Chapter 16
Magnesite and Olivine Deposits of Turkey

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Abstract Two types of magnesite occurrences have been identified in Turkey based on their origin of formation. The first is of sedimentary type magnesite occurrences. This type of magnesite is found in Denizli–Çardak and Erzincan–Çayırlı. The second cryptocrystalline type of magnesite constitutes the remainder of the entire resources of Turkey (İrkeç T, Kapkaç F. Türkiye'de Bilinen Manyezit Yatak ve Zuhurlarının Değerlendirilmesi ile Aramalara Yönelik Öneriler [Evaluation of known magnesite deposits and occurrences of Turkey with suggestion for exploration]. General Directorate of the Mineral Research and Exploration Report no 8863, Ankara (in Turkish, unpublished, 1989). There are three main magnesite provinces in Turkey, namely the Kütahya–Eskişehir–Bursa province, the Konya Province and the Çankırı–Erzincan–Erzurum–Sivas Province (Fig. 16.1). Kütahya–Eskişehir–Çankırı and Konya Provinces have the largest magnesite reserves in Turkey. Magnesite reserves of Turkey as of 2016 vary considerably with respect to sources. According to the MTA data, Turkey has about 111 million tonnes of magnesite (41–48% MgO) (www.mta.gov.tr, 2015). Ophiolites in Turkey are quite widespread as a result of the geological evolution of the country. Ophiolitic units have economic potential in terms of hosting industrial raw-materials and metallic-mineral systems. One of the important industrial raw material in ophiolitic units is olivine. The ophiolites expose in Bursa, Muğla, Konya, Isparta, Hatay and Erzincan provinces in Turkey have important olivine occurrences. The Bursa and Erzincan occurrences are situated in the İzmir–Ankara–Erzincan suture zone, whereas the olivine occurrences in Hatay exposed in the northernmost part of the Dead Sea Fault Zone. Olivine occurrences in Muğla are in the westernmost edge of the Taurus Mountains, and lastly, the olivine occurrences in Konya and Isparta are situated in Central Anatolia.

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16.1 Introduction

Ophiolitic rocks in Turkey are widespread as a result of country's geotectonic settings and position. Various mineralization types can be observed in these ophiolitic rocks. One of the most important mineralisations is magnesite. Another important raw material occurring in the ophiolitic rocks is olivine.

The İzmir–Ankara–Erzincan Suture zone, in the Bursa–Kütahya–Eskişehir region, Çankırı–Sivas–Erzincan–Erzurum region and Konya–Isparta region in central Anatolia are important locations in terms of magnesite occurrences, whereas Bursa, Konya–Isparta, Muğla, Erzincan and Hatay regions have significant resources of olivine. Both magnesite and olivine are currently produced in the mentioned regions.

16.2 Magnesite Deposits of Turkey

16.2.1 Cryptocrystalline (Gel) Magnesite Deposits

16.2.1.1 Eskişehir–Kütahya–Bursa Province

Numerous magnesite deposits of various sizes are observed in a 200-km long zone extending from Bursa–Harmancık to Tavşanlı–İnönü–Eskişehir–Mihallıçcık eastward. More precisely, we describe individual deposits in Eskişehir–central, Türkmentokat, Mihallıçcık, Beylikova, Alpu and İnönü, Kütahya-central, Tavşanlı, Domaniç ve Seyitömer and Bursa–Harmancık (Figs. 16.1 and 16.2).

Magnesite deposits in this province are hosted either by ophiolite suite itself or serpentinites of the tectonic mélange in the İzmir–Ankara suture (Sarıfakıoğlu

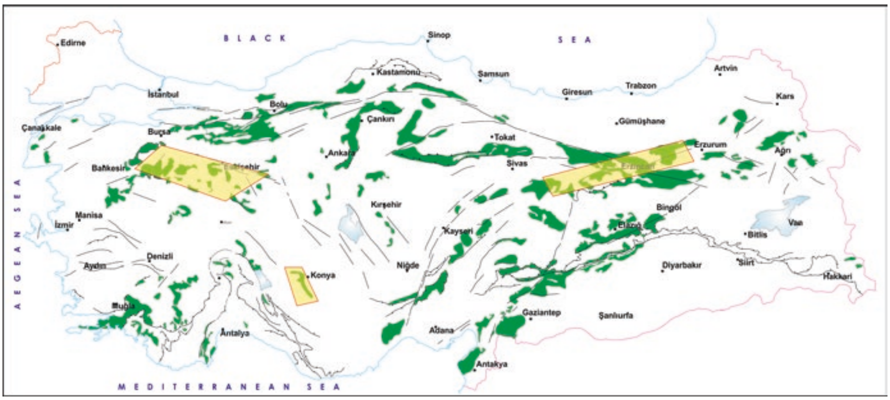

Fig. 16.1 Distribution of ophiolitic rocks and main magnesite areas in the red rectangles. (Simplified from MTA 1:500.000 Geological Map)

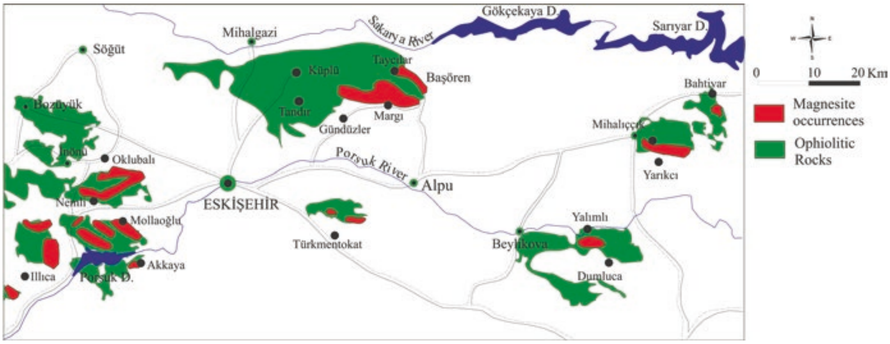

Fig. 16.2 Distribution of magnesite occurrences in the Eskişehir-Kütahya area. (Modified after Çubuk et al. 2011)

2011). Here, the ophiolite suite comprises mostly harzburgites and a lesser amount of dunite, cumulates of gabbros and dolerites. Tectonic mélange on the other hand is composed of serpentine blocks, spilitic basalt, gabbro, diabase, radiolarite and limestone, always with in fault contacts with each other.

CO_2-rich waters play a significant role in the formation of magnesites. Various views are presented regarding the origin of CO_2. These may be of volcanic origin, decarbonatisation of dolomites, meteoric and an origin involving degradation of organic material in soils and decarbonisation of sediments. A mixed origin comprising several of the above mechanisms is also probable (Yılmaz and Kuşcu 2012).

Magnesite deposits are observed in altered peridotites and serpentinites as stockworks, veins, lenticular or nodular bodies developed within joints and fractures of tectonic origin (İrkeç and Kapkaç 1989; Sarıiz 1990; Yersel and Ayday 1992; Çubuk et al. 2011) (Fig. 16.3).

Sarıiz (1990) suggested that magnesites in Türkmentokat area (Eskişehir) are of infiltration type (gel-type) and hydrothermal, with the latter formed under the pressure of 2 kbar and a temperature of 150 °C and with various mole fractions of CO_2. For infiltration type, it is suggested shallow depth (~1 to 2 m). The mineralisation age is proposed as pre-Pliocene, probably Miocene, since magnesite gravels and blocks are observed in the basement gravels of Upper Neogene in the eastern Eskişehir. Mineralisation contains on average magnesite 91.74%, quartz 0.074%, dolomite 2.47%, calcite 1.17% and serpentine 1.72%.

According to Öncel and Denizci (1982), the CO_2 gas from nearby volcanism interacted with groundwater and produced carbonic acid. At a later stage, these CO_2-saturated water infiltrated through the ophiolitic rocks causing serpentinisation and resulting in the formation of magnesites. Subsequent tectonic events further complicated the geometry of deposits.

Magnesites in Mihalıççık area occur as veins and stockworks. Veins are localised either in serpentines or through the boundary with the Middle-Late Miocene siliciclastics. Stockwork magnesites are mostly seen in serpentines underlying the listvenites. The average content of the individual magnesite veins are 43.73%

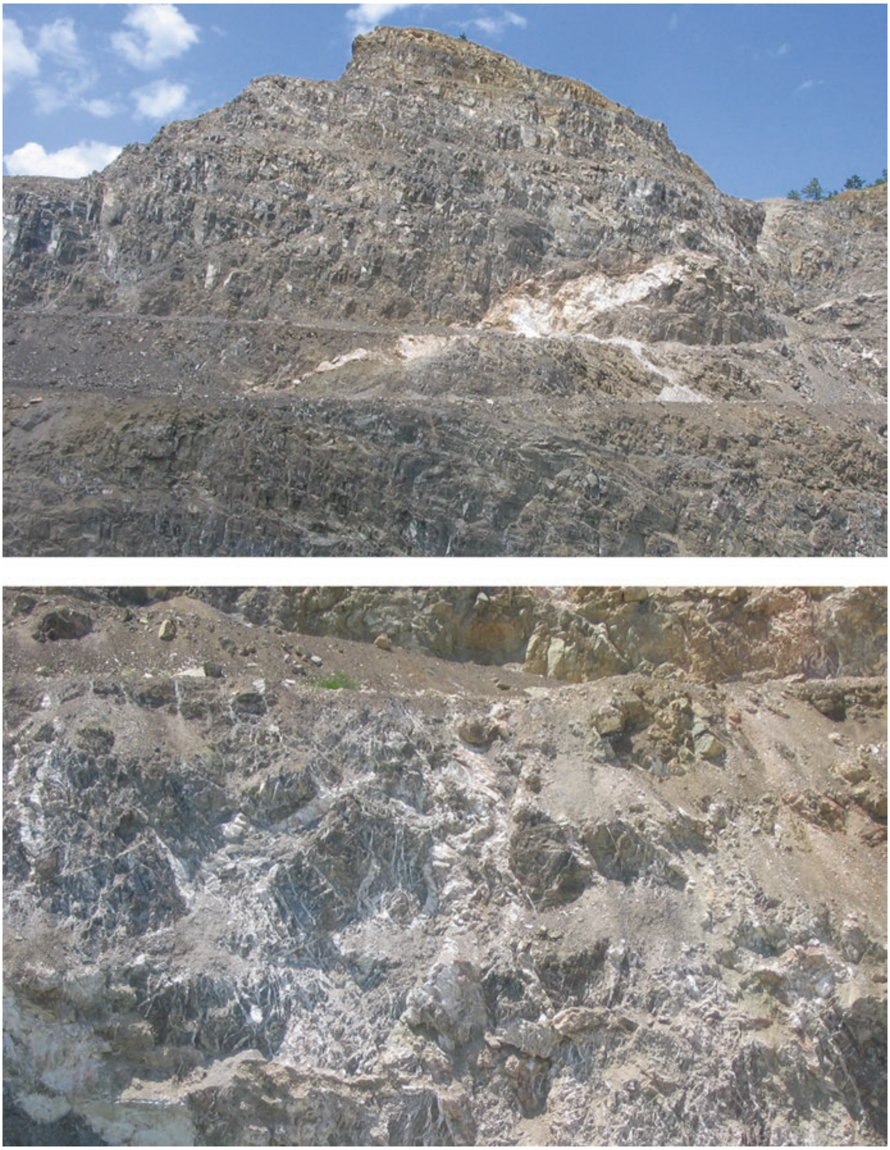

Fig. 16.3 Vein and stockworks of magnesite occurrences in the Eskişehir-Kütahya area

MgO, 2.95% SiO_2, 0.75% Fe_2O_3 and 3.73% CaO while stockwork is 47.04% MgO, 0.39% SiO_2, 0.55% Fe_2O_3 and 1.15% CaO (Yılmaz and Kuşcu 2007).

Isotopic studies by Yılmaz and Kuşcu (2008) indicated two end processes, such as the atmospheric CO_2 and decarbonisation of organic-rich sediments. They suggested that an origin involving a mixture of the above end members and even volcanic CO_2 is also probable. They proposed that the magnesite deposition occurred after the serpentinisation in low temperatures close to surface.

The Bursa region is located in the westernmost part of the province. Ophiolitic rocks in the region comprises dunite, harzburgite, serpentinised ultramafics and a lesser amount of gabbro. Magnesites are related to serpentinites and occur as nodular and stockwork bodies (Çubuk et al. 2011).

This province is one of the most important province of Turkey economically in terms of hosting significant magnesite deposits that have been mining for many years.

16.2.1.2 Konya Province

Magnesite deposits occurring in Meram, Yunak, Ereğli and Karaman were developed specifically within serpentinites in the altered ultramafic rocks in the Konya Province (İrkeç and Kapkaç 1989; Çubuk et al. 2011) (Fig. 16.4). Some parts of the mineralisation occurs as stockworks and bands in serpentinites and are probably related to the folding, fracturing and overthrusting processes during the obduction of ophiolites (Şimşek 1975). The remaining mineralisation occurs as irregular blocks and lenses of massive nodules (Yeniyol and Önder 1978).

The Çayırbağ magnesite mineralisation is of cryptocrystalline texture developed in the late Cretaceous altered serpentinites. Here, one can distinguish the secondary magnesites that cut across the primary ones. The primary magnesites are more compact and display concoidal fracturing due to higher silica content while the secondary type is softer. Another type of mineralisation in the same area is formed in Miocene sediments in relation to surficial conditions (Tuncay 2000).

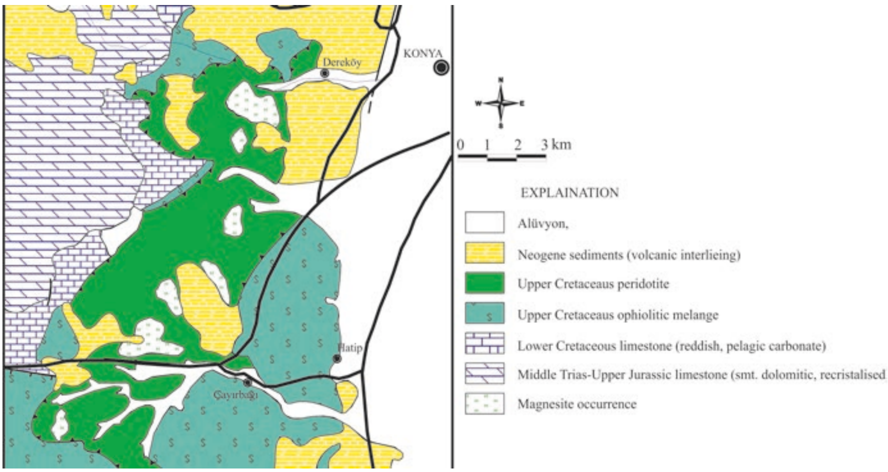

Fig. 16.4 Geological map of the Konya area. (Modified after Çubuk et al. 2011; Şimşek 1975; Kıyıcı and Bayböru 1978)

Yılmaz and Kuşçu (2007) reported that, according to Zedef et al. (2000), the origin of the CO_2 that resulted in the magnesite mineralisation in this province is organically rich sedimentary rocks that are underlain by ophiolites and the mineralisation temperature was in the range 80–100 °C.

According to Önal (2007), the origin of the water that gave rise to the formation of magnesite mineralisation is meteoric or vadose. In Önal opinion, magmatic water was not primarily effective, but they cannot be totally ignored in the formation of secondary magnesites related to the fault zones. According to some diagrams, the mineralisation temperature is lower than 300 °C and CO_2 containing fluid is less than 4%.

Average chemical composition of the province is as follows: 2–6% SiO_2, 0.3–1.2% CaO and 44.3–47.79% MgO (İrkeç and Kapkaç 1989).

16.2.2 Sedimentary Magnesite Mineralisation

16.2.2.1 Denizli Province

The Çardak–Çameli Neogene basin where the sedimentary magnesites are hosted is a depression surrounded by Mesozoic-aged ultramafics and limestones and the Paleocene-aged siliciclastics and carbonates. Neogene sediments are of Late Miocene (?) to Lower Pliocene, and are composed of a lower alternating conglomerate-sandstone-mudstone, a middle limestone–marl–clayey limestone and an upper dominantly limestone subunit (Fig. 16.5). The Lower subunit is formed in alluvial fan environment. The middle subunit is attributed to a lake coastal plain and the limestones at the top were formed in the lake environment. Magnesites accompanied by huntite and sepiolites are observed in ancient coastal plains and lake environments (Akbulut 2003).

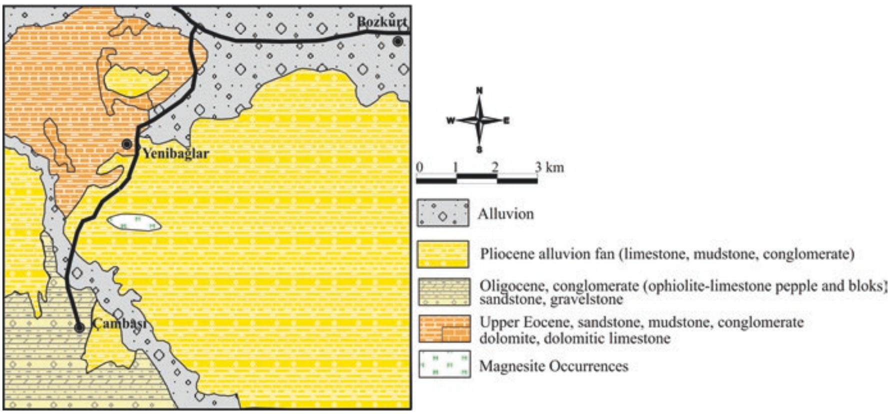

Fig. 16.5 Geological map of the Denizli area. (Modified after Çubuk et al. 2011; Şenel 1997)

Mineralisation is surrounded by the Pliocene sediments and sandwiched between dolomites. The transition between the units is sharp. Transition between sepiolite and magnesite is rather gradual and generally lower part is sepiolitic. Mineralisation here comprises dolomite, hydrated silicates and magnesite (Brennich 1958, 1959).

According to İrkeç and Kapkaç (1989), the average chemical composition is 43.8% MgO, 1.6–3.6% SiO_2 and 2.20–3% CaO, and the proven reserve is 450,000 tonnes.

16.2.2.2 Erzincan Province

In the Çayırlı area where magnesites occurrences are observed, the oldest rocks units are Palaeozoic metamorphic rocks and Anatolian ophiolitic melange. These basement rocks are unconformably overlain by Lower-Middle Miocene detrital and marl units, which are thought to be deposited in marine, lagoonal to lake environments. Magnesites are observed within the lacustrine intervals of marl, mudstone and gravelly mudstone (Arslan 1987; Çubuk et al. 2011).

Individual magnesite levels display bedding. Each magnesite level is high-quality in its medial part and is increasingly siliceous towards the upper and lower contacts. Lower and upper siliceous magnesites would be 15–20 cm thick (İrkeç and Kapkaç 1989; Kocaefe 1982; Çubuk et al. 2011).

The mineralisation has the following composition: 2% SiO_2, 1% CaO, 44–46% MgO and 50–52% LOI (Çubuk et al. 2011; İrkeç and Kapkaç 1989).

16.2.2.3 Isparta Province

Magnesite occurrences in the Isparta province are of sedimentary type. The excess Mg for the formation of magnesite was derived from the alteration of ultramafic rocks and transported by surface and groundwater to the site of deposition. The origin of the CO_2 is supposed to be atmospheric or derived from anaerobic reactions in lignites in deeper levels. Formation temperature of magnesite ranges from 13 to 42 °C. Mineral paragenesis is calcite, dolomite, Mg-calcite, huntite and magnesite ($MgCO_3$). This formation that occurs in freshwater lacustrine is a sedimentary, massive magnesite occurrence (Topak 2006).

16.2.3 Other Mineralisation Sites

16.2.3.1 Erzurum–Erzincan Province

In this province, magnesite mineralisation occurs in three areas, namely Erzurum-Centre, Oltu and Aşkale. Ophiolitic rocks in the area comprise gabbro, microgabbro, diabase and peridotite, while meta-ophiolites are derived from pyroxenite, olivine-gabbro and sheeted dykes. It is suggested that hot fluids entrained through tectonic fractures gave rise to the formation of listvenite, magnesite, opal and serpentinites (Çubuk et al. 2011).

Magnesites are formed in fault zones juxtaposing various lithologies or in serpentinised dunite and harzburgite bodies (Kocaefe 1982).

Major oxide chemistry of the magnesites of this area is as follow: 42–47% MgO, 0.04–7.10% CaO and 0.05–3.05% SiO_2 (Çubuk et al. 2011).

In the Refahiye district of the Erzincan province, one of the secondary splays of the North Anatolian Fault Zone display magnesites mineralisation within the carbonated and silicified ultramafic rocks. More specifically, the mineralisation has various shapes including lodes, lenses, nodules and blocks at the contacts between silicified and unaltered serpentinites (Çubuk et al. 2011; Kocaefe 1982).

Downward in the mineralisation, SiO_2 decreases to 0.03–13%, while other major oxides are as follow: 41.05–47.75% MgO, 0.11–0.57% CaO and 48.9–51.9% LOI (Kocaefe 1982).

16.2.3.2 Çankırı Province

In the vicinity of Eskipazar, Şabanözü, Kurşunlu and Ilgaz, vein and stockwork mineralisation occurs in ophiolites along the North Anatolian Fault Zone (İrkeç and Kapkaç 1989). The highly fractured nature of rocks along the North Anatolian Fault Zone provided favourable environment for magnesite occurrence (Çubuk et al. 2011).

Ertuğrul (1978) stated that the magnesites in Çankırı city centre are of massive or cauliflower-type and have developed along the fractures (Çubuk et al. 2011).

Average composition of magnesites in the Kurşunlu–Ilgaz area are: 8.26% SiO_2, 1.76% CaO and 42.58% MgO. In other fields nearby, the composition changes significantly: 0.24% SiO_2, 0.9% CaO and 47.37% MgO.

Apart from the above provinces, there are peridotite-hosted veins and stockworks in the Mersin, Balıkesir, Burdur and Kars provinces, and sedimentary magnesites in the Isparta province (İrkeç and Kapkaç 1989).

Magnesites in Mersin province are found in Tarsus. The stratigraphy of this area comprises upper Cretaceous igneous rocks and an ophiolitic suite, Oligocene to Middle Miocene-aged clastic sediments and Quaternary alluvial deposits (Önal 2007). Magnesites occur as dyke-like and small veins of various sizes along the fractures in ultramafic rocks. Tectonic movements following the mineralisation caused local brecciation along the contacts with host rocks (Önal 2007).

16.3 Olivine Deposits of Turkey

16.3.1 Bursa Province

Emre (1986) described the ophiolitic rocks of the Bursa–Orhaneli area (Fig. 16.6) as than "incomplete ophiolitic suite". According to this author, the primary positions of the ophiolitic sub-units are not preserved, cumulates are observed at the base and the tectonites are at the top. Emre (1986) reported that the dunitic host rocks of olivine occur as lenses in the cumulate sub-unit of the ophiolitic suite. The modal mineralogical composition of dunites comprises 93–94% forsterite with an average value of 91%.

Ophiolites in this province exhibit alternations of dunite, wherlite and clinopyroxenite. The trend is N–S with a steep dip (Fig. 16.7). Dunites are mainly composed of olivine and euhedral/semi euhedral chromite. Olivine crystals display deformation twins. Based on these features, they are attributed to the base of the cumulate suite where plastic deformation may have occurred (Ağrılı et al. 2001).

The chemical composition of the dunites with economic olivine occurrences is as follow: 40–50% MgO, 7.2–13.87% total iron oxide, 37.6–41% SiO_2 and 0.33–3.99% Loss on Ignition (LOI) (Ağrılı et al. 2001).

The dunites were derived from a mantle source, while harzburgites have hybrid origins including both the mantle and subducting plates (Çevik 2006). As a result, the chemical composition of dunites is somewhat different: 40.99–50.2% MgO, 34.67–40.6% SiO_2, 6.8–13.7% Fe_2O_3 and 0.1–0.83% Al_2O_3.

16.3.2 Konya-Antalya-Isparta-Burdur Province

Ophiolites in this province are common in the Akseki, Beyşehir, Eğirdir, Yeşilova–Tefenni and Yalvaç areas. Ophiolitic rocks in the Akseki–Beyşehir area are considered part of the Bozkır Unit by Özgül (1976), while Koçyiğit (1983) considered

Fig. 16.6 Geological map of the Bursa-Orhaneli area. (Compiled from Ağrılı et al. 2001)

Fig. 16.7 A view of Bursa–Orhaneli dunites

them as part of the Inner Tauride Ophiolitic Complex. Ophiolitic rocks crop out in Kızıldağ, which is situated in northwestern of Akseki–Antalya and continue through Beyşehir–Konya to the northwest (Fig. 16.8). They thrust over the sedimentary units comprising upper Cretaceous limestone, nummulite-bearing limestone and flysch (Döyen and Zedef 2002).

Olivine minerals are dominant (90–95%) in dunites of the Akseki–Beyşehir area (Fig. 16.9). It is accompanied by 2–3% dark-coloured minerals (possibly chromite) and 1–2% serpentinite (or talc?) developed mostly in fracture zones and a lesser amount of asbestos minerals. The average chemical composition of dunites in the area is as follows: 50.25% MgO, 37.5% SiO_2 and 8.3% Fe_2O_3 (Zedef and Döyen 2001).

Ophiolites in the south of Beyşehir consist of the tectonites (harzburgite, dunite, gabbro, pyroxenite, pegmatoid gabbro) and amphibolite. Dunites occur as irregular bands and lenses in harzburgites, where the thicknesses vary from 1 to 15 m. The unit is typical with its dominant porphyroclastic texture. Dunites consist chiefly of olivine with small amount of orthopyroxene-chromite (Arat et al. 2012).

Ophiolitic rocks in the Yeşilova area belong to the Lycian Nappes of the Alpine zone in the Western Taurides. They are believed to have formed in relation to the northern branch of the Neotethys Ocean. Ophiolites in the area have harzburgite and dunite at the base with lesser chromite patches. They grade upward into dunite, wherlite, clinopyroxenite, banded or massive gabbro and plagiogranite. The ophiolite units are cut by isolated gabbro and diabase dykes (Döyen et al. 2014).

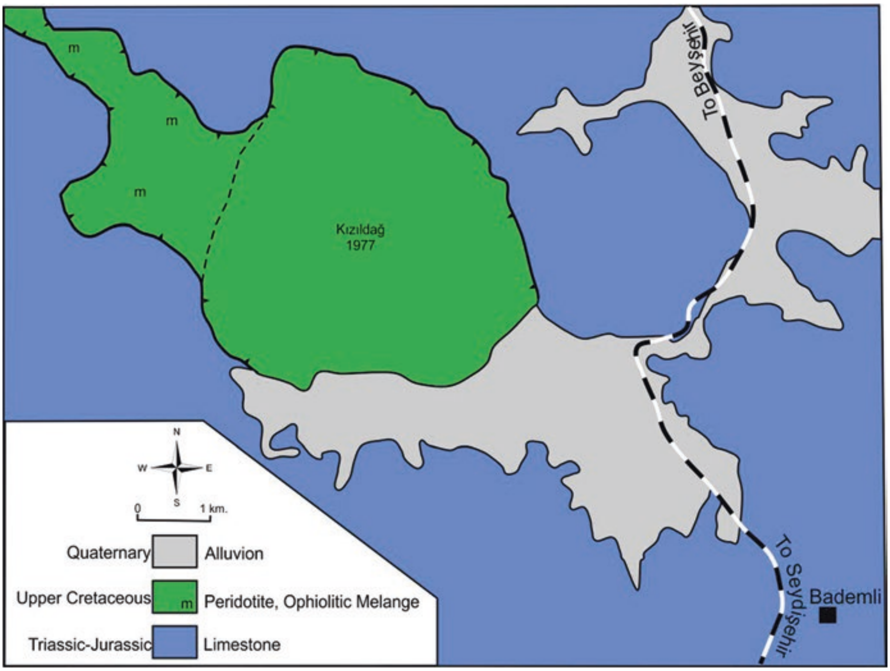

Fig. 16.8 Geological map of Kızıldağ (Beyşehir–Akseki area). (Compiled from Döyen and Zedef 2002)

Fig. 16.9 A view of the Akseki-Beyşehir dunites

Similarly, ophiolites of the Şarkikaraağaç (Isparta) comprise dunite and harzburgite. Dunite and harzburgite mostly display porphyroclastic textures indicating the effects of plastic deformation of these ultramafic tectonites in the upper mantle. Giant crystalline pyroxenites composed of orthopyroxenite and websterite are observed as small dykes and veinlets in the ultramafic tectonites (Elitok 2000).

16.3.3 Muğla Province

Ophiolites of this area are represented by clinopyroxene-rich harzburgite, depleted harzburgite and dunite (Uysal et al. 2009, 2012). They were derived from a depleted mantle source via variable degrees of melting.

Mineral chemistry, whole-rock trace elements analyses and PGE data indicate that the genesis of the Muğla peridotites can be explained by two-stages of melting and re-fertilization processes (Uysal et al. 2009, 2012). The clinopyroxene–harzburgites are the products of first-stage melting and low degrees of melt–rock interaction, formed in a mid-ocean-ridge (MOR) environment. However, the depleted harzburgites and dunites are the products of second-stage melting and related re-fertilization that took place in a supra-subduction zone (SSZ) environment (Uysal et al. 2009, 2012).

Ophiolites in the north of Köyceğiz locally display low LOI values (1%). Chemical compositions of locally 2-m thick dunites that alternate with harzburgites are as follows: 45.50–49.60% MgO and 37.50–40% SiO_2 (Ovayurt et al. 2007).

16.3.4 Hatay Province

Ophiolitic rocks in this province crop out across the Amanos Mountains and display a complete ophiolitic suite (Fig. 16.10). These rocks, from bottom to top, include:

– tectonite peridotites that comprise mainly harzburgites and lesser dunites
– banded gabbro alternating with wherlite and gabbro
– isotropic gabbro that formed from non-cumulus clinopyroxene and gabbro
– mafic-dyke complex
– volcanic rocks comprising pillowed or massive basaltic lava flows (Tekeli and Erendil 1986).

Peridotites comprise two main rock types. Harzburgites (70%) and dunites (30%). Harzburgite contains olivine, orthopyroxene and spinel. Dunites in harzburgites are found as irregular masses reaching kilometre size at some localities. These dunite bodies randomly cut the harzburgite foliations (Tekeli and Erendil 1986).

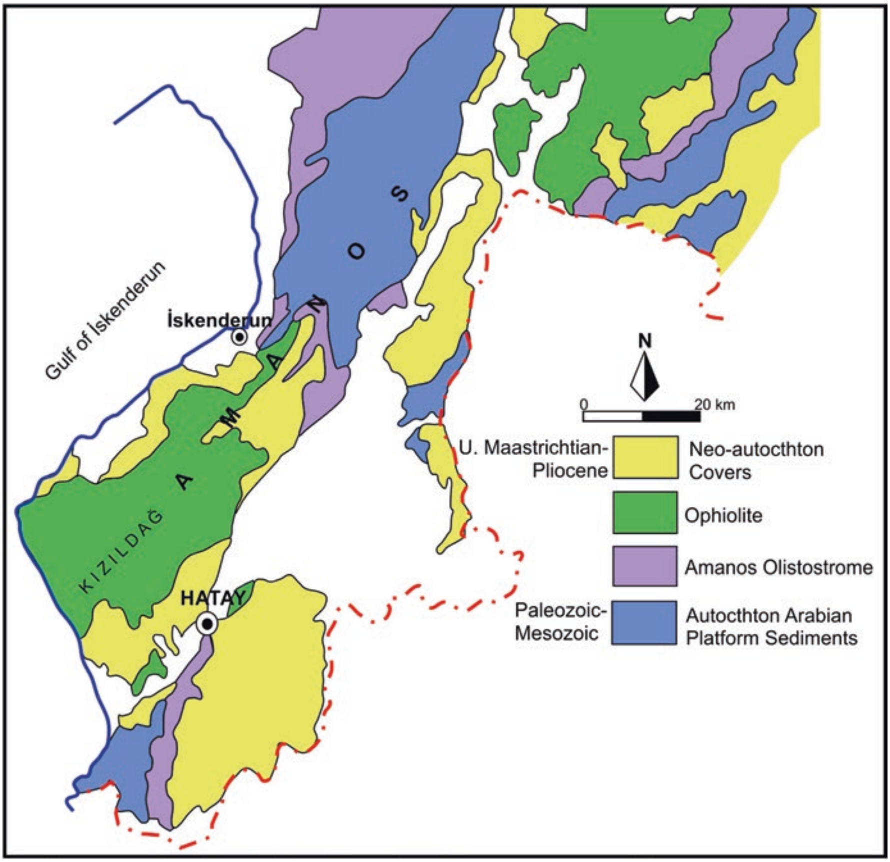

Fig. 16.10 Simplified geological map of Amanos Mountain. (After Tekeli and Erendil 1986)

16.4 Conclusions

Turkey, China and Russia are the leading countries for magnesite reserves and production (USGS Mineral Yearbook 2015). Turkey is favourable in terms of olivine reserves and quality, and its importance is increasing substantially. In terms of genesis, two types of magnesite formations are observed in Turkey. The first of these is the sedimentary magnesite formations located in Denizli–Çardak and Erzincan–Çayırlı. The other one is cryptocrystalline (gel) magnesite, and in fact all the remaining deposits are of these types (İrkeç and Kapkaç 1989).

Olivine can be observed as layers of igneous banding and also as lenses in peridotites associated with unaltered dunites. These raw materials can be of good quality and supplied to both foreign and domestic markets. Due to the commonality of the ophiolitic rocks in Turkey, exploration for the targeting of economic magnesite and olivine occurrences is encouraged.

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