Geology, published online on 15 June 2012 as doi:10.1130/G33059.1

Geology

Tristan da Cunha: Constraining eruptive behavior using the $^{40}Ar/^{39}Ar$ dating technique

Anna Hicks, Jenni Barclay, Darren F. Mark and Sue Loughlin

Geology published online 15 June 2012;
doi: 10.1130/G33059.1

Email alerting services	click www.gsapubs.org/cgi/alerts to receive free e-mail alerts when new articles cite this article
Subscribe	click www.gsapubs.org/subscriptions/ to subscribe to Geology
Permission request	click http://www.geosociety.org/pubs/copyrt.htm#gsa to contact GSA

Copyright not claimed on content prepared wholly by U.S. government employees within scope of their employment. Individual scientists are hereby granted permission, without fees or further requests to GSA, to use a single figure, a single table, and/or a brief paragraph of text in subsequent works and to make unlimited copies of items in GSA's journals for noncommercial use in classrooms to further education and science. This file may not be posted to any Web site, but authors may post the abstracts only of their articles on their own or their organization's Web site providing the posting includes a reference to the article's full citation. GSA provides this and other forums for the presentation of diverse opinions and positions by scientists worldwide, regardless of their race, citizenship, gender, religion, or political viewpoint. Opinions presented in this publication do not reflect official positions of the Society.

Notes

Advance online articles have been peer reviewed and accepted for publication but have not yet appeared in the paper journal (edited, typeset versions may be posted when available prior to final publication). Advance online articles are citable and establish publication priority; they are indexed by GeoRef from initial publication. Citations to Advance online articles must include the digital object identifier (DOIs) and date of initial publication.

© Geological Society of America

THE
GEOLOGICAL
SOCIETY
OF AMERICA

Tristan da Cunha: Constraining eruptive behavior using the $^{40}Ar/^{39}Ar$ dating technique

Anna Hicks[1]*, Jenni Barclay[1], Darren F. Mark[2], and Sue Loughlin[3]
[1]Department of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich, Norfolk NR4 7TJ, UK
[2]NERC Argon Isotope Facility, Scottish Universities Environmental Research Centre, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride G75 0QF, UK
[3]British Geological Survey, Murchison House, West Mains Road, Edinburgh EH9 3LA, UK

ABSTRACT

The historically active volcanic ocean island of Tristan da Cunha exhibits a complex and dynamic history, with numerous, often compositionally distinct, parasitic centers punctuating the large edifice. To date, the temporal relationship between differing styles of activity has been unclear. We have applied high-precision $^{40}Ar/^{39}Ar$ dating to 15 carefully selected samples from Tristan da Cunha to ascertain spatio-temporal relationships of recent volcanism, explore episodicity, and establish if the most recent summit activity post-dated eruptions from parasitic centers lower on the flanks. This has yielded a new suite of reliable Holocene ages, with the youngest dated deposit at 3 ± 1 ka (1σ). A recent flow at the summit was constrained to 5 ± 1 ka (1σ), confirming that summit and parasitic activity on the volcano's flanks overlap in time. The oldest dated deposits were 118 ± 4 ka (1σ) from a parasitic cone in the southern sector, and 81 ± 10 ka (1σ) from one of the lowest sub-aerial shield-forming lava flows in the northern sector. Large-scale sector collapse is bracketed between 34 ± 1 ka and 26 ± 5 ka (1σ) via dating of the youngest headwall lava flow and oldest sub-aerial scarp-filling deposits. No systematic relationship between the new temporal framework, vent location, and eruptive compositions was found. Although magmatic flux has been inferred to be relatively low, Tristan da Cunha is capable of relatively frequent eruptions from a wide variety of vent locations across a broad range of compositions.

INTRODUCTION

Determining the timing and frequency of past eruptive activity is one of the most critical components in evaluating the potential for when and how volcanoes are likely to erupt (Newhall and Hoblitt, 2002). Innovation in isotope extraction techniques and noble gas mass spectrometry, as well as reduction in systematic uncertainties associated with the $^{40}Ar/^{39}Ar$ dating technique, are allowing for improved temporal dissection of volcanic deposits (e.g., Smith et al., 2011; Ellis et al., 2012). By combining precise and accurate age data with information from other geological techniques, a detailed history of both rates and changing styles of volcanism emerges, and this can form a quantitative basis for understanding and assessing the future risk of volcanic eruptions (e.g., Sparks et al., 2008).

Tristan da Cunha ("Tristan" hereafter) (Fig. 1) is the emergent top of an active volcano situated in the South Atlantic Ocean, and has been populated since 1817. Today 262 people reside on Tristan. The last eruption on Tristan was in 1961–1962, producing a tephri-phonolitic dome and flows. Due to its close proximity to the island's only settlement, the eruption forced the temporary evacuation of all islanders. Further recent activity is evident on the southern coastal strip (Baker et al., 1964), fresh tephra has been found in lake cores (Ljung et al., 2006), and fresh phonolitic pumice rafts were observed east of Tristan and as blocks washed up on the shores in 2004 (Reagan et al., 2008).

This emphasizes the need to appraise the past eruptive phases of Tristan and to characterize past magmatic processes in an attempt to inform future eruptive scenarios. However, this is challenging due to the wide dispersal of morphologically young (<50 ka) parasitic vents and the broad compositional range (medium-to-low K) represented within erupted material.

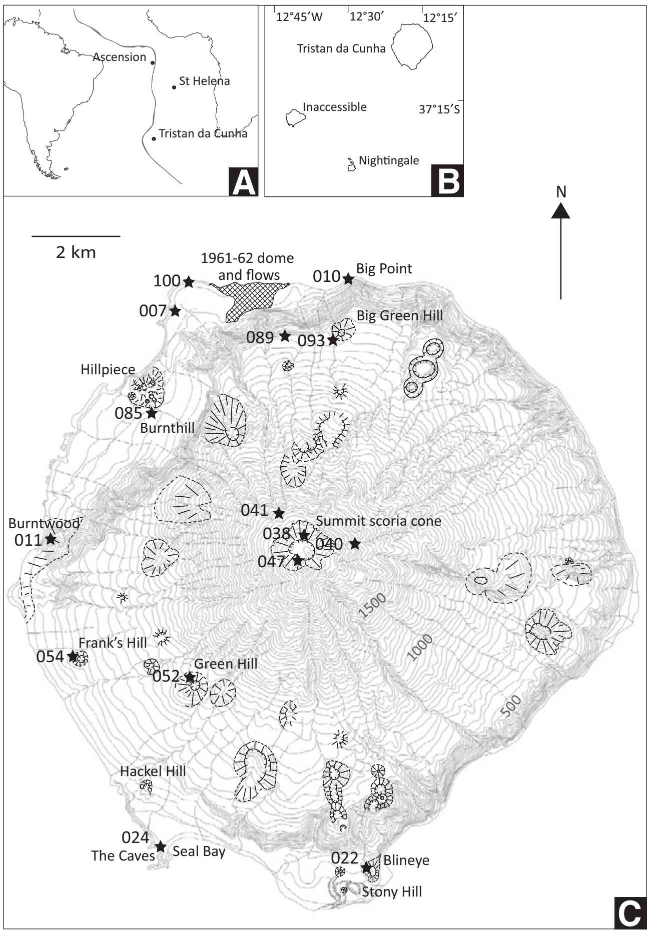

Figure 1. A: Global location map of Tristan da Cunha. B: Relative positions of the Tristan da Cunha Island Group. C: Plan view of Tristan da Cunha with sample locations. Contour intervals in feet, altitudes in meters. Modified from Dunkley (2002).

Here we present 15 new $^{40}Ar/^{39}Ar$ ages from Tristan which, when coupled with compositional information and vent distribution (Fig. 1C), place important constraints on the recent eruptive history of the island, and provide insights into the manner in which the volcanic edifice was constructed. Strategic sampling identifies possible temporal correlations between eruptive style, composition, or vent location. The focus is on the stratigraphically and morphologically younger deposits (usually parasitic centers) in order to bracket age ranges for recent summit and flank activity, and for the flank collapse. Figure 1C provides locations

---

*E-mail: a.hicks@uea.ac.uk.

doi:10.1130/G33059.1; 2 figures; 1 table; Data Repository item 2012200.

of sample sites. Additional information relating to sample composition, morphological features, and ^{40}Ar/^{39}Ar particulars are provided in the GSA Data Repository[1].

GEOLOGICAL BACKGROUND

Tristan has a relatively steep conical edifice, with a maximum sub-aerial diameter of 12 km, and rises ~5.5 km from the seafloor. The uppermost 2 km is exposed sub-aerially and has a volume of ~75 km^3. The outer flanks are truncated by sea cliffs up to 900 m high, which descend either to the shore or to two recently constructed coastal strips. At the cliff edge, the flanks gradually steepen toward the summit (~30°). Tristan is part of an exclusive group of ocean island volcanoes devoid of a caldera, although collapse has occurred in the past in the form of large-scale flank failure. Evidence of collapse is preserved as a significant amphitheater carved into the northwest sector of the island, and debris avalanche deposits on the seafloor (Holcomb and Searle, 1991).

Very little is understood about either the deep or shallow magma storage and plumbing system feeding volcanism on Tristan, although magmatism has been attributed to a deep-seated mantle plume (e.g., Courtillot et al., 2003, and references therein). Le Roex et al. (1990) suggested that the compositional variation of erupted lavas on Tristan can be explained by melting of a heterogeneous source at depth, which siphoned off as small, separate magma bodies, undergoing mixing and sometimes rapid fractionation in conduits, transient chambers, and dikes nearer the surface (Reagan et al., 2008).

Mapped eruptive deposits on Tristan demonstrate strong heterogeneity in composition, volume, and eruptive style. Sub-aerial deposits are generally silica-undersaturated volcanic rocks, spanning a compositional sequence from basanite to phonolite (Le Roex et al., 1990) (0.76–6.52 wt% K_2O). The earliest sub-aerial eruptions appear to represent a shield-building stage that is now manifest as well-stratified basanitic and tephritic lava flows, intercalated with localized pyroclastic deposits. The edifice was constructed very rapidly, probably with initial asymmetry to the south (Dunkley, 2002; McDougall and Ollier, 1982). The main, gently sloping shield sequence is succeeded by steeply dipping lavas and pyroclastics intruded by radial tephritic dikes and trachytic plugs. Recent summit-centered lavas display wider compositional heterogeneity, including small-volume phonolitic flows. Styles of activity at the summit have varied, although effusion dominates, with lavas radiating seaward from the central summit vent. Evidence of Strombolian and phreatic activity is also present and not solely confined to the summit (Baker et al., 1964). Over 30 diffuse parasitic centers of variable volume punctuate the flanks and two low-lying coastal strips. The sector collapse pre-dates the construction of the northern coastal strip, which was subsequently formed from a lava delta issuing from a breached parasitic center. Lavas from breached scoria cones also display compositional variations spanning the full basanite-to-phonolite series. The two most recent sub-aerial eruptions were entirely effusive, producing small-volume tephri-phonolitic domes and flows on coastal strips at opposite ends of the island (1961–1962 eruption and Stony Hill center; Fig. 1C).

RESULTS

Our methods are presented in the Data Repository. Results are summarized in Table 1 and illustrated in Figure 2. Compositions of dated samples are given in Table DR1 in the Data Repository. ^{40}Ar/^{39}Ar ages were calculated relative to Alder Creek sanidine at 1.193 ± 0.001 Ma (Nomade et al., 2005). Samples were step-heated using a scanning CO_2 laser, and isotopes were measured using a MAP 215–50 mass spectrometer. All 15 samples yielded statistically sound ^{40}Ar/^{39}Ar plateau ages. Furthermore, all plateau and inverse isochron (and most total fusion) ages overlap at the 1σ confidence level, while trapped components (^{40}Ar/^{36}Ar) all overlap with the atmospheric Ar isotope ratios of Nier (1950), showing the data to be robust. Throughout the remainder of this paper we discuss the plateau ages. All age data are reported at the 1σ (68%) confidence level.

Ages for dated parasitic centers (Fig. 1C) considered to be post-shield volcanism range from 118 ± 4 ka to 3 ± 1 ka. The oldest dated deposit was from Frank's Hill on the southwestern flank (sample 054 in Fig. 1C). At the far south of the island, the Blineye center yielded an age of 75 ± 9 ka (sample 022) and is considered to be the source vent of the Stony Hill coastal strip lavas (Baker et al., 1964). Lava from the Seal Bay coastal strip (sample 024) yielded an age of 29 ± 4 ka; the uppermost of seven sub-aerial flows generated from Hackel Hill center. The comparably large northwestern coastal strip was constructed from younger lavas that issued from the Hillpiece-Burnthill parasitic complex. Two substantial lava flows crop out above sea level, the oldest (sample 007) yielding an age of 26 ± 5 ka. Scoria deposits from the Burnthill cone (sample 085) yielded a very young age of 3 ± 1 ka. These deposits are succeeded by a younger, low-volume center next to Burnthill.

TABLE 1. SUMMARY OF ^{40}Ar/^{39}Ar AGE DATA (DISPLAYED IN CHRONOLOGICAL ORDER)

			Plateau							Inverse isochron					Total fusion	
Sample	**Material**	**Mass (mg)**	**Age (ka)**	**± 1σ (ka)**	**^{39}Ar (%)**	***n* (total)**	**Ca/K**	**± 1σ**	**MSWD**	**Age (ka)**	**± 1σ (ka)**	**^{40}Ar/^{39}Ar**	**± 1σ**	**MSWD**	**Age (ka)**	**±1σ (ka)**
#085	Gm	200	3	1	88	6 (8)	1.44	0.03	0.5	6	3	290	10	0.6	3	1
#040	Gm	150	5	1	96	7 (8)	1.20	0.04	0.3	4	3	297	12	0.4	5	1
#093	Gm	175	15	2	100	8 (8)	3.37	0.09	1.0	15	4	296	6	1.2	15	2
#041	Gm	175	16	3	100	8 (8)	2.00	0.04	1.1	9	7	299	15	1.3	16	3
#100	Gm	100	16	6	100	8 (8)	1.59	0.03	0.7	10	5	296	15	0.8	16	6
#007	Gm	150	26	5	67	4 (8)	2.85	0.06	1.4	18	12	300	60	2.1	26	5
#024	Hb	150	29	4	100	9 (9)	7.32	0.22	0.5	26	6	297	3	0.5	29	4
#011	Gm	150	30	3	100	8 (8)	2.56	0.05	0.6	19	8	300	6	0.6	30	3
#089	Gm	100	34	1	70	5 (9)	1.17	0.04	0.3	33	2	297	5	0.4	33	1
#038	Gm	100	42	6	89	7 (8)	1.54	0.33	0.5	33	18	297	11	0.6	42	6
#052	Hb	100	44	4	100	8 (8)	8.26	0.03	0.4	45	9	295	4	0.5	44	4
#022	Hb	100	75	9	100	7 (7)	5.96	0.04	0.8	83	17	294	3	0.9	75	9
#047	Hb	150	81	8	100	7 (7)	3.86	0.12	0.3	80	20	296	9	0.4	81	8
#010	Gm	175	81	10	100	8 (8)	1.38	0.03	0.1	100	60	294	6	0.1	81	10
#054	Gm	175	118	4	100	9 (9)	3.11	0.11	0.9	100	20	304	9	0.9	118	4

Note: Gm—groundmass; Hb—hornblende.

---

[1] GSA Data Repository item 2012200, methods, raw isotope data, ^{40}Ar/^{39}Ar data plots, Figures DR1 and DR2, and Table DR1, is available online at www.geosociety.org/pubs/ft2012.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

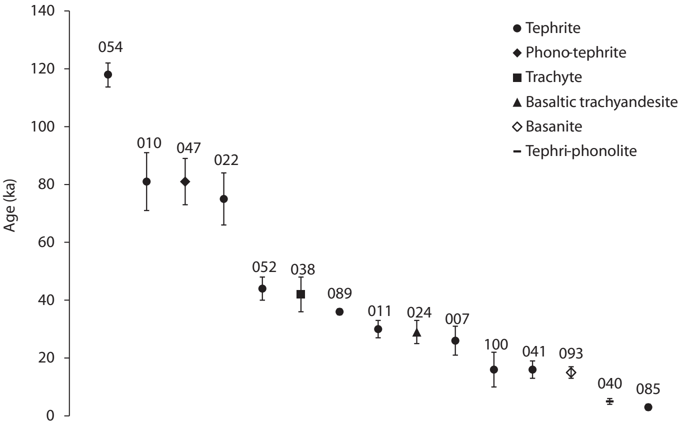

Figure 2. Summary plot of ^{40}Ar/^{39}Ar age data relative to variation in erupted compositions through time.

The latest activity at the summit is constrained by ages measured on summit flows (samples 041 and 040), pyroclastic deposits (sample 047), and a trachytic plug (sample 038). These range in age from 81 ± 8 ka to 5 ± 1 ka, illustrating continued volcanism, of varying styles, from this region since shield construction. Sector collapse has been constrained to between 34 ± 1 ka (sample 089) and 26 ± 5 ka (sample 007), assuming the altitudinally highest lava flow cut by the landslide headwall is the last flow before collapse. The bottommost, and therefore presumed oldest, stratigraphic unit in the north of the island was dated at 81 ± 10 ka (sample 010), sampled at Big Point (Fig. 1C).

DISCUSSION

^{40}Ar/^{39}Ar dating of significant recent eruptions has confirmed that, since edifice construction, there is no dominant control on spatio-temporal locations of volcanism or style. Eruptions appear to be frequent (presently over 20 undated parasitic centers) but of comparatively low volume. Compositionally, both lavas and pyroclastics are primarily tephritic, but sporadic eruptions of more-evolved lavas have occurred since the inception of shield building (Fig. 2).

The apparent random physical and compositional distribution of parasitic centers through time suggests that the plumbing system beneath Tristan is not dominated by one large storage region, but rather smaller individual pockets of magma that source rapidly from depth. This is consistent with the relatively low plume buoyancy flux (Sleep, 1990) that would be unlikely to sustain a larger magma reservoir and to erupt lavas of markedly differing compositions in a relatively narrow time frame. The 2004 phonolitic pumice was inferred to come from rapid, extensive fractionation of a small parental magma body, unrelated to the 1961 tephri-phonolitic magma (Reagan et al., 2008). Although the significance and relationship of the recent north-south–aligned tephri-phonolitic dome complexes (Fig. 1C) have yet to be determined, their positioning relative to regional compressive stress supports the absence of evidence for a sizeable crustal magma body (Nakamura, 1977). However, it is not inconceivable that these low-volume leaks of evolved lava signal a prelude to a caldera-forming event, as inferred from deposits at Teide (Canary Islands), Krakatau (Indonesia), and Santorini (Greece) (Bacon, 1985; Druitt et al., 1989; Newhall et al., 1984).

Ages of two recent summit flows (samples 040 and 041; Figs. 1C and 2) indicate that the summit was contemporaneously active with parasitic centers on the lower flanks *and* the coastal strips. A summit eruption has very different hazard implications than localized coastal lava flows, due partly to the steep slopes (20°–30°) and deeply incised gulches capable of rapidly channeling eruptive products toward inhabited coastal areas. Owing to intense erosion on the upper flanks of the edifice, it is possible that summit activity further post-dates our inferred youngest sampled deposit from this locality, (sample 040; 5 ± 1 ka; Figs. 1C and 2). Future summit-centered eruptions cannot be any less likely than eruptions elsewhere on the island. At present, there is no residual thermal activity on the upper flanks or the summit that could indicate recent or renewed activity; however, fumarolic activity is virtually absent all over the island, perhaps indicative of a very high water table in the edifice (Dunkley, 2002). Pyroclastic flow deposits are also absent, but varying styles of eruption, composition, and volumes of lava do not preclude the possibility of large-scale explosive events centered on the summit.

The youngest samples were from the Hillpiece-Burnthill complex and from a flow on the east side of the summit cone (Fig. 1C). The extensive Hillpiece-Burnthill complex has been active for at least 26 ± 5 ka (sample 007), since lava accumulated sub-aerially within the collapse embayment. Given that (1) the large Burnthill scoria cone was still active at 3 ± 1 ka (sample 085); (2) a younger, smaller cone exists within the complex; and (3) intercalated tephra layers within the Hillpiece lake core have been dated using ^{14}C at ca. 0.62 kyr B.P. (Ljung et al., 2006), we can conclude that there have been several recent episodes of volcanic activity at this location. Hillpiece volcanism is dominantly tephritic, whereas the lavas of the 1961 eruption 2 km west are tephri-phonolitic. Evolved lavas have also erupted from the Stony Hill effusive center on the southern coastal strip. This dome and flow is also considered (on morphological criteria) to be very young, possibly in the region of 0.2–0.3 ka (Baker et al., 1964). The two eruptive centers nearby pre-date the Stony Hill eruption but are also young. As the majority of eruptions within the recent past have occurred on the two low-lying coastal strips, it seems likely that magma is now preferentially erupting at these locations. The hazard implications of eruptions here are greater, because the coastal strips are the focus for island accommodation and livelihoods.

Our sampling strategy allows inference of a model for island construction. Unweathered pyroclastic material sampled from the inner crater of the summit scoria cone (sample 047; Fig. 1C) yielded an age of 81 ± 8 ka. This is comparable to the age of lavas at the base of the northern succession at Big Point (sample 010; 81 ± 10 ka), implying a more complex evolution of island growth. These data suggest that the edifice was constructed piecemeal, and that there were several stages of shield building. This is supported by the eruption of the small, heavily eroded parasitic center, Frank's Hill (sample 054; 118 ± 4 ka), on the lower southwest flanks, which implies that the edifice underlying Frank's Hill must have formed before the northern sector. In the northern sector, 50 ka separates the lowest exposed and uppermost flows. Approximately 60 episodic summit-centered flows streamed down the northern flanks to the coast during this time, now exposed in the cliff face. This suggests that the summit erupted lava at least every 0.83 ka, based on this sector alone. The frequencies of eruptions in the other sector(s) of the shield remain temporally unconstrained.

A large sector collapse, with an associated submarine avalanche of ~150 km^3 (Holcomb and Searle, 1991), has been constrained to a 14 ka period by the new ages. No obvious tsunamigenic deposits have yet been discovered on Tristan or on nearby Inaccessible Island, although an anomalous boulder bed on Nightingale Island (38 km southwest) yielding a ^{14}C date of older than 37 kyr B.P. (Wace and Dickson, 1965) from entrained plant matter could potentially be a proximal tsunami deposit. Flank instability and collapse commonly punctuates the life cycle of volcanoes (e.g., Lipman et al., 1988) and it is probable that Tristan has undergone other large collapse events during its growth.

SUMMARY

On Tristan, we found no spatio-temporal pattern to parasitic center activity, and recent volcanism from these centers varies in style, volume, and composition with time. Our study constrained the timing of the large-scale sector collapse in the northwest, and determined that the northern sector of the edifice was built very rapidly. It seems likely that the entire edifice was constructed piecemeal, and has a far more complex evolution than previously assumed. Of particular significance to hazard assessment is the discovery that the summit was contemporaneously active with recent parasitic center activity on the flanks and coastal strips.

These data add to a growing suite of reliable ^{40}Ar/^{39}Ar ages from the Holocene (e.g., Renne et al., 1997; Scaillet et al., 2011; Wijbrans et al., 2011) and show that, with continued developments in Ar isotope extraction tools and noble gas mass spectrometer technology (e.g., Mark et al., 2009; Mark et al., 2011), the Holocene will become increasingly accessible to the ^{40}Ar/^{39}Ar geochronologist, and precision and accuracy will continue to improve.

ACKNOWLEDGMENTS

This work was funded by a joint Natural Environment Research Council (NERC)–Economic and Social Research Council (ESRC) studentship, the British Geological Survey University Funding Initiative, and a NERC grant (IP-1152-1109). It is published by permission of the Executive Director, British Geological Survey (NERC). The clarity and content of the manuscript were improved by comments from three anonymous reviewers.

REFERENCES CITED

Bacon, C., 1985, Implications of silicic vent patterns for the presence of large crustal magma chambers: Journal of Geophysical Research, v. 90, p. 11,243–11,252, doi:10.1029/JB090iB13p11243.

Baker, P.E., Gass, I.G., Harris, P.G., and Le Maitre, R.W., 1964, The volcanological report of the Royal Society expedition to Tristan da Cunha, 1962: Royal Society of London Philosophical Transactions, ser. A, v. 256, p. 439–575.

Courtillot, V., Davaille, A., Besse, J., and Stock, J., 2003, Three distinct types of hotspot in the Earth's mantle: Earth and Planetary Science Letters, v. 205, p. 295–308, doi:10.1016/S0012-821X(02)01048-8.

Druitt, T.H., Mellors, R.A., Pyle, D.M., and Sparks, R.S.J., 1989, Explosive volcanism on Santorini, Greece: Geological Magazine, v. 126, p. 95–126, doi:10.1017/S0016756800006270.

Dunkley, P., 2002, Volcanic hazard assessment of Tristan da Cunha: British Geological Survey Commissioned Report CR/02/146N, 46 p.

Ellis, B.S., Mark, D.F., Pritchard, C.J., and Wolff, J.A., 2012, Temporal dissection of the Huckleberry Ridge Tuff using the ^{40}Ar/^{39}Ar dating technique: Quaternary Geochronology, doi:10.1016/j.quageo.2012.01.006 (in press).

Holcomb, R.T., and Searle, R.C., 1991, Large landslides from oceanic volcanoes: Marine Georesources and Geotechnology, v. 10, p. 19–32, doi:10.1080/10641199109379880.

Le Roex, A.P., Cliff, R.A., and Adair, B.J.I., 1990, Tristan da Cunha, South Atlantic: Geochemistry and petrogenesis of a basanite-phonolite lava series: Journal of Petrology, v. 31, p. 779–812.

Lipman, P.W., Normark, W.R., Moore, J.G., Wilson, J.B., and Gutmacher, C.E., 1988, The giant submarine Alika debris slide, Mauna Loa, Hawaii: Journal of Geophysical Research, v. 93, p. 4279–4299, doi:10.1029/JB093iB05p04279.

Ljung, K., Björck, S., Hammarlund, D., and Barnekow, L., 2006, Late Holocene multi-proxy records of environmental change on the South Atlantic island Tristan da Cunha: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 241, p. 539–560, doi:10.1016/j.palaeo.2006.05.007.

Mark, D.F., Barfod, D.N., Stuart, F.M., and Imlach, J.G., 2009, The ARGUS multicollector noble gas mass spectrometer: Performance for ^{40}Ar/^{39}Ar geochronology: Geochemistry, Geophysics, Geosystems, v. 10, p. 1–9.

Mark, D.F., Stuart, F.M., and de Podesta, M., 2011, New high-precision measurements of the isotopic composition of atmospheric argon: Geochimica et Cosmochimica Acta, v. 75, p. 7494–7501, doi:10.1016/j.gca.2011.09.042.

McDougall, I., and Ollier, C.D., 1982, Potassium-argon ages from Tristan da Cunha, South Atlantic: Geological Magazine, v. 119, p. 87–93, doi:10.1017/S0016756800025681.

Nakamura, K., 1977, Volcanoes as possible indicators of tectonic stress orientation: Journal of Volcanology and Geothermal Research, v. 2, p. 1–16, doi:10.1016/0377-0273(77)90012-9.

Newhall, C., and Hoblitt, R., 2002, Constructing event trees for volcanic crises: Bulletin of Volcanology, v. 64, p. 3–20, doi:10.1007/s004450100173.

Newhall, C., Dzurisin, D., and Mullineaux, L.S., 1984, Historical unrest at large Quaternary calderas of the world, with special reference to Long Valley, California: U.S. Geological Survey Open-File Report 84-939, p. 714–742.

Nier, A.O., 1950, A redetermination of the relative abundances of the isotopes of carbon, nitrogen, oxygen, argon and potassium: Physical Review, v. 77, p. 789–793, doi:10.1103/PhysRev.77.789.

Nomade, S., Renne, P.R., Vogel, N., Deino, A.L., Sharp, W.D., Becker, T.A., Jaouni, A.R., and Mundil, R., 2005, Alder Creek sanidine (ACs-2): A Quaternary ^{40}Ar/^{39}Ar dating standard tied to the Cobb Mountain geomagnetic event: Chemical Geology, v. 218, p. 315–338, doi:10.1016/j.chemgeo.2005.01.005.

Reagan, M.K., Turner, S., Legg, M., Sims, K.W.W., and Hards, V.L., 2008, ^{238}U- and ^{232}Th-decay series constraints on the timescales of crystal fractionation to produce the phonolite erupted in 2004 near Tristan da Cunha, South Atlantic Ocean: Geochimica et Cosmochimica Acta, v. 72, p. 4367–4378, doi:10.1016/j.gca.2008.06.002.

Renne, P.R., Sharp, W.D., Deino, A.L., Orsi, G., and Civetta, L., 1997, ^{40}Ar/^{39}Ar dating into the historical realm: Calibration against Pliny the Younger: Science, v. 277, p. 1279–1280, doi:10.1126/science.277.5330.1279.

Scaillet, S., Rotolo, S.G., Felice, S.L., and Scaillet, G.V., 2011, High-resolution ^{40}Ar/^{39}Ar chronostratigraphy of the post-caldera (<20 ka) volcanic activity at Pantelleria, Sicily Strait: Earth and Planetary Science Letters, v. 309, p. 280–290, doi:10.1016/j.epsl.2011.07.009.

Sleep, N., 1990, Hotspots and mantle plumes: Some phenomenology: Journal of Geophysical Research, v. 95, p. 6715–6736, doi:10.1029/JB095iB05p06715.

Smith, V.C., Mark, D.F., Staff, R.A., Blockley, S.P.E., Bronk-Ramsey, C., Bryant, C.L., Nakagawa, T., Han, K.K., Weh, A., Takemura, K., Danhara, T., and Suigetsu 2006 Project Members, 2011, Toward establishing precise ^{40}Ar/^{39}Ar chronologies for Late Pleistocene palaeoclimate archives: An example from the Lake Suigetsu (Japan) sedimentary record: Quaternary Science Reviews, v. 30, p. 2845–2850, doi:10.1016/j.quascirev.2011.06.020.

Sparks, R.S.J., Folkes, C.B., Humphreys, M.C.S., Barfod, D.N., Clavero, J., Sunagua, M.C., McNutt, S., and Pritchard, M., 2008, Uturuncu volcano, Bolivia: Volcanic unrest due to mid-crustal magma intrusion: American Journal of Science, v. 308, p. 727–769, doi:10.2475/06.2008.01.

Wace, N.M., and Dickson, J.H., 1965, The terrestrial botany of the Tristan da Cunha Islands: Part II in the biological report of the Royal Society expedition to Tristan da Cunha, 1962: Royal Society of London Philosophical Transactions, ser. B, v. 249, p. 273–360.

Wijbrans, J., Schneider, Kuiper, K., Calvari, S., Branca, S., De Beni, E., Norini, G., Corsaro, R.A., and Miragalia, L., 2011, ^{40}Ar/^{39}Ar geochronology of Holocene basalts; examples from Stromboli, Italy: Quaternary Geochronology, v. 6, p. 223–232.

Manuscript received 28 November 2011
Revised manuscript received 24 February 2012
Manuscript accepted 5 March 2012

Printed in USA