Thermochimica Acta, 148 (1989) 485-492
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

DETERMINATION OF THE INTENSITY OF AN EARLY IRON AGE CONFLAGRATION AT TEL-HADAR, ISRAEL

S. Shoval[1,2], Z. Erez[1], Y. Kirsh[1], Y. Deutsch[2], M. Kochavi[3], and E. Yadin[3]

1. Geological and Physics Group, The Open University of Israel, Tel Aviv.
2. Geological Survey of Israel, Jerusalem.
3. Institute of Archaeology, Tel Aviv University.

ABSTRACT

The intensity of a conflagration that consumed an early Iron Age public building at Tel-Hadar, on the eastern shore of the Sea of Galilee, Israel, was determined by thermal simulation. A thick slag layer was found in some ground floor rooms of the building. Fragments of burnt brick were found in the slag layer while unfired mud bricks were found outside these rooms.

- The maximum firing temperature of the conflagration is estimated from the mineral assemblage in the slag. The slag was formed by partial melting of the mud bricks at about 1200°C. The burnt brick was heated to 1100°C.
- The duration of the conflagration is estimated from the relative amount of cristobalite in flint pebbles that were found in the slag and burnt brick. The cristobalite was formed by the heating and its amount indicates that the maximum temperature reached, 1200°C, was maintained for a short time (less than one hour), indicating a short intense conflagration.
- The intensity and the high temperature of the conflagration indicates that the rooms contained large amounts of combustible material. Carbonized grain found in the ash may indicate that a storeroom full of grain was burnt.

INTRODUCTION

During the excavation of Tel-Hadar, on the eastern shore of the Sea of Galilee, an early iron age (11th century B.C.E.) large public building was discovered [1,2]. The ground floor rooms of the building were used for storage and were built of stone, while the upper story and roof were built of sun-dried mud bricks. Burnt bricks were found in the ground floor rooms where they fell when the building burnt. A thick layer of slag was found in some of these rooms.

Thermal Analysis Highlights, 9th ICTA, Jerusalem, Israel, 21-25 August 1988.

0040-6031/89/$03.50

The burning of the building and subsequent abandonment of the site indicate that the fire was caused by hostile forces. As the event occurred in the late eleventh century B.C.E. it may have been burnt during the wars of King Saul against enemies of the Israelite settlers in Gilead (II Samuel 2:9) [1, 2].

The aim of this study was to estimate the intensity of the conflagration at Tel Hadar by determining the mineral composition of the burnt brick and slag. The minerals present in fired material depend on the temperature of the fire [3-10].

EXPERIMENTAL

The minerals were identified by X-ray diffraction with a Philips PW-1050/80 diffractometer. Cobalt lrradiation was used. Infrared spectra were recorded in KBr disks (1%) with a Nicolet ZDX FT-IR spectrometer. The disks were dried at 250°C.

Thermal simulation was done in an electric kiln under oxidizing conditions at 1000, 1050, 1100, 1150, 1200 and 1250°C for 1, 6, 12 and 24 hours at maximum temperature. Thermal analysis - DTA, TG and DTG - was done in a Stanton Redcroft apparatus (STA 780). The samples (50 mg of powdered sample) were heated to 1300°C. The heating rate was 10°C per minute.

RESULTS AND DISCUSSION

Brick and Slag

Unburnt brick, burnt brick and slag from the conflagration area were examined. Their X-ray diffractograms are shown in Figure 1a-c:

- The unburnt brick (Fig. 1a) contains mostly the clay-montmorillonite, calcite, quartz and a moderate amount of plagioclase.
- The burnt brick (Fig. 1b) and slag (Fig. 1c) contain large amounts of the high temperature minerals: pyroxene-diopside [$CaMg(SiO_3)_2$] and plagioclase-anorthite [$CaAl_2Si_2O_8$], that were formed by high temperature chemical reactions between the clay and the calcite [4]. The burnt brick also contains well crystallized high temperature hematite [Fe_2O_3] and some gehlenite [$Ca_2Al_2SiO_7$]. The latter minerals are absent in the slag, indicating that they were decomposed at higher temperatures [8]. The slag contains glassy material (amorphous material, indicated by the rise of the base line in the diffractograms) that was formed as a result of the heating. The decrease of the amount of quartz, seen in the diffractions of the burnt brick and slag, as compared to the unburnt brick, may be due to its assimilation in the high temperature minerals [8].

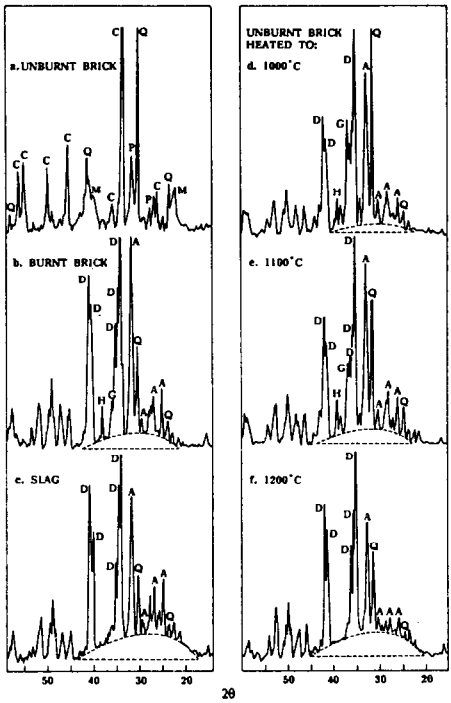

Fig. 1: X-ray diffractograms (cobalt irradiation) of: a. unburnt brick, b. burnt brick, and c. slag; comparison to samples from the unburnt brick heated for 1 hour to: d. 1000°C, e. 1100°C and f. 1200°C (M = montmorillonite, C = calcite, Q = quartz, P = plagioclase, G = gehlenite, A = anorthite, D = diopside and H = hematite. Amorphous or glassy material indicated by the rise of the base line).

IR spectra of the unburnt brick, burnt brick and slag are shown in Figure 2:

- In the unburnt brick the OH and SiO stretching bands appear at 3623 and 1038 cm^{-1}, respectively, and characterize montmorillonite [11]. The CO_3 main band appears at 1431 cm^{-1} and characterizes calcite.
- In the burnt brick, the OH stretching band disappears and the main SiO stretching band broadens and splits into four distinct bands at 1064, 969, 916 and 877 cm^{-1} due to the crystallization of the high temperature minerals [4]. The CO_3 main band becomes weaker, indicating that the original calcite decomposed upon heating and secondary calcite was formed.
- In the slag, the main SiO stretching band appears broad at 1064 cm^{-1} without splitting (except some shoulders). The disappearance of the these absorptions may be due to partial melting at higher temperature. The CO_3 main band is absent due to complete reaction that formed the high temperature silicates.

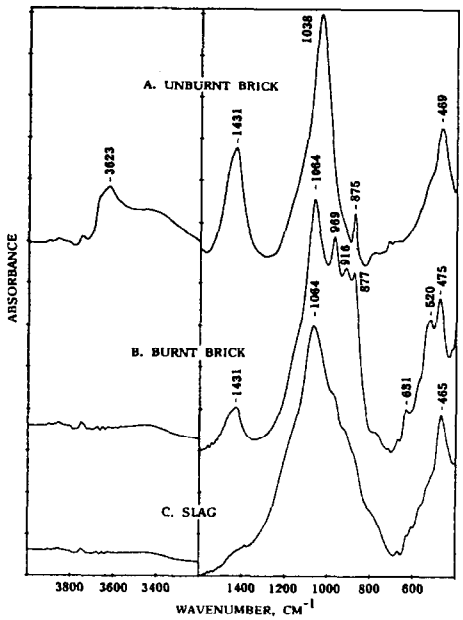

Fig. 2: IR spectra of: a. unburnt brick, b. burnt brick and c. slag. The disks are dried at 250°C.

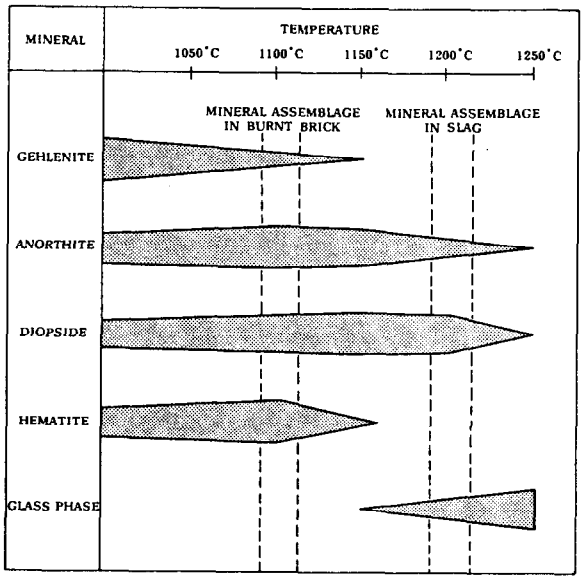

Fig. 3: Changes in mineral composition when samples from the unburnt brick are heated. The mineral assemblage in the burnt brick was compatible with a firing temperature of about 1100°C and the assemblage in the slag with a firing temperature of about 1200°C.

Determination of the Temperature of the Conflagration

In order to determine the temperatures at which the mineral assemblage of the burnt brick and slag were formed, samples from the unburnt brick were heated to various temperatures for different times and the consequent changes in the mineral compositions were defined. X-ray diffractions of these samples heated to 1000, 1100 and 1200°C for 1 hour are shown in Figure 1d-f. The results are summarized in Figure 3. The changes in mineral composition after one hour of heating are:

- At 1000°C (Fig. 1d) and 1050°C the samples contain mostly diopside, anorthite and quartz, a moderate amount of gehlenite and a small amount of hematite.
- At 1100°C (Fig. 1e) some of the gehlenite disappeared, and at 1150°C no gehlenite was observed. Most of the hematite was also destroyed at 1150°C.
- At 1200°C (Fig. 1f) the diopside diffractions became sharper and probably some of the anorthite and quartz disappeared. No gehlenite or hematite was observed. Glassy material was formed due to partial melting.
- At 1250°C the diffractions of all the above-mentioned minerals disappeared and the base line rose strongly due to melting and formation of glassy material.

When the samples of unburnt brick were heated at the above-mentioned temperatures for 6, 12, and 24 hours there was almost no change in the mineral assemblages except for slight changes in the relative amounts of the minerals and increased sharpness of diopside diffractions.

The slag has a significant glassy and porous structure. Samples of the unburnt brick heated to 1100 and 1150°C did not show this structure even after 24 hours of heating. However, when the samples were heated at 1200°C for one hour the slag structure appeared due to partial melting. The samples melted at 1250°C and the porous structure of the slag collapsed to form, after cooling, a dark massive glass. These heating stages were also detected by thermal analysis. A large endothermic peak in the DTA curve that begins above 1150°C and becomes stronger at 1250°C is attributed to partial melting and melting, respectively. A parallel exothermic effect in the cooling curve is attributed to solidification.

A comparison between the minerals formed by heating the unburnt brick to the assemblage found in the burnt brick and slag shows that they are compatible with an assemblage formed when the unburnt brick is heated to about 1100 and 1200°C, respectively (Fig. 3):

- The minimum firing temperature of the burnt brick can be estimated from traces of gehlenite in this sample. Gehlenite is formed by heating marl rocks to about 800-850°C, which is below the temperature of formation of anorthite (850-900°C) and diopside (1000-1050°C) [8]. The amount of gehlenite decreased above 1100°C (Fig. 1e), and may indicate that the brick was heated to this temperature. On the other hand, gehlenite can decompose with time during burial in humid climate [12], and the traces of this mineral in the burnt brick may be a result of this process. In any case, the heating of this brick was above the temperature of formation of diopside.
- The maximum temperature to which the burnt brick was heated can be estimated from the presence of hematite and the absence of glassy porous structure. Hematite is decomposed at about 1150°C (Fig. 1f) and glassy porous structure is formed at about 1200°C.
- The minimum firing temperature of the slag can be estimated from its glassy porous structure that formed at about 1200°C. The absence of hematite in the slag also indicates that the heating temperature was above 1150°C (Fig. 1f).
- The maximum temperature to which the slag was heated can be estimated from the collapse of the slag structure at about 1250°C and the destruction of the minerals mentioned.

Flint Pebbles in Bricks and Slag

X-ray diffractograms of flint pebbles that were found in the unburnt brick, burnt brick and slag are shown in Figure 4a-c. The pebbles in the unburnt brick contained quartz only. Those in the burnt brick and slag contained quartz and its high temperature variant, cristobalite. The slag contained increased amounts of cristobalite.

Determination of the Duration of the Conflagration

In order to determine the temperature and the period of heating at which cristobalite is formed in the flint, samples of the flint pebbles from the unburnt brick were heated to various temperatures for different times and the amount of cristobalite was determined. X-ray diffractograms of these samples heated to 1000, 1100 and 1200°C for 1 and 6 hours are shown in Figure 4d-f.

The relative amount of cristobalite was found to be dependent on the temperature and the period of heating. A small amount of cristobalite formed at 1000°C, and increased amounts at 1100 and 1200°C. At the latter temperatures the amount of cristobalite increased as a function of the heating period.

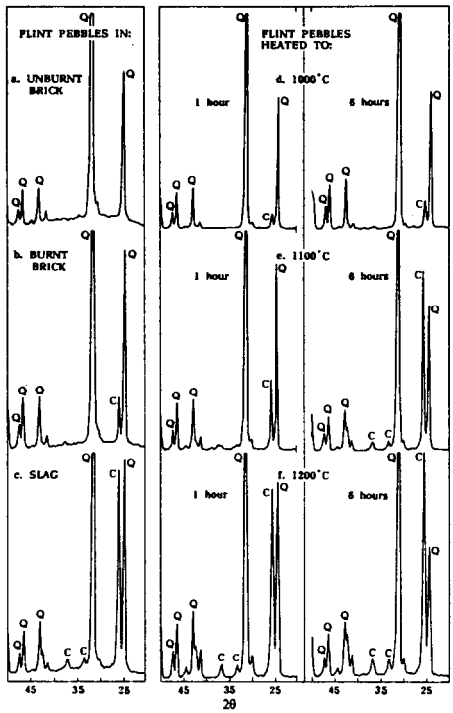

Fig. 4: X-ray diffractograms (cobalt irradiation) of flint pebbles found in: a. unburnt brick, b. burnt brick and c. slag; compared to flint pebbles from the unburnt brick heated for 1 and 6 hours at: d. 1000°C, e. 1100°C and f. 1200°C (Q = quartz, C = cristobalite).

The temperatures of the conflagration are known from the mineral assemblages of burnt brick and slag, as 1100 and 1200°C, respectively. Therefore, the period of heating can be evaluated from the amount of cristobalite that formed at these temperatures. The amount of cristobalite that was found in flint pebbles from the burnt brick and slag (Fig. 4) is compatible with the amount formed when the flint pebbles from the unburnt brick were heated to 1100 and 1200°C, respectively, for less than one hour. It can be concluded that the maximum temperature reached, 1200°C, was maintained for a short time (less than one hour), indicating a short intense conflagration.

ACKNOWLEDGEMENTS

This work was carried out while the first author was a Visiting Scientist at the Geological Survey of Israel. The authors thank Dr. Jacob Nathan of the Geological Survey for many helpful discussions.

REFERENCES

1. M. Kochavi, The Land of Geshur Project: Regional Archaeology of the Southern Golan (1987-88 seasons). Accepted for Publication, Israel Exploration Journal.
2. M. Kochavi, The Land of Geshur Project - 1988. Internal Publication, Institute of Archaeology, Tel Aviv University (1989).
3. R.C. Mackenzie, "Differential Thermal Analysis". Academic Press, London (1970, 1972).
4. S. Shoval, Thermochimica Acta, 135(1988)243.
5. E. Gardner, Am. J. Arch., 74(1970)2.
6. W.D. Kingery and J.D. Friedman, Proc. Prehistoric Soc., 40(1974)204.
7. M. Maggetti, British Museum Occasional Paper, 19(1981)33.
8. M. Maggetti, H. Westley and J.S. Olin, in "Archaeological Chemistry", Amm. Chem. Soc. (1984)151.
9. M.S. Tites, Nature, 222:5199(1969)81.
10. Y. Maniatis, and M.S. Tites, J. Arch. Sci., 8(1981)59.
11. V.C. Farmer, "The Infrared Spectra of Minerals". (Ed.). Mineralogical Society, London (1974).
12. R.B. Heimann and M. Maggetti, British Museum Occasional Paper, 19(1981)163.