2,000 Year-old Roman Cement and Modern Geopolymer Cement: Vitruvius' Work *De Architectura* re-visited

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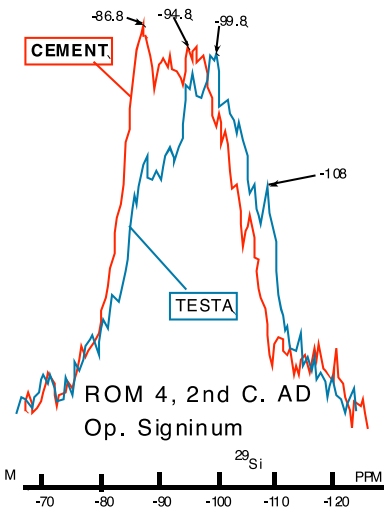
In *De Architectura*, Book II, the Latin author Vitruvius describes the reactive raw-minerals involved in the making of the Roman cement. The rock-forming minerals (coined in our modern language "*pozzolan*") are listed as "*harena fossicia*", e.g. volcanic tuffs. According to Vitruvius, the best mineral of this type is called "*carbunculus*" and was extracted in Etruria, north of Rome, in the volcanic region of the lakes. New deciphering of Vitruvius' text highlights the geological origins of this extraordinary pozzolan. It is identical to the volcanic tuffs selected by the European Research project GEOCISTEM (1994-1997) dedicated to rock-based geopolymer cement. Civil infrastructures, especially works related to water storage (cisterns, aqueducts) required a high-performance material and a special technology. This technology was known under the generic technical term of *Opus Signinum, Opus Testacaeum* and *Opus Caementicum*.

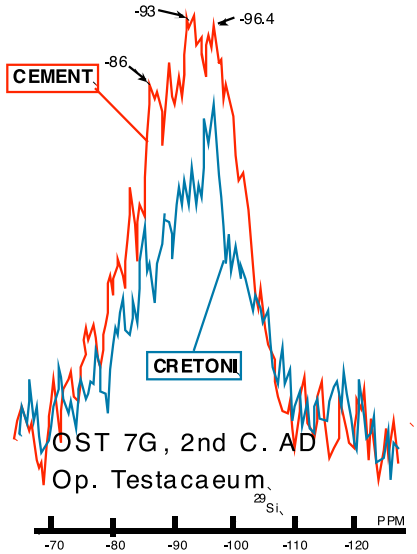


Opus Signinum with Testa (metakaolin)

The *Opus Signinum* contains the element *testa*, a calcined kaolinitic clay equivalent to the metakaolin MK-750 used in the geopolymer cements.

Sample ROM 4, is from a Cistern coating, Trajan Baths, 2nd Century AD. 29Si NMR Spectroscopy shows the *testa* and the cement. The spectrum is similar to those of modern MK-750-based geopolymer cements.

The chemical reaction yields an alumino-silicate structure with a major resonance at -86 ppm suggesting a Si(Q3.1OH) hydrated gehlenite geopolymer and at -90 ppm Si(Q4) for hydrated poly(sialate) geopolymer.



Opus Testacaeum - Caementicum with Carbunculus

Sample OST 7G is from Ostia harbour, 2nd Century AD. The mortar usually contains carbonated lime and volcanic tuff aggregates and sand called in Italian *cretoni*. Some of the *cretoni* could be the element *carbunculus*, which is equivalent to the volcanic tuffs used in rock-based geopolymer cements.

Alumino-silicate structure with resonances at -86 ppm Si(Q3.1OH) and at -90 ppm Si(Q4) for hydrated poly(sialate) geopolymer. The spectrum is similar to those of modern geopolymer cements and different from regular pozzolan-lime hardening (CSH and aluminate CAH).

Details in the book *Geopolymer Chemistry & Applications*