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# MINERALOGY AND ULTRASTRUCTURE OF SOME ALTERATION PRODUCTS OF YAMATO-86032 METEORITE

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***Abstract:*** White products of Yamato-86032 meteorite sample have been studied using linear localization detector method and TEM (powders examination and ultramicrotomed thin-sections). In addition to the mineral phases of the meteorite (olivine, pyroxene, labradorite), calcium sulfate and hydrous minerals have been identified. The observed glassy matrix has high silica content and the alteration products in contact with glass are mainly Fe-Al and Fe-Al-Na-K-S compounds. The presence of these mineral phases suggests that a sulfuric acid alteration has to be involved for the formation of the white products studied.

## 1. Introduction

Yamato(Y)-86032 is the largest lunar meteorite ever recovered. Examinations and reports of the consortium group showed this meteoritic material has an anorthositic composition (YANAI and KOJIMA, 1987) and may be classified between feldspathic fragmental breccias and true regolith breccias (TAKEDA *et al.*, 1989, 1990). Chemical data on major and trace elements confirm the lunar origin (KOEBERL *et al.*, 1989).

Besides the chemical and petrographical investigations necessary for reconstitution of the history of the meteorites (BISCHOFF *et al.*, 1987; EUGSTER and NIEDERMANN, 1988; TAKEDA *et al.*, 1990), some investigations about alteration of meteorites give other informations. Because terrestrial weathering might significantly affect trace-element and isotopic studies of Y-86032, it is important that weathering products be thoroughly documented. GOODING (1986) previously reported that gypsum and jarosite are common products in Antarctic stony meteorites.

Based on assumptions that anorthosites were exposed parts of the surface of the early Earth with atmosphere rich in $CO_2$ and $H_2O$ and that calcium leached from plagioclase was important to fix $CO_2$, SUZUKI *et al.* (1994) performed experiments on hydrothermal treatments of plagioclase. This approach seems well adapted to model the development of alteration products and then for a better understanding of the early Earth's evolution. Although there may be significant difference in the weathering conditions, observation of natural products of weathering of anorthositic breccias will give us better understanding on such environmental changes of the early Earth. This paper summarizes some mineralogical investigations on white products on the surface of the meteorite and, on the other hand, on the alteration of the glassy matrix.

## 2. Sample and Experimental Techniques

We studied one fragment of the meteorite Y-86032, provided by the National Institute of Polar Research (Committee on Antarctic Meteorite Research). The sample is referenced as: Y-86032, subnumber 123; 0.48 g weight).

According to the sample size, the results concern only characterisation of powders obtained from the crushing of the white products extracted from the surface of the sample (diffraction by X-ray diffractometry—XRD, transmission electron microscopy—TEM) and direct study of the sample by means of ultramicrotomed thin-sections studied by TEM. We do not perform other observations such as Scanning Electron Microscopy.

The two special techniques we used for this study are:
*—for XRD: linear localization detector method*

This method is very useful for diffraction of very small quantities of materials and for focusing the X-ray beam on a small part of the sample by localization with a laser beam (BEAUFORT *et al.*, 1983; RASSINEUX *et al.*, 1988). The linear localization detector was fixed on the worm drive wheel ($2\theta$ movement) of a Philips 1050/25 vertical goniometer. Data were acquired with a Philips 1730 generator. The X-ray incident beam (CoK$\alpha$, 40 kV, 40 mA) was focused using a collimator 0.8 mm in diameter which gives a 8 mm×2 mm irradiated area at the selected zone (scanning of 14° $2\theta$). The studied sample was microdrilled from the surface and led on the sample holder without any treatment before studying.

*—for TEM: ultramicrotomed thin-sections*

Besides investigations on powders, ultramicrotomed thin-sections of meteorite sample were prepared (50 nm thickness) with a diamond cutter (ultramicrotome Reichert Jung *Super Nova*). The ultramicrotomed thin-sections were collected onto a copper grid and then studied by TEM (Philips CM 12, acceleration voltage 120 keV, EDAX Si-Li detector, nanoprobe mode with diameter beam less than 50 nm). The k factors used are those from the EDAX software PVSUPQ, version 2.18. They were determined by ZALUZEC (1979). The semi-quantitative results obtained by X-EDS analysis performed on large sections of the ultramicrotomed sections were compared with those obtained by chemical analysis. The standard error deviation was so small that the k factor was not changed.

## 3. Mineralogy

The determination by XRD of the phases in the white product extracted on the surface of the sample (Fig. 1) indicates the presence of most of minerals of the parent body meteorite, such as olivine, pyroxene, labradorite and may be magnetite. We also found some peaks related to the presence of gypsum and of one phase with a $d$ basal spacing equal to 1.02 nm. According to some microanalyses recorded by TEM, this last phase could be a clay-mineraloid weathering product as previously observed by GOODING (1986).

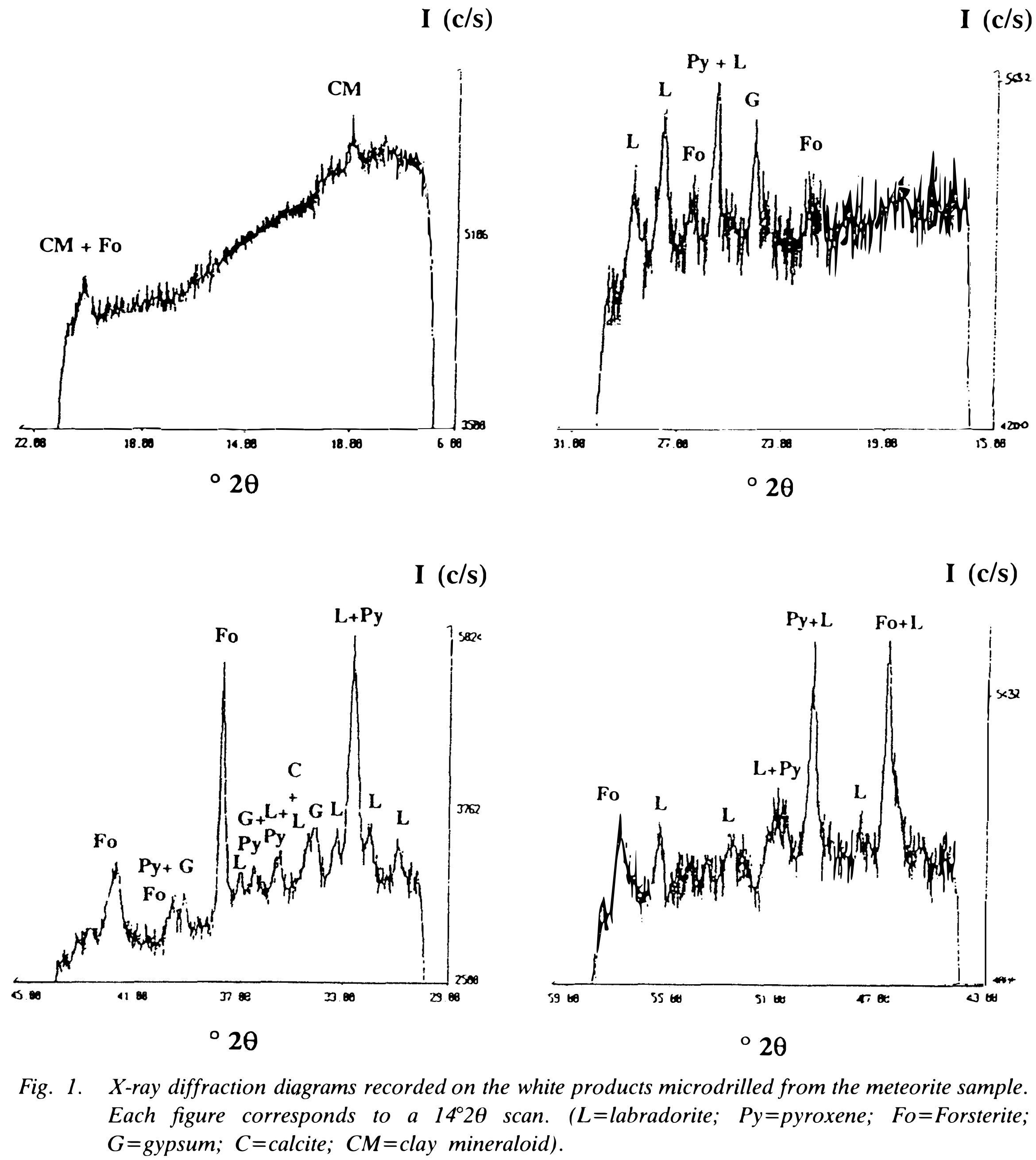


*Fig. 1. X-ray diffraction diagrams recorded on the white products microdrilled from the meteorite sample. Each figure corresponds to a 14°2θ scan. (L=labradorite; Py=pyroxene; Fo=Forsterite; G=gypsum; C=calcite; CM=clay mineraloid).*

From the powders examined with TEM, the presence of calcic compound (Fig. 2) was found, may be calcite. In the present mineralogical determination, this product could not be exactly identified because of radiation damage in TEM. But with no low-Z analysis, it is difficult to confirm this determination, although XRD indicated a small diffraction peak which could be characteristic of carbonate phase (Fig. 1). An other unexpected mineral (Fig. 3) was also identified. It corresponds to kaolinite with a typical hexagonal platy shape whose composition is related to an aluminosilicate phase.

On the ultramicrotomed thin-sections, it is possible to study the relationship

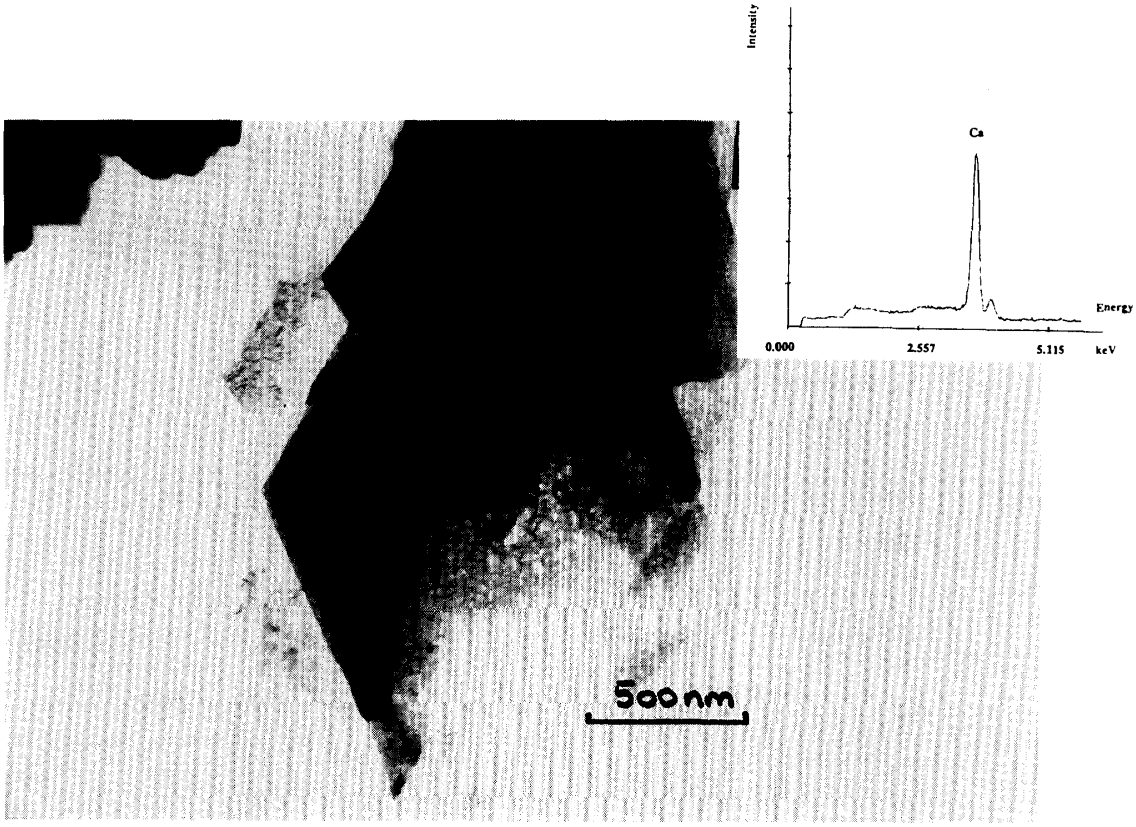


*Fig. 2. TEM micrograph and composition of euhedral calcite crystal recorded in the white product of Y-86032 meteorite.*

among alteration products and minerals or glassy matrix (CROVISIER *et al.*, 1983; THOMASSIN, 1984; BRADLEY, 1988). So, we studied the different alteration products in contact with the glassy material (Figs. 4 and 5) which is quite recognizable as chips regularly cut, surrounded by amorphous or nearly amorphous substances. Two chemical profiles were analysed since the glass to the outer part ( Table 1, a and b). The results indicate that the glassy matrix has a high silica content, whereas the alteration layers present two different compositions: Al-Fe oxides, and on the other hand, the same elements associated with Na, K and S. On the same sample, we also found Fe-Mg silicate phases (Table 1, analyses c and d).

## 4. Discussion

With respect to the cosmochemistry, observation of natural products of the alteration of anorthositic breccias can give us informations about changes of the early environment of the Earth. Some phases we identified in the Y-86032 sample correspond to alteration products which can be mainly attributed to terrestrial weathering (GOODING, 1986; MITTLEFEHLDT and LINDSTROM, 1991; VELBEL *et al.*, 1991). On a geochemical point of view, our main contributions concern the presence of sulfates (gypsum, Al-Fe sulfates and Al-Fe-Na-K sulfates) and the behaviour of the glassy matrix.

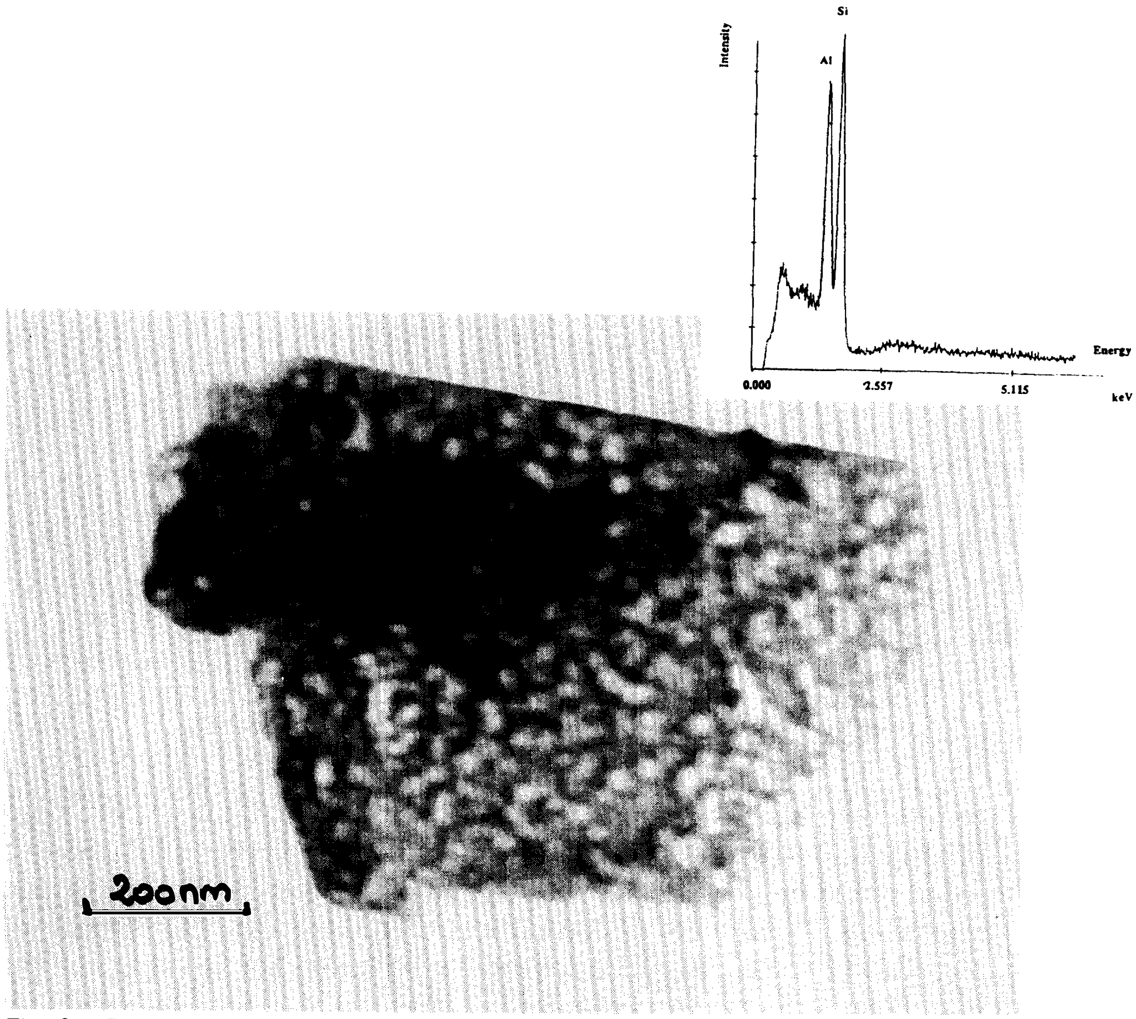


*Fig. 3. TEM micrograph and composition of kaolinite-like mineral recorded in the white product of Y-86032 meteorite.*

From the sampling of the white product on the outer part of the Y-86032 meteorite, the presence of sulfates seem quite consistent with a recent alteration, probably a terrestrial weathering postulated by GOODING (1986) from the determination of gypsum and jarosite-like phase. The presence of Al-Fe-Na-K sulfates underline this assumption because Na is one of high water-soluble elements. The sulfate formation may be related to sulfuric acid conditions resulting from the reaction between a weak carbonic acid solution (water in equilibrium with atmosphere) and sulfides present in meteorite (MITTLEFEHLDT and LINDSTROM, 1991). These conditions can lead to hydrolysis of silicates and glass (VELBEL *et al.*, 1991; BOURDIN *et al.*, 1995) and the formation of hydrous minerals such as kaolinite (THOMASSIN *et al*, 1992).

Thin sections of the glassy matrix examined by TEM have revealed the relationship among glass with porous products. Only one composition of glass (high-silica content without iron) has been found. This composition is rarely mentioned in such examination of the meteorite (TAKEDA *et al.*, 1990). As an

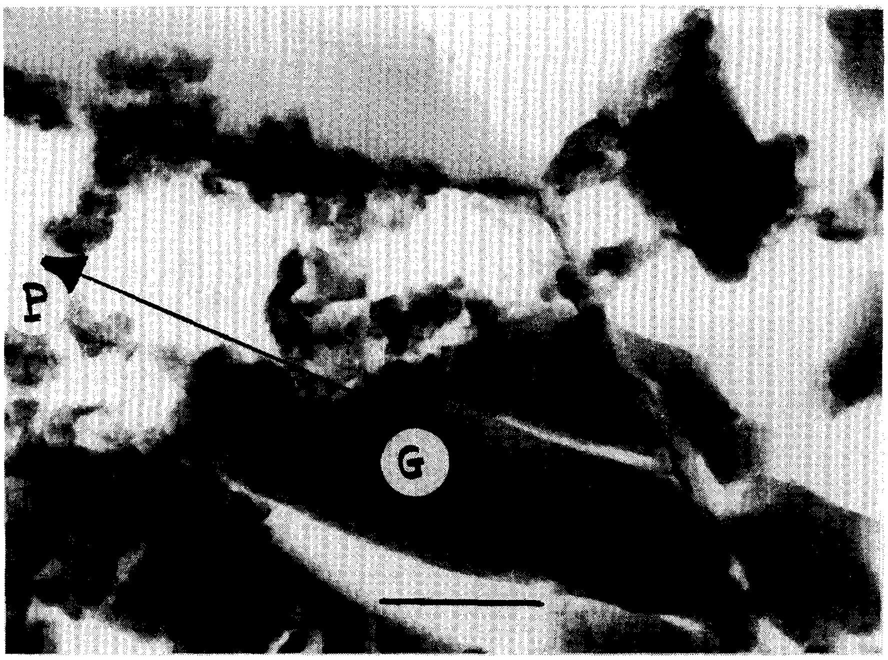


*Fig. 4. TEM images of the relationship among glassy matrix (G) and alteration products (P) in Y-86032 meteorite (The arrow indicates the direction of the description of a analyses in the Table 1. Scale bar=300 nm).*

interpretation of the presence of silica-rich glass, SUZUKI *et al.* (1994) have experimentally found an alteration product (silicagel) of plagioclase which may be solidified as silica amorphous material. The relation of the glass with the iron-rich products suggests that it may have formed by condensation onto the surface of pre-existing minerals - olivine, pyroxene, plagioclase (BRADLEY and BROWNLEE, 1986; BRADLEY, 1988). Because impact glasses of anorthositic compositions may have been found on the surface of the early Earth, weathered products observed in this paper will contribute to our understanding on basic processes taken place in the beginning of the Earth's history, and in turn such information will help us to consider an environmental problem related to the Ca-$CO_2$ interaction on the surface of the present Earth.

## 5. Summary and Conclusion

In examining the meteorite Y-86032 sample, the following results concern:

1) the mineralogy of the meteorite and the white products extracted at the surface sample: olivine, pyroxene and plagioclase (labradorite) and magnetite (?) for the major components, with gypsum (detected XRD), a calcium-rich phase that might be calcite, one phase with a *d* basal spacing equal to 1.02 nm (detected by TXRD) and kaolinite (?) only observed by TEM and analysed by EDS.

2) the chemical composition of the alteration products determined on ultrathin sections with a special insight on iron-rich silicate phase and the relationships between Fe-Al/Fe-Al-S/Si-Al bearing phases.

The chemistry of some alteration products underline the accumulation of iron

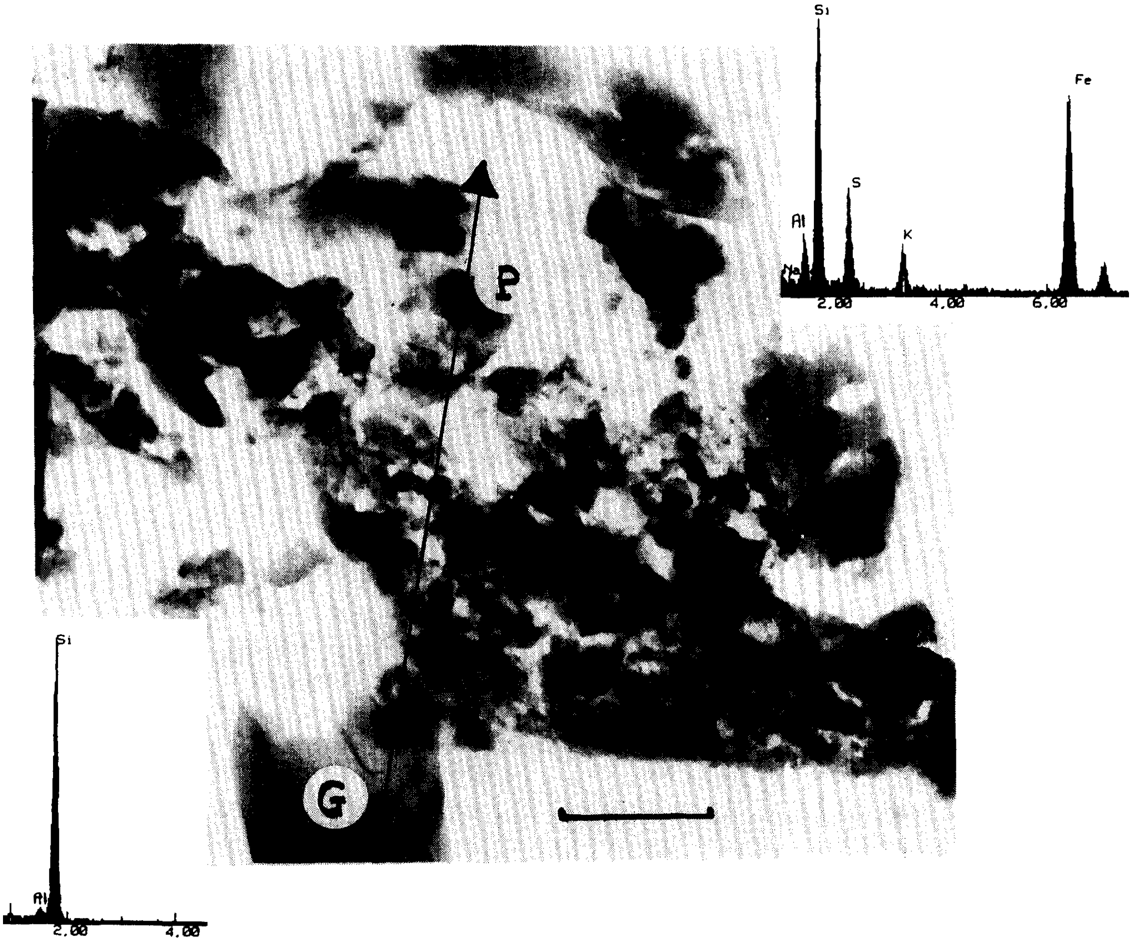


*Fig. 5. TEM images of the relationship among glassy matrix (G) and alteration products (P) in Y-86032 meteorite. The AEM analyses correspond to the glass composition and a representative alteration product (The arrow indicates the direction of the description of b analyses in the Table 1. Scale bar = 300 nm).*

*Table 1. Representative compositions (wt%) of alteration products in contact with the glassy matrix (a, see Fig. 4; b, see Fig. 5) and of Mg-Fe rich silicate phases (c and d).*

| | | $Na_2O$ | MgO | $Al_2O_3$ | $SiO_2$ | $Fe_2O_3$ | CaO | $TiO_2$ | $SO_3$ | $K_2O$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | alteration | 0 | 0 | 33.8 | 2.9 | 58.4 | 1 | 0.8 | 0.7 | 1.2 | 0.3 |
| | alteration | 3.8 | 0 | 29.5 | 0.8 | 36.7 | 0.7 | 0.4 | 21.4 | 6.1 | 1 |
| a | alteration | 2.9 | 0 | 21.4 | 1.3 | 36.2 | 0.5 | 0.4 | 26.4 | 9.6 | 1.3 |
| | glass | 0 | 0 | 6.2 | 92.3 | 0.4 | 0 | 0 | 1 | 0 | 0 |
| | glass | 0 | 0 | 6.6 | 92.5 | 0.3 | 0.3 | 0 | 0.2 | 0 | 0 |
| | glass | 0 | 0 | 6.8 | 92.4 | 0.2 | 0.3 | 0 | 0.3 | 0 | 0 |
| | alteration | 10.7 | 0 | 36.2 | 0 | 28.9 | 2.7 | 0.3 | 12.2 | 9 | 0 |
| | alteration | 0 | 0 | 41.4 | 0.8 | 52 | 2.7 | 0.5 | 0.6 | 1.9 | 0 |
| b | alteration | 3.7 | 0.8 | 43 | 5.4 | 30.5 | 0.8 | 0.3 | 11.5 | 3.3 | 0.8 |
| | glass | 0 | 0 | 9.3 | 78.5 | 8.1 | 0.7 | 0 | 2.6 | 0.7 | 0 |
| | glass | 0 | 0 | 6.3 | 91.6 | 0.2 | 1.2 | 0 | 0.7 | 0 | 0 |
| | glass | 0 | 0 | 5.6 | 94.1 | 0 | 0 | 0 | 0.3 | 0 | 0 |
| c | particle | 0 | 9 | 0.8 | 23.5 | 56.9 | 7.7 | 0.7 | 0 | 0 | 0 |
| d | particle | 0 | 14 | 2.5 | 36.2 | 35.1 | 11.9 | 0.3 | 0 | 0 | 0 |

and the role of sulfur. For a better understanding of the evolution of the meteorite, other investigations have to be performed with a special emphasis on the complementarity of the presented methods.

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