upper crustal sections reveals main escape conduits along faulted rock volumes. Surface hydrocarbon occurrences are represented by gas and oil seeps and mud volcanoes. At time gas seeps are accompanied by cold or warm water springs due to gas interactions with less deep groundwater circulation paths. Mud volcanoes are well-known gaseous seepages bubbling in a liquid consisting of clay minerals and brackish water. They are chiefly related to areas of tectonic compression characterized by thick sedimentary sequences. Their occurrence is limited to the continental Appeninic chain and Sicily. Some hydrocarbons seeps, sinkholes and mud volcanoes were reported offshore within a few kilometers of the coast and their origin has been recognized to be similar to continental hydrocarbon emissions (Curzi et al. 1998; Camerlenghi and Pini 2009; Fusi et al 2006;Praeg et al. 2009; Holland et al.2003).

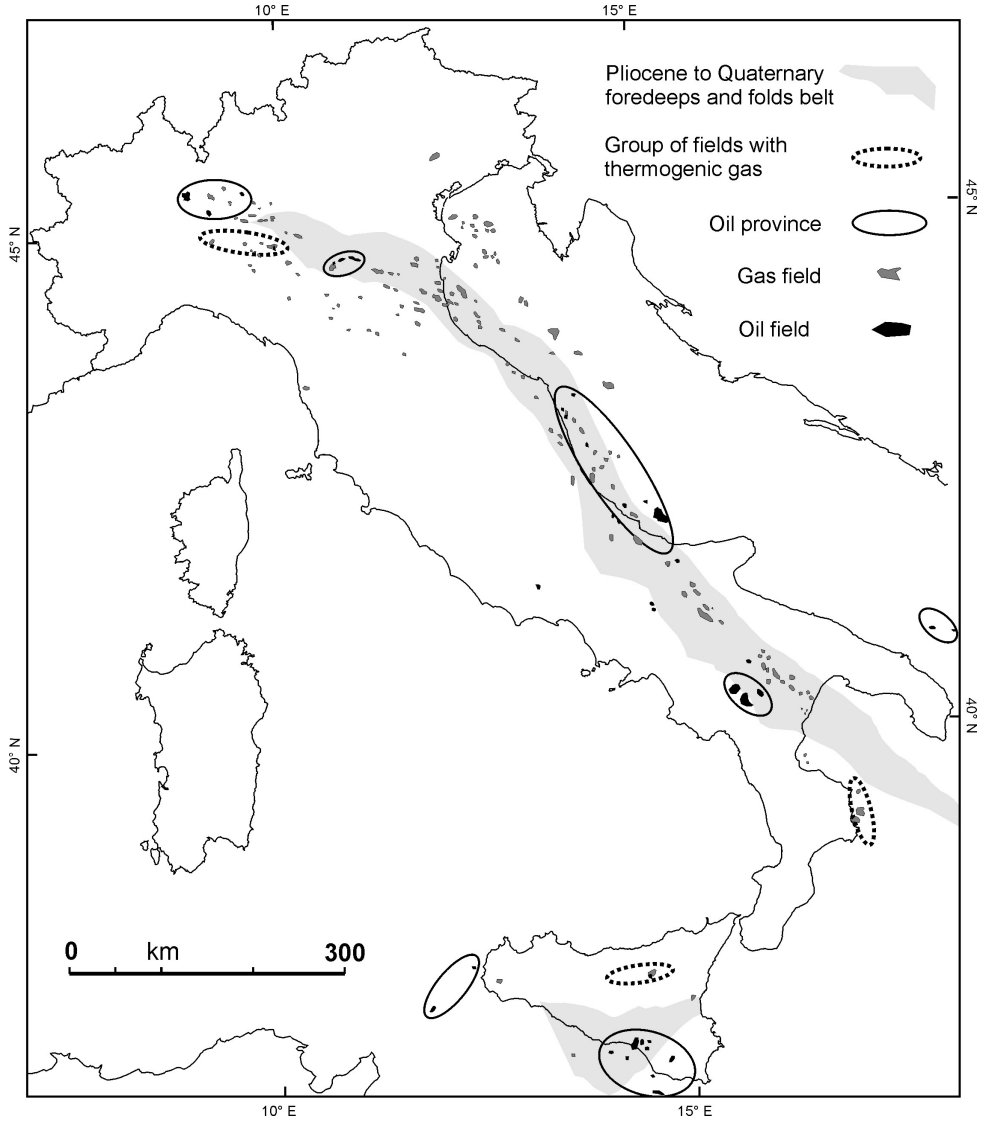

Fig. 1. Distribution of main hydrocarbon reservoirs in Italy
(after Casero 2004, Sheet 1 and Bertello et al. 2010; redrawn).

2. Geological framework

Two main tectonic events are responsible for Italy's present geological setting: 1) extensional tectonics from the Jurassic to the Early Cretaceous; 2) compressional tectonics from the Cretaceous to the Quaternary. The extensional tectonics occurred during the separation of Africa and Europe determining the origin of a new ocean (Tethis). Therefore, the Italian

peninsula and Sicily, as a part of an African microplate (Adria or Apulia indenter), was affected by subsidence and fragmentation as an isostatic response to crustal thinning of the passive continental margin. Triassic to early Cretaceous carbonate sediments were mainly deposited during the extensional tectonics that preceded and accompanied the oceanic opening. Euxinic conditions were present before and during this passive margin regime in the Middle-Late Triassic (pre-rifting stage). The Triassic source rocks are formed by thick black limestones and shales and were deposited in lagoons or mainly in narrow discontinuous troughs, originated by rifting and/or transcurrent movements (Catalano and D'Argenio 1982). Compressional tectonics due to the convergence of African and European plates began in the Cretaceous and caused the Alpine orogeny. The Alps and then the Apennines were thus formed and the Italian peninsula took shape. The origin of these chains was complex and occurred during various tectonic phases characterized by different vergences. The Alpine structures, north of the Insubric line, were piled up onto the European continental margin according to a north-vergence and the southern Alps and Apennines were pushed onto the African margin. Southern Alps and the Apennines were formed more recently than the Alps and their origin was mainly due to the Neogene tectonic events (Castellarin et al. 1992; Vai and Martini 2001). In particular, the earliest compressive phases, which occurred during the Aptian-Albian and Cenomanian-Turonian, were accompanied by anoxic events. Nevertheless, Cretaceous organic rich sediments were characterized by a more widespread distribution but distinctly thinner sequences in comparison with Triassic and Jurassic anoxic facies. The deposition of the terrigenous sediments mainly during compressional tectonics was a consequence of the generation of the new mountain belts. These deposits are chiefly formed by thick Tertiary turbidites, deposited in elongated basins parallel to the Apennines chain (Mutti and Ricci Lucchi 1972). Anoxic facies were not recognized in Tertiary sequences but the preservation of organic matter deposited in the external part of the turbidites was favored by a rapid burial in the more active subsiding areas (Mattavelli and Novelli, 1988). Thus, the origin and distribution of gas fields in Italy was linked to the Neogene tectonic and sedimentary events related to the Southern Alps and the Apennines surrection. During the Neogene three main tectono-sedementary domains characterized the general framework of Italy: Southern Alps; Apennine chain with its foredeep, the related foreland. Most of the Italian gas fields were discovered in the Neogene turbiditic sequences of the Plio Pleistocene. Condensate gas fields have been also found in the deep Mesozoic carbonate rocks of Northern Italy and some gas accumulations of Central and Southern Italy were found in Late Cretaceous limestones.

3. Liquid hydrocarbons source rocks

At least five important source rocks have been recognized which are distributed in age from Mesozoic to Pleistocene. Three of them were deposited during Mesozoic crustal extension and are mainly oil-prone. The deposition of organic-rich sediments in restricted basins began during the Middle-Late Triassic and Early Jurassic extensional phases pre-dating the break-up of Pangea. Discontinuous anoxic basins developed in the southern Alps, southern Apennines and Sicily (Pieri and Mattavelli, 1986). Hydrocarbon occurrences associated with these sources are usually found in complex carbonate structures along the Apennines thrust-and-fold belt and in the foreland. Two other important source rocks were generated in the foredeep terrigenous units which formed during the Alpine and Apennine Cenozoic orogenesis (Casero 2004; Bertello et al., 2010). The older source rocks are thermogenic gas-prone and are found in the highly tectonized Oligo-Miocene foredeep wedges: gas

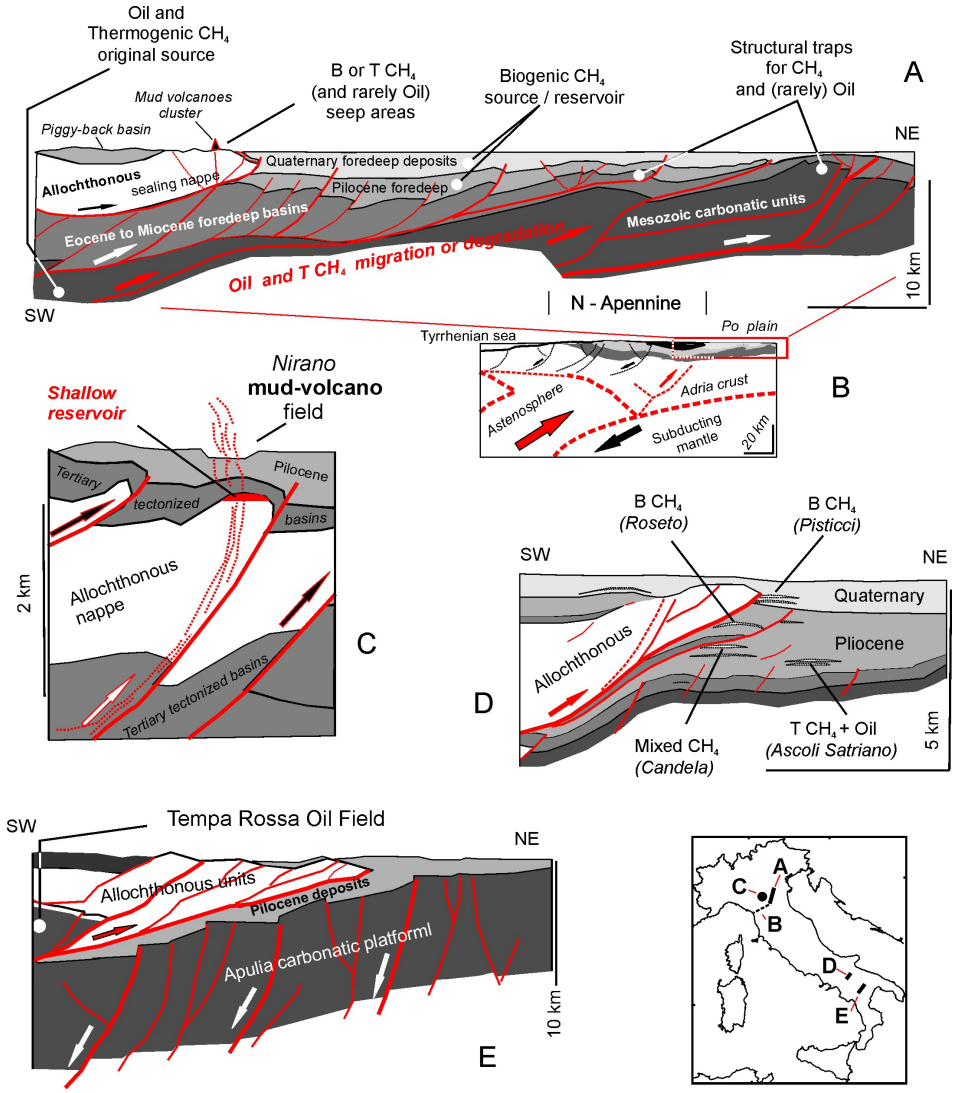

Fig. 2. Schematic transects of gas setting across the Apennine Chain (related location are shown in the vignette lying in the lower right corner). A) Ideal, simplified stratigraphic section (after Boccaletti and Martelli 2004, redrawn) showing an average outline of the relationships existing among lithology, tectonics, oil and methane types in the northern Apennine and related foredeep. B) Outline of the structural setting of the northern Appennine Chain (after Picotti and Pazzaglia, fig. 1, redrawn). C) An explaining model for a mud volcano activity in the northern Apennine (*Nirano* case) (after Bonini 2007, fig 5 and 9, redrawn). D) Hydrocarbon trends geological setting in the *Candela-Roseto* gas field (after Casero 2004, Plate 4, section 4a bis, redrawn). E) Geological setting of the *Tempa Rossa* oil field (after Bertello at al. 2010, fig. 6C, redrawn).

occurrences associated with the gas source are mainly concentrated along the northern Apennines margin, in Calabria and Sicily. The younger source rocks are biogenic gas-prone and are located in the outer and recent Plio-Pleistocene foredeeps of Po plain and northern Adriatic Sea. (eg. Casero 2004; Ministero Sviluppo Economico and Assomineraria 2008). About 95% of Italian oils were generated from source rocks related to the first described group (Mattavelli et al 1993). Anyway, no significant reservoired hydrocarbons can be correlated to these deposits due to migration processes linked to the subsequent tectonism . In the Tertiary era the organic content of the flysch shales also generated a minor amount of oil in the northern and southern Apennines. Maturation of the above-mentioned Mesozoic and Tertiary source rocks was induced by regional tectonic factors characterizing the different structural settings. The Late Neogene tectonism had a major role in the fold and thrust belt, both for the burial and maturation of source sediments under thick thrust sheets and for the development of hydrocarbon traps (Mattavelli and Novelli, 1990). However oil was generated during Jurassic-Palaeogene times from Late Triassic sources and could possibly have been preserved by early migration in traps at the top of the carbonate sequence (Casero et al., 1991). Heavy oils are prevalent in the foreland and foredeep domains, whereas light oils prevail in the thrust belt. Thermogenic gas was also generated during oil maturation (Mattavelli et al.1993). (Fig. 2)

4. Gas source rocks

Most of the Italian natural gases have been generated through bacterial fermentation and/or low temperature thermochemical reactions in immature Plio-Pleistocene sediments of the Apennine foredeep (Mattavelli and Novelli 1988). Bacterial gas is characterized by almost pure and isotopically light methane (Mattavelli et al., 1983). Its generation and accumulation is essentially favoured by high sedimentation rates, the deposition of alternating sands and shales, and synsedimentary tectonics, with the early genesis of structural traps (Pieri and Mattavelli 1986). The distribution of discovered original gas reserves is shown in Fig. 1. Thermogenic gas is confined to the thrust belt structural domain, whereas bacterial gas is distributed in the Pliocene-Pleistocene reservoirs of the external thrust belt and of the foredeep. The rapid burial and turbiditic sedimentation associated with very early compressional tectonics represented the ideal conditions for the formation and accumulation of biogenic gases. The peculiarity of the Apennine foredeep is the high percentage of biogenic gas which is great part of the total amount of hydrocarbons discovered over the past half a century in Italy (Mattavelli and Novelli, 1988). A lesser amount of gases was produced by thermal degradation of organic matter at great depths (in general >5000 m) either in the foredeep or in the thrust belts, where a considerable increase in temperature, caused by the emplacement of the thrust sheets, fostered the generation of thermogenic gases. Nevertheless, the tectonic movements, active during the entire Neogene, represent a limiting factor for the preservation of such generated gases. The small quantity (10%) and the uniform make-up of the gases (99% biogenic gases) discovered in the foreland are strictly related to the peculiar characteristics of this tectonic regime. In the immature Tertiary sediments the reduced thickness of the terrigenous deposits generated only a limited amount of bacterial and /or diagenetic gases. On the other hand in Mesozoic sediments, mainly formed by

thick carbonate sequences, the possible present thermogenic gases were lost by diffusion through poorly efficient cap rocks (Mattavelli and Novelli, 1988; Buttinelli et al. 2011). Geochemical and geological evidences indicates that migration and accumulation of gaseous hydrocarbons took place mostly during the Plio-Pleistocene. In particular , migration is still active in the gas fields of the northern Apennine foredeep (Dal Piaz 1959), owing to the presence of thin impervious layers. In this area, in fact, a kind of steady state equilibrium has been reached between losses through diffusion and the continuous supply of newly generated natural gases.

5. Types of gaseous hydrocarbons

Biogenic, mixed, and thermogenic gases were found in Italy. Biogenic gases are usually found in Plio-Pleistocene sediments and are characterized by almost pure and isotopically light methane. The more negative isotopic values accompanied by the absence of heavier homologues were observed in Pleistocene shallow reservoirs. The chemical and isotopic composition of these gases is considered as evidence for their *in situ* formation through bacterial or diagenetic processes (Schoell 1980, 1983; Mattavelli, et al. 1983). Mixed gases were discovered in reservoirs from Middle Pliocene to Cretaceous and are characterized by a wide range of mixing proportions between biogenic and thermogenic gases. Thermogenic gases migrated from deeper layers and mixed in different amounts with shallower biogenic gases. Thermogenic gases are generally found in the pre-Pliocene reservoirs they are characterized by $^{13}C/^{12}C$ values ranging from -31 to -51‰. Italian thermogenic gases reflect all stages of maturation of organic matter. Condensate and dry thermogenic gases are enriched in heavy carbon ($^{13}C/^{12}C$ -31 to -36‰) and Deuterium which indicate a generation from highly mature source rocks (Mattavelli and Novelli, 1988).

6. Hydrocarbon accumulations

Biogenic gas pools were found in shallow marine sands and foredeep turbiditic multi layer sands and sandstones involved in thrust folds and their source is in the interbedded clays. Thermogenic gas pools are in turbiditic sandstones involved in thrust folds in foothill areas. The gas generated at great depth in the flysch, migrated laterally-updip along the inner flank of the folds. Liquid hydrocarbons are reservoired in carbonatic series in foothills and foreland domains. In the foothills belts ther traps are thrust folds. In the foreland the oils are stored in carbonates involved in paleostructures of different nature (Casero 2004; Bertello et al. 2010;). Some biogenic gases originated at a very shallow depth (i.e. less than 100 m) mask the exact localization of deep reservoirs and justify the need of geophysical and geochemical prospection to better constrain deep gas accumulations. Sometimes a mixing between very shallow biogenic gas and deep originated methane occurs generating mixing phenomena (Cremonini et al. 2008). In the subaerial environment the same biogenic gases generate and/or use shallow/surficial systems of fractures and faults as escape paths (Bonori et al. 2000; Castellarin et al. 2006; Cremonini et al. 2010; Cremonini 2010a) and some authors suggested also the possibility of identifying subaerial pockmarks (Curzi et al. 1987; Marabini et al. 1987; Cremonini 2010b). Usual pockmark morphologies are known to exist on the

Adriatic Sea bottom along the Meso Adriatic Depression (Curzi and Veggiani 1985; Curzi et al. 1987; Praeg et al. 2009; Geletti et al. 2008;Mazzotti et al.,1987; Trincardi et al. 2011c), on the Sardinian continental shelf (Dalla Valle and Gamberi 2011) and at the bottom of Lake Garda in northern Italy (Violante and Michetti 2010). Unfortunately, for all of those features no data concerning the seeping gas are available. Other well known morphologies linked to sure shallow gas seepage on the Northern Adriatic sea floor are generating small carbonatic mounds and layers (Conti et al. 2002; Panieri 2006), but also no analytical data are available for these.

7. Comments on database and maps

Historical scientific literature (Camerana et al. 1926; Zuber 1940; Martinis 1969, Fig. 8 and previous references therein; Martinelli 2007) have also reported the location of natural hydrocarbon occurrences not always considered in the recent scientific literature (Martinelli and Judd 2004). In any case, all the available sampling points or historically recognized points have been mapped and shown in figures 3a-d. The location data related the previous figures are recorded in Tables 1 to 4 . Due to the fact that the geographical location of the majority of the considered points cannot be gleaned from any other original edited source, the related coordinates were graphically extrapolated and as a consequence each georeferenced location must be understood as the barycentre point of a circular area in a possible location having a radius of up to 5 km in length. The related municipality quoted in the Tables 1 to 4 is the biggest one existing near the location point. Hence, they will be merely indicative even if significant on the scale of the present study. Seepages occurring in Italy are represented by : i) dry gas emissions; ii) gas bubbling in mud-volcanic waters; iii) gas bubbling in ground waters; iv) oil spills; v) asphalts and bitumen; vi) solid waxes. Figure 3 collects the related locations subdivided into four subsets, i.e. gas (Fig. 3a), Oil (Fig. 3b), Solid (Fig. 3c) and Mud-Volcanoes (Fig. 3d). The whole seepage set vs. the structural map of Italy is provided in Fig. 4. The available updated natural gas analyses are collected in Table 5 and their location and kind are shown in Fig. 5. When more than one site reported in the scientific literature was found within the same municipality then the most significant and representative of them or the main centre itself was selected as being representative. The analytical data were kept by the reference sources quoted in Table 5 (Borgia et al. 1988; Minissale et al. 2000; Duchi et al. 2005; Etiope 2007; Heinicke et al. 2010). In some cases, the original analytical strings have been completed by means of data published by the authors referenced in the reported list. Analytical data usually refer to dry gases and to the gases bubbling in mud volcanoes. Some low-depth wells (<200m) drilled close to natural gaseous emissions have been considered as well as some wells characterized by the certain representativeness of local seepages. All the sampling points have been georeferenced. Analytical data have been plotted and are shown in Figure 6. The graphs obtained indicate that only a minority of considered gases has biogenic origin, while all the others are thermogenic or mixed thermo-biogenic. Due to fact that analytical data obtained from the gases sampled in deep industrial wells highlight the same proportions of biogenic and thermogenic gases, we can conclude that the surface seepages are representative of a deep hydrocarbon setting and, in principle, could be still exploited as indicators of deep-seated reservoirs.

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
1	Piemonte	Alessandria	Casale Monferrato		45 08 14	08 27 03	Camerana et al., 1926
2	Piemonte	Alessandria	**Gabiano		*45 09 38	*08 11 44	Martinis 1969, Fig. 8
3	Piemonte	Alessandria	**Casale Monferrato		*45 09 52	*08 23 55	Martinis 1969, Fig. 8
4	Lombardia	Pavia	Casteggio	Casteggio	45 00 43	09 07 24	Camerana et al., 1926
5	Lombardia	Pavia	Salice Terme	Salice Terme	44 54 51	09 01 38	Camerana et al., 1926
6	Lombardia	Pavia	Rivanazzano Terme	Rile dell'olio	44 55 37	09 00 51	Camerana et al., 1926
7	Lombardia	Pavia	**Rocca Susella		*44 55 25	*09 06 49	Martinis 1969, Fig. 8
8	Trentino-A.A.	Trento	**Brentonico	Castione	*45 48 46	*10 57 07	Martinis 1969, Fig. 8
9	Trentino-A.A.	Trento	**Ala	S. Margherita	*45 44 48	*11 04 16	Martinis 1969, Fig. 8
10	Veneto	Belluno	**Feltre		*45 58 29	*11 49 15	Martinis 1969, Fig. 8
11	Friuli V. G.	Udine	**Ovaro		*46 28 34	*12 52 53	Martinis 1969, Fig. 8
12	Emilia Romagna	Bologna	Casalfiumanese	Cà Bordona	44 17 55	11 37 16	Martinelli 2007, tab 6.1
13	Emilia Romagna	Bologna	Castel del Rio	Molinaccio	44 12 56	11 30 14	Martinelli 2007, tab 6.1
14	Emilia Romagna	Bologna	Castiglione dei Pepoli	Creda	44 08 35	11 09 51	Martinelli 2007, tab 6.1
15	Emilia Romagna	Bologna	Gaggio Montano	**5** sites: Rovine Tommasi, Saldine, Cà Masera, Molinazzo,Cà di Riccio	44 11 53	10 56 01	Martinelli 2007, tab 6.1
16	Emilia Romagna	Bologna	Grizzana Morandi	Cà Bellavista	44 15 28	11 09 08	Martinelli 2007, tab 6.1
17	Emilia Romagna	Bologna	Lizzano in Belvedere	Grecchia	44 09 42	10 53 38	Martinelli 2007, tab 6.1
18	Emilia Romagna	Bologna	Monterenzio	Casa Domenicali	44 19 31	11 24 16	Martinelli 2007, tab 6.1
19	Emilia Romagna	Bologna	Porretta Terme	**2** sites: Cà Salgastri, Sasso Cardo.	44 09 15	10 58 32	Martinelli 2007, tab 6.1
20	Emilia Romagna	Bologna	S. Benedetto Val di Sambro	Castel dell'Alpi	44 12 56	11 14 04	Martinelli 2007, tab 6.1
21	Emilia Romagna	Bologna	Sasso Marconi	Reno river bed	44 23 44	11 14 53	Martinelli 2007, tab 6.1
22	Emilia Romagna	Bologna	Savigno	Monte Falò	44 23 27	11 04 29	Martinelli 2007, tab 6.1
23	Emilia Romagna	Ferrara	Cento	Corpo Reno - Casa "Il Gas"	44 45 22	11 18 08	Martinelli 2007, tab 6.1
24	Emilia Romagna	Ferrara	Comacchio	Valli del Mezzano	44 40 37	12 01 44	Cremonini et al. 2008
25	Emilia Romagna	Forlì-Cesena	Bagno di Romagna	**3** sites: Terme, Cimitero, S. Martino di Larciano	43 50 02	11 57 33	Martinelli 2007, tab 6.1
26	Emilia Romagna	Forlì-Cesena	Bertinoro	Rio Salso	44 08 56	12 07 58	Martinelli 2007, tab 6.1
27	Emilia Romagna	Forlì-Cesena	Castrocaro Terme	Bollirone	44 10 20	11 56 51	Martinelli 2007, tab 6.1
28	Emilia Romagna	Forlì-Cesena	Galeata	**2** sites: Casa Tolice, Rio Suasia	43 59 48	11 54 43	Martinelli 2007, tab 6.1
29	Emilia Romagna	Forlì Cesena	Portico e S. Benedetto	Portico di Romagna	44 01 31	11 46 57	Martinis 1969, Fig. 8

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
30	Emilia Romagna	Forlì-Cesena	Rocca San Cascaino	**3** sites: Case Budria, Casalecchio, Fosso di Rinaldo,	44 03 30	11 50 30	Martinelli 2007, tab 6.1
31	Emilia Romagna	Forlì-Cesena	Sogliano al Rubicone	Torrente Torchio	44 00 18	12 18 01	Martinelli 2007, tab 6.1
32	Emilia Romagna	Forlì-Cesena	Tredozio	Busca	44 04 41	11 44 35	Martinelli 2007, tab 6.1
33	Emilia Romagna	Modena	Castelvetro di Modena	S. Luigi	44 30 12	10 56 35	Martinelli 2007, tab 6.1
34	Emilia Romagna	Modena	Fanano	Chiesa di Trignano	44 12 39	10 50 29	Martinelli 2007, tab 6.1
35	Emilia Romagna	Modena	Lama Mocogno	**3** sites: Barigazzo, Lagadelle, Case di Sotto,	44 18 25	10 43 47	Martinelli 2007, tab 6.1
36	Emilia Romagna	Modena	Maranello	**2** sites: Torre Maina, La Govana	44 31 31	10 51 59	Martinelli 2007, tab 6.1
37	Emilia Romagna	Modena	Marano sul Panaro	Prediera	44 27 21	10 57 58	Martinelli 2007, tab 6.1
38	Emilia Romagna	Modena	Montefiorino	**4** sites: Macognano, Farneta, Il Fuoco, Cà Medole	44 21 31	10 37 24	Martinelli 2007, tab 6.1
39	Emilia Romagna	Modena	Montese	Cà Boschi	44 16 06	10 56 27	Martinelli 2007, tab 6.1
40	Emilia Romagna	Modena	Palagano	Casa Bottega	44 19 14	10 38 52	Martinelli 2007, tab 6.1
41	Emilia Romagna	Modena	San Possidonio	Fondo Bordina	44 53 30	10 59 45	Martinelli 2007, tab 6.1
42	Emilia Romagna	Modena	Medolla		44 50 55	11 04 14	Gasperi, Pellegrini 1981
43	Emilia Romagna	Modena	Sassuolo	**3** sites: Gozzano, Salsa di sotto, Salvarola	44 32 30	10 46 54	Martinelli 2007, tab 6.1
44	Emilia Romagna	Modena	Serramazzoni	**2** sites: Pozzi dell'olio. Campodolio	44 25 33	10 47 15	Martinelli 2007, tab 6.1
45	Emilia Romagna	Modena	Sestola	**5** sites: Troncoscaglia, Bandita, Cà Boldrini, Fontanine, Trignano	44 13 50	10 46 14	Martinelli 2007, tab 6.1
46	Emilia Romagna	Parma	Bardi	**3** sites: Ormei, Volpi, Tosca	44 37 55	09 43 53	Martinelli 2007, tab 6.1
47	Emilia Romagna	Parma	Berceto	**7** sites: Scorza, Costa d'Asino, Molinari, Borgallo, Castellonchio, Macchie di Monte Marino, Lagodignano	44 30 38	09 59 22	Martinelli 2007, tab 6.1
48	Emilia Romagna	Parma	Berceto	Berceto	44 30 39	09 59 24	Martinis 1969, Fig. 8
49	Emilia Romagna	Parma	Berceto	Castellonchio	44 32 59	10 00 25	Martinis 1969, Fig. 8
50	Emilia Romagna	Parma	Collecchio	Cà Ginestra	44 45 06	10 12 54	Martinelli 2007, tab 6.1
51	Emilia Romagna	Parma	Corniglio	**3** sites: Miano, Prella, Rividulano	44 28 33	10 05 18	Martinelli 2007, tab 6.1
52	Emilia Romagna	Parma	Corniglio	Grammatica	44 26 21	10 05 15	Martinis 1969, Fig. 8
53	Emilia Romagna	Parma	Fornovo Taro	**4** sites: Riccò, Ozzano, Case Folli, Vallezza	44 41 29	10 05 49	Martinelli 2007, tab 6.1
54	Emilia Romagna	Parma	Fornovo Taro	Vallezza	44 39 36	10 09 14	Martinis 1969, Fig. 8

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
55	Emilia Romagna	Parma	Medesano	**4** sites: Miano, Casa Goletta, Casa Brozzi, Sant'Andrea Bagni	44 45 23	10 08 27	Martinelli 2007, tab 6.1
56	Emilia Romagna	Parma	Neviano degli Arduini	**2** sites: Case Cavandola, Villa	44 34 56	10 18 57	Martinelli 2007, tab 6.1
57	Emilia Romagna	Parma	Salsomaggiore	Centopozzi	44 48 58	09 58 43	Martinelli 2007, tab 6.1
58	Emilia Romagna	Parma	Valmozzola	Valmozzola	44 34 08	09 53 01	Martinis 1969, Fig. 8
59	Emilia Romagna	Piacenza	Agazzano	**2** sites: Casa Boriona, Cà Ragaiona	44 56 48	09 31 12	Martinelli 2007, tab 6.1
60	Emilia Romagna	Piacenza	Bobbio	**4** sites: Piancasale, Case Canneto, Ponte San Martino, S. Salvatore	44 46 02	09 23 12	Martinelli 2007, tab 6.1
61	Emilia Romagna	Piacenza	Castell'Arquato	Villa S. Lorenzo	44 51 04	09 52 02	Martinelli 2007, tab 6.1
62	Emilia Romagna	Piacenza	Farini d'Olmo	**3** sites: Troncamorso, Case Tornara, Case Chiappetti	44 42 49	09 34 11	Martinelli 2007, tab 6.1
63	Emilia Romagna	Piacenza	Gazzola	Casa Mirabello	44 57 32	09 32 50	Martinelli 2007, tab 6.1
64	Emilia Romagna	Piacenza	Lugagnano Val d'Arda	Velleia: Velleia	44 47 07	09 43 18	Martinelli 2007, tab 6.1
65	Emilia Romagna	Parma	Palanzano	Palanzano	44 26 08	10 11 32	Martinis 1969, Fig. 8
66	Emilia Romagna	Piacenza	Podenzano	Cà dei Gatti	44 57 24	09 41 08	Martinelli 2007, tab 6.1
67	Emilia Romagna	Parma	Travesetolo	Torre di Rivazzano	44 37 11	10 20 44	Martinis 1969, Fig. 8
68	Emilia Romagna	Piacenza	Travo	Campo dei Re (o Statto)	44 51 36	09 32 36	Martinelli 2007, tab 6.1
69	Emilia Romagna	Piacenza	Vigolzone	Carmiano	44 54 49	09 40 08	Martinelli 2007, tab 6.1
70	Emilia Romagna	Ravenna	Brisighella	**3** sites: Cà Domenico, Cà Poriva, Monticello	44 13 29	11 46 33	Martinelli 2007, tab 6.1
71	Emilia Romagna	Ravenna	Riolo Terme	Rio vecchio	44 16 31	11 43 19	Martinelli 2007, tab 6.1
72	Emilia Romagna	Reggio Emilia	Correggio	Correggio	44 46 16	10 46 50	Martinelli 2007, tab 6.1
73	Emilia Romagna	Reggio Emilia	Reggio Emilia	S. Bartolomeo	44 41 52	10 37 51	Martinelli 2007, tab 6.1
74	Emilia Romagna	Reggio Emilia	Toano	Quara	44 22 35	10 33 34	Martinelli 2007, tab 6.1
75	Emilia Romagna	Reggio Emilia	Vezzano sul Crostolo	**2** sites: La Vecchia, Casola Canossa	44 36 03	10 32 46	Martinelli 2007, tab 6.1
76	Emilia Romagna	Reggio Emilia	Viano	Fattoria del Lupo	44 32 37	10 37 09	Martinelli 2007, tab 6.1
77	Emilia Romagna	Reggio Emilia	Villa Minozzo	**2** sites: Casa Salata, Cà dell'Onestà	44 21 54	10 28 03	Martinelli 2007, tab 6.1
78	Emilia Romagna	Rimini	Viserba	seafloor	44 05 18	12 32 01	Martinelli 2007, tab 6.1
79	Toscana	Firenze	Firenzuola	Pietramala	44 07 14	11 22 49	Martinis 1969, Fig. 8
80	Toscana	Firenze	Montespertoli		43 38 36	11 04 28	Camerana et al., 1926, p 276
81	Toscana	Lucca	Viareggio	**Torre del Lago	*43 49 23	*10 20 36	Martinis 1969, Fig. 8
82	Toscana	Arezzo	**Pieve S. Stefano		*43 42 59	*12 03 59	Martinis 1969, Fig. 8
83	Toscana	Pisa	Pisa	Fornaci (e varie località)	43 40 49	10 20 28	Camerana et al., 1926, p 274

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
84	Toscana	Firenze	**S. Casciano Val di Pesa		*43 36 26	*11 09 21	Martinis 1969, Fig. 8
85	Toscana	Siena	**Poggibonsi		*43 30 00	*11 10 10	Martinis 1969, Fig. 8
86	Toscana	Livorno	**Collesalvetti		*43 30 41	*10 28 34	Martinis 1969, Fig. 8
87	Toscana	Pisa	Volterra		43 25 03	10 55 35	Martinis 1969, Fig. 8
88	Toscana	Siena	Siena	Montarioso	43 21 01	11 18 37	Camerana et al., 1926, p 276
89	Toscana	Siena	**Casole d'Elsa		*43 19 02	*11 02 51	Martinis 1969, Fig. 8
90	Toscana	Siena	**Monteroni d'Arbia		*43 15 38	*11 24 06	Martinis 1969, Fig. 8
91	Toscana	Livorno	**Suvereto		*43 04 55	*10 44 57	Martinis 1969, Fig. 8
92	Toscana	Grosseto	**Roccastrada		*43 02 56	*11 10 29	Martinis 1969, Fig. 8
93	Toscana	Grosseto	**Santa Fiora		*42 51 29	*11 34 39	Martinis 1969, Fig. 8
94	Toscana	Grosseto	Grosseto	Fondo Casone	42 49 17	11 05 58	Camerana et al., 1926, p 275
95	Toscana	Grosseto	Grosseto	Fondo Tripoli	42 42 59	11 05 14	Camerana et al., 1926, p 275
96	Toscana	Grosseto	**Manciano		*42 33 35	*11 28 40	Martinis 1969, Fig. 8
97	Emilia Romagna	Rimini	**Montefiore Conca		*43 54 06	*12 34 21	Martinis 1969, Fig. 8
98	Emilia Romagna	Rimini	**Novafeltria		*43 53 28	*12 17 35	Martinis 1969, Fig. 8
99	Marche	Ancona	**Agugliano		*43 32 50	*13 24 52	Martinis 1969, Fig. 8
100	Marche	Macerata	**Montecosaro		*43 19 26	*13 37 18	Martinis 1969, Fig. 8
101	Marche	Macerata	**Petriolo		*43 10 27	*13 22 25	Martinis 1969, Fig. 8
102	Marche	Fermo	**Lapedona		*43 06 05	*13 44 17	Martinis 1969, Fig. 8
103	Marche	Macerata	**Sernano		*43 01 50	*13 18 38	Martinis 1969, Fig. 8
104	Marche	Fermo	**Montefortino		*42 54 45	*13 17 38	Martinis 1969, Fig. 8
105	Marche	Ascoli Piceno	**Force		*42 55 57	*13 31 04	Martinis 1969, Fig. 8
106	Abruzzo	Teramo	**Civitella del Tronto	Valle Tronto a N Civitella	*42 47 45	*13 31 29	Martinis 1969, Fig. 8
107	Marche	Ascoli Piceno	Offida		42 56 13	13 42 01	Zuber 1940
108	Marche	Ascoli Piceno	near Maltignano	Villa Passo	42 49 57	13 41 13	Camerana et al., 1926
109	Umbria	Perugia	**Gubbio		*43 26 44	*12 33 16	Martinis 1969, Fig. 8
110	Umbria	Perugia	Perugia		43 08 50	12 23 59	Martinis 1969, Fig. 8
111	Umbria	Terni	**Montecastrilli		*42 39 49	*12 24 38	Martinis 1969, Fig. 8
112	Lazio	Rieti	**Montopoli Sabina		*42 13 14	*12 40 12	Martinis 1969, Fig. 8
113	Lazio	Roma	**Ostia		*41 44 57	*12 23 19	Martinis 1969, Fig. 8
114	Lazio	Frosinone	**Pontecorvo		*41 27 60	*13 35 28	Martinis 1969, Fig. 8
115	Abruzzo	Pescara	**Collecorvino		*42 28 13	*14 02 05	Martinis 1969, Fig. 8

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
116	Abruzzo	L'Aquila	**Ofena		*42 18 38	*13 46 57	Martinis 1969, Fig. 8
117	Abruzzo	Pescara	**Bussi sul Tirino		*42 14 34	*13 48 16	Martinis 1969, Fig. 8
118	Abruzzo	L'Aquila	Avezzano	Pozzone di Paterno -Fucino	42 03 06	13 28 51	Ciotoli et al. 1998
119	Abruzzo	L'Aquila	**Trasacco		*41 58 33	*13 34 25	Martinis 1969, Fig. 8
120	Abruzzo	L'Aquila	**Pescocostanzo		*41 53 01	*14 04 03	Martinis 1969, Fig. 8
121	Molise	Campobasso	**Mafalda		*41 58 05	*14 43 01	Martinis 1969, Fig. 8
122	Molise	Isernia	**Rocca Sicura		*41 41 15	*14 13 17	Martinis 1969, Fig. 8
123	Molise	Isernia	**Macchiagodena		*41 35 24	*14 22 56	Martinis 1969, Fig. 8
124	Molise	Campobasso	**S. Paolo Matese		*41 26 39	*14 30 42	Martinis 1969, Fig. 8
125	Molise	Campobasso	**Sepino		*41 22 23	*14 37 06	Martinis 1969, Fig. 8
126	Campania	Benevento	**Morcone		*41 19 51	*14 44 34	Martinis 1969, Fig. 8
127	Campania	Avellino	**Andretta		*40 57 26	*15 21 09	Martinis 1969, Fig. 8
128	Campania	Avellino	**Bagnoli Irpino		*40 49 04	*15 00 40	Martinis 1969, Fig. 8
129	Basilicata	Potenza	Tramutola	Cavolo and Agri rivers junction	40 20 53	15 47 05	Camerana et al., 1926
130	Basilicata	Matera	Nova Siri	Fontana di Sant'Alessio	40 08 57	16 32 29	Camerana et al., 1926
131	Basilicata	Potenza	Rapolla	Colle S. Lucia	40 58 37	15 40 19	Camerana et al., 1926
132	Basilicata	Matera	**Pisticci		*40 25 51	*16 31 31	Martinis 1969, Fig. 8
133	Basilicata	Matera	**Scanzano Ionico		*40 16 12	*16 40 27	Martinis 1969, Fig. 8
134	Basilicata	Matera	**Colobraro		*40 10 37	*16 22 21	Martinis 1969, Fig. 8
135	Calabria	Cosenza	**Montegiordano		*40 01 50	*16 30 43	Martinis 1969, Fig. 8
136	Calabria	Cosenza	**Corigliano Calabro		*39 41 04	*16 25 31	Martinis 1969, Fig. 8
137	Calabria	Cosenza	S. Vincenzo la Costa		39 21 53	16 09 03	Martinis 1969, Fig. 8
138	Calabria	Crotone	**Verzino		*39 20 16	*16 50 13	Martinis 1969, Fig. 8
139	Calabria	Crotone	**Cutro		*38 59 17	*16 59 07	Martinis 1969, Fig. 8
140	Calabria	Crotone	**Isola Capo Rizzuto		*38 59 39	*17 06 04	Martinis 1969, Fig. 8
141	Calabria	Reggio Calabria	**Rosarno		*38 30 28	*16 00 36	Martinis 1969, Fig. 8
142	Calabria	Reggio Calabria	**Staiti		*37 58 56	*16 02 52	Martinis 1969, Fig. 8
143	Sicilia	Messina	Mistretta	Castel di Lucio, Rocca Pizzutella	37 55 46	14 21 46	Camerana et al., 1926
144	Sicilia	Enna	Cerami	Monania	37 48 42	14 30 31	Camerana et al., 1926
145	Sicilia	Enna	Troina	verso Bronte, Pianezze	37 47 10	14 36 10	Camerana et al., 1926
146	Sicilia	Palermo	Caltavuturo	Pagliuzza	37 49 19	13 53 28	Camerana et al., 1926
147	Sicilia	Agrigento	Bivona	Censo, Casa il Censo	37 37 11	13 26 22	Camerana et al., 1926

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
148	Sicilia	Palermo	Bagni di Sclafani		37 49 18	13 51 17	Camerana et al., 1926
149	Sicilia	Enna	Piazza Armerina	Piazza Armerina	37 23 05	14 21 52	Camerana et al., 1926
150	Sicilia	Catania	**Bronte		*37 45 21	*14 53 50	Martinis 1969, Fig. 8
151	Sicilia	Enna	**Cerami		*37 46 18	*14 28 05	Martinis 1969, Fig. 8
152	Sicilia	Palermo	**Polizzi Generosa		*37 50 05	*13 59 04	Martinis 1969, Fig. 8
153	Sicilia	Trapani	**Santa Ninfa		*37 44 43	*12 51 05	Martinis 1969, Fig. 8
154	Sicilia	Agrigento	**Sant'Elisabetta		*37 27 21	*13 33 13	Martinis 1969, Fig. 8
155	Sicilia	Enna	**Valguarnera Caropepe		*37 28 13	*14 24 20	Martinis 1969, Fig. 8
156	Sicilia	Catania	**Raddusa		*37 29 56	*14 31 07	Martinis 1969, Fig. 8
157	Sicilia	Catania	**Paternò		*37 35 52	*14 53 35	Martinis 1969, Fig. 8
158	Sicilia	Catania	**Catania		*37 24 48	*15 00 42	Martinis 1969, Fig. 8
159	Sicilia	Siracusa	**Lentini		*37 25 35	*14 52 16	Martinis 1969, Fig. 8
160	Sicilia	Catania	**Palagonia		*37 17 36	*14 42 55	Martinis 1969, Fig. 8
161	Sicilia	Catania	**Vizzini		*37 09 60	*14 47 21	Martinis 1969, Fig. 8
162	Sicilia	Siracusa	**Noto		*36 55 32	*15 01 18	Martinis 1969, Fig. 8
163	Sicilia	Caltanissetta	**Caltanissetta		*37 23 04	*14 04 09	Martinis 1969, Fig. 8
164	Sicilia	Agrigento	**Racalmuto		*37 19 24	*13 47 30	Martinis 1969, Fig. 8
165	Sicilia	Agrigento	**Canicattì		*37 20 07	*13 54 42	Martinis 1969, Fig. 8
166	Sicilia	Agrigento	**Ravanusa		*37 16 52	*13 59 57	Martinis 1969, Fig. 8
167	Sicilia	Agrigento	**Campobello di Licata		*37 15 31	*13 51 53	Martinis 1969, Fig. 8
168	Sicilia	Agrigento	**Palma di Montechiaro		*37 12 49	*13 44 08	Martinis 1969, Fig. 8
169	Sardegna	Carbonia-Iglesias	**Iglesias		*39 20 36	*08 34 10	Martinis 1969, Fig. 8

** = the main municipality nearest to the point location (not necessarily coinciding with the real seep location Municipality).
* = approximate value obtained by means of original map georeferencing.

Table 1. List of natural GAS seepages in Italy.

order No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
1	Piemonte	Alessandria	**Cuccaro Monferrato		*45 00 28	*08 27 07		Martinis 1969, fig 8
2	Piemonte	Cuneo	**S. Vittoria d'Alba		*44 43 27	*07 55 23		Martinis 1969, fig 8
3	Lombardia	Pavia	**Zavattarello		*44 53 16	*09 16 47		Martinis 1969, fig 8
4	Trentino-A.A.	Trento	Taio	Mollaro	46 19 06	11 11 02		Martinis 1969, fig 8
5	Veneto	Belluno	**Forno di Zoldo		*46 21 44	*12 13 25		Martinis 1969, fig 8
6	Emilia Romagna	Piacenza	**Coli		*44 44 37	*09 25 25		Martinis 1969, fig 8
7	Emilia Romagna	Piacenza	**Morfasso		*44 43 21	*09 40 04		Martinis 1969, fig 8
8	Emilia Romagna	Piacenza	** Val d'Arda		*44 50 07	*09 48 37		Martinis 1969, fig 8
9	Emilia Romagna	Parma	**Bore		*44 43 17	*09 49 39		Martinis 1969, fig 8
10	Emilia Romagna	Parma	**Bardi		*44 37 41	*09 46 12		Martinis 1969, fig 8
11	Emilia Romagna	Reggio Emilia	**Castelnuovo Monti		*44 28 01	*10 28 44		Martinis 1969, fig 8
12	Emilia Romagna	Modena	**Maranello		*44 30 31	*10 50 08		Martinis 1969, fig 8
13	Emilia Romagna	Bologna	**Pianoro		*44 22 46	*11 18 54		Martinis 1969, fig 8
14	Emilia Romagna	Bologna	**S. Lazzaro di Savena	(S. Ruffillo)	*44 27 38	*11 26 06		Martinis 1969, fig 8
15	Emilia Romagna	Forlì-Cesena	**Forlì		*44 15 18	*12 06 25	(Not reliable)	Martinis 1969, fig 8
16	Toscana	Arezzo	**Pieve S. Stefano		*43 40 18	*12 11 15		Martinis 1969, fig 8
17	Toscana	Siena	**Pienza		*43 06 58	*11 38 14		Martinis 1969, fig 8
18	Marche	Macerata	**Sarnano		*43 00 10	*13 11 36		Martinis 1969, fig 8
19	Marche	Macerata	**Porto S. Elpidio	Fontespina	*43 17 33	*13 49 39	1.7km Offshore	Martinis 1969, fig 8

order No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
20	Lazio	Frosinone	**Monte S. Giovanni Campano		*41 37 28	*13 33 53		Martinis 1969, fig 8
21	Lazio	Frosinone	**Ceccano		*41 33 32	*13 18 45		Martinis 1969, fig 8
22	Lazio	Frosinone	**Amaseno		*41 27 22	*13 22 21		Martinis 1969, fig 8
23	Lazio	Frosinone	**Arce		*41 31 59	*13 35 06		Martinis 1969, fig 8
24	Abruzzo	Pescara	**Torre dei Passeri		*42 15 13	*13 54 02		Martinis 1969, fig 8
25	Abruzzo	Pescara	**Caramanico Terme		*42 10 52	*14 01 49		Martinis 1969, fig 8
26	Abruzzo	L'Aquila	**Sulmona		*42 01 07	*13 55 06		Martinis 1969, fig 8
27	Abruzzo	Chieti	**Scerni		*42 05 20	*14 32 32		Martinis 1969, fig 8
28	Campania	Avellino	**Guardia Lombardi		*41 00 30	*15 13 59		Martinis 1969, fig 8
29	Basilicata	Potenza	**Baragiano		*40 40 48	*15 37 28		Martinis 1969, fig 8
30	Basilicata	Potenza	**Marsico Nuovo		*40 26 45	*15 45 56		Martinis 1969, fig 8
31	Basilicata	Potenza	**S. Chirico Raparo		*40 12 00	*16 05 41		Martinis 1969, fig 8
32	Basilicata	Potenza	**Sant'Arcangelo		*40 13 58	*16 17 41		Martinis 1969, fig 8
33	Basilicata	Cosenza	**Alessandria del Carretto		*40 00 01	*16 23 38		Martinis 1969, fig 8
34	Calabria	Cosenza	**Campana		*39 24 26	*16 51 40		Martinis 1969, fig 8
35	Calabria	Crotone	**Belvedere di Spinello		*39 14 59	*16 53 19		Martinis 1969, fig 8
36	Sicilia	Enna	**Cerami		*37 50 56	*14 25 28		Martinis 1969, fig 8
37	Sicilia	Catania	**Bronte		*37 48 04	*14 47 40		Martinis 1969, fig 8
38	Sicilia	Palermo	**Petralia Sottana		*37 44 28	*14 08 17		Martinis 1969, fig 8
39	Sicilia	Caltanissetta	**Villalba		*37 39 53	*13 48 37		Martinis 1969, fig 8
40	Sicilia	Caltanissetta	**Serradifalco		*37 25 35	*13 51 29		Martinis 1969, fig 8
41	Sicilia	Catania	**Paternò		*37 29 12	*14 51 07		Martinis 1969, fig 8
42	Sicilia	Catania	**Vizzini		*37 08 03	*14 52 07		Martinis 1969, fig 8
43	Sicilia	Ragusa	**Ragusa		*37 00 43	*14 42 09		Martinis 1969, fig 8
44	Sicilia	Ragusa	**Modica		*36 55 10	*14 50 45		Martinis 1969, fig 8
45	Sicilia	Ragusa	**Ispica		*36 46 06	*14 57 10		Martinis 1969, fig 8

** = the main municipality nearest to the point location (not necessarily coinciding with the real seep location Municipality).
* = approximate value obtained by means of original map georeferencing.

Table 2. List of natural oil occurrence in Italy.

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
1	Piemonte	Cuneo	La Morra		44 38 23	07 56 01	Martinis 1969, fig 8
2	Piemonte	Cuneo	Bene Vagienna		44 32 44	07 49 59	Martinis 1969, fig 8
3	Trentino-A.A.	Trento	**Molina di Ledro		*45 50 44	*10 43 33	Martinis 1969, fig 8
4	Lombardia	Brescia	**Bedizzole		*45 32 03	*10 27 05	Martinis 1969, fig 8
5	Lombardia	Brescia	**Brescia		*45 33 04	*10 13 39	Martinis 1969, fig 8
6	Trentino-A.A.	Trento	**Pozza di Fassa		*46 26 02	*11 44 55	Martinis 1969, fig 8
7	Trentino-A.A.	Rovereto	**Pamarolo		*45 56 27	*11 00 58	Martinis 1969, fig 8
8	Trentino-A.A.	Trento	Taio	Mollaro	46 17 39	11 04 18	Martinis 1969, fig 8
9	Trentino-A.A.	Trento	**Pinzolo		*46 08 50	*10 50 34	Martinis 1969, fig 8
10	Veneto	Belluno	**Lozzo di Cadore		*46 29 47	*12 21 49	Martinis 1969, fig 8
11	Veneto	Belluno	**Valle Agordina		*46 18 10	*12 07 28	Martinis 1969, fig 8
12	Trentino-A.A.	Trento	**Fiera di Primiero		*46 13 51	*11 51 44	Martinis 1969, fig 8
13	Veneto	Treviso	**Crespano del Grappa		*45 53 19	*11 48 13	Martinis 1969, fig 8
14	Friuli V. G.	Udine	**Moggio Udinese		*46 27 26	*13 07 03	Martinis 1969, fig 8
15	Friuli V. G.	Udine	**Socchieve		*46 26 27	*12 45 50	Martinis 1969, fig 8
16	Friuli V. G.	Pordenone	**Clauzetto		*46 18 50	*12 55 14	Martinis 1969, fig 8
17	Friuli V. G.	Udine	**Reana del Roiale		*46 06 52	*13 17 15	Martinis 1969, fig 8
18	Friuli V. G.	Udine	Resiutta		46 23 33	13 13 07	Martinis 1969, fig 8
19	Friuli V. G.	Udine	**Tarcento		*46 12 53	*13 12 46	Martinis 1969, fig 8
20	Emilia-Romagna	Bologna	Savigno	M. Falò	44 23 27	11 04 29	Bombicci 1881
21	Toscana	Siena	**Colle Val d'Elsa		*43 22 52	*11 03 48	Martinis 1969, fig 8
22	Marche	Pesaro-Urbino	**Auditore		*43 48 45	*12 33 19	Martinis 1969, fig 8
23	Marche	Pesaro-Urbino	**Fermignano		*43 39 55	*12 40 41	Martinis 1969, fig 8
24	Marche	Ancona	**Genga		*43 26 03	*12 57 21	Martinis 1969, fig 8
25	Marche	Ancona	**Fabriano		*43 17 60	*12 52 40	Martinis 1969, fig 8
26	Marche	Macerata	**Pioraco		*43 12 33	*12 59 27	Martinis 1969, fig 8
27	Abruzzo	L'Aquila	**Avezzano		*42 00 13	*13 24 57	Martinis 1969, fig 8
28	Lazio	Roma	**Vallepietra		*41 56 07	*13 11 52	Martinis 1969, fig 8
29	Lazio	Frosinone	**Guarcino		*41 51 35	*13 19 37	Martinis 1969, fig 8
30	Abruzzo	L'Aquila	**Civitella Roveto		*41 56 14	*13 27 31	Martinis 1969, fig 8
31	Lazio	L'Aquila	**Villa Valle Roveto		*41 49 35	*13 34 37	Martinis 1969, fig 8

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
32	Lazio	Frosinone	**Veroli		*41 43 20	*13 31 20	Martinis 1969, fig 8
33	Lazio	Frosinone	**Sora		*41 44 05	*13 39 26	Martinis 1969, fig 8
34	Lazio	Frosinone	**Rocca d'Arce		*41 35 16	*13 38 19	Martinis 1969, fig 8
35	Lazio	Frosinone	**Pastena		*41 29 15	*13 29 25	Martinis 1969, fig 8
36	Lazio	Frosinone	**Castrocielo		*41 30 55	*13 40 50	Martinis 1969, fig 8
37	Lazio	Frosinone	**Pontecorvo		*41 24 15	*13 39 25	Martinis 1969, fig 8
38	Lazio	Rieti	**Amatrice		*42 38 01	*13 14 15	Martinis 1969, fig 8
39	Abruzzo	L'Aquila	**Scoppito		*42 32 01	*13 21 35	Martinis 1969, fig 8
40	Abruzzo	L'Aquila	**S. Stefano di Sessanio		*42 18 09	*13 39 09	Martinis 1969, fig 8
41	Abruzzo	L'Aquila	**Avezzano		*42 10 33	*13 23 17	Martinis 1969, fig 8
42	Abruzzo	L'Aquila	**Celano		*42 07 30	*13 28 47	Martinis 1969, fig 8
43	Abruzzo	L'Aquila	**Celano		*42 04 06	*13 34 14	Martinis 1969, fig 8
44	Abruzzo	L'Aquila	**Raiano		*42 06 03	*13 47 13	Martinis 1969, fig 8
45	Abruzzo	L'Aquila	**Pratola Peligna		*42 05 28	*13 52 52	Martinis 1969, fig 8
46	Abruzzo	Pescara	**Caramanico Terme		*42 06 49	*14 02 29	Martinis 1969, fig 8
47	Abruzzo	Chieti	**Fara San Martino		*42 04 32	*14 06 05	Martinis 1969, fig 8
48	Marche	Ascoli Piceno	**Acquasanta Terme		*42 43 48	*13 26 19	Martinis 1969, fig 8
49	Abruzzo	Teramo	**Isola del Gran Sasso		*42 31 13	*13 32 46	Martinis 1969, fig 8
50	Abruzzo	L'Aquila	**Collelongo		*41 52 27	*13 33 41	Martinis 1969, fig 8
51	Molise	Isernia	**S.Angelo del Pesco		*41 52 13	*14 15 15	Martinis 1969, fig 8
52	Molise	Isernia	**Isernia		*41 42 21	*14 18 58	Martinis 1969, fig 8
53	Molise	Campobasso	**Boiano		*41 33 03	*14 28 34	Martinis 1969, fig 8
54	Campania	Avellino	**Savignano Irpino		*41 12 49	*15 13 54	Martinis 1969, fig 8
55	Campania	Avellino	**Cardito		*41 08 41	*15 00 59	Martinis 1969, fig 8
56	Puglia	Foggia	**Anzano di Puglia		*41 07 10	*15 17 53	Martinis 1969, fig 8
57	Campania	Avellino	**Caposele		*40 48 31	*15 16 38	Martinis 1969, fig 8
58	Campania	Salerno	**Acerno		*40 44 58	*15 03 12	Martinis 1969, fig 8
59	Campania	Salerno	**Colliano		*40 42 48	*15 16 58	Martinis 1969, fig 8
60	Campania	Salerno	**Castelcivita		*40 27 55	*15 14 27	Martinis 1969, fig 8
61	Campania	Salerno	**Bellosguardo		*40 24 38	*15 19 08	Martinis 1969, fig 8

lunicipality).

No.	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Reference
62	Campania	Salerno	**Sacco		*40 21 20	*15 26 38	Martinis 1969, fig 8
63	Campania	Salerno	**Trentinara		*40 22 19	*15 06 18	Martinis 1969, fig 8
64	Campania	Salerno	**Stio		*40 18 14	*15 14 36	Martinis 1969, fig 8
65	Campania	Salerno	**Vallo della Lucania		*40 15 25	*15 21 57	Martinis 1969, fig 8
66	Campania	Salerno	**Castiglione dei Genovesi		*40 43 38	*14 51 44	Martinis 1969, fig 8
67	Campania	Salerno	**Sanza		*40 11 44	*15 37 21	Martinis 1969, fig 8
68	Basilicata	Potenza	**Maratea		*40 03 11	*15 39 09	Martinis 1969, fig 8
69	Basilicata	Potenza	**Castelsaraceno		*40 10 34	*15 57 11	Martinis 1969, fig 8
70	Basilicata	Matera	**Rotondella		*40 08 23	*16 28 56	Martinis 1969, fig 8
71	Sicilia	Messina	**Tripi		*38 01 24	*15 04 40	Martinis 1969, fig 8
72	Sicilia	Messina	**Montalbano Elicona		*37 59 16	*14 57 30	Martinis 1969, fig 8
73	Sicilia	Catania	**Maletto		*37 49 40	*14 53 35	Martinis 1969, fig 8
74	Sicilia	Palermo	**Petralia Sottana		*37 47 36	*14 06 14	Martinis 1969, fig 8
75	Sicilia	Palermo	**Sclafani Bagni		*37 52 32	*13 50 50	Martinis 1969, fig 8
76	Sicilia	Palermo	**Montemaggiore Belsito		*37 51 45	*13 43 48	Martinis 1969, fig 8
77	Sicilia	Palermo	**Vicari		*37 50 34	*13 28 26	Martinis 1969, fig 8
78	Sicilia	Palermo	**Corleone		*37 51 25	*13 20 10	Martinis 1969, fig 8
79	Sicilia	Palermo	**Camporeale		*37 54 14	*13 01 12	Martinis 1969, fig 8
80	Sicilia	Trapani	**Alcamo		*37 55 49	*12 56 20	Martinis 1969, fig 8
81	Sicilia	Palermo	**Palazzo Adriano		*37 42 33	*13 23 14	Martinis 1969, fig 8
82	Sicilia	Agrigento	**Bivona		*37 35 24	*13 33 21	Martinis 1969, fig 8
83	Sicilia	Catania	**Palagonia		*37 19 34	*14 38 16	Martinis 1969, fig 8
84	Sicilia	Catania	**Licodia Eubea		*37 11 32	*14 42 20	Martinis 1969, fig 8
85	Sicilia	Siracusa	**Sortino		*37 09 47	*15 03 09	Martinis 1969, fig 8
86	Sicilia	Ragusa	**Giarratana		*37 00 32	*14 48 24	Martinis 1969, fig 8
87	Sicilia	Ragusa	**Ragusa		*36 54 56	*14 46 25	Martinis 1969, fig 8
88	Sicilia	Ragusa	**Scicli		*36 48 54	*14 42 12	Martinis 1969, fig 8
89	Sicilia	Ragusa	**Modica		*36 48 47	*14 48 24	Martinis 1969, fig 8
90	Sicilia	Siracusa	**Pachino		*36 42 28	*15 04 05	Martinis 1969, fig 8
91	Lombardia	Varese	Besano	Besano	45 53 23	08 53 24	Martinis 1969, fig 8

Table 3. List of solid hydrocarbon occurrence in Italy.

No	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
1	Emilia Romagna	Bologna	Casalfiumanese	Casa Bubano	44 15 05	11 28 35		Martinelli, Judd 2004, Table 1
2	Emilia Romagna	Bologna	Casalfiumanese	Casa Campagnola	44 20 32	11 35 20		Martinelli, Judd 2004, Table 1
3	Emilia Romagna	Bologna	Casalfiumanese	Case Nuove di Rifiano	44 19 23	11 34 20		Martinelli, Judd 2004, Table 1
4	Emilia Romagna	Bologna	Castel S.Pietro Terme	San Martino in Pedriolo	44 21 13	11 34 22		Martinelli, Judd 2004, Table 1
5	Emilia Romagna	Bologna	Imola	Bergullo	44 18 32	11 44 14		Martinelli, Judd 2004, Table 1
6	Emilia Romagna	Bologna	Imola	Campo di Fondo	44 21 12	11 42 50		Martinelli, Judd 2004, Table 1
7	Emilia Romagna	Bologna	Monterenzio	Mercatale (Dragone Ardito Desio)	44 23 01	11 26 18		Cantelli 1994
8	Emilia Romagna	Bologna	Monterenzio	San Clemente (or Dragone, or Sassuno)	44 20 09	11 27 18		Martinelli, Judd 2004, Table 1
9	Emilia Romagna	Bologna	Ozzano Emilia	Montebugnolo	44 26 38	11 28 25		Martinelli, Judd 2004, Table 1
10	Emilia Romagna	Modena	Fiorano Modenese	Salsa (di Monte Ave) di Fiorano	44 31 46	10 48 33		Camerana, Galdi 1911
11	Emilia Romagna	Modena	Fiorano Modenese	Nirano	44 30 48	10 49 25		Martinelli, Judd 2004, Table 1
12	Emilia Romagna	Modena	Maranello	Puianello	44 28 36	10 52 00		Martinelli, Judd 2004, Table 1
13	Emilia Romagna	Modena	Marano sul Panaro	Ospitaletto	44 26 11	10 52 54		Martinelli, Judd 2004, Table 1
14	Emilia Romagna	Modena	Polinago	Canalina	44 24 49	10 43 42		Martinelli, Judd 2004, Table 1
15	Emilia Romagna	Modena	Sassuolo	La Rovina di Montegibbio (S. del Rio dei Bagni 1)	44 30 45	10 47 19		Camerana, Galdi 1911
16	Emilia Romagna	Modena	Sassuolo	La Rovina di Montegibbio (S. del Rio dei Bagni 2)	44 30 41	10 47 48		Camerana, Galdi 1911
17	Emilia Romagna	Modena	Sassuolo	La Rovina di Montegibbio (S. "dei Cinghiali")	44 30 58	10 47 59		//

No	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
18	Emilia Romagna	Modena	Sassuolo	La Rovina di Montegibbio (archaeological excavation)	44 30 47	10 47 08		Borgatti et al. 2010
19	Emilia Romagna	Modena	Sassuolo	Montegibbio (S. di sotto)	44 30 55	10 46 39		Martinelli, Judd 2004, Table 1
20	Emilia Romagna	Modena	Sassuolo	Montegibbio (Salsa storica o grande)	44 31 07	10 46 45		Camerana et al., 1926
21	Emilia Romagna	Modena	Sassuolo	Montegibbio (S. di sopra)	44 31 15	10 46 43		Camerana et al., 1926
22	Emilia Romagna	Modena	Serra Mazzoni	Centora-Montardone	44 28 07	10 47 42		Martinelli, Judd 2004, Table 1
23	Emilia Romagna	Parma	Lesignano Bagni	Rivalta	44 37 45	10 19 34		Martinelli, Judd 2004, Table 1
24	Emilia Romagna	Parma	Traversetolo	Torre	44 37 13	10 20 19		Martinelli, Judd 2004, Table 1
25	Emilia Romagna	Reggio Emilia	Viano	Casola - Querciola	44 45 44	10 31 38		Martinelli, Judd 2004, Table 1
26	Emilia Romagna	Reggio Emilia	Viano	Regnano	44 33 27	10 34 34		Martinelli, Judd 2004, Table 1
27	Marche	Ancona	Ancona	Serra dè Conti	43 32 33	13 02 12		Martinelli, Judd 2004, Table 1
28	Marche	Ancona	Ancona	Aspio di Ancona	43 32 00	13 30 04		Martinelli, Judd 2004, Table 1
29	Marche	Ancona	Maiolati Spontini	Moie	43 30 10	13 07 48		Martinelli, Judd 2004, Table 1
30	Marche	Ancona	Maiolati Spontini	Contrada Calapigna	43 28 34	13 07 13		Martinelli, Judd 2004, Table 1
31	Marche	Ancona	Monte Roberto	Monte Roberto	43 28 50	13 08 18		Martinelli, Judd 2004, Table 1
32	Marche	Ancona	Osimo	Santo Stefano	43 30 30	13 27 40		Martinelli, Judd 2004, Table 1
33	Marche	Ancona	San Paolo di Jesi	Battinebbia	43 27 27	13 10 03		Martinelli, Judd 2004, Table 1
34	Marche	Ancona	San Paolo di Jesi	Bagno	43 27 14	13 10 26		Martinelli, Judd 2004, Table 1

No	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
35	Marche	Ascoli Piceno	Fermo	Capodarco	43 11 19	13 45 41		Martinelli, Judd 2004, Table 1
36	Marche	Ascoli Piceno	Monte Rinaldo	Contrada Crocchia	43 01 39	13 34 47		Martinelli, Judd 2004, Table 1
37	Marche	Ascoli Piceno	Offida	Offida	42 56 06	13 41 26		Martinelli, Judd 2004, Table 1
38	Marche	Ascoli Piceno	Rotella	Madonna di Montemisio	42 57 14	13 33 38		Martinelli, Judd 2004, Table 1
39	Marche	Ascoli Piceno	Rotella	Contrada Osteria	42 56 47	13 32 33		Martinelli, Judd 2004, Table 1
40	Marche	Ascoli Piceno	Senigallia	Vallone	43 08 18	13 43 22		Martinelli, Judd 2004, Table 1
41	Marche	Macerata	Macerata	Mogliano	43 11 07	13 28 45		Martinelli, Judd 2004, Table 1
42	Marche	Pesaro-Urbino	Isola del Piano	Isola del Piano	43 44 11	12 46 57		Martinelli, Judd 2004, Table 1
43	Marche	Pesaro-Urbino	Petriano	Petriano	43 46 47	12 44 02		Martinelli, Judd 2004, Table 1
44	Marche	Pesaro-Urbino	Saltara	Saltara	43 45 12	12 53 50		Martinelli, Judd 2004, Table 1
45	Abruzzo	Chieti	Frisa	Frisa	42 15 42	14 22 03		Martinelli, Judd 2004, Table 1
46	Abruzzo	Chieti	Poggiofiorito	Poggiofiorito	42 15 19	14 19 24		Martinelli, Judd 2004, Table 1
47	Abruzzo	Pescara	Penne	Picciano	42 28 26	13 59 27		Martinelli, Judd 2004, Table 1
48	Abruzzo	Teramo	Bisenti	Chiovano	42 32 07	13 40 16		Martinelli, Judd 2004, Table 1
49	Abruzzo	Teramo	Cellino Attanasio	Astelina	42 35 08	13 51 34		Martinelli, Judd 2004, Table 1
50	Abruzzo	Teramo	Cellino Attanasio	Pian Palazzo	42 35 08	13 51 34		Martinelli, Judd 2004, Table 1
51	Abruzzo	Teramo	Pineto	Pineto	42 36 29	14 04 02		Martinelli, Judd 2004, Table 1

No	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
52	Abruzzo	Teramo	Torano Nuovo	Frola	42 39 31	13 42 14		Martinelli, Judd 2004, Table 1
53	Campania	Benevento	Castelfranco in Misciano	Malvizza	41 17 49	15 05 06		Martinelli, Judd 2004, Table 1
54	Basilicata	Potenza	Cancellara	Contrada Bòfete	40 43 51	15 55 23		Martinelli, Judd 2004, Table 1
55	Calabria	Cosenza	San Vincenzo la Costa	San Sisti	39 21 50	16 09 04		Martinelli, Judd 2004, Table 1
56	Calabria	Reggio Calabria	Palizzi	Rocchette	37 55 09	15 59 11		Martinelli, Judd 2004, Table 1
57	Sicilia	Agrigento	Aragona	Zorba	37 23 32	13 37 26		Martinelli, Judd 2004, Table 1
58	Sicilia	Agrigento	Cammarata	Cammarata	37 37 57	13 38 13		Martinelli, Judd 2004, Table 1
59	Sicilia	Agrigento	Casteltermini	Casteltermini	37 32 24	13 38 42		Martinelli, Judd 2004, Table 1
60	Sicilia	Agrigento	Cattolica Eraclea	Bissana	37 26 20	13 23 42		Martinelli, Judd 2004, Table 1
61	Sicilia	Caltanissetta	Caltanissetta	Xirbi	37 29 25	14 03 24		Martinelli, Judd 2004, Table 1
62	Sicilia	Catania	Paternò	Simeto	37 33 57	14 54 06		Martinelli, Judd 2004, Table 1
63	Sicilia	Catania	Paternò	Stadio	37 33 50	14 54 11		Martinelli, Judd 2004, Table 1
64	Sicilia	Catania	Paternò	Vallone Salato	37 33 47	14 54 15		Martinelli, Judd 2004, Table 1
65	Sicilia	Enna	Aidone	Aidone	37 24 52	14 26 47		Martinelli, Judd 2004, Table 1
66	Sicilia	Enna	Valguarnera Caropepe	Valguarnera Caropepe	37 29 42	14 23 20		Martinelli, Judd 2004, Table 1
67	Sicilia	Enna	Villarosa	Villarosa	37 35 08	14 10 24		Martinelli, Judd 2004, Table 1
68	Sicilia	Palermo	Lercara Friddi	Lercara Friddi	37 44 51	13 36 12		Martinelli, Judd 2004, Table 1

No	Region	Province	Municipality	Place name	φ WGS 84	λ WGS 84	Note	Reference
69	Sicilia	Palermo	Palazzo Adriano	Palazzo Adriano	37 40 52	13 22 44		Martinelli, Judd 2004, Table 1
70	Puglia	Ionian Sea	Apulian plate	offshore	39 31 05	18 33 02	inferred location	Fusi et al. 2006
71	Puglia	Ionian Sea	Apulian plate	offshore	39 29 07	18 27 46	inferred location	Fusi et al. 2006
72	Puglia	Ionian Sea	Apulian plate	offshore	39 22 05	18 18 05	inferred location	Fusi et al. 2006
73	Calabria	Ionian Sea	Calabrian Outer Arc	offshore	38 49 25	17 23 20		Fusi et al. 2006
74	Calabria	Ionian Sea	Calabrian Outer Arc	offshore: *Pythagoras*	37 48 20	17 16 20		Praeg et al. 2009
75	Calabria	Ionian Sea	Calabrian Outer Arc	offshore: *Madonna dello Ionio*	38 12 00	16 56 00		Praeg et al. 2009
76	Sicilia	Canale di Sicilia	Malta Plateau	offshore	36 36 25	14 37 37	inferred location	Holland et al. 2003
77	Marche	Adriatic Sea		offshore	43 56 08	13 41 54		Camerlenghi, Pini 2009, Fig.4
78	Marche	Adriatic Sea		offshore (*Bonaccia Field*)	43 28 51	14 22 06		Curzi et al. 1998, Fig.1
79	Lombardia	Mantova	Poggio Rusco	Corte Vulcanello	44 56 57	11 09 17	Toponym	Castellarin et al 2006; Cremonini 2010
80	Emilia Romagna	Modena	Finale Emilia	Bollitora (Reno Finalese)	44 50 23	11 22 53	Toponym	Cremonini 2010; Cremonini et al. 2010
81	Emilia Romagna	Modena	Sassuolo	Sarzola	44 30 47	10 48 29	Toponym	//
82	Piemonte	Torino	Verrua Savoia	Verrua Savoia	45 09 42	08 07 16	Miocene fossil m.v.	Clari et al. 2004

Table 4. List of mud volcanoes known in Italy.

No.	Table reference	Region	Province	Municipality	Place name	References
//	//	//	//	//	Atmosphere	
1	//	Emilia Romagna	Bologna	Castel di Casio	Gaggiola	Borgia et al. 1988, Tab. 1
2	G15	Emilia Romagna	Bologna	Gaggio Montano	Gaggio Montano	Duchi et al. 2005 , Tab 5
3	G 15	Emilia Romagna	Bologna	Gaggio Montano	Molinazzo	Borgia et al. 1988, Tab. 1
4	G 16	Emilia Romagna	Bologna	Grizzana M.	Ca Bellavista	Borgia et al. 1988, Tab. 1
5	V 5	Emilia Romagna	Bologna	Imola	Bergullo	Etiope et al. 2007, Tab.
6	V 8	Emilia Romagna	Bologna	Monterenzio	Drag. Sassuno = S. Clemente	Etiope et al. 2007, Tab.
7	G 19	Emilia Romagna	Bologna	Porretta Terme	Cà Salgastri	Borgia et al. 1988, Tab. 1
8	G 19	Emilia Romagna	Bologna	Porretta	Porretta	Borgia et al. 1988, Tab. 1; *Minissale et al. 2000, Tab. 2, 3
9	G 20	Emilia Romagna	Bologna	S. Benedetto V.Sambro	Castel dell'Alpi	Duchi et al. 2005 , Tab 5; *Borgia et al. 1988, Tab. 1
10	G 23	Emilia Romagna	Ferrara	Cento	Corporeno	Etiope et al. 2007, Tab.
11	G 24	Emilia Romagna	Ferrara	Comacchio	Valli Mezzano	Cremonini et al. 2008, Tab. 1
12	G 25	Emilia Romagna	Forlì-Cesena	Bagno di Romagna	Terme di S. Agnese	Duchi et al. 2005 , Tab 5
13	G 27	Emilia Romagna	Forlì-Cesena	Castrocaro	Bolga well	Capozzi and Picotti 2010, Tab.3
14	G 32	Emilia Romagna	Forlì-Cesena	Tredozio	Monte Busca	Etiope et al. 2007 , Tab.
15	G 34	Emilia Romagna	Modena	Fanano	Trignano	Borgia et al. 1988, Tab.1; *Minissale et al. 2000, Tab. 2, 3
16	V 11	Emilia Romagna	Modena	Fiorano Modenese	Nirano	Etiope et al. 2007 , Tab.
17	G 35	Emilia Romagna	Modena	Lama Mocogno	Barigazzo	Borgia et al. 1988, Tab. 1
18	V 13	Emilia Romagna	Modena	Marano Panaro	Ospitaletto	Etiope et al. 2007, Tab.
19	V 12	Emilia Romagna	Modena	Maranello	Puianello	Duchi et al. 2005 , Tab 5

20	G 36	Emilia Romagna	Modena	Maranello	Govana	Duchi et al. 2005 , Tab 5
21	G 39	Emilia Romagna	Modena	Montese	Montese 19	Borgia et al. 1988, Tab.1
22	V 19	Emilia Romagna	Modena	Sassuolo	Montegibbio	Duchi et al. 2005 , Tab 5
23	//	Emilia Romagna	Modena	Serramazzoni	Selva	Borgia et al. 1988, Tab.1
24	G 45	Emilia Romagna	Modena	Sestola	Ca Boldrini Roncoscaglia	Borgia et al. 1988, Tab.1
25	G 53	Emilia Romagna	Parma	Fornovo Taro	Vallezza	Borgia et al. 1988, Tab.1
26	V 23	Emilia Romagna	Parma	Lesignano Bagni	Rivalta	Etiope et al. 2007, Tab.
27	G 51	Emilia Romagna	Parma	Corniglio	Miano	Heinicke et al . 2010; *Duchi et al. 2005 , Tab 5
28	G 57	Emilia Romagna	Parma	Salsomaggiore	Salsomaggiore	Duchi et al. 2005, Tab 5; *Borgia et al. 1988, T. 1
29	V 24	Emilia Romagna	Parma	Traversetolo	Torre	Etiope et al. 2007, Tab.
30	//	Emilia Romagna	Piacenza	Gropparello	Montechino	Etiope et al. 2007, Tab.
31	V 25	Emilia Romagna	Reggio Emilia	Viano	Casola-Querciola	Duchi et al. 2005, Tab 5
32	V 26	Emilia Romagna	Reggio Emilia	Viano	Regnano	Etiope et al. 2007, Tab.
33	//	Emilia Romagna	Rimini	S. Agata Feltria	Caioletto	Duchi et al. 2005, Tab 5
34	G 79	Toscana	Firenze	Firenzuola	Pietramala	Minissale et al. 2000, Tab. 2, 3
35	//	Toscana	Pistoia	Larciano	Larciano	Duchi et al. 2005 , Tab 5
36	V 51	Molise	Teramo	Pineto	Pineto	Etiope et al. 2007, Tab.
37	V 53	Campania	Benevento	Castelfranco Misciano	Malvizza	Etiope et al. 2007, Tab.
38	G 129	Basilicata	Potenza	Tramutola	Tramutola	Etiope et al. 2007, Tab.
39	V 57	Sicilia	Agrigento	Aragona	Maccalube	Etiope et al. 2007, Tab.
40	G 147	Sicilia	Agrigento	Bivona	Censo	Etiope et al. 2007, Tab. 1
41	V 60	Sicilia	Agrigento	Cattolica Eraclea	Bissana	Etiope et al. 2002, Tab. 2
42	V 63	Sicilia	Catania	Paternò	Salinelle di S. Biagio	Etiope et al. 2002, Tab. 2

* = data source.

Table 5A. Analytical data concerning natural gaseous hydrocarbon manifestations in Italy.

No.	Place name	Lat ° ' ""	Long ° ' ""	CH4 %	CO2 %	N2 %	He%	Ar %	δ13C ‰ PDB	δD ‰ SMOW	Origin	Depth (m)
//	Atmosphere	//	//	0,0002	0,03	78,1	0,0005	0,9	//	//	//	//
1	Gaggiola	44 10 47	10 59 46	95,74	0,96	0,81	n.a.	n.a.	-36,7	-141,8	T	w+s, 160
2	Gaggio Montano	44 11 53	10 56 01	99,35	0,29	0,2	0,002	0,002	n.a.	n.a.	n.a.	s
3	Molinazzo	44 12 34	11 01 23	98,11	0,73	0,45	n.a.	n.a.	-32,7	-129,6	T	w+s, 530
4	Ca Bellavista	44 15 28	11 09 08	98,06	1,6	0,13	n.a.	n.a.	-29,1	-142,8	T	w+s, 170
5	Bergullo	44 18 32	11 44 14	98,61	0,27	0,89	< 0,001	0,02	-69,43	-180,2	B	mv
6	Drag. Sassuno S. Clem.	44 20 09	11 27 18	88,85	2,9	4,15	< 0,001	0,01	-58,4	-219	M	mv
7	Cà Salgastri	44 09 15	10 58 32	98,41	0,99	0,54	n.a.	n.a.	-32	-131	T	w+s, 130
8	Porretta	44 09 04	11 58 01	99,62	0,35	*0,35	*0,0021	*0,0039	-31,3	-138,1	T	w, < 100
9	Castel dell'Alpi	44 12 56	11 14 04	94,54	4,57	0,78	< 0.001	0,009	*-37,4	n.a.	n.a.	s
10	Corporeno	44 45 22	11 18 08	66,52	5,1	26,53	< 0.001	0,51	-65,98	-174,1	B	s
11	Valli Mezzano	44 40 37	12 01 44	66,81	16,03	16,73	0,0027	0,41	-76,14	-223	B	s
12	Terme di S. Agnese	43 50 02	11 57 33	95,85	0,32	3,7	0,006	0,03	n.a.	n.a.	n.a.	s
13	Bolga well	44 10 20	11 56 51	91,68	8,32	n.a.	n.a.	n.a.	-75,5	-171	B	w
14	Monte Busca	44 04 41	11 44 35	58,44	0,45	37,96	0,163	0,06	-35,81	-160,9	T	s
15	Trignano	44 12 39	10 50 29	98,58	0,81	0,24	*0,003	*0,0127	-31,4	-141,9	T	w+s,<100
16	Nirano	44 30 48	10 49 25	98,26	0,58	0,97	0.02	0,01	-45,65	-185,5	T	mv
17	Barigazzo	44 18 25	10 43 47	96,49	1,83	0,21	n.a.	n.a.	-31,8	-140,6	T	w+s,<100
18	Ospitaletto	44 26 11	10 52 54	96,62	2,16	1,07	0,0026	1,01	-45,6	-183,3	T	mv
19	Puianello	44 28 36	10 52 00	95,91	2,35	0,67	< 0,001	0,008	n.a.	n.a.	n.a.	mv
20	Govana	44 31 31	10 51 59	89,26	0,03	10,14	< 0.001	0,11	n.a.	n.a.	n.a.	s
21	Montese 19	44 16 06	10 56 27	97,44	0,1	0,13	n.a.	n.a.	-33,2	-140,3	T	w+s, 190
22	Montegibbio	44 30 55	10 46 39	98,34	0,11	1,4	n.a.	0,006	n.a.	n.a.	n.a.	mv
23	Selva	44 23 46	10 47 38	96,41	0,07	0,32	n.a.	n.a.	-40,2	-147,3	T	s
24	Ca Boldrini Roncoscagli	44 13 50	10 46 14	93,41	1,51	0,01	n.a.	n.a.	-38,8	-140,6	T	w+s,<100
25	Vallezza	44 41 29	10 05 49	88,52	0,17	0,5	n.a.	n.a.	-40,6	-150,7	T	w+s,1500
26	Rivalta	44 37 45	10 19 34	98,32	1,24	0,42	0,0034	0,01	-41,38	-180,6	T	mv
27	Miano	44 29 37	10 06 05	98,62	0,44	0,91	0,0019	*0,051	-39,38	-168,4	T	w+s,1040
28	Salsomaggiore	44 48 58	09 58 43	98,13	0,14	0,61	0,02	n.a.	*-48,1	*-184,2	M	s
29	Torre	44 37 12	10 20 17	96,79	2,73	0,4	0,0013	0,01	-39,1	n.a.	n.a.	mv
30	Montechino	44 48 17	09 41 21	95,3	0,05	0,42	0,0017	0,01	-33,98	-132,6	T	w+s,<100

No.	Place name	Lat ° ' ""	Long ° ' ""	CH4 %	CO2 %	N2 %	He%	Ar %	δ13C ‰ PDB	δD ‰ SMOW	Origin	Depth (m)
31	Casola-Querciola	44 45 44	10 31 38	92,16	0,71	5,79	0,003	0,066	n.a.	n.a.	n.a.	mv
32	Regnano	44 33 25	10 34 34	96,78	2,12	0,92	0,0016	0,01	-45,72	-152,6	M	mv
33	Caioletto	43 49 11	12 10 57	97,83	0,13	1,54	n.a.	0,018	n.a.	n.a.	n.a.	s
34	Pietramala	44 07 14	11 22 49	93,49	0,87	0,22	0,002	0,0021	-36,6	n.a.	n.a.	s
35	Larciano	43 50 00	10 53 24	97,6	0,98	1,3	n.a.	0,08	n.a.	n.a.	n.a.	s
36	Pineto	42 36 52	14 03 41	94,13	0,36	5,4	0,0016	0,11	-73,11	-188,2	B	mv
37	Malvizza	41 17 49	15 05 06	95,64	1,66	1,94	0,025	0,03	-59,09	-163,8	M	mv
38	Tramutola	40 18 56	15 47 23	82,61	2,17	15,12	0,0026	0,01	-42,12	-193,8	T	s
39	Maccalube	37 23 32	13 37 26	91,2	0,73	6,46	0,0071	n.a.	-48,07	-189,6	M	mv
40	Censo	37 37 11	13 26 22	86	2,2	9,66	0,0367	n.a.	-35,1	-146	T	s
41	Bissana	37 26 20	13 23 42	96,2	2,9	0,83	0,0501	n.a.	n.a.	n.a.	n.a.	mv
42	Salinelle di S. Biagio	37 33 50	14 54 11	35,1	64,6	0,78	0,0151	n.a.	n.a.	n.a.	n.a.	mv

Table reference: G = data from Table 1 (gas), V = data from Table 4 (mud volcano). ° ' " = sexag degrees. % = by volume. Origin : B = biogenic, M= mixed; T= thermogenic. Depth (m): s = gas seep, mv = mud volcano, w = well. n.a. = not available.

Table 5B. Analytical data concerning natural gaseous hydrocarbon manifestations in Italy.

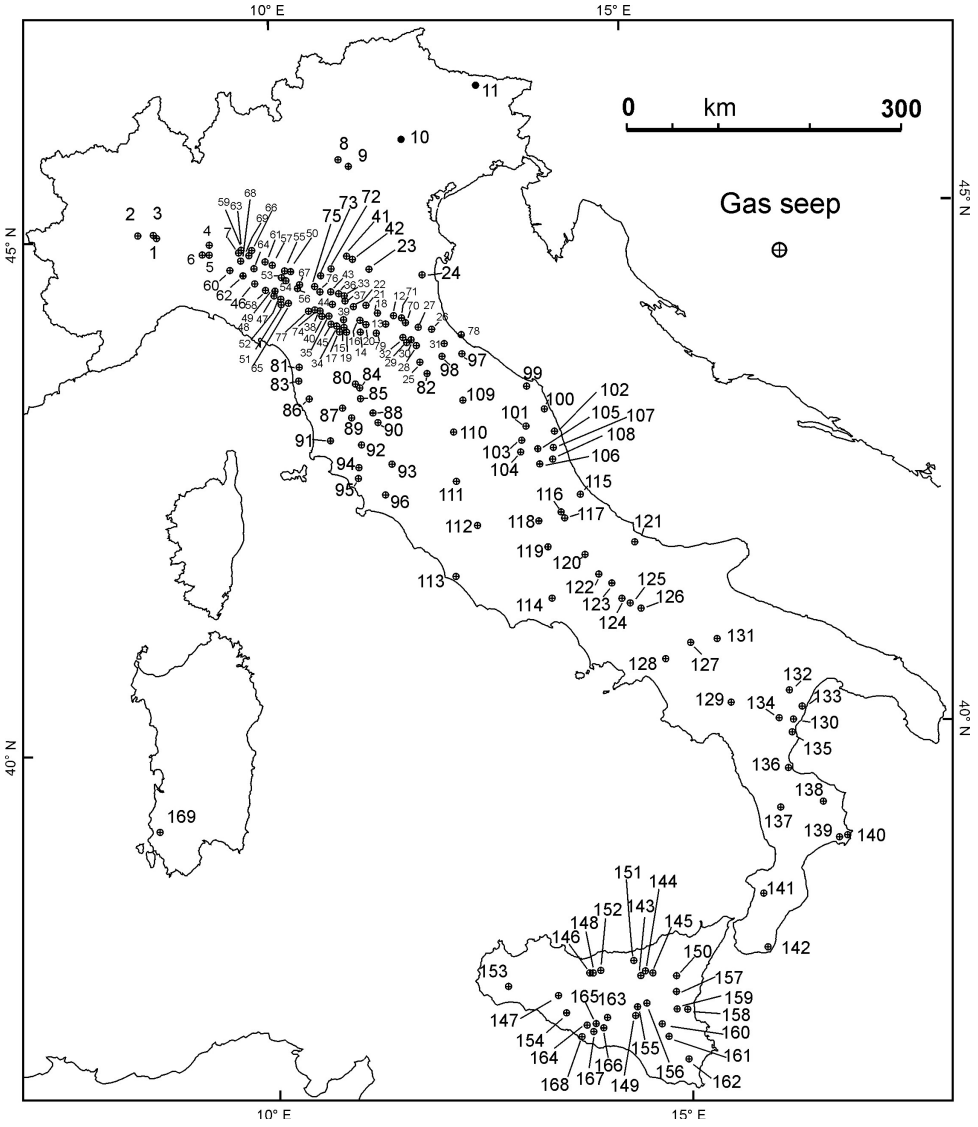

Fig. 3A. Map of natural gas seepages in Italy. Coordinates and related references are given in Table 1.

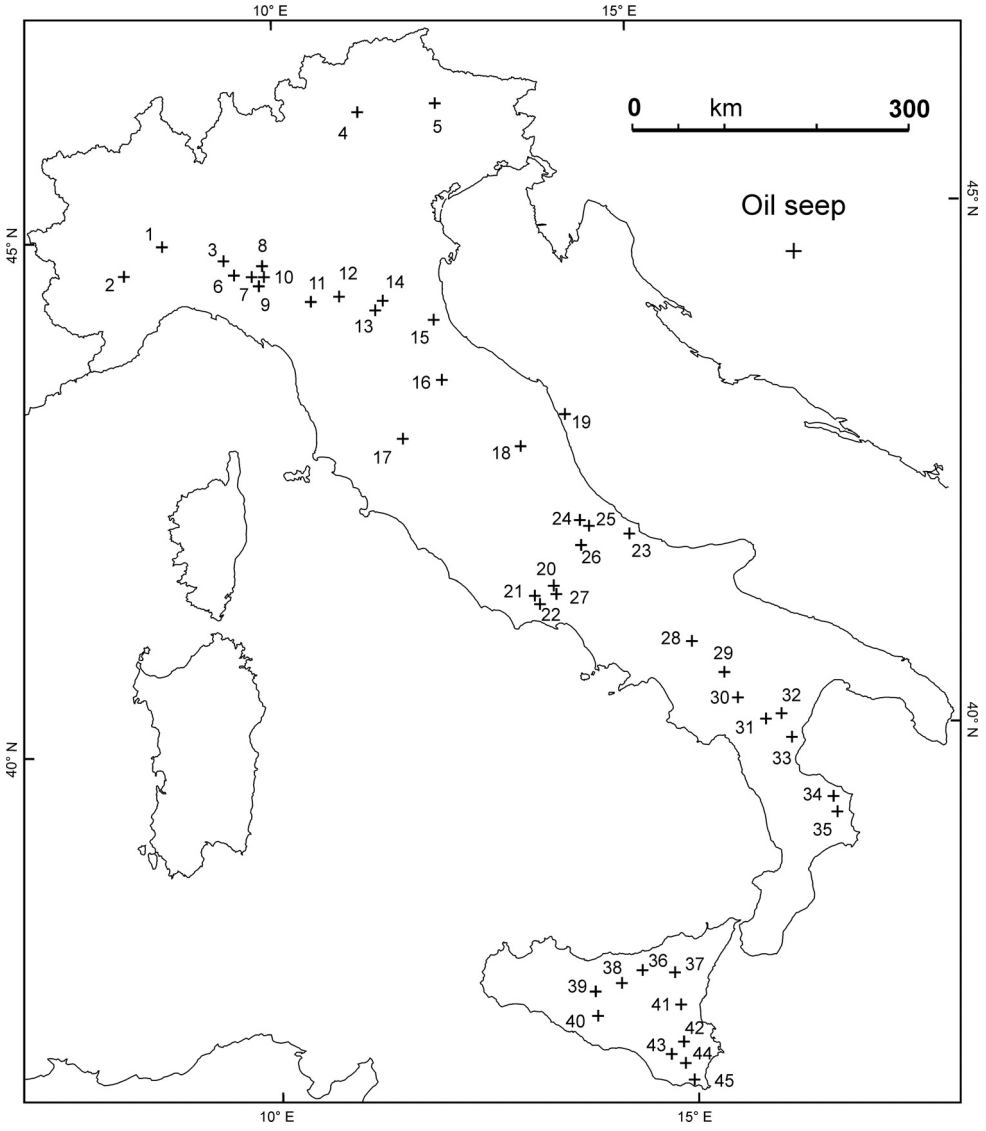

Fig. 3B. Map of natural oil occurrence in Italy. Coordinates and related references are given in Table 2.

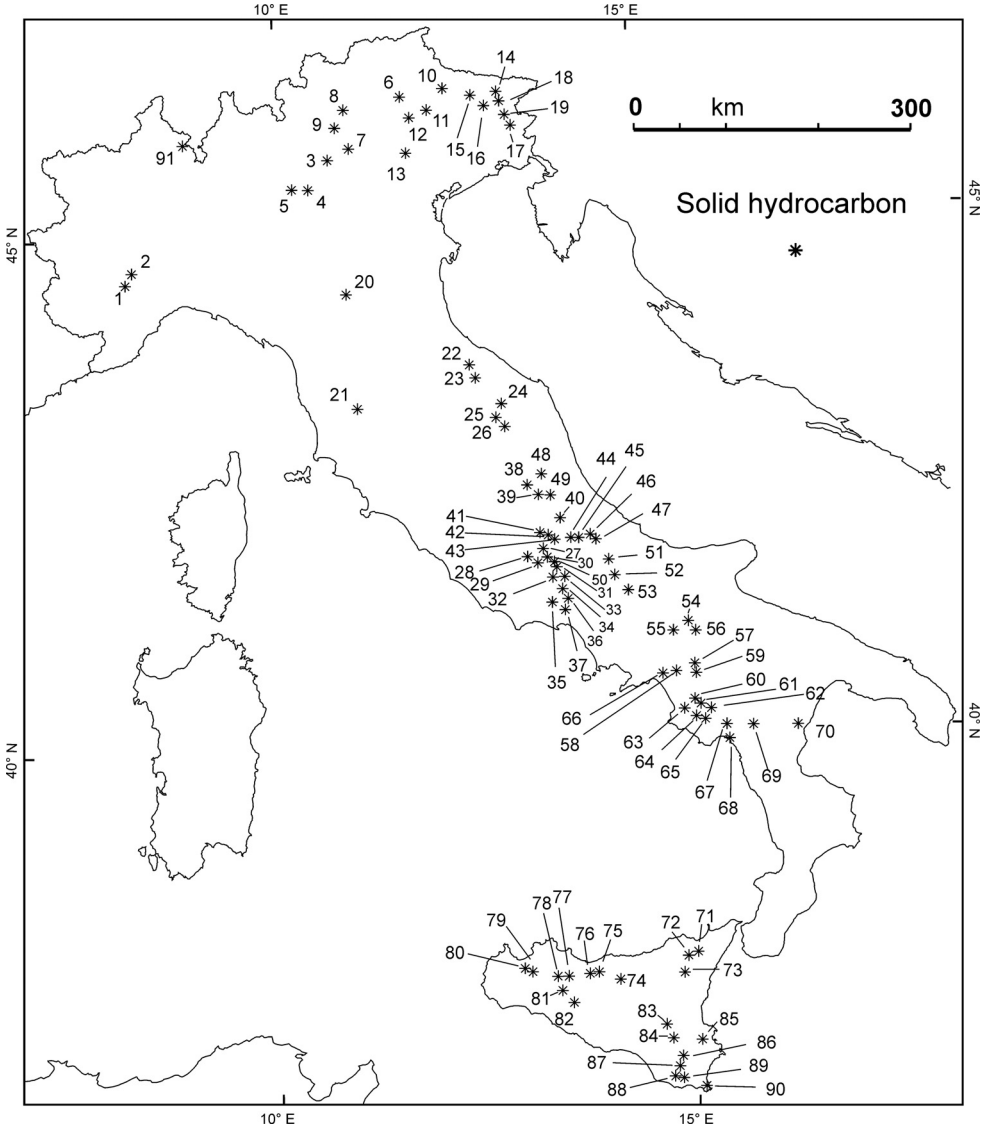

Fig. 3C. Map of natural solid hydrocarbon occurrence in Italy. Coordinates and related references are given in Table 3.

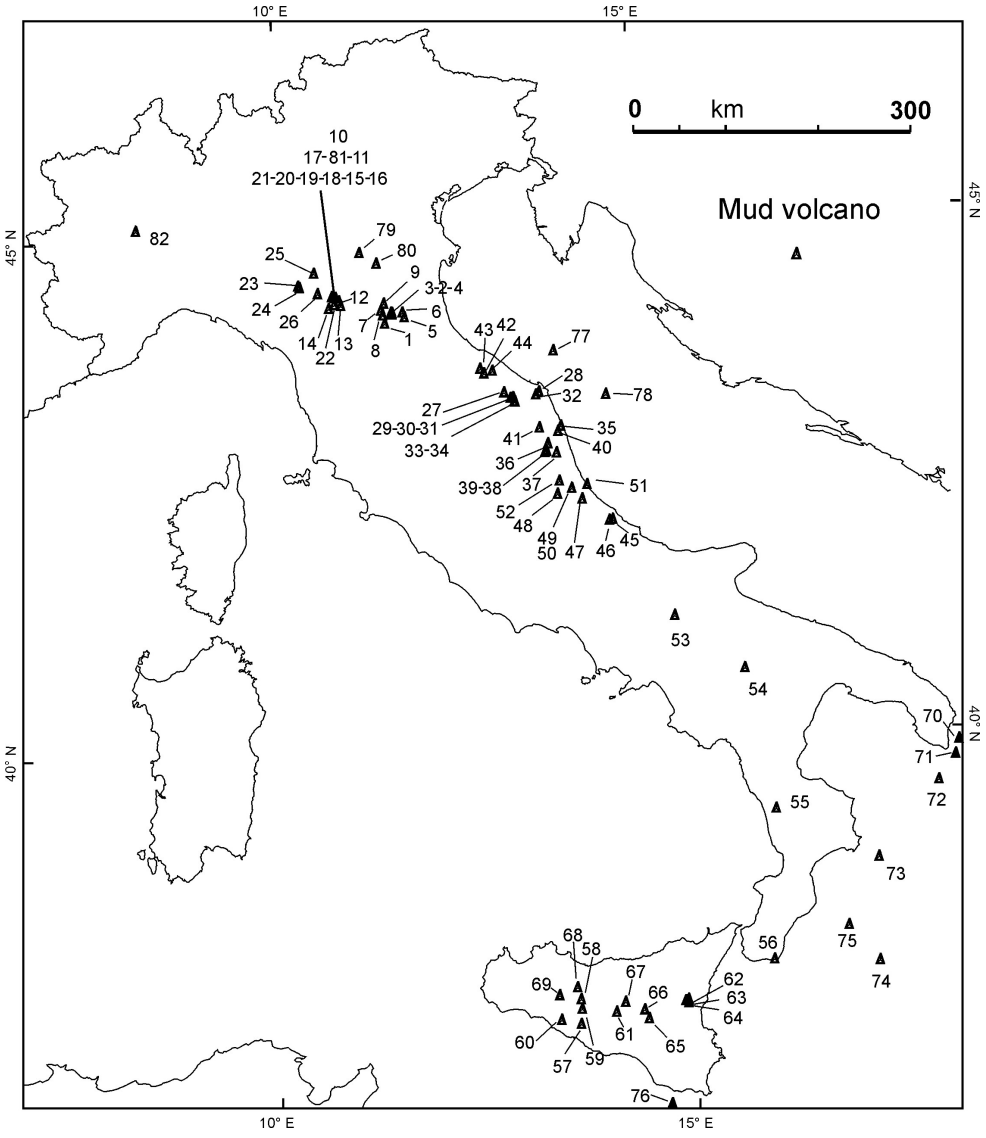

Fig. 3D. Map of mud volcanoes in Italy. Coordinates and related references are given in Table 4.

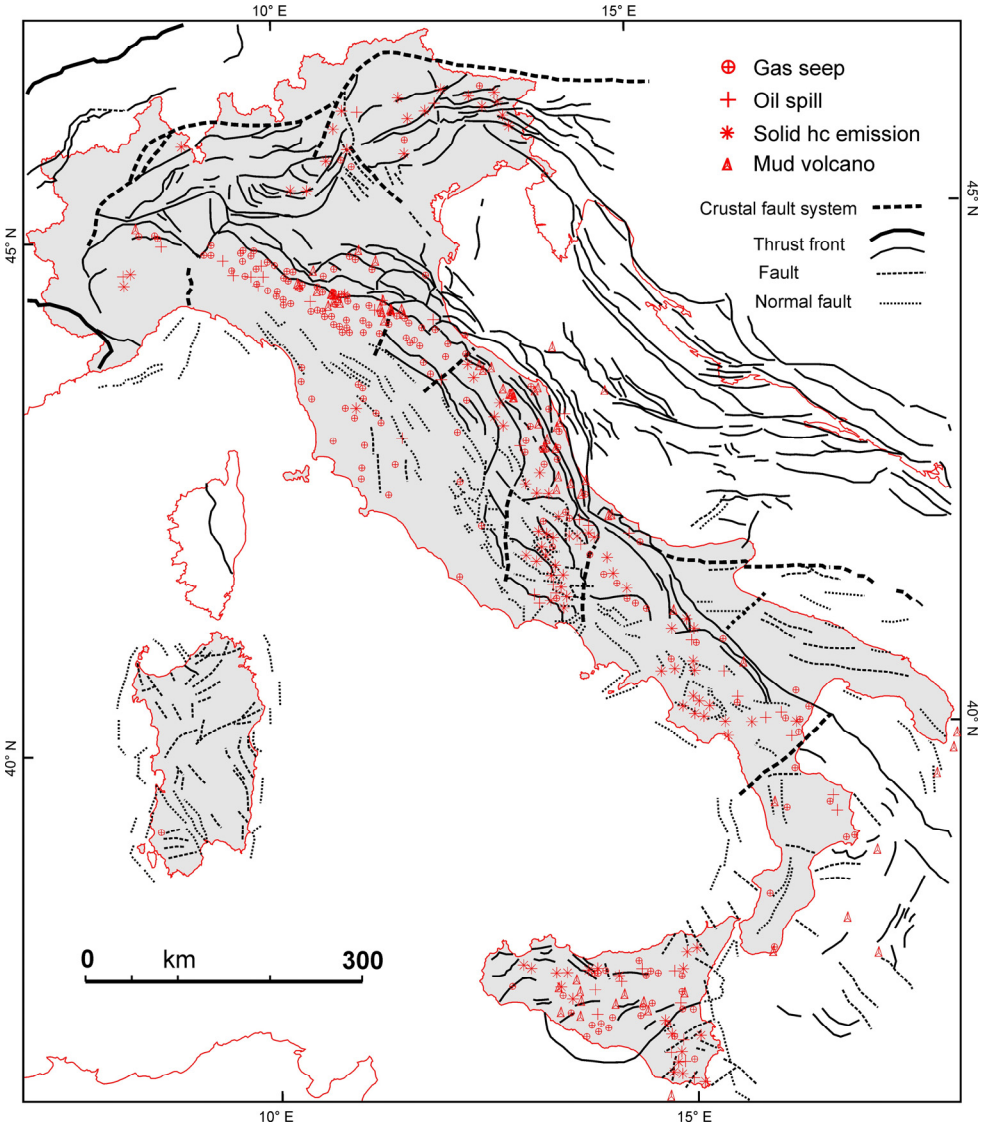

Fig. 4. Relationships existing between Hydrocarbon occurrences and main structural setting of Italy. The structural frame was simplified and redrawn after (CNR 1990; Fantoni and Franciosi 2010, fig. 5).

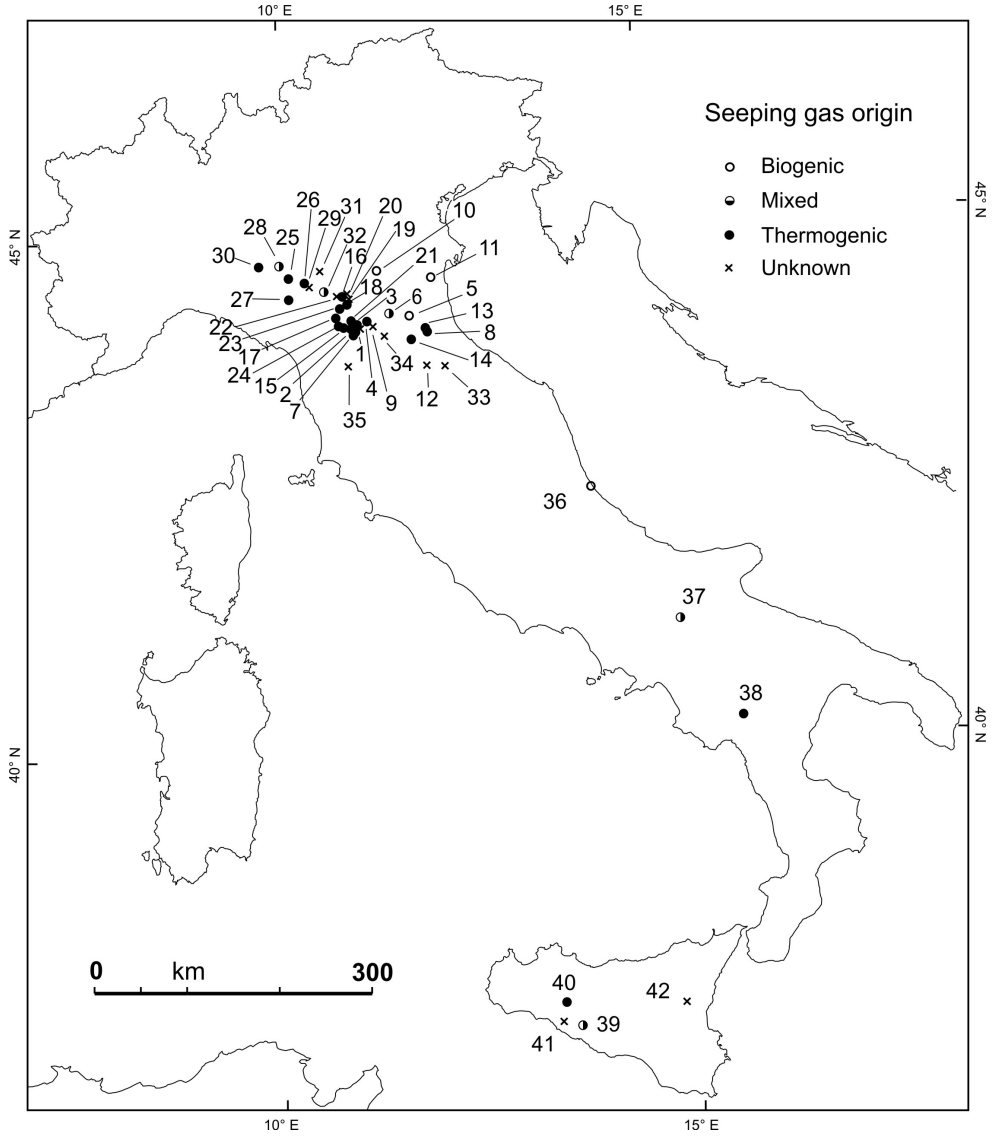

Fig. 5. Location map of gas seepage points in Italy for which analytical data are available in Table 5.

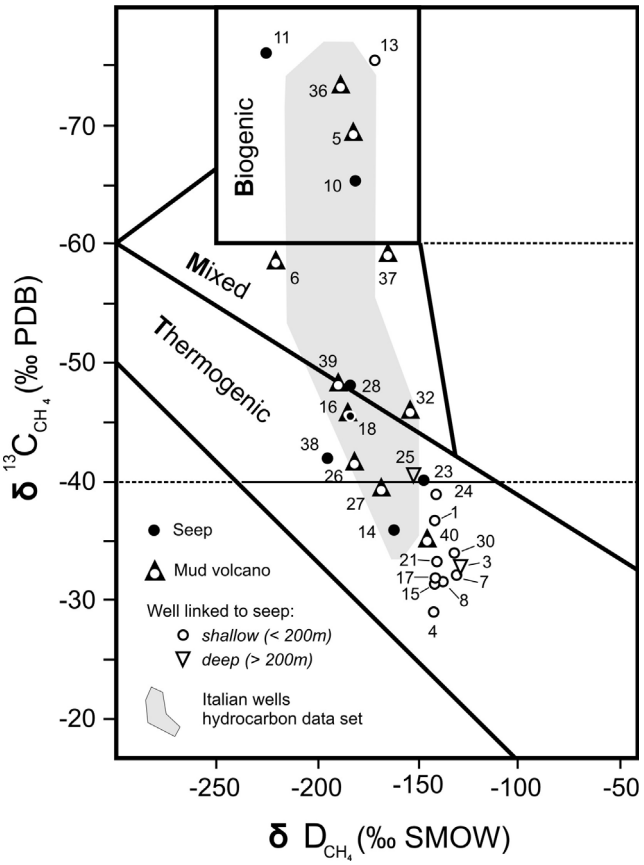

Fig. 6. Simplified Schoell's diagram evidencing biogenic, mixed and thermogenic characters of natural gaseous hydrocarbon seepages in Italy. The cluster of Italian hydrocarbon wells analytical data (gray area) is also shown (after Mattavelli and Novelli 1988).

8. Tectonic stress field in Italy and seepages

A stress field map (Montone et al. 2004) can be used (Fig. 7) for a better understanding of active tectonic processes, to understand the behavior of faults recognized by other methods (CNR 1990) and to infer the origin of surficial manifestations of hydrocarbons (Figs. 3 and 8). The map shows that an extensional regime affects most of the Apenninic belt. Conversely, a compressional (or transpressional) regime characterizes the eastern Alps, the eastern side of the northern Apennines, and the South Tyrrhenian to Northern Sicilian zone. An abrupt change in stress directions marks the transition between northern and southern Apennines, suggesting that the two arcs are characterized by a different tectonic setting and recent evolution. Present stress field probably have not changed significantly in last 10 kyr; thus hydrocarbon seepages are due to rock fracturing, overpressure phenomena and tectonic pumping processes constantly generated in the upper crustal layers. In particular, the intense tectonization of the orogen (Montone et al.,2004; Picotti and Pazzaglia 2008) can

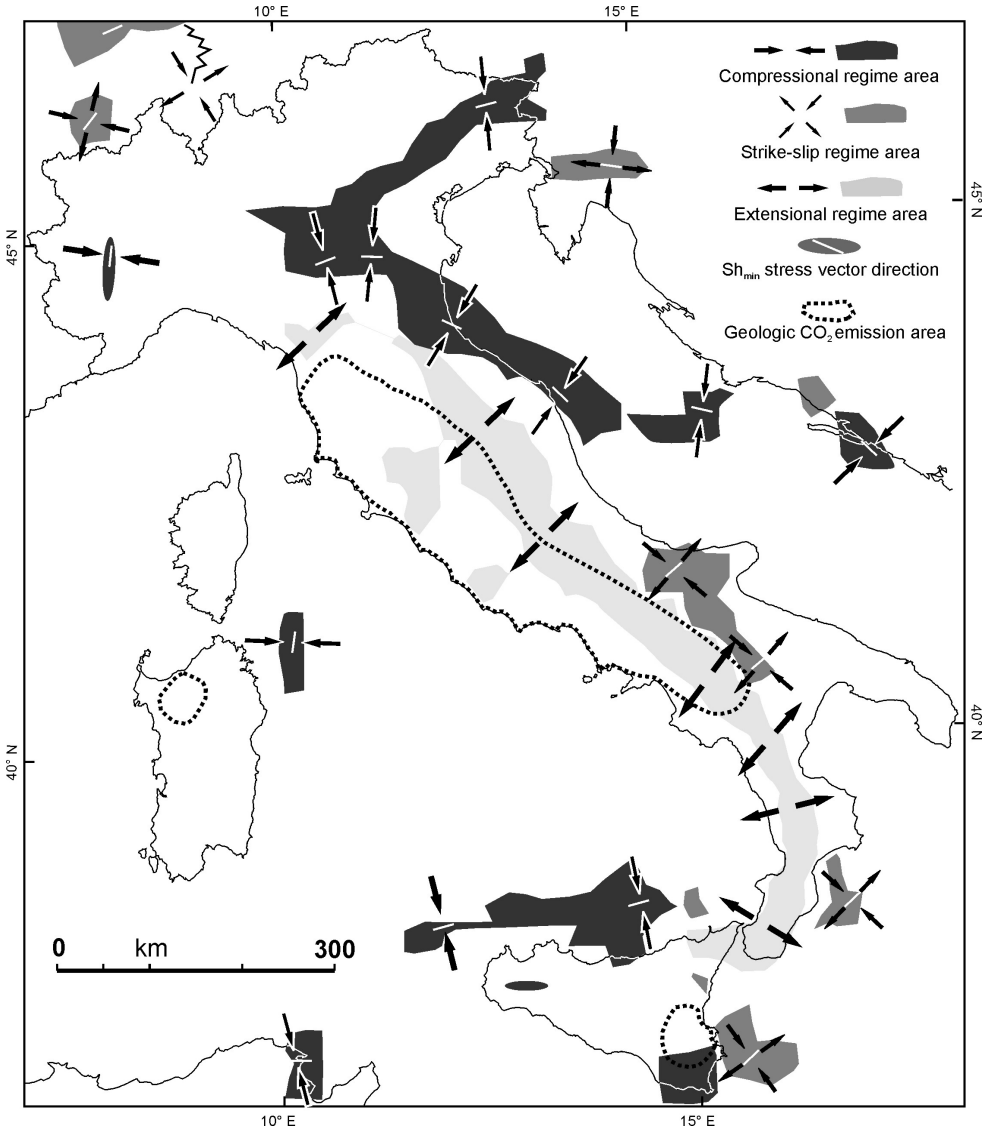

Fig. 7. Stress field data in Italy (after Montone et al.2004, redrawn) and crustal carbon dioxide degassing areas (Frezzotti et al. 2009).

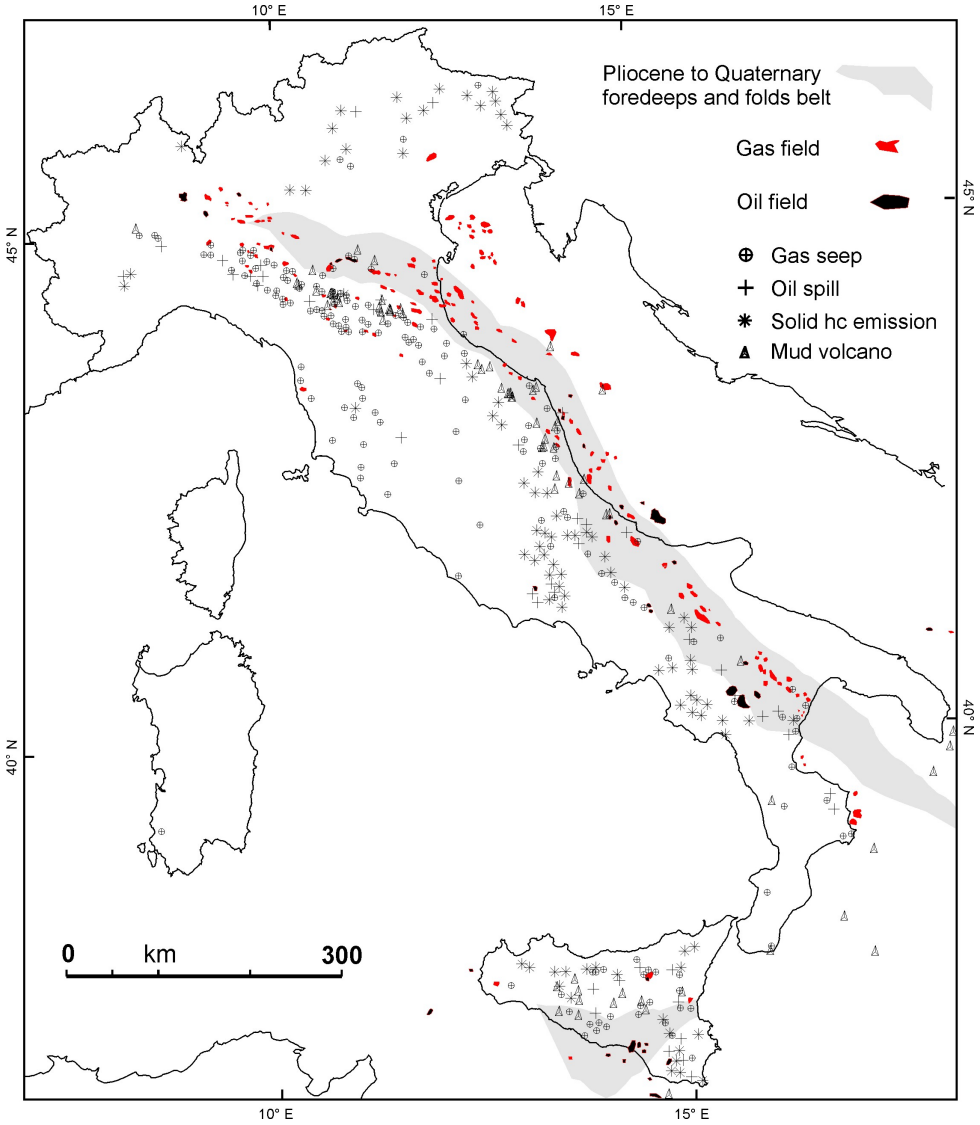

Fig. 8. Spatial comparison between exploited hydrocarbon fields and natural seeps in Italy (from figures 1 and 3).

be responsible for the high number of hydrocarbon seepages of whole Apennines (Martinelli and Judd 2004; Capozzi and Picotti 2010). The distensive behavior of central Italy is probably responsible for the high heat flow values recorded in the Tuscany and Latium areas unfavourable to hydrocarbon accumulations. The western part of the Italian peninsula is characterized by intense CO_2 degassing activity (Minissale et al 2004). Carbon dioxide is chiefly originated by mantle degassing, and by crustal thermometamorphic reactions (e.g.

Chiodini et al. 2004; Frezzotti et al. 2010). Conversely carbon dioxide degassing is lacking in the outer (eastern) flexural domain of the Apennine chain due to higher crustal thickness and to the relatively low geothermal gradient (Buttinelli et al. 2011 and therein references).

9. Conclusions

The mapping of most important gas emissions (Fig.8) shows that the hydrocarbon domain is chiefly located in the core of the raised Apennine belt immediately behind the chain front at the boundary of and its related Plio-Quaternary foredeep, whereas CO_2 emissions are located in the Apennine backdeep area. The geographic distribution of important gas accumulations in Italy does not show a highly significant correlation between surface seepages and the exploited reservoirs and it could also suggest the existence of other still unknown deep reservoirs (Pieri 2001) or their small remnants difficult to be checked up. The majority of the hydrocarbon wells is characterized by biogenic gases, while thermogenic methane is predominant in surface seeping, confirming the sealed condition of most of the biogenic reservoirs and that they still have not experienced the complete evolution of organic matter towards the thermogenic terms induced by pressure and temperature.

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