GEOTHERMAL ENERGY IN THE MEDITERRANEAN AREA BEFORE THE MIDDLE AGES

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ABSTRACT

Archeological finds dating from the *Lower* and Middle Neolithic, and a number of considerations on the degree of refinement reached several millennia before Ihe Christian era by certain customs, myths and cults linked to different manifestations of terrestrial heat. indicate that in h e Mediterranean arra the *man/geothermal energy relationship* can be traced back at least to the Upper Paleolithic.

After outlining man's first contacts with the various geothermal manifestations in prehistoric periods and in the times of the most ancient Mediterranean civilizations, the paper illustrates the development of h e exploitation of hydrothermal products by h e Etruscans and the great impetus given by the Romans to the spread of hemal bathing.

Mention is then made of the major Greek and Latin authors who, from Ihe 61h century B.C. to the 4th century A.D., described numerous aspects of geothermal manifestations or speculated on their genesis, and who must therefore be considered the historical fathers of scientific thought on geothermal energy

Key words: Geothermal mergy, Mcditrrranean area, early uses, historical development, ancient theories.

1. MAN'S FIRST CONTACTS WITH THE EARTH'S ENERGY

The oldest archeological document that we have found in the literature on man's interest in geothermal phenomena dater from the 7th millennium B.C. (Mellaan. 1967). It is a painting that shows an erupting volcano (probably Hásan Dág) in thr background of a Neolithic settlement which already displays a highly evolved dwelling structure (Figure 1).

The degree of detail with which the painting illustrates not Just the morphological features of the volcanic edifice but also the particulars of h e eruption (explosion plume, volcanic bombs, etc.), indicates that by the Lower Neolithic man in the Mediterranean area had already developed a kern spirit of observation and a capacity for describing natural phenomena that must be considered quite advanced for those times. On the collective level he must therefore have already possessed. at least in certain places. a large store of empirical knowledge on h e different forms in which the earth's energy showed itself to his eyes: hot springs. fumaroles, volcanic eruptions, etc.

Such knowledge must, in turn. have matured on the individual level over the course of many thousands of years (perhaps even tens of thousands) as a result of direct contacts with various manifestations of terrestrial heat. contacts which over countless centuries must have resulted in the formation of a quite complex *man/geothermal energy relationship*. Indeed, it is likely that man war attracted to settle In certain grothermal localities by Ihe presence of "peaceful" *manifestations and/or the* occurrence of by-products of geothermal energy; localities where he could develop cooking and bathing. or find useful materials such as hydrothermal incrustations. obsidian and other volcanic products suitable for making lithic instruments. But in other localities. it seems certain that the occurrence of paroxysmal phenomena (volcanic eruptions. earthquakes, etc.) produced h e opposite effect, discouraging man from frequenting them. In other words, ever since the earliest days of prehistory, first on the individual level, then on the collective, a *relationship* of "confidence" in some places and of "diffidence" in other places was being shaped in regard to the various types of geothermal phenomena.

Among Ihr reasons which attracted man to settle in "peaceful" geothermal areas, in addition to Ihe direct causes mentioned above, one must also cite such indirect causes as the fertility of volcanic soils, the security of some lacustrine basins molded by caldera rims, and the availability of freshwater springs on volcanic outcroppings. This second group of causes, however. must have become important only after the end *of the* nomadic *period*.

Besides the effects ot attraction or aversion due to the practical reasons pointed out above, since prehistory the relationship of "confidence" or "diffidence" established in some pans of the Mediterranean area between man and the different types of geothermal manifestations must also have gradually involved the spiritual and rational sphere of man. with features in some ways transcendent (and hence "religious") and in others intellective (hence

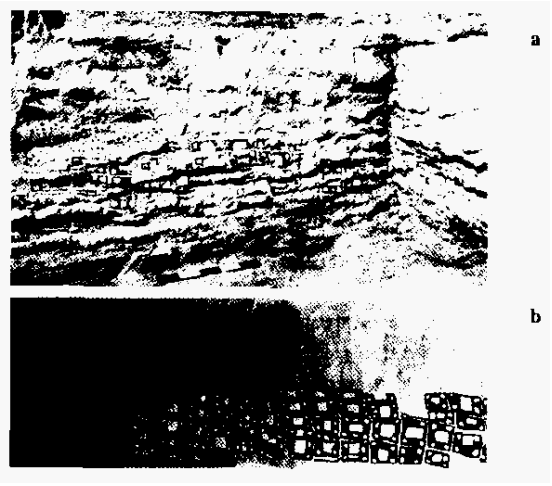


Figure 1. Wall painting found inside a room in the so-called *level vii* of the Neolithic settlement of Çatal Hiiyuk (southeast Anatolia), dating from *6200* B.C. a) photo of the excavation; b) reconstruction of the original painting.

"cultural"), in the broadest sense of thrrr terms.

With regard to the transcendent aspects. and therefore for the imponance that crnain types of manifestations must have had in prehistory in the formation of man's religious sphere, one direct proof is the fact that some ancient megalithic constructions are only found next to fumaroles and hot springs. Such is the case, far example, with the so-called *divine stones* on the volcanic island of Pantelkria (southern Italy), which date from the 3rd millennium B.C.

An indirect proof of this importance comes, on the other hand, from he established presence, and hence the high degree of evolution already reached at the dawn of the oldest Mediterranean civilizations, of numerous cults and myths clearly inspired by the occurrence of natural manifestations. This is the case. for example, of the cults of the Great Mother, of Hephaestus and Mephitis. the myth of the "theft of fire" by Prometheus, and the various attestations of reverence towards protective divinities of thr thermal waters (*health divinities*). Articles used for such attestations (stone statuettes called *veneri votive*, bone amulets, etc.) have been found from as early as the Late Neolithic in various geothermal localities in the islands and coastal sectors of the Mrditerranean.

All these cults. myths and customs could not have sprung up all of a sudden with passage from the Stone Age to the Metal Age. Instead, it is likely that they represent the fruit, by accretion and successive refinements, of "religious" sentiments horn in much earlier times than those in which the cults, myths and legends formed and spread among the people. According to Cataldi *et al.* (1992-'93), these times might even stretch hack to the Late Mousterian (30,000-35,000 years ago) when. with the onset ot the practice of inhuming the dead, the possibility of the existence of a "... dynamic subterranean world, inhabited by endogenous forces capable of giving rise to external manifestations of heat, sometimes benevolent and peaceful, others violent and destructive..." must havc made its way into man's mind

More or less the same goes for those aspects of the *man-geothermal energy relationship* that regard man's intellective sphere. Indeed. apart from what was said at the outset of this paper on the basis of the illustration of a volcanic eruption found at Çatal Hüyük, it is likely that thousands of years before the Neolithic, Mrditerranean man, having come to find himself in localities with active geothermal manifestations and stimulated by empirical observations, somehow sensed that the manifestations were all attributable to a generative "cause" located underground. The fact that this "cause" may have corresponded to a subterranean entity towards which embryonic "religious" sentiments were being formed is of no importance to us here; rather, what is important is the possibility that, at a moment of the Upper Paleolithic (which Cataldi *et al.*, 1992-'93, place between 10,000 and 30,000 years ago, i.e. at the beginning of the culture called *homo sapiens* sapiens). man hcgan to reason in terms of a correlation between cause and effect with regard to the earth's energy. At the same time, it appears probable that, by virtue of daily empirical observations of the ways in which the different geothermal phenomena manifested themselves. Mediterranean man in that period had already started to recognize the various types of manifestations, thus beginning to tell those of the "peaceful" type (usable in some way for practical purposes) from those of the "violent" type before which he was forced to flee.

All these aspects (i.e. the first practical utilizations. the accumulation of empirical knowledge, the formation of embryonic "religious" sentiments towards benefic or malefic divinities dwelling underground, the beginning of a correlation between the presence of manifestations and their possible cause) denote the multifariousness of the *relationship* established in prehistory between man and geothermal energy in the Mediterranean arra. This *relationship* must have begun in the Paleolithic, probably over 50,000 years ago, and then gradually developed and enriched itself until the end of the Neolithic over lhat long, lung span of time that Cataldi *et al.* (1992-'93) have called the year *zero of geothermics*.

2. GEOTHERMAL *ENERGY* AMONG THE ANCIENTMOST MEDITERRANEAN CIVILIZATIONS

The presence in a number of nonvolcanic islands in the eastern Mediterranean (Cyprus, Crete, etc.) of tools made from obsidian and lava, dating from the 5th to the 3rd millennium B.C., indicates lhat in the Neolithic certain volcanic materials and some by-products of geothermal energy were not only utilized on the spot, but were also used as barter among the first trihcs of the peoples that a millennium or two later would give rise to the oldest Civilizations of he Mediterranean arca: Hattis, Hittites and Phoenicians in Anatolia, Minoans in Crete and in the southern Cyclades, Mycenaeans and other peoples in the coastal sectors of the northeast Aegean.

One of the main zones of origin of thrrr materials and by-products was Western Anatolia where, in addition to Çatal Hüyük, other important settlements formed in the Neolitic (Mellaart, 1967). The development of these settlements was probably favored by the abundance of the aforesaid materials, as well as by the presence of sulfur and cinnabar, at first probably used only to obtain pigments.

In the course of the Neolithic. however. and later in protohistoric limes, also the volcanic islands of the Aegean (Lesbos, Lemnos, Chios, Nisyros. Thera, Milos and others). as well as other geothermal localities along the eastern Mediterranean coasts. must have taken an a certain importance as places of origin for the exportation of obsidian and other by-products of geothermal energy. In all these places. in fact. numerous hydrothermal compounds and other by-products of terrestrial heat (alum, bentonite, borates, iron oxides. kaolin. lapilli, perlite, pozzolan. silica and sulfur) were plentiful, and heir extraction is documented since the 3rd or 2nd millennium B.C.

In this period, the first applications of all these compounds and by-products started to occur at the artisanal level among the most ancient Mediterranean civilizations for making pottery and pigments, tanning hides, coloring glass and other craftwork. Moreover, it is probable lhat the cooking of food and the practice of thermal bathing. as well as the use of thermomineral muds ior the cure of Certain skin diseases, became relatively common on the local scale in those times. At any rate, all ot these uses, although limited to the areas with active geothermal manifestations. appear firmly established among the peoples of the eastern Mediterranean as early as he middle of the 2nd millennium B.C.

Contemporaneously with these uses, numerous myths. legends, cults and beliefs inspired by geothermal phenomena flourished and spread among the Mediterranean peoples, a flourishing that represented the maturation of the embryonic rational thoughts and religious sentiments that had gradually taken shape in the mind and spirit of man since the darkness of prehistory. Aside from the cults and myths (some of which were mentioned in the preceding section). among he many legends originated by the occurrence of geothermal phenomena we shall cite here that of *Atlantis* ("the lost continent"). which seems to have been inspired by the huge volcanic explosion that eviscerated the island of Thera around 1450 B.C., causing its nearly complete disappearance (J.V. Luce, 1982).

The rising tide of colonization and the resulting land and rea traffic.

which took place in the Mediterranean arra thanks chiefly In the Cretans, Phoenicians and Mycenaeans beginning in the second half of the 2nd millennium B.C., also brought to the fore numerous geothermal localities of insular (Pantelkria, Aeolian archipelago, Ischia, etc.) and peninsular Italy (Phlegraean Fields, western Latium, south-central Tuscany, Euganean sector. etc.) which were rich in hot springs, active manifestations. hydrothermal minerals and various by-products of terrestrial heat. All there localities therefore began to take on a crnain importance not so much for balneology but fur the mining and exportation of the hydrothermal compounds and other by-products previously mentioned for the islands of the Aegean and the coastal sectors of the eastern Mediterranean.

The frequentation of the Italian geothermal localities funher caused the formation of new cults and legends inspired by the natural manifestations, cults and legends that were in pan autochtonous and in pan grafted onto previous cults, legends and myths that had already taken root on the eastern shores of the Mediterranean.

Concerning the cults, it is enough to cite, by way of example, the cult of the caretaker gods of the thermal waters of *Fons Aponi* (present-day Abano in the Euganean sector of Italy), whose furmation, attested by the discovery of abundant votive offerings, dates back to thr early Venetic period (>1000 years B.C.).

As for the legends, among thr many, one must recall that of the Phlegraean Fields, identified as the scene of the struggle of Typhoeus, the giant with a hundred fire-spewing heads, against Zeus in a vain attempt to contest the latter's dominion over the world. Beyond the transposition in a mythological key to signify the victory of the order instituted by Zeus over the disorder generated by the "rebel" forces of nature (or, in other words, the legitimacy of the Mycenaean expansion in southern Italy), this legend Contains a very evolved core of ideas on the attempt by the ancient Mediterranean peoples to explain the numerous craters. domes. fumaroles, jets of boiling water, eruption cones and steaming grounds present in the Phlegraean Fields and in the volcanic Islands of the Tyrrhenian. It is therefore a legend that, above and beyond the identification of paroxysmal manifestations of terrestrial heat with monstrous figures, points to man's mature desire. at least a millennium before our age, to explain the existence of those manifestations and to find, therefore, a cause and effect relationship for the must evident geothermal phenomena.

3. THE ETRUSCANS "HISTORICAL FATHERS" OF THE GEOTHERMAL INDUSTRY

The frequenting of the Tyrrhenian islands and coasts by the Mycenaeans and Phoenicians coincides with the development in Italy, between the 15th and 10th centuries B.C., of the so-called "Villanovan culture", one of whose characteristics was the tendency of the ancient Italic populations to group together in fairly large villages. This grouping process was particularly marked in the Tyrrhenian sector of central Italy, where we find the Etruscan people already settled in the 10th century B.C., ready for rake-off.

Indeed, in the space of just two or three centuries this people attained one of the highest degrees of civilization at that time in all the sectors of activity then practiced in the Mediterranean area, including (but not limited to) the mining of metal-bearing and nonmetalliferous ores. The rapid rise of the Etruscans, favored by commercial contacts with the Mycenaean and Phoenician navigators, was also facilitated by the presence in maritime Etruria of numerous metal-bearing ores (Ag, Cu, Fe, Mn, Pb, Zn, etc.), evaporitic minerals (alabaster, gypsum, sodium chloride) and rich hydrothermal deposits (alum, borates. hydrated silica, iron oxides, kaolin, sulfur. travertine, etc.). These deposits were all associated with the active and fossil manifestations in which Etruria abounded. especially in the area today known as the "Boraciferous Region" (Larderello and surrounding area).

The exploitation of the hydrothermal deposits made it possible for the Etruscans to offer the Mediterranean market a wide variety of useful products for the crafts and industries of the day. It must be pointed out, however. that thr Etruscans did not confine themselves to simply mining and selling the untreated saline gangues to the Mycenaean and Phoenician traders: they also sorted these gangues at the worksite to obtain finished products ready fur use in thr places of destination.

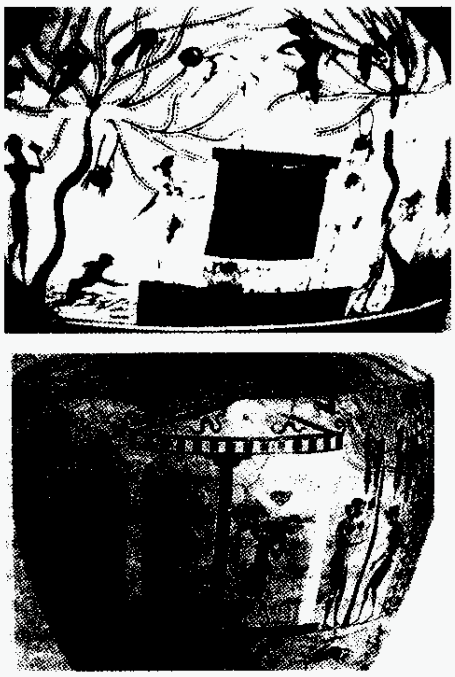
It must also be added that the Etruscans had developed refined techniques of grinding. processing and proportioning the various finirhrd products. which they themselves used in the numerous industrial and anisanal activities they practiced: making pottery. paints, glazes and pigments, preparing ointments and salves, fusing and coloring glass, bleaching wool, treating fabrics, etc. All the above is documented by numerous archeological finds. among which it is enough to cite some very fine ceramics of the epoch in whose glares and paints traces of boric salts have been found (Fiumi, 1943).

The above does not exhaust the range of activities of the Etruscans in the geothermal sector but merely outlines their interests in the mining. selling and applications of the by-products of geothermal energy. Together with these interests one must also remember the impulse given by the Etruscans to balneotherapy in the thermal localities, as testified to by wall-paintings, paintings on vases (Figure 2) and citations in works of Latin authors such as Tibullus and others. In addition to the gaiety of group participation, the paintings shown in Figure 2 illustrate the degree of sophistication of the installations used fur thermal bathing, and indicate that the balneological practices were common chiefly among the upper classes.

The transcendent (i.e. "religious" *sensu latu*) aspects of the relationship established between the Etruscans and the active manifestations of terrestrial heat would need a separate treatment. In shon, it can be said that the worship of Velchans as the equivalent of the Greek god Hephaestus (keeper of fire and volcanoes) seems to be a practice borrowed from the Hellenic world. This worship must initially have been transposed tu the localities of Tuscany and western Latium with fumaroles and spouts of boiling water, and later extended to Vesuvius and the neighboring volcanic edifices after the Etruscans created colonies and trading outposts (Capua, Cuma, etc.) on the southern Tyrrhenian coast.

However, the presence in classical Etruria of many spectacular manifestations (steaming grounds, steam jets, etc.) must have influenced the Etruscans on thr religious level, contributing to the formation of an idea ot tlir afterlife and a conception of thr netherworld as a sad, dark, inhospitable place which the ghosts of the dead were obliged to share with subterranean gods who were anything but kind. It is a conception similar to that of the ancient Greeks with regard to Hades. and perhaps this too was borrowed through the Etruscans' contacts with the Greek world; however. we are still far from thr concept of hell as a gathering place for souls condemned to suffering among perpetual flames.

Finally, it must be pointed out that many Etruscan centers (Populonia, Saturnia, Bolsena, Tarquinia, Cerveteri, Veio, Cuma, etc.) arc located next lo thermal manifestations, a fact that Seems anything but a coincidence in the light of what was said earlier on the mining and processing of hydrothermal products by the Etruscans. Such location, in our opinion, evidences the attraction exerted by certain thermal manifestations on man, as well as the



a

b

Figure 2. Attic-style ceramics of the 6th century B.C. showing bathing scenes in Etruscan spas. **a)** group bath in a hot spring; **b)** *lion's mouth* shower, probably fed with thermal water.

propelling role played by these manifestations in antiquity in the development of civilization.

The merit of the Etruscans is thus having fully grasped the many important aspects of the geothermal manifestations, exploiting all their potential: use of the hot waters and thermomineral muds for therapeutic and recreational purposes, extraction, processing, commercialization and utilization of a wide variety of hydrothermal products, urban development of localities close to thermal springs. For all these reasons, and thus for the impulse they gave to the integrated use of terrestrial heat, one must agree with Burgassi (1987) that the Etruscans impressed an innovative direction on the use of geothermal energy and its by-products. The definition of the Etruscans given by Cataldi *et al.* (1992-'93) as the "historical fathers" of the geothermal industry therefore appears more than justified.

4. THERMAL BATHING AND OTHER DIRECT USES OF GEOTHERMAL ENERGY IN THE ROMAN PERIOD

The Romans' interest in geothermal energy began to emerge in the early 4th century B.C. when they were able to increase their political and military pressure on the nearby peoples with the goal of expanding the rule of Rome over the whole Italian peninsula. This pressure was also directed at Etruria, both for reasons of territorial contiguity and because of the region's richness in the metal-bearing ores and hydrothermal deposits mentioned in the preceding section. Furthermore, the Romans already had a clear grasp of the strategic importance of Etruscan roads, which often linked towns (Cerveteri, Veio, Tarquinia, Saturnia, Massa Marittima and others) situated near thermal localities (Cataldi, 1993). The interest in question thus appears to have been aroused by political and economic concerns, certainly not by any need to frequent hot springs for therapeutic or recreational purposes.

There is no doubt, however, that as early as the 4th century B.C., Roman soldiers and travelers began to assimilate many of the Etruscan traditions, among them the frequenting of spas for cures and rest. In this way, a first nucleus of balneological customs was formed, which in Rome (given the absence of thermal springs) could initially be put into practice only in *artificial spas* specially built in the private residences of the principal Roman families.

Practicing balneology in artificial spas made inroads among the Roman middle classes after the Etruscans were crushed (late 3rd cent. B.C.); but it did not spread widely among the people until the early 1st century B.C. when, Roman rule having been extensively affirmed, the Romans could start to build large *public spas* in the capital.

On the other hand, in the whole period that preceded the constitution of the Empire (29 B.C.), a strong boost to the spread of thermal bathing among the Romans came from the meeting/clash not just with the Etruscans but also with the peoples of Greek culture in southern Italy, Greece and the eastern sector of the Mediterranean. In fact, even if it was practiced only in natural baths, thermal balneology had already established itself as a local tradition among all these peoples several centuries before the arrival of the Romans. Among other things, this practice had resulted in the formation of numerous cults of protective divinities of the thermal waters, the most prominent of which were those of Aesculapius and Hygeia.

It must also be said that in some of the thermal localities existing in the sectors of Greek influence, a differentiation had already been made, before the arrival of the Romans, between three main types of baths: the sweat bath in a hot dry cavern *(laconicum)*, the hot water bath, and the steam bath. The rooms for this last type of bath were obtained by channeling the steam of fumarolic manifestations into artificial caverns dug into the ground *(hypocausts)*.

One of the most important spas where this type of differentiation had been achieved before Roman times was Baia (to the north of Naples), which was later developed by the Romans in the 1st century B.C. and reached the height of its splendor in the imperial period.

And it is precisely the arrangement achieved in this natural spa that, in the early 1st century B.C., gave an ingenious citizen of Baia (a certain Caius Sergius Orata) the idea of reproducing it in the artificial public thermae of Rome, by creating a series of contiguous bathing rooms that would have three different temperature levels. To do this Caius Sergius Orata used a common boiler heated with firewood and air as a carrier fluid for the heat (Figure 3).

All the public baths of the capital thus came to have three different bathing rooms: the *laconicum* for sweating, the *calidarium* for bathing in hot water, and the *tepidarium* for bathing in warm water. Downstream from the latter was located the *frigidarium*, a pool of water at ambient temperature, used to tonify the body (Figure 4).

As will be noted, this type of thermal scheme was conceived to use the heat "in cascade." And although in the thermae of Rome the scheme in question did not use terrestrial heat, it was nonetheless realized on the basis of applications that had been experimented with over the span of several centuries in different geothermal localities of the Mediterranean and in particular in the area of Baia.

Over the next 3-4 centuries this scheme was adopted in the public and private artificial baths not just of Rome and all the towns far from active manifestations, but also in those fed by natural hot water or steam. It therefore contributed decisively to the rapid growth of the practice of thermal bathing and to its capillary diffusion in every social class of the day, in the whole area under the rule of Rome until the early 4th century A.D. To get an idea of this growth, it is enough to recall that in the 3rd century A.D. in Rome alone there were over 1000 public baths: approximately one spa for every 1000 inhabitants!

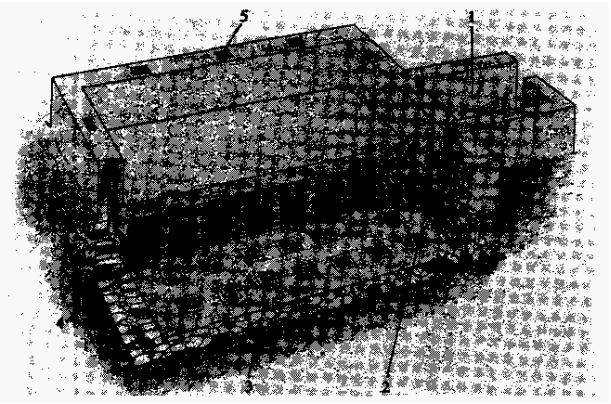


Figure 3. Artificial heating system using hot air circulation in the thermal baths of ancient Rome.
1. Boiler room; 2. Hot air vent; 3. Foundations of the baths; 4. Underfloor interspace for the circulation of hot air (*hypocaust*); 5. Vents carrying hot air upward (*alveolae*).

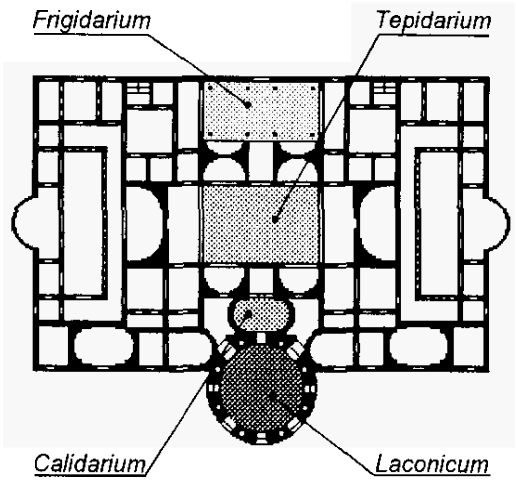


Figure 4. Scheme of a typical Roman thrrmal bath.

Thus, in the first three centuries of the Christian era, the practice of thermal bathing became such a deeply rooted popular custom in *the* whole Mediterranean area as to make the baths a daily meeting place. and thus one of the main points of reference of civic life. Indeed, in the last decades of the republican period. and even more so during the imperial period. the thermae had evolved tu the point where they were no longer just baths but also beauty institutes (massages. depilation, hair styling. etc.), gymnasiums (hall games, etc.), libraries, reading centers. meeting places, and complexes equipped with all kinds of services (restaurants. etc.), open to men and women of all ages and every social class (Pasquinucci, 1987). So, it is easy to understand why the baths became, not only in Rome but even in the towns farthest from the capital. centers of formation of public opinion capable of influencing political decisions on all levels. Thus, the thermae played a very imponant social role.

It must also be stressed that in the localities with natural manifestations the spas were also places for worship and oracular practicer. as is attested by the existence, within or in the vicinity of each thermal complex, of temples, inscribed pillars, statues, altars, and other votive artifacts in honor of the gods or the protective divinities of the hot waters. It is therefore not surprising that. in a time of dominant paganism as was that in which the rule of Rome was established, the *cult of the hot waters* was largely practiced.

Together, all these aspects illustrate the imponancr taken on hy thrrmal bathing until the fall of the Empire (5th century A.D.); they are widely described in works of numerous thinkers (ports, philosophers, historians, etc.) as well as in treaties of medicine. natural sciences, and engineering by Greek and Latin authors.

The imponance reached in the imperial period by some thrrmal stations can funher be deduced from the *Tabula Peutingeriana*, a cartographic work from the early 4th century A.D. which had been conceived as the official geographic atlas of the Roman Empirr (Figure 5). The fact that a number of these stations were reponed with particular graphic evidence in this atlas indicates that they had acquired great importance not just as spas but also as commercial and strategic centers (Cataldi *et al.*, 1992-'93).

As to the use of the hydrothermal minerals and other by-products of terrestrial hrat. it can he said that its growth started to occur in Roman times after the end of the 2nd century B.C. when. having consolidated their control over the land and sea routes and brought floridity to the state, the Romans could develop a series of industrial and anisanal activities and begin a vast construction program (public buildings, temples. monuments, stadia, villas, etc.) everywhere they governed. In addition to the increased use of the products mentioned earlier in regard to the Etruscans and the other ancient Mediterranean peoples, in the period between ths heginning of the 1st century B.C. and about the middle of the 4th century A.D. the following applications wrre panicularly developed by tlir Romans:

- the use of pyroclastic and fumarolized products (hmtanite, perlite, pozzolan, etc.) for the preparation of cement slurries,
- the utilization of various volcanic materials (lavas, tuffs, lapilli. etc.), as well as travertine, in the building industry;
- the use of kaolin for the making of fine ceramics and to obtain bleaching solutions for the textile industry;
- the use of boracic products and iron oxides for the preparation of the glazer and enamels necessary for the painting of fine potteries;
- the fabrication and commercialization of the so-called *palle do cane (balls for dogs)*, i.e. soap-like masses of smectic clays, rich in hydrothermal salts. used to cure skin diseases (Burgassi, 1987).

However, these uses and those mentioned in the previous sections with regard to the applications of the hydrothermal minerals and other by-products. as well as the practice of thermal bathing, began to decline in the second half of the 4th century A.D., becoming gradually less important in the succeeding decades until they totally faded away towards tlir beginning of the 6th century.

Geothermal development was now faced with a long period of lethargy that extended beyond the threshold of the second millennium.

5. THE FIRST NUCLEUS OF SCIENTIFIC THOUGHT ON GEOTIIERMAL ENERGY

It has already been pointed out in the previous sections that in the Mediterranean area man's rational relationship in regard to geothermal phenomena dates from very ancient times. One demonstration is the Neolithic painting shown in Figure 1, which depicts various details of a volcanic eruption. Oilier elements mentioned in the previous sections on the formation of myths and legends inspired by geothermal phenomena also indicate that man's desire to fmd an explanation for tlir various manifestations of terrestrial heat date back to protohistoric times.

However, the search for systematic elements on the treatment of geothermal aspects takes us to historical times (6th century B. C.), in

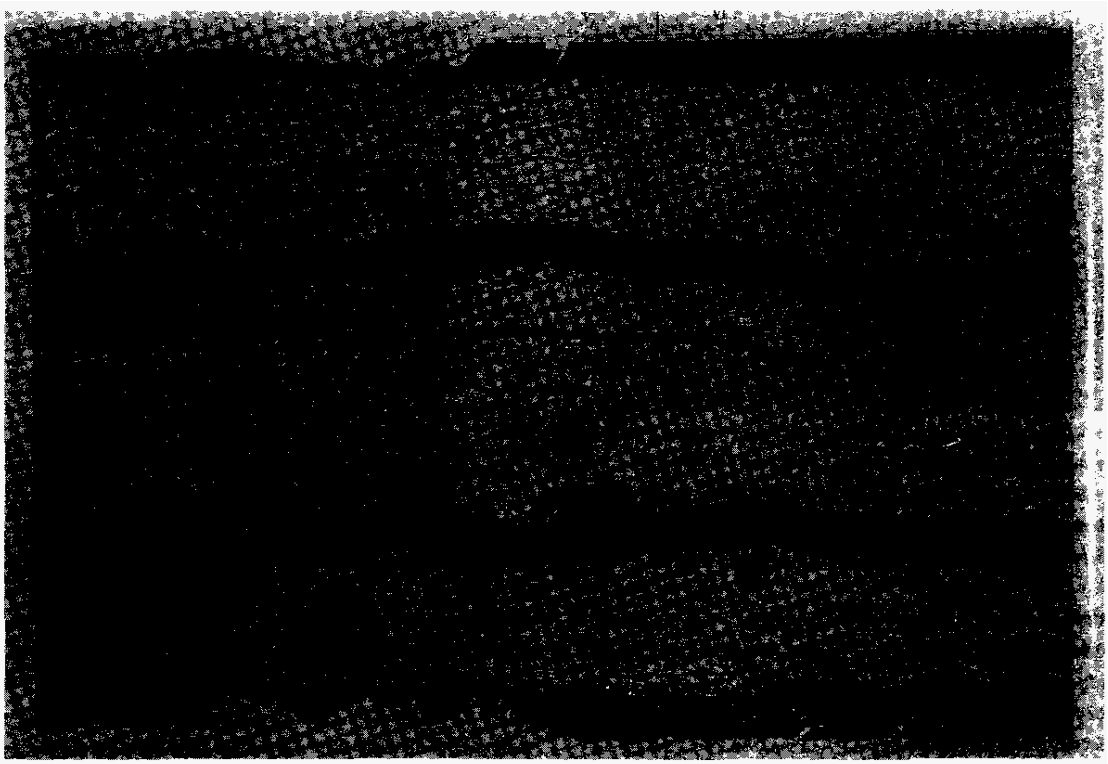


Figure 5. *TABULA PEUTINGERIANA*: portion relative to central Italy, with a sector of central and eastern Europe in the top part and northern Africa in the bottom part.

particular to the description tlie Egyptian priests gave Salon, according to accounts handed down orally from generation to generation, with regard to a natural catastrophe that occurred in the southern Aegean nearly a millennium before Solon's visit to Egypt. The priests were likely referring to the huge explosion which eviscerated the original island of Thera around 1450 B.C.

As of that moment the writings that directly or indirectly deal with geothermal phenomena become *more* and inure numerous and include the works of illustrious Greek and Latin thinkers. The main authors. their works and the geothermal aspects treated in them are summarized in Table I

As will he noted. the description of the geothermal phenomena is often accompanied hy speculations on the genesis of the phenomena themselves. From these speculations many scientific concepts can be drawn with regard to: existence of a heat source (called *internal fire),* classification of spring waters on the basis of temperature and chemical characteristics. encrusting properties of the water, CO_2 stratification as a function of density. chemical reactions occurring underground in geothermal areas, etc.

These concepts indicate haw the need to explain geothermal phenomena concerned Greek and Laun thinkers, giving rise to the first "logical" interpretations of the geothermal phenomena in the light of the philosophical and naturalistic theories of tlie times. Taken as a whole, there concepts illustrate tlic formation of a first "body of lhought" that will form the basis. in later centuries, for the development of more articulated scientific theories on geothermal phenomena. Thus, the cited authors must be considered the historical fathers of scientific thought on geothermal energy

6. RECAPITULATION AND CONCLUDING REMARKS

Man's *relationship* with the earth's energy in the Mediterranean area has its roots in the night of time, in a moment of the Paleolithic that cannot be specified but which dates back many tens of thousands, maybe even hundreds of thousands of years. From that moment on, this *relationship* must have slowly matured over all lhat long. long period of time thal has been called the *year zero of geothermics*. During most of this period, man's "contact" with the earth's heal probably remained confined to only a few of the numerous geothermal localities of the arca in question, and limited to tlie cooking of food and the occasional practice of thermal bathing; hut it war gradually enriched with the first utilizations of some by-products of geothermal rnergy, such as obsidian for the manufacture of stone tools, the use of thermomineral muds tor rudimentary therapeutic applications (drying of sores, hemostasis, etc.), and the use of a few hydrothermal compounds (cinnabar, iron oxides. sulfur, etc.) to obtain pigments.

Towards the end of the *year zero*, more or less at the start of the Metal Age (~5000 years ago). the initial utilizations mentioned above began to lake root in other gcothcrmal localities on the mainland and in the major volcanic islands of the Mediterranean as well, with basically similar kinds of applications in the various localities hut with experience gained independently from zone to zone.

A numhcr of autochthonous centers of utilization of the natural heal and its by-products thus came to be formed; they remained isolated from each other for many centuries, until systematic contacts between neighboring peoples started to occur and the first trade in raw materials began. The by-products mentioned above, as well as other hydrothermal compounds (alum, borates, kaolin, etc.), then came to be used as barter, resulting in a first form of "market" for them. However, it was a "market" limited to a few arras, radiating out from a few production centers, tlir most imponant of which were located in western Anatolia.

In historical times, 1500-2000 years before the Christian era, while

Table 1. CHRONOLOGICAL DEVELOPMENT OF ANCIENT SCIENTIFIC THOUGHT ON GEOTHERMAL ENERGY (6th cent. B.C. - 4th cent. **A.D.**)

Period	Author	Work	Subject treated	Speculation or Theory
VI B.C.	**Anaximenes**	Cf. Aristotle (Meteorology)	Earthquakes	Origin of earthquakes due to deformation of the earth's Crust. caused by "drying up of the soil" during arid periods, or by "swelling up of the soil" during rainy periods
V B.C.	**Herodotus**	The Nine History Books	Thermal manifestations	Description of many Greek thermal manifestations. Some of them would form after volcanic eruptions accompanied by "great clouds of fire"
V B.C.	**Hippocrates**	Air, Water. Land	Organoleptic and physio-chemical characteristics of the waters	Classification of natural waters into three main groups: 1) stagnant: 21 springs: 3) thermal. The salinity of the thermal waters is a function of temperature
V-IV B.C.	**Democritus**	Cf. Aristotle (Meteorology)	Earthquakes	Origin of the earthquakes due to subterranean water flaws. with formation of hydrostatic overpressure. or pressure drops, in correspondence to underground cavities
IV B.C.	**Aristotle**	Meteorology	Earthquakes	Origin of the earthquekes due to "gas streams" caused by "thermal expansion' arising from the "earth's internal fire". or from the sun's heat
III B.C.	**Lycophron**	Alexandra lor Cassandra)	Physio-chemical characteristics of the water	Description of the healing properties of boric waters from the main geothermal area of Tuscany (Larderello)
II-I B.C.	**Poseidonius**	Cf. Strabo (Geography)	Volcanism and seismo-volcanic phenomena	Description of changes in the earth's surface due to various natural phenomena Ifioods. erosion, etc.), especially volcanic phenomena
I B.C.	**Strabo**	Geography	Volcanism, volcanic phenomena and thermal manifestacions	Description of the main geothermal manifestations in the Mediterranean area. Moreover, detailed description of the volcanic explosion on Thera at the beginning of the 2nd century, and of the encrusting properties of thermal wafers
I B.C.	**Pompeius Trogus**	Cf. Justin (Epitome of Phil. Hist. by P. Trogus)	Volcanism and seismo-volcanic nhenomena	Description of earthquakes in the south eastern hector of the Aegean Sea. Moreover. description of the volcanic explosion at Thera in 197 (?) B.C.
I B.C.	**Tibullus**	Elegies	Thermal manifestations	Comparison between the natural manifestations of Turcany and of the area near Naples
I B.C.	**Ovid**	Methamorphoses	Earthquakes and phreatic explosions	Description of earthquakes, volcanic eruptions and hot springs. In particular, description of the explosiion at Methana (Greece) in the 2nd century B.C.: a phreatic explosion ?
I B.C.	**Vitruvius**	Architecture	Volcanism and thermal manifestations	Genetic interpretation of the manifestations of the Phlegrean Fields. due to decomposition of minerals in the subsoil (esothermal reactions ?)
I B.C. - IV **A.D.**	**Various Greek and Latin authors**	Cf. A.Corretti (Baia)	Volcanism, thermal manifestations and physio- chemical characteristics of the waters	Description and/or comparison of various geothermal localities in the Mediterranean area. Notably, according to Straba. the manifestations of the Phlegrean Fields can all be attributed to the same volcanic phenomenon
I **A.D.**	**Pliny the Elder**	Natural History	Volcanism and thermal manifestations	Description of almost all main thermal manifestations of southern Europe and of the Mediterranean area. Notably, description of the eruption of Vesuvius in 79 A.D.
II **A.D.**	**Pausanias**	Description of Greece	Earthquakes, natural manifestations and physio-chemical characteristics of thermal waters	Inventory of almost all the thermal springs of Greece and southern Italy. Morever, description of the warning signs of earthquakes
I-1VA.D.	**Apuleius and Others**	Cf. T.Ritti (Hierapolis: excavations and research)	Thermal manifestations	Description of the phenomenon of gar (CO_2 and H_2S) stratification

the practice of balneotherapy continued to develop slowly in some arras with hot springs, the commercialization of hydrothermal products began to expand to various coastal sectors of the Mediterranean mainly thanks to Cretan and Phoenician navigators. causing the gradual enlargement of the "market" mentioned above. Indeed, in the 2nd millenium B.C., Compounds derived from hydrothermal mineralizations became increasingly sought after among the ancient Mediterranean civilizations for numerous anisanal uses, such as making pottery and pigments. coloring glass, preparing ointments and salves, tanning hides, and others.

All there uses then began to proliferate, becoming more and more numerous and refined over the centuries until, with the Etruscans (staning around the 7th century B.C.), they formed an integrated group of activities in the extraction, processing a d commercialization of finished products of great economic imponance: so much so as to result in the formation of a true "geothermal industry", capable of satisfying not only the needs of Etruria but also much of the demand that. far these same products, came from other coastal sectors of the Mediterranean through the Mycenaean and Phoenician traders. Thus. between the 6th and the 3rd century B.C., a geothermdl "market" on an international Scale was formed.

This "market" became firmly established at the height of Rome (1st century B.C. - 3rd century A.D.). spreading to all the territory under Roman rule and enriching itself with the opening of new mines in Italy and in other geothermal localities of the Mediterranean area. The "market" in question then reached a level of great prosperity in the imperial period due to the systematic use of all the above products and of other useful by-products of thr earth's energy: travertine, bentonite, pozzolan. perlite, lavas, pyroclastites and various tuffs: all materials used In the construction industry.

From the foregoing one can see the great importance reached in antiquity by nearly all the by-products of geothermal energy.

Keeping pace with the development of these by-products, the practice of thermal balneology became deeply rooted in historical times. In fact, even before the Roman period, thermal bathing had reached a quite evolved therapeutic level in some places of Anatolia, the Peloponnesus, the Phlegrean Fields and Etruria.

The boom in thermal balneology between the 1st century B.C. and the early 4th century A.D.. due to the impulse given hy the Romans through the building of countless spas in all the localities with hot springs and in many other towns far from natural manifestations, was truly exceptional. In the imperial period the practice of thermal bathing in fact became a popular daily custom everywhere, involving several million people of every social class, without regard to ethnic group or gender. In this period, besides hcing complete health service centers, the thermae also became places for meetings, debates. entertainment, reading, business dealings, sport and culture. thus functioning as a catalyst for numerous social activities.

For these reasons - but also bearing in mind the fact that (despite having reached its apex in the imperial age) the practice of thermal bathing had already been widespread for many centuries in various localities of the area in question - it must be said that thermal bathing should be considered as a common socio-cultural heritage of all the ancient Mediterranean peoples.

In addition to the practice of thermal bathing and the commercialization of the by-products cited earlier, one must also mention the influence geothermal phenomena exerted in ancient times on the formation of cults that worshiped the protective divinities of the hot waters, and on the birth in an etiological key of numerous myths and legends inspired by such phenomena.

Moreover, it must be remembered that the widespread existence in the Mediterranean area of thermal manifestations and active volcanoes. as well as the occurrence of other phenomena directly or indirectly controlled by the eanh's energy, stimulated almost all the great Greek and Latin thinkers to search for explanations for them. This enabled the formation of the first systematic nucleus of ideas and theories on the genesis of geothermal energy and on some of the phenomena controlled by it.

For all the aspects cited above one must conclude by affirming that. from at least the Upper Neolithic until the breakup of the Roman Empire. with a "logical" continuity that appears almost surprising today, the development of geothermal energy represented one of the propelling factors of civilization in the whole Mediterranean area.

7. BIBLIOGRAPHIC NOTE

The bibliography regarding the historical background of the topic treated in the paper is extremely vast. Therefore, in order not to weigh dawn the text, it was decided to make citations for specific aspects only.

Interested rrdders, howrver, can refer to the bibliographies contained in the works cited in the text. as well as tu those of the following additional authors: Burgassi P.D. et al. (1992), Nenci - Vallet (1984), Pallottino (1984), Panessa (1991), Ritti (1985).

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