What Can We Learn from Natural Releases of CO_2?

Jennifer L. Lewicki

Earth Sciences Division

Lawrence Berkeley National Laboratory

Background

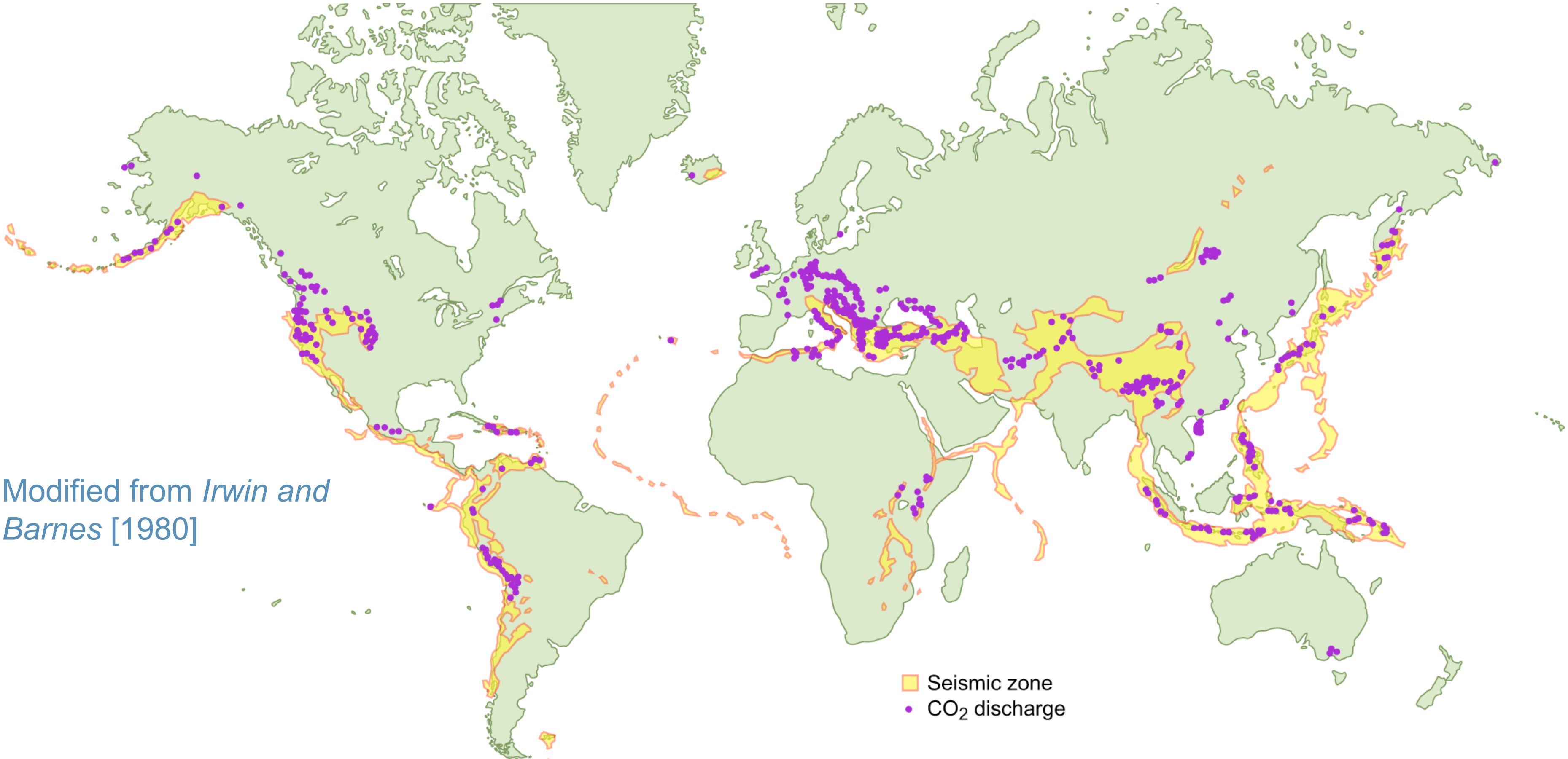
- For geologic carbon sequestration (GCS) to be an effective greenhouse gas mitigation strategy and implemented on a large scale, CO_2 storage must be safe and secure.
- Careful site selection, development of risk assessment procedures, and design of effective monitoring strategies are key aspects to achieving this goal.
- Natural CO_2 releases are not regarded as analogues for GCS, but valuable lessons can be learned to minimize leakage risk and assure public.

Primary Questions

- Where and how do releases of CO_2 typically occur?
- How is CO_2 leakage expressed in the near-surface environment (rates and spatio-temporal distributions)?
- What are the mechanisms of CO_2 transport in the near-surface environment? Influence of topography, meteorology?
- What are the environmental, health, and safety (EH&S) impacts of CO_2 emissions?
- What are effective strategies for near-surface CO_2 leakage detection, monitoring, and hazards mitigation?

  – Talk will address questions generally with brief examples from a few of the many studies conducted around the world
  – Will leave the details to following workshop presenters…

Locations and Mechanisms of CO_2 Releases



Modified from *Irwin and Barnes* [1980]

-Natural CO_2 releases strikingly correlated with zones of active seismicity worldwide.
-CO_2 primarily derived from magma and metamorphic processes. Migrates to the surface along fault/fracture zones. May drive seismicity.

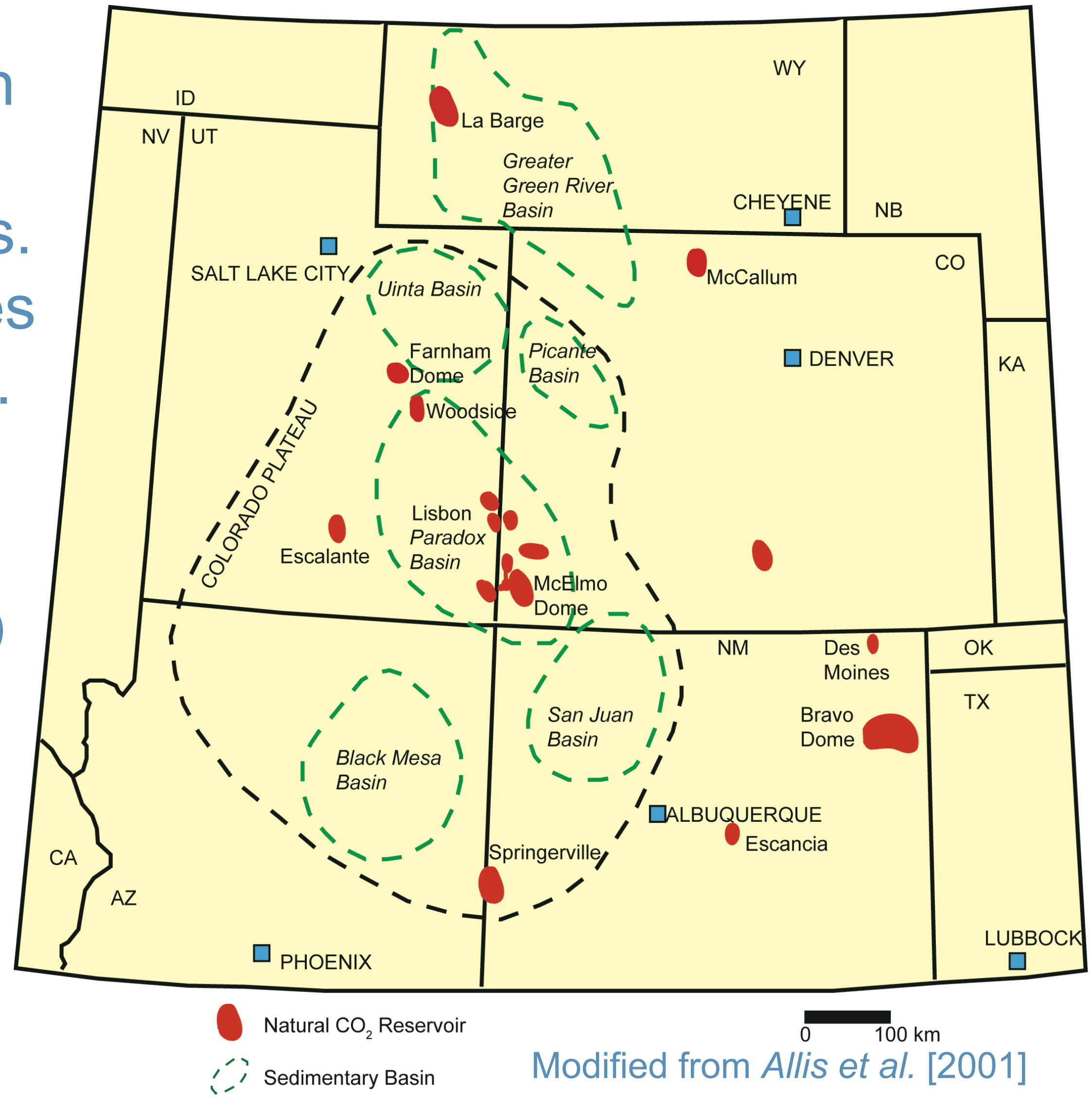
Locations and Mechanisms of CO_2 Releases

- Volcanic systems. A few examples:
  - Solfatara di Pozzuoli, Aeolian islands (Italy)
  - Mammoth Mountain, Yellowstone (USA)
  - Dieng volcanic complex (Indonesia)
  - Lakes Nyos and Monoun (Camaroon)
  - Nisyros (Greece)
  - Masaya volcano (Nicaragua)
  - Eifel volcanic district (Germany)

- General mechanism: migration of magmatic/metamorphic CO_2 through faulted/fractured volcanic rocks. May be triggered by geomechanical damage of sealing caprocks by volcanic/seismic activity. CO_2 may be temporarily trapped between source and surface in secondary reservoirs.
- Pervasive natural leakage indicates these systems generally not preferable GCS sites

Locations and Mechanisms of CO_2 Releases

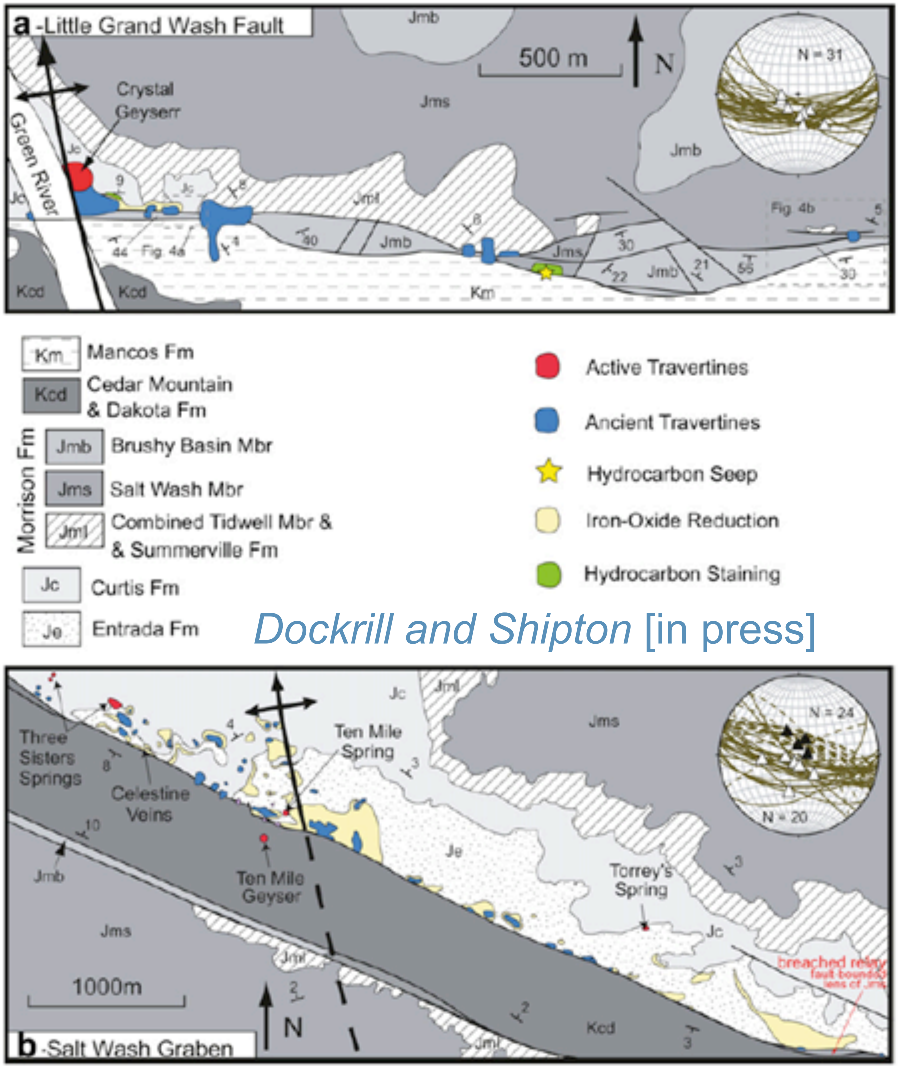
- Sedimentary basins with natural CO_2 reservoirs: analogues for GCS sites. Fewer (known) examples of near-surface leakage.
- CO_2 releases:
  - Florina basin (Greece)
  - Southeast basin (France)
  - Cheb basin (Czech Republic)
  - Springerville (USA)



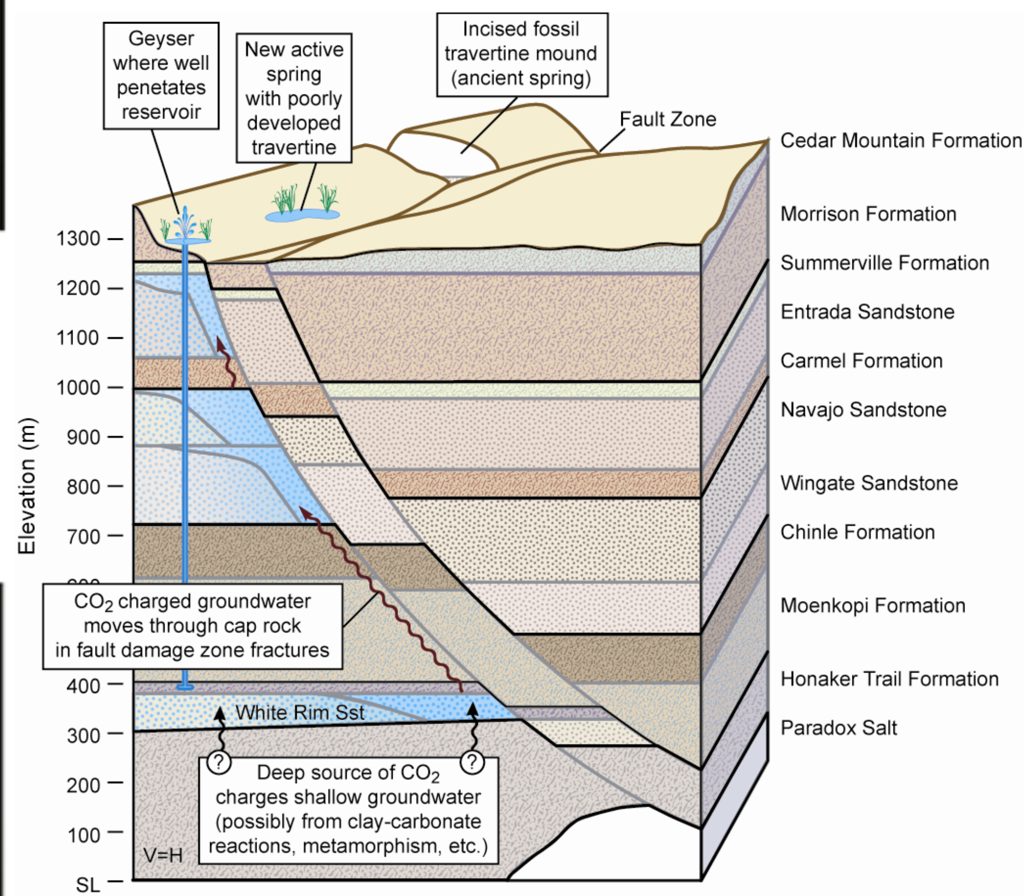
Modified from *Allis et al.* [2001]

Locations and Mechanisms of CO_2 Releases

Paradox Basin (USA)



Dockrill and Shipton [in press]



Modified from *Shipton et al.* [2005]

Faults as permeable pathways for leakage still must be considered and well characterized in sed. basins

Surface Emission Styles

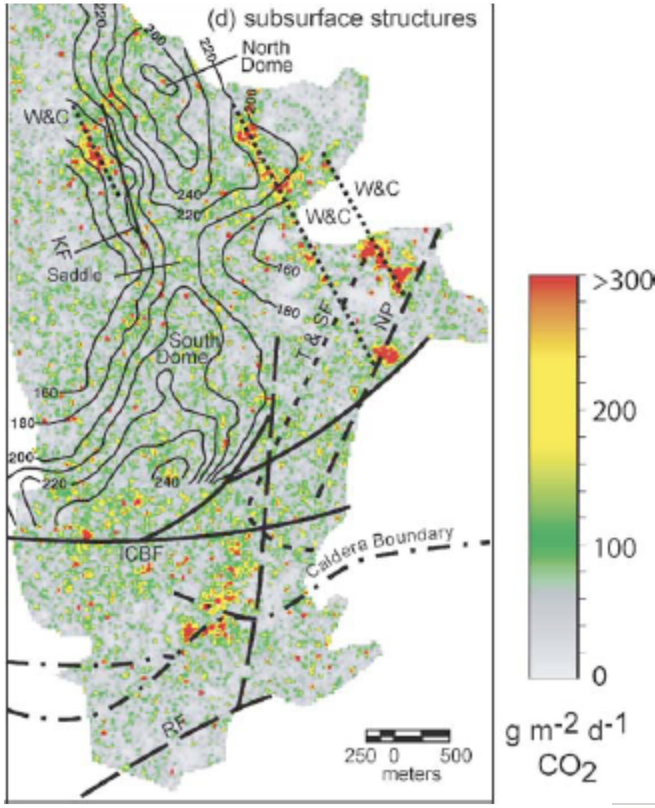
Carbonated springs

Vents: fumaroles, mofettes

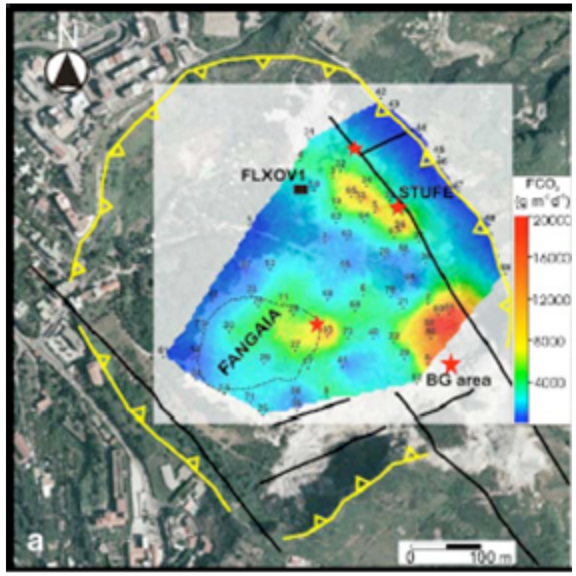
Diffuse soil degassing

Sudden / large emissions (e.g., volcanic plume, lake overturn, gas burst)

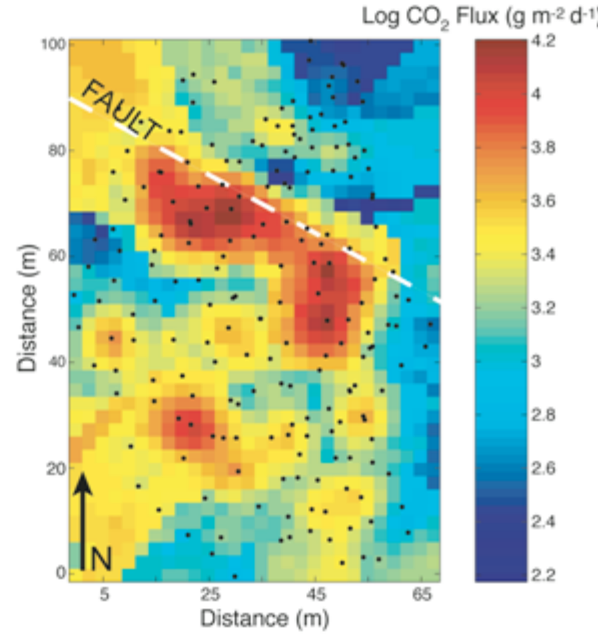
Emission Rates: From Soil



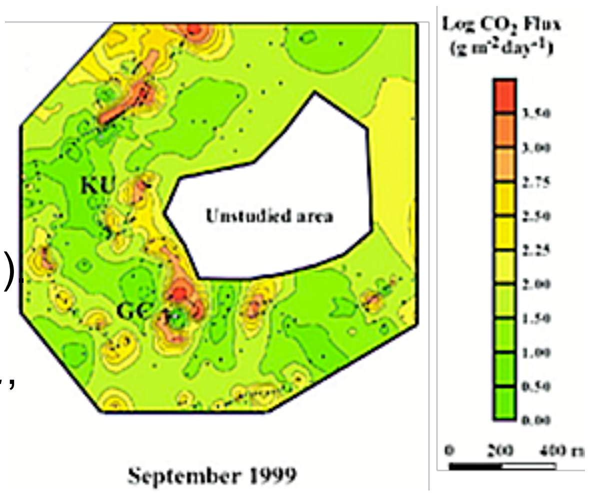
Rotorua geothermal system (New Zealand). 620 t CO_2 d^{-1} [*Werner and Cardellini* 2006]



Solfatara di Pozzuoli (Italy). 677 t CO_2 d^{-1} [*Granieri et al.*, 2010]



Masaya volcano (Nicaragua). 20 t CO_2 d^{-1} [*Lewicki et al.*, 2003]

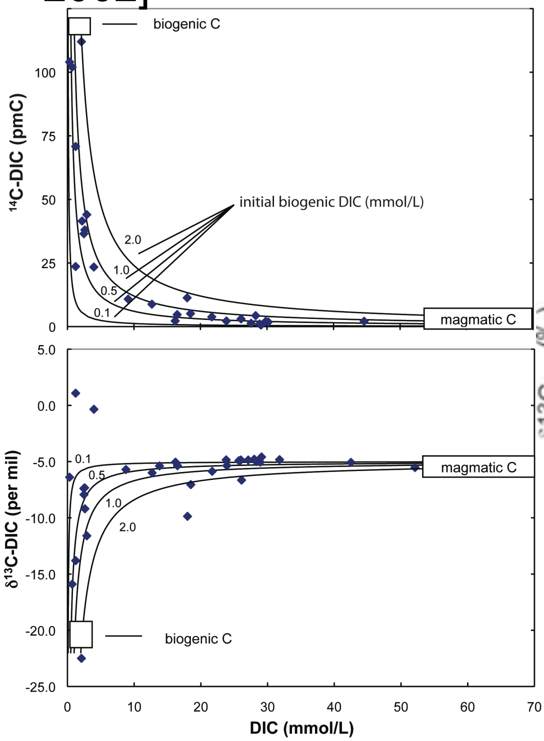


Usu volcano (Japan) 340 t CO_2 d^{-1} [*Hernandez et al.*, 2001]

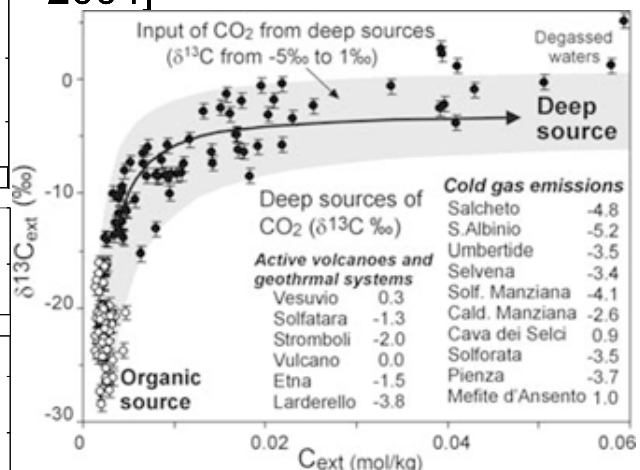
Soil CO_2 emission rates associated with different leakage pathways and geologic settings can be quantified using standard approaches

Emission Rates: Into Ground and Surface Water

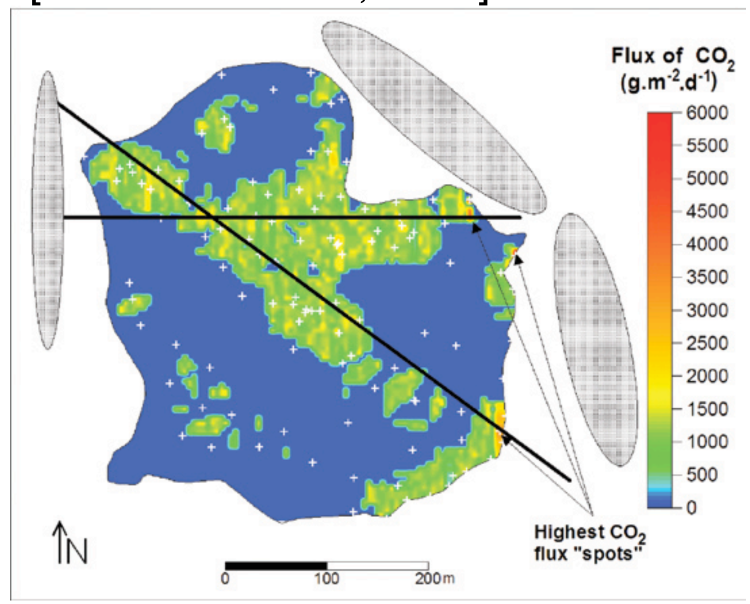
Mammoth Mountain (USA). 55 t CO_2 d^{-1} [*Evans et al.*, 2002]



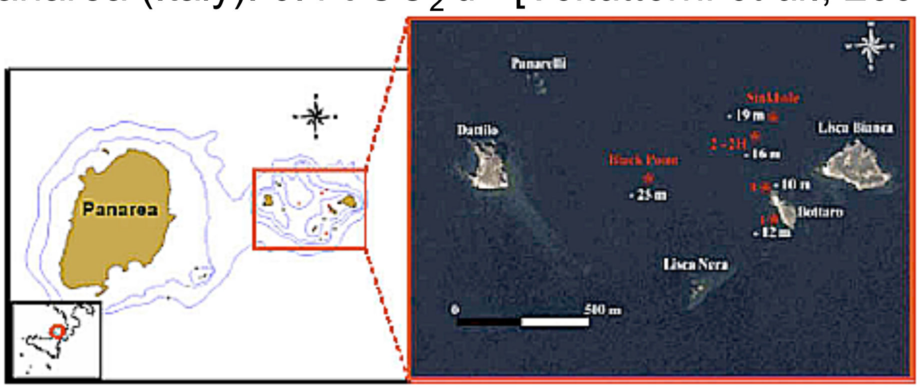
Central and South Italy. 2.5 x 10^4 t CO_2 d^{-1} [*Chiodini et al.*, 2004]



El Chinchon (Mexico). 164 t CO_2 d^{-1} [*Mazot and Taran,* 2009]



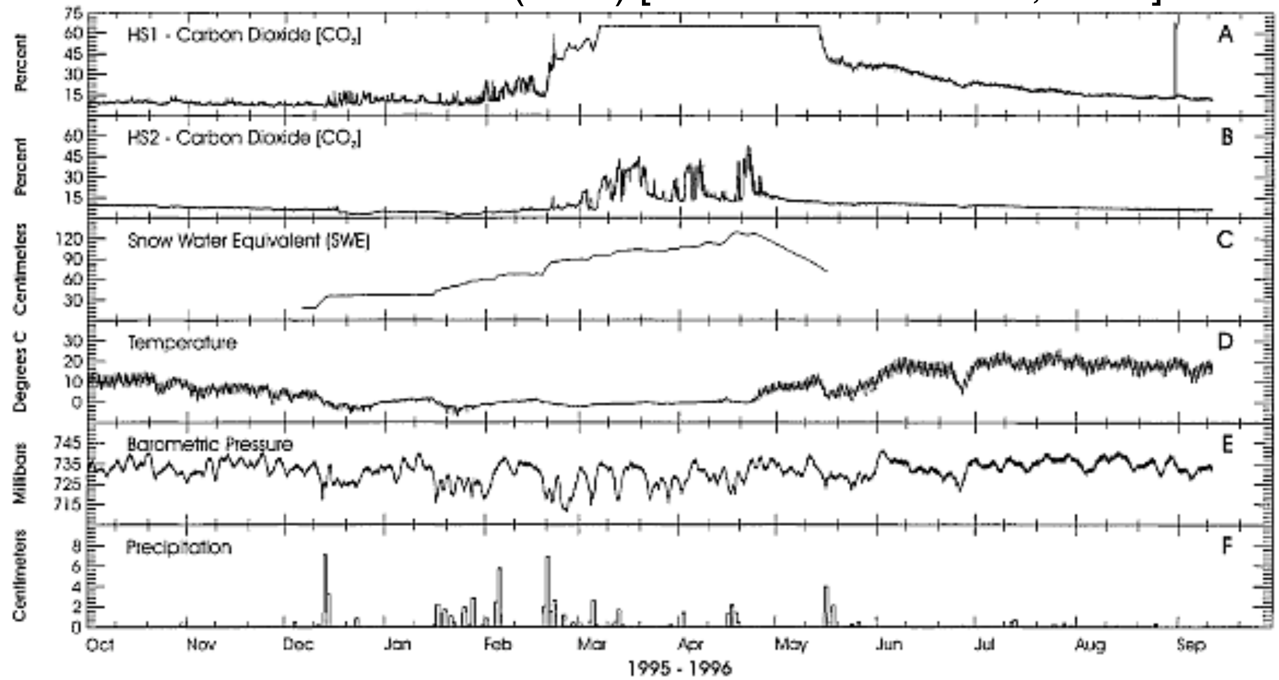
Panarea (Italy). 0.4 t CO_2 d^{-1} [*Voltattorni et al.*, 2009]



CO_2 emission rates into ground and surface waters can be estimated for different leakage pathways and geologic settings

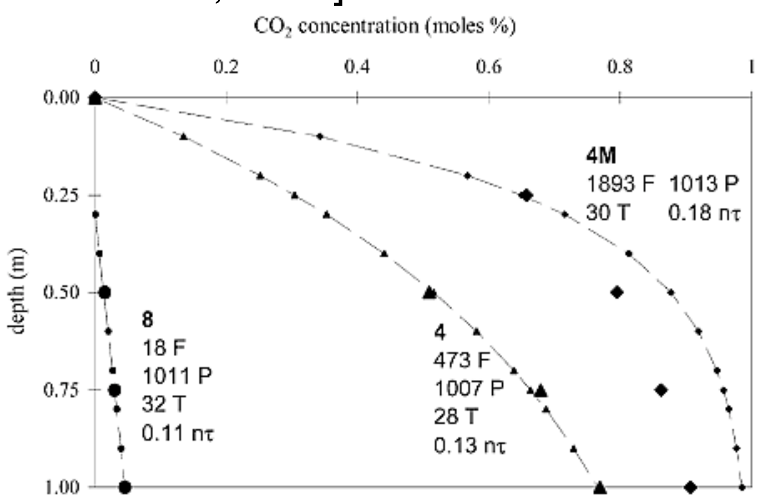
Near-Surface Gas Transport

Mammoth Mountain (USA) [*McGee and Gerlach,* 1998]

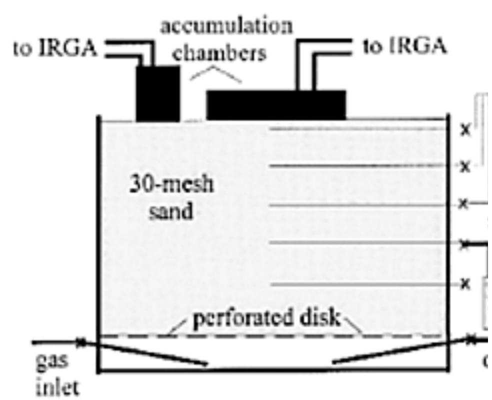


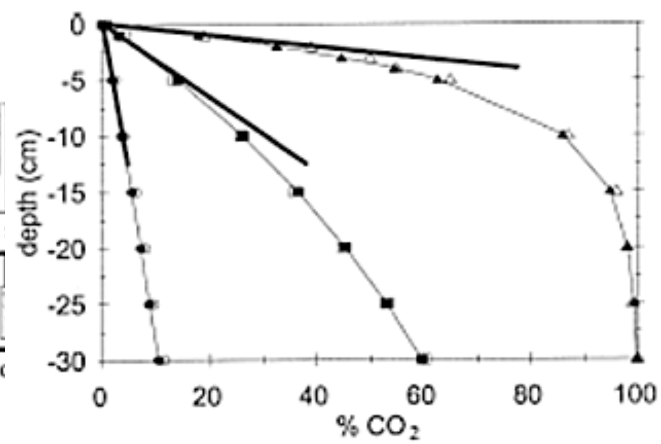
Subsurface, surface, and atmospheric measurements of CO_2 concentrations and fluxes at natural release sites elucidate gas transport processes, effects of soil physical properties, meteorology and topography on transport

Vulcano (Italy) [*Carapezza and Granieri,* 2004]



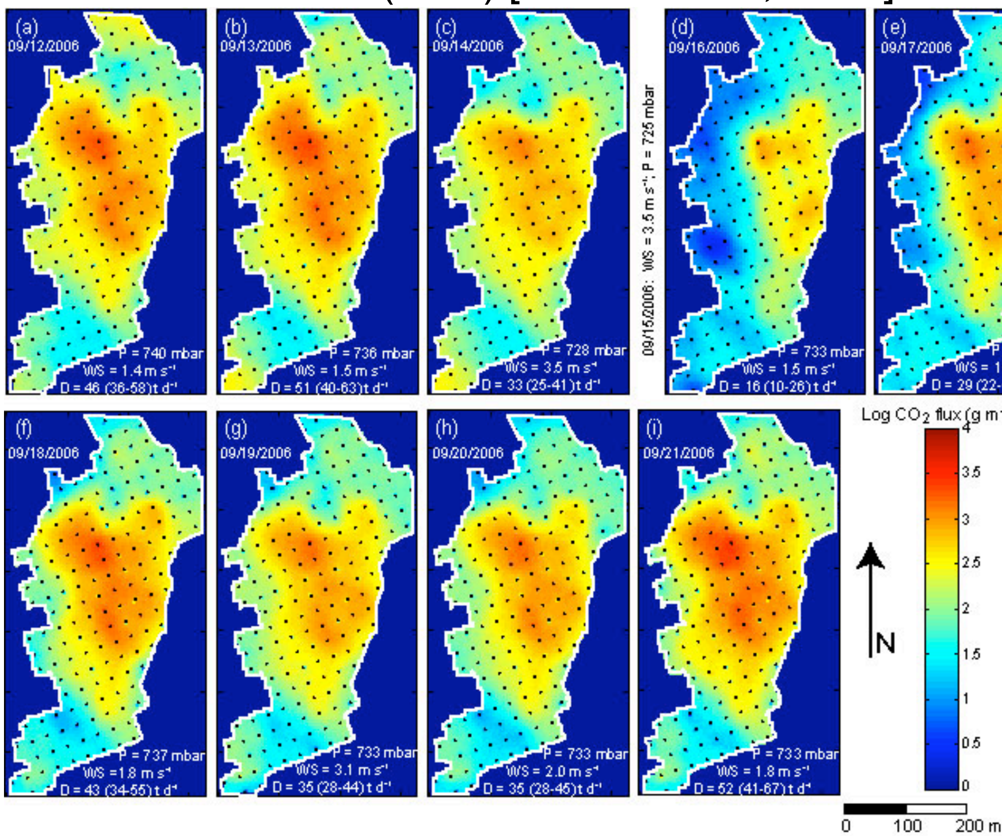
Inspired by CO_2 emissions at Mammoth Mountain (USA) [*Evans et al.* 2001]



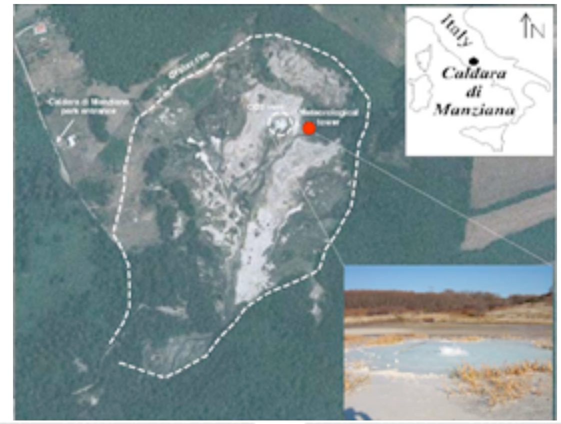


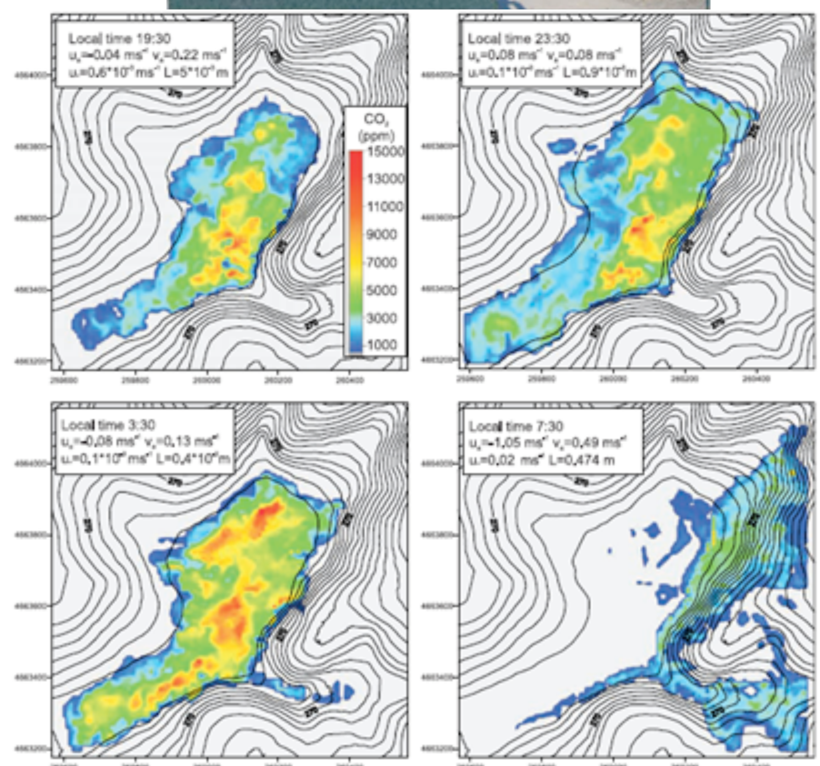
Near-Surface Gas Transport

Mammoth Mountain (USA) [*Lewicki et al.*, 2007]



Caldara di Manziana (Italy) [*Costa et al.*, 2008]

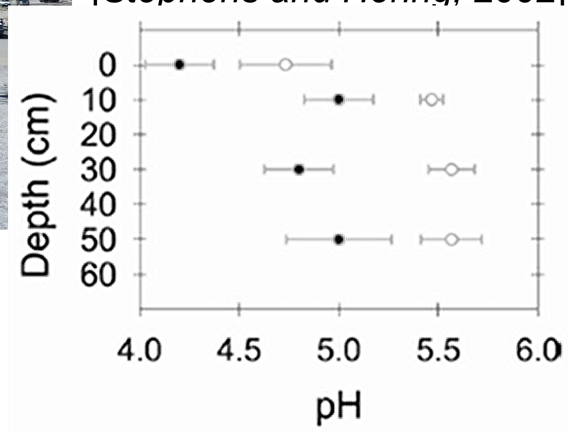


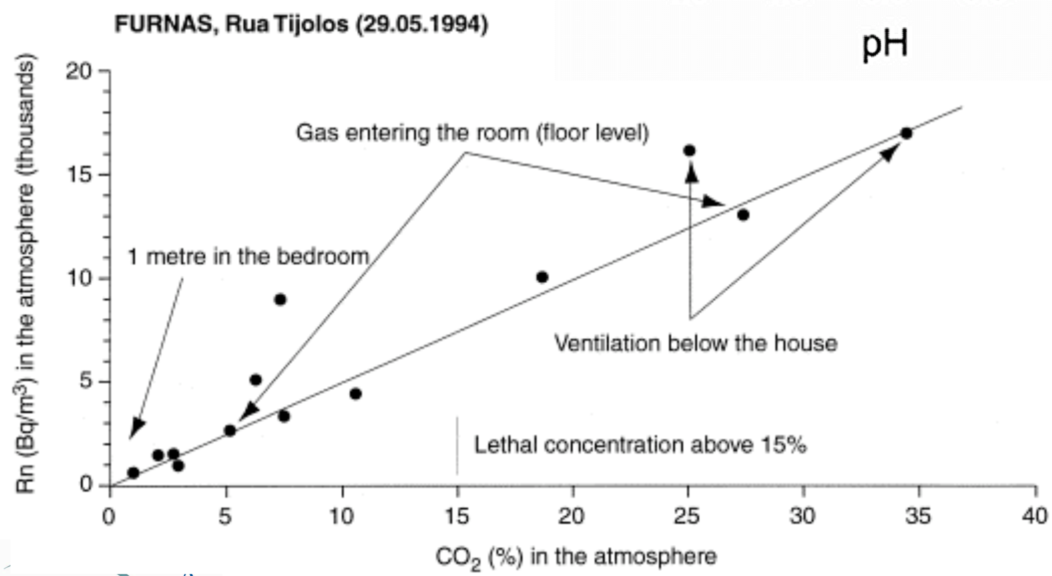


Natural releases motivate and validate modeling studies to better understand and forecast the flow and transport of CO_2, assess hazards, and design mitigation strategies

EH&S Impacts: Soil and Atmosphere

Mammoth Mountain (USA)
[*Stephens and Hering*, 2002]





Baxter et al., [1999]

Effects of elevated CO_2 concentrations in soil, atmosphere, and surface water on human, plant, and animal life can be better understood based on historic records and present-day monitoring

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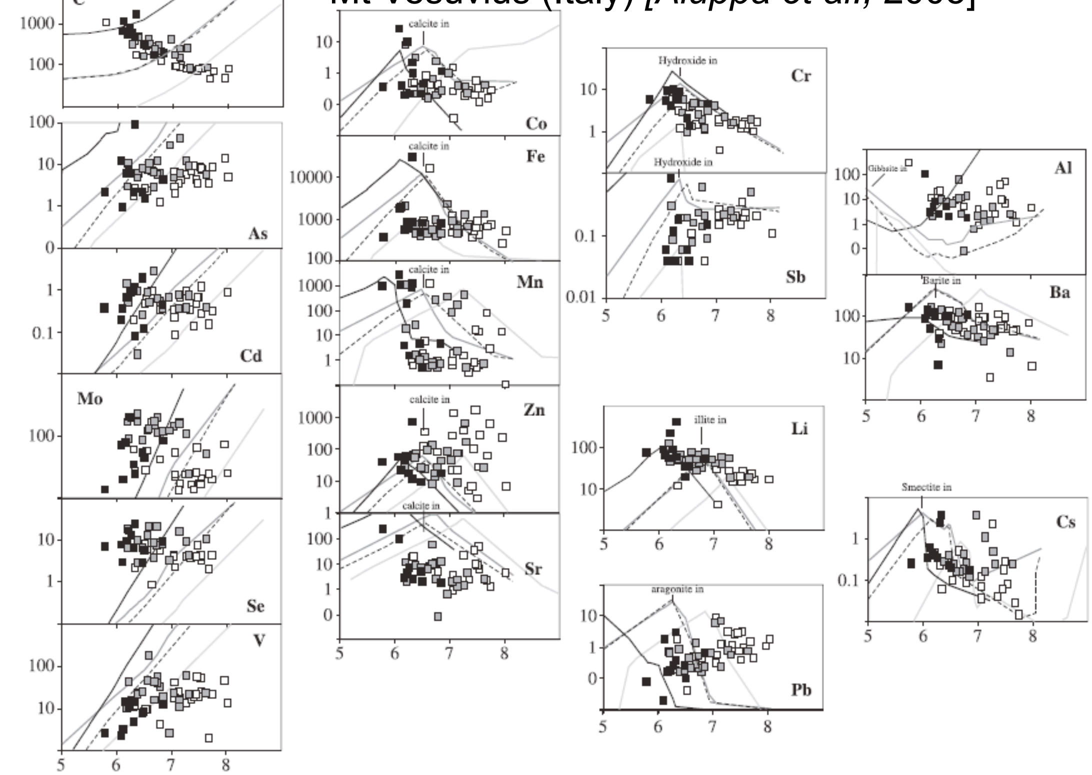
EH&S Impacts: Shallow Groundwater

-CO_2 emissions into shallow aquifers and release of trace metals a concern. Natural CO_2 releases provide opportunity to monitor and model groundwater geochemistry.

-Impacts of elevated CO_2 in shallow groundwaters investigated: Chimayo, NM (USA) [*Keating et al.*, 2010], Mt Vesuvius (Italy) [*Aiuppa et al.*, 2005; *Federico et al.*, 2004], Mammoth Mountain (USA) [*Evans et al.*, 2002], Florina basin (Greece) and San Vittorino (Italy) [e.g., *Beaubien et al.*, 2004]

- Influence of water-rock interactions (e.g., buffering capacity of aquifers, trace metal scavenging by secondary minerals) on water quality can be investigated

Mt Vesuvius (Italy) *[Aiuppa et al.*, 2005]



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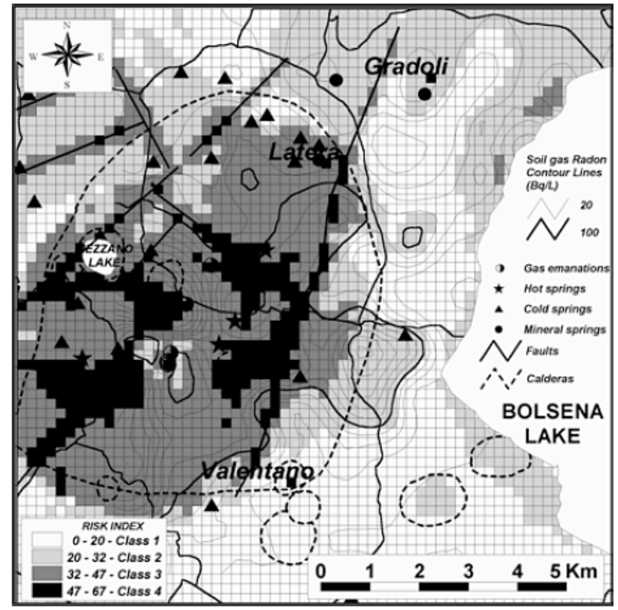
Hazard Mitigation

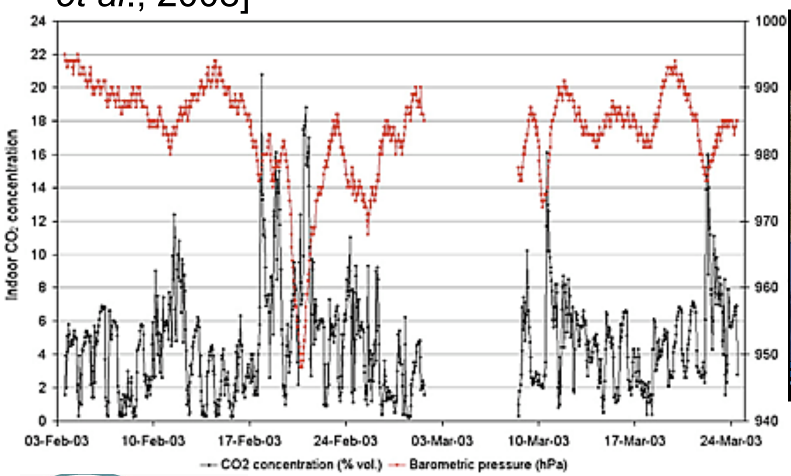
Mammoth Mountain (USA)

Lake Nyos (Camaroon)

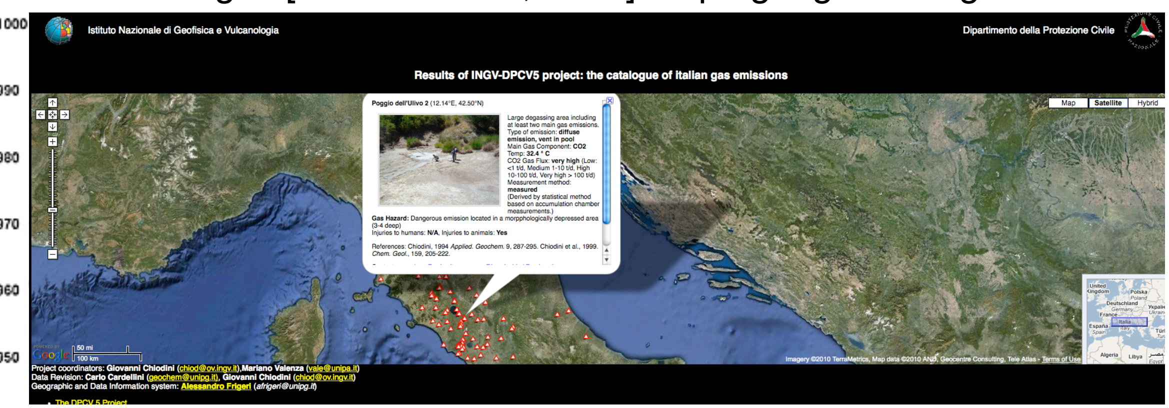
Latera (Italy) [*Beaubien et al.*, 2004]



Furnas volcano (Portugal) [*Viveiros et al.*, 2008]



Googas [*Chiodini et al.*, 2008]: http://googas.ov.ingv.it/



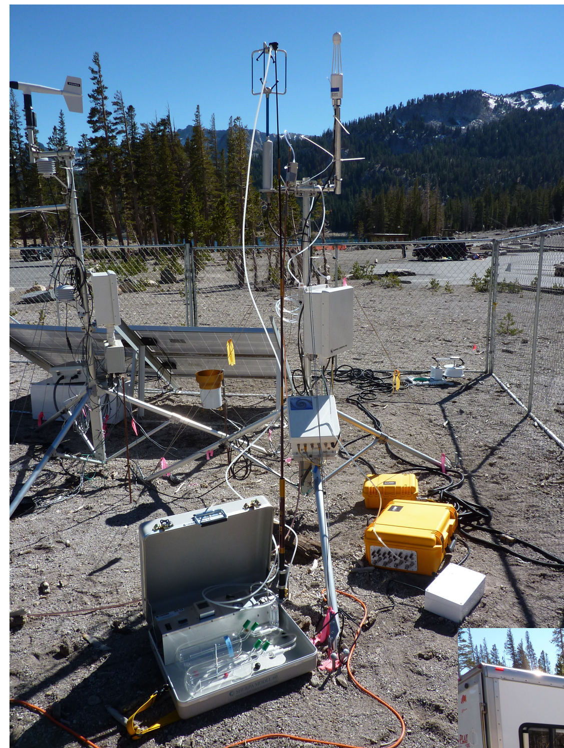
Effective hazard mitigation strategies can be selected, as appropriate, and integrated into GCS monitoring and mitigation plans

GCS Leakage Monitoring and Detection

Detecting, mapping, and quantifying CO_2 leakage through soils using accumulation chamber and eddy covariance techniques

Photo courtesy of Deborah Bergfeld

Detection and quantification of CO_2 leakage in soil, atmosphere, and groundwater using field-portable radiocarbon analyzer integrated with CO_2 flux and geochemical measurements



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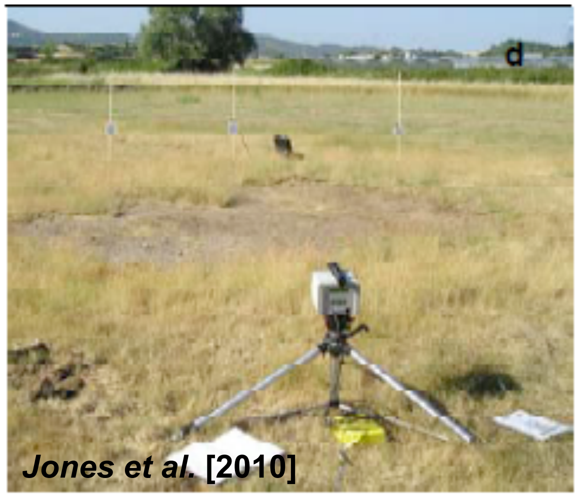
GCS Leakage Monitoring and Detection

Tracing and quantifying CO_2 leakage into groundwater using geochemical and hydrologic methods

Monitoring CO_2 emissions using open path laser measurements of atmospheric CO_2 concentrations



Jones et al. [2010]

Remote sensing detection of vegetation stress associated with CO_2 emissions

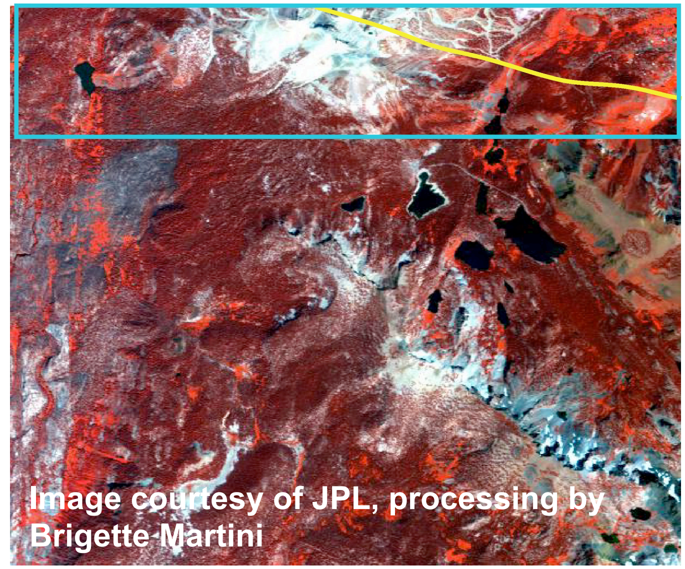


Image courtesy of JPL, processing by Brigette Martini

Monitoring submarine CO_2 emissions using geochemical methods

www.co2geonet.com

CO_2 release sites excellent "natural laboratories" to design and test measurement and monitoring strategies over a broad range of CO_2 leakage styles, geologic environments, and background ecosystems.

What We Can Learn for Safe and Secure GCS

1) Where CO_2 leakage is more likely to occur, the geologic and structural controls on leakage

- Tectonically active areas with faulted and fractured rocks
- Many releases correlated with a specific triggering event (e.g., seismic, volcanic activity). Processes that could cause geomechanical damage to sealing cap rocks and trigger leakage from a storage reservoir should be evaluated
- Even stable, sedimentary basins require careful examination of pre-existing faults. Study of leaky (past and present) faults in outcrop important

What We Can Learn for Safe and Secure GCS

2) Potential CO_2 leakage rates, spatio-temporal distributions, and transport processes

- Magnitude and spatio-temporal distributions of CO_2 leakage highly variable within and between sites
- Soil physical properties, meteorological variations and topography strong influences on gas transport and resulting near-surface CO_2 fluxes and concentrations
- Site-specific modeling of near-surface CO_2 flow and transport potentially useful for design of monitoring strategies and hazard mitigation

What We Can Learn for Safe and Secure GCS

3) How humans, plants, and animals impacted by CO_2 leakage and the strategies successfully employed to mitigate hazards

- Relative to the number of humans living near natural CO_2 emissions, the hazard to human health has been small. Successful hazard mitigation strategies can be learned from and applied to GCS.
- While groundwater chemistry can be altered by CO_2 leakage, many (studied) waters remain potable. Site-specific geochemical measurements and modeling should be carried out to predict and monitor for potential changes in groundwater quality
- Further investigation of impacts of CO_2 leakage on marine ecosystems required

What We Can Learn for Safe and Secure GCS

4) Design of effective monitoring strategies

- Detection of small-magnitude/geometry leakage signals will be challenging within the large background variability of ecosystem CO_2
- Natural CO_2 release sites offer broad range of CO_2 leakage styles, geologic environments, and background ecosystems to design and test measurement techniques and monitoring strategies.
-While not emphasized here, sites can also be used to test subsurface imaging of CO_2 migration using geophysical techniques

Thank You

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Photo courtesy of Deborah Bergfeld