LAND. THERMAL EFFECTS

LITHOSPHERE

Some review on notation is important here:

- Land, refers to the solid part of the surface of the earth, the continents or terrestrial surface, as distinct from seas, lakes, etc. Land is a combination of soil and rocks. Ground, is a synonym of land in this context (soil is occasionally used as a synonym of land).
- Soil, is the top layer of the land surface, composed of loose disintegrated rock particles, humus (the dark brown mass of decaying organic matter), water solutions, and trapped air (the latter two within the pore spaces of the loosely-packed solids). Pedology (Gr. πέδον*,* soil) is the study of soils in general (e.g. formation, morphology, evolution…), whereas edaphology (Gr. *ἔδαφος,* ground) studies the influence of soils on living things, particularly concerning man's use of land for plant growth. Anthropic changes in soil usage have an influence in local and global climate.
- Crust, refers to the outermost solid shell of the planet, both as continental crust on land (30..70 km thick) and as ocean crust under the seas (5..10 km thick), with special chemical composition (igneous, metamorphic, and sedimentary rocks), that distinguishes it from the rest of the lithosphere.
- The lithosphere, is the rigid outer layer of the earth, including the crust and the solid part of the mantle (denser than the crust), and having an average thickness of about 100 km. The lithosphere is formed by eight large plates (plus some smaller ones) that slowly move over the asthenosphere (a 100..200 km thick plastic layer of mantle below the outer rigid lithosphere). The plates have three types of motions (the typical speed is 0.05 m/yr), resulting in three types of boundaries: sliding towards each other (subduction zones), sliding away (ridge axes), and sliding along (transform faults). The lithosphere accounts for more than 80% of the ecosphere (with hydrosphere some 8%, atmosphere less than 1%, and biosphere just 0.8 ppm).

When studying the environment, we may put lithosphere on equal grounds as atmosphere and hydrosphere, in spite of the fact that most often we have in mind just human interaction with land.

Land use may be:

- For farming (fields, pastures).
- For dumping (organic and inorganic, including CO_2 capture).
- For urbanization, including recreational resorts and sewage systems.
- For transportation and communication tracks (including airports).

- For industrial ground and industrial exploitation, including mining and energy capture on solar, wind, and geothermal fields.

Land is the first place for humans to get rid of sanitary residues that may cause disease transmission. Sanitation duties include solid waste management, water and wastewater treatment, and industrial waste. Urban sanitation technology consists on the collection of wastewater in sewers, its treatment in wastewater treatment plants for reuse on irrigation or industry, or for disposal in rivers, lakes or the sea.

A landfill (also known as a dump), is a site for the disposal of waste materials by burial and is the oldest form of waste treatment. In recent years, some countries, such as Germany, Austria, Belgium, and Switzerland, have banned the disposal of untreated waste in landfills. In these countries, only the ashes from incineration or the stabilized output of mechanical biological treatment plants may still be deposited.

Physical properties of soil depend on composition (Table 1), particularly on moisture ratio, w (mass of water over mass of dry soil). Water content is best measured using a dielectric permittivity probe, due to its large sensibility, since the dielectric constant of water (relative permittivity, ε_r), around 81, is significantly larger than that of dry soils (in the range 3..7), and those of the air (practically 1). Thermal conductivity k and thermal diffusivity a are measured using an electrical-resistance thermometer with a heat pulse (in the same resistor or in a nearby one); thermal capacity c can be deduced from $c=k/(\rho\alpha)$. Soil properties depend on temperature, as for any substance, but in the case of soil (and other open moist systems), temperature changes may cause moisture changes (by evaporation/condensation or by migration), which amplify the effect.

Table 1. Physical properties of dry and wet soils: density (ρ), thermal capacity (c), thermal conductivity (λ), and thermal diffusivity, $\alpha\equiv\lambda/(\rho c)$, for different moisture ratio, w.

Soil, 40 % porosity	ρ [kg/m^3]	c [J/(kg·K)]	λ [W/(m·K)]	α [m^2/s]
Sandy soil, w=0	1600	800	0.30	$0.24\cdot10^{-6}$
Sandy soil, w=0.4	2000	1480	2.20	$0.74\cdot10^{-6}$
Clay soil, w=0	1600	890	0.25	$0.18\cdot10^{-6}$
Clay soil, w=0.4	2000	1550	1.50	$0.51\cdot10^{-6}$

THERMAL EFFECTS

Land is in thermal contact with air above, with the deeper lithosphere underneath, and may also be in contact with the hydrosphere (at coastal, lacustrine, and riverside areas, and even with ice in some places), although water is always present on land through precipitations from the atmosphere.

Land, as part of the Earth's surface, is the place where solar radiation is mainly absorbed, heating the air above by thermal convection, and the soil below by thermal conduction; hence, the wider bounds of the temperature excursion on diurnal or seasonal cycles takes place at the surface, decreasing both upwards and downwards.

Land thermal properties have important effects on the natural environment, and in human use, e.g. agriculture, and infrastructures (foundations for buildings, roads, bridges, dams; underground pipelines, etc.). There are some application where one looks for thermally conducting soils (e.g. to dissipate power loses in underground power lines), and others where one looks for thermally insulating soils, (e.g. for hot water and steam pipes). Thermo-optical properties are important at the land surface, controlling the amount of solar absorptance. As a rule, land is quite insulating to heat flow, dry soil and rocks particularly.

Amongst the many thermal effects associated to the lithosphere (from volcanos to desertification) we only consider:

- Thermal inertia.
- Land icing and thawing.
- Geothermal energy flow.

Thermal inertia

The large thermal inertia of soil in comparison with air greatly damps temperature oscillations, limiting its effective penetration depth to about 0.5 m for diurnal oscillations and to about 10 m for year around seasonal oscillations.

A few meters below ground, diurnal and seasonal temperature variations are so damped that caves (and thick walls) on temperate climates are warm in winter and fresh in summer, what has always been advantageously used by humans, animals, and plants (which may come to life again after a severe frost).

A properly impervious land mass may be used as a diurnal or seasonal energy storage, according to size.

Land icing and thawing

Perhaps the more drastic thermal effect on soil is the phase changes of water in their pores and cracks in cold climates. Globally, about 40% of the land surface is frozen all time (in January, 50 % of the northern hemisphere land). When moist land freezes, the volume expansion due to its density jump (from 1000 kg/m^3 to 917 kg/m^3) originates huge pressure forces that may fracture the hardest rock (the process may give rise to karstic formation on limestone). When frozen soil thaws, it loses most of its mechanical strength and contracts. This frost heave poses important construction problems on cold climates regions, as may be found at high latitudes (Scandinavia, Russia, Alaska, and Canada), or at high altitudes (e.g. China, India). This cold climate regions can be generally divided into seasonal frost and permafrost areas (see also Hydrosphere and Cryosphere). The thaw line is the depth to which the permafrost soil will normally thaw each summer in a given area; roots of plants cannot extend underneath, and, if it is close to the surface, building foundations should penetrate downward to avoid thawing problems. The counterpart of the thaw line is the frost line, i.e. the depth to which the groundwater in soil is expected to freeze in winter. Permafrost occurs when the depth of freezing is greater than the depth of thaw.

Approximately 4000 degrees-day of annual freezing is required to maintain continuous permafrost; degrees day, DD, is a time-integrated local-weather index relative to a specified bound (a base temperature and the intended side); e.g.:

- The cooling degree day (CDD) is intended to measure the refrigeration needs of air conditioning in summer, and it is defined as CDD$\equiv\int(T-T_0)\mathrm{d}t$ with T_0=25 ºC (or any other agreed setting) for values of $T>T_0$ (the integrand is multiplied by zero if $T<T_0$). $T(t)$ is the local outside-air-temperature series.
- The heating degree day (HDD) is intended to measure the demand for space heating in winter, and it is defined as HDD$\equiv\int(T_0-T)\mathrm{d}t$ with T_0=20 ºC (or any other agreed setting) for values of $T<T_0$ (the integrand is multiplied by zero if $T>T_0$).
- The freezing degree day (FDD) is intended to account for the periods with freezing temperature; i.e. FDD$\equiv\int(T_0-T)\mathrm{d}t$ with T_0=0 ºC for values of $T<0$ ºC (the integrand is multiplied by zero if $T>0$ ºC).
- The growing degree day (GDD), is a measure of heat accumulation used to predict plant development state (and animals naturally feeding on them).

There are other thermal changes of anthropogenic origin, due to different land use (agrarian or urban).

Geothermal energy

Earth's interior temperature increases with depth with a mean gradient of 10 ºC/km in the crust, i.e., from 0..30 ºC at the surface, to 200..400 °C at the boundary between the crust and the underlying mantle, some 30 km below. The gradient varies a lot from place to place depending on the geologic formations present in an area, what renders some sites with gradients >100 ºC/km (up to 800 ºC/km have been found) amenable to economical exploitation as geothermal heat sources.

Temperature in the Earth's interior further increases down the rest of the lithosphere up to 1000..1200 ºC in the fluidised asthenosphere (from 100 km to 250 km). Increments in seismic wave speed at 400 km and 700 km down may indicate solid phase transitions at around 1500 ºC and 1900 ºC, respectively. Transversal seismic waves fail to propagate below 2900 km, implying that a fluid phase starts at that depth (the outer core), with an estimated temperature of 3700 ºC (considering it is an iron solution at great pressure). Transversal transmission reappears at around 5100 km depth, indicating a solid inner core; the extrapolated temperature at the centre of the Earth may be around 5000 ºC.

The average geothermal energy flux is 0.05 W/m^2 (see Exercise). This energy derives from the decay of nuclides in the Earth's interior (uranium, thorium, and potassium), from the original heat from the gravitational collapse of the early Earth, and to a lesser extent from dissipation of tidal forces in the solid Earth. While the nuclear materials generate approximately $30\cdot10^{12}$ W (30 TW) thermal energy and the solid Earth tidal dissipation is about 0.2 TW, it is not enough to balance the 45 TW conduction losses to the surface, allowing the Earth to slowly cool.

Exercise. Take the temperature at the interface of the crust and the mantle at 30 km deep to be 600 K. Consider a reasonable thermal conductivity, and compute the flow of geothermal exergy into the Earth's surface.

Geothermal energy is difficult to grasp because of the solid media involved, and intensive local exploitation has shown non-renewable (exhausting). Direct use is confined to available hot-water and pressurised-vapour sources, or to available hot dry rocks underground. Applications are:

- Geothermal power stations, for electricity production from pressurised-vapour sources or very hot dry rocks. There are a few large commercial exploitations round the world (the largest one, 1300 MW, in California, The Geysers), and some more under construction (the largest, 10 000 MW, in Australia), and many others for research and development.
- Geothermal heat, for space and water heating, from hot-water springs (used since Roman times), usually grouped in: low-temperature sources (<90 ºC), medium, and hot-temperature sources (>150 ºC), the latter enabling district heating.
- Geothermal heat pumps, for space and water heating, from any underground site, since it is the operating substance in the heat pump that is either cooled or heated relative to the ground, which is used as a thermal reservoir.

Perhaps the simplest way to take advantage of geothermal energy is to pump the hot-water source through a heat exchanger where an appropriate clean fluid takes it, and using standard procedures to take advantage of this second hot stream. But most geothermal water sources carry along lots of dissolved salts and gases that will foul their side of the heat exchanger.

Producing a clean fluid directly has been tried, e.g. in a flash chamber, but the generated steam may carry along tiny brine droplets (similarly as when salty lips are felt near the seashore, due to micro-droplets in suspension). And overall efficiency is very low because of the small steam mass-fraction obtained in the flash chamber.

The most efficient method to generate power with such dirty waters is to convert most of the thermal energy into kinetic energy in a nozzle, and either drive a Pelton wheel (an impulse turbine), or a Hero’s wheel (a reaction turbine). In either case, the nozzle is of a converging-diverging type, with supersonic two-phase flow in the diverging zone.

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