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澳亞撞擊事件定年分析

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澳亞撞擊事件定年分析

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計畫主持人： 羅　清　華
共同主持人：
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中　華　民　國　九十三　年　十　月　一　日

中文摘要

隕石撞擊事件可能引發起地球內部的大規模岩漿作用、大型礦床的形成、地磁反轉與氣候變遷，進而導致生物大規模絕滅等地球演化上的重大事件。因此，隕石撞擊事件的研究工作對地球演化之研究具有相當程度的重要性。亞洲、澳洲、西太平洋與印度洋地區廣佈 tektite 與 microtektite，統稱為”Australasian tektites”，雖然這個撞擊事件跟生物絕滅與地磁逆轉等效應間的關係，還不是很清楚；而且撞擊事件形成的隕石坑構造位置，仍有待找尋。但由於 Australasian strewn field 堪稱地表分布面積最大，也是最年輕的 Strewn field，且與石器時代人類生活有著密切關係，因此，相關之研究工作更形重要。在探討隕石撞擊與地球演化事件關聯性時，事件發生的時序與時間是項最為關鍵性的角色，因此，本研究計畫就 Australasian strewn field 內的 Australasian tektite 與 Darwin Glass 進行定年學與地球化學分析工作，期望結果能提供時間的控制點，討論撞擊與地球演化事件間之因果關係。

截至目前，本工作已完成 Darwin Glass 的分析工作，並已發表一篇論文：Lo, C.-H., Howard, K.T., Chung, S.-L. and Meffre, S. (2002) Laser-fusion $^{40}Ar/^{39}Ar$ ages of Darwin impact glass. Meteoritics & Planetary Science 37, 1555-1562

關鍵詞：澳亞隕石撞擊事件、氬同位素定年學

ABSTRACT

Darwin Glass represents the impart-related siliceous glass that formed in Tasmania, close to the Australasian Strewn Field. Three samples of such glass were dated using $^{40}Ar/^{39}Ar$ single-grain laser fusion technique, yielding isochron ages of 796-815 ka with an overall weighted mean of 816 ± 8 ka. These age data are statistically indistinguishable from those recently reported for the Australasian tektites from Southeast Asia and Australia (761-816 ka). However, considering the compositional and textural differences and the disparity from the presumed impact crater area for Australasian tektites, the Darwin glass is more likely to have resulted from an individual impact event. We therefore infer that multiple impacts, owing probably to a cometary explosion in the atmosphere, may have occurred in SE Asia and Australia during the mid-Pleistocene.

Keywords: Darwin Glass, Australasian tektites, Impact event, $^{40}Ar/^{39}Ar$ dating

INTRODUCTION

Darwin glass was first discovered and traded by Tasmanian aborigines thousands of years prior to its discovery by Europeans in the middle nineteenth century (Storey, 1987). The glass occurs within an area of ~400 (20x20) km^2 in western Tasmania, often as irregular fragments, twisted masses or chunks, which, up to 10 cm in size, show color range from white/clear, light green, dark green, dark brown to black. According to Storey (1987), the glass was first examined by Charles Darwin in the voyage of the *HMS Beagle* and considered volcanic in origin. Subsequent studies (Taylor and Solomon, 1964; Meisel *et al.*, 1990) suggested, however, a terrestrial origin because its geochemical composition, marked by anomalous Cr/Ni, Ni/Co and Fe/Ni ratios and high Ni abundance, resembles to that of argillaceous sandstones. This latter argument was further evidenced by argon and oxygen isotope data (Zähringer and Gentner, 1963; Taylor and Epstein, 1969). Moreover, the discovery of coesite and tourmaline within the glass (Reid and Cohen, 1962) led to the classification of Darwan Glass as an impact glass (Reid and Cohen, 1962; Koeberl, 1998). Although no firmly established source is known, a large circular depression, with negative gravity anomaly, was later identified in the thick rainforest area of ~1 km in diameter, which is located ~7 km southwest of Mt. Darwin and coined the Darwin Crater suggestive of a meteorite impact crater (Ford, 1972; Fudali and Ford, 1979). This is consistent with the synchronism between the Darwin Glass and glasses found in the Darwin Crater based on K-Ar and fission track age data (Gentner *et al.*, 1973). The Darwin Glass is generally vesicular and shows flow/layering structures in thin section, marked by bands of elliptical bubbles or vesicles without strain, a characteristic texture that is observed in the Muong Nong-type tektites which landed as plastic glasses with a slow cooling history near the crater (Barnes, 1963).

The Darwin Glass occurs close to the margin of the field of the Australasian tektites which are named australite for those occurring in Australia. The Darwin Glass and Australasian tektites have been dated repeatedly using K-Ar and fission track techniques, which yielded a broadly coincident, though rather large, age range from 720 to 803 ka (Gentner *et al.*, 1969, 1973; Storzer and Wagner, 1980a, b; Izett and Obradovich, 1992; Kunz *et al.,* 1995; Yamei *et al.*, 2000). This coincidence, along with the geographic association led some workers (Fleischer and Price, 1964; Gentner *et al.*, 1969; Storzer and Wagner, 1980a, b) to propose that the Darwin Glass and Australasian tektites are genetically related, despite the Glass has textural, geochemical and oxygen isotopic features that are distinct from the Australasian tektites (Taylor and Solomon, 1964; Taylor and Epstein, 1969; Meisel *et al.*, 1990).

The Australasian Strewn Field covers an immense area, i.e., one tenth of the Earth's surface, from SE Asia, through India Ocean down to Australia. By identifying geochemically distinct groups of impact glasses in the field, Meisel et al. (1995) proposed a multiple, rather than single, impact event for producing the entire strewn field. Viewing from the Muong Nong-type tektites that are widespread in the field, Wasson (1991, 1995) suggested a so-called "multiple melt pool hypothesis" which argues that these layered tektites should be deposited within a few radii of the source crater and thus many craters and melt pools are required. Taylor (1969) claimed that explosion of a low density comet in the atmosphere would have melted a thin surface layer of terrestrial sediments, thereby capable of causing such a widespread impact glass in the Strewn Field. To further explore these hypotheses, it is obvious that precise dating is urgently necessary. In comparison to the Australasian tektites that have been precisely and repeatedly dated using the ^{40}Ar/^{39}Ar method (Izett and Obradovich, 1992; Kunz *et al.,* 1995; Yamei *et al.*, 2000), good-quality age data have never been available for the Darwin Glass. This study presents the first set of precise ^{40}Ar/^{39}Ar age data for the Darwin Glass samples, in attempting to better appreciate the temporal and causal relations between the two types of impact glasses. Then, a detailed evaluation on the above hypotheses for multiple impact events in the Australasian Strewn Field may become possible.

SAMPLES AND ANALYTICAL METHOD

Some Darwin Glass fragments, massive chunk in form, were collected from a ~15-cm thick soil-gravel horizon, located ~20-30 cm below the surface, near Bird River, Tasmania. All these glass fragments are black in colour and rich in bubble. Three glass samples (DC1, DC2 and DC3), with least internal bubbles, were extracted from these fragments for a dating study using the laser ^{40}Ar/^{39}Ar single-grain fusion method. Samples were first crushed and disintegrated. After sieving, glass chips in the range of 140-250 贡m were ultrasonically cleaned in distilled water, then dried and handpicked to remove visible contamination and to avoid bubbles as well. The glass chips were then irradiated together with the LP-6 Biotite standard (Odin *et al.,* 1982) and known-composition salts in the VT-C position at the THOR Reactor in Taiwan for 30 hours. To monitor the neutron flux in the reactor, three aliquots of the LP-6 standard, weighted in the range of 6-10 mg, were stacked with samples in the irradiation canister with a length of ~9 cm. After irradiation, standards and samples were totally fused using a US LASER Nd-YAG laser operated in continuous mode for fusing the glass grains in single steps. The gas was purified by two Zr/Al getters and then was measured by a VG3600 mass spectrometer at the National Taiwan University. The J values were calculated from argon compositions of the LP-6 biotites, with a $^{40}Ar/^{39}Ar$ age of 128.4 ± 0.2 Ma, calibrated according to the age of the Fish Canyon biotite by assuming that it has the same age as the Fish Canyon sanidine (28.02 ± 0.28 Ma) (Baksi *et al.*, 1996; Renne *et al.*, 1998). The mean of J-values obtained from the monitor standards was adopted in age calculation, because the gradient of neutron flux across the canister appears to be 0.52%; which is rather small. The isotope interferences caused by Ca, K and Cl, were calibrated by the analytical results for the co-irradiated salts. Ages were calculated from Ar isotopic ratios measured after corrections made for mass discrimination, interfering nuclear reactions, procedural blanks, and atmospheric Ar contamination. The analytical procedures are outlined in detail by Lo *et al.* (2001).

ANALYTICAL RESULTS

Fusion of thirty-three single grains was carried out for sample DC1, which gave an age range from 731 to 868 ka and a total gas age of 808 ± 8 ka. The data points plot linearly in the $^{36}Ar/^{40}Ar$ – $^{39}Ar/^{40}Ar$ isotope correlation diagram, yielding an intercept age of 814 ± 16 ka and a trapped argon composition with $^{40}Ar/^{36}Ar$ ratio of 295.5 ± 0.5, with a values of mean square of weighted deviates (MSWD) = 1.235. Similarly, sample DC2 gave $^{40}Ar/^{39}Ar$ ages in the range of 744 – 862 ka and the sum of gas compositions suggesting a weighted mean age of 802 ± 7 ka. Regression of the data points in the isotope correlation diagram indicates an intercept age of 812 ± 9 ka, with an initial $^{40}Ar/^{36}Ar$ value of 295.3 ± 0.1 that is indistinguishable from the atmospheric composition. In contrast, DC3 glass yields an intercept age of 795 ± 17 ka, which is slightly younger than its respective weighted mean age (802 ± 9 ka) although they appear to agree with each other within 1钋. Given that the MSWD values (0.899-1.364) for data regressions of the samples are close to unity, and that the isochron analysis is considered to be able to accommodate deviations from atmospheric $^{40}Ar/^{36}Ar$ composition in the samples (see McDougall and Harrison, 1999, for discussion), the intercept ages should be more reliable than their respective weighted mean ages, although they match generally with each other.

The obtained intercept ages for the Darwin samples, ranging from 795 ± 17 ka to 814 ± 16 ka, match with each other within ±1钋. This agreement suggests that the Darwin Glass dated in the present study originated from the same impact event. In order to achieve the best age estimate, all the data were plotted together in an isotopic correlation diagram. This regression of all data gave an age of 816 ± 7 ka, with MSWD value of 1.204 and $^{40}Ar/^{36}Ar$ initial value of 295.3 ± 0.1 for the trapped argon. More than 91% of argon in the samples is trapped argon with $^{40}Ar/^{36}Ar$ composition in the range of 295.3 – 295.6. These $^{40}Ar/^{36}Ar$ values are in perfect agreement with the present-day atmospheric value (295.5), indicating that the trapped argon is mainly atmospheric and held tightly in the glass during the melt solidification after impact. This confirms previous notion that noble gas components of the Darwin Glass were mainly derived from the atmosphere and that there is no sign of excess argon contamination from the country rocks or the impacter during the impact processes (Zähringer and Gentner, 1963; Matsuda *et al.*, 1989).

DISCUSSION AND CONCLUSION

Our new result is coincident with a fission-track age (810 ± 4 ka) reported by Storzer and Wagner (1980a, b), but apparently older than K-Ar and fission track ages (0.73 ± 0.04 and 0.72 ± 0.02 Ma, respectively) reported by Gentner *et al.* (1969, 1973) for the Darwin

Glass. Fleischer and Price (1964) carried out an even younger fission track age of 0.65 ± 0.1 Ma for the Darwin Glass. Based on a broadly synchronous fission-track date of 820 ± 5 ka for the Australasian tektites, Storzer and Wagner (1980a, b) concluded that the Darwin Glass and Australasian tektites are genetically related. Recently, tektites in the Australasian Strew Field have been repeatedly dated by $^{40}Ar/^{39}Ar$ methods, yielding ages ranging from 761 ± 17 ka to 816 ± 7 ka for australites, indochinites, and philippinites (Izett and Obradovich, 1992; Kunz *et al.,* 1995; Yamei *et al.*, 2000). The present results, showing $^{40}Ar/^{39}Ar$ ages in the range of 795–814 ka with a best age estimate of 816 ± 8 ka for the Darwin Glass, match very well with the $^{40}Ar/^{39}Ar$ ages reported for tektites and microtektites in the Australasian Strew Field (Izett and Obradovich, 1992; Kunz *et al.*, 1995). More significantly, the age range (796-815 ka) and overall weighted mean of the isochron ages (816 ± 8 ka) we obtained here are in excellent agreement with the recently reported $^{40}Ar/^{39}Ar$ ages for Australasian tektites within ±2钋 (with an age range of 761-816 ka and a weight mean of 803 ± 3 ka) (Yamei *et al.*, 2000). This agreement in precise age data using modern techniques reconfirms the notion that the impact events for the Darwin Glass and Australasian Strewn Field occurred coincidently in the Mid-Pleistocene.

However, the coeval Darwin Glass and Australasian tektites appear to have different geochemical and isotope compositions (Taylor and Solomon, 1964; Taylor and Epstein, 1969; Meisel *et al.*, 1990). For examples, the Darwin Glass usually contains higher SiO_2 and water contents (> 0.047 wt.%) and lower cation oxides than those of the Australasian tektites (Chao, 1963; Gilchrist et al., 1969; Glass, 1990). At least two geochemically distinct groups of the Darwin Glass have been identified, resulting from melting of mixtures of quartzite and shale in the Darwin crater area, with an enrichment by the impacting bodies or ultrabasic rocks and losses of volatile elements during impact processes being also observed (Taylor and Solomon, 1964; Taylor and Epstein, 1969; Meisel et al., 1990). In contrast, the Australasian tektites are relatively more uniform in composition as that they resulted likely from melting of homogenous post-Archean alluvium sediments, such as the Jurassic alluvium deposits in Indochina (Shaw and Wasserburg, 1982; Koeberl, 1990; Schnetzler, 1992; Blum et al., 1992).

As mentioned above, Ford (1972) and Fudali and Ford (1979) suggested the possible source structure for the Darwin Glass to be located in a circular depression near Mts. Darwin, on the basis of gravity anomaly data. The suggestion has been supported by geochemical, isotopic and dating investigations on the glasses and target rocks (Taylor and Solomon, 1964; Taylor and Epstein, 1969; Genter *et al.*, 1973; Meisel et al., 1990). In addition, texture of the Darwin Glass is similar to that of the Muong Nong-type tektites, indicating that these glasses were formed under low temperature-pressure conditions during impact processes, and landed whilst still plastic with a slow cooling history around the crater (Barnes, 1963; Ford, 1988; Schnetzler, 1992; Koeberl, 1994). The texture character is consistent with the requirement for having a source in western Tasmania. Given the fact that Tasmania is several thousand kilometers away from the most possible impact site for the Australasian tektites in Indo-China (see McCall, 2001, for a recent review). The geochemical and chronological data allow the conclusion that the Darwin Glass that formed coincidently with the Australasian tektites was produced by a separate impact event. Thus, the hypothesis that the Darwin Glass and Australasian tektites were caused by different impacts (Gentner *et al.*, 1969, 1973; Storzer and Wagner, 1980a, b; Meisel *et al.*, 1995) can be further confirmed. It is likely that there was a large meteorite shower in the Australasian Strewn Field, covering an area of about one tenth of the Earth's surface and causing a multiple impact event in about two third million years. As proposed by Taylor (1969) and Wasson (1991, 1995), an explosion of a light-density comet in the atmosphere may therefore have been responsible for such a large and widely distributing meteorite shower.

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REFERENCES

BAKSI A. K., ARCHIBALD D. A.AND FARRAR E. (1996) Intercalibration of ^{40}Ar/^{39}Ar dating standards. *Chem. Geol.* **129**, 307-324.

BARNES V. E. (1963) Detrital mineral grains in tektites. *Science* **142**, 1651-1652.

BLUM J. D., PAPANASTASSIOU D. A., KOEBERL C. AND WASSERBURG G. J. (1992) Neodymium and strontium isotopic study of Australasian tektites: new constraints on the provenance and age of target materials. *Geochim. Cosmochim. Acta* **56**, 483-492.

BRERETON N. R. (1970) Corrections for interfering isotopes in the ^{40}Ar/^{39}Ar dating method. *Earth Planet. Sci. Lett.* **8**, 427-433.

CHAO E. C. (1963) The petrographic and chemical characteristics of tektites. In *Tektites* (ed. J. O'Keefe), pp. 51-94, University of Chicago Press, New York, USA.

FLEISCHER R. L. AND PRICE P. B. (1964) Fission track evidence for the simultaneous origin of tektites and other natural glasses. *Geochim. Cosmochim. Acta* **28**, 755-760.

FORD R. J. (1972) A possible impact crater associated with Darwin glass. *Earth Planet. Sci. Lett.* **16**, 228-230.

FORD R. J. (1988) An empirical model for the Australasian tektite strewn field. *Australian Jour. Earth Sci.* **35**, 483-490.

FUDALI R. F. AND FORD R. J. (1979) Darwin Glass and Darwin Crater. *Meteoritics* **14**, 283-296.

GENTNER W., STORZER D. AND WAGNER G. A. (1969) New fission track ages of tektites and related glasses. *Geochim. Cosmochim. Acta* **33**, 1075-1081.

GENTNER W., KIRSTEN T., STORZER D. AND WAGNER G. A. (1973) K-Ar and Fission Track Dating of Darwin Glass. *Earth Planet. Sci. Lett.* **20**, 204-210.

GILCHRIST J., THORPE A. N. AND SENFTLE F. E. (1969) Infrared analysis of water in tektites and other glasses. *Jour. Geophys. Res.* **74**, 1475-1483.

GLASS B. P. (1990) Tektites and microtektites: key facts and inferences. *Tectonophysics* **171**, 393-404.

GLASS B. P. AND PIZZUTO J. (1994) Geographic variation in Australasian microtektite concentrations: implications concerning the location and size of the source crater. *Jour. Geophys. Res.* **99**, 19075-19091.

GLASS B. P., CHAPMAN D. R. AND SHIYAM PRASAD M. (1996) Ablated tektite from the central Indian Ocean. *Meteorit. Planet. Sci.* **31**, 365-369.

IZETT G. A. AND OBRODAVICH J. D. (1992). Laser-fusion ^{40}Ar/^{39}Ar ages of Australasian tektites (abstract). *Proc. The 23st Lunar and Planetary Science Conference*, 593-594.

KOEBERL C. (1990) The geochemistry of tektites: an overview. *Tectonophys.* **171**, 405-422.

KOEBERL C. (1994) Tektite origin by hypervelocity asteroidal or cometary impact: target rocks, source craters, and mechanisms. *Geol. Soc. Amer. Spec. Paper* **293**, 133-151.

KOEBERL C. (1998) Identification of meteoritic components in impactites. In *Meteorites: Flux with Time and Impact Effects* (eds. M. M. Grady, R. Hutchison, G. J. H. McCall and D. A. Rothery) *The Geological Society, London, Special Publication* **140**, 133-153.

KUNZ J., BOLLINGER K. AND JESSBERGER E. K. (1995) Ages of Australasian Tektites (abstract). *Proc. The 26th Lunar and Planetary Science Conference*, p. 809.

LO C.-H., WANG P.-L., YANG H.-C., LIOU Y.-S. AND TSOU T.-Y. (2001) The Laser ^{40}Ar/^{39}Ar Dating Microprobe of National Taiwan University. *Western Pacific Earth Sci.* **1**, 143-156.

McDOUGALL I. AND HARRISON T. M. (1999) *Geochronology and thermochronology by the ^{40}Ar/^{39}Ar method* (2'nd edition). Oxford University Press, New York, 269 pp.

MATSUDA J., MATSUBARA K., YAHIMA H. AND YAMAMOTO K. (1989) Anomalous Ne enrichment in obsidians and Darwin Glass: Diffusion of noble gases in silica-rich glasses. *Geochim. Cosmochim. Acta* **53**, 3025-3033.

McCALL J. (2001) *Tektites in the geological record: showers of glass from the sky.* The Geological Society, London, 256 pp.

MEISEL T., KOEBERL C. AND FORD R..J. (1990) Geochemistry of Darwin impact glass and target rocks. Geochim. et Cosmochim. Acta 54, 1463-1474.

MEISEL T., BIINO G. G., VILLA I.M., CHAMBERS J. E. AND MCHONE J. F. (1995) Darwin glass and Darwin Crater revisited; multiple impacts in the Australasian strewn field? *Meteorit. Planet. Sci.* **30**, 545.

ODIN G.S. AND 35 COLLABORATORS (1982) Interlaboratory standards for dating purposes. In *Numerical dating in stratigraphy* (ed. G.S. Odin), pp. 123-149, Wiley, Chichester.

REID A. M. AND COHEN A. J. (1962) Coesite in Darwin glass. *Jour. Geophys. Res.* **67**, 1654.

RENNE P. R., SWISHER C. C., DEINO A. L., KARNER D. B., OWENS T. L. AND, DEPAOLO D. J. (1998) Intercalibration of standards, absolute ages and uncertainties in ^{40}Ar/^{39}Ar dating. *Chem. Geol.* **145**, 117-152.

SCHNETZLER C. C. (1992) Mechanism of Muong Nong tektite formation and speculation on the source of the Australasian tektites. *Meteoritics* **27**, 154-165.

SCHNETZLER C. C. AND MCHONE J. F. (1996) Source of Australasian tektites: investigating possible sites in Laos. *Meteorit. Planet. Sci.* **31**, 73-76.

SHAW H. P. AND WASSERBURG G. J. (1982) Age and provenance of target materials for tektites and possible impactites as inferred from Sm-Nd and Rb-Sr systematics. *Earth Planet. Sci. Lett.* **60**, 155-177.

STEIGER R. H., AND JÄGER E. (1977) Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. *Earth Planet. Sci. Lett.* **36**, 359-362.

STOREY J. (1987) Darwin Glass: Gift from the heavens. *Australian Geographic* **8**, 39-43.

STORZER D. AND WAGNER G. A. (1980a) Australites older than indochinites – Evidence from fission-track plateau dating. *Naturwissenschaften* **67**, 90-91.

STORZER D. AND WAGNER G. A. (1980b) Two discrete tektite-forming events 140 thousand years apart in the Australian – Southeast Asian area. *Meteoritics* **15**, 372.

TAYLOR H. P. AND EPSTEIN S.E. (1969) Correlations between ^{18}O/^{16}O ratio and chemical compositions of tektites. *Jour. Geophys. Res.* **74**, 6824-6844.

TAYLOR S. R. (1969) Criteria for the source of australites. *Chem. Geol.* **4**, 451-459.

TAYLOR S.R. AND SOLOMON M. (1964) The Geochemistry of Darwin Glass. *Geochim. Cosmochim. Acta* **28**, 471-494.

WASSON J. T. (1991) Layered tektites: a multiple impact origin for Australasian tektites. *Earth Planet. Sci. Lett.* **102**, 95-109.

WASSON J. T. (1995) The disintegration of the comet Shoemaker-Levy 9 and the Tunguska object and the origin of Australasian tektites. *Lunar Planet. Sci.* **26**, 1469-1470.

YAMEI H., POTTS R., BAOYIN Y., ZHENGTANG G., DEINO A., WANG W., CLARK J., GUANGMAO X. AND WEIWEN H. (2000). Mid-Pleistocene Acheulean-Like Stone Technology of the Bose Basin, South China. *Science* **287**, 1622-1626.

ZÄHRINGER J. AND GENTNER W. (1963) Radiogenic and atmospheric argon content of tektites. *Nature* **199**, 583.