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11. Geothermal Energy in the Mediterranean before the Middle Ages, A Review

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Abstract: Archaeological finds dating from the Lower and Middle Neolithic and considerations of refinement of customs, myths, and cults linked to manifestations of terrestrial heat several millennia before the Christian era indicate that the human-geothermal energy relationship can be traced at least to the Upper Paleolithic in the Mediterranean.

After outlining the first human contacts with geothermal manifestations in prehistoric periods and the earliest Mediterranean civilizations, this chapter explains how the Etruscans developed hydrothermal products and how the Romans spread thermal bathing. Major Greek and Latin authors are also mentioned who, from the 6th century B.C. to the 4th century A.D., described many aspects of geothermal manifestations or speculated on their geneses, and who thus may be considered the historical fathers of scientific thought on geothermal heat.

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Early Contacts of Mediterranean People with the Earth's Heat

The oldest known artifact reflecting Mediterranean peoples' interest in geothermal phenomena dates from the 7th millennium B.C. (Mellaart, 1967). It is a painting from Çatal Hüyük in Western Anatolia that shows an erupting volcano (probably Hasan Dağı) behind a Neolithic settlement with a highly evolved dwelling structure (see Chapter 2 in this volume). The painting's details illustrate not just morphological features of the volcano but also particulars of the eruption itself, such as the explosion plume and volcanic bombs. Thus by the Lower Neolithic, some Mediterranean peoples already had developed a keen sense of observation and an advanced ability to depict natural phenomena. These peoples must have possessed, collectively, much empirical knowledge on manifestations of the Earth's energy, such as hot springs, fumaroles, and volcanic eruptions (Cataldi et al., 1992-93; Cataldi, 1993a).

Such knowledge probably matured on the individual level over many thousands of years (perhaps even tens of thousands) as direct contacts with manifestations continued, yielding a complex relationship between prehistoric people and geothermal phenomena. Indeed, it is likely that people chose to settle in geothermal localities with "peaceful" manifestations and/or geothermal by-products, places ideal for cooking, bathing, and finding useful materials such as hydrothermal encrustations, obsidian, and other volcanic products suitable for many practical purposes. Other benefits indirectly resulting from the Earth's heat, important at the end of the nomadic period, were the fertility of volcanic soils, the security of some lake basins molded by caldera rims, and the availability of freshwater springs on volcanic outcroppings.

In other localities, it seems certain that the occurrence of volcanic eruptions and earthquakes had the opposite effect, discouraging early peoples from frequenting them. Ever since the earliest days of prehistory, first on an individual level and then collectively, people developed a pragmatic relationship with different types of geothermal phenomena: attraction to some features and avoidance of others (Cataldi, 1992 and 1993b).

Although still rooted in Paleolithic times, this relationship must have evolved gradually and widened in scope, affecting people's spiritual sphere and resulting in the formation of religious sentiments toward underground entities located in geothermal areas (Cataldi et al., 1992-93). Neolithic artifacts found near natural manifestations in the Mediterranean, such as stone statuettes known as *veneri votive*, bone amulets, food offerings, and other objects, clearly relate to religious beliefs in underground entities (Cataldi, 1993a; Grifoni Cremonesi, 1999), as do the megalithic constructions known as "divine stones," found near fumaroles on the volcanic island of Pantelleria in the Western Mediterranean and dating from the 3rd millennium B.C. (Burgassi et al., 1992).

Indirect proof of geothermal influence on prehistoric peoples' spiritual sphere comes from later evidence of customs, cults, and sophisticated myths clearly inspired by natural manifestations and volcanoes. Some examples are the cults of the Great Mother in Western Anatolia, Hephaestus in Greece, and Mephitis in Southern Italy; the myth of Prometheus' theft of fire; and evidence of reverence paid to the nymphs of the thermal waters and the health divinities, such as Asclepius and Hygieia. These cults, myths, and customs could not have appeared suddenly in passage from the Stone Age to the Metal Age. Most likely they represent refinements of religious sentiments born in much earlier times, perhaps stretching back to the

Late Mousterian (35,000 to 40,000 years ago) when, with the onset of burial practices, the possibility of a "dynamic subterranean world, inhabited by endogenous forces capable of giving rise to external manifestations of heat, some benevolent and peaceful, others violent and destructive...entered the mind of mankind" (Cataldi, 1992).

A similar process must have occurred in the evolution of a rational rapport between prehistoric people and geothermal phenomena. Probably thousands of years before the Neolithic, Mediterranean peoples observed volcanoes, natural manifestations, and other geothermal phenomena with curiosity and intellectual interest, eventually thinking that they all could be controlled by an underground cause. That this cause may have been a subterranean entity toward which embryonic religious sentiments were expressed is not important here. What is important is that, at a moment of the Upper Paleolithic, which Cataldi (1992) places between 10,000 and 30,000 years ago, humans began to reason about the Earth's heat in terms of cause and effect. Mediterranean peoples started to differentiate, by at least the Middle Paleolithic, between the "peaceful" and "violent" types of geothermal phenomena.

Thus a complex relationship—with utilitarian, religious, and intellectual aspects—was established between prehistoric people and geothermal heat in the Mediterranean. The relationship must have begun in the Paleolithic, probably over 50,000 years ago, and gradually developed and enriched itself until the end of the Neolithic over that long, long span of time that Cataldi (1992) has called the *year zero* of geothermics.

Geothermal Heat in the Oldest Mediterranean Civilizations

On several important nonvolcanic islands in the Eastern Mediterranean, such as Cyprus, Rhodes, and Crete, excavations have revealed obsidian and lava tools dating from the 5th to the 3rd millennium B.C. They indicate that volcanic materials and other geothermal by-products were used not only in the site of origin but were bartered among the first tribes of people that a millennium or two later would give rise to the oldest civilizations of the Mediterranean area: the Hattis, Hittites, and Phoenicians in Anatolia; Minoans in Crete and the Southern Cyclades; and the Mycenaeans and others on the Aegean coast.

Many of these materials and by-products came from Western Anatolia where, in addition to Çatal Hüyük, other important Neolithic settlements had formed (Mellaart, 1967). Their development probably was helped by the abundance of geothermal by-products in the area, including sulfur and cinnabar, probably first used for pigments.

During the Neolithic, however, and even earlier in protohistoric times, the volcanic islands of the Aegean, such as Lesbos, Limnos, Chios, Nisyros, Yialí, Santorini, and Milos—and other geothermal localities along the Eastern Mediterranean coast—became important for mining and exporting obsidian and other plentiful geothermal by-products (Fytikas et al., 1999), such as alum, bentonite, borates, iron oxides, kaolin, lapilli, perlite, pozzolan, silica, and sulfur. The extraction is documented from the 3rd or 2nd millennium B.C. Neolithic artisans started using some of these compounds and their by-products to make pottery and pigments, tan hides, and color glass. Cooking, thermal bathing, and curing skin diseases with thermo-mineral muds probably became common on a local scale (Cataldi, 1992, 1993b; Fytikas et al., 1999).

At the same time, numerous myths, legends, cults, and beliefs inspired by geothermal phenomena flourished and spread among the Mediterranean peoples, a maturing of the first rational thoughts and religious sentiments growing in the mind and spirit of humans since the darkness of prehistory (Cataldi, 1992). One of many legends is that of Atlantis, which may have been suggested to Plato by an account of the huge volcanic explosion that almost completely obliterated the island of Thera (the present-day Santorini) in about 1630 B.C. (Fytikas et al., 1998; Luce, 1969).

A rising tide of colonization and increased land and sea traffic took place in the Mediterranean area thanks chiefly to the Cretans, Phoenicians, and Mycenaeans from the second half of the 2nd millennium B.C. It extended to many geothermal localities in Italy, such as the Phlegraean Fields, Western Latium, Central-southern Tuscany, the Euganean sector, and islands such as Pantelleria, the Aeolian and Pontine archipelagos, and Ischia, rich in hot springs, active manifestations, hydrothermal minerals, and other by-products of terrestrial heat. All of these localities gained importance for mining and exporting hydrothermal compounds, as did some Aegean islands and other geothermal localities along the Eastern Mediterranean coast.

Cults and legends grew as well, inspired by the Italian natural manifestations. Some were new, and some were grafted onto prior beliefs from other Mediterranean areas (Burgassi

et al., 1992). One cult is that of the caretaker gods for the thermal waters of *Fons Aponi* (present-day Abano in the Euganean sector of Italy). Abundant votive offerings date this cult back to the early Venetic period, beyond 1000 B.C.

Among the many Italian legends formed in Antiquity is one where the Phlegraean Fields (Naples) were the scene of a struggle between Hercules and Typhoeus, the giant with 100 fire-spewing heads, who vainly contested Zeus' dominion over the world. Hercules' victory signified the victory of the order instituted by Zeus over the disorder from the "rebel" forces of nature (in other words, a political parable advocating the legitimacy of Mycenaean expansion in Southern Italy). The legend includes a sophisticated attempt by ancient Mediterranean peoples to explain the numerous craters, domes, fumaroles, jets of boiling water, eruption cones, and steaming grounds that existed in the Phlegraean Fields and on the volcanic islands of the Tyrrhenian Sea. The legend points to people's mature desire, at least 1,000 years before the Christian era, to explain the formation of high-temperature manifestations and to find a cause-and-effect relationship for some geothermal phenomena.

The Etruscans: Historical Fathers of the Geothermal Industry

Mycenaeans and Phoenicians frequented the Tyrrhenian islands and coasts between the 15th and 10th centuries B.C., coinciding with the development of the Italian "Villanovan culture," during which ancient Italic populations grouped into fairly large villages. This characteristic was prominent in the Tyrrhenian sector of Central Italy, where the Etruscans established an organized community starting in about the 12th century B.C. Just a few centuries later, they attained one of the highest degrees of civilization in all activities then practiced in the Mediterranean area, including mining metallic and nonmetallic ores. The rapid rise of the Etruscans was favored by their commercial contacts with Mycenaean and Phoenician navigators, who carried Etruria's riches to foreign markets:

- Metallic minerals: copper, iron, manganese, lead, silver, and zinc
- Evaporitic minerals: alabaster, gypsum, and sodium chloride
- Hydrothermal minerals: alum, borates, hydrated silica, iron oxides, kaolin, sulfur, and travertine

Hydrothermal deposits were mined in the abundant Etrurian areas of active and fossil geothermal manifestations, particularly in the present-day Larderello region (Cataldi and Burgassi, 1992a). This allowed the Etruscans to offer the Mediterranean market a wide variety of products useful for the crafts and industries of the day. Not only did the Etruscans mine many hydrothermal minerals, they sorted, processed, and sold finished products in distant markets. The Etruscans also refined techniques for grinding, processing, and mixing the products, using them to make pottery, paints, glazes, and pigments; prepare ointments and salves; fuse and color glass; bleach wool; and treat fabrics (Burgassi, 1987; Cataldi and Burgassi, 1992a). Numerous archaeological finds prove this, including some very fine ceramics with glazes and paints that have traces of boron compounds (Fiumi, 1943). This list does not exhaust the range of Etruscan activities in the geothermal sector but merely outlines the skill of this people in mining and using hydrothermal minerals. In addition, the Etruscans valued balneotherapy, as recorded by a number of Greek and Latin authors (Burgassi, 1987; Cataldi and Burgassi, 1992a and 1992b).

The relationship between the Etruscans and active geothermal manifestations included religious aspects, such as divination based on the shapes of the steam plumes from fumaroles, a unique belief in the afterlife, and the formation of cults for subterranean divinities. The worship of Velchans (the equivalent of the Greek god Hephaestus, keeper of fire and volcanoes) seems a practice initially borrowed from the Hellenic world. However, the Etruscans elaborated on it and brought the cult first to Etruria proper and afterwards to Southwestern Italy, site of Etruscan colonies and trading outposts, such as Capua and Cuma.

The presence of many spectacular geothermal manifestations, such as steaming grounds and steam jets, deeply influenced the Etruscan concept of the netherworld. They thought it a sad, dark, inhospitable place that the ghosts of the dead were obliged to share with the subterranean gods, who were anything but kind (Pallottino, 1984). This concept is similar (but not identical) to the ancient Greek notion of Hades.

Many important Etruscan centers—Populonia, Saturnia, Bolsena, Tarquinia, Cerveteri, Veio, and Cuma—grew up next to thermal manifestations, a fact that hardly seems coincidental (see Chapter 9 in this volume). We may conclude that the Etruscans fully grasped the importance of geothermal manifestations and exploited their full potential: using hot waters and

thermo-mineral muds for therapeutic and recreational purposes; extracting, processing, selling, and using a wide variety of hydrothermal products; and developing urban communities near thermal springs. For these reasons, they have been dubbed the historical fathers of the geothermal industry (Cataldi and Burgassi, 1992a).

Thermal Bathing and Other Uses of Geothermal Resources in the Roman Period

Roman interest in geothermal resources began emerging in the early 4th century B.C., as they increased political and military pressures on nearby peoples to expand Roman rule over the whole Italian peninsula. These pressures were also directed at Etruria, because of territorial contiguity and the region's rich metal-bearing ores and hydrothermal deposits (Cataldi and Burgassi, 1992a, 1992b). The Romans understood the strategic importance of Etruscan roads, which often linked towns near thermal localities: Cerveteri, Veio, Tarquinia, Saturnia, and Massa Marittima (see Chapter 9 in this volume). Initial Roman interest in geothermal localities appears to be based on political and economic concerns, not a need to frequent hot springs for therapeutic or recreational purposes (Cataldi, 1993b). However as early as the 4th century B.C., Roman soldiers and travelers undoubtedly began assimilating many Etruscan traditions, including spa visits for cures and rest. From this early contact, Roman balneological customs grew. Although Rome itself had no thermal springs, the upper-class Romans compensated by bathing in artificial spas built in all luxurious private residences. Balneology in artificial spas made inroads among the Roman middle classes after the Etruscans were crushed in the 3rd century B.C. However it did not become widespread until the early 1st century B.C. when Roman rule over the Mediterranean was more secure and the Romans had started to build large public spas in the capital.

Before the Empire was established in 29 B.C., however, strong support for the spread of thermal bathing among Romans came from interaction with Greeks in Southern Italy, Greece, and the Eastern Mediterranean. Here thermal balneology was established as a local tradition several centuries before the Romans arrived, although it was practiced only in natural baths. Moreover, numerous cults had formed outside Rome with protective divinities of the thermal waters, the most prominent of which were those of Asclepius and Hygieia (Cataldi and Burgassi, 1992b; Fytikas et al., 1999).

In some natural thermal spas under Greek influence, three main types of baths were used: the sweat bath in a hot dry cavern (*laconicum*), a hot-water bath, and a steam bath. The steam bath was made by channeling steam from natural fumaroles into artificial caverns dug in the ground (*hypocausts*). Baia, north of Naples, was one of the most important spas where the three types of rooms were used before Roman times. Baia was developed further by the Romans in the 1st century B.C. and reached its height during the imperial period (Cataldi and Burgassi, 1992b; Pasquinucci, 1987).

It was precisely the arrangement of Baia's natural spa that gave Caius Sergius Orata, an ingenious Baian citizen in the early 1st century B.C., the idea of reproducing it in the artificial public thermae of Rome by building a series of adjoining bathing rooms with three different temperature levels (Cataldi and Burgassi, 1992b). To do so, he heated water in an ordinary wood-burning boiler and used air as a carrier for the heat (see Chapter 10 in this volume). Thus, the public baths in Rome had three main thermal rooms: the *laconicum* with steam for sweating, the *calidarium* with hot water for bathing, and the *tepidarium* with warm water for bathing. Afterwards, the *frigidarium*, a pool at ambient temperature, was used to tone the body. Other rooms were used for physiotherapy. This orderly thermal scheme used heat in cascade, going from hot to cold. A similar process is used in many projects today, and it all started in Mediterranean geothermal localities, especially Baia.

For the next three to four centuries, this scheme was used for public and private artificial baths, not only in Rome and important localities of the Empire, such as the baths of Curium in Cyprus far from active geothermal manifestations, but also in places with natural hot water or steam. The balneological scheme developed by Caius Sergius Orata was thus fundamental to the rapid growth of thermal bathing in every social class in the Roman Empire until the early 4th century A.D. In the 3rd century in Rome alone, 1,000 public baths existed—about one spa for every 1,000 inhabitants (Montanelli, 1969).

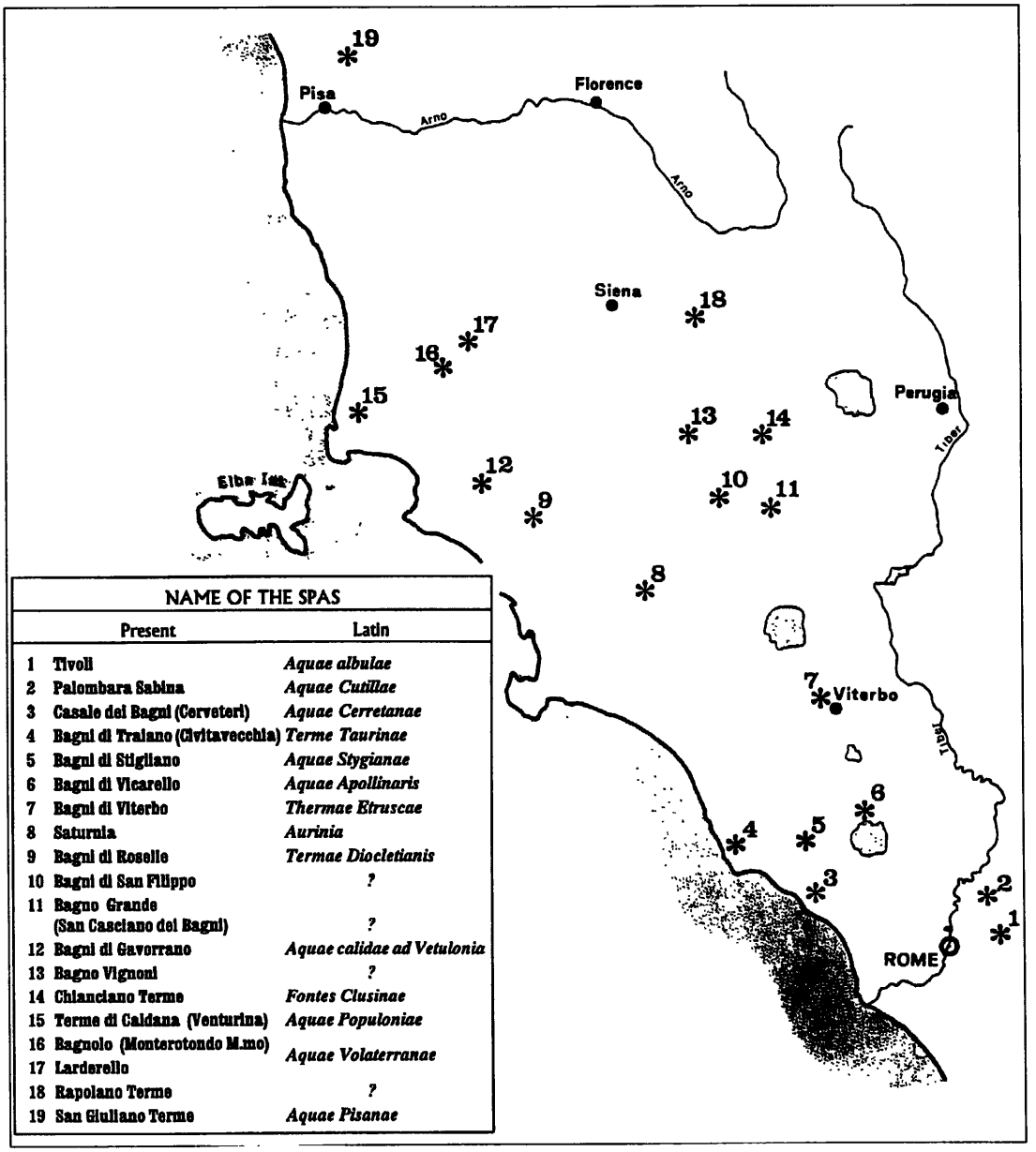
In the first three centuries of the Christian era, thermal bathing became deeply rooted in the Mediterranean: the baths were a daily meeting place and a main site for civic life. In the last decades of the republican period and even more so during the imperial period, the thermae were no longer just baths. They were also beauty institutes (massages, depilating, and hair styling), gymnasiums (ball games and physical exercise), libraries, reading centers, meeting places, and complexes equipped with all kinds of services, such as

Hypocaust of the ancient thermae of Kourion (Curium), West of Limassol, Cyprus, dated to the imperial period of Rome. *R. Cataldi*

restaurants and shops—open to men and women of all ages and social classes (Pasquinucci, 1987; Cataldi and Burgassi, 1992b). Everywhere the baths became socialization sites and centers where public opinion was formed, capable of influencing political decisions on all levels.

Spas located near natural manifestations were places for worship and religious practices. Temples, inscribed pillars, statues, altars, and other votive artifacts in honor of the gods or the protective divinities of hot waters have been found in or near each thermal complex. In Roman times, betrothed young ladies used to go through a cycle of ritual baths at natural spas immediately preceding their marriages. According to popular beliefs, this cycle was needed to appease the gods of fertility through purification of the female body. It was believed that, if performed in thermal waters with particular therapeutic properties, these ablutions enabled deflowered young ladies to recover their chastity. This practice seems to have occurred in the San Casciano dei Bagni thermal springs. Such ritual practices recall the legend of the goddess Hera (Juno) who, before retiring into the bridal room with her demanding spouse Zeus, would fly every evening to the sacred thermal spring of Kanathos, near ancient Nauplia, taking a warm bath to restore her virginity (Pausanias, 155-170 A.D.).

These practices show the importance of thermal bathing in the first four centuries of the Christian era until the fall of the Roman Empire in the 5th century A.D. They are described by many poets, philosophers, geographers, and historians, including treatises on medicine, natural sciences, and engineering by Greek and Latin authors (Cataldi and Burgassi, 1992b; Fytikas et al., 1999). The importance of some thermal sites in the imperial period is also illustrated in the *Tabula Itineraria Peutingeriana*, from the early 4th century, the official geographic map of the Roman Empire during its final period (see Chapter 10 in this volume). This map shows several



NAME OF THE SPAS	
Present	Latin
1 Tivoli	*Aquae albulae*
2 Palombara Sabina	*Aquae Cutiliae*
3 Casale dei Bagni (Cerveteri)	*Aquae Cerretanae*
4 Bagni di Traiano (Civitavecchia)	*Terme Taurinae*
5 Bagni di Stigliano	*Aquae Stygianae*
6 Bagni di Vicarello	*Aquae Apollinaris*
7 Bagni di Viterbo	*Thermae Etruscae*
8 Saturnia	*Aurinia*
9 Bagni di Roselle	*Termae Diocletianis*
10 Bagni di San Filippo	?
11 Bagno Grande (San Casciano dei Bagni)	?
12 Bagni di Gavorrano	*Aquae calidae ad Vetulonia*
13 Bagno Vignoni	?
14 Chianciano Terme	*Fontes Clusinae*
15 Terme di Caldana (Venturina)	*Aquae Populoniae*
16 Bagnolo (Monterotondo M.mo)	*Aquae Volaterranae*
17 Larderello	
18 Rapolano Terme	?
19 San Giuliano Terme	*Aquae Pisanae*

Main natural thermae in operation during Etruscan and Roman times between the Tiber and Arno Valleys.

thermal stations, indicating their great importance not just as spas but as commercial and strategic centers (Cataldi and Burgassi, 1992b). These thermal stations, however, are only a few of those operating at the end of the 3rd century; many hundreds of thermae were spread throughout the territory of the Roman Empire. For example, in only the western sector of Central Italy, some 20 thermal stations could be found in a territory of about 20,000 km^2, most of them dating to Etruscan times (7th-4th century B.C.).

Beginning near the end of the 2nd century B.C., the Romans started systematically developing industrial and artisanal activities everywhere they governed. They began a vast construction program that included public buildings, temples, monuments, stadiums, and villas. At the same time, they greatly expanded the use of hydrothermal minerals and other by-products of terrestrial heat.

Over five centuries, the Romans developed the following uses of geothermal by-products (Cataldi and Burgassi, 1992b):

- Pyroclastic and fumarolized rocks, and hydrothermal minerals, such as bentonite, perlite, and pozzolan, to prepare cement slurries
- Travertine and volcanic materials, such as lavas, tuffs, and lapilli, for building
- Kaolin to make fine ceramics and bleaching solutions for the textile industry
- Boron compounds and iron oxides to prepare glazes and enamels for painting fine pottery
- Preparation and wide commercialization of *palle da cani* ("balls for dogs"), soap-like masses of smectic clays rich in hydrothermal minerals used to cure skin diseases (Burgassi, 1987)

The importance of these uses and of ones previously mentioned, including thermal bathing, began to decline in the second half of the 4th century. In the next two centuries, they almost disappeared in many areas of Europe. Especially in Italy, thermal balneology and the use of hydrothermal by-products started to fade in the second half of the 5th

Chronological development of ancient scientific thought on geothermal heat (6th century B.C.-4th century A.D.) Revised from Cataldi, 1993b

Century	Author	Work	Subject Treated	Speculation or Theory
6th B.C.	**Anaximenes**	See 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.
5th 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."
5th B.C.	**Hippocrates**	*Air, Water, Land*	Organoleptic and physio-chemical characteristics	Classification of natural waters as stagnant, springs, and thermal. Salinity of the thermal waters is a function of temperature.
5th-4th B.C.	**Democritus**	See Aristotle, *Meteorology*	Earthquakes	Origin of earthquakes due to subterranean water flow, with formation of hydrostatic overpressure, or pressure drops, in underground cavities.
4th B.C.	**Aristotle**	*Meteorology*	Earthquakes	Origin of earthquakes due to "gas streams" caused by "thermal expansion" arising from the Earth's "internal fire," or from the sun's heat.
3rd B.C.	**Lycophron**	*Alexandra* (or *Cassandra*)	Physio-chemical characteristics of the waters	Description of the healing properties of boric waters from the main geothermal area of Tuscany (Larderello).
2nd-1st B.C.	**Poseidonius**	See Strabo, *Geography*	Volcanism and seismo-volcanic phenomena	Description of changes in the Earth's surface due to various natural phenomena (floods, erosion, etc.), especially volcanic phenomena.
1st B.C.	**Strabo**	*Geography*	Volcanism, volcanic phenomena, and thermal manifestations	Description of the main geothermal manifestations in the Mediterranean area. Detailed description of the volcanic explosion on Thera at the beginning of the 2nd century B.C., and of the encrusting properties of thermal waters.

1st B.C.	**Pompeius Trogus**	See Justin, *Epitome of Phil. Hist.* by P. Trogus	Volcanism and seismo-volcanic phenomena	Description of earthquakes in the southeastern sector of the Aegean Sea and the volcanic explosion at Thera in 197(?) B.C.
1st B.C.	**Tibullus**	*Elegies*	Thermal manifestations	Comparison between the natural manifestations of Tuscany and the area near Naples.
1st B.C.	**Ovid**	*Metamorphoses*	Earthquakes and explosions	Description of earthquakes, volcanic eruptions, and hot springs. In particular, description of the explosion at Methana (Greece) in the 2nd century B.C. (probably a phreatic explosion).
1st B.C.	**Vitruvius**	*Architecture*	Volcanism and thermal manifestations	Genetic interpretation of the manifestations of the Phlegraean Fields, due to decomposition of minerals in the subsoil. The author probably had in mind a heat-formation process now called "exothermal reactions."
1st B.C.-4th A.D.	**Various Greek and Latin authors**	See 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. According to Strabo, the manifestations of the Phlegraean Fields can all be attributed to the same volcanic phenomenon.
1st A.D.	**Pliny the Elder**	*Natural History*	Volcanism and thermal manifestations	Description of most main thermal manifestations in Southern Europe and the Mediterranean area. Description of the eruption of Vesuvius in 79 A.D.
2nd A.D.	**Pausanias**	*Description of Greece*	Earthquakes, natural manifestations, and physio-chemical characteristics of thermal waters	Inventory of most thermal springs of Greece and Southern Italy. Description of the warning signs of earthquakes.
1st-4th A.D.	**Apuleius and others**	See T. Ritti, *Hierapolis: Excavations and Research*	Thermal manifestations	Description of the phenomenon of gas stratification.

century, marking a long period of recession that would extend beyond the threshold of the second millennium (Cataldi and Burgassi, 1992b).

The First Nucleus of Scientific Thought on Geothermal Heat

A depiction of how volcanic eruptions were seen by early prehistoric peoples in the Mediterranean area is in a painting from the Early Neolithic settlement of Çatal Hüyük in Western Anatolia (see Chapter 2 in this volume). Ancient myths and legends illustrate indirectly the desire of protohistoric Mediterranean peoples to find a cause and effect relationship for manifestations of the Earth's heat. Such elements formed a foundation for later scientific study of geothermal phenomena.

The first direct description of events caused by the Earth's heat dates to the 6th century B.C., when Egyptian priests gave Solon a detailed oral account of a natural catastrophe that had occurred about a thousand years earlier. The account, handed down orally by Egyptian priests from generation to generation, most likely referred to the huge volcanic explosion on Thera around 1630 B.C. (Fytikas et al., 1999).

After the 6th century B.C., scientific information about geothermal phenomena is found in the works of numerous Greek and Latin thinkers. The main authors, their works, and the geothermal aspects treated in them are summarized in the table. The geothermal phenomena described in some of these works are often accompanied by speculation on their causes, such as the existence of a heat source (the "internal fire" of the Earth). Other works deal with the classification of spring waters on the basis of temperature and chemical characteristics, the encrusting properties of water, the stratification of CO_2 as a function of density, some underground chemical reactions, and the surface characteristics of geothermal areas. The need to explain geothermal phenomena concerned Greek and Latin thinkers, who, of course, developed their interpretation using the logic of the philosophical theories of their time. Together, these concepts form the first scientific body of thought on geothermal energy, knowledge that gradually evolved and enriched itself with time, remaining an indispensable basis for understanding the development of scientific approaches to this matter. For this reason, these authors should be considered the historical fathers of geothermal science.

Summary and Concluding Remarks

The relationship of humans and the Earth's energy in the Mediterranean has roots in the night of time, in a moment of the Paleolithic that cannot be specified but which dates back many tens of thousands, perhaps even hundreds of thousands, of years. From that moment on, this relationship must have slowly matured over that long, long period called the *year zero* of geothermics (Cataldi, 1992). During this period, people's contact with the Earth's heat was probably confined to a few localities and limited to cooking and occasional thermal baths. Gradually, however, it included the use of geothermal by-products: obsidian to make stone tools; thermo-mineral muds for therapeutic applications, such as drying sores and hemostasis; and hydrothermal compounds for pigments, such as cinnabar, iron oxides, and sulfur.

Toward the end of the *year zero*, at the start of the Metal Age about 5,000 years ago, all of these uses began to take root in other geothermal localities on the Mediterranean mainland and the major volcanic islands. Thus, indigenous centers formed naturally, harnessing natural heat and its by-products, but they remained isolated for many centuries until systematic contacts began among distant populations and trade developed in a number of raw materials, including obsidian and hydrothermal compounds such as alum, borates, and kaolin. At first, these materials were bartered and the market was limited. A few production centers existed in some places, the most important of which were probably located in Western Anatolia.

In historical times, 2,000-1,500 years before the Christian era, the market for hydrothermal products gradually expanded to the Mediterranean coastal areas under the influence of Cretan and Phoenician navigators. As a result, the popularity of hydrothermal compounds increased, and they were used systematically for making pottery and pigments, coloring glass, preparing ointments and salves, and tanning hides. Near the end of the 2nd millennium B.C., these uses began to proliferate, taking root in the geothermal and nongeothermal areas of the Mediterranean coast.

Starting around the 7th century B.C., thanks chiefly to the Etruscans, methods for extracting and processing hydrothermal compounds improved remarkably, resulting in wide commercialization throughout the Mediterranean. An important industry and a true international market based on geothermal by-products formed between the 6th and the 3rd centuries B.C. This market boomed between the 1st century B.C. and the 2nd century

A.D., spreading to all territories under Roman rule and growing richer still at the height of the Roman Empire when new mines opened in Italy and other Mediterranean geothermal localities. During the imperial period, systematic use was made of all hydrothermal compounds and of many other geothermal by-products, such as travertine, bentonite, pozzolan, perlite, lavas, pyroclastics, and tuffs, which were important in the building industry (Cataldi and Burgassi, 1992b). Nearly all geothermal by-products held great importance in Antiquity.

At the same time, the practice of thermal balneology grew gradually in the early and ancient Mediterranean civilizations. Even before the Roman period, thermal bathing was popular in Western Anatolia, Eastern and Southern Greece, and peninsular Italy (especially in the Phlegraean Fields and Etruria). The boom in thermal balneology between the 1st century B.C. and the early 4th century A.D. came from the Romans, who built countless spas in localities with and without hot springs. Thermal bathing was so popular in the imperial period that it became a daily custom for several million people of every social class, ethnic group, and gender. The thermae became complete health service centers, places for meetings, debates, entertainment, reading, business dealings, sports, and cultural events—all catalysts for many social activities. Considering that each ancient Mediterranean people made its own contribution to thermal bathing, its development in Antiquity must be considered a common sociocultural heritage of them all (Cataldi and Burgassi, 1992b).

In addition, geothermal manifestations in Antiquity also influenced the formation of cults to worship the protective divinities of hot waters and the creation of many myths and legends. Many Greek and Latin thinkers sought to explain geothermal events (Cataldi, 1993b), resulting in the formation of the first nucleus of systematic ideas and theories on the genesis of the Earth's heat and related phenomena.

From at least the Upper Neolithic until the end of the Roman Empire, the development of geothermal energy was an important facet of Mediterranean civilization.

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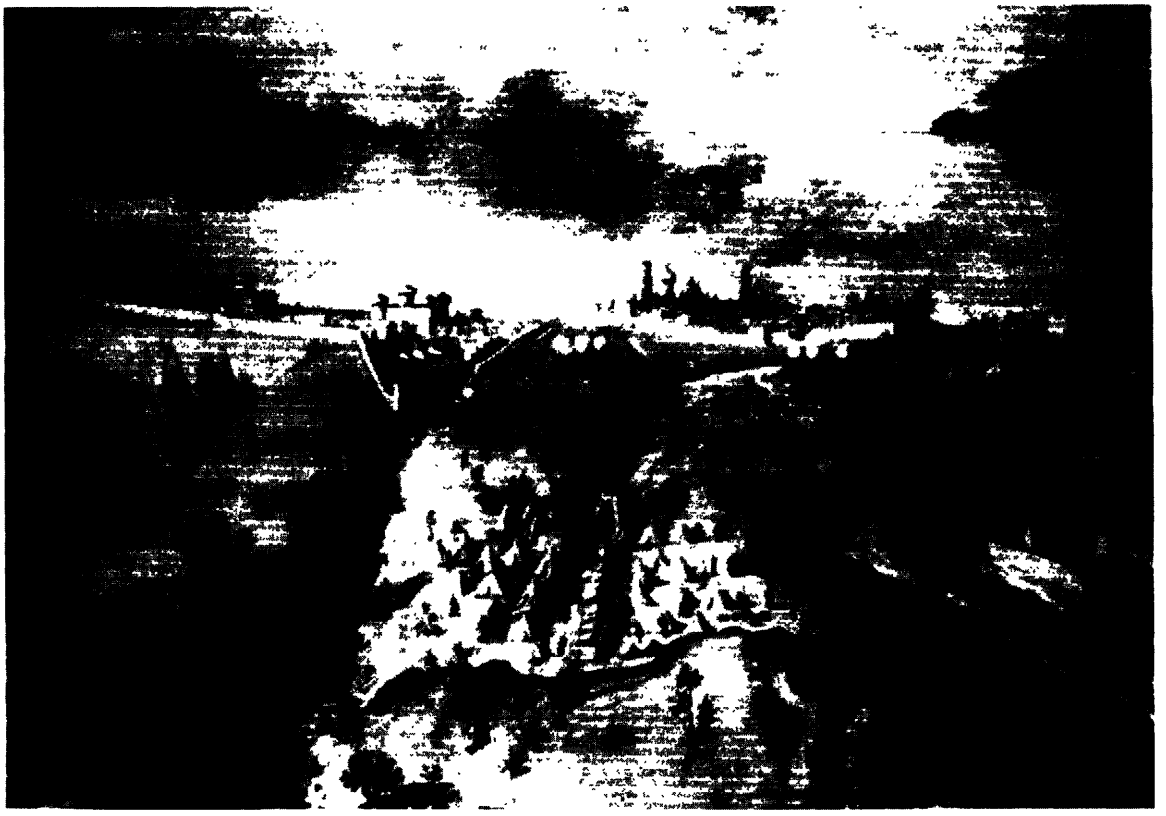

Portion of the G. Vasari wall painting in the Clement VII (Giulio de'Medici) salon of the Palazzo Vecchio in Florence (c. 1560). The painting depicts the siege of Volterra by the Florentine army during the "War of the *Allumiere*" (1470-1472) between the towns of Volterra and Florence, which were fighting for possession of the Boraciferous region in Southern Tuscany. This region held rich deposits of hydrothermal minerals, locally called *allumiere*, very important for the Italian wool processing industry in the Late Middle Ages. *Courtesy of the Commune of Florence, Department of the Culture-Conservancy of Museums*