Geologic CO_2-CH_4 flux database (updated 2000)

(from Morner and Etiope, 2002, Carbon degassing from the lithosphere. *Glob.Planet.Change*, 33, 1-2, 185-203)

Abstract - So far, the role of present-day Earth degassing in global C budget and climate effects has been focused to volcanic emissions. The non-volcanic escape of CO_2-CH_4 from the upper mantle, from carbonate bearing rocks in the crust, from hydrocarbon accumulations and from surface deposits and processes is here discussed in detail. An inventory of recent available data is presented. For the first time a so large quantity of data are considered all together showing clearly that the geological flux of carbon was previously significantly underestimated. Several lines of evidence show that non-volcanic C fluxes in «colder» environments are much greater than generally assumed. Local and regional data suggest that metamorphic decarbonation, hydrocarbon leakage and mud volcanoes could be significant CO_2-CH_4 sources at global scale. Moreover, extensive surface gas-geochemical observations, including soil-atmosphere flux investigations, open the possibility that ecosystems controlled by biogenic activity (soil, permafrost, seawater) can host important components of endogenous C gas (geogas), even in absence of surface gas manifestations. This would imply the existence of a geological diffuse, background emission over large areas of our planet. New theories concerning the occurrence of pervasive geogas and lithospheric processes of C gas production («lithospheric loss in rigidity»), can be taken as novel reference and rationale for re-evaluating geological sources of CO_2 and CH_4, and an important endeavour and work prospect for the years to come.

Our survey shows that it is still very hard to arrive at a meaningful estimate of the lithospheric non-volcanic degassing into the atmosphere. Orders of 10^2-10^3 Mt CO_2/y can be provisionally considered. Assuming as lower limit for a global subaerial volcanic degassing 300 Mt/y, the lithosphere may emit directly into the atmosphere at least 600 Mt CO_2/y (about 10% of the C source due to deforestation and land-use exchange), an estimate we still consider conservative. It is likely that temporal variations of lithosphere degassing, at Quaternary and secular scale, may influence the atmospheric C budget. The present-day lithosphere degassing would seem higher than the value considered to balance at My time-scale the CO_2 uptake due to silicate weathering

Note: The inventory is updated to the year 2000; contributions for improvements (communication of new data or correction of eventual inaccuracies and mistakes) will be greatly appreciated; they can be sent to G. Etiope (Etiope@ingv.it).
The methods used to measure C fluxes (soil-atmosphere flux density and output) may differ from author to author (for further details concerning methods and numerical values, refer to individual references).

References: Request the file to Etiope@ingv.it

Table 1
CO_2 emission rates and flux data from active volcanoes

1a. Volcano	Reference	Output (Mt y^{-1})
Augustine	Symonds et al. (1992)	2.2
Erebus	Wardell and Kyle (1998)	0.66
Erta'Ale	Le Guern et al. (1979)	0.02
Etna (1976-1985)	Allard et al. (1991)	25.5
Etna (1993-1997)	Allard (1998)	4 - 13
Grimsvotn	Agustsdottir and Brantley (1994)	0.19
Kilauea (1983-84)	Greenland et al. (1985)	0.5 - 1.32
Kilauea (Pu'u'O'o cone)	Gerlach et al. (1998)	0.11
Niragongo	Le Guern (1987)	1.2
Oldoinyo Lengai	Koepenick et al. (1996)	2.2 - 2.6
Pinatubo (1991 event)	Gerlach et al. (1996)	42
Popocatepetl	Delgado et al. (1998)	14.6 (36.5 max)
Popocatepetl	Gerlach et al. (1997)	3.3
Redoubt	Casadevall et al. (1994)	0.66
Spurr	Doukas (1995)	~1
St. Helens	Harris et al. (1981)	1.76
Stromboli	Allard et al. (1994)	1-2
Vulcano	Baubron et al. (1990)	0.066
White Island	Rose et al. (1986)	1.32
White Island	Wardell and Kyle (1998)	0.95

1b. Soil degassing	Reference	Flux (kg m^{-2} y^{-1})	Output (t y^{-1}) [km^2]
Canadas caldera (Tenerife)	Hernandez et al. (1997)	0.69-252	205000
Cerro Negro (Nicaragua)	Salazar et al. (2000)	<60000	$2x10^6$
El Hierro (Canary)	Martin et al. (1998)	<12	-
Etna Pernicana fault (Italy)	Giammanco et al. (1997)	~50-100	-
Hakkoda (Japan)	Hernandez et al. (2000)	5-13900	43800 [0.5]
Masaya (Nicaragua)	Perez et al. (2000)	-	$10 x10^6$
Miyake-jima (Japan)	Hernandez et al (1998)	0.04 –6661	-
Nea Kameni Santorini (Greece)	Chiodini et al. (1998)	0.73-2409	5621 [0.28]
Rabaul caldera (Papua N.G.)	Perez et al. (1998)	94	876000 [9.5]
Santorini flanks (Greece)	Barberi and Carapezza (1994)	≤40	-
Stromboli (Italy)	Carapezza and Federico (2000)		70000-90000
Teide Volcano (Tenerife)	Salazar et al. (1997)	-	224000 [144]
Teide Volcano (Tenerife)	Castro et al. (2000)	<108400	229000
Vulcano flanks (Italy)	Baubron et al. (1990)	≤45	11000
Vulcano caldera (Italy)	Baubron et al. (1991)	-	42000 [2.6]
Vulcano Fossa crater (Italy)	Chiodini et al. (1996)	~146	73000 [0.65]
Vulcano plains (Italy)	Chiodini et al. (1998)	0.07-1058	27500 [1.9]
Vulcano fumaroles (Italy)	Italiano et al. (1998)	-	127700

In this and following tables data refer to mean values, ranges or maximum values, as available from the literature. Area investigated is in square brackets.

Table 2
Non-volcanic CO_2 emission rates and flux data from geothermal or active tectonic zones

2a. Diffuse soil degassing	Reference	Flux (kg m^{-2} y^{-1})	Output (ton y^{-1}) [km^2]
Cava dei Selci (Italy)	Rogie et al. (2000)	-	7300
Cover Fort-Sulphurdale (Utah)	Klusman et al. (2000)	0.1 - 4.9	-
Dixie Valley (Nevada)	Bergfeld et al. (1998)	0-73	-
Latera (Italy)	Rogie et al. (2000)	-	>73000
Mammoth Mount. (California)	Rahn et al., (1996)	0-2876	146000 [0.4]
Mammoth M. Horseshoe (Cal.)	Rogie et al. (1998)	730	-
Manziana Caldara (Italy)	Rogie et al. (2000)	-	58400 [0.25]
Manziana Caldara-Solfat. (Italy)	Chiodini et al. (1999)	-	70000 [0.15]
Massif Central (France)	Hermansson et al. (1991)	> 6	-
Matraderecske (Hungary)	Vasarhelyi et al. (1995)	279	-
Poggio Olivo (Italy)	Chiodini et al. (1999)	-	73000 [1.5]
Roosevelt Hot Spring (Utah)	Klusman and LeRoy (1996)	0 - 2.9	-
Salton Sea Mud V. (California)	Rogie, p.c.	-	5400 [0.035]
San Andreas Fault (California)	Lewicki and Brantley (2000)	0.4 – 23	>300000 [60]
San Vincenzo la Costa (Italy)	Etiope, unpub. data	2-250	29 [300 m^2]
Selvena (Italy)	Rogie et al. (2000)	3285	3285 [0.01]
Siena Graben faults (Italy)	Etiope (1995)	0.83 - 1123	>500000 [20]
Siena G. Arbia Fault (Italy)	Etiope (1999)	12.4 - 74.4	7700 [0.3]
Solfatara Pozzuoli (Italy)	Chiodini et al. (1998)	8.8 – 3650	48500 [0.09]
Solfatara Pozzuoli (Italy)	Italiano et al. (1984)	-	58200
Solforata (Italy)	Rogie et al. (2000)	-	18250
Ustica Island (Italy)	Etiope et al. (1999)	6.9 - 94	260000 [9]
Ustica Arso fault (Italy)	Etiope et al. (1999)	77.3	-
Yangbajain (Tibet)	Chiodini et al. (1998)	0.36 - 2555	50370 [3.2]
Yellowstone Mud V. (Wyoming)	Werner et al (2000)	1.5 - 11900	48400 [3.5]

2b. Gas vents	Reference	Output (ton y^{-1})
Bossoleto, Siena (Italy)	Raschi and Menegali, p.c.	3500
Castiglioni, Siena (Italy)	Etiope (unpub. data)	4400
Manziana Caldara (Italy)	Rogie et al. (2000)	4800
Massa Martana (Italy)	Martinelli, p.c.	1800
Mefite d'Ansanto (Italy)	Rogie et al. (2000)	102200
Mefite d'Ansanto (Italy)	Italiano et al. (2000)	310000
Montecastello Vibio (Italy)	Martinelli, p.c.	1800
Nyos Lake- 1986 event (Cameroon)	Kling et al (1987)	2.3 Mt
Pienza (Italy)	Rogie et al. (2000)	4015
Poggio dell'Ulivo (Italy)	Rogie et al. (1996)	73000
Rapolano Cecilia (Italy)	Rogie et al. (2000)	17520
Rapolano Ambra (Italy)	Rogie et al. (2000)	35040
Salton Sea Mud V. (California)	Rogie, p.c.	7300 – 18300
San Sisto (Italy)	Italiano et al. (2000)	21600
Selvena (Italy)	Rogie et al. (2000)	2920
Telese (Italy)	Italiano et al. (2000)	20000
Umbertide, Umbria (Italy)	Martinelli, p.c.	5475
Umbertide, Umbria (Italy)	Rogie et al. (2000)	5840
Yellowstone all Mud Volc. (Wyom.)	Werner et al (2000)	33400 - 110000

(continue)

2c. Regional output estimates	Reference	Output (ton y^{-1})
Azerbaijan mineral springs	Feyzullayev, p.c.	88400
Cascade Range (Oregon)	James et al. (1999)	400000 [1200 km of arc]
Central Apennine (Italy)	Chiodini et al. (2000)	4.4–13.2 x 10^6 [12564 km^2]
Central Italy	Rogie et al., (2000)	> 4 x 10^6
Indonesia-Philippines	Seward and Kerrick (1996)	> 1.8 x 10^6
Larderello and Amiata (Italy)	Chiodini et al. (2000)	2.2 x 10^6
Taupo Volcanic Zone (N.Z.)	Seward and Kerrick (1996)	~ 440000
Salton Trough (California)	Kerrick et al., (1995)	44000
Subaerial Pacific Rim	Seward and Kerrick (1996)	~ 44 x 10^6
Western Eger Rift (Czech Rep.)	Weinlich et al. (1999)	16000 [1500 km^2]
Yellowstone Mud Volc. (Wyoming)	Werner et al. (2000)	176000 [3.5 km^2]

Table 3
CO_2 global flux estimates (Mt y^{-1})

Subaerial Volcanism (ARC+PLUME)	Varekamp et al. (1992)	145
	Williams et al (1992)	65±46
	Marty and Tolstikhin (1998)	242
Submarine Volcanism (MOR)	Varekamp et al. (1992)	66
	Le Cloarec and Marty (1991)	66
	Marty and Tolstikhin (1998)	97
Global Volcanism (subaerial+submarine)	Gerlach (1991)	130-175
	Le Cloarec and Marty (1991)	100-180
	Varekamp et al. (1992)	210
	MOR+PLUME by Marty and Tolstikhin (1998) + ARC by Sano and Williams (1996)	367
Volcanism + Metamorphism	Brantley and Koepenick (1995)	270
	Berner (1991)	295

Table 4
CH_4 flux data from geothermal (g), hydrocarbon-prone areas (h) or simple active tectonic zones (f).

4a. Mud Volcanoes (h)	Reference	Output (ton/y)
19 m.v. in Azerbaijan	Feizullayev p.c.	≈ 45
Akhtarma (Azerbaijan)	Feizullayev p.c.	11.26
Ayrantekyan (Azerbaijan)	Feizullayev p.c.	2.8
Cheildag (Azerbaijan)	Feizullayev p.c.	5.6
Utalgi (Azerbaijan)	Feizullayev p.c.	4.68
Nirano (Italy)	Martinelli p.c.	> 0.17
Pujanello (Italy)	Martinelli and Ferrari (1991)	0.12
Regnano (Italy)	Martinelli p.c.	0.44
S. Vincenzo la Costa (Italy)	Etiope, unpub. data	0.02 [300m^2]
Savan Fault (Kamchatka)	Kudryatseva et al. (1974)	7.8
4b. Soil degassing	**Reference**	**Flux (mg m^{-2} d^{-1})**
Cove Fort Sulphurdale (Utah) (g)	Klusman and LeRoy (1996)	-4.01 /7.68
Denver-Julesburg basin (Colorado) (h)	Klusman and Jakel (1998)	-40.99 / 43.07
Matraderecske (Hungary) (f-g)	Vasarhelyi et al. (1995)	31,250 (?)
Music Mt. (Pennsylvania) (h)	Duchscherer (1981)	100/200
Piceance (Colorado) (h)	Klusman et al. (1998)	-6.05 / 3.11
Powder River (Wyoming) (h)	Klusman et al. (1998)	-24.37 / 19.13
Railroad Valley (Nevada) (h)	Klusman et al. (1998)	-6.09 / 4.76
Roosevelt Hot Sprngs (Utah) (g)	Klusman and LeRoy (1996)	-11.2 / 20.8
S. Vincenzo la Costa, m.v. (Italy) (h)	Etiope, unpub. data	-3 / 600
Siena Graben Arbia Fault (Italy) (f-g)	Etiope (1999)	4.8 / 78
Siena G. unfaulted area (Italy)	Etiope (1999)	-1.2 / 4.8
Ustica Island (Italy) (f)	Etiope et al. (1999)	2.9 / 54.9
4c. Regional and global estimates	**Reference**	**Output (Mt y^{-1})**
Azerbaijan mud volcanoes	Sokolov et al. (1969)	1
Azerbaijan mineral springs	Feyzullayev, p.c.	0.002
Global volcanism	Cadle (1980)	0.34
On-shore microseepage		
Global sedimentary basins	Klusman et al. (1998)	7
Pennsylvania gas field	Duchscherer (1981)	3
Off-shore microseepage		
UK continental shelf	Judd et al. (1997)	0.12 -3.5
European shelf	Klusman et al. (1998)	2 - 57
All continental shelfs	Watson et al. (1990)	5 - 15 (?)
World Ocean Ridge system	Welhan and Craig (1979)	0.11

Table 5
Reference normal biologic fluxes of CO_2 and CH_4

CO_2		(kg m^{-2} y^{-1})
Temperate climate fields	Bonan (1995)	0.6-3.5
Global mean flux	Raich and Schlesinger (1992)	1.8
CH_4		(mg m^{-2} d^{-1})
Aerobic environment		
Dry soil (mean)	Klusman et al. (1998)	-0.5
Temperate forest soil	Dong et al. (1998)	-1.7
Anaerobic environment		
Wet tropics-temper.-subarctic	Batjes and Bridges (1994)	2.7 - 550
Peatlands Hudson bay	Klinger et al. (1994)	10 - 100