REPORT

Carrara Marble

The most famous decorative stone in the world: what other stone might contest this claim? Larvikite clads banks around the world, and there are some spectacular granites used on counter tops, but only marble has been favoured for so many decorative uses. It is worked for many external and internal architecture structures and features, as monuments and gravestones, as household ornaments and objects, and into the finest statuary. The exceptional fame of the perfect, white marble of Carrara stems from an ideal combination of geology, location, topography, history and human physical endeavour, leading to its great output over the millennia, providing material for some of man's finest artistic and architectural achievements.

***Figure 1**. Location of Carrara in northern Italy.*

Marble

Marble is a fairly common rock, with one of the simplest geological definitions – metamorphosed limestone or dolostone – in which sufficient of the carbonate grains have recrystallized to largely obscure or obliterate the original sedimentary structures, texture and fossil content, but the essential mineralogy is unaltered. This generally means metamorphism to the lowest, greenschist, facies with typical temperatures of 300–450°C and pressures of 2–10 kilobars (200–1000 MPa). Many marbles are generated by regional metamorphism, during continental collisions and orogenesis, but they also occur at contacts with igneous intrusions. Their huge variety of colours, patterns and structure within occurrences around the world result from their original sedimentary content, their structures, included minerals and impurities, and the variety of processes that they have undergone. However, this heterogeneity can occur at a local scale, and may impart great variability in grain-size, strength and texture, such that extracting a consistent high-quality stone is expensive and may generate much waste.

The most important physical properties of marble as a material are its density, ranging 2.6–2.8 g/cm^3, its compressive strength of typically 50–100 MPa (stronger than most concretes), and its hardness, which is critical to its processing and finishing for so many end uses. Hardness on Mohs' scale ranges from 3 for calcite, to nearly 4 for dolomite. However, this conceals the variability inherent in grain-size, degree of crystal interlocking and flaws that affect cutting, carving and polishing. Certain impurities of very different hardness such as emery (the local quarryman's term for any hard mineral), quartz (as sand grains and chert nodules or veins) and concentrations of layer-silicate minerals (clay and mica) may also affect usability to the extent of rejection, but the last particularly may also impart the colours and patterns that are sought by the client.

***Figure 2**. The Apuan Alps, with white scars formed by the marble quarries, seen from stonemason's yards in Carrara.*

Figure 3. Marble quarries in the Torano Basin, with rubble screes (ravaneti) from the higher one. The Polvaccio Quarry, to the right, was favoured by Michelangelo for his statue marble.

In the Mediterranean region, the use of marble for building and statuary began in classical Greece nearly 3000 years ago, using coarse-grained, grey-blue marble from Naxos (which is still being worked today). The white marble used to build the Acropolis of Athens from the 5th Century BC is from the quarries on Mount Pentelicus, 18 km northeast of the city, but the finest Greek statuary marble, rivalling Carrara, is from Paros, and this was the source for the Venus de Milo.

Architects and stonemasons define marble as a carbonate rock that can be finely carved and polished, so this includes dense limestones that do not comply with the geological definition. In Britain, there are many named marbles, notably Alwalton, Frosterley, Marston and Purbeck, all of which are well-cemented and generally fossiliferous limestones used for ornamental purposes including finely-carved ecclesiastical effigies. True, metamorphic, marbles in Britain include Ledmore and Skye, both of which are early Palaeozoic Durness Group dolostones that have been thermally metamorphosed, by the Caledonian Loch Borallan intrusion and by a Palaeogene granite respectively.

Carrara

Carrara is a small industrial town about 6 km inland from the Ligurian Sea in northwest Tuscany (Figs 1 and 4). The nearby popular seaside resorts have a spectacular backdrop of the jagged ridge of the Apuan Alps (Fig. 2), the slopes of which even in high summer are cloaked in brilliant white – not snow but cliffs and screes of marble. Parallel to but topographically separate from Italy's spinal Apennine chain, the Apuan Alps are similarly a consequence of Alpine orogenesis in Palaeogene times.

Carrara stands in a gap in the Apuan foothills below a confluence that forms the River Carrione. Upstream, three main valleys comprise the 'basins' of the marble quarrying district – from west to east Torano, Fantiscritti and Colonnata. The town is at about 85 m elevation, and the highest summit around the valleys is Monte Sagro, at 1749 m and just 6.5 km away. The neighbouring district, 10 km to the southeast, centred on the towns of Pietrasanta and Seravezza, has also long supplied fine marble, and there is an ancient rivalry. The landscape of the Carrara valleys is now alien – dominated by steep, barely-vegetated slopes cut into by vertical, white and streaked, quarry faces and masked by huge rubble screes (*ravaneti*) that are largely man-made but barely stable (Figs 2 and 3).

Geology of the Apuan Alps

Towering over the Ligurian Sea coast, the metamorphic rocks of the Apuan Alps might appear at first sight to be a tectonic outlier (klippe). However, at least four thrust sheets have been emplaced above the Palaeozoic to Tertiary-age Apuane Unit succession and all have been subsequently uplifted, exhumed and deeply eroded, such that the Unit's outcrop now forms a tectonic window (Fig. 4).

The geological history of northern Italy is dominated by the results of interaction and eventual collision between the European Plate, including the Brianconnais (Iberia plus Sardinia and Corsica) Microplate to the west and north, the Apulia (or Adria) Plate (eastern Italy, Balkans and Greece) in the centre and east, and the African Plate to the south. In Triassic through to Palaeogene times, an arm of the Tethyan Ocean, the 'Alpine Tethys', opened through this region and was eventually occluded. In the late Triassic to early Jurassic, this was a centre for prolonged and substantial platform carbonate deposition (hundreds of metres thick) unconformably on a complex of quartz-muscovite phyllites, metamorphosed porphyritic rhyolites, limestones, dolostones, quartzites and schists probably of Palaeozoic age. Together with a flysch sequence of clastic and carbonate sediments, with minor extrusive rocks, of Triassic to Tertiary age, these formed the foreland on the western edge of the Apulian Plate.

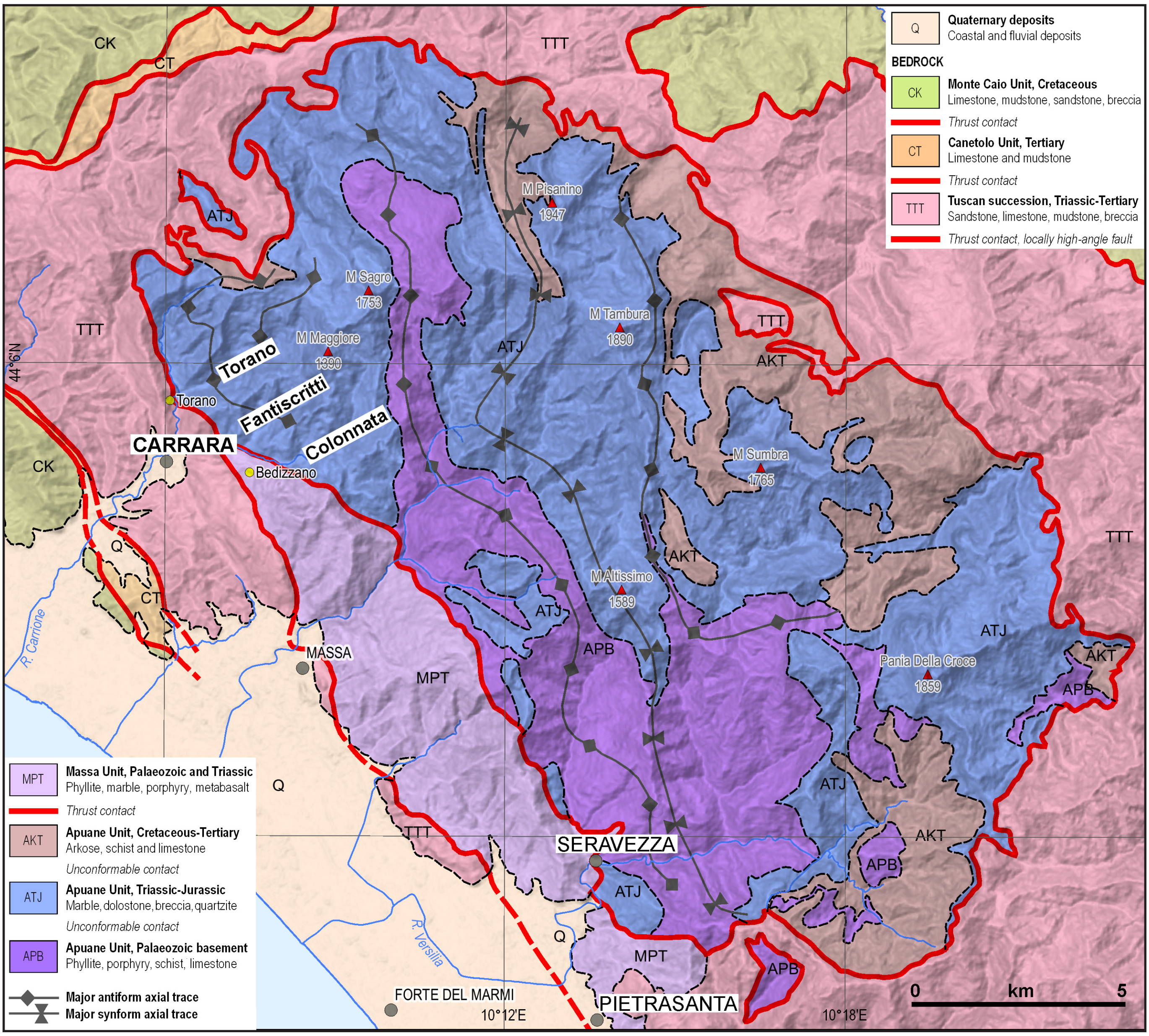

Figure 4. *Generalised geology of the Apuan Alps tectonic window (after Carmignani et al., 2000, and Cerrina Feroni et al., 2004; with background hill-shading from a digital terrain model by NASA).*

Following late Oligocene to early Miocene collision, westerly-directed subduction beneath the Brianconnais Microplate commenced, and compression was largely taken up through multiple episodes of top to east thrusting and nappe formation. Around 27 Ma, the unmetamorphosed Tuscan Nappe (TTT in Figure 4), many hundreds of metres thick, was emplaced to bury this succession sufficiently deeply to develop greenschist facies in the Triassic-Jurassic carbonates. This led to formation of the limestone and dolostone marbles of the Apuane Unit (ATJ) with recrystallization destroying most primary features and textures of the protolith. The overthrusting also formed northeast-facing isoclinal folds and cleavage, and later emplaced an out-of-sequence, more strongly metamorphosed, Palaeozoic to Triassic succession (Massa Unit, MPT) above the Apuane Unit. Transport of further unmetamorphosed thrust sheets (CT, CK) into the Apuan Alps region was followed by extension caused by early Miocene slab retreat, leading to uplift and exhumation of the northern Apennines.

The Apuane Unit Palaeozoic basement (APB) in the core of the Apuan Alps window comprises the oldest rocks cropping out in the northern Apennines. The marble-bearing succession above, although locally overturned, measures more than 1000 m thick. Although it includes breccia layers and chert beds at some levels, it forms a huge mass of potentially workable, fine-grained stone of excellent quality. Relict bedding is represented by dark, clay-mineral layers (Fig. 5) known as *madrimacchie* (master veins) that tend to break apart and enclose *ovuli* (irregular, sometimes egg-shaped pods, commonly tens of metres across) of more homogeneous marble. Within this, the dominant cleavage direction or *verso* tends to dictate the easiest cutting direction (at least for manual chiselling).

The Apuan Alps window is some 24 km by 14 km, with an area of around 300 km^2, of which the marble beds outcrop forms at least half. Even allowing for the deep valley erosion, the marble succession more than 1000 m thick appears to offer several hundred cubic kilometres of stone.

Marble quarrying at Carrara

The history of marble extraction from the Carrara district probably goes back more than 2300 years, which may make it the place in the world that has depended for longest on the ongoing exploitation of a single mineral product. There is radiometric evidence of pre-Roman (Etruscan) quarrying at Fantiscritti, and although the Romans originally took marble from coastal quarries near La Spezia (Punta Bianca), they must have been aware of stories of huge quantities of fine white stone nearby, and they came to Carrara in the 1st Century BC.

Unlike the Greeks, the Romans tended to build with cheap local materials and then clad in marble, but using solid marble for columns and pediments, as well as for carved statues. However, they brought in many Greek techniques for working, handling and transporting the stone, and ingeniously developed cables, cranes, ramps, wedges, levers and other devices. However, these still relied entirely on power from man and beast, along with basic physics (freezing of water, floating of rafts, wind, fire and gravity), and these methods were only incrementally refined through the centuries until the 1800s. The improvement of steel tools was particularly important, as was rope technology.

***Figure 5**. High wall of the Crestola quarry, with steeply dipping bedding features crossed by the working benches.*

***Figure 6**. Re-creation of the sledge transport (lizzatura) in the Marble Museum at Fantiscritti.*

Given that the underlying strata were an apparently inexhaustible mass of almost pure marble, the precipitous slopes of the Carrara basins offered considerable advantages in that the rock was largely exposed at the surface and could be inspected for quality and ease of winning by the quarrymen (*cavatori*). Hence many of the quarries (*cave*, or singular *cava*, whether open pits or underground mines) were, and are, worked into the hillsides rather than excavated downwards, and are nowadays worked in sequential benches (Fig. 5). Quarrying in Italian Renaissance times (14th to 17th Centuries) required roped climbers (*tecchiaioli*) to laboriously chisel round and prise out selected blocks of marble, and ease them down onto wooden runners on beds of rubble. Then the sled men (*lizzaturi*) and cable men (*mollatori*) would control their further descent (Fig. 6) on slopes of up to 60° down to the working area (*poggio*). The perilous *lizzatura* method is celebrated by re-enactment in Carrara every August.

Once the raw blocks were safely at the working area, skilled stone-cutters (*scarpellini*) would rough them out for the intended purpose. This stage included checking the blocks for suitable quality or imperfections (cracks, impurities) that might negate any contract, reducing the weight and size (to ease transport and reduce carriage costs and duties), and marking them for the client or owner. However, they took care not to reduce too far the cross-section of blocks that were to be trans-shipped, to avoid introducing any weakness. Blocks for building or slabs were squared off by a further group of quarrymen (*riquadraturi*).

Blocks were then loaded onto ox-drawn carts. They were measured to calculate weights; one *carrata* (about 850 kg) was the weight two oxen normally drew, and weights of 8 *carrate* were fairly commonly handled, very exceptionally over 20, using teams of oxen. The loads were drawn down rough tracks to the yards or through the town the further 6 km to the beach for shipping; overland transport, even for the 50 km to Pisa, was uneconomic.

Figure 7. A recent image of a bench currently being worked in the Crestola quarry, with faces that have been cut by crawler-mounted chain-saws.

Figure 8. An older image of stacked marble blocks that had been cut out with wire-saws and the use of line-drilling.

There was no quay at Carrara until the late 1800s, so loading the blocks onto boats drawn up onto the sand involved further effort by men and oxen, along with mechanical ingenuity. The local tidal range of up to 40 cm provided some assistance, but the boat size and type was a compromise between handling and loading, and seaworthiness (marble was exported at least as far as London). For Pisa and Florence (up the River Arno after a sea journey of 43 km) or Rome (320 km by sea, then up the Tiber), the boats would navigate the rivers (often assisted by draught animals), preferably on the higher water levels of winter, so timing was important. Larger blocks might be slung between two boats, further testing the skills of the seamen. Unloading at the river ports, and transport to the client's yard, were similarly problematic, although the smaller blocks might have been craned off boats onto carts at Pisa from the 1500s. However, marble blocks were commonly damaged in accidents, or were stained and spoiled by long stays exposed on sand or mud. Throughout the Middle Ages, carriage commonly cost much more than quarrying the marble.

Explosive charges in shot-holes were sometimes used from the 1800s onwards, but could crack good blocks, and a greater innovation was the electric-powered wire-saw (a continuous cable studded with corundum or diamond). Transport between and from the quarries was revolutionised by the Marmifera railway network (Fig. 9), which opened in 1876 and was used until 1964 when it was superseded by road vehicles. Trucks now use the extensive system of old railway tunnels, and can also been seen descending the precarious zig-zag tracks from the higher quarries. Mechanical cranes and loaders have also taken over many labour-intensive quarry tasks. Huge rectangular holes cut in quarry walls (Fig. 7) show where blocks of a particular quality, possibly following an *ovule*, have been extracted with the use of crawler-mounted chain-saws and high-pressure hydraulic cushions. Off one of the rail tunnels, deep below Monte Torrione, a huge cathedral-like mine chamber, known as the Cave Galleria Ravaccione, has been excavated (Fig. 10).

One of the largest single blocks of marble ever extracted and moved came from Carrara. In 1926, Mussolini ordered a huge obelisk for the Stadio Olimpico, and a 300-tonne, 17-metre-long block of *bianco* white marble was cut from Fantiscritti and moved on a 50-tonne sledge to the port. *Il monolitico* still stands in Rome.

Figure 9. Ponti di Vara, one of the viaducts on the former Marmifera marble railway.

***Figure 10**. The large underground quarry of Ravaccione.*

***Figure 11**. Samples of Carrara marble on display at the Marble Museum in Fantiscritti.*

Varieties of Carrara marble

Carrara's fame essentially derived from its capacity to supply reliably large quantities of consistently high-quality, white, cream and grey marble, of the types that have always been in demand (Fig. 11). The main varieties of *bianco* (white marble that forms about 85% of production) include *chiaro*, which is pure or flecked white, *venato* (veined), *brouille* (with smoky swirls), and *arabescato* (with streaks and swirls). *Bardiglio* marbles are grey, both plain and streaked, and together with the stones with more colour (including *cippolino* with thin stripes of green and white, bluish and violet varieties, and breccias) make up the remaining 15%. The hardest Carrara marble is from Colonnata, but this isn't necessarily the best for statue carving. Most believe the finest *statuario* is from Cava del Polvaccio in the Torano Basin: it is tight, close-grained, with high brightness (*vivacissimo*), is semi-transparent, easy under the chisel, weather resistant and free of mineral veins (but tiny grains of hard mineral are sometimes found), and is able to yield large blocks of top-quality marble.

Its fame as an extraordinary location drew visitors from early on: after exile from Florence the poet Dante wrote part of his Divine Comedy in Carrara during 1306, and arguably some of the deeper *cave* might have inspired his *Inferno*. Five hundred years later, Charles Dickens also wrote evocatively about Carrara. Many visitors try *lardo*, the local delicacy of pork fat cured in salt, herbs and spices for six months in marble tubs (*conche*). Vehicle tours of the quarries, including underground, are now available from Carrara town.

These days, production of the ninety or so working quarries (divided about equally between the three basins) is around 1.5 million tonnes of squared and unshaped blocks, and more than 2 million tonnes of calcium carbonate for industry. From around the world a further 2 million tonnes of stone comes to the region's yards to be cut, finished and re-exported. However, the many billion tonnes of marble reserves in the Apuan Alps have been barely scratched by the historic and present extraction in the three Carrara basins, and in quarries between Seravezza and Monte Altissimo.

Michelangelo and Carrara

The story of Michelangelo's involvement with Carrara marble starts ten years before his birth. Agostino, protégé of Michelangelo's illustrious predecessor Donatello, was commissioned by the overseers (*Operai*) of Florence's cathedral (*Duomo*) to carve a statue of David (from the Old Testament, and a symbol of Florence), 3.5 m tall, to stand high up on its eastern end. This was intended to be formed in the Roman fashion from several blocks, but in 1465 Agostino travelled to Carrara to source his marble and acquired a huge block of *bianco ordinario* from Fantiscritti. Described as nine *braccia* (over 5 metres) long, and 'rather shallow', its original maximum dimensions are otherwise unknown, but from the resulting statue the block must have been at least 2.2 m wide and 1.2 m deep. As a cuboid block, this would have measured 13.7 m^3, and at least 35 tonnes in

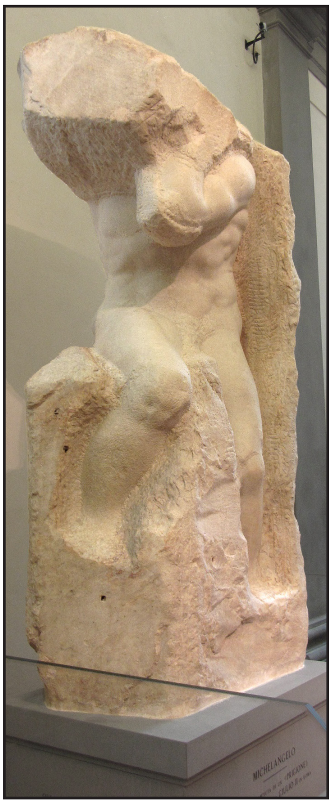

Figure 12 *[left]. The incomplete Atlas Captive, 2.82 m tall, carved by Michelangelo 1520-30, and now in the Galleria dell' Accademia in Florence.*

Figure 13 *[right]. The well-known statue of David, 5.17 m tall, carved in Carrara marble by Michelangelo between 1501 and 1504, now in the Galleria dell' Accademia in Florence.*

weight, an extraordinary mass to convey by *lizzatura*. This would have been roughed out to its intended design at the *poggio*, perhaps into a coffin-shape, but is likely still to have weighed more than 25 tonnes. Carriage to Florence proved problematical, and by the time it arrived in December 1466, Agostino had lost the commission, possibly relinquished on the death of Donatello. The block, now known as *il gigante* (the giant), was further roughed out and 'spoiled' in 1476–7 by Rossellino, and then sat for 25 years being *cotto* ('cooked' by the weather) in the Duomo yard, waiting for its genius.

Born in 1475, Michelangelo Buonarroti was apprenticed at 13 to a Medici-sponsored sculpture garden in Florence. His extraordinary marble-carving talents were spotted early, and he made his first visit to Carrara during 1497, to source a block for a statue of Mary with the body of the dead Christ, commissioned by a cardinal in Rome. He found a large piece of *bianco statuario* from Polvaccio in the Torano Basin (Fig. 4) and the resulting *Pieta*, completed in 1499 and now in St Peter's Basilica, is regarded as one of his most exquisite masterpieces. Over the next 35 years he made at least ten, and possibly over twenty, visits to either Carrara or Seravezza, each more than 100 km from Florence and requiring two or three days hard walking or riding. On occasions he travelled the 350 km from Rome, and some stays lasted many months in the search for many blocks for complex commissions.

In 1501 Michelangelo gained the David commission that was worth 400 ducats (about £50,000 today) and succeeded spectacularly in overcoming the shortcomings of *il gigante*. He is likely to have made models in clay or wax, though not full-sized, but his sculpting methods are famously idiosyncratic. He used a variety of steel chisels that he made himself, mainly a pointed *subbia* for initial work, a three-toothed *gradina* and a flattened curve *unghietto* (fingernail), and also a bow-driven drill (*arco/archo*). Polishing, which might take half of the time, utilised pumice, Libyan chalk, leather and straw, and the 1499 *Pieta* is the most perfectly polished of his sculptures. However, he 'invented' the *non-finito* treatment, with rough, chisel-marked surfaces on parts of completed and delivered works, and he also seems to have developed many of his greatest statues by nearly completing one side before even roughly shaping some other parts. This is most vividly seen in the four incomplete 'Captives' (Fig. 12), intended for Pope Julius II's tomb in Rome, but now in Florence, where for instance a torso is well-polished but limbs or head are raw stone. The image of a figure struggling to escape from the block is extraordinarily arresting.

The David statue was of course completed (Fig. 13), and installed in 1504 in the Piazza dell Signoria. Damaged in a riot in 1527, repaired in 1543, it was moved to the Accademia in 1873 (after 370 years in the open), and a replica was placed at the original site in 1910. The statue weighs 5660 kg, thus Michelangelo removed at least 20 tonnes of marble chips and powder by manual means to 'release' his masterpiece.

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