How to form blocks into a durable structure was a dilemma that confronted our ancestors almost as soon as they decided to settle in one place. Getting the blocks was laborious but simple; if there were no stones around to quarry and dress, a sun-dried or baked mix of mud and straw could make a decent brick. But putting these blocks together into a wall that could withstand time and the elements? That took one of two things: money, or lime.

From Mexico to Mycenae, the wealthiest could afford to have teams of masons cut and dress stones and fit them together like a jigsaw puzzle. Not even a knife blade could slide between the cracks of this Cyclopean or megalithic (sometimes called drystone) construction.

What remains of most ancient civilizations consists disproportionately of such majestic stonework. But these massive structures represent average ancient living about as well as the Lincoln Memorial represents the modern way of life. All around the ancient world, anyone without the means to hire laborers by dozens and masses by batches had to use some kind of mortar to hold brickwork or stones together. The peasantry of Babylon and Assyria would gather bitumen from nearby oil seeps and use it as mortar between bricks. The Indus Valley civilizations, lacking natural asphalt, stuck bricks together with a “Vajjalepa mortar” tentatively identified as a plaster made with turpentine and various herbs. Later, the settlers of Iceland would put patches of living moss between stones, letting it grow into a tough binder for the wall. Most civilizations did not have such options, though, and for them, mud was the easiest, cheapest, and first mortar. The hubs of ancient Egypt were made of bricks held together with Nile mud, slapped on when wet and dried in place. Such mud mortars between stone or brick were also common in much of the rest of Africa and probably in most of the rest of the prehistoric world as well (Carran et al. 2003).

But mud has never been a good substitute for money, especially in construction and most especially in any climate where it rains. That was why standards of living around the world took a big step up when people began using mortars based on lime. A calcium oxide produced by burning or calcining limestone in a kiln, lime is white, alkaline, caustic, incredibly sticky when wet, and hardens into a tough, long-lasting cement.

Lime predates letters by millennia, so nobody is quite sure exactly how it originated. Neolithic people of the ancient Middle East were burning lime by 12,000 BC, long before they ever began firing pottery (Kingery et al. 1988). They gathered limestone and gypsum and heated them, leaving behind white powders. Mixed with water and left to dry, such powders would set into a hard white mass that made a fine plaster to coat floors and walls with (Fig. 1) and, in the case of lime, a pretty good adhesive too (the gypsum version was much less sticky, more like modern wallboard).

Where fuel was scarce, most people preferred to make their plasters and whitewashes from gypsum. Unlike limestone, it only had to be burned to about 200–400 °C, a temperature range easily reached over an open fire. Even when limestone littered an area and was the building stone of choice, gypsum was what the inhabitants of a fuel-poor region would calcine into a plaster. The ancient Egyptians lived on limestone but went on making plaster out of gypsum right up until the Romans arrived.

Limestone was much harder to calcine. It took three or four days of heating at close to 900 °C to burn off carbon and form pure anhydrous calcium oxide or quicklime (CaO). Such temperatures are reachable in an open fire, but hard to maintain for remotely that long. Producing lime with any kind of scale and efficiency required a furnace, and the kilns developed for calcination were probably the direct ancestors of those that would later fire ceramics around the Middle East (Frierman 1971). Even in a kiln, lime-burning was a difficult and fuel-intensive process, requiring two tons of hardwood fuel and 1.8 tons of limestone to produce a single ton of quicklime (Kingery et al. 1988). Once produced, this would be mixed with water to form a paste of slaked lime (Ca(OH)₂). This was stored in tight containers until it was needed, then taken out and applied to the target surface. As slaked lime dried and cured, it absorbed CO₂ from the atmosphere, returning to its original calcium carbonate form and coating whatever it stood on with the equivalent of a limestone cement. As a plaster, it was only a marginal improvement on gypsum, but when mixed with sand, ground limestone, or other aggregate, it made a hard, strong, moisture-resistant, and tough cement (Kingery et al. 1988).

Making and slaking lime was a mature industry by the time Methuselah was in diapers. Archaeologists at Hayonim Cave in Israel have excavated the remains of a lime kiln almost eight feet in diameter, dated to before 10,000 BC (Kingery et al. 1988). The Cementerio de Nanoch in Peru housed a major multi-hearth lime-burning operation dated between 5300 and 4800 BC (Dillehay et al. 1997). In India, the early Proto-Harappans made lime plasters between 3500 and 2500 BC, but only on an occasional basis. In China, the first firm evidence dates from the Shang dynasty in the second millennium BC (Carran et al. 2003). This may have been about the same time that lime-burning developed into a large-scale industry in ancient Mesoamerica, where the Mayas were burning lime by 1100 BC in pit-kilns more than 13 feet in diameter, and the Oaxacans may have started even earlier (Seligson et al. 2019).

In northern Africa and Eurasia, almost all ancient societies first used lime for stuccos and particularly for plasters (Carran et al. 2003). Dishware was another use; ancient Mesopotamians had bowls and jars made of lime plaster centuries before they fired their first clay pots (Frierman 1971). In contrast, the prehispanic civilizations of the Americas burned lime mostly for ingestion. For the Mayas, lime was an additive to maize and perhaps to tobacco, whereas for pre-ceramic Peruvians, the main purpose of lime-burning was producing cal to mix with coca leaves (Dillehay et al. 1997; Seligson et al. 2019).

Perhaps because most people there were more accustomed to chewing than troweling it, use of lime as mortar was late and sparse in the Americas. Peruvian masons in the Andes continued carving and jigsaw-fitting megalithic stones into place for millennia right alongside of what was apparently a large-scale lime-burning industry. Only during the Inca period, and in the cheaper types of construction, was lime used for mortar. To the north, the opposite trend prevailed among the Aztecs, whose elites enjoyed houses built with dressed stone and lime mortar while the commoners lived amid adobe (Carran et al. 2003). The only ancient American civilization that routinely built with lime on a large scale was the Mayas, whose capital laid on the extensive limestone layers of the Yucatan Peninsula. While plasterers and food additives also remained the principal use of lime among the Mayas, many of their large monuments from the mid-first millennium BC and later are held together partly by lime mortars (Fig. 2). Over time, Mayan plasters and mortars became thicker, stronger, and more durable as lime-burning and associated technology grew more sophisticated. A particularly notable Mayan development was the mixture of local volcanic ash with...
the lime to create a pozzolanic cement, an exceptionally strong binder otherwise found only in ancient Roman and modern Portland cements (Carran et al. 2003).

Eurasian and North African civilizations, lacking coca and maize, used lime primarily in plasters and began applying it in mortars at a relatively early date. Possibly this was due to the observation that a good lime plaster could outlast some of the walls and floors it covered, which might have suggested that it could hold the walls together better than mud. In the first millennium BC, the Chinese began using lime mortars in the tombs of departed dukes, and a few centuries later, every major construction project had a set of lime kilns on site. Mixed with sand, various fruit and vegetable juices, and loess, the resulting cement called tabia proved widely popular for numerous centuries (Carran et al. 2003). The addition of sticky rice vastly improved the compressive strength and toughness of the mortar; some archaeologists credit this with the survival of multiple medieval Chinese towers through several large earthquakes and the Cultural Revolution’s bulldozers. Such organic admixtures were common for various purposes. In Mauryan India, hemp was mixed with lime mortar to hold floors together and improve water absorption. Ordinary mixtures of lime with sand and other aggregates were common around the Eurasian and North African sphere during classical times (Carran et al. 2003).

By far the most prolific ancient users of lime were the Romans. Mortars made of lime were common during the early Republican period, and by the second century BC, Roman mortars and cements had developed into the famous Roman concrete. This, like mortar, was a mix of lime with aggregate. But instead of being trodled onto bricks, it was poured into a mold and allowed to harden into its final shape. When the lime was mixed with a volcanic ash, as well as with aggregate, the result was even better. Ordinary or non-hydraulic lime mortars and cements could harden only if the air and surrounding brick or block absorbed the water from them and supplied carbon dioxide. In contrast, volcanic ash could make a hydraulic cement that hardened by chemical reactions between the calcium in the lime and the highly reactive aluminum and silica in the ash. These reactions would take place dry or under-water and keep going for millennia, producing a tough binder that grew tougher over time (Jackson et al. 2017). The best volcanic ash for such purposes was found near Puteoli, and the cement bore a mildly mangled version of its name, pozzolana. “Impregnable to the waves and every day stronger” as Pliny the Elder described it, the concrete made with this ancient version of Portland pozzolanic cement was the mainstay of Rome’s more monumental constructions. Everything from run-of-the-mill harbor walls to the Pantheon’s 43-meter-wide dome (Fig. 3) relied on volcanic ash and lime. According to mineralogists, the surviving pozzolanic concretes the Romans built continue to grow stronger and harder even today (Jackson et al. 2017).

Lime was late to appear in some regions of the globe, probably for reasons related to global trade routes and geology. As one example, Sub-Saharan Africa was virtually isolated from Eurasian and North African trade until about the ninth century AD, when Muslim traders began routine trade around the Horn of Africa and down the Swahili coast. Around that time, lime plaster appeared in Tanzania, made in large kilns set up near ancient coral outcrops (Ichumbaki and Pollard 2015). Otherwise, the use of lime was rare in Sub-Saharan Africa until relatively recent times. It was not for lack of technology: by the time lime kilns appeared, the southern African iron-smelting tradition was centuries old and similar furnaces could easily have calcined lime. It is possible that they simply lacked the obvious and widespread limestone resources of other regions. The places with early and extensive lime use tended to coincide with large outcrops of limestone or chalk. Scarcity of suitable carbonate did not necessarily condemn an area’s residents to a limeless life, as ancient Peruvians demonstrated. But, as with most other natural resources, geology did give an advantage to civilizations that lived around shelf carbonates.

Lime, of course, had many more uses and a much broader history than this article has space to cover. As Portland cement, it continues to hold the building blocks of modern civilization together. But I hope this short discussion has helped introduce how lime, as plaster and then mortar and finally concrete, evolved from floor to more.

REFERENCES

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