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News Notes

Geoarcheology

Cracking ancient quarry codes

When a fine eye for art was not enough, museum curators and scientists sleuthed out the identity of ancient marble statues using oxygen isotopes. But comparing a work of art to its source rock was often hit or miss — few quarries have undergone the extensive fieldwork needed to provide a detailed understanding of the area.

Now, a doctoral student at the University of Georgia has completed the first systematic characterization of the Pentelic marble quarries on Mount Pentelikon in Greece, providing a geographically detailed isotopic database that will help source some of the world's most prized Greek antiquities.

Increasing the resolution of the Pentelic database will have a tremendous effect on the field of marble studies, says Scott Pike, who spoke about his study at the Geological Society of America meeting in November. "Archeologists, art historians and museum curators may be able to probe further into questions concerning trade and commerce, development of aesthetic values and modern forgeries, ancient copies and disassociated fragments."

In fact, Pike's work has already helped to pinpoint the small group of quarries that supplied the source rock for the Elgin Marbles — sculptures that adorned the Parthenon as early as the fifth century B.C. Pike first mapped out all of the existing quarries in the ancient quarry region — studying a 500-meter wide and 1.2-kilometer long stretch up the south slope of Mount Pendeli. He then collected multiple marble samples from all the ancient quarries and analyzed the isotope ratios of carbon and oxygen in the calcite, the primary mineral in marble.

Pike noticed that three neighboring quarries in the upper section of the quarry area have marbles with very high oxygen-18 ratios when compared to samples from all of the other Pentelic quarries, ratios that correlate with the published values of the Elgin marbles. "The data not only confirms that the Elgin marbles are Pentelic, we can now pinpoint the exact quarries from which the marble was extracted," he says.

His work has also helped document the unique isotopic differences among quarries found along what Norman Herz, the pioneer of the isotopic technique and now an professor emeritus of geology at Georgia, calls "one of the most important quarry sites in classical archeology."

But isotopic analysis is not always a guarantee of a sculpture's origin. A combination of expertise is needed to pinpoint a marble artifact's origin. Sometimes it does take an expert with an eye for marble to tell the difference. Marble at Cape Vathy on the Greek Island of Thasos has an isotopic signature similar to the Pendeli marble, says John Herrmann, curator of ancient art at the Boston Museum of Fine Arts. The same signature is also found in marble from the island of Naxos. Identifying the different marbles comes down to grain size. Unlike the fine-grain marble of Pendeli, Thasos and Naxos sport coarse-grain



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Rocks of Ages

by Tom Zoellner

In the rugged hills that surround Athens, Greece, a single peak yielded much of the stone that for nearly 2,500 years supplied some of history's most famous sculptors and architects.

That Mt. Pentelikon was the source for such works as the Parthenon was well-known. But now, thanks to a UGA geology student, scholars are closer to determining exactly where on the mountain a given stone originated.

A view of Mount Pentelikon Quarry — the primary marble source for famous historical sculptors and architects — near Athens, Greece.

Photo by Scott Pike



“The ability to identify the source of the marble assists archaeologists, art historians and museum curators in piecing together ancient trade routes, dating artifacts, giving insight into changing aesthetic values and determining modern forgeries,” said Scott Pike, who reported his findings at the 112th annual meeting of the Geological Society of America.

In his doctoral dissertation, Pike divided Mt. Pentelikon into three basic marble units, which he called — in true classical style — I, II and III.

“Each quarry area has isotopically distinct areas,” he said. Using chemical analysis, scientists now can trace many statues and columns to one of these areas.

Pike said he hopes eventually to calibrate his database further, to a point where even specific quarries can be identified as the original home of a given piece of Grecian marble.

“We can increase our understanding of how the marble was quarried from the mountain and how it was transported into the city,” he said. “We may also be able to distinguish between those quarries that were privately owned and those that were public.”

The first large-scale project to use Pentelic marble was the “older” Parthenon. Destroyed in 480 B.C., it was a precursor to the famous temple of the same name that later sat on the same site.

Perhaps the most famous chiseled pieces of Pentelic marble are the Elgin Marbles — the original statues that decorated the later Parthenon — which were taken to England in 1806. They are now on display in the British Museum, despite demands from the Greek government for their repatriation.

The mining of Mt. Pentelikon didn't end in antiquity. Marble quarrying continued up until the early 1970s, about the same time scientists developed ways to measure stable isotopes of carbon and oxygen as a method of distinguishing between types of marble.

Pike's database, the first systematic characterization of the quarries, builds on this science and related techniques pioneered by UGA professor emeritus Norman Herz. The underlying assumption is that calcite — the primary mineral in marble — would crystallize in different chemical environments within each quarry region and thus reflect its own distinct isotopic ratio.

For more information, e-mail spike30030@yahoo.com.

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CULTURE

Tracing the stones of classical brilliance

Demokritos scientists at the cutting edge of research into geographical origin of marbles



Confident claims about the genesis of much of the marble used in the famed classical sculptures and buildings can now be made, thanks to a scientific technique developed over the past 15 years at the Demokritos institute, Greece's national centre for scientific research, which this year celebrates its 40th anniversary. So promising is the technique that physicist Yiannis Maniatis, director of the institute's archaeometry laboratory, is cautiously optimistic about eventually being able to date marble - at least closely enough to detect fakes.

A recent success for the laboratory has been to produce decisive proof that the most famous surviving statue of Roman antiquity, the Augustus of Prima Porta, located in the Vatican Museum, is not of Carrara marble, as supposed, but sculpted in premium grade lychnites from the Greek island of Paros. In collaboration with young physicist Kyriaki Polykreti, Maniatis carried out spectroscopic testing on a small, two-centimetre sample from the Augustus statue. The technique in scientific parlance is called electron paramagnetic resonance (EPR) spectroscopy and measures the physical and chemical parameters of atoms. The process involves scanning the magnetic field on a small amount of powdered marble in a long, slender quartz tube inserted between coils in a spectrometer. A wealth of detail is revealed and methods of studying the full range are being devised. Contributing importantly to this research has been a young chemist, Vicky Mandi, in the course of work for her doctorate.

Under spectroscopic analysis, some marbles are readily identifiable. The almost pure calcitic marble of Mount Pendeli, north of Athens, can be distinguished from the Dolomitic marble of the northern Aegean island of Thassos in 10 minutes with the test, because of the presence of a high manganese signal and trace elements, including magnesium and iron, silicon and aluminium oxides in Pendelic marble. The trace elements give Pendelic the tawny hue familiar from the Parthenon. Marbles from the island of Paros and Mount Hymmetus as well as other marbles are similarly recognisable due to their own particular composition.

Basic to the success of spectroscopic analysis is a database.

"As with any source identification technique, the most arduous part of the project is creating an adequate database," Maniatis emphasises.

Demokritos' international reputation for authoritatively pronouncing on marble provenance is above all a result of the painstaking collection of a huge quantity of marble samples from quarries throughout Greece and beyond, since the mid-1980s.

"The database is expanding all the time," says Maniatis, who admits tramping round quarries can be a boring business. "But to start answering inquiries from archaeologists and art historians, you must have a respectable database."

The marble-testing project dates from a brainchild he had in the early '80s while using spectroscopic analysis to date stalactites and stalagmites from a cave in the Mani region of southeastern Peloponnese, where an anthropologist was studying human skeletal remains. It occurred to him one day that the technique could also be used on marble, which has a calcitic crystal formation similar to that of stalactites and stalagmites.

The Demokritos team began by collecting powder from drillings in the Parthenon made during ongoing restoration to replace the iron reinforcing used in the 1920s, which had rusted, with titanium rods. For a corresponding database, they amassed 500 chips of marble from Pendeli, known from classical Athenian

chroniclers to be the source of the temple marble.

"Demokritos has invested a lot brain power, time and money in marble research because of the importance of the material for Greek civilisation. Cultural and commercial links in the world of antiquity, the movements of artists and the distribution of sculptural workshops can be clarified by knowing where the marble in buildings and statues came from," says Maniatis, who started out in opto-electronics and moved into archaeometry during doctoral studies on ancient ceramics at Essex University.

Types of marble differ depending partly on the degree of metamorphosis of the original limestone while under pressure, deep in the earth's crust at temperatures up to 700 degrees centigrade.

The beautiful, trans-lucent, white lychnites from Paros are a fluke of nature, say geologists. An exceptionally peaceful micro-environment prevailed as evaporation took place in a saline lagoon or salt-flat about 200 million years ago. Hundreds of thousands of years of tectonic activity caused the resultant limestone - calcium carbonate - to metamorphose into the sought-after sculptural material in a two-metre thick convex layer in the ground.

Accessed by underground shafts, the marble was hewn out by the light of oil lamps (lychni), hence the name. Lower grade Paros marble was extracted from surface quarries in the Marathon valley, located in the central highlands, as well as many other locations on the island.

Once discovered, the rich vein of marble brought great prosperity to Paros. On the Greek mainland, Paros marble is thought to have first been used in the Doric-temple style Athenian treasury at Delphi, dated to round 508 BC, later in the pediments of the Temple of Zeus at Olympia, built in 470-56, and in the friezes both of the mid-fifth century Temple of Hephaestos (known as the Thisseion) in the Athens agora and the late-fifth century Erechtheion on the Acropolis.

The Venus of Nib, a prized exhibit at the Louvre Museum in France, and the Hermes of Praxiteles found at Olympia are also considered to be made of Paros marble, but have yet to be scientifically tested. The Winged Victory of Samothrace, also found in the Louvre, is often claimed to be of Paros marble, but top Athenian art historian Olga Palagia, an expert on the provenance of marble in ancient sculpture, who scrutinised the statue during restoration, says categorically it is of Pendelic marble.

Greece has a wide variety of other marbles currently being exploited commercially: beige of Ioannina; beige, brown and red from the Argolida plain; pink from central Volos; black from central Farsala, and green from the island of Tinos. Following restrictions on open-pit quarrying at Pendeli, due to environmental considerations, the epicentre of the industry has moved to the mountains in the Drama region of northern Greece, extending to Kavala and Thassos.

Demokritos has so much marble offered for analysis, that testing is done daily.

"Demand is increasing as archaeologists and art historians realise the possibilities of our technique," comments Maniatis.

Recently tested was the life-size, female Cycladic figure of the third millennium BC from the Goulandris Museum of Cycladic Art, found to be of marble from southern Naxos, the largest island in the Cyclades.

A sequence of Archaic equestrian statuettes from the famed islet of Delos was found to be of Paros marble. Also tested were some Cypriot-style limestone figurines held in various museums, on behalf of distinguished Cypriot archaeologist Vassos Karageorgis of the Leventis Foundation.

The archaeometry team has assigned identity tags to marble in a wide range of Greek works, often in a long-standing collaboration with Associate-Professor Georgia Alewras, of Athens University.

A set of marble inscriptions from the "Hekatompedon", the 100-foot-long, mid-sixth-century temple preceding the Parthenon, was found to be of Hymettian and not of Paros marble, as thought. Twenty colossal statues at Olympia from the Hadrian-period Nymphaion built by a rich Athenian aristocrat, Herodes Atticus, were discovered to be Pendelic.

Pioneer identification in 1985-86 was of two marble slabs at Athens' epigraphic museum. The pieces were shown to be of Hymettian marble, with spectroscopic parameters so close that they must have come from the same block. Epigraphers could thus assume the text, an agreement between Philip II and Athenians after the Battle of Chaironeia in 338, should be read as a whole.

Ascribing sources to marble used in seventh and sixth century BC Archaic kouroi and kores has given valuable insight into the location of marble workshops in the Aegean world of the time.

"We have studied more than 50 ancient sculptures from different museums and provided much information on Naxos and Paros workshops," said Maniatis, who hopes the work will continue to complete the marble history of the Aegean in the Archaic era.

He has roamed Naxos and observed the type of marble in the south of the island, surmising that the long, narrow slabs possibly dictated the shape of the famously lean, angular Cycladic figurines. A flood of queries about the use and movement of marble during the Macedonian hegemony has prompted a sampling project round northern Greece being carried out by doctorate student Themis Vakoulis. Sampling also proceeds from quarries on the Aegean coast of Turkey in a project run jointly with scientists at the Middle Eastern Technical University in Ankara.

An invitation to test the illustrious Roman Augustus came to Demokritos from John Pollini, professor of classical art and archaeology at the University of Southern California. When at a conference on Paros in October of 1997, Pollini related that he was struck, when studying the statue, that nobody seemed sure of what sort of marble it was carved from. Lychnites, being famously white, were never suspected, as the statue of the first Roman emperor - dated, on the basis of a breastplate motif to about 20 BC - had a yellowish patina. Pollini learnt this was because it had been anointed with olive oil, when plaster moulds were made after its discovery in 1863 in a Roman villa which had belonged to Livia, Augustus' wife.

After a persuasion campaign of one and a half years, he was granted permission from the Vatican Museum to take small chip samples from the work, one of which he submitted to US geologist Norman Herz from the University of Georgia, a specialist in stable isotopic marble analysis. Since being taken on 20 years ago as a consultant to the American School of Classical Studies in Athens, Herz had built up a database of isotopic fields of the marbles often used in ancient statues and architectural sculptures.

Isotopic analysis measures the ratio of carbon and oxygen in samples, says Herz, but a drawback is that some isotopic marble fields - Parian and Ephesian, for instance - overlap. His analysis showed the Augustus could be Parian or Ephesian, though marble from Ephesus was ruled out, being coarser grained and generally used for building or sarcophagi. Demokritos EPR spectroscopy was at first unclear, showing that the Augustus marble had similarities with Hymettian and Proconnesian - from the island of Marmaras in present-day Turkey, after which the material has been named since Hellenistic days. Isotopic analysis eliminated such possibilities. Complete matching in databases was seen only with lychnites.

Results of the latest indisputable tests are to be published in full for the first time during the Paria Lithos conference in Athens in late May.

Pollini, for one, is not surprised Paros marble was used for such a statue. The Cycladic marble was a byword in early imperial Rome for a precious material of rare beauty, he says. In the Aeneid, which Virgule finished just before he died in 19 BC, Dido, queen of Carthage, praises Aeneas' good looks by saying he is as handsome as though "skilled hands had applied gilding to silver or Parian marble."

Demokritos is also developing other techniques to corroborate EPR spectroscopy. One is a thermoluminescence test, measuring the amount of sunlight to which a given sample has been exposed. This enables the dating of monuments, buildings or quarry faces continuously exposed to sunlight with an error margin of plus or minus 300 years. The results are detailed in Polykreti's recently completed doctoral thesis. Tricky cases, though, are pieces which have been buried for years, perhaps centuries, then exposed to sunlight again.

The researchers have also learnt that measuring maximum grain size in a sample may be crucial. For this reason alone, they want chip, not powder samples.

Using the institute's nuclear reactor, the archaeometry laboratory may also confirm EPR spectroscopy results by means of neutron activation, which causes all elements in a sample - most significantly telltale trace elements - to emit gamma rays.

The alluring hope is to develop a generally applicable technique for dating or authenticating marble. Much sampling and testing and a good deal more research - "which means more funds," says Maniatis - are necessary for this to be achieved. "It's clearly possible, though the dating may sometimes have a

large margin of error," he warns, "but at least it would show if a work is a fake."

Ann Elder



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Intra-Quarry Sourcing of the Parthenon Marbles: Applications of the Pentelic Marble Stable Isotope Database

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Mount Pentelikon in northern Attica, Greece is known to have produced the white marbles used exclusively for the construction of the Parthenon and its accompanying sculptural components. The Pentelic quarries were first opened on a large scale for the construction of the earlier Parthenon in c. 490 BC and were extensively utilized in Attic architecture and sculpture. The Romans also held the fine-to-medium grained white marble in high regard and exported it throughout their empire. A topographic survey of the quarry region indicates over 160 discernible quarry pits. In an effort to interpret ancient quarry management and commerce, a systematic geologic and geochemical characterization study of the Mount Pentelikon marble quarries was undertaken. The project produced a stable isotope database that is able to distinguish between distinct geologic units within the ancient quarry area.

In the first application of the database, published stable isotope data from Parthenon sculptural elements currently housed in the British Museum were analyzed (Matthews et al. 1992). The samples indicate an origin from the northeast portion of the ancient quarry region in Marble Unit 3. This suggests that the first exploitation of marble on Mount Pentelikon occurred near the top of the north slope. These findings are inconsistent with Korres' (1995) speculation that the large architectural blocks required for the construction of the Parthenon were extracted from the *Spilia Divali* quarry pit further down slope.

In an effort to address these apparent inconsistencies, it is anticipated that marble from architectural blocks from the Parthenon will be permitted to be sampled and analyzed. Such a study will shed light on marble procurement practices in place during the construction of the Parthenon. Data from the architectural blocks will allow us to determine if the same quarry pit or pits produced marble for both the architectural and sculptural programs or if marbles from individual quarries were earmarked for a specific use. Applications of the Pentelic marble database may also correlate quarry management to construction phases of the Parthenon. For instance, analysis may reveal if blocks were extracted in order of emplacement in the Parthenon superstructure or if they were extracted by architectural block type. With the continued refinement of marble characterization methodologies these and many other research questions concerning the use of marble can be addressed.

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