predominantly dry steam; but the problems of power evaluation, development and production here are even greater, largely because of dissolved minerals. The natural pressures in most hydrothermal reservoirs are too low to maintain artesian flow, so the water must be pumped to the surface. But the hot brines rapidly destroy drilling equipment, borehole casings, pumps, valves and the rest of the hardware required to bring the fluid to the surface and extract heat from it. And once the heat is extracted the residual highly-concentrated brines then pose waste (thermal and chemical) disposal problems. The removal of large quantities of subsurface fluid can also lead to extensive subsidence. According to Smith, therefore, "the widespread exploitation of a large and readily available geothermal resource will evidently be delayed for some years until economic solutions to [these problems] have been demonstrated".

Where, then, does the long-term future of geothermal energy exploitation lie? The answer favoured by the Los Alamos group and currently being investigated by them is the extraction of heat from dry rock. Even in steam and water reservoirs well over half of the thermal energy resides in the rock, and rocks at depth are hot even when fluid is absent. In principle, therefore, it should be possible to extract geothermal heat anywhere in the world as long as sufficiently high temperatures are reached at depths to which drilling is economic.

Although it is seldom, if ever, acknowledged, the simplest way of achieving this dream was described in some detail by Hodgson in his talk in 1927 when he proposed an artificial version of the hydrothermal system that nature itself rarely provides. In other words, he suggested that cold water should be passed through the hot rock at depth and then recovered in the form of hot water or steam. This is almost exactly the method now adopted by the Los Alamos group with the difference that, whereas Hodgson envisaged a closed pipe circulation, the modern version has the injected water making direct physical contact with the hot rock and rising through a second borehole. An obvious unknown in either system, however, is whether there is an adequate area of contact at depth to achieve sufficient rock-to-water heat transfer. Hodgson's solution was to increase the length of his pipe at the bottom of the borehole if necessary; the modern idea is to fracture the rock at depth.

But whereas Hodgson's proposal was destined to remain unrealised, the Los Alamos suggestion is actually being put to the test at a site in New Mexico. According to Laughlin (*Geotimes*, 20, March 1975), the main hole has already been drilled to a depth of 2,929 m in impermeable rock where the bottom-hole temperature is 196 °C. Hydraulic fracturing of the surrounding rock was successfully carried out at 1,981 m and will be repeated at the bottom. A second, somewhat shallower, hole is then to be drilled into the lower fracture zone to act as the hot fluid ascent route.

If the dry rock experiment in New Mexico proves scientifically and technically successful and an economically viable geothermal heat extraction system results, the way would clearly be open to a staggering increase in the use of this widely available and relatively pollution-free energy resource. Presumably it is still far too early to say when, or even whether, this ideal state will ever be reached. In the meantime, however, it must be evident that, other things being equal, both science and economics would benefit from application to areas where the heat flow is relatively high and the thermal energy is close to the surface.

The high heat flow anomaly in the Gulf of California, whose discovery is reported by Lawver *et al.* on page 23 of this issue of *Nature*, fulfils both of these criteria, having a remarkably high maximum value of 30 μcalorie cm^{-2} s^{-1} (which compares with 4-5 μcalorie cm^{-2} s^{-1} at the New Mexico site) and coming from a basaltic intrusion within 100 m of the surface. Admittedly the heat source is not continental; nor is it entirely clear to what extent, if any, hydrothermal fluids are involved. What is certain, however, is that Lawver and his colleagues have discovered one of the Earth's major geothermal resources and that it is in just such areas that the real case for geothermal power will be fought. □

A hundred years ago

Professor Palmieri has discovered a new instrument which he calls a "diagometer," and which is constructed for the rapid examination of oils and textures by means of electricity. What the apparatus will do, Prof. Palmieri details thus:—1. It will show the quality of olive oil. 2. It will distinguish olive oil from seed oil. 3. It will indicate whether olive oil, although of the best appearance, has been mixed with seed oil. 4. It will show the quality of seed oils. 5. Finally, it will indicate the presence of cotton in silken or woollen textures. The professor has been complimented for this invention by the Chamber of Arts and Commerce at Naples, who have published a full description of the apparatus, with instructions for use.

from *Nature*, **12**, 427; September 9, 1875

X-ray sources and the ionosphere

from L. J. C. Woolliscroft

The lower ionosphere is a complex region of the upper atmosphere, with several ionisation mechanisms and high enough neutral species densities to cause many ion and electron reactions with the weakly ionised plasma. The production of ionisation by non-solar sources has been calculated by, for example, Velinov (*J. atmos. terr. Phys.*, **30**, 1891; 1968) for the influence of galactic cosmic radiation on the bottom of the D-region. More recently other non-solar objects have been invoked as sources of ionisation in certain conditions.

The propagation of low frequency (LF) and very low frequency (VLF) radio waves from extremely stable transmitters such as those used to broadcast atomic time allows the bottom of the ionosphere to be monitored continuously. Small changes in the phase and amplitude of the received LF and VLF signals from distant transmitters are used and some of these have been associated with the meridian transit of a strong X-ray source. Edwards *et al.* (*Nature*, **222**, 1053; 1969) found a nocturnal VLF effect from Scorpius XR-1 and the same source was found to give an effect at LF by Ananthakrisknan and Ramanathan (*Nature*, **223**, 488; 1969). Later positive results have included other celestial X-ray sources and also flare effects in Sco XR-1.

That these radio propagation effects are due to X-ray sources was challenged by Poppoff and Whitten (*Nature*, **224**, 1187; 1969) who showed that the ionisation production rate was at least an order of magnitude lower than that due to other mechanisms, especially that of Lyman α radiation ionising nitric oxide. A difficulty exists, however, in calculating the production of ionisation by Lyman α because the concentration of NO is somewhat uncertain.

A further complication comes from the masking effect of precipitating electrons producing ionisation at other than low latitudes which may account for some of the negative results such as those of Burgess and Jones (*Nature*, **224**, 680; 1969).

In this issue Karszenboum and Gagliardini (page 34) have calculated the production rate of ionisation due to several galactic X-ray sources using more recent spectra which extend to