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Geothermal energy: a suitable choice for isolated/island communities

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Introduction

Isolated habitats and/or communities are or resemble islands. Oceanic islands are extensions of the sea-floor above sea level. These are the result of geotectonic/volcanic processes. Volcanic setting is the main reason for the prevailing geothermal potential. This indigenous energy potential can often be harnessed to an extent, which nearly or completely satisfies local needs.

There are numerous examples for successful geothermal development on islands; they are present on a great variety of scales: from large islands of country size like Japan, Indonesia, the Philippines, Taiwan, New Zea-land, Iceland, down to small islands like São Miguel/Azores, or Bouillante/Guadeloupe.

The geologic characteristics of island settings like island arcs, hot-spot trace islands, seamounts are decisive for the geothermal potential. The potential needs to be specified by resource assessment and by addressing utilization possibilities, mainly for power generation.

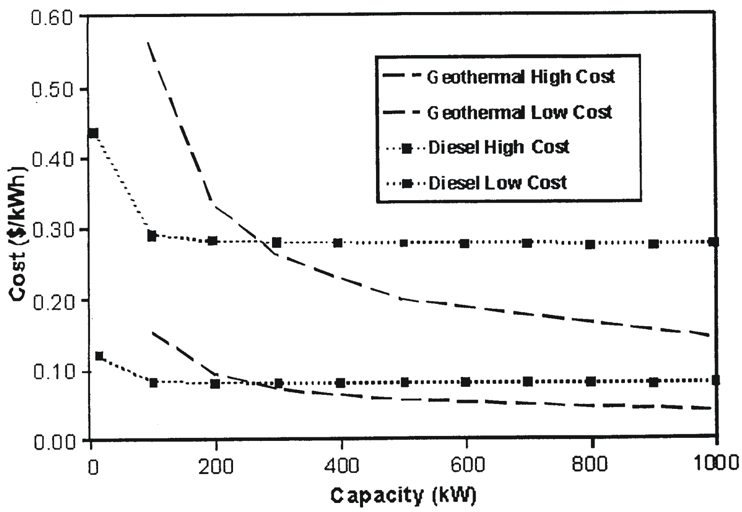

Figure 1. Cost comparison of diesel generation and geothermal generation with capacity (from Vimmerstedt 1999).

The necessary steps in development (surface exploration, drilling, plant design and installation) are to be addressed, with special emphasis on the utilization technology. The latter comprises mainly small electric power plants (< 5 MWe). Small geothermal power plants can supply electricity in remote areas ("village power", "off-grid power"; Lund and Boyd, 1999). Entingh et al. (1994a) estimate that the demand for electricity capacity per person at off-grid sites range from 0.2 kW in less developed areas to 1.0 kW or higher in developed areas. Thus a 100 kWe plant could serve 100 to 500 people and a 1 MWe plant would serve 1'000 to 5'000 people.

Any future development must comply with the criteria of environmental concern, sustainability and social benefits. Already in the early phases of exploration these influence factors need fully to be considered (Cataldi 2001).

The geothermal option on islands is often in competition with diesel fuel. Unless the plant size is very small, even the economics of geothermal is comparable (Figure 1), not to mention the environmental benefits, which are of paramount importance for the locals as well as for tourism.

Geological/geothermal features of islands

Islands and volcanoes are products of plate tectonic processes. Along subduction zones where two oceanic plates converge, distinctive chains of volcanic islands called island arcs are formed. Hot spot islands are formed in a lithospheric plate which overrides a stationary hot spot.

In island arcs a chain of volcanoes is formed parallel to the axis of subduction simultaneously (see Figure 2). Hot spot-trace islands show a typical age dependence: the island most distant from the one with active volcanism is the oldest (typical example: the Hawaiian island chain).

The islands/volcanoes do not appear along a line as continuous feature (which could be expected by geometry) but are present at distances on the order of 100 km between them, i.e. at distances which correspond to lithospheric thickness. Several features are responsible for this non-continuity: lithospheric stresses, plate thickness, melt availability, magma driving pressure (for details see Vogt 1974, Ten Brink 1991).

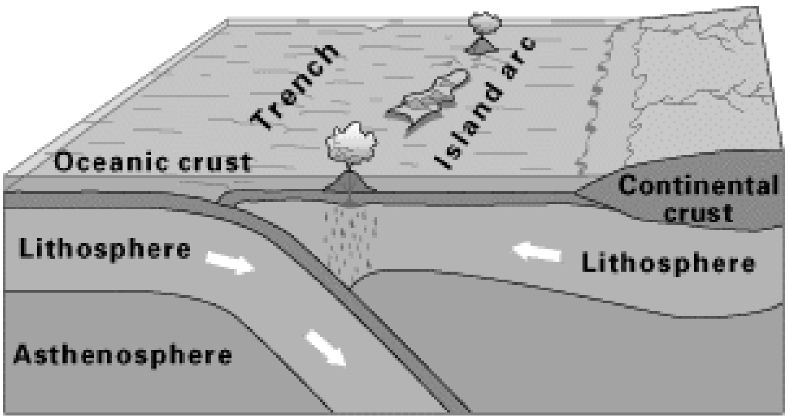

Figure 2. Island arcs are formed as a chain of volcanoes along subduction zones, at a certain distance from the subduction trench. The distance depends on the angle of subduction; the main volcanic axis develops approx. 150 km above the downgoing lithosphere (Rybach 1981).

The geothermal potential of islands is clearly related to the volcanic features. Active volcanoes represent a major, often repleni-shing subsurface heat source whereas extinct volcanoes are, with increasing age, less ef-ficient to form geothermal resources. Rock permeability from surface to reservoir depth, recharge by precipitation, chemical rock-water interaction are all decisive factors, even in the presence of a powerful heat source. All factors depend mainly on the local situation; correspondingly the formation of geothermal fluids at depth –the dominant issue of the geo-thermal resource– will be the result of nume-rous influences. In general it can be said that geothermal fluids in a volcanic setting, due to rock composition, are less saline than fluids in a sedimentary environment.

Exploration and resource definition

Several phases need to be performed *en route* from first considerations of the geothermal option all the way to the construction and operation of a power plant. They follow in a logical succession, interrupted by “stop or go” decision points.

Exploration and *reconnaissance* include first the reviews of geothermally relevant literature, analysis of airphotos, geologic mapping, petrographic studies of fresh and altered rock samples, geochemistry including isotopes of thermal and non-thermal waters. Equally important is the collection of non-resource information like data regarding electric power demand and distribution, environmental topics, permitting, government philosophies about the use and support of indigenous resources etc. High priority must be given, from the very beginning, to societal issues like acceptance, attitude of local citizens and other issues which might hinder development (Cataldi 2001). Open information policy and, if necessary, mediation between developers and opponents is indispensable.

The second work stage includes detailed field studies, mainly by geophysics (resistivity, magnetotellurics, gravity and/or magnetic surveys), soil geochemistry (Hg, radioactivity, CO_2) and shallow drilling (thermal gradient or slim-hole).

The results of these two steps enable an advanced characterization of the geothermal potential (“*Prefeasibility study*”) in terms of the chemistry, temperature and depth of the resources. This first assessment provides approximate figures of the estimated potential (GJ/m^2 or MW_t).

The prefeasibility study also identifies targets for deep drilling. For small power plant projects the slim-hole drilling technique is increasingly used. A phase with production tests follows immediately. This phase needs considerable finances (several million US$). All results are assembled in the *feasibility study* which identifies the usable resources (in MW_e).

More details on geothermal exploration and resource assessment, especially for small projects, can be found in Hochstein (1990) and Benderitter and Cormy (1990).

The power generating potential of a proven resource depends on the geothermal fluid temperature and production flowrate (see Figure 3). The figure gives the net power output which accounts for parasitic loads caused by the condenser and feed pump power requirements. The output power from two-phase water-steam or steam alone is much greater than the curves shown for liquid in Figure 3.

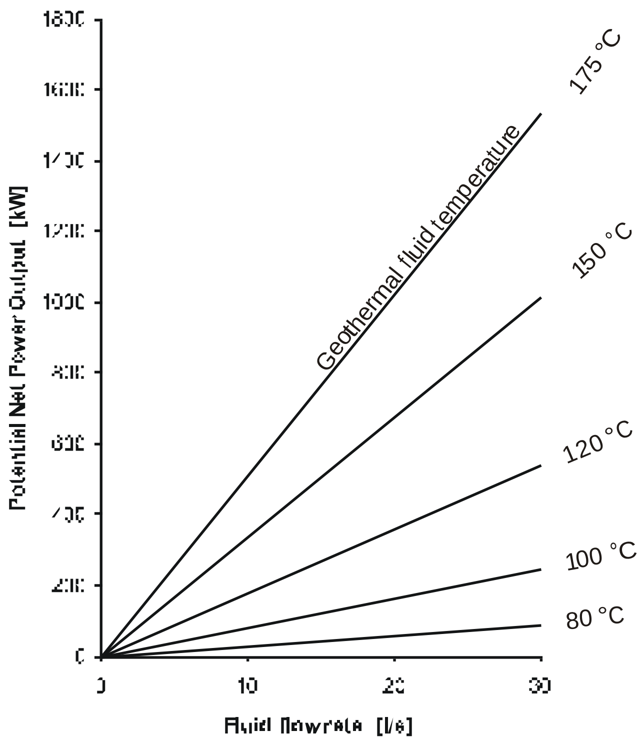

Figure 3. Geothermal power generation capacity of a geothermal resource. Feed pump and condenser parasitic power have been accounted for (redrawn after Nichols 1986).

Utilization technology

The technology choices for small power plants (< 5 MWe) are flash steam or binary cycle. *Flash steam systems* can be used at higher geothermal fluid temperatures (> 150 ºC). When the fluid is flashed to steam, precipitation of solids might pose problems. Also the non-condensable gases (mainly H_2S) need to be treated ("condensing cycle", see Figure 4). In such design the steam from the turbine is discharged to a condensing chamber which is maintained at low pressure (around 10 kPa). Because of the large pressure drop across the condensing turbine more power can be generated for typical inlet conditions than with simpler design (conventional atmospheric exhaust steam turbine; for details see Hudson 1998).

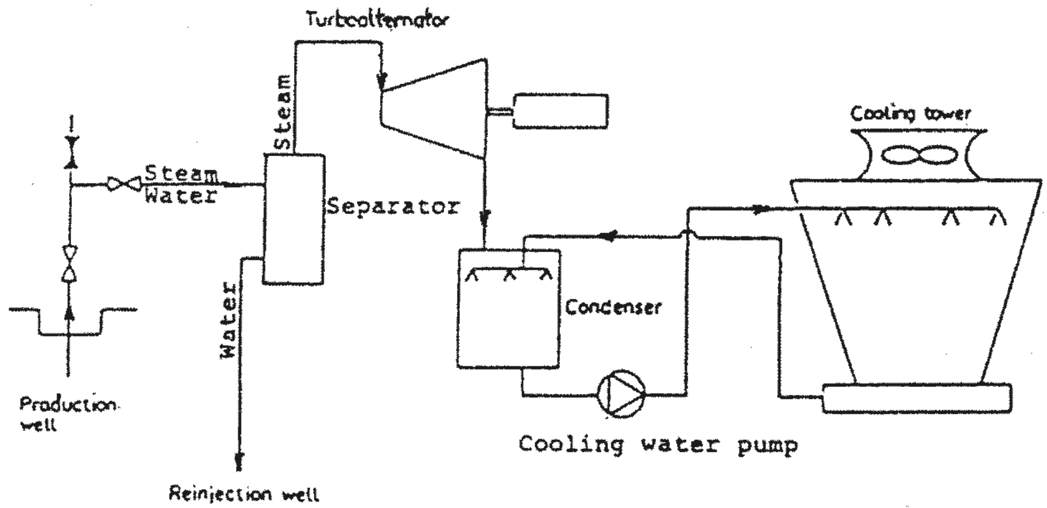

Figure 4. Simplified schematics of Condensing Cycle-type power plant (from Hudson 1998).

The *binary system* utilizes a seconddary working fluid (like isobutane C_4H_{10}, R600a), which has a low boiling point and high vapor pressure at low temperature relative to steam. This secondary fluid is operated through a conventional Rankine cycle; heat is transferred from the geothermal fluid to the binary cycle via heat exchangers where the working fluid is heated and vaporized before being expanded in the turbine (Figure 5). By selecting the appropriate working fluid, binary systems can operate with fluid inlet temperatures as low as 85 ºC. Binary plants are traditionally small, modular units varying in size from a few hundred kilowatts to several megawatts (Hudson, 1998).

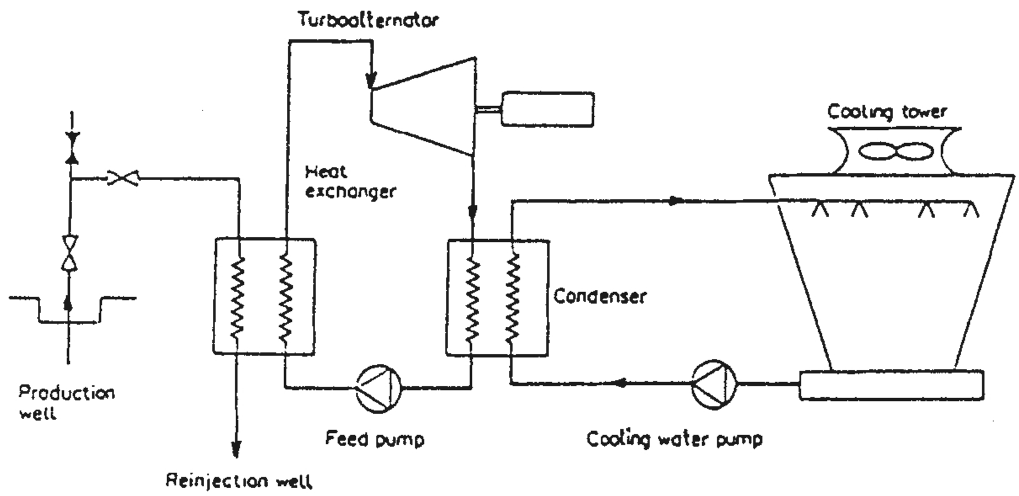

Figure 5. Simplified schematics of Binary Cycle-type power plant (from Hudson 1998).

The efficiency ξ of conversion (generated electric power/available thermal power) is a function of the inlet temperature T_f (in ºC):

$$\xi\ (\%) = 0.36\ (0.18\ T_f - 10)\ ,$$

i.e. a geothermal fluid inlet temperature of 140 ºC yields a net conversion efficiency of 5.5 % whereas with 100 ºC only ξ = 2.9 % achieved.

Further details about small geothermal power plant design, performance, and economics can be found in DiPippo (1999).

Geothermal *direct-heat applications* can be attached to these electric systems inexpensively. Applications needing temperatures not higher than 65 ºC might be attached (cascaded) in series to the power plant fluid outlet line (Lund and Boyd, 1999). There is a whole spectrum of possible direct-use applications, depending on the fluid temperature, which range from industrial over space heating/ cooling to agricultural uses. These are descrybed in detail in Dickson and Fanelli (1990, 1995).

Development costs, financing and regulatory issues

The development of a suitable geothermal resource for power generation leads to various costs, covering all steps from exploration to operation. Entingh et al. (1994a, 1994b; in Lund and Boyd 1999) developed a computer code GT-SMALL to evaluate the costs for small binary systems in the range of 0.1 – 1.0 MWe range. The example below (Table 1) is for a system cost of US$ 0.105/kWh.

Table 1. Small binary plant (net capacity 0.3 MWe) technical data and costs

Technical data	Resource temperature System net capacity Number of wells Capacity factor Plant lifetime Investment return rate kWh/year produced	120 ºC 0.3 MWe 2 0.8 30 years 12%/year 2.10^6
Capital costs (US$)	Exploration Wells Field (steam lines etc.) Power plant	200’000 325’000 94’000 695’000
	Total	*1'278’000*
Plant cost/installed kW 2'200 US$* *Annual capital recovery cost 158'650 US$		
Operation and Maintenance cost (US$)	Field Plant Backup system	32’000 26’000 5’000
	Total/year	*63’000*

For small geothermal projects appropriate financial arrangements are critical to success. In any *financing scheme*, the allocation and mitigation of risk as well as subsidies are essential. The various risks related to small geothermal projects (sponsor, resource, completion, operation, offtake and sales, political/country, permits/regulatory/environmental, force majeure risks) are addressed in detail in Battocletti (1999). There is now a large number of potential financing institutions (Multilateral Development Banks like EIB, UNDP, WB/GEF etc.). It is far beyond the scope of this paper to review them and the various, often time consuming efforts to deposit successful funding applications.

Policies and regulations which apply to geothermal development vary greatly from country to country. The prerequisites for permitting/licensing are correspondingly different. Also the degree of control of e.g. drilling operations can change from state to state. The only advise which can be give here is that sufficient time must be set aside to go through all stages of necessary negotiations, especially for environmental and social issues.

The economic success of small-scale geothermal development will depend on the electric sector environment and its change with time. Currently the electricity market under-goes fundamental changes (privatization). This process transforms the potential owners and operators of small geothermal projects from public utilities to private power producers. The reform is intended to improve the overall economic efficiency of the electric sector and may open new opportunities for small geothermal projects in this more competitive environment. On the other hand the reform may change the roles of public utilities and governments such that they do not provide as much support to geothermal projects as they have in the past. Private power producers are likely to make electric capacity investment decisions that favor technologies with a lower share of capital costs as a fraction of total cost, and lower financing costs than what small geothermal power plants require (Vimmerstedt 1999).

Examples

Presently there are approximately 50 geothermal power plants operating worldwide at or below 5 MWe. Lund and Boyd (1999) describes many examples of small geothermal power plants. Only a few of them are on is-lands, their technical and operational data are summarized in Table 2. Some photographs and schemes follow. Huttrer (1999) summarizes small-scale power generation opportunities in the Caribbean islands. Further information about small-scale geothermal power projects “on land” can be found in Popovski et al. (1999).

Table 2. Small geothermal power plants on islands (after Lund and Boyd 1999)

Location	Ribeira Grande	Ribeira Grande	Bouillante	Hachijomija
Island	Saõ Miguel	Saõ Miguel	Guadeloupe	Hachijomija
Country	Azores/Portugal	Azores/Portugal	Caribbean/France	Japan
Power plant type	Single steam flash	Binary	Condensing steam flash	Condensing steam flash
Turbine rated capacity (MWe)	3.0	2x2.5 2x4	5.0	3.3
Net power (MWe)	0.8	12	4.2	?
Availability (%)	95	99.5	97	?

The realization of geothermal projects depends on the acceptance by the local residents. Prevention or minimization of detrimental impacts on environment and people as well as the creation of benefits for local communities are indispensable to obtain social acceptance. Therefore the social acceptance of geothermal development must be considered at in all project phases with high priority. The Environmental Impact Statement (EIS), needed for licensing, should include a plan of measures to prevent (or at lest to minimize) the effects of any undesirable impact.

Several examples show that local opposi-tion can hinder or even stop geothermal project realization: Milos and Nysiros (Greece), Mte. Amiata and Latera (Italy), Ohaaki (New Zealand), Mt. Apo (The Philippines), Puna (USA). The necessary prerequisites to secure agreement of local people are (Cataldi 2001):

- Prevention of adverse effects on people’s health
- Minimization of environmental impacts; and
- Creation of direct benefits for the resident communities.

Cataldi (2001) makes also clear that obtaining local consensus will have its price; however the investment needs for this amount only to 2 – 4 % of the total project cost, i.e. a small but worthwhile investment which can be decisive for the fate of the entire project.

Conclusions

- Small is beautiful ! The disadvantages of isolated communities are outweighed by the freedom of choice and flexibility to adapt and apply independent, indigenous solutions. For energy supply the geothermal option is competitive or even a better solution than burning diesel oil, not to speak of environmental benefits, vital for tourism.
- On many islands the volcanic setting is the basis of an interesting and often significant geothermal potential. This potential needs to be carefully evaluated , by well-established methods of exploration and resource assessment described above.
- For development, small geothermal power plants (< 5 MWe) are the main targets. The choice of suitable technology/power plant type depends mainly on the resource/geothermal fluid characteristics: for fluid temperatures > 150 ºC the flash cycle-type plant design is advisable, whereas for temperatures < 150 ºC the binary cycle-type is appropriate.
- Direct heat applications can be attached to the electric systems inexpensively, provided that enough customers are situated nearby. There is a whole spectrum of possible direct use applications, depending on the fluid temperature, which range from Industrial over space heating/cooling to agricultural uses.
- Appropriate financing for development is a key issue. In the financing scheme the allocation and mitigation of risks as well as subsidies are essential. There are now various financing institutions like Development Banks which can be approached for financing.
- National policies and regulation are insurmountable boundary conditions to be taken into account. Permitting, licensing and, most importantly local groups and potential opponents must be addressed from the very beginning of any geothermal-related activity.
- The various successful examples descrybed above demonstrate the scientific-technical feasibility and economic viability of the geothermal solution on islands. Thus the runway is clear for the take-off of widespread, small-scale geothermal development all around the world!

References

Battocletti, L. (1999): Financing small-scale geothermal power projects. In: K. Popovski, J.W. Lund, D. Gibson, T.L. Boyd (eds.): Proc. International Geothermal Days Oregon on Small-Scale Electric Power Generation & Geothermal Heat Pumps. Geo Heat Center, Klamath Falls, Oregon/USA, p. 93-102

Benderitter, Y., Cormy, G. (1990): Possible approach to geothermal research and relative cost estimate. In: M. H. Dickson & M. Fanelli (eds.): Small Geothermal Resources – A Guide to development and Utilization. UNITAR/UNDP Centre on Small Energy Resources, Rome/Italy, p. 61-72

Cataldi, R. (2001): Social acceptance of geothermal projects: problems and costs. In: M. Rosca (ed.): Proc. European Summer School on Geothermal Energy Applications. Oradea/RO, p. 343-351

Dickson, M.H; Fanelli, M., eds. (1990): Small Geothermal Resources – A Guide to Ddevelopment and Utilization. UNITAR/UNDP Centre on Small Energy Resources, Rome/Italy, 274 p.

Dickson, M.H; Fanelli, M., eds. (1995): Geothermal Energy. John Wiley & Sons, Chichester/UK, 214 p.

DiPippo, R. (1999): Small geothermal power plants: Design, performance and economics. In: K. Popovski, J.W. Lund, D. Gibson, T.L. Boyd (eds.): Proc. International Geothermal Days Oregon on Small-Scale Electric Power Generation & Geothermal Heat Pumps. Geo Heat Center, Klamath Falls, Oregon/USA, p. 1-12

Entingh, D.J., Easwaran, E., McLarty, L.(1994a): Small geothermal electric systems for remote power, GRC Bulletin November 1994, p. 331-338

Entingh, D.J., Easwaran, E., McLarty, L.(1994b): Small geothermal electric systems for remote powering. GRC Transactions 18, p. 39-45

Hochstein, M. (1990): Classification and assessment of geothermal resources. In: M. H. Dickson & M. Fanelli (eds.): Small Geothermal Resources – A Guide to development and Utilization. UNITAR/

UNDP Centre on Small Energy Resources, Rome/Italy, p. 31-56

Hudson, R.B.(1998): Electricity production from geothermal energy. In: V.H. Forjaz, C.A. Bicudo Ponte, K. Popovski (eds.): Proc. International Summer School "Electricity Production from geothermal Energy", Ponta Delgada/PT, p. 4.3-4.31

Huttrer, G. (1999): Geothermal small power generation opportunities in the leeward islands of the Caribbean Sea. GRC Bulletin, June 1999, p. 30-33

Lund, J.W., Boyd, T. (1999): Small geothermal power project examples. GRC Bulletin, June 1999, p. 9-26

Nichols, K.E. (1986): Wellhead power plants and operating experience at Wendel Hot Springs, GRC Transactions 10, p. 341-346

Popovski, K., J.W. Lund, D. Gibson, T.L. Boyd (eds.): Proc. International Geothermal Days Oregon on Small-Scale Electric Power Generation & Geothermal Heat Pumps. Geo Heat Center, Klamath Falls, Oregon/USA, 192 p.

Rybach, L. (1981): Geothermal systems, conductive heat flow, geothermal anomalies. In: L. Rybach & L.J.P. Muffler (eds.): Geothermal Systems – Principles and Case Histories. John Wiley & Sons, Chichester/UK, p. 3-36

Ten Brink, U. (1991): Volcano spacing and plate rigidity. Geology 19, 397-400

Vimmerstedt, L. (1999): Opportunities for small geothermal power projects. GRC Bulletin, June 1999, p. 27-29

Vogt, P.R. (1974): Volcano spacing, fractures, and thickness of the lithosphere. Earth. Planet. Sci. Lett. 21, 235-252