Modern Approaches in Solid Earth Sciences

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M. Bahadır Şahin *Editors*

# Mineral Resources of Turkey

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*We dedicate this book to Mustafa Kemal ATATÜRK, a great leader and the founder of Republic of Turkey.*

*A visit by Mustafa Kemal Atatürk (4th from left; grey jacket) to the Ergani Copper Mine (Elazığ-Türkiye) in 1937.*

*In the early years of the Turkish republic, Mustafa Kemal Atatürk, who understood the importance of mining, stated that establishment and development of a national industry strictly depended on mineral* *exploration and exploitation. The development of Turkish mining in this period is related to his efforts and the following of his policies. Within these policies, in 1933 two independent institutions were established, namely: "Petroleum Exploration and Operation" and "Gold Exploration and Operations Administration", under the Ministry of Economy in order to obtain and evaluate the resources of the young Republic of Turkey. Then, for more comprehensive and systematic investigation of the mineralization and in order to reveal the geological structure of the country, on 22 June 1935, under the instruction of Atatürk, the Mineral Research and Exploration Institute (MTA) was established to work with modern scientific methods.*

*The MTA, has experienced many national and international research projects and plays a role in the discovery of several mineral deposits currently being operated, and is also continuing to work under the name of General Directorate of Mineral Research and Exploration as an international geological survey operating in all areas of geosciences. The mining operations in Turkey, built on a foundation laid by Atatürk in almost a century before, has made significant progress and is achieving a high economic potential.*

*Atatürk selected and sent five students for learning mining to Bergakademi in Freiberg (Germany) during late 1930s. These students returned to Turkey after graduation and began to work at MTA and established the Mining Department at Istanbul Technical University.*

***Mustafa Kemal Atatürk (1881–1938): Founder and first President of the Turkish Republic***

*"It is impossible to come across with leaders in every country, who change the course of history, impress a seal on it or stop grave dangers. Atatürk is a genius that the World History has rarely witnessed. After World War I, in a time that no defeated nation set up resistance, he defied the world with the civilians and the soldiers."*
*-Prof. Dr. İlber ORTAYLI- (Gazi Mustafa Kemal Atatürk Back cover)*

# Preface

Today's Turkey occupies an important geopolitical location: the junction of Europe and Asia. Geographically, Turkey is composed of Anatolia (the so-called Asia Minor) and Thrace, an eastern section of Europe. The Sea of Marmara, which is an inland sea, together with the Dardanelles and the Bosphorus separates Anatolia from Thrace and, at the same time, Asia from Europe. Being surrounded on three sides – by the Mediterranean Sea to the south, the Aegean Sea to the west and the Black Sea to the north – Turkey offers the characteristics of a peninsula.

Turkey is one of the charter members of the Organisation for Economic Co-operation and Development (OECD) and G20 (the Group of 20) where the world's leading industrialised and developing countries meet to gather and discuss international affairs. The Customs Union Agreement between Turkey and the European Union plays a significant role in the development of the foreign trade capability of the country. Construction, automotive, electronics, banking, textiles, petrochemistry, food, mining, agriculture and machinery industries are currently the leading sectors of Turkey's economy.

Turkey falls within the top five countries in the world in the production of glass, ceramic and cement industries, all of which are based on the mining sector. The most important items produced from the mining industry include metallic ores, such as chromite, copper, lead, zinc, iron, gold and industrial raw materials, such as borate, trona, feldspar, quartz sand, pumice, perlite, magnesite and marble. Nearly 60 different ore minerals are mined in Turkey today. This variety is a natural consequence of the complex geological structure of the country.

The Anatolian Peninsula is one of the areas where some of the oldest settled communities have been found. Many settlements were scattered across the Anatolian landscape dating from the Neolithic period onwards. The entity of several nations and states, so-called Anatolian civilisations, is noticeable. The early inhabitants first quarried rocks, such as limestone, flint and obsidian, for building materials and tools. Later they learned to transform ores into metals, such as lead, silver, copper and iron. They shaped simple clays into elegant pottery forms and baked them hard in hot furnaces. Gemstones also attracted the interest of the Anatolian civilisations, and they were mined and traded far and wide. Over the long stretches of time, sophisticated material cultures emerged thanks to Turkey's earth and stones.

When we consider the antiquity of mining and quarrying in Turkey, it can be said to go back as far as 12000 Before Present (BP). The site of Göbekli Tepe (Şanlıurfa) is one of the oldest known constructions in Turkey. It is there where huge limestone blocks, weighing as much as 50 tonnes, were quarried to build impressive pillars decorated with carved reliefs. The structures at Göbekli Tepe have been described as a sanctuary of worship (Schmidt 2010) and are one of the most impressive examples of stonework from Turkey's remote past. Likewise impressive is the excavation of the Neolithic town Çatalhöyük (Konya) where archaeologists revealed one of the finest examples of settled society dating back to 8400 years BP. The stoneworkers at Çatalhöyük were very busy craftsmen. The excavations yielded a broad range of artefacts made of natural materials, such as obsidian mirrors, apatite and carnelian stone beads numbering in the thousands, grinding stones of basalt and andesite, decorative flint knives and carved limestone figurines (Birch et al. 2013). The residents of Çatalhöyük took advantage of local natural materials. Their source of obsidian came from Hasandağı, one of the most important volcanoes in central Anatolia, and they exploited the salt from Ilıcapınar, located near the Tuz Gölü (Salt Lake) Basin.

Early artisans did not restrict themselves to just stone. They explored how materials could be changed and altered. Artefacts of native copper have been found at Çatalhöyük, Çayönü Tepesi (Kaptan 1990; Mellaart 1966) and elsewhere in Turkey, bearing witness that artisans experimented with other materials. It has been suggested that early copper originated from the massive copper deposit at Ergani Maden (Kaptan 1990; Çambel and Braidwood 1970), first in native copper form and later smelted from malachite ores. These early experiments with copper and copper ore ultimately led to alloying with tin and arsenic. This technological development ushered in a period we refer to as the Bronze Age, ranging from ca. 5000 to 3200 BP.

The use of tin in Anatolia was once a mystery, as there was limited evidence where Anatolian cultures obtained this metal. However, thanks to the work of Aslihan Yener and the support from MTA, an ancient tin mine was located at Kestel near Çamardı, Niğde, along with a processing site and a village, Göltepe. Subsequently, two other ancient tin mining operations, at Hisarcik and Kıranardı, were discovered north of Çamardı (Yener 1989, 2000, 2009; Yener and Özbal 1987; Ünsal 2009; Yener et al. 2015). The discovery of these sites, together with tablets from Kültepe mentioning tin imports, set the stage for new ideas regarding the supply of tin metal in the Bronze Age.

The story of iron in Turkey is unique. Iron was first known in the Early Bronze Age (5000-4000 BP), turning up first at Alaca Hüyük. Analyses have shown that a number of iron artefacts from a tomb are meteoritic iron in origin. However, an iron dagger with a gold handle from a tomb at Alaca Hüyük was shown to be non-meteoritic (now in the Anatolian Civilizations Museum, Ankara). This provides good evidence that at least some terrestrial iron was produced in the Early Bronze Age Period (ca. 4400 BP) (Waldbaum 1978). Iron production must have been small and a carefully guarded secret known only to a select group of Anatolian metallurgists. In the course of time, "Hittite iron" became known throughout the ancient Near East, and many sovereigns sought to have a sword or weapon made from it.

It has been suggested that the exact transition from a bronze industry to an iron technology in Anatolia took place at ca. 3200 BP. Many cultures in Turkey may have greatly contributed to the technology of iron working, particularly the Phrygian and Urartu civilisations (Özdemir 2007), but bronze production continued well into the Classic Period.

Precious metals, such a silver and gold, have been produced in Anatolia since the beginning of ore mining. Gold was known and plentiful in the Bronze Age and continued to be produced in various parts of Turkey (Sagona and Zimansky 2009: 201). The Lydian Kingdom (900–750 BP) that reigned in western Anatolia was an important metallurgical and industrial centre where gold was produced from placers in the Pactolus River (Sart Creek) (Kaptan 1990; Sükun 1943). The Lydians are considered the first people to produce coinage (Sagona and Zimansky 2009: 364).

Thanks to the Anatolian geographer, Strabon, who lived in the first century of present era, we learn about many of the mining activities that took place during his time. His major work (Strabon 2012), *Geographica*, provides valuable information on mining yields and insights into mining techniques. Mining operations continued at many sites over long periods. In fact, many of the mining operations today were exploited in antiquity, such as the copper mine at Ergani being.

The geology of Turkey is complex involving the collision of continents, closure of oceans, widespread volcanism and plutonic activity. The Turkish landmass was subject to many types of terrains from Precambrian to more recent times, including inland seas and enormous lacustrine basins. At one point in the geological past, Turkey was located between two supercontinents, Gondwana and Laurasia, which were made up of several continental fragments. The separation of these continental fragments from the mainland by rifting or their amalgamation eventually resulted in the landmass of Turkey. The result was a landform assembled from a few continental and oceanic crust pieces with different geological features (Göncüoğlu 2010). According to Okay (2008), Turkey is divided into three tectonic units: Pontides, Anatolide-Tauride and Arabian platform (Ketin 1966). These units, which were earlier surrounded by the oceans, are presently separated by sutures that define tectonic lines or zones along the demised oceans.

The complex geotectonic setting of Turkey has given rise to the occurrence of several ore types. Of the 90 ore types listed in *Mineral Commodity Summaries* (MCS 2017) published by USGS, 68 are present in Turkey, most of which are currently exploited and traded.

Based on the Metallogeny Map of Turkey prepared by Engin et al. (2000), there are several lithological and structurally controlled metallogenic provinces in Turkey with varying ages and genetic characteristics (Engin 2002). Chromite, magnesite, olivine, asbestos and copper are found in ophiolites belts; copper, copper-lead, copper-lead-zinc and manganese occur in volcano-sedimentary basins associated with felsic volcanism; copper, copper-lead-iron, porphyry copper, skarn-type iron, hydrothermal copper-lead-zinc, wolfram, lead-zinc, gold, antimony, iron-wolfram-molybdenite, iron, fluorite, copper-lead-zinc, mercury, mercury-antimony, barite and iron-phosphate are found in basins associated with felsic-intermediate magmatism; manganese, iron, red bed-type iron, copper, phosphate, strata-bound barite-lead and zinc-lead occur in sedimentary ore basins; borate, trona, salt (halite), gypsum and celestite are found in evaporitic basins and bauxitic iron, bauxite, nickel, gold deposits and occurrences are recognised in laterite and placers (Engin 2002). Pumice, perlite and zeolite deposits as the products of widespread volcanism in Turkey carry economic value. As a result of a complex formation and lithological diversity, Turkey provides a significant potential of natural stone and marble for future mining endeavours.

In the first chapter of this book, we have selected and discussed several mined or quarried materials. Chapter 2 reviews the geological evolution of Turkey that relates to the formation of ore deposits. Chapter 3 deals with ophiolites and chromitite deposits as important production and export items in Turkey's mining industry.

Precious metals such as gold and silver occurring in epithermal systems are the subject of Chap. 4 with their genetic properties, while Chap. 5 provides a general view of the iron deposits of Turkey. In Chap. 6, manganese deposits in Turkey have been categorised into four basic groups based on host rock type, geological-tectonic setting and formation processes. In Chap. 7, skarns and skarn-type deposits in Turkey take regional geological properties into account and classify them in provincial zones. Chapter 8 takes up the topic of porphyry deposits with special emphasis on geological evolution and geological setting.

Volcanogenic massive sulphide (VMS) deposits in Turkey are the subject of Chap. 9 where the mining history of Turkey is summarised. In Chap. 10, carbonate-hosted lead-zinc deposits are discussed with insights regarding their location.

Turkey's borate deposits, containing nearly two-thirds of the world's reserves, are discussed in Chap. 11. Chapter 12 explores trona deposits, another type of evaporitic mineral.

Chapter 13 summarises lateritic nickel deposits with an emphasis on their geology and economic potential. Radioactive elements, such as uranium and thorium and rare earth elements, are outlined in Chap. 14, and bauxite deposits of Turkey are the topic of Chap. 15. Finally, Chap. 16 includes olivine and magnesite mineralisation.

The purpose of the current publication is to provide a cogent overview of Turkey's mineral resources with special emphasis on geological characteristics, genetic features and economic indicators of pertinent deposits. To ensure accuracy, these studies have been written by professionals and academicians who deal intimately with mineral resources in Turkey. It is our hope that we have succeeded in our goal.

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# Contents

## Chapter 1
# Comments on the Antiquity of Mining Rocks and Minerals

**Prentiss S. de Jesus**

**Abstract** The history of mining can be written from many perspectives: mining technology, labour inputs, economic impact or materials exploitation. Hard materials were needed to advance the material culture of civilisation, and this need drove the mining and quarrying activities of antiquity. This article discusses a selected number of materials that were commonly mined or quarried in the ancient Near East. The author seeks to illustrate the value of hard rock materials, their variety and exploitation requirements. He also notes the lack of information available on human groups, communities, and the social networks involved in exploration, quarrying and mining. This article is an appeal for more research on this topic.

## 1.1 Introduction

As we walk along a gravel road or drive our car on a paved highway, we may not give much thought to their construction, nor the events that led up to it. The common stones and materials that make up roadways have enabled civilisation to thrive as we know it. Our association with stone, rocks and earthen materials began early in the history of humankind and has not ceased to the present day. We are still exploring the earth for useful materials, stones of all kinds for our buildings, our bridges and walkways, stones as grinding tools, vessels, beads, amulets and jewellery. When ground, pulverised, heated or fashioned in some way rocks and minerals provide us with the products that our civilisation requires. In this sense, we have never left the Stone Age.

The history of stone materials is certainly a long one and nonetheless interesting from the point of view of humanity's on-going reliance on natural materials. Here I would just like to sketch out a few cases that illustrate our binding relationship with our planet Earth and the materials it provides. Human life is, and always has been, inextricably linked to natural resources. It can be said that we have been mining the

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**Fig. 1.1** Chopper from Olduvai Gorge, dated 1.8 Myrs. (Courtesy of Smithsonian Institution)

Earth since the ancestors of our species could walk. In fact, mining is probably the earliest of *Homo sapiens*' industries.

We know little how ancient humans prospected for raw materials. However, various kinds of stones and rocks show up in excavations, thereby giving us an idea of what materials were needed or coveted. Our dependency on natural materials began long before *Homo sapiens* emerged from Africa and spread across Europe and Asia. The early hominids, Australopithecines, were the first to adapt to multi-zone primate living, which exposed them to different environments (Picq 2013).[1] Their mobility gave them the opportunity to see and explore different terrains, observe surface materials and, perhaps have the opportunity to adopt stone tools. It is not totally certain that they did. On the other hand, it is the view of many anthropologists that *Homo habilis* was the first hominid to make and use stone tools (Rudgley 1999). The rounded volcanic basalt stones found in riverbeds and strewn across the African landscape would serve aptly as pounders for food extraction or as the defense against predators. Ultimately, *Homo habilis* devised a sharp edge on a stone was intentionally designed for cutting. One such example is represented here by the Olduvai chopper in Fig. 1.1, which shows a crude retouch to form a cutting edge. This simple tool suggests two things: (1) early hominids were including a larger portion of meat in their diets, thus requiring a chopping implement to cut through tough skin and break bones (Pfeiffer 1982); and (2) they were discriminatory in selecting a material that was locally available and best suited for making such a tool. While we cannot call this crude chopper a work of art, it was the beginning of early man's use of natural materials that would improve his life and better his chances of survival. In this way, *Homo habilis* may be labelled the first manipulators of the Earth's resources.

[1] It is acknowledged that Australopithecines have now been classed in at least five different categories (Picq 2013: 70–71). I use the general term Australopithecus to represent the whole group.

Early hominids did not formally distinguish the different categories of rocks as metamorphic, sedimentary or igneous. The origins of such rocks were surely ignored, and early tool makers simply exploited stones for their convenience and immediate use. It is logical that exposed extrusive rocks would attract the attention of early toolmakers. It is not surprising, then, that basaltic rocks were selected for their weight and robust forms and were used as hammers and pounders.

Stones may even have had an aesthetic value, as early hominids collected brightly coloured silica rocks that served as decorative ornaments, amulets or talismans. As early hominids modified things to make life and survival easier, they acquired a measure of independence far above other primates. From materials that were readily available, such as animal bones, antlers and sticks, early hominids fashioned different kinds of implements to be used in food preparation or wearing apparel. Social conditions also changed which gave them an advantage over competing species. Their social structure provided superiority by virtue of numbers, both in terms of safety and communal activities. The subsequent formation of clans led to the construction of crude communal structures, such as windbreakers and walls in protection against predators, with some parts being made of stones. Along with this social organisation came an increased use of stone as a practical material and a greater need for stone tools. The type of tool, the material used, and the variations of its use represented technical choices that translate into cultural traditions (Pfeiffer 1973: 91–2). These traditions gradually became distinct from other clans. The resulting cultural repertoire of early hominids demonstrated their increased exploitation of raw materials, if not ownership of their physical environment. They may even have become protective of their territory because of the resources that it contained.

Rocks with cryptocrystalline or glass structure, like chalcedony and obsidian, break with a conchoidal fracture and can be flaked, chipped, and made into points and keen cutting edges. Gradually, tools became more distinguishable, individualised and refined, but the development of better and specialised tools at this time was still a slow process.

Even with the advent of *Homo sapiens* about 300,000 years ago (Hublin et al. 2017) the stone tools had shown only a marginal improvement (Pfeiffer 1973). Eventually, *Homo sapiens* became the dominant species and pushed its way into Europe and beyond. By 40,000 B.P humans had developed a range of craft-making skills that included many fine points and blades. Prehistorians see this period as a cultural explosion of artistic and social advances. With refined tools came the use of fire, cave art and evolved social roles. Communal life gave rise to hierarchy and ritual practices. The wonderfully expressive figurine Venus[2]of Willendorf (Fig. 1.2) reflects certain cultural elements that prehistorians have long pondered[2]. The figurine has been labelled a fertility goddess or, more personably, a self-portrait. Despite its intended use, certain details of the figurine reveal something about women of the Upper Paleolithic period. The pleated hair indicates that even at this remote time in the past women took the vain practice of presenting themselves in a beautified fashion. This may represent just one of the many hairstyles worn by women. The finding

[2]Figure 1.2, Image #326474, courtesy of the American Museum of Natural History Library.

**Fig. 1.2** Venus of Willendorf. Oolitic limestone figure dating to 28,000 B.P

of beads in the Upper Paleolithic may suggest that decorative items were worn by women as well as men, which also suggests a growing self-awareness amongst humans. What is relevant to this discussion here is the use of oolitic limestone to make the Venus figurine and the dexterity required to represent the details. A *Homo sapiens* craftsman quarried this piece and carved it with great care, and importantly, the refined skill to create stonework of this quality would be passed on to succeeding generations. Stone working had become a cultural tradition.

When we look at the development of civilisation in the ancient Near East we normally use Mesopotamia (now Iraq) as our measuring stick, as that is where the first urbanized settlements developed. With that development came the exploitation of materials to sustain the economies, crafts and livelihoods of settlements. Thanks to the comprehensive work by P.R.S. Moorey on Mesopotamian materials we have a sense of where many materials came from within the borders of ancient Mesopotamia as well as from abroad. The documentation and information on materials used in ancient Turkey, on the other hand, are still scattered throughout the archaeological literature. At the moment we are only able to make sporadic references to natural materials and resources. Another problem we encounter is that rocks and minerals are not systematically and precisely identified in archaeological reports. The term marble is often loosely used and could be other substances like alabaster, even limestone. Chlorite and steatite are frequently lumped together because of their similar appearance. Some stonework is simply designated by its colour (i.e. “ black stone”), and we have no idea from what kind of mineral the artefact is made. These everyday challenges should be viewed as an incentive as well as an appeal to archaeologists working in Turkey to begin compiling accurate data and information on natural materials.

Fig. 1.3 Obsidian blades from Çatal Höyük dated to ca. 6200 B.C

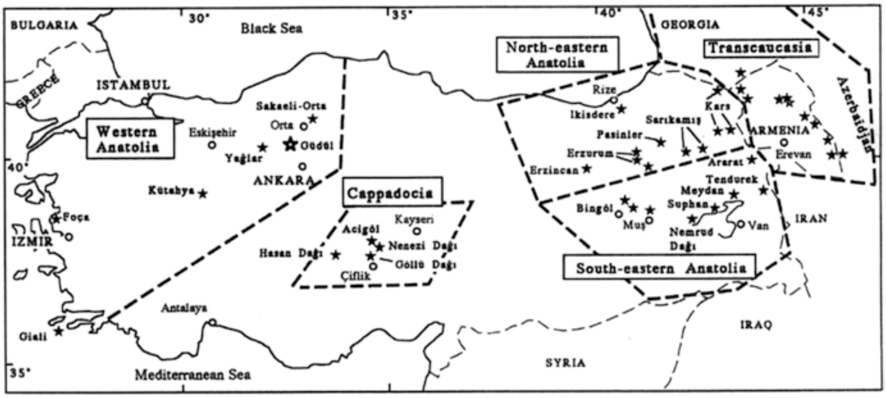


Fig. 1.4 Map showing Anatolian obsidian sources. (Courtesy C. Chataigne)

Turkey played a central role in the supply of materials, not only for its own indigenous cultures, but also for trading with neighbouring regions. Some materials traded throughout the Near East are found only in Turkey or on its borders. Take, for example, obsidian whose deposits at Hasan Dağı, and Acıgöl (Figs. 1.3 and 1.4) were exploited as early as the Neolithic (ca. 6500 B.C.). Because of its ability to be made into refined tools obsidian was traded as far away as the Arabian Peninsula, more than 1000 km to the south.

It is not my intent in this article to trace the historical use of every material found in archaeological contexts, rather raise some points for reflection and hopefully encourage subsequent research. But let us just briefly look at the extent of the rock and mineral industry in antiquity. The following materials are known to have been found in archaeological excavations (Nazaroff et al. 2013; Moorey 1999; Lucas and Harris 1962; Nicholson and Shaw 2009; Rapp and Hill 1998; Rosenfeld 1965).

| | | |
|---|---|---|
| Alabaster | Granite | Pumice |
| Amber | Gypsum | Rhyolite |
| Basalt | Jasper | Salt |
| Chalk | Limestone | Sandstone |
| Chert | Marble | Schist |
| Chlorite | Natron | Serpentine |
| Diorite | Obsidian | Steatite |
| Flint | Onyx | Talc |
| Gabbro | Porphyry rock | Trachyte |

Among the ornamental stones, we find

| | | |
|---|---|---|
| Agate | Chrysophrase | Quartz |
| Amethyst | Haematite | Rock crystal |
| Augite | Jasper | Sphalerite |
| Carnelian | Lapis lazuli | Turquoise |
| Chalcedony | Pyrites | |

One of the goals of geology is to find materials that are economically viable for the support of an economy. We are indebted to hard rocks and materials, for without them we would be a struggling agricultural society. And even an agricultural economy is reliant on hard materials of some kind. Flint, and the above-mentioned obsidian were used in early agrarian societies for cutting tools in the harvest of wheat and grains. Basalt slabs and rubbing stones were used for grinding grains into flour. Soft materials were made into useful hard materials. Clays were used to make sickles, bricks, hearths, pottery, and one of the most valuable items in history: clay tablets (e.g. Moorey 1999). That said, let us now look at a few examples of how ancient societies used natural materials.

## 1.2 Agate

Agate is a variegated cryptocrystalline variety of chalcedony and can be found in vugs (fractures) in volcanic rocks. It is generally classed and often found with other cryptocrystalline varieties of quartz such as onyx; hence, it is not surprising then that we find both agates and onyx in archaeological excavations. There is little distinction between the two. Agate can contain patches of banding colours, varying from red, grey to brown. When the colours are in black and white flat bands, it is classed as onyx (or sardonyx if there are white and reddish brown bands).

The earliest related examples of agate from archaeological excavations come from Iraq where chalcedony is reported at Yarim Tepe I. They date to the mid-sixth millennium B.C. and were certainly imported, as there are no known deposits in the Mesopotamian basin of chalcedony or any of its related minerals (agate, sardonyx). Agate is native to Egypt, where deposits and quarrying have been located in the eastern desert. Agate pebbles and beads have been found in Predynastic graves (i.e. before 3000 B.C.; Nicholson and Shaw 2009; Lucas 1962; Moorey 1999 for Mesopotamia), and the in Mesopotamian river basin agates turn up in graves as a popular gemstone in the third millennium B.C. Agate and chalcedony became very popular from the Neo-Assyrian period onward (ca. seventh century B.C.). They were readily available in later Classical times and used extensively in jewellery (Caley and Richards 1956). The Classical Greek botanist and philosopher Theophrastus (b. 371 B.C.) mentions agates in his treatise on stones. At that time appearance was the criteria for classifying stones, and it is possible that any attractive stone with streaks or markings against a contrasting background could be grouped under the same name (Caley and Richards 1956: 128–9). What is significant is the use of this category of stone over such a long period which entailed a fair amount of committed labour in its production and trade.

Agates have not been reported extensively in Turkey, though there is one occurrence in a burial at Kültepe Level II. In view of the Mesopotamian influence at the site at this time, it is possible that this piece was imported and not of Anatolian origin (Joukowsky 1996). Agates have one characteristic that stands out: the crafted pieces were usually small, such as amulets, beads, seals and decorative items. This may suggest something about its high intrinsic value. According to Moorey (1999) agates, along with chalcedonies, may originate from sources to the east in Iran or India. The distant source of this material should not surprise us. It has been noted by archaeologists and anthropologists that the more valuable the material, the farther it can be traded (Renfrew 1977). This is also reflected in the early trade of lapis lazuli, chlorite stone, obsidian, jade, cornelian, sea shells and processed materials such as tin (see also Moorey1999 for further examples).

## 1.3 Obsidian

Obsidian is a volcanic glass that has a very homogeneous structure. Being non-crystalline, its fracture is conchoidal and can be flaked into elegant forms, even bowls. It has a hardness of almost seven which means that it is harder than most organic materials. It is also harder than some rocks, such as steatite and marble, and may have been used to carve softer stones (Rosenfeld 1965). The exploitation of obsidian began very early in prehistory before established agricultural practices demanded keen-cutting harvesting tools. Obsidian has been found as early as 7500 B.C. at the site of Mureybat in Syria and continues through the Ubaid Period (ca. 5500–4000 B.C.) at many sites in Northern Mesopotamia (Wright 1969). Some of the finest Anatolian examples of worked obsidian come from Neolithic Çatal Höyük (Fig. 1.3). The spread of obsidian over a wide area of the Near East attests to its desirability as a material that could be formed into different, even elegant, shapes.

Analyses been carried out to identify the sources of obsidian artifacts found in excavations, and two general regions are considered key sources. One is in Central Turkey that comprises three volcanic areas: Göllü Dağ, Nenezi Dağ, Hasan Dağ, and Erciyes Dağ (Balkan-Atli et al. 1999; Rapp and Hill 1998; Gourgaud et al. 1998). The other is in Lake Van area and comprises a site near the lake itself, and another flow near Bayezid lies 310 km northeast of the lake. There are other flows nearer to Lake Urmia in Iran (Moorey 1999; Wright 1969). Other studies have identified outflows in northeastern and western Anatolia (see Fig. 1.4).

## 1.4 Albaster

This stone is a fine-grained compact form of gypsum and has been commonly found in archaeological excavations. It is often translucent and lends itself to being worked into vessels, figures, and statuary. Beads of alabaster were found at Yarim Tepe in northern Iraq dating to the mid-sixth millennium B.C. as well as at Jarmo located in northeastern Iraq in the foothills of the Zagros. For Yarim Tepe it is reported that "fragments of ten polished marble or alabaster bowls and jars and seven palettes" were recovered (Moorey 1999), here blurring the clarification between marble and alabaster. The Jarmo finds are outlined in Mellaart (1973: 80) who suggests that the source material of the latter may have come from the boulders gathered from the wadi below the site or from a ridge nearby. We can conclude from this synopsis that stonework was firmly established as a craft by the time alabaster was first used, and it was merely added to the stone craftsman's repertoire. The ease of working with this stone ensured its use over time. One has to mention here one of the most famous Mesopotamian documents of alabaster, the tall Uruk vase from a treasure hoard dated to ca. 3000 B.C. This vase is discussed in many books and documents because of its important ritual scenes carved on six registers (Parrot 1960; Oates and Oates 1976; Hansen (2003). The value of the alabaster would seem to reflect the significance of the ritual scenes of homage to the goddess Ishtar. Alabaster was frequently used for goddess figurines, such as those from Kültepe dating to Early Bronze Age II (4800–4400 B.P.; Bilgi 2014).

Moorey (1999) correctly points out that alabaster is often misreported in the archaeological literature and has been variously described as calcite, gypsum, marble and limestone. As for sources, Moorey quotes Layard who states that alabaster (called "Mosul marble") was available in northern Iraq to the east and in those parts of the Tigris and the Euphrates that emerge out of the Taurus in Turkey (Moorey 1999). Turkish studies show a major deposit at Gaziantep west of the Euphrates (MTA 1966).

## 1.5 Chlorite

Chlorites belong to a mineral group closely linked to micas. To the touch, they are pasty or soapy and often appear greenish. Their colour reflects their chemical composition which includes aluminium, iron magnesium, silica and magnesium. Chlorites are derived from hydrothermal alteration of silicate minerals, and their resulting chemical composition varies depending on the original mineral from which they are derived (Rosenfeld 1965). While they are similar chemically, chlorites are often confused with massive steatite because of their colour and softness. The softness of chlorites lends itself to carving, hence its use in the past for crafted items, particularly bowls.

One of the earliest attempts to sketch out the mines-to-market process of chlorite as a resource material was carried out a number of years ago in Iran by Philip Kohl (Kohl et al. 1978). He documented the extraction points, manufacture and trade in chlorite, used for luxury items, primarily carved stone bowls but also cylinder seals and other small artefacts. He initiated his study at Tepe Yahya, Iran where carving workshops were uncovered dating to 2600–2500 B.C. He identified the sources of the stone in the mountains north and west of the Soghun Valley in the southern Zagros Mountains. This research confirmed that the settlement of Tepe Yahya relied heavily on its crafted bowls and their export primarily to Mesopotamian sites in the west. Kohl (1978) tracks the export of both finished and raw cut bowls using different trade routes. Other works that have contributed to the documentation on chlorite stonework and trade can be found in Lamberg-Karlovsky (1988), Potts (1989), Aruz (2003), Potts et al. (2001) and Kohl (2001).[3] While scholars have not always identified very precisely the specific material of stonework, Kohl et al. (1978) confidently identifies the carved bowls from Tepe Yahya as chlorite.

The trade in stone bowls has aroused much attention both as an item of trade and as a material that linked different parts of the Near East. The irregular use and appearance of stone vessels over time starting in the middle of the fourth millennium B.C indicate that the supply of the basic material or finished products fluctuated for reasons we do not know (Moorey 1999). Perhaps the quarrying operations encountered difficulties involving labour availability or political control. Potts (1989) argues that the fluctuation of supply was linked not to any trade or production-related factors, but the stone bowls found in southern Mesopotamian sites were actually booty from Elam and elsewhere.

Whatever reasons governed the supply of chlorite bowls for parts of the ancient Near East, they were always highly valued. We are told that large numbers were given as offerings to gods (Potts 1989).

[3] Unfortunately I was not able to consult the latter publication for the current study.

## 1.6 Gypsum and Lime Plaster

Craftsmen of antiquity were more interested in what gypsum could be turned into, namely plaster, and not so much its natural form. Gypsum is a relatively common mineral and has a wide distribution in Turkey as well as elsewhere. One typical gypsum deposit is located at Sivas (Günay 2002). In its natural state, it is a hydrous calcium sulphate: $CaSO_{4}{\cdot}2H_2O$. Gypsum can be crystalline and monoclinic in form, but it also exists as a rock in which case it is granular, massive or fibrous (Rosenfeld 1965). When heated to a temperature of 100–200 °C gypsum undergoes a partial dehydration to form what we commonly call plaster of Paris. This is a somewhat unstable state, for if we add water back to the dehydrated substance rehydration occurs, and the material reverts back to gypsum and reacquires it original hardness (Blackman 1982; Gourdin and Kingery 1975). Because of its sensitivity to humidity, gypsum plaster does not store well in the open air.

Lime, a calcium carbonate $CaCO_3$, was also used as a source of plaster. Like gypsum, lime can be converted to plaster by dehydration of limestone, but for calcium carbonate to become lime it must reach a temperature of approximately 900 °C, and this temperature must be maintained for several hours (Blackman 1982). The resulting calcium oxide is also called *quicklime*. When quicklime is mixed with water (i.e. slaked) it becomes slaked lime. It can then be allowed to set and dry hard and become lime again due to the evaporation of the water. Lime plaster is not particularly strong and is often combined with sand, thereby converting it to a kind of mortar. Other fibrous materials can also be used in this way, such as chaff and straw (Rosenfeld 1965).

It is not a simple matter to distinguish between gypsum plaster and lime plaster. The simple test of fizzing acid with limestone that does not occur with gypsum is not conclusive proof. Gourdin and Kingery (1975) pointed out that many gypsum and limestone deposits are not pure and may be contaminated with one another. Moreover, clay inclusions may also be present that allows an acceptable cohesion between the two, resulting in an acceptable plaster. The two authors claim that the only way to determine the true composition of plaster is through precise microscopic examination as well as chemical analysis.

Indeed, both gypsum and lime plasters reveal a close relationship with clay. In the Neolithic period, liquid clay was smeared on the walls of dwellings inside and out to give them a smooth surface. Ultimately pleasing white plaster was discovered and developed into a more desirable substitute. The smooth white walls were an invitation for decoration as we find at Çatal Höyük (Figs. 1.5 and 1.6). What is important about the production of plaster in antiquity is that a heat treatment is required, resulting in the chemical transformation of material (Blackman (1982). Gourdin and Kingery (1975) cite Aşıklı Hüyük as the first occurrence of lime plaster in Anatolia in the 7000–6500 B.P. timeframe. They state that the burning of limestone at the high temperature of 750–850 °C required the use of kilns, a process that predated the introduction of fired ceramics. Based on this evidence, it can be safely argued that the development of plaster was the debut of true pyro technology. From

**Fig. 1.5** A painted plaster figure of a hunter-dancer from a shrine at Çatal Höyük level III dated to ca. 5750 B.C

**Fig. 1.6** Flint blade with bone handle from a Çatal Höyük burial in Level VI. Dated to ca. 5800 B.C

this point onwards, craftsmen explored other ways in which fire could transform materials. This curiosity ultimately led to the discovery of fired pottery and the smelting of metallic ores. It can hence be said that a simple pyrotechnological process gave rise to new materials and applications from which we benefit today.

## 1.7 First Mining and Quarrying Operations

Quarrying operations were equally demanding, and we do not know from where all the natural materials stated at the beginning of this chapter came from. There is much work to do to bring to light the natural sources of commonly used materials, such as flint, marble and steatite. Egypt is a notable exception, as we have documentation on where, for example, limestone quarries were located and insights into the time periods during which they were exploited. Lucas (1962) reports that limestone occurs in the hills bordering the Nile from south of Cairo to Esna and sporadically in other localities. The quarry at Tura may have been exploited as early as the fourth Dynasty. Nicholson and Shaw (2009: 40–42) write that limestone quarries have been identified in Wadi Zubeida, at Beni Hasan, Qau el-Kebir, and el-Sawayla. It has been well established that limestone was exploited extensively in Egypt in pre-Dynastic times (Teeter 2011), a testimony to its long stone working tradition. Storemyr et al. (2010: 39) state that there are more than 200 Egyptian quarries (not all limestone) identified as possible ancient quarrying sources.

**Fig. 1.7** Archaeologist Klaus Schmidt pictured here with one of the carved limestone pillars at Göbekli Tepe

In Anatola limestone quarrying has a history of its own. The limestone quarries at the pre-Neolithic site of Gölbekli Tepe are scattered around the temple site. Schmidt (2000) states that the quarries are "located all over the limestone plateaus around Göbekli Tepe". Quarrying was not just a question of chipping away blocks of desired material, but an ambitious undertaking that harnessed a massive workforce. The late Klaus Schmidt (2012) estimated that to move a block of limestone 7 m long from its quarry emplacement, it would take close to 700 labourers. What is impressive is that such a large number of workers could be gathered from dispersed groups or clans that had not yet settled in large communities. Despite the disparity of the population at that time, there was nevertheless an underlying cultural unity that served as a basis for a common calling. While we assume that the motivation was to establish a place of worship, it is nevertheless surprising that the religious beliefs were so coherent for such a rural and dispersed population.

The location of Göbekli Tepe must have been selected for a number of strategic reasons, one being the presence of a massive limestone outcrop that would serve as the basic raw material for the shrines' pillars (Fig. 1.7). The choice also suggests that the prospective pre-Neolithic worshippers of the shrines knew the kind of stone that would best work for them. This presupposes that they already had a competent knowledge of stone working. Evidence of their previous experience with quarrying and stone carving must, therefore, exist elsewhere. The significant number of workers involved in just the quarrying operations must have required the support of a whole community that included housing, feeding and possibly tool supply. It is this aspect of the mining and quarrying activities of the past that has not yet been adequately addressed. Apart from a few disparate references to mining and quarrying activities in the Near East, the characterization of the communities that supported them is largely absent in the archaeological literature. Surveys have been carried out in many different areas of Turkey with the intent of documenting mining and smelting sites, but their nature and their available resources did not allow them to extend their research and seek out mining communities. Hence, there are many loose ends. For a sampling of past surveys, see Ryan 1960; Yalçın et al. 2008; Kaptan 1991,

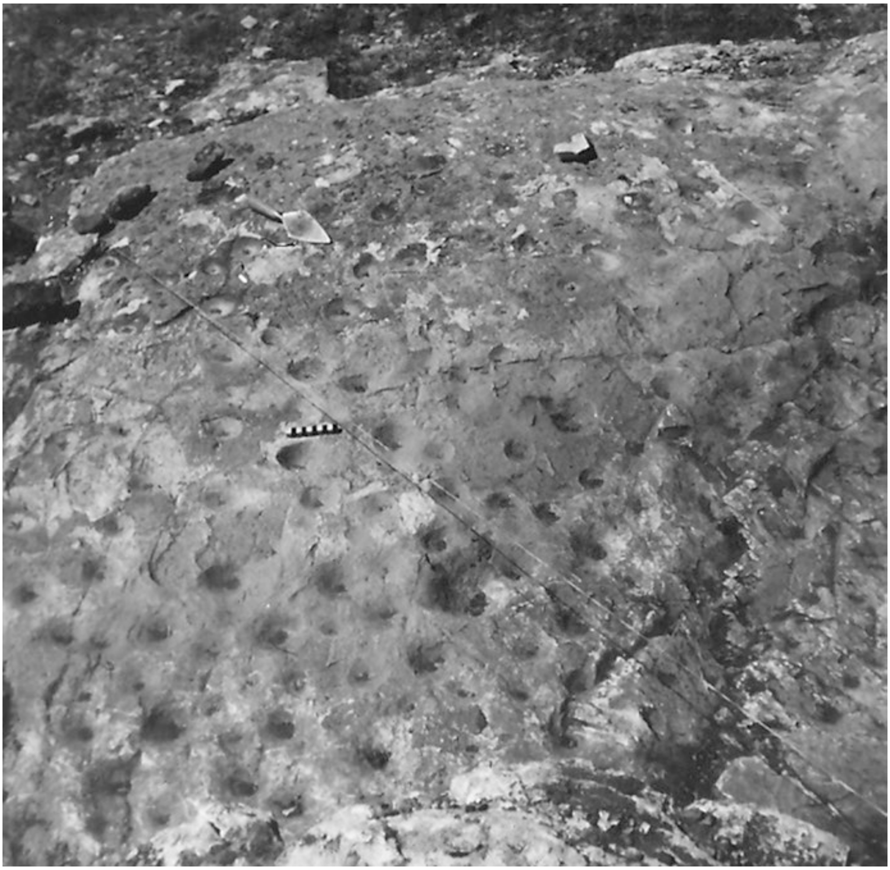

**Fig. 1.8** Marble outcrop showing numerous grinding sockets at Kestel tin ore mining site. (Courtesy A. Yener)

1986, 1984, 1982; Wagner et al. 1986; Wagner 1989; Palmieri et al. 1993; de Jesus 1978, 1980, 1981.

One notable exception is the tin mining operation at Kestel that comprises an Early Bronze Age tin mine, settlement, and the ancillary work areas that processed the ore. Yener (2000) provides a cogent description of the mining operations and settlement area. Other reports complement the studies performed there (Özbal 2009; Yener and Vandiver 1993; Yener and Özbal 1987). The operation at Kestel was fully supported by the neighbouring settlement, Göltepe, whose population could have been as high as 2000 inhabitants.[4]

The grinding areas where the newly mined ore was crushed and concentrated represent the core activity of the site (Fig. 1.8) (Yener 2000). Yener (2000) reports that 50,000 ground stone tools were found "on the surface of the site". Although she

[4] This population figure is the present author's estimate, not that of the site's excavators.

classifies the operation as a “cottage industry”, the scope of the production appears to have been significant. Moreover, the very existence of Kestel and its ancillary settlement are indicative of a focused industry that produced one product: tin ore. No smelting took place at the mining site or the settlement. Yener (2000) states that the ore was “transported elsewhere, presumably to a second-tier, lowland, urban workshop as yet not identified, for the next stage of processing which was alloying and casting it into a diversity of artefacts.” This tells us that a single valuable product can comprise the destiny and livelihood of an entire community, just as the chlorite bowls were for Tepe Yahya. If we look at the list of natural materials above, it is not difficult to imagine that countless communities scattered across the Near East and beyond were involved in quarrying mining and processing. To a great extent only their products have been recognized in the archaeological literature. For the most part, the producing communities remain largely unidentified and unacknowledged for their contribution to the material culture of urban settlements.

## 1.8 Ancient Resource Exploitation and the Supernatural World

The exploitation of Earth’s materials was not solely an industrial affair. Archaeology has clearly determined that there was a spiritual connection between ancient man and the earthly materials that he used. By mythological definition, the mundane world was related to the supernatural and cosmic domains, and the materials that depicted mythical beings or cosmic forces were imbued with special significance, if not power. Let us not forget the limestone pillars in the shrines at Göbekli Tepe, the stone bowls that were dedicated to Mesopotamian gods or the hundreds of goddess figurines made of marble or alabaster. The spirits were constantly honoured by human worshipers with a medium of earthy materials, worthy of the gods.

The remains of artefacts found in mines give us a sense of the level of mysticism and ritual that surrounded the act of mining. Topping and Lynott (2005) point out that stone hand axes were left behind and backfilled in the flint mines at Cissbury, England. Could this represent a symbolic effort to return material back from where it came? In one case bird remains were found in a mine, and other artefacts – pottery, offerings of different kinds and graffiti – have also been found and thought to be symbols, messages, or payment for extracting a material. In a general sense, materials brought up from deep within the Earth held a higher value than identical examples found on the surface. Topping and Lynott (2005) suggest mines may have been perceived as portals to the underworld or to an alternative dimension. Descending into a mine may have been equivalent to going through a series of transitions and accessing a spiritual world. Whatever came out from the depths of the Earth was not only highly valued but spiritually endowed, see Topping (2010), Topping and Lynott (2005), and O’Brien (2015).

The mining, and quarrying of Earth's materials required formalities or rituals before extraction could take place – a practice that was wide spread. Scott and Thiessen (2005) point out an example from the quarrying of catlinite (a native American stone) in Minnesota where it was used in the making of ceremonial pipes. North American ethnographic documents reveal that to dig in a catlinite quarry a worker had to be upstanding and beyond reproach, and he had to undergo a purification ritual before he was allowed to work in the quarry.

Not all miners saw the mines as a sanctified place. In 1556 Agricola reports that evil beings inhabited the mines: "Demons ('of ferocious aspect') are expelled and put to flight by prayer and fasting." (Agricola 1950). It is not certain that Agricola was referring to animal or insect "pests" or whether he believed, as many did in his day, that mines were inhabited by real demons or gnomes. Miners viewed their underworld in distinct ways, as not only did it contain mythical spirits, but it was deep in the hollows of the Earth where they made their livelihood. They considered mining a special opportunity and may have felt a kind of symbiosis and respect for being so close to the inner holiness of the Earth.

## 1.9 Conclusions

In this chapter we have reviewed a number of materials exploited in pre–Classical antiquity. Agate was used as a coveted decorative piece. Obsidian was a material worked into tools and weapons. Alabaster was shaped into vases, trinkets and goddess figurines. Chlorite was carved into bowls for export and offered as gifts to gods. Plaster was made from gypsum and lime, which introduced craftsmen to the role of fire to transform materials. In every case a hard material or mineral was mined or quarried then processed in some way.

While objects in an archaeological excavation may be viewed for their craftsmanship, they also represent a vast network of human activity. The mining and quarrying of materials often took place in remote areas, which meant that in order to exploit them workers had to travel inconvenient distances. The support system for maintaining a workforce would eventually be established, thus constituting what some refer to as "*la chaine opératoire*": a network chain that allowed support to flow in one direction and the mined product to flow in the other. For this system to be successful a number of social components had to be in place. First, a potential market had to exist, connections and agreements for trade with that market had to be firmly established, and finally, a defined and determined portion of the population had to commit to the different stages of the production-to-trade process. An excellent review of these issues is provided by O'Brien (2015) and Knapp and Piggott (1998).

Not less important is the cultural orientation that such groups had with the known mainstream populations in the market regions. Other gnawing questions arise. Were women employed in some part of the production process, or young boys who could crawl into small confined spaces of a mine? We know that there were mining operations devoted to one product, as we saw at the Kestel tin mine. To what extent were communities interwoven and interdependent? Were there many communities devoted to a selected range of economic activities that included not only the exploitation of material but complementary crafts such as charcoal making, textiles, or leather production? The availability of firewood (charcoal) may have lent itself to other industries such as pottery making or plaster production in addition to supplying charcoal to the metallurgical industry. Many configurations are possible, and hopefully, future archaeological work in the remote areas of Turkey and elsewhere in the Near East will reveal for us essential details of natural resource exploitation, and the communities involved will gain a place in the archaeological record.

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