Geol. Bull. Univ. Peshawar, 1988, Vol. 21, pp. 49–56

RECOGNITION OF METEORITIC IMPACT BY FISSION TRACK DATING (FTD) TECHNIQUE

A.A. QURESHI & H.A. KHAN

SSNTD-Laboratory, NED, PINSTECH, Nilore, Islamabad

ABSTRACT

Fission track dating (FTD) is a relatively new dating technique. By this, interesting problems concerning rock dating, flight and fall of 'mysterious' glass objects-the tektites and meteorites can be studied and solved. This paper describes the general details of the FTD technique and the age determination work carried out on Libyan desert glass. Based on these studies a meteoritic impact, which caused the fusion of Nubian sand or sandstone and resulted in the formation of Libyan desert glass 28.36 m.y. ago, has been recognised.

INTRODUCTION

Fission track dating (FTD) is a relatively new technique which has proved extremely successful in solving problems of diverse nature related to geochronology, geophysics and archaeology. The technique is based on the principle that radioactive element spotaneously fission at a known fixed rate and by measuring the effects of fission as "tracks" one can find out the ages of minerals and rocks. Among radioactive elements, the U-238 is relatively more abundant in minerals having the property of fission to create tracks. So it is used for the age determination of minerals/rocks.

The tracks are the latent damage trails created in minerals (also in plastics and glasses) by the fission of radioactive elements. During fission the fission fragments move apart from each other, resulting in thin linear tracks in the body of the mineral. Originally the tracks are small (3–10 microns), but can be enlarged by etching so as to be seen under an ordinary microscope. The shape of the tracks depends upon detector type, etching conditions and incident particles. A few types of tracks are shown in Fig. 1.

The tracks are recorded by almost all minerals but sphene, zircon, apatite, micas and natural glasses are more suitable for FTD work due to higher U–238 content and well known track registration and etching characteristics. So all those rocks, artifacts, etc. can be dated easily which contain the above-mentioned minerals. In case of other minerals, considerable labour is required for age determination. The technique is analogous to other dating methods except that in this case fission effect (as tracks) is measured whereas in other cases fission products as daughter isotopes are accounted for (Fleischer et al., 1975).

Let us suppose a unit area of a mineral (sphene, zircon, apatite or mica) having a reasonable U–238 content of about 50 ppm. Since the time of its formation a part of U–238 must have fissioned spontaneously which can be expressed as:

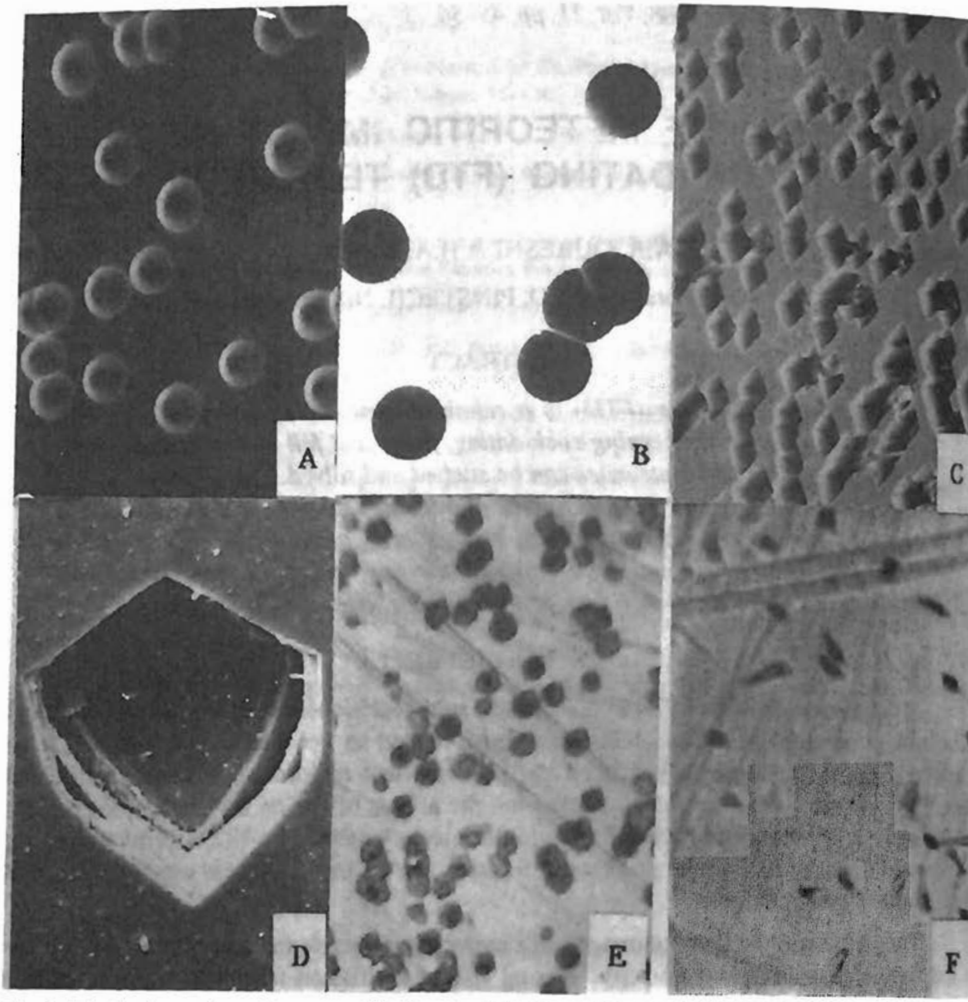


Fig. 1. Tracks in various detectors (A) Plastic (B) Glass (C) Mica (D) Single enlarged mica track (E) Apatite (F) Zircon

$$NUf = NUp \times T \times \lambda$$

where NUf = No of U–238 atoms which underwent fission during time T, NUp = No of unfissioned U–238 atoms still present in the mineral, T = Time of formation age of the mineral and λ = decay constant of U–238 having a value of $8.4 \times 10^{-17} yr^{-1}$.

The NUf can be calculated by counting the spontaneous tracks created due to the fission of U–238. The NUp is calculated by inducing fission in U–235 (which is always present with U–238 in a fixed ratio), by irradiating the mineral with slow neutrons in reactor. By this new or induced tracks will appear which would represent the number of U–238 atoms present in the mineral. The present day ratio of U–238 and U–235 as 140:1 in terrestrial samples is known; we can find out the number of unfissioned U–238 atoms still present in the mineral by multiplying the number of induced tracks with 140. This value is placed instead of NUp in the above equation and value of T or age of the mineral can be calculated. However, certain considerations like decay constant of U–238 and certain other factors like fission cross section and range or the fission fragments of U–235 and neutron fluence value, etc. are to be accounted for before age interpretation is made.

The usual FTD practice begins with the isolation of mineral grains of about 200 micron size by crushing/ sieving the rock specemin and subsequent treatment with heavy liquids (Durrani et al., 1987). Jones (1987) has described that sphene, zircon and apatite (SG = 3.5, 4.7 and 3.2 respectively) can be separated from bulk rock material quartz and feldspar (SG = 2.6 and 2.5 – 2.9) by using bromoform or methylene iodide (SG = 2.89 and 3.2). The sphene, zircon or apatite can further be separated from each other by a hand lens. The mineral grains are then mounted in araldite for easy handling. They are then ground and polished with diamond paste to obtain smooth surfaces. The mineral are now etched to reveal spontaneous tracks. The spontaneous tracks density is calculated and recorded. After this, the mineral grains alongwith an external detector (mica or lexan) are irradiated in a reactor for a few minutes to induce fission in U–235. The external detector records the induced fission tracks which are revealed on etching. The induced tracks are counted and recorded. By using simplified equation (Durrani et al., 1987) given below, which originally contains a number of constants, the age of the mineral and hence that of a rock or a stone artifact which contains that mineral can be calculated.

$$Age = 5 \times 10^{-8} \times Std/Itd \times F$$

where Std = Spontaneous track density, Itd = Induced track density, and F = Neutron fluence.

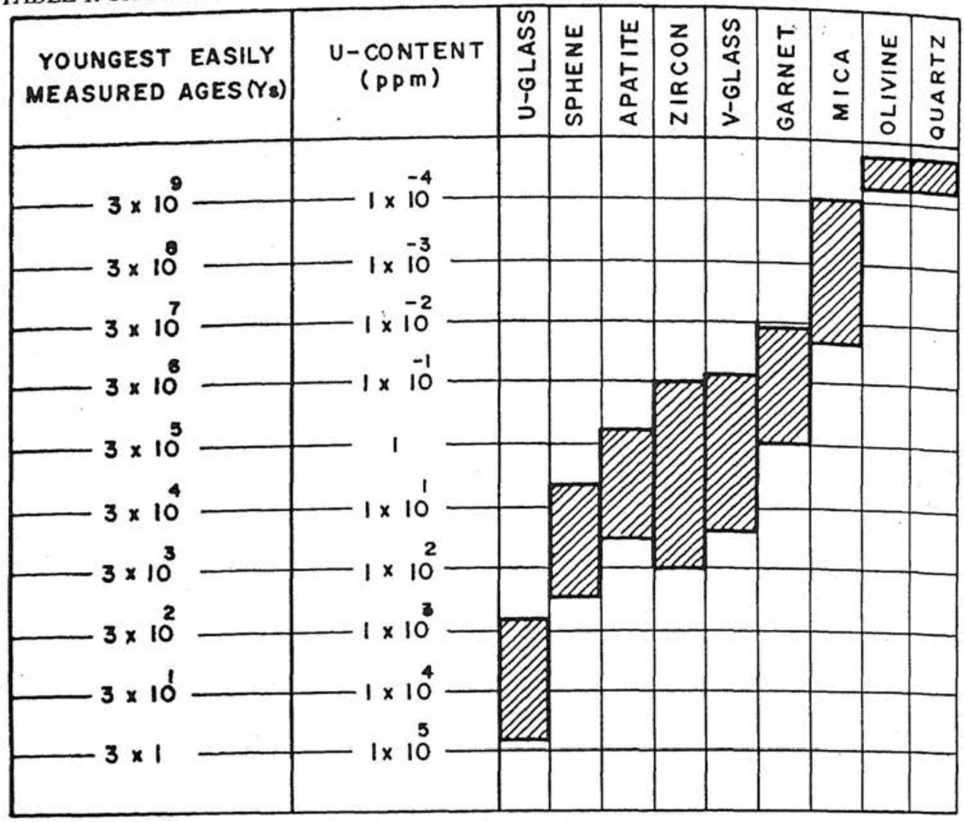
The FTD technique has diverse applications in geology, geophysics and archaeology, and problems like uplift/thermal histories of rocks, ocean floor spreading, archaeological forgeries and presence of Pu-244 tracks and cosmic ray induced fission spallation recoil tracks in extraterrestrial samples have very successfully been studied by this technique. Another merit of this technique is that it has broad time range, from most recent to samples as old as the creation of the universe (see Table 1), provided the sample used for dating has not undergone a severe thermal episode. All other methods have always certain lower or upper limits. Moreover very small sample, about one mg, is enough for FTD analysis.

LIBYAN DESERT GLASS

Spenser et al. (1939) have described the occurrence of silica glass as strewn between sand dunes of the Libyan desert over on oval area measuring about 50 x 125 km in an EW and NS direction. The glass pieces are of different sizes, the largest reaching 7.25 kg in weight. Well-developed rounded cherty/quartzitic pebbles, cobbles and artifacts are found inbetween them. Minor outcrops of the Nubian sandstone occur in the areas but the glass is nowhere in direct contact with it or forms a part of it (Barnes et al., 1976).

The glass is mostly transparent to translucent and colourless, but yellowish, greenish and milky shades are also seen. Elliptical, spherical and sometimes elongated bubbles have been noted in certain samples. Referactive index and specific gravity have been reported as 1.459 to 1.4642 and 2.120 to 2.203 respectively by Barnes et al. (1973). Chemical analyses of the glass have been reported by Kleinmann (1969). It is mainly composed of SiO_2 (96.9–99.7%), the other elements include Al_2O_3 (0.04–1.54%), Fe_2O_3 (0.08 – 0.53%), TiO_2 (0.02 – 0.21%) and ZrO_2 (0.003–0.02%), with very low quantities of other elements. Zircon ($ZrSiO_4$), rutile (TiO_2), devitrified products of zircon and silicon oxide-baddeleyite (ZrO_2) and cristobalite (SiO_2) have also been recognised in the glass.

TABLE 1. URANIUM CONTENTS AND EASILY MEASURABLE AGES BY FID



Baddeleyite is a mineral of carbonatites and alkaline rocks and its presence in the Libyan desert glass has been attributed to the breakdown of zircon of Nubian desert sand or sandstone at high temperature of 1676°C or more (El Goresy, 1965, 1968). Such a high temperature is rare for terrestrial rocks and is only imaginable during a meteoritic impact. Presence of hafnium in glass analyses also indicates its relation to zircon of desert sand or sandstone.

To find out the time of the meteoritic impact and origin of Libyan desert glass and its relation to the associated Nubian sand or sandstone, the fission track dating studies have been carried out on a few glass pieces, supplied to us by Dr. Klaus Theil, University of Kolon, West Germany, for which we are thankful to him.

EXPERIMENTAL DETAILS

The glass pieces were crushed to 200 micron size grains, washed with acetone and mounted in araldite. They were then ground and polished with 6, 3, 1 and 1/4 grade diamond pastes to obtain clean surfaces. After washing and cleaning, the grains were etched in 24% HF for two minutes to reveal spontaneous tracks. After etching, the sample was thoroughly washed and cleaned in ultrasonic bath for a few hours to remove HF traces and dried with hot air. After this, the mount was checked at low magnification and seven grains having better resolution were selected and marked for further studies. The spontaneous track density was computed from the seven grains and recorded.

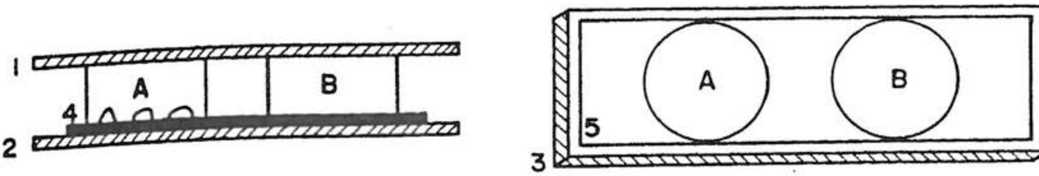


Fig. 2. Assembly for the irradiation of sample in reactor

1–3 Perspex Strips
A Mount containing Mineral Grains
4–5 External Detector (Lexan o Mica)
B Standard Reference Glass

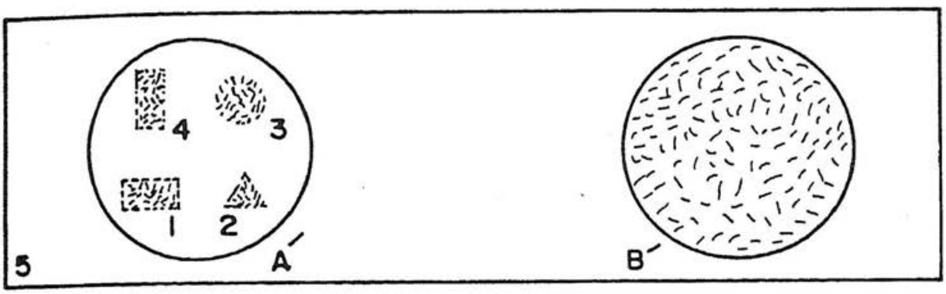


Fig. 3. Induced tracks in external detector due to mineral grains and standard reference glass

A — Araldite Mount containing Mineral Grains 1–4.
B — Standard Reference Glass.
A′ — Replica of 'A' containing Induced Track due to Mineral Grains 1–4.
B′ — Replica of 'B' containing Induced Tracks due to 'B'.
5 — Lexan Strip.

Now the mount containing glass pieces and a standard reference glass (No. SRM–963a) having calibrated track vs neutron fluence ratio were placed on a lexan strip and clamped between perspex strips as shown in Fig. 2. This assembly was then irradiated for four minutes in Pakistan Research Reactor (PARR) at PINSTECH having a thermal flux of 2×10^{13} n. sec^{-2} to induce fission in U–235 present in the glass grains. After irradiation, a three days cooling time was given to the sample during which activity level went below the safe limits for carrying out further work. At this stage, the lexan was detached from mount and reference glass and etched in 6.5N NaOH at 50°C for 45 minutes to develop induced tracks. The induced tracks on lexan due to various glass grains and reference glass were counted at the respective points as shown in Fig. 3.

The specific gravity of the glass was calculated using Cardinal Principle and formula SG=Wa/Wa-Ww. The Wa and Ww are the weights of sample in air and in distilled water at 23°C. The refractive index measurements were made using refractometer and oil immersion methods.

RESULTS

Fluence Calculation

Fluence is the number of neutrons which have been incident on glass pieces and standard reference glass surface having unit area, during irradiation in reactor. Calculation of fluence is of basic importance as its value is required for age determination. The fluence was calculated by using standard reference glass (No. 963a) for which data has been provided by National Bureau of Standards USA (Carpenter et al., 1974) for lexan and gold foil. The fluence value calculated and used by us for age determination was 19.08×10^{14} n.cm^{-2}

Age calculation

The age was calculated using formula given by (Durrani et al., 1987). The induced track density calculated from lexan for respective grains was doubled so as to get the actual value of induced track density as the fission events from one side of the glass grains have contributed towards the formation of tracks in lexan as compared to the spontaneous track density calculated from the grain surface where track formation is due to two sides of the grains as shown in Fig. 4. From spontaneous and induced track density the age has been calculated as 28.36 ± 0.72 m.y. The data for the age calculated is given in Table 2.

Specific Gravity and Refractive Index

The specific gravity measurements were made on a few glass pieces and the values range from 2.207 to 2.215. The available glass pieces seem to be somewhat heavier than the

TABLE 2. FISSION TRACK AGES AND SPONTANEOUS/INDUCED TRACK DENSITIES OF SEVEN GLASS CRYSTALS USED FOR FISSION TRACK DATING STUDIES

Std	2. Itd	Age = $5 \times 10^{-6} \times$ Std/2. Itd $\times$ F (after Durrani *et al* 1987)
101	332	29.09 m.y.
217	720	28.71 "
97	340	27.28 "
242	812	28.43 "
85	290	27.26 "
159	522	29.05 "
121	402	28.71 "

Average = 28.36 ± 0.72 m.y.

Following constants have been used for age determination

Constants: $\lambda = 8.4 \times 10^{-17}$ yr^{-1} $\sigma^{235} = 5.8 \times 10^{-22}$ cm^2,
$U^{235}/U^{238} = 7.26 \times 10^{-3}$, $F = 19.08 \times 10^{14}$n.cm^{-2}

Std =Spontaneous track density, Itd = Induced track density

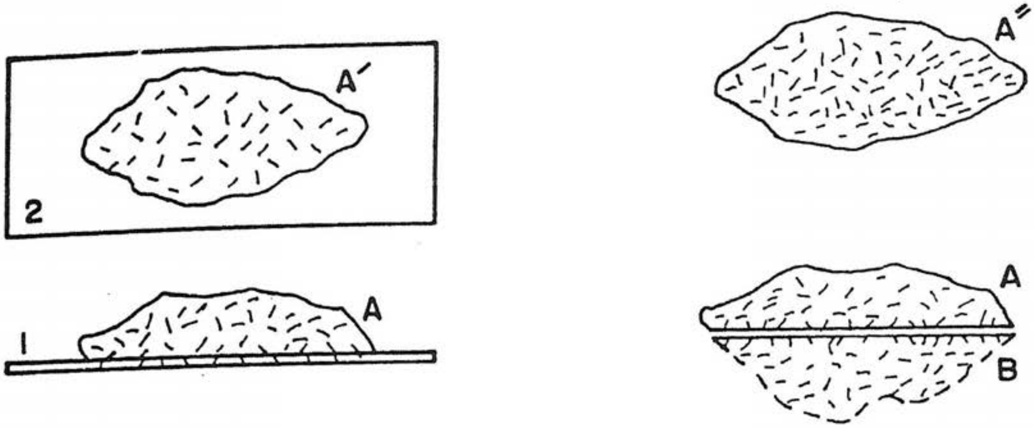


Fig. 4. Induced track density ratio of 1:2 on external detector and mineral grain surface

1 & 2 — External Detectors (Mica or Lexan).
A — Mineral Grain with Lower Half (B) Removed by Polishing.
A′ — Induced Tracks on External Detector due to the Upper Half of the Grain (A).
A″ — Induced Tracks on Mineral Surface due to Upper and Lower Halves (A & B) Mineral.

average value reported by Barnes et al. (1973). The repractive index values measured by us using refractometer and oil immersion methods were found to be 1.48–1.50.

CONCLUSION

The young age (28.36 ± 0.72 m.y.) of Libyan desert glass demonstrates that it has been derived from the associated Nubian sand or sandstone by a severe meteoritic impact. No evidence of an Oligocene igneous or metamorphic activity in the area has so far been traced which could yield glass from the desert sand or sandstone. Moreover, no igneous or metamorphic process is yet known which would produce silica melt as clear and pure as the Libyan desert glass. Temperatures related to the impact were as high as 1676°C. This temperature estimate is from the minerals present in the glass. As SiO_2 melts at 1700°C the actual temperature generated would have been higher than this, because the Nubian sand or sandstone got melted and fused to form desert glass. Such a high temperature is usually rare for terrestrial rocks. The oval shape of the area over which the glass pieces are strewn is also suggestive of impact origin. No uplift, tectonic or erosive event seems to be involved in changing the geological history of the area, therefore we think that the age data most probly records the age of meteoritic impact which resulted in the formation of Libyan desert glass. The claim is also supported by the presence of baddeleyite and hafnium in the glass which have most probably been derived from zircon present in the associated sand or sandstone.

REFERENCES

Barnes, V.E. & Underwood, J.R., Jr., 1976. New investigations of the strewn field of Libyan desert glass and its petrography. Earth Planet. Sci. Lett. 30, 117–122.

Carpenter, B.S. & Reimer, G.M., 1974. Calibrated glass standards for fission track use. NBS, Special Publ. No. 260–49.

Durrani, S.A. & Bull, R.K., 1987. Solid state nuclear track detection, principles, methods & applications. Pergamon Press, Oxford.

Fleischer, R.L., Price, P.B. & Walker, R.M., 1975. Nuclear tracks in solids: Principles & applications. University of California Press, Berkeley.

El Goresy, A., 1965. Baddeleyite and its significance in impact glasses. J. Geophys. Res. 70, 3453–3459.

El Goresy, A., 1968. The opaque minerals in impact glasses. In Shock Metamorphism of Natural Material. (B.M. French & N.M. Short eds.) 531–534.

Jones, M.P., 1987. Applied Mineralogy. Alden press, Oxford, U.K.

Kleinmann, B., 1969. The breakdown of zircon observed in the Libyan desert glass as evidence of impact origin. Earth Planet. Sci. Lett. 5, 497–501.

Spenser, L.J., 1939. Tektites and silica glass. Min. Mag. 25, 425–428.

Barnes, V.E. & Barnes, M.A., 1973. Tektites, World wide investigations of tektites continued. Eds. Dowdens Hutchinson and Ross, Stroudsburg. Lapidary J. 26, 18–21.