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New ^{40}Ar/^{39}Ar and K/Ar ages of dikes in the South Shetland Islands (Antarctic Peninsula)

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Abstract Eighteen plagioclase ^{40}Ar/^{39}Ar and 7 whole rock K/Ar ages suggest that dikes in the South Shetland Islands (Antarctic Peninsula) are of Paleocene to Eocene age. The oldest dikes are exposed on Hurd Peninsula (Livingston Island) and do not yield ^{40}Ar/^{39}Ar plateaux. Our best estimates suggest dike intrusion at about the Cretaceous/Paleogene boundary. An older age limit for the dikes is established by Campanian nannofossil ages from their metasedimentary host. Dike intrusion began earlier and lasted longer on Hurd Peninsula (Danian to Priabonian) than on King George Island (Thanetian to Lutetian). Arc magmatism on King George Island, possibly accompanied also by hypabyssal intrusions, began in the Cretaceous as indicated by ages from the stratiform volcanic sequence. The dikes on King George Island were emplaced beginning in the late Paleocene and ending 47–45 Ma. The youngest arc-related dikes on Hurd Peninsula were emplaced ~37 Ma.

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Introduction

A magmatic arc developed on the Antarctic Peninsula as part of the Andean-West Antarctic continental margin from late Triassic to recent times. Volcanism in the South Shetland Islands at the northern tip of the Antarctic Peninsula (Fig. 1) was widespread from Cretaceous (130 Ma) to Miocene (14 Ma) times and later during the Late Pleistocene (Birkenmajer et al., 1991; Smellie et al., 1984). Much of the South Shetland Islands are rocks related to arc magmatism, including numerous hypabyssal intrusions that pierce the stratiform volcanic sequence.

Dike swarms are ubiquitous throughout the archipelago. They are particularly numerous on Hurd Peninsula (Livingston Island), and can potentially illuminate magmatic and tectonic processes because they reflect the geochemical and isotopic characteristics of their magma source and the tectonic regime at the time of emplacement. Their crosscutting relationships establish a relative intrusion sequence and serve as a check on the reliability of radiometric ages.

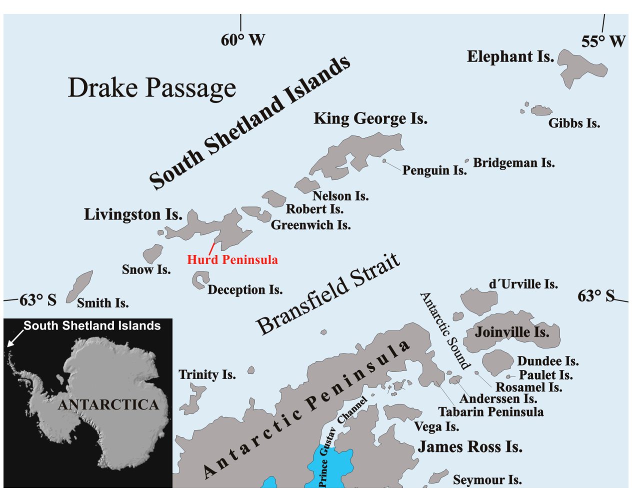

Figure 1. Location map of the South Shetland Islands. Modified after Veit (2002).

Dike systems covering areas of up to 100,000 m^2 were mapped at several locations in the South Shetland Islands during austral summers 2000/2001 and 2001/2002, particularly on King George (KGI) and Livingston Island (LI). Analysis by Kraus (2005) included measurements of joint systems of about 250 dikes and their hosts. Orientation and crosscutting relationships identified six different intrusive events on Hurd Peninsula (LI), and seven on King George Island. Additional dikes on Nelson Island were studied but not dated.

Sample selection and methodology

Eighteen basaltic to rhyolitic dikes from Livingston and King George Island were selected for ^{40}Ar/^{39}Ar dating (Table 1). Feldspar phenocrysts are ubiquitous in these dikes, with plagioclase occurring in basic to intermediate rocks and plagioclase and K-feldspar occurring in the more acidic rocks. Samples containing inclusion-rich plagioclase and adhering phases were avoided because pyroxene fragments, olivine fragments, glass and fluid inclusions can contain significant excess ^{40}Ar that can yield artificially old ages (McDougall and Harrison, 1999).

Feldspar content ranged from 10 to 50% in 0.5–8 mm grains with variable degrees of alteration. Considerable effort was spent in removing altered minerals and purifying the plagioclase separates. Final purity exceeded 99%. ^{40}Ar/^{39}Ar ages were measured by stepwise heating. Seven whole-rock K-Ar ages were measured at the Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI). These were determined from dikes of the Hurd Peninsula, where the relative intrusion sequence allowed assessment of the quality of the K-Ar ages. The oldest ages from Hurd Peninsula are of interest because they constrain the age and deformation of the host Miers Bluff Formation. Samples HP-1A and HP-23 were dated by both methods as a check on the reliability of the K-Ar ages and possible alteration effects. Sample preparation details, analytical methods and isochron diagrams are presented by Kraus (2005); the data are available at http://edoc.ub.uni-muenchen.de/archive/00003827/.

Sample selection was based on the degree of alteration and whether the respective dike forms part of a dike system, i.e. whether field relationships revealed a clear relative age. Preference was given to dikes with known relative ages. At least one dike from each intrusive event was dated on Hurd Peninsula, but the earliest intrusions are highly altered. While not of the highest quality, these results are in good agreement with field observations.

Results and discussion

Correlation of the radiometric ages with the geologic timescale follows the IUGS *International Stratigraphic Chart* (ICS, www.stratigraphy.org). The ages generally confirm the relative time sequence as deduced from field relationships.

The K/Ar ages are broadly correlated with the $^{40}Ar/^{39}Ar$ ages (Table 1), but some ages from Hurd Peninsula yielded disturbed apparent age spectra and isochron diagrams (Kraus, 2005), probably due to advanced alteration and/or excess argon. An earliest Danian age seems likely for the oldest dikes from the initial phase. They are restricted to Hurd Peninsula (LI) and cluster around 65–60 Ma. The second and third magmatic phases occur also on King George Island (KGI). The second phase took place during the Thanetian and Ypresian (57-53 Ma) and is expressed on Hurd Peninsula (LI), Fildes Peninsula, Weaver Peninsula and in Admiralty Bay (all KGI). The third phase is the main phase of dike intrusion everywhere, and is restricted to 48–43 Ma (Lutetian) concentrated strongly at 47–45 Ma (Table 1). A final fourth phase is restricted to Hurd Peninsula and comprises Bartonian and earliest Priabonian dikes (40–37 Ma).

Comparison with previous results

Willan and Kelley (1999) and Zheng et al. (2003) reported $^{40}Ar/^{39}Ar$ and K/Ar ages from dikes of the Hurd Peninsula. It was then believed that the host rocks were of Triassic age. The Miers Bluff Formation is now known to be not older than Campanian (Pimpirev et al., 2006; Stoykova et al., 2002), requiring re-evaluation of previous ages. Willan and Kelley (1999) distinguished eight groups of mafic dikes and related stocks of mid Cretaceous to Oligocene (~108–29 Ma) age. Their $^{40}Ar/^{39}Ar$ and K/Ar ages were derived from plagioclase separates, but only two dikes and one stock yielded Cretaceous ages (108 ± 5, 67 ± 2 and 74 ± 13 Ma, respectively). Their 108 Ma age was considered problematic because a muscovite $^{40}Ar/^{39}Ar$ age of 62 ± 1 Ma had been measured from the same rock. The 67 ± 2 Ma age obtained for the second dike and the 74 ± 13 Ma age for the

Table 1. Summary of the $^{40}Ar/^{39}Ar$ and K-Ar ages and relevant information on the analyzed dikes.

Locality / Sample	latitude UTM, WGS 84	longitude UTM, WGS 84	strike	dip	thickness	lithology (TAS-geochemistry)	LOI (wt%)	$^{40}Ar/^{39}Ar$ age (Ma)	MSWD (Ar-Ar)	K-Ar age (Ma)	K-Ar age (Ma, 2nd run)
King George Island											
Admiralty Bay											
KP-1	422579	3113331	164	89NE	5.5 m	bas. andesite	1.15	**45.41** ± 0.61	4.3		
SH-1	424421	3104230	115	90NE	min. 100 m	rhyolite	1.41	**47.09** ± 0.56	2.3		
AP-1	425284	3102865	72	90SE	70 m	bas. andesite	1.95	**54.0** ± 1.5	9.9		
Potter Peninsula											
PP-32B	412529	3097149	35	76SE	7.6 m	rhyolite	4.08	**45.7** ± 1.2	184		
PP-33	412546	3097200	140	60SW	70 cm	trachyandesite	5.76	**46.43** ± 0.56	1.6		
PP-11	414308	3098266	15	72W	4 m	andesite	3.05	**46.61** ± 0.37	5.8		
PP-31B	412514	3097131	110	71N	6.2 m	bas. andesite	2.76	**46.98** ± 0.62	10.6		
PP-32C	412529	3097149	35	76SE	1.0 m	andesite	2.35	**47.19** ± 0.50	0.61		
Weaver Peninsula											
WP-20B	407062	3101977	3	71W	~50 cm	basalt	6.75	**54.6** ± 3.8	4.4		
Fildes Peninsula											
FP-8	401204	3103845	88	66S	~8 m	dacite	3.48	**57.4** ± 2.1	1.5		
Livingston Island											
Hurd Peninsula											
HP-23	635368	3051794	135	79SW	~6 m	andesite	3.35	**37.16** ± 0.92	10.5	**39.99** ± 1.74	
HP-1A	635142	3051777	54	78SE	5.5 m	bas. andesite	2.96	**39.8** ± 7.3	8.6	**56.38** ± 3.27	
HP-10B	635315	3051673	64	90S	8 m	dacite	---			**43.32** ± 1.73	
HP-17	635287	3051758	141	74SW	90 cm	trachybasalt	4.51			**44.52** ± 1.81	
HP-7G	635503	3052309	85	73S	3 m	trachyandesite	4.41			**47.43** ± 2.13	
HP-10A	635315	3051673	149	90NE	90 cm	bas. trachyandesite	2.82	**48.3** ± 1.5	1.7		
HP-7D	635539	3052276	138	74SW	55 cm	trachyandesite	5.43	**53** ± 16	5.3		
HP-26	635246	3051788	60	59SE	min. 3 m	rhyolite	2.97	*55-60*	n.d.		
HP-7J	635517	3052303	83	63S	~2.5 m	andesite	3.32	*55-65*	n.d.		
HP-19	635293	3051812	26	55E	~1 m	tephrite	7.79			**56.45** ± 2.28	
HP-7A	635548	3052291	63	70NW	30 cm	andesite	6.96	**64** ± 13	18		
HP-33	635363	3051694	44	49NW	2.0 m	dacite	4.48	*60-90*	n.d.		
HP-15	635337	3051807	21	78SE	1.6 m	dacite	4.03			**80.12** ± 3.12	**82.73** ± 3.28

Note: Bold ages are reliable, whereas italic ones do not represent formal plateau ages but best estimates as deduced from age spectra. The isochron diagrams are presented by Kraus (2005); the full datasets may be downloaded from http://edoc.ub.uni-muenchen.de/archive/00003827/.

stock cannot rule out a Danian age within analytical uncertainty. The other Cenozoic ages agree with our results, suggesting a 51–45 Ma peak in intrusive activity.

Zheng et al. (2003) reported 15 K/Ar and 3 $^{40}Ar/^{39}Ar$ ages ranging from 79–31 Ma for dikes from Hurd Peninsula. Their results are interesting because they also studied the northwest Hurd Peninsula near the Bulgarian Base. Their K/Ar and $^{40}Ar/^{39}Ar$ ages were determined from whole-rock powders, making the reliability of these data questionable in the light of the strong alteration evident throughout Hurd Peninsula. They identified four intrusive events between 79 and 31 Ma with only one Cretaceous K-Ar age (79 ± 2 Ma). Intrusive activity between 56–52 and 45–42 Ma identified by Zheng et al. (2003) corresponds to the second and third phase determined by us. The youngest 38–31 Ma ages obtained by these authors possibly reflect the 37.16 Ma age obtained for HP–23 (Table 1) in our study.

Every previous study of Hurd Peninsula dikes has emphasized problems with alteration. With the new knowledge that the host Miers Bluff Formation contains Campanian nannofossils, we conclude that the Cretaceous ages might be an artifact of excess argon, and that dike intrusion on Hurd Peninsula did not begin before Danian times.

In contrast to Hurd Peninsula (LI), the host rocks on King George Island are volcanic units related to arc magmatism. Cretaceous and Cenozoic Rb/Sr and whole rock K/Ar ages are known from lava flows, plugs and other magmatic rocks (e.g. Smellie et al., 1984). The majority of the ages from King George Island range from 60–40 Ma. Pre-Cenozoic ages have not been confirmed. This agrees with our results, which are restricted to the Cenozoic (Paleocene and Eocene). We conclude that pre-Cenozoic intrusive activity on King George Island cannot be excluded, but has yet to be confirmed.

Constraints on the deformation history at Hurd Peninsula (Livingston Island)

Campanian nannofossils in the Miers Bluff Formation host (Pimpirev et al., 2006; Stoykova et al., 2002) establish a maximum age for the Hurd Peninsula dikes. Our $^{40}Ar/^{39}Ar$ and K/Ar ages for dikes that cut the metasedimentary sequence include reliable Paleocene and Eocene ages as well as some less certain ages. Of these, HP-7J and HP-26 are probably Paleocene. Two dikes yielded less reliable older ages. HP-33 yielded an uninterpretable age spectrum (Fig. 5-3 in Kraus, 2005) that does not exclude an earliest Paleocene (Danian) age. HP-15 was dated by whole-rock K/Ar; excess ^{40}Ar may explain its Campanian apparent age. We conclude that dike intrusion on Hurd Peninsula most probably was restricted to the Cenozoic (Paleocene and Eocene), starting shortly after the Cretaceous/Paleogene boundary.

Considering the Campanian nannofossil age for the host rocks and the supposedly Danian age for the oldest dikes intruding them, an interval not exceeding 10 m.y. and comprising most of Maastrichtian time was available for the deformation of the host rocks. This would at first seem a short interval, but the metasedimentary host represents a fossil accretionary wedge in a subduction zone where rapid burial and deformation is possible if not likely.

Summary

Eighteen plagioclase $^{40}Ar/^{39}Ar$ and 7 whole rock K/Ar ages from magmatic dikes in the South Shetland Islands suggest that dike intrusion occurred from Paleocene to Eocene times. Intrusion began earlier and lasted longer on Hurd Peninsula (Livingston Island) than on King George Island and probably also Nelson Island. The oldest dikes from Hurd Peninsula yielded no $^{40}Ar/^{39}Ar$ plateaux, but best estimates indicate a Cretaceous/Paleogene boundary age. The Campanian age of the host and the inferred Early Danian age for the oldest dikes allows 5–10 m.y. for deformation of the metasedimentary host. Dike intrusion in the South Shetland Islands climaxed between 47 and 45 Ma and ended during the Priabonian. The youngest dikes are restricted to Hurd Peninsula.

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