14

The Dodecanese and the Carian Shore

The Dodecanese ('Twelve Islands') are situated off the south-west coast of Turkey (Fig. 14.1). The term Dodecanese is of recent origin (1908): there are in fact fourteen major islands and numerous smaller ones. Most are dry and barren, but two of the largest, Rhodes and Kos, together with Leros, are exceptional for their fertility.

The islands have a long history. A limited Minoan presence on Rhodes and elsewhere from about 1700 BC was followed by substantial Mycenaean settlement from 1450 to 1150 BC. Around 1000 BC there was a general occupation by Dorian Greeks from the Argolid. For the next 1,500 years the islands flourished, following the fortunes of Rhodes, which for much of this period was one of the leading maritime states of Greece. A period of stagnation started in the sixth century AD and lasted till 1309, when the islands were occupied by the Knights of St John (the Hospitallers), whose domination lasted till 1522. There ensued nearly 400 years of Turkish rule, followed by Italian occupation from 1912 until 1947 when the Dodecanese were united with Greece. In the hinterland, now part of western Turkey, the history of Knidos, Bodrum (ancient Halicarnassus) and Iasos runs in general parallel to that of the Dodecanese.

The region covers a wide variety of different geological environments. In the north metamorphic rocks of the Menderes massif crop out on the mainland and probably continue further south and west as the Palaeozoic metamorphic basement of Patmos, Leros, Kalymnos and Kos. Over these rocks have been thrust shallow water limestones and ophiolite fragments during the Alpine compressions. These rocks are fragments of continental crust and adjacent sea-floor. On the Greek side of the border these nappes are considered to be part of the Pelagonian and Sub-Pelagonian zones, but on the Turkish side they are called the Lycian nappes.[28] Further south, Rhodes contains rocks of the Ionian and Gavrovo zones that have been further stacked up onto the pile of nappes.

Subduction of the African plate beneath the Aegean plate and broadly synchronous crustal stretching during the Neogene had an important role in shaping the landscape we see today. In the north it produced a series of east-west grabens than start deep in the mainland to the east and continue westwards into the Aegean Sea. Sediments have accumulated in many of the Neogene grabens and basins in this region, including the low-quality coal called lignite. Lignite was formed by the action of pressure, temperature and time on decayed vegetation accumulated in swamps. Seams up to 20 m thick are present in many of the basins 40 to 80 km east of Bodrum.[121]

Further south crustal stretching took a slightly different role: extension north of the ancestral arc stretched it out, and broke it up into the four main islands of the non-volcanic Hellenic arc, Crete, Karpathos, Kasos and Rhodes. In the west of the arc the crust goes down the subduction zone into the mantle, but further east the story changes: here, changes in the direction of movement of the plates since the inception of the arc have resulted in movements of the African plate, with respect to the Aegean plate, which are parallel to the arc. Hence there is no subduction and the plates move horizontally along several major strike-slip faults.

Some of the smaller islands, together with the Bodrum peninsula, are dominated by caps

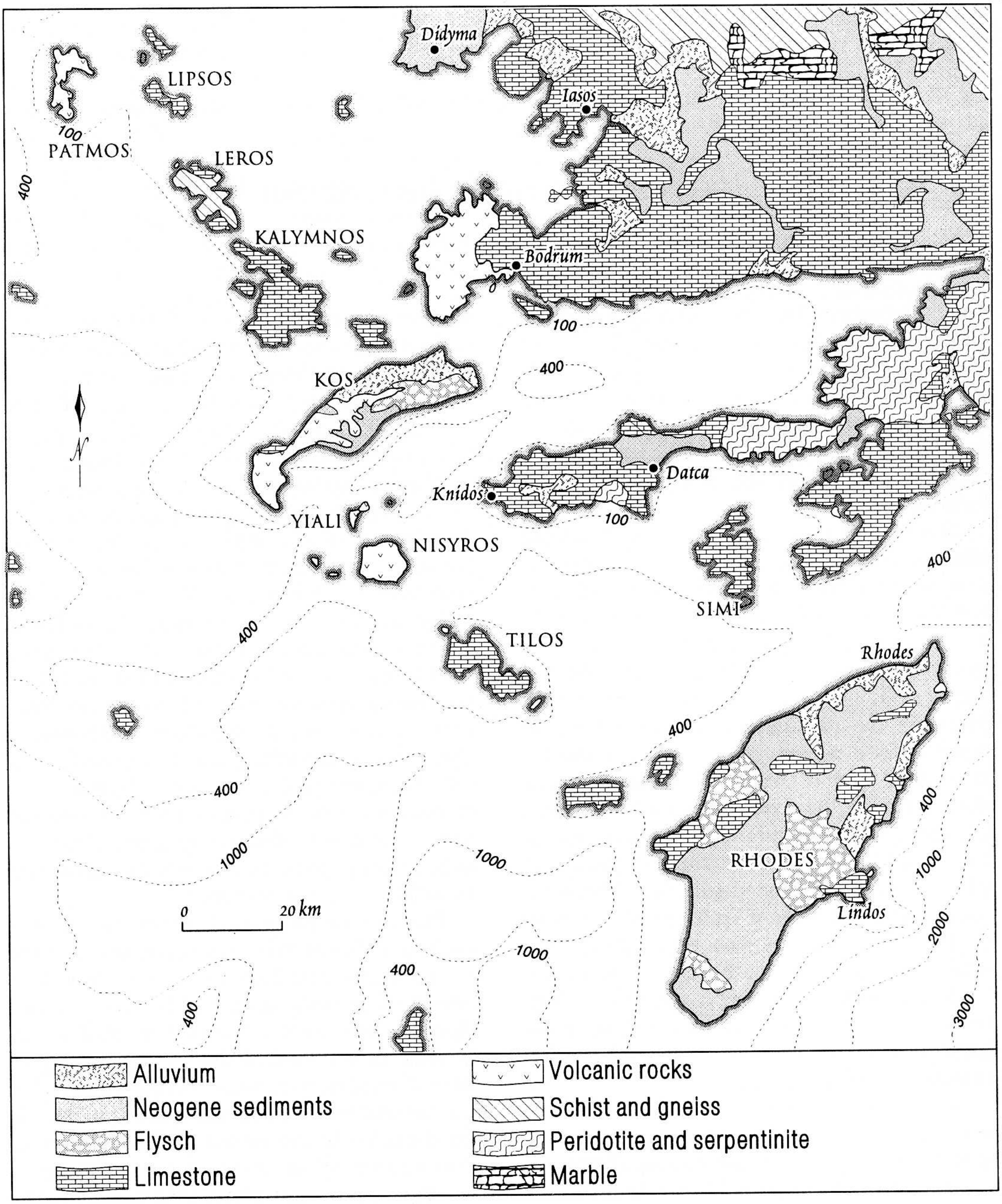

Fig. 14.1. The Dodecanese and the Carian shore of Turkey.

of volcanic rocks related to subduction of the ocean floor during the last 12 million years. All these volcanos were built on existing continental rocks.

Rhodes

Rhodes is by far the largest island of the Dodecanese and is dominated lengthwise by a mountain range which culminates in Mt Ataviros (1,215 m; Fig. 14.2). The climate is excellent and the soil extremely fertile. The poet Pindar in his Olympian odes relates the myth that this island arose from the sea to become the domain of the Sun God Helios, who was indeed the patron deity of Rhodes in Classical times.

The first settlers were Minoan colonists, who arrived from Crete about 1700 BC, and lived in the north of the island. They were followed by Mycenaean Greeks, in about 1450 BC, and Dorians around 1000 BC. The latter divided the island into three parts ruled from Ialysos, Lindos and Kamiros. They soon grew rich and joined Kos, Knidos and Halicarnassus in a commercial and political league. In 408 BC, faced with shrinking markets, the three city-states amalgamated and built a federal capital on the north tip which they named Rhodes, after the island. With five harbours and a fertile hinterland the new city soon became the capital of a great maritime state. In 305 BC Demetrius of Macedon attacked Rhodes and was defeated. The proceeds of the sale of his siege equipment was used to construct a bronze statue of the sun god Helios, over 30 m tall. Considered one of the Seven Wonders of the Ancient World, the Colossos of Rhodes stood until 226 BC, when it was knocked down by an earthquake. The island continued to flourish until the sixth century AD. In 1309 the Knights of St John conquered the island and held it until expelled by the Turks in 1522. The restored fortifications which we see today are those of the Knights.

Rhodes is separated from Turkey by a channel almost 400 m deep (Fig. 14.1). A deep trough to the south-west, between Rhodes and Karpathos, resulted from the Neogene stretching of the Hellenic arc. To the south-east the sea-floor drops off rapidly to a depth of over

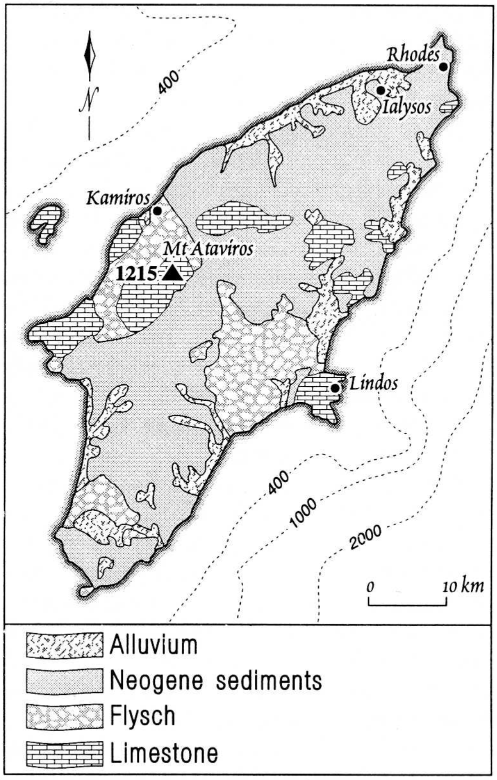

Fig. 14.2. Rhodes (after 186).

3,000 m in the Rhodes basin, a block of crust dropped down between two of the major strike-slip faults that are here the boundary between the African and Aegean plates. The proximity of Rhodes to these faults has made for frequent earthquakes.

The earlier geological history of Rhodes resembles that of Crete, much of the Peloponnese and western Greece.[186] The oldest rocks still close to their original place of deposition are Jurassic to Cretaceous deep-water cherty limestones of Mt Ataviros (1,215 m) and the peninsula to the south-west (Fig. 14.2). The relief of Mt Ataviros and the headland to the south-west reflects the resistance to erosion of these rocks. During the Oligocene period sedimentation changed and flysch was deposited, indicating the presence of land nearby, raised up by Alpine compressions. This flysch crops out throughout the southern part of the island.

Over these rocks have been thrust Triassic to Early Tertiary limestones, which underlie all the other important hills on the island, including the Lindos peninsula.

Major compression and mountain-building ceased during the Pliocene. Erosion of the mountains produced sediments, such as sands, conglomerates and brown marls, which were deposited initially in basins on land. As the land subsided incursions of the sea increased until much of the area was below sea-level, except for the limestone hills. The rocks formed at that time today yield the most fertile soils, especially the marls. It was also at this time that Rhodes was severed from the Turkish coast to become an island.

The top of the Neogene series of rocks is marked by a thin limestone locally called 'panchina', which is very important from a geomorphological and cultural point of view. The panchina is a 2 m thick layer of limestone made up of broken shells, typically 2-3 mm long (similar to 'coquina' elsewhere). The shells grew in a vast expanse of shallow water that stretched as far south as Lindos during the Early Pleistocene. Some of the piles of shell fragments were lithified in place, but some were blown by the wind into sand dunes, and then cemented. This rock is much more resistant to erosion than the underlying sediments and where it has been removed there is rapid erosion. It covers much of the surface in the northern part of the island and was an important construction material (see City of Rhodes below).

Finally, much of the interior is covered with a soft limestone, usually without shelly fossils, locally known as 'poros'. This rock is a type of caliche, an impure, porous limestone which forms in the soils of arid regions from the evaporation of mineral-laden groundwater below the surface. It was formed during the Pleistocene and is presently being eroded.

There have been large and rapid changes in the height of the land, with respect to sea-level, in this region probably because of the proximity to the edge of the Aegean tectonic plate. Such changes during the last 10,000 years are recorded in up to eight different ancient sea-levels which can be seen in wave-cut notches in sea-cliffs and ancient beaches above the present sea-level.[221] The ancient sea-levels are very variable throughout the island, indicating that large blocks of the island, each up to 20 km long, have moved independently. Relative movements between blocks were accommodated by movements along faults and accompanied by earthquakes (see City of Rhodes below). Large earthquakes have also been produced south of the island on the strike-slip faults that form the boundary between the African and Aegean plates.

The city of Rhodes and the acropolis

The northern tip of the island of Rhodes has emerged from the sea during geologically recent times (Fig. 14.3). This area is underlain by soft, largely weakly cemented sediments that were deposited on land from rivers about between 3 and 1 million years ago. At the end of this period the area was submerged below sea-level and the panchina was laid down. Subsequent uplift, faulting and erosion have created the present landscape.

The most important construction material

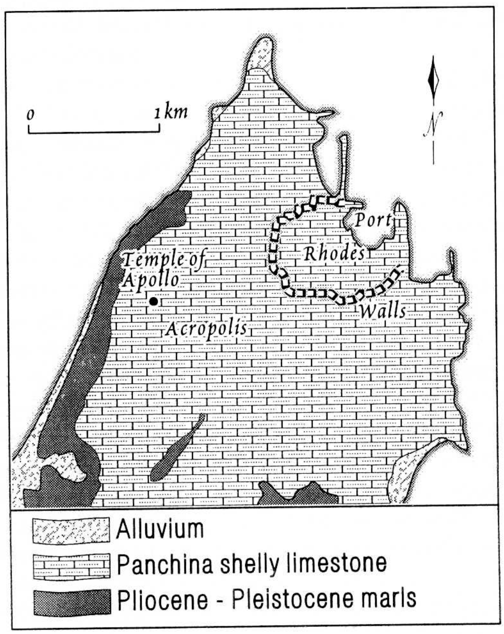

Fig. 14.3. The city of Rhodes (after 186).

of the ancient city of Rhodes, the Castle of the Knights and the ancient acropolis was panchina. This rock was available close by and was easily cut as it is so porous. However, the less well-cemented parts of the unit are readily eroded, though more resistant than the underlying sedimentary rocks. It was extracted from a number of quarries around the city and also from a series of quarries along the east coast, 2-8 km to the south of the city.[221]

The ancient acropolis of Rhodes is situated on a low hill (Ayios Stephanos) west of the centre of the modern city, formed by geologically recent uplift and tilting. The extent of the movement can be estimated from the altitude of the panchina rocks, which were close to sea-level during the early Pleistocene, but are now at altitudes up to 110 m. These gentle slopes terminate to the north-west in steep cliffs, formed as a result of offshore faulting parallel to the coast. This recent uplift reached its maximum, 270 m, on Mt Philerimos, which can be seen to the west.

The acropolis was originally completely covered with panchina, but this was extensively quarried for construction, and the foundations of the major buildings were laid on the underlying Pliocene sedimentary rocks. A particularly good section can be seen in the Temple of Pythian Apollo (Plate 13). The underlying rocks are less permeable than the panchina, hence wells were dug through this unit to the aquifer.

The coast of northern Rhodes has recorded many ancient changes in sea-level.[221] Many of the coastal quarries, thought to be Roman, have been submerged to a depth of 40 cm, indicating that the land has gone down since that time. However, there is a prominent sea-level notch in the cliffs at a height of 3.4 m, dated at 300 BC. The land must therefore have risen about 3.8 m between 300 BC and Roman times. The mostly likely cause was the earthquake of 222 BC, which toppled the Colossos of Rhodes and was the largest earth movement in the region during the last 10,000 years.

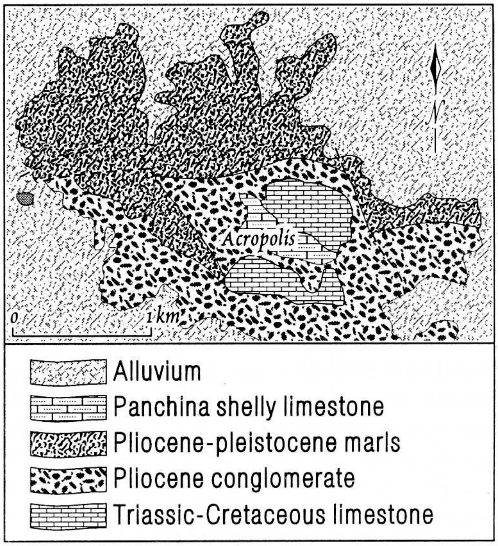

Fig. 14.4. Ialysos (after 186).

Ialysos and Mt Philerimos

About 15 km south-west of the city of Rhodes, Mt Philerimos rises sharply from the surrounding plains to a height of 270 m. The summit of this hill is occupied by the monastery of Philerimos and the acropolis of the ancient city of Ialysos (Fig. 14.4). This hill is a horst surrounded by down-dropped blocks. Much of the upper part of the hill is made up of Late Triassic limestone with bands of chert, which is more resistant to weathering than the surrounding rocks. Panchina and poros also occur here, indicating considerable uplift in geologically recent times.

Lindos

Lindos was the chief of the three cities of the island before the foundation of Rhodes. The site was occupied in the third millennium BC, but major construction on the acropolis did not start until the tenth century BC with the Temple of Athena and other buildings. Those visible today were mostly built after the fire of 348 BC. Later on the acropolis was converted into a fortress by the Knights of St John.

As approached from the north, the whole peninsula of Lindos stands up dramatically from the plains. The peninsula is dominated by grey Cretaceous crystalline limestone which is harder than the surrounding rocks and consequently tends to form headlands (Fig. 14.5). During the Neogene the limestones of the peninsula have been broken up by vertical faults into large blocks, forming a series of horsts and grabens. At times of high sea-level the horsts were islands and sediments were deposited in the grabens.

The acropolis of Lindos town was built on a block of hard, grey Cretaceous limestone that rises 120 m from the sea. It is part of a discontinuous horst that extends north-eastwards across the bay to the next headland, and south-westward for 1 km. A small graben, about 500 m wide, runs north-east/south-west and contains the town of Lindos and the big harbour.

During the Neogene sedimentary rocks were deposited in this graben. They can now be seen as two ledges, resembling bath-tub rings, one at about 50 m, which carries the road, and a lower one at 20 m, which covers much of the low land of the peninsula to the north. The rocks of the upper ledge are also seen on the top of the acropolis as a layer about 5 m thick. This rock is pale-brown silty marl, similar to the poros that covers much of the interior of the island. The lower ledge is made of panchina, the shelly limestone so common around the city of Rhodes. This rock does not crop out on the acropolis.

Neither the grey limestone nor the poros were much used in the construction of the monuments and buildings on the acropolis. Instead the builders commonly used panchina, from quarries that can be seen across the bay to the north. They used this material because it has few joints and is very easy to cut. However, it is not always very well cemented, and some blocks can weather very easily. A grey marble, cut by white calcite veins, was also used in the construction of some of the buildings.

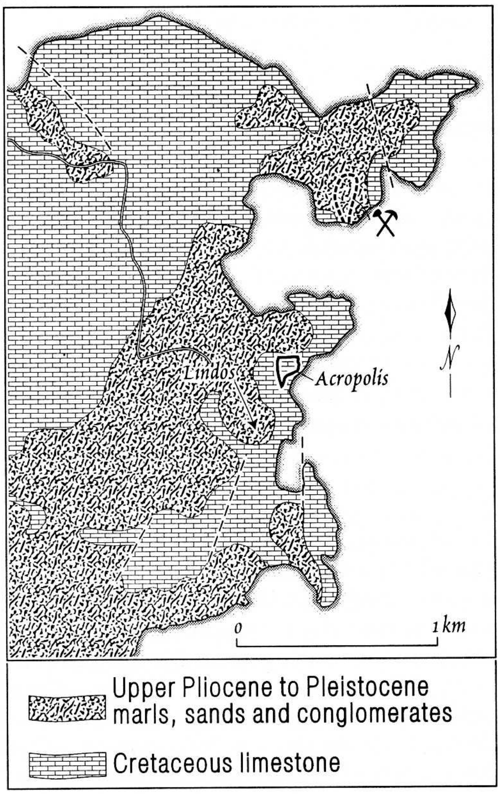

Fig. 14.5. Lindos (after 186).

Iasos

Iasos occupied a small peninsula on the coast of Asia Minor, between Didyma and Bodrum (Fig. 14.1). Its excellent harbours and rich fishing attracted Carian settlers as early as 3000 BC. In about 2000 BC Minoans arrived from Crete; they were replaced by Mycenaeans from the Argolid around 1400 BC. About 1000 BC, after the fall of Mycenae, more Greeks arrived and henceforth their fortunes were tied to those of Rhodes.

Iasos had another asset, which was exploited in Roman and later times: its marble quarries. Some of these were located outside the city in the direction of the modern village of Abkuk. They yielded two sorts of marble: one was fine-grained, red with white bands, the other white. The red marble was used by the Romans in the third century AD and became very popular in Byzantine times. Known as Marmor Carium or Iassense to the Romans, and Cipollino Rosso or Africanone to the Italians, it closely resembles the Rosso Antico of the Mani Peninsula.[160] The white marble was also used in Classical antiquity. It has actually been identified among the marbles used to decorate the Mausoleum at Halicarnassus. These marbles are part of the Menderes massif, and are probably of Palaeozoic or Mesozoic age.

Patmos

The small island of Patmos is the northernmost of the Dodecanese (Fig. 14.1). It is also the holiest to Christians, and one of the driest. Little is known of its early history, but it seems to have been inhabited from Mycenaean times. In Classical Greek times a temple of Artemis is recorded where the monastery now stands, and a temple of Apollo by the harbour. The Romans used Patmos for deporting political exiles, such as St John the Divine who arrived here in AD 95. During his exile he is said to have composed the Book of Revelation in a cave on the hill below the present monastery. Churches were built on the island from the fourth to the sixth century; but in the seventh century Patmos was deserted as a result of the unceasing assaults of the Arabs. This changed in 1088 when Christodoulos built a monastery in honour of St John on the high ground above the cave.

Patmos is an irregularly shaped island made up almost exclusively of volcanic rocks, but the island is not now volcanically active. The rounded hills of weathered volcanic rocks contrast strongly with those of the metamorphic islands to the north and west and the young volcanic islands to the south. The island is situated on the edge of a shallow shelf projecting from the Turkish coast (Fig. 14.1). There do not appear to be any major active faults in the area and there are relatively few earthquakes.

The overall structure of Patmos is that of a graben: faults running north-west/south-east have cut the island into vertical slices and the central slice has dropped down (Fig. 14.6). The result is that the oldest rocks are exposed at the extremities and the youngest in the middle.[232, 291]

The only non-volcanic rock exposed on Patmos is a patch of marble in the south-west, which is probably part of the Attic-Cycladic metamorphic belt. However, this patch is isolated from the rest of the island by a fault and it is therefore uncertain whether these marbles are part of the basement on which this volcanic island was constructed.

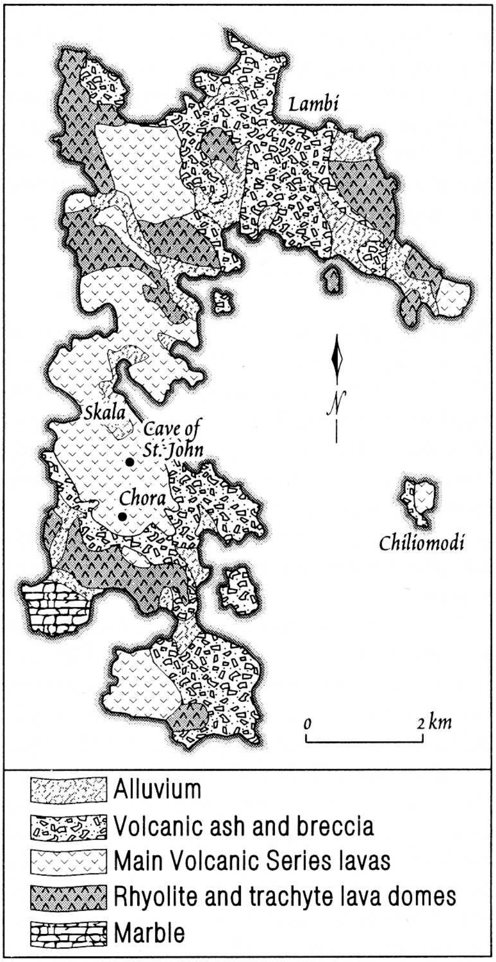

Fig. 14.6. Patmos (after 232).

The volcanism on Patmos is ultimately related to the subduction of the African plate, portions of which are currently about 300 km beneath Patmos.[193] The earliest volcanic rocks are a series of rhyolite and trachyte domes, now seen in the northern and southern parts of the island.[232] They were followed by basalt, trachyandesite and trachyte lavas of the Main Volcanic Series. These rocks were erupted about 7-5 million years ago from several different volcanic vents. The last volcanic activity occurred about four million years ago and produced sodium-rich basalt and phonolite lavas which are exposed on the small island of Chiliomodi, east of Patmos. It is not known which eruption(s) produced the volcanic ash and breccias that cover much of the island.

Skala and Chora

The town of Skala is built on sediments recently shed from the surrounding volcanic hills. The different colours of the rocks in the hills largely reflect their history following crystallisation. Where rainwater, heated by the volcanism, has circulated through the rocks they may be oxidised to pink and red, or finally reduced to clay. Black and brown iron oxides can also be deposited from these circulating waters.

The path from Skala towards Chora leads past the 'Cave of St Anne', where St John is said to have written the Book of Revelation. The cave is a natural overhang, produced by the erosion of weaker underlying rock, which has been artificially enlarged. The bedrock is part of a thick flow or dome of trachyandesite lava containing large crystals of plagioclase and biotite. The clefts attributed to the voice of God appear to be joints in the rock produced either by contraction during cooling or by reduction of pressure following the erosion of overlying rocks.

The town of Chora lies round a monastery 152 m above sea-level. This hill is the remains of the volcano that produced the surrounding trachyandesite lavas of the Main Volcanic Series. Erosion has reshaped the volcano and in some places may have removed large amounts of rock. The buildings of Chora are largely constructed of the lavas which form the bulk of the hill.

Lipsos, Leros and Kalymnos

Although these three islands lie between the largely volcanic islands of Patmos to the north and Kos to the south they contain no volcanic rocks (Fig. 14.1). Instead they are dominated by Triassic to Jurassic limestones of the Pelagonian zone. The basement on which these limestones were deposited is exposed on Leros, where these schists make up most of the interior of the island.[134] These rocks weather more readily than the limestones and produce a better soil, which accounts for the fertility of Leros.

Kos

The island of Kos is second in importance after Rhodes in the Dodecanese. It is the best watered of all the islands. Along the north side is a fertile coastal plain, which grows cereals, fruit and vegetables. Further south, a mountain range runs the length of the island. It was famous in antiquity for its springs, which were used for medicinal purposes even before the time of the great Hippocrates, the father of Greek medicine (*c.* 460-357 BC).

The early history of Kos parallels that of Rhodes. There was prehistoric occupation on the site of present-day Kos town, where there is an excellent harbour; but when the Dorians arrived around 1000 BC, they made their capital far to the south, near the present village of Kephalos. Here Hippocrates would have lived and worked. In 366 BC the capital was transferred to the site of modern Kos town. With its excellent harbour it soon became a great maritime power, and the island also became famous for its wines and silks. However, the great feature of Kos was the Asklepieion, or Sanctuary of Asklepios, the Greek God of Healing.

Kos is separated from Kalymnos and the Bodrum peninsula by a shallow underwater shelf (Fig. 14.1). To the south-east of the island the sea-floor descends rapidly into a small basin, which is part of an important graben stretching from the Cretan Sea via the gulf that separates the Bodrum and Datca peninsulas in Turkey. The frequency of earthquakes and the presence of hot springs, as well as the recent volcanism, attest to the presence of active faults in the area.

The central highlands of the island, including Mt Dicheos (Mt Oromedon; 847 m), are dominated by schist and marble, probably part of the Menderes massif of the Turkish main-

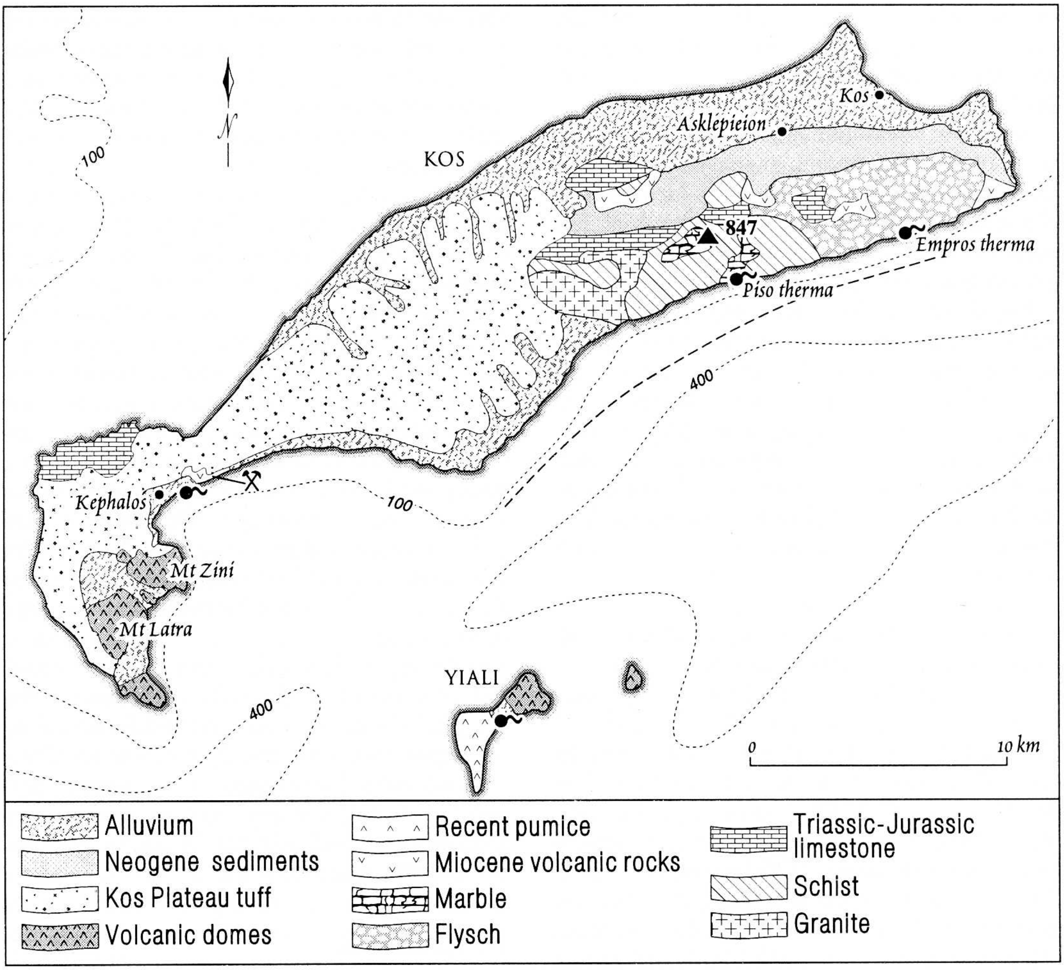

Fig. 14.7. Kos and Yiali.

land (Fig. 14.7). Triassic to Jurassic limestones and flysch lie on top of the metamorphic rocks and are exposed in the central and north-western parts of the island. They are covered in turn with a series of Neogene sediments, exposed on the northern slopes of the Dicheos range and beneath recent volcanic rocks on the plateau to the west.

Volcanic activity started on Kos about 10 million years ago during the Miocene period,[27] as part of a widespread zone concentrated in the north-western part of Turkey. The volcanism is probably related to subduction of oceanic crust further south, with the magmas guided to the surface by the faults of the Neogene grabens that figure so importantly in the history of the Aegean.

The earliest product was a thick, widespread ignimbrite (welded tuff) which is exposed sporadically over the whole island. This rock was quarried extensively near Kephalos bay for construction of the substratum of Hellenistic temples and parts of the Asklepieion.[39] Some magma never reached the surface but crystallised as monzonite, a granite-like rock, exposed today south of Pyli.[6] Erosion then reduced much of the western part of Kos to a plain close to sea-level, but preserved highlands in the east and west. This plain was then lifted up, along with the rest of the island, at some time before the eruption of the Kos Plateau tuff (see below).

The most recent phase of volcanism, and the most important, began about three million years ago with the eruption of two large domes of rhyolite on the Kephalos peninsula at the south of the island.[204] These domes are still relatively uneroded today, with the peak of Mt Latra at 428 m. Volcanic activity continued with the eruption of pumice from a vent in the bay of Kamares 550,000 years ago.[51] This eruption ended when the magma chamber was empty and the overlying, now unsupported, crust collapsed into the cavity along a circular fracture to produce a caldera (see Thera below in Chapter 15). During the final phase rhyolitic magma oozed up the southern part of this fracture to produce the Mt Zini dome.

The most recent eruption occurred 145,000 years ago and was one of the most powerful eruptions in the eastern Mediterranean in recent times: 35-55 cubic km of volcanic ash was erupted covering an area of 5,000 square km.[50] This enormous amount of material did much to shape the landscape of Kos, as its products (the Kos Plateau tuff) blanket most of the western part of the island. Pumice from this eruption also covers the islands of Kalymnos, Tilos and Chalki, as well as parts of western Turkey. The vent has not been located, but is thought to lie in the sea between Kos and Yiali, though at the time of the eruption there must have been land here.

The eruption had several phases: the first was plinian (see Thera) and produced a layer of fine pumice about 30 cm thick. This was followed by another explosive phase which produced a series of well-bedded pumice deposits about 3 m thick. These rocks were deposited from surges of hot, dust-charged gas moving at great speed from the volcanic vent. Finally, the eruption developed its full fury and produced a deposit of volcanic ash up to 30 m thick. This phase initially produced relatively fine pumice from hot gas and dust-charged flows. The increasing size of blocks of pumice (up to 40 cm) and rock (up to 3 m) torn from the sides of the volcanic conduit and ejected with the pumice in the later deposits indicates that the violence of the eruption reached a maximum towards the final stages. This mighty eruption culminated in the production of a caldera 5-12 km in diameter between Kos and Yiali, which was invaded by the sea.

Kos has been well known since ancient times for its springs. The hottest (45°C) are on the south-east coast at Piso Therma (Ayios Irene) and Empros Therma (Ayia Phokas). They are unrelated to the recent volcanic activity in the west, and are channelled up a major fault running parallel to the coast. Cool sulphurous springs, gas vents and hydrothermally altered, sulphur-rich rocks occur on the western part of the island near Volcania, north-west of Kephalos.[22] Gas vents also occur in the sea nearby at 'Paradise Bubble Beach'. These features may be related to the presence of a shallow magma chamber and there may be potential for geothermal energy in this area.

The city of Kos is built on recent alluvial sediments shed off the hills to the south. The Knights' Castle was constructed from a wide variety of materials mostly recycled from the ancient town. Two types of rock, a green tuff and a pink, big-feldspar trachyandesite, were probably obtained from the Mausoleum at Bodrum on the opposite coast.

The Asklepieion

The Asklepieion was started about 350 BC, soon after the inauguration of the new capital, on the site of a sacred spring 5 km south-west of the city. The sanctuary took a long time to complete; in its final form it occupied three terraces with a dramatic vista over the sea. It was in fact a sort of health centre, where the precepts of Hippocrates were followed. Although various religious practices were also observed, the Asklepieion was a much more scientific institution than Epidauros. The sanctuary continued into the fourth century AD. When it was destroyed by a terrible earthquake in AD 554, the Temple of Asklepios had already been converted to a church.

The Asklepieion was built on a series of terraces at the foot of Mt Dicheos. Most of the upper parts of this mountain are made of Triassic-Jurassic flysch and limestone, but lower down, south of the Asklepieion, the bedrock is Neogene sediments, including conglomerates, sandstones and limestones, all of which crop out at the site. The Dicheos range has been recently uplifted along a fault that runs east-west, along the base of the mountains, near the site of the Asklepieion. The famous medicinal springs may have been forced to the surface along this fault.

The cold springs debouche towards the lower part of the site and have coated the ancient fountains in travertine. The original springs must have formed travertine terraces on these slopes, most of which were quarried for construction materials in antiquity. Some of the travertine blocks in the walls have abundant plant fossils. The springs are now dry, except in the winter, but were perennial in antiquity. These changes probably reflect deforestation of the slopes of Dicheos, which has increased run-off and hence reduced the amount of water that can soak into the rocks.

The sanctuary was largely constructed of local travertine and limestone, partly quarried from above the site, and a pink tuff, also used for the reconstruction. The tuff is a Miocene ignimbrite that covers much of the island. It was extracted from quarries in western Kos, on the coast immediately east of the Bay of Kephalos.[39]

Yiali

The volcanic island of Yiali lies between Kos and Nisyros, but it is a separate volcano (Fig. 14.7).[62] Although undoubtedly built on a non-volcanic basement, no pre-volcanic rocks are exposed. The island is composed of two volcanic units joined at a narrow waist.

The north-eastern part of the island consists of a lava dome 24,000 years old, with a core of obsidian and a rind of perlite. The obsidian is quite distinctive: black with white spots. The spots are spherulites, areas of the glassy obsidian which have started to crystallise: The tiny crystals all point outwards from the original point of crystallisation, giving a radial structure. They reflect more light than the surrounding glass and hence appear paler. This rock was occasionally used by Minoan craftsmen for stone vases. However, unlike the extensively used black obsidian of Melos, it was not suitable for making blades.

The south-western part of the island is composed of sedimentary rocks and pumice. The presence of these sediments at elevations up to 140 m above sea-level indicate that the island has been strongly uplifted by tectonic forces. The pumice has not been dated but must be very young as it covers soils containing Neolithic implements.[136] The pumice is mined in large quantities for lightweight concrete aggregates and other uses, such as 'stone-washing' jeans. Warm springs (14-33°C) issue underwater, just off Yiali bay, around the pumice loading terminal.[272] Iron oxides are being deposited from these waters, a phenomenon similar to that seen around the Kameni islands (see Thera below in Chapter 15).

Bodrum peninsula

The ancient city of Halicarnassus (now Bodrum) was founded by Dorian Greeks at around 1000 BC. They integrated with the local Carians and produced a mixed population, which was eventually absorbed by the Ionians from further north. In about 550 BC they were conquered by the Persians and, apart from a brief interval in the fifth century BC, were part of the Persian Empire until liberated by Alexander the Great in 334 BC.

One of the great Halicarnassians was Herodotus and another was Mausolus, a Carian and Governor of the Persian province of Caria in the fourth century BC. A great admirer of things Greek, in 377 BC he transferred his capital from Mylasa to the Greek city of Halicarnassus. He rebuilt the city on a much larger scale, including a palace (which no longer survives) of brick with facings of Proconnesian marble. And he built for himself a tomb, known later as the Mausoleum, so magnificent that it was classed as one of the Seven Wonders of the Ancient World.

The Bodrum peninsula lies on the northern edge of an east-west graben that extends deep

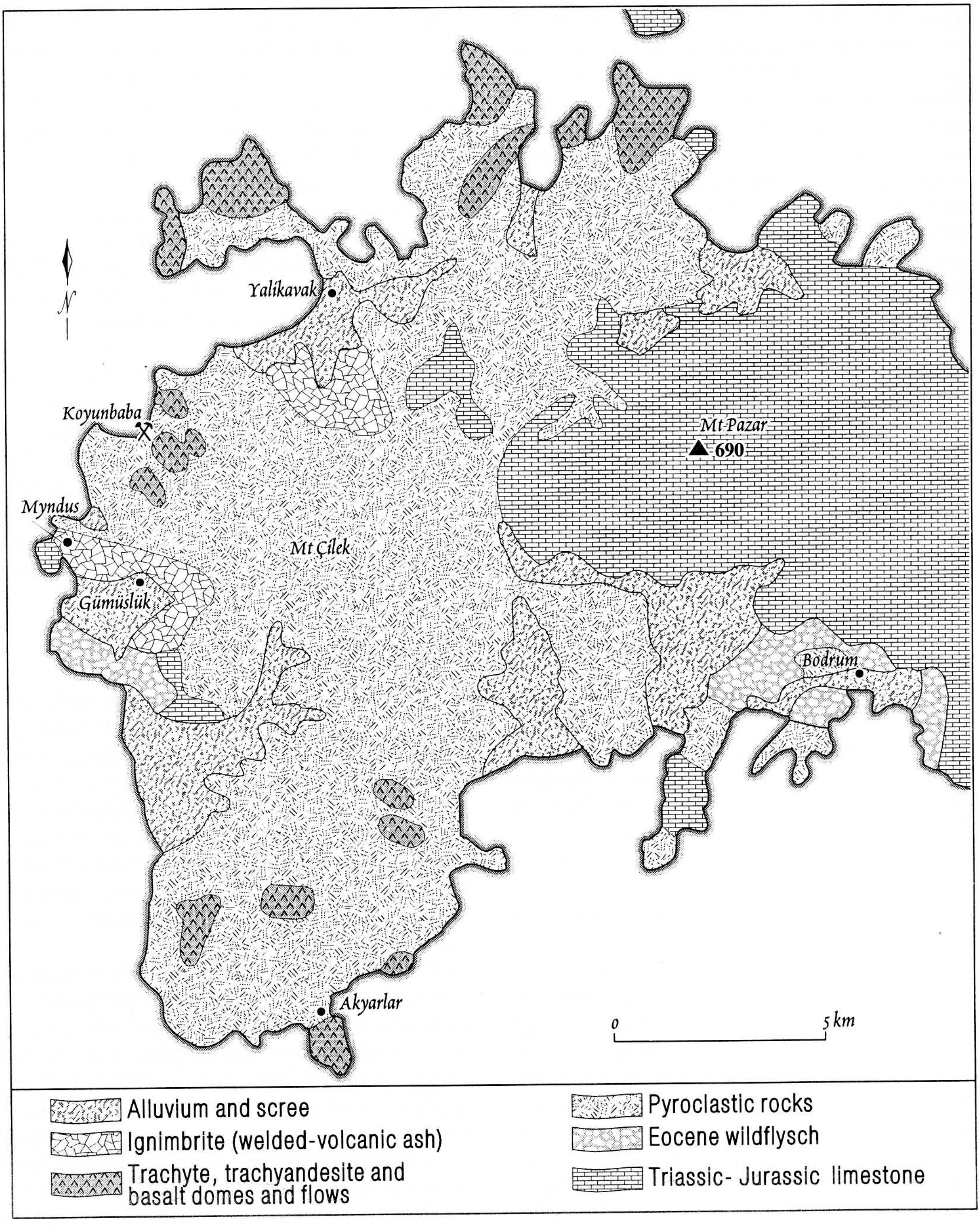

Fig. 14.8. Bodrum peninsula (after 233).

into the continent (Fig. 14.1). In the east the main graben fault lies to the south of the peninsula, but further west it passes south of Kos. The sea to the north is shallow, less than 100 m, and is part of the continental shelf.

The exposed basement of the Bodrum peninsula is dominated by limestones (Fig. 14.8). The oldest are a series of pale, massive, shallow-water limestones of Late Triassic to Jurassic age. Later on the water deepened and yellow to grey limestones with layers rich in chert were deposited. Finally, during the Late Cretaceous, a rock with the delightful name of wildflysch was formed. This is a series of shales and sandstones with included blocks of limestone up to 500 m long. Active faults produced underwater cliffs of this older limestone. Underwater landslides then broke off blocks and transported them to deeper water where the shales were accumulating. These limestone blocks are important from a geomorphological viewpoint as they are harder than the shales and strongly shape the topography (see below). None of these rocks is thought to be in its original position, but to have been thrust onto the older rocks of the Menderes massif during the Eocene compression of the region.

These older series of rocks are covered by Miocene volcanic rocks, a southern extension of a broad swathe of Miocene volcanism that extended from the eastern Aegean to western Turkey (see Kos above). Bodrum is the only one of these Miocene volcanic centres that has conserved its volcanic structure against the forces of erosion.[233] This volcano is made up of about 500 m of pyroclastic rocks, mostly block and ash flows, together with some lavas. Most of these rocks were intensely altered by circulating hot water, probably soon after their emplacement. Alteration is most intense north and west of Mt Cilgri, beneath the original volcanic centre. The volcanic rocks range in composition from basalts to rhyolites, but were dominated by trachyandesites. The main phase of volcanism appears to have been rather short, about 10-9 million years ago.[233] In places erosion has revealed plutonic rocks that originally crystallised underneath the volcano. Since then the region has not been volcanically active, although parts of the peninsula are covered by ash from the eruption of Kos 145,000 years ago.

The city of Bodrum

The bedrock geology has controlled the local topography around the city of Bodrum (Fig. 14.9). The hills to the north and east of Bodrum are made of Jurassic limestone which is resistant to erosion. This same rock can been seen in the slabs used to pave some of the streets of Bodrum. Many surfaces are covered with fossil animal tracks, probably from worms, some in the form of rosettes. The basin in which the city lies is underlain by soft, easily eroded Late Cretaceous shale. Within these shales are blocks of Jurassic limestone up to 500 m long. These blocks are again more resistant to erosion than the shales and stand up as small hills, one such hill making up the peninsula on which the castle stands. The harbour has formed by erosion of shale between this block and another that makes up the adjacent headland.

The peninsula to the south-west is made of

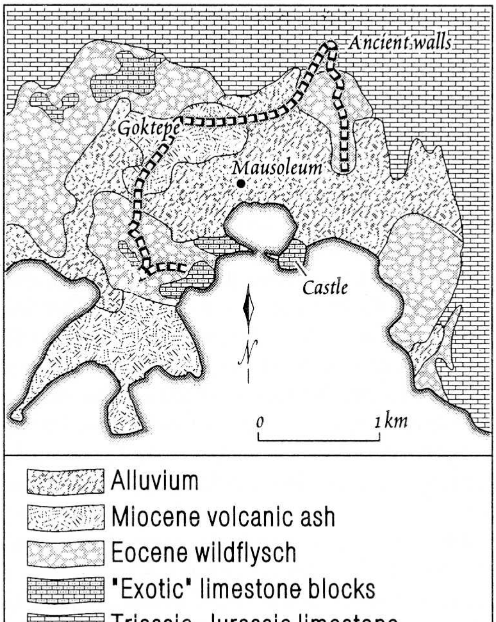

Fig. 14.9. Bodrum town.

younger volcanic rocks, mostly block and ash flows, as is the hill of Goktepe to the north-west. These beds of ash are nearly horizontal, suggesting that they are the erosional remnants of a much larger volcanic pile. Numerous tombs have been cut into the upper parts of the hill of Goktepe, because the ash is so easily excavated and the resulting caves are dry.

Near the western point of the harbour there was a spring, reputed in antiquity to induce effeminacy (a view doubled by Strabo). It is difficult to test this quality as rising sea-levels have drowned this spring and it now bubbles up in the sea adjacent to the lighthouse fenced off in the military reserve. Perhaps the military still believes in its effects!

The Mausoleum

The Mausoleum was started by King Mausolus in 355 BC and completed by his wife and other relatives. It probably measured about 32 m square and 55 m high, but most reconstructions are very conjectural. It survived more or less intact until the thirteenth century AD, but was reduced to ruins by an earthquake some time before the arrival of the Knights of St John in 1402. They used the ruin as a quarry to build their castle at Bodrum (as Halicarnassus was now called). A certain amount of fragmentary sculptural and architectural decoration has been recovered from the castle and used, together with ancient descriptions, to make numerous reconstructions of the monument.

The bedrock in the area of the Mausoleum is a white poorly-welded tuff either from the eruption 145,000 years ago between Kos and Yiali (see Kos above) or from the Bodrum volcano. This rock was occasionally used as ashlar blocks. In places the builders of the Mausoleum excavated down through this rock into the underlying ancient soil and the Bodrum shale. Good sections can be seen in the pre-Mausolus tomb chamber.

The foundations and the core of the platform on which it stood were of a Miocene green tuff extracted from quarries near the modern Koyunbaba, on the western coast of the Bodrum peninsula north of Gümüslük. These quarries were developed down to sea-level, but subsidence of the land has since partially drowned them. This rock contains many fragments of older volcanic rocks, set in a poorly sorted fine-grained green matrix. It is moderately well welded, but is easy to cut. It made a good material for the interior of the building, but weathers easily when exposed to the elements, as can be seen at the castle.

The upper parts of the building were sheathed in marble and decorated with marble sculptures from a wide variety of different sources: Penteli, Paros, Iasos, Phrygia (central Turkey) and probably other nearer sources. The lower parts of the building were covered in a local grey limestone from quarries in the surrounding hills.

The peribos wall was partly constructed from a coarse-grained pink trachyandesite, with large feldspars up to 4 cm long. This rock occurs in rounded hills in the south-west of the peninsula and small rocky islets towards Kos (Fig. 14.8). These hills are lava domes or subvolcanic intrusions. No quarries have yet been located, and it may have been extracted from surface boulders.

The Castle of St Peter

The Castle of St Peter is built on a block of Late Cretaceous limestone, transitional to marble. The contact with the Bodrum shales, within which this block 'floats', can be seen on the east side of the peninsula. The castle was constructed of a variety of materials, but a dominant rock is the green tuff that originally comprised the core of the Mausoleum. The Knights also used blocks of pink trachyandesite, grey limestone and marble, mostly also from the Mausoleum.

Knidos and the Datca peninsula

About 1000 BC Dorian Greeks established a city on the tip of the Datca peninsula, which they named Knidos (Fig. 14.1). With two excellent harbours, the city grew rich from colonisation and commerce and was generous in support of the Sanctuary at Delphi. By the end of the fourth century BC, Knidos was famous for its medical school, its astronomical observatory, its Temple of Aphrodite with the famous cult-statue by Praxiteles, and its wine.

The Datca peninsula is separated from the Bodrum peninsula to the north by a deep gulf (Fig. 14.1). This gulf, together with the lowlands further inland, is a graben similar to those that form some of the valleys to the north (see Pergamon, Ephesus and Priene above in Chapter 13). It was formed as a result of the stretching of western Turkey in a north/south direction during the Neogene period. There is probably another graben to the south, making the Datca peninsula a horst.

The Datca peninsula divides into two parts, both geologically and topographically. The highlands of the western part of the peninsula, including the ancient port of Knidos, are made of sedimentary rocks, dominantly limestones, of Late Triassic to Eocene age. The eastern part of the peninsula is dominated by peridotites and their metamorphosed equivalents serpentinites, which are part of an ophiolite complex.

Explosive volcanic eruptions on Nisyros, 18 km to the west, showered the peninsula with up to 40 m of ash.[77] Much of this was rapidly eroded, but some has remained in valleys, particularly around ancient Knidos and the village of Cesmekoy, 10 km to the east. Pumice also fell in the sea and was floated onto the beaches of the peninsula, where it forms deposits up to 1 m thick, with blocks as large as 50 cm in diameter.

Nisyros

The small, almost circular, island of Nisyros lies off the Turkish coast, opposite Knidos (Fig. 14.1). The land rises steeply from the shore to the rim of a huge volcanic crater, 4 km in diameter, filled with smaller craters and a high volcanic cone and smelling strongly of sulphur. Nisyros was celebrated in antiquity for its hot springs, its millstones, and its excellent wine. It is also noted today for the almond trees which cover the hillsides.

The early history of Nisyros is not known, but it is mentioned by Homer as taking part in the Trojan War. In the fourth century BC the city possessed a fine circuit wall with square towers and gateways, much of which has been preserved. In the Middle Ages the Knights of Rhodes built a castle here, which still survives, though ruined. The subsequent history of the island is that of the Dodecanese in general.

Nisyros is the easternmost active volcano of the South Aegean volcanic arc, with much potential for further explosive eruptions in the future.[252] It has the classic form of a stratovolcano with a large central caldera, almost half the size of the island (Fig. 14.10). The last eruptions were phreatic (steam) explosions in AD 1887.

Older sedimentary and metamorphic rocks are not exposed on the island, but their presence as xenoliths in the lavas and at a depth of 700 m in a drill-hole indicates that the island was built on continental crust like the other islands of the South Aegean volcanic arc. The basement is probably a horst extending out from the Datca peninsula to the east.

Volcanic activity probably started on Nisyros about 200,000 years ago with the eruption of lavas underwater.[62, 280, 292] These rather untidy rocks are exposed immediately to the west of the village of Mandraki: rounded, pillow-like blocks of black andesite float in a matrix of smaller blocks and fine-grained yellowish material. The pillows in this rock indicate that it formed by an underwater eruption. The matrix is devitrified and altered volcanic glass. The next eruptions had exactly the same chemical composition, but were erupted on land, and hence had a very different physical appearance. They can be seen as a few relatively thin flows above the pillow lavas.

Most of the island is covered with lava and tuff deposited by a number of explosive eruptions 66,000-10,000 years ago. They range in composition from andesite to dacite and contain crystals of plagioclase (pale), pyroxenes (brown to black) and other minerals. These eruptions created an island about 7 km in diameter and 1,000 m high. This phase finished with a major eruption: loss of magma from a magma chamber beneath the volcano was followed by collapse of the central part of the island into the chamber and the formation of the caldera seen today. We do not know when this occurred, but it must have been quite

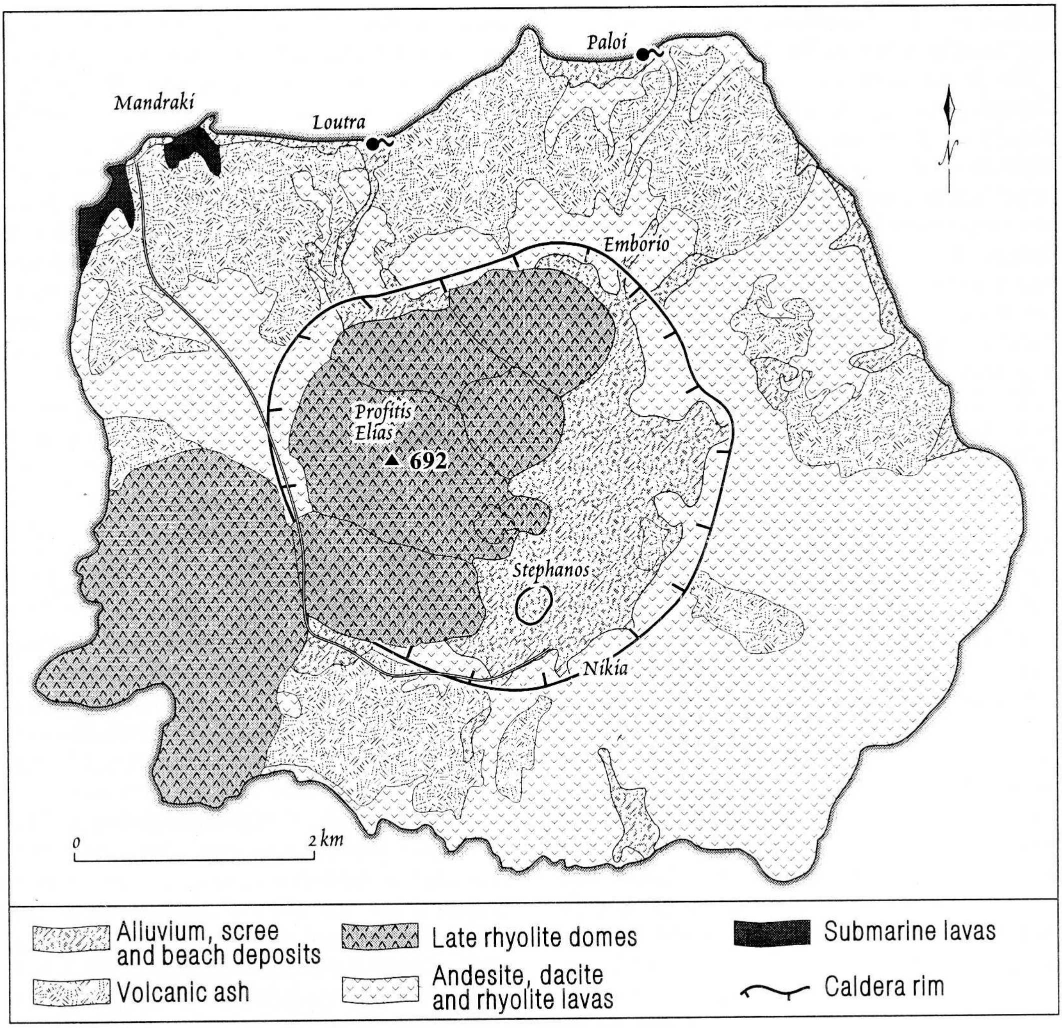

Fig. 14.10. Nisyros (after 280).

recently, possibly 10,000 years ago.

Since the formation of the caldera several very large dacite lava domes have erupted and flowed both away from the caldera and into the caldera, half filling it. These domes are really very short, thick lava flows (1 to 3 km by 500 m) and can form very quickly – within a few months or years. A similar dome has formed in the crater of Mt St Helens, USA, since the catastrophic eruption of 1980. No volcanic ashes have been found, so it likely that these eruptions were relatively quiet. The rocks are very rich in crystals of plagioclase (pale) together with minor pyroxene (dark). The steep slopes of the domes, the presence of volcanic spines up to 7 m high and the lack of soil all indicate that these domes are very young, possibly as little as 1,000 years old.

The most recent activity is the formation of small craters on the floor of the caldera by phreatic (steam) explosions. Some of these craters are only a little over 100 years old (see below) and formed in the following way. The process started when rainwater seeped into the loose sediments of the caldera floor. As the water descended it was heated by the hot rocks surrounding the magma chamber until it turned to steam. The force of the steam pushed up and removed some of the overlying rocks and hence lowered the pressure at depth. The reduced pressure then lowered the boiling point of the water, which had been increased by the pressure, and turned it instantly to steam. Geysers, as seen in Iceland and elsewhere, are produced by exactly the same agency, which is similar to opening a pressure-cooker without first reducing the pressure.

There are many fumaroles on the caldera floor and on some of the lava domes. These emit superheated steam (hotter than 100°C) together with other gases, including hydrogen sulphide ('rotten-egg gas'). When these gases meet the atmosphere the hydrogen sulphide is oxidised and forms needles of sulphur, which crystallise around the vents and in the rocks. Nisyros was an important source of sulphur, both in antiquity and during the eighteenth century.

Several warm, saline springs occur along the northern and southern coasts. The source of water for the springs is the sea, which descends along faults, is heated by residual volcanic heat or the normal increase in temperature with depth, and rises up other faults.[65] Two springs on the north coast, at Loutra (47°C) and Paloi (40°C), have both been exploited recently by spas, now defunct, and there is currently no access to the springs. Hot, humid air vents from the ground just below Emborio, to the north, forming a natural Turkish bath.

Mandraki and environs

The oldest rocks on the island crop out to the west of Mandraki and underlie the Kastro (Fig. 14.11). These rocks weather readily and the cliff under the Kastro has been reinforced with brown cement painted with yellow lines, just to confuse the unwary. The other side of this promontory shows many ancient sea-level stands, indicating recent uplift. The most obvious is a wave-cut platform at 2 m, but there are notches at up to 15 m. This is the only part of the island where there is such evidence of uplift.

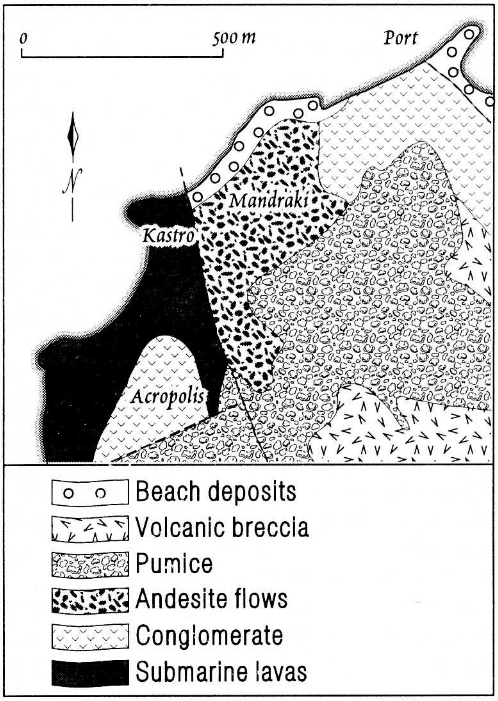

Fig. 14.11. Mandraki (after 280).

The Kastro itself was constructed from a variety of different volcanic rocks, but the favoured material was a beige welded pumice tuff, presumably because it was so easy to cut. However, like many weak materials, it is also easily eroded. As elsewhere, the Knights did not build for posterity, but considered speed of construction more important.

The ancient acropolis lies on Palaeokastro hill, above and to the south of Mandraki (Fig. 14.11). The hill is made of erosion-resistant andesite lavas that cover the submarine volcanic rocks of the Kastro. The walls of the acropolis were beautifully constructed from these lavas, quarried on the site itself. Blocks of marble from the acropolis must have been imported, probably from the mainland.

The track to the caldera

A very interesting walking track leaves from near the acropolis for the caldera (Fig. 14.10).

The first kilometre goes over pumice, block and ash flows, and small lava flows. At a point where the track turns sharply from a westward direction to the south there are three lava tubes, just upslope. The first is about 2 m wide and 5 m deep, and preserves all its original features, the second has been converted into a cistern and the third, although intact, is very small. This ridge is formed by a series of andesite lava flows. Such lavas tend to flow in tubes, which are commonly drained as the flow of lava diminishes.

The track climbs over the caldera rim to a pass between the post-caldera lava domes, actually within the caldera. The volcanic spines visible on the domes are produced when molten lava is squeezed out like toothpaste from between solid blocks on the exterior of the dome. Such spines topple easily, so their presence indicates that the domes are very young.

As the track leaves the pass the scenery changes: the steep slopes of the domes are replaced by more gentle slopes of lava and volcanic ash formed before the caldera. Finally the track recrosses the caldera wall and the floor of the caldera, with its phreatic explosion craters, is visible.

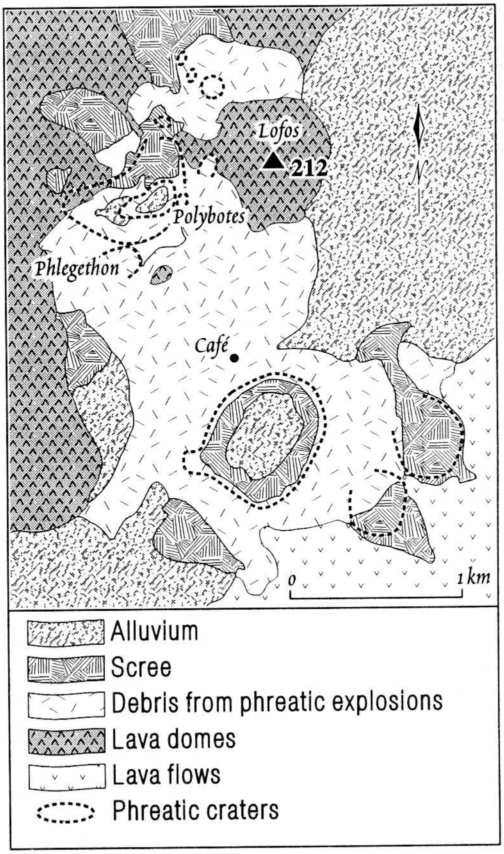

Fig. 14.12. Nisyros caldera (after 170).

The caldera and craters

Much of the floor of the caldera not filled by the domes is a gently sloping plain, covered by sediments washed from the walls (Fig. 14.10). But in the south there are many phreatic explosion craters, both in the floor and the walls of the caldera and in the volcanic domes (Fig. 14.12).[170] The floor of the craters is generally flat, covered with sediments washed in since the explosion. The state of erosion of the sides gives an indication of the relative age of the craters.

The largest of the phreatic craters, Stephanos, is about 300 m in diameter and 25 m deep (Plate 12B), but it is not the youngest as the more recent craters lie about 700 m to the north, at the base of the main lava domes. Here several smaller lava domes have been partly destroyed by many phreatic explosions. The walls of the largest crater here reveal a long history of repeated phreatic explosions in this area, and there is no reason why this will not continue in the future.

The phreatic eruptions of the nineteenth century have been well described.[170] In late 1871 a violent earthquake took place, followed by phreatic explosions. Two small craters opened up: Polybotes, in the Polybotes Megalos depression, and another on the southern side of the Lofos dome, Phlegethon (Fig. 14.13). Activity recommenced in 1873 again with an earthquake. Initially rocks were ejected and hot brine flowed from the crater. Soon, however, this was replaced by dark mud, which flowed from both craters onto the plain for three days. The area of this flow is known today as Ramos, 'burnt area', as the high sulphur content of the material, and lack of soil, restrict plant growth. Another explosion occurred in

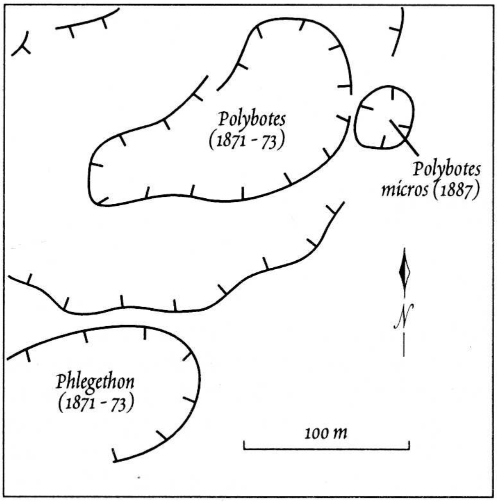

Fig. 14.13. The craters Polybotes, Phlegethon and Polybotes micros in Nisyros caldera.

1887, in the eastern part of the crater area. This produced a small crater, Polybotes Micros, about 20 m in diameter.

There are fumaroles in almost all the craters, but there are also steam vents in the centre of Stephanos, which do not deposit sulphur. In the winter rainwater flows into this crater as it is the lowest point in the caldera. The water is heated by the gases from the fumaroles and boils, producing the steam vents.

Two wells were drilled near the craters to depths of 1.5 and 1.8 km during the 1980s to determine the potential for the generation of electricity from geothermal energy. Although the holes tapped very hot water in suitable quantities (up to 210°C), environmental and political considerations have prevented the exploitation of this resource.