The impact of the Minoan eruption of Santorini on Mochlos, a small Minoan town on the north coast of Crete

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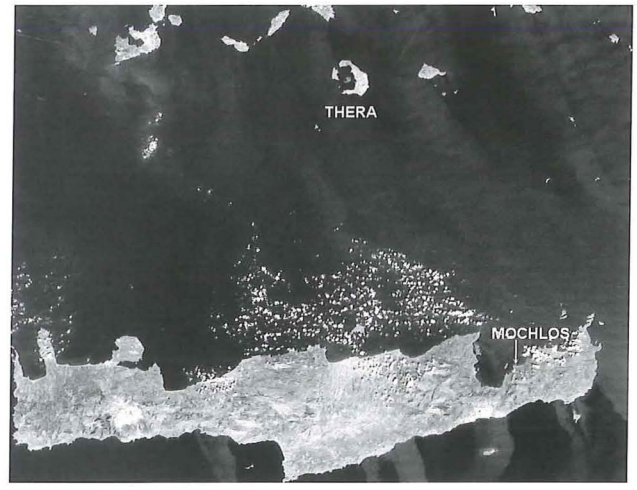


Fig. 1. Satellite photograph showing relationship of Thera to Mochlos (NASA image).

At the time of the Minoan eruption of Santorini toward the end of the LM IA period, Mochlos was a small harbour town in east Crete, a second order site in a region dominated by the larger town of Gournia where a small palace stood.[1] It was located *c.* 140 kilometres southeast of Santorini along the eastern side of the Bay of Mirabello and lay directly in the path of the tephra fall and tsunami that resulted from the eruption (Fig. 1).

A Greek-American team, led by the author of this paper and Costis Davaras, resumed excavations here in 1989 after an interval of 81 years when the site was first excavated.[2] The modern excavations, conducted in two campaigns in 1989-1994 and 2004-2005, have revealed dramatic evidence for the impact of the eruption on a small town that was located directly on the north coast of Crete. In the first year of the excavation, a thick deposit

[1] Soles 1991.

[2] Soles & Davaras 1992, 1994, 1996; Seager 1909.

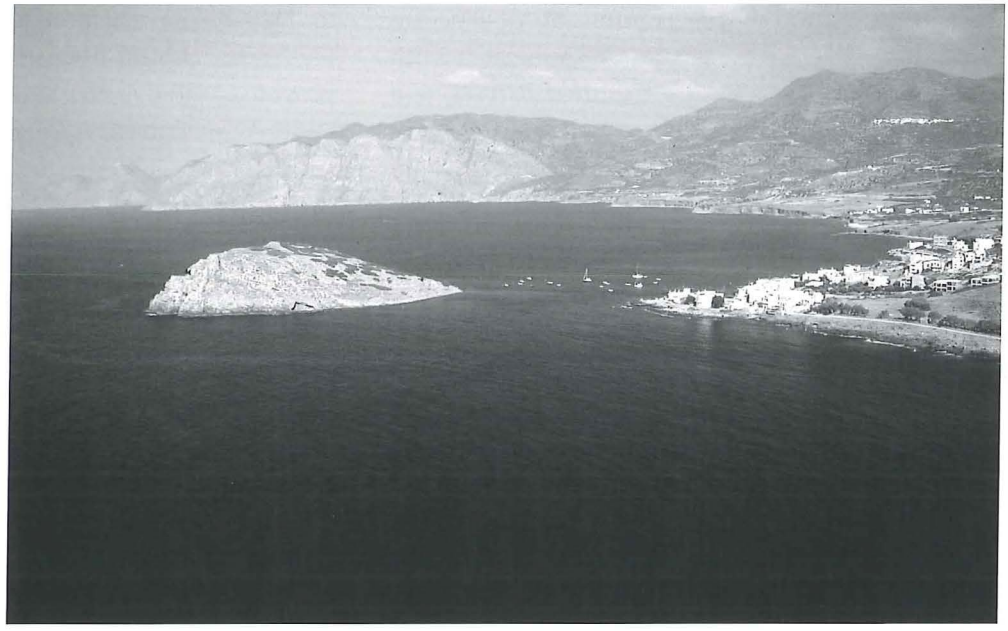


Fig. 2. The island of Mochlos (from the west).

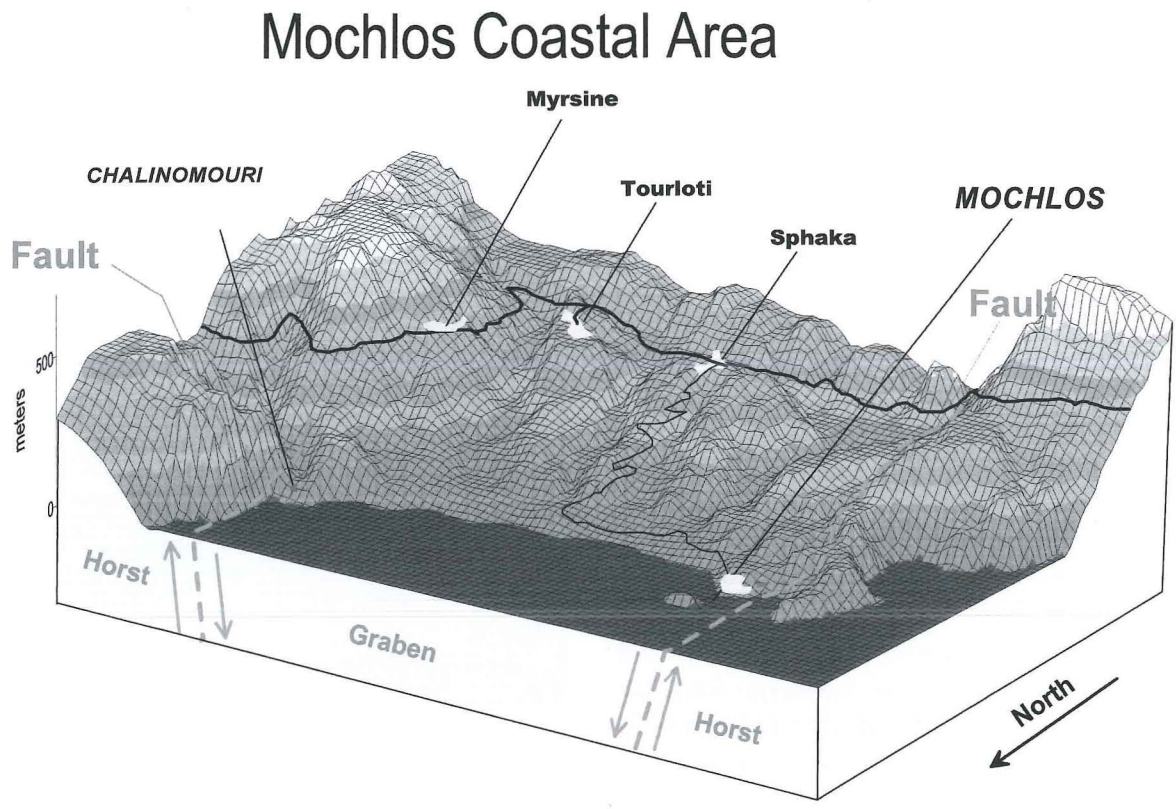


Fig. 3. Topography of the Mochlos Coastal Area (drawing by J.C. Patton).

of Santorini tephra was found in the settlement and immediately reported in the *New York Times*;[3] additional evidence has come to light since in practically every year of excavation. The evidence is of three kinds: (1) deposits of tephra that fell on the site at the time of the eruption, (2) destruction of buildings caused by earthquake associated with the eruption or possibly by the ash fall itself, and (3) rebuilding that altered the whole nature of the settlement.

The site is an island today that lies *c.* 120 m offshore (Fig. 2), but in 1600 BC the topography of the area was quite different. The site is located at the western edge of a tectonic valley with two fault lines running down either side of the valley, one just east of a Minoan farmhouse at Chalinomouri and the other along the western side of the island where the site is located (Fig. 3). The valley is flanked by mountain blocks; extension of the earth's crust is accommodated near the surface by faulting, and when this occurs the valley drops with respect to the blocks on either side. As a result, Mochlos has been sinking for some time and we have been able to measure the rate of its submergence with some degree of accuracy. Fish tanks dating to the Hellenistic period, the 2nd and 1st centuries BC, which are located along the Cretan coast, lie up to 1 m below sea level today;[4] to operate in the Hellenistic period however the inlet channels that provided water to the tanks, which are cut out of bedrock, need to have been located at or just below sea level, so they give us a good fix on sea level in the 1st century. In 2006 we found submerged structures off the southwest side of the island which lie about 2 m below sea level resting on bedrock. It's not clear what these structures are yet (one is a long wall, the other is a rectangular structure with megalithic floor slabs and a low surrounding wall that may have served as a fish tank), but their construction suggests that they are Late Bronze Age,

[3] Wilford 1989.

[4] Leatham & Hood 1958/1959.

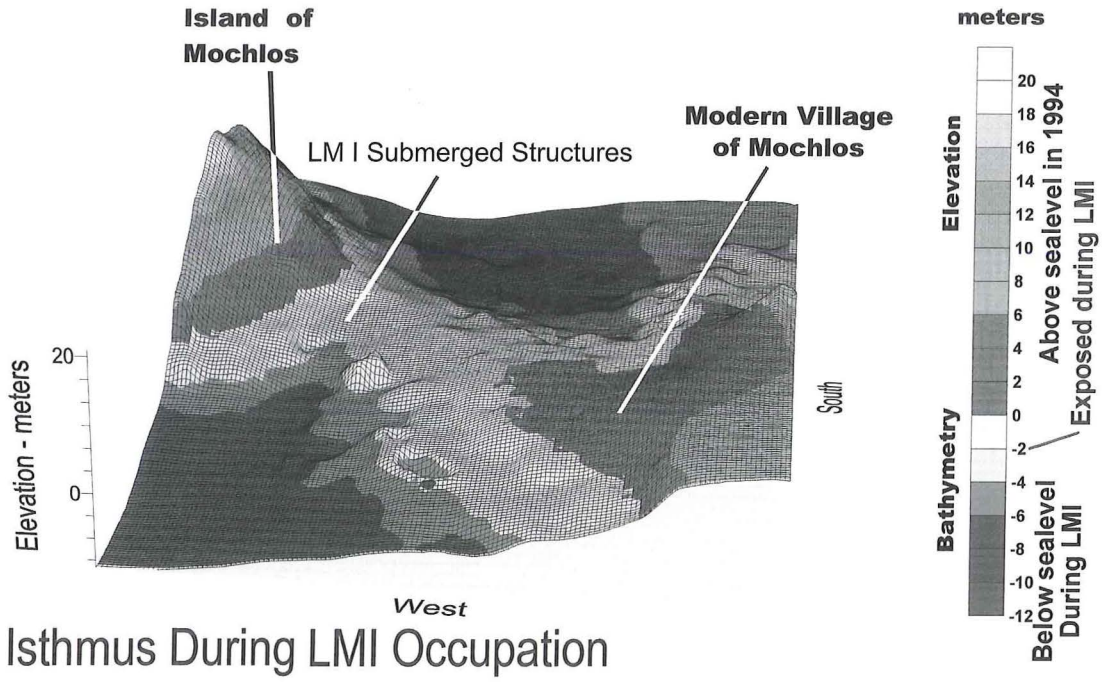


Fig. 4. The Mochlos Isthmus during the LM I Period (drawing by J.C. Patton).

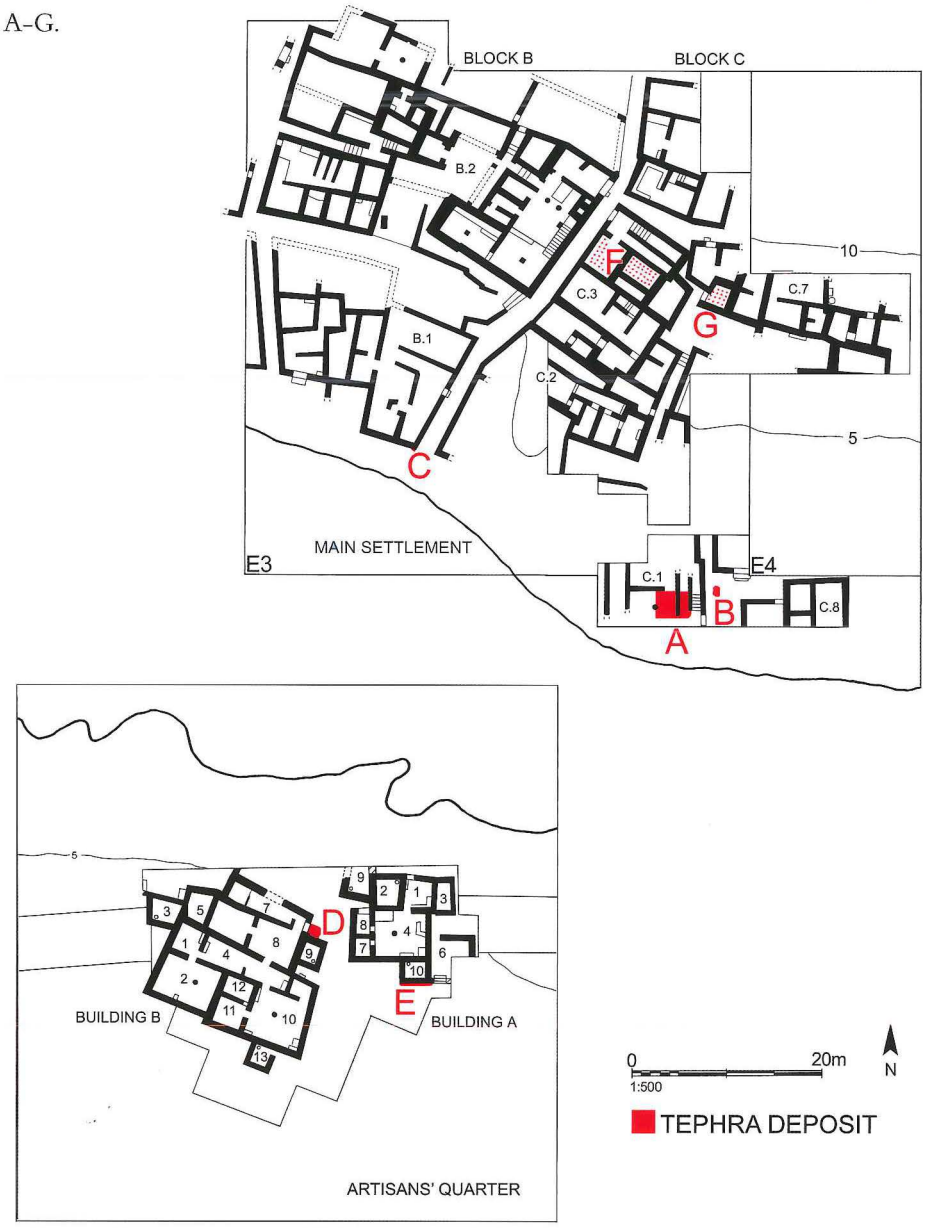
and probably LM I in date. They would have been located above but near sea level at this time and suggest that the shore line was at least 3 m lower in 1600 BC than it is today (Fig. 4). Thus, at the time of the Santorini eruption, Mochlos was connected to Crete by a low isthmus or tombolo; the island, which rises steeply on its north side to a height of *c.* 45 m above sea level and slopes more gently on its south, was then an offshore hill that bent the incoming waves around it so that their energy swept sand and gravel onto the tombolo from both sides. As a result, it probably rose 3-4 m above sea level and resembled many tombolos that can be seen today, such as the one at Goat Rock, CA.[5]

The settlement was located on the southern slope of the hill; there was no building on the shore opposite that we know of when the volcano erupted. If the eruption created a tsunami 30-40 m high, as some have suggested, the back of the hill would have protected the settlement on the south slope from the full force of the tsunami. The distribution of tephra on the site, which fell before a tsunami hit and which would have been washed away by a tsunami, suggests that it did not in fact cause much if any damage to the main area of settlement. The impact of a tsunami on the tombolo would have been another matter, but since it is now submerged no evidence remains.

Before the final cataclysmic collapse of the Santorini volcano, tephra from the initial eruption was blown by the prevailing winds and settled over the site. We have found seven deposits since the excavations began in 1989 which we have identified as Deposits A-G (Fig. 5). They belong to three different kinds of deposits. Some fell in open spaces and were buried soon afterwards by subsequent construction on the site (Category 1); some fell on the roofs of houses, probably contributing to the collapse of these roofs, and are preserved in the rubble debris of collapsed roofs and walls inside houses that were subsequently rebuilt (Category 2); one or two were collected after they fell and put to use in one way or another (Category 3). Deposits A and B, and maybe C and D, belong to the first category. They fell in open spaces and were preserved by structures that were

[5] http://geology.about.com/od/structureslandforms/ig/tombolos/tombologoatrock.htm.

Fig. 5. Mochlos tephra, Deposits A-G.



built on top of them before the tephra could be eroded by wind or rain. A is the most famous of these.[6] It is also the largest, thickest, best preserved, and best documented (Fig. 6). It lies beneath the eastern side of House C.1, which was built soon after the tephra fell.[7] LM IB pottery lay on the floor of the house above the tephra layer, and LM IA pottery was found in and around a plastered pit beneath the tephra layer. Its importance then was its stratigraphy; sandwiched as it was between these two levels with their two different pottery styles, it placed the ash fallout at the end of one pottery style and the beginning of the other. It covered an area of approximately 7.5 m^2, extending beneath walls of the house, and averaged 5-10 cm in depth; where a stone column base was bedded in the tephra, the tephra was scooped up and formed a mound 20 cm thick. Originally the deposit extended over a much larger area and it was clear at the time of the 1989 excavation that the western side of the deposit had been dug away along a straight line in the earlier 1908 excavation of the site although no

[6] Wilford 1989.

[7] Soles & Davaras 1990; 1992, 434–8, figs. 1–2, pls. 98–100.

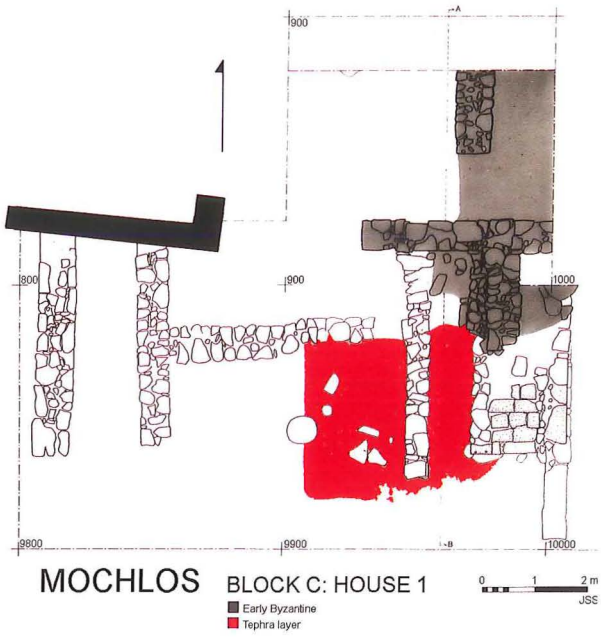


Fig. 6. Tephra in House C.1 (Drawing by J.S. Soles).

mention of its discovery was ever made at the time. Further traces of the deposit lay just to the east of the house's façade, much smaller in area however and only 1-2 cm thick (Deposit B) and to the west of the house, still smaller in size but nearly 5 cm deep (Deposit C).

This deposit was analyzed by Vitaliano and Taylor and the results published in *Archaeometry*.[8] Fig. 7, which is reproduced from *Archaeometry*, illustrates the elemental compositions of the Mochlos tephra and that from Santorini (Fig. 7 top) and the rare earth element abundances in the Mochlos and Santorini tephras (Fig. 7 bottom). Vitaliano and Taylor's great discovery was that the Mochlos tephra bears a close resemblance to the Upper Minoan Pumice that forms the thick white mantle over much of Santorini, but its closest correlation is with sample C-1 taken from the base of the Rose Pumice that forms the lowermost unit of the Upper Minoan Pumice and represents the first eruptive product of the Minoan eruption. The composition of the major elements of the two tephras, shown in columns 1 and 2 (at the top), are closely equivalent, and the elements Si and Mg which are the most critical indices of differentiation are within 2%. The correspondence is also shown clearly by the

Mochlos

Element	*1*	*2*	*3*	*4*
SiO_2	69.0	70.7	76.8	74.3
TiO_2	0.45	0.44	0.29	–
Al_2O_3	14.9	14.9	14.2	14.0
FeO	3.60	3.14	2.2	2.0
MnO	0.10	0.09	0.08	–
MgO	0.95	0.97	0.13	0.3
CaO	3.89	2.46	1.4	1.1
Na_2O	4.11	3.94	2.0	4.9
K_2O	2.96	2.99	3.0	3.4
Σ	99.98	99.7	100.1	100.00

1 Volcanic tephra, Mochlos, Crete.
2 Volcanic tephra, base of 'Rose Pumice', Phira Quarry, Santorini (sample C-1, Vitaliano *et al.* 1990, 62, table 5).
3 Glass from tephra, Mochlos, Crete (I. A. Nichols electron probe).
4 Glass from C-1 sample, base of 'Rose Pumice', Phira Quarry, Santorini (Vitaliano *et al.* 1990, 60, table 2).

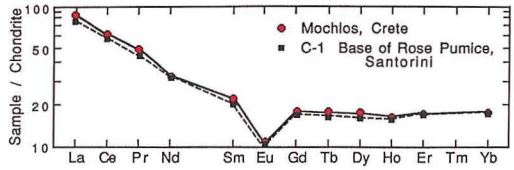


Figure 7 *Comparison between rare-earth element (REE) abundances in the Mochlos tephra and the 'Rose Pumice' at Santorini. The Mochlos sample shows a slight enrichment in the light REE. The REE data are normalized in the conventional manner to the REE abundances in chondritic meteorites ('chondrites'). These are believed to represent samples of the undifferentiated solar nebula and their elemental abundances are therefore thought to represent those of the bulk earth. Geochemists favour this convention as the normalized values provide a convenient visual impression of the extent to which a magma is removed from, or has* evolved *from, its parental material in the earth's mantle (see Taylor and McLennan 1988, for a full discussion of normalization procedures and REE geochemistry).*

Fig. 7. Elemental Analysis and Rare Earth Abundances, Mochlos and Santorini Tephra (drawing by C.J. Vitaliano and S.R. Taylor).

rare-earth element data (at the bottom). The compositions of the glass in the two deposits, on the other hand, shown in columns 3 and 4 (at the top), illustrates that the Mochlos glass was derived from a slightly more evolved magma than the glass of the Rose Pumice C-1 sample. Vitaliano and Taylor concluded that both could have come from the same magma chamber, but the Mochlos glass from a higher level.

We have also found traces of the ash fall on the Cretan coast opposite the main site where an artisans' quarter manufacturing pottery, bronzes and other goods was established at the beginning of the LM IB period (Fig. 5 bottom), one deposit behind Building A, the other in front of Building B. Deposit D is located under the pavement at the entrance to Building B about 300 m to the southwest

[8] Soles, Vitaliano & Taylor 1995.

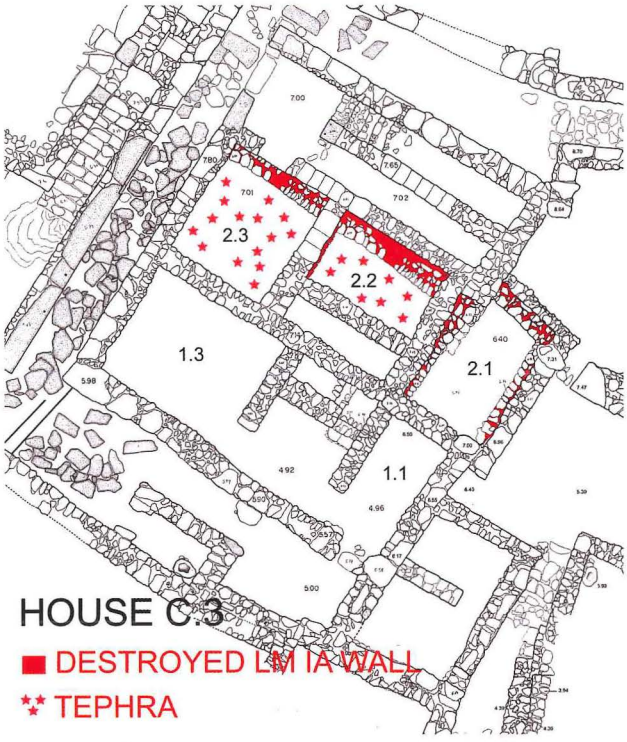


Fig. 8. Tephra in House C.3 (Drawing by D. Faulmann).

of the deposits on the island.[9] The paving stones are bedded on the ash which also extends in front of the pavement and covers an area about 1.5 by 3 m in size and 5 to 10 cm thick. The tephra is compact and hard unlike the soft and sandy deposits on the island, but it is unclear whether it belongs to the first or third category of deposit: it may have been packed down by traffic on the modern road that lies above or it may have been mixed with water and laid in place to form a bedding for the stones of the landing.[10] Deposit E on the other hand apparently belongs to the third category, *i.e.* tephra that was collected after the fallout and put to use for some particular purpose. This deposit lies alongside the rear of Building A extending a distance of *c.* 6.5 m, varying from 40-80 cm in width and only 3 to 5 cm in depth.[11] It appears to have been collected and stored here for use as an abrasive in the stone-vase making industry that was located inside the building and outside in its rear yard where the tephra lay.

In the 2004-2005 excavations more tephra deposits, which have not been reported yet, were found in two buildings in Block C on the island (Fig. 5 top). They are especially interesting because they belong to the second category, *i.e.* tephra mixed with LM IA destruction debris beneath LM IB rebuilding, and so bear witness to the actual destruction of the buildings that occurred at the time of eruption. The deposit in House C.3, the House of the Metal Merchant, is probably the best example (Fig. 8). Tephra was found in two rooms on the ground floor of this building, Rooms 2.2 and 2.3, beneath the later LM IB floor levels in the rooms. Both these rooms had basement rooms beneath them in the original LM IA house, but when the ash fell the ceilings and floors above, the interior walls on the north and east, and the roof of the house collapsed, and these basement spaces were filled in with the collapse material; they were never cleared out again, unlike Room 2.1 to the east, which was cleared out and restored as a basement room. The earlier IA walls, contemporary with the ash fall, which were not rebuilt, are shown in red. In the photograph of Room 2.2 (Fig. 9), the earlier IA collapse material is exposed beneath the metre stick surrounded by IA walls, the upper parts of which had collapsed, and IB walls that were built on top of the earlier walls. The tephra in the IA debris is fine and dispersed through the earth with small pockets scattered here and there. This house like many others in the settlement was badly damaged by the earthquake that accompanied the eruption and had to be rebuilt after the eruption. The tephra deposit in Building C.7, Deposit G, is very similar. This deposit is also located beneath the later LM IB floor levels in Room 1, the southwest room of the building (Fig. 5 top), and is scattered in small pockets around the room. The stratigraphy closely resembles that in House C.1. The tephra is not so dense or well preserved, but is also sandwiched between LM IB and LM IA pottery. The LM IA pottery in C.7 is more plentiful however and much better preserved than that in C.1 and belongs to a transitional phase that may be dated to the very end of LM IA and beginning of LM IB.[12] It confirms our initial dating of the eruption to the end of the

[9] Soles 2003, 45, fig. 25, pl. 14C.
[10] See Stamatopoulos *et al.* 1990.
[11] Soles 2003, 10, 36, pl. 14C.
[12] Barnard & Brogan forth.

LM IA ceramic sequence and contradicts an earlier date within the IA sequence.[13]

At the time of the Minoan eruption of Santorini there was a large influx of population to Mochlos and a lot of new building. Four or five farmhouses were established alongside ravines on the coast,[14] an artisans' quarter was built on the south side of the tombolo opposite the main settlement,[15] an ashlar quarry was opened nearby,[16] new buildings were erected in the settlement using the sandstone ashlar from this quarry, including House C.1, and a ceremonial building which may have been the locus of ancestor worship.[17] As a result, Mochlos was transformed from a small sleepy harbour town to a major port and regional hub with both its farms and artisans' quarter producing goods for a market of potential customers and its ceremonial centre attracting pilgrims from other parts of east Crete. Our working hypothesis is that the population boom and transformation of the site was partially due to the arrival of refugees from Thera. These settlers are thought to have escaped in ships with many of their possessions shortly before the eruption; prevailing winds would have carried them directly to east Crete so they did not need to wander for any great interval and were able to settle at Mochlos before the actual eruption occurred. The hypothesis is not yet proven, but is being tested using two different tools: the petrographic analysis of imported ceramics dating to the time of the eruption, and the architectural analysis of buildings erected on the site immediately after the eruption.

Among the possessions refugees might be expected to have collected upon their departure were ceramic objects, principally pottery and loom weights, which can be identified petrographically. Petrography is a powerful analytical technique that can help explore issues of ceramic production and distribution, clay recipes and pottery traditions through space and time.[18] Deposits A, F and G are especially important in this regard since they all contain pottery that dates to the time of the eruption. Trade between Mochlos and Thera was interrupted at this time, and imported Theran pottery found in these deposits may be classified as "refugee pottery" instead of the product of trade. The LM IA transitional pottery found with the tephra in Building C.7 is especially important in this regard since an imported Theran jug (P 6065) has already been identified macroscopically in this deposit; the microscopic analysis of additional pottery in the deposit may reveal additional Theran wares. The room was being used for cooking at the time of the destruction, and if imported Theran cooking ware can be identified it would be especially significant since it is exactly the kind of household pottery that refugees might bring with them. The LM IA pottery from the foundation pit in House C.1 is also potentially significant since it also dates to the time of the eruption. No sooner was it laid in place than tephra from the eruption covered it;

Fig. 9. House C.3, Room 2.2 (from east).

[13] Soles & Davaras 1992, 438, n. 46.
[14] Soles 2003, 103–32.
[15] Soles 2003, 7–100.
[16] Soles 1983.
[17] Soles & Davaras 1996, 184–94.
[18] Day, Joyner & Relaki 2003.

Fig. 10. House C.8, fallen quoins at northwest corner.

the building of the house was suspended until the tephra fall ceased, the tsunami receded, and life returned to normal. It is a smaller deposit than that found in C.7 and ceremonial in nature, but might also include pottery brought from Thera.[19]

The same petrographic analysis used on pottery may also be used on loom weights. Weavers, who were probably women, have been shown to travel with loom weights, which are normally not objects of trade since they have little or no value to anyone but their owners,[20] and any Theran weights that might be identified in the destruction deposits or in later LM IB deposits would provide further evidence for the arrival of refugees. Indeed a comparative study of loom weights from Mochlos and Thera might be instructive since different sites in the Aegean produced their own distinctive loom weights with different sizes and weights.[21]

In the meantime, we are also testing our hypothesis through a study of the new LM IB buildings that went up in the settlement immediately after the eruption. They display many architectural features that are typical of the houses of Thera, which are not to be found in the neighbouring LM I settlements at Gournia and Pseira. The Theran builders were master stone masons and used ashlar in ways that it was not normally used in Crete.[22] They used it for quoins at the corners of houses that were built predominantly in rubble; they used it to frame windows and doorways that were invariably flanked by windows resting on ashlar orthostates; they used it for coping blocks that projected between floors and at the roof line below parapets that surrounded the roofs; and they used it for steps in staircases and for the blocks that support the timber frames of these staircases. Outside of Zakros, which may also have received a wave of Theran refugees at the same time as Mochlos, few of these practices can be documented in Crete. As J.W. Shaw demonstrates in his study of Minoan architecture, the standard use of ashlar masonry in Crete was for the building of coursed ashlar masonry,[23] a use also found in Thera. These were solid ashlar walls that may have supported rubble walls above, but did not involve the combination of ashlar quoins and coping blocks with walls that were otherwise predominantly

[19] Soles & Davaras 1992, 437, n. 45.
[20] Soles *et al.* 2004, 28–9.
[21] Marie-Louise Nosch (pers. comm.).
[22] Palyvou 2005, 115–20.
[23] Shaw 1973, 92–109.

Fig. 11. House C.3, aerial view (photograph by J. Driessen).

rubble. Shaw states categorically that "coping blocks are not typical of Minoan architecture".[24] He is also unable to report any examples of ashlar quoins at exterior corners of rubble walls although larger, roughly shaped stones might be used for this purpose.[25]

Therans could not build without ashlar, and it is probably significant therefore that the ashlar quarry at Mochlos was opened only at the beginning of the LM IB period and that ashlar was employed everywhere post-eruption building occurred at Mochlos and in all of the ways that it was used at Thera. Some coursed ashlar walls survive, notably in the east wing of the town's ceremonial building, but most ashlar has been found lying in the streets around buildings that were destroyed in the final LM IB destruction of the site. Measured drawings of these blocks, begun only recently, have revealed that many of these do not belong to coursed ashlar walls; instead, they belong to rubble walls and were used as quoins, coping blocks, framing stones, in short all the ways they were used at Thera. They fell into the streets when the rubble walls collapsed because they were once placed in these rubble walls. House C.8 illustrates just what happened to the ashlar when the rubble walls collapsed since the blocks that formed the quoins at one corner of the house fell in a row with the two bottom quoins still in place and those above toppled one on top of another into the street (Fig. 10). House C.3, the House of the Metal Merchant, provides one of the best illustrations of the use of ashlar in a rebuilt house. As the overhead photograph of the house shows (Fig. 11), most of the fallen blocks are clustered at the northwest and southwest corners of the façade; this is no accident since most of these blocks were quoins that sat at the corners of the rubble walls. Another block found fallen in front of the doorway, which is narrower than the ashlar orthostate next to the doorway that probably supported an adjacent window, can only have fallen from above the doorway where it was used as part of the doorway frame or from higher up in the wall where it formed a coping stone.

The best illustration of Theran architectural practices at Mochlos however is House C.1 which was built on top of tephra Deposit A immediately after the ash fall ceased (Fig. 12). It resembles

[24] Shaw 1973, 98, note 3.
[25] Shaw 1973, 83, fig. 82.

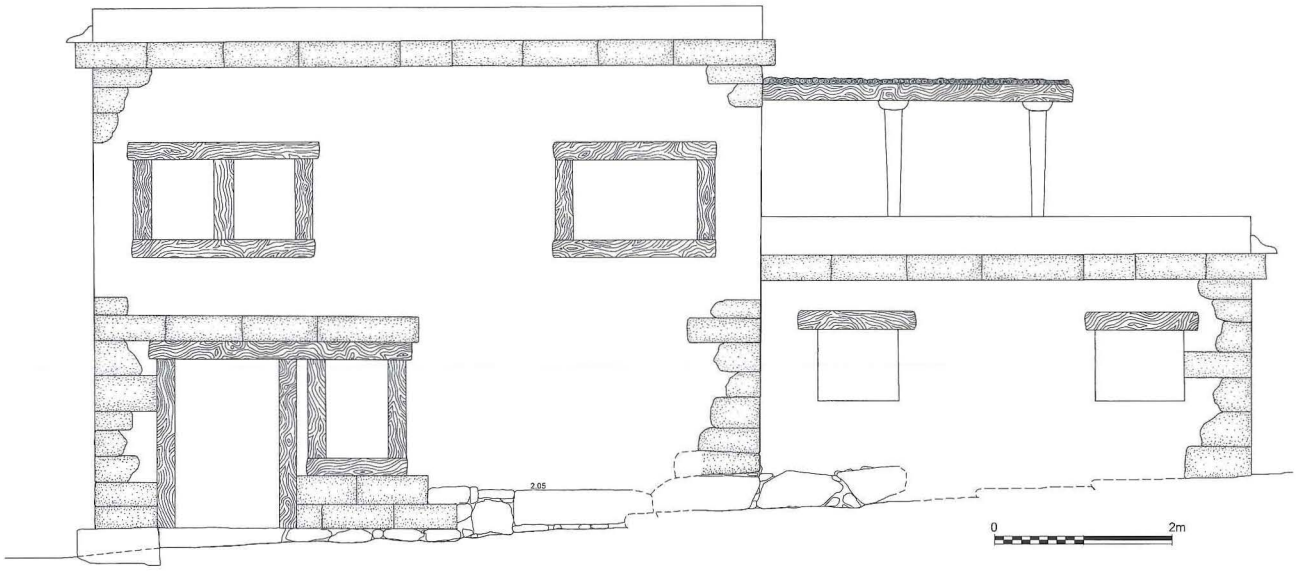


Fig. 12. House C.1, Reconstruction of West Façade (drawing by J.F. Roberts).

Theran houses in many details. Much of its ashlar was found still *in situ*, and it was used as in Theran houses to frame the main doorway from the street, to provide a base for an adjacent window, for the steps of the staircase and the block that supports its timber frame, and for quoins at the setback in its façade. In plan it also resembles Theran houses, especially House Delta-South.[26] In both houses the entrance is located at one corner of the house and opens onto a small vestibule, to one side of which a Π-shaped staircase is located which leads to the upper floor; a main room with a central column lies just beyond. The parallels between House C.1 and Theran houses are so numerous that we have even identified the house as "The House of the Theran Refugee" in an earlier publication.[27] It now appears that it was one of many buildings that the new settlers added to the town.

[26] Palyvou 2005, 71–5, figs. 90, 96.
[27] Soles & Davaras 1995.