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Age of volcanism on Keller Peninsula and assessment of age-constrained volcanic activity on King George Island, West Antarctica

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Abstract: Studies of isotopic ages were conducted for rock samples of the Keller, Visca Anchorage and Domeyko Glacier formations. Together they form a part of the Martel Inlet Group, a terrestrial calc-alkaline volcanic and volcanoclastic suite and they crop out along the Keller Peninsula on King George Island. The U-Pb and $^{40}Ar/^{39}Ar$ isotope data from the Keller Peninsula lava flows, although differing in quality, made it possible to obtain reliable age intervals. The stratified volcanogenic rocks of Keller Peninsula, Visca Anchorage and Domeyko Glacier formations of the Keller Peninsula were emplaced there near the Early/Late Palaeocene boundary (*ca.* 62.11 ± 0.66 Ma ago), in the Early Eocene (*ca.* 56.3–51.9 Ma) and near the Early/Middle Eocene boundary (*ca.* 49.9–47.9 Ma), respectively. A certain difference in the ages of Eocene volcanogenic formations, in particular tectonic blocks of King George Island, may indicate a migration of centres of volcanic activity over time, from northwest to southeast.

Keywords: Antarctica, South Shetland Islands, U-Pb and $^{40}Ar/^{39}Ar$ isotopic ages, volcanogenic rocks.

Introduction

Cenozoic volcanogenic rocks are frequent in Western Antarctica, (*e.g.* Grikurov and Leychenkov 2012) but their precise dating in many places is still in progress. Accurate ages of volcanic activity are very important not only for detailed geological cartography of ice-free areas of Western Antarctica, but also for time frames of past climate changes, metallic mineralization and tectonic evolution. Glaciogenic sediments related to the Oligocene and Miocene glaciations of Antarctica are preserved in some regions of Western Antarctica. Their precise dating is possible due to isotope ages of the surrounding or interbedded volcanic rocks, as well as strontium isotope stratigraphy of carbonate shells (*e.g.* Dingle and Lavelle 1998; Troedson and Smellie 2002). Apart from thermal isolation of Antarctica accredited to the opening of the Drake Passage in the Eocene (*e.g.* Barker and Burrell 1977; Livermore *et al.* 2005), extensive volcanic activity could be an additional factor responsible for the initial phases of climate cooling and glaciations of Antarctica (Nawrocki *et al*. 2011). However, to prove this thesis, a precise and credible dating of the Cenozoic volcanogenic rocks should be conducted in the entire region of Western Antarctica.

The polycyclic nature of volcanism caused by continuous subduction of the Pacific Plate under the Antarctic Plate can result in K-Ar and Ar-Ar dating to be somewhat problematic. Said problems are caused by the older rocks being heated by younger intrusions, resulting in multiple locations for their transformation and therefore argon gas lost due to reheating (*e.g.* Pankhurst and Smellie 1983). On the other hand, the U-Pb dating of zircons from andesite and basaltic-andesite lavas can provide the ages of their crystallization in the magma chamber, *i.e.* ages slightly older than the magma emplacement. Results of complementary Ar-Ar and U-Pb dating, and magnetostratigraphic studies of the same samples of volcanogenic rocks from King George Island (Nawrocki *et al.* 2010, 2011; Pańczyk and Nawrocki 2011) show that such a complex methodology seems to be the best solution to precisely date the Cenozoic volcanogenic successions in Western Antarctica.

King George Island is located in the middle of the South Shetland archipelago. The South Shetland Islands arc was formed after the breakup of Gondwana, during the subduction of the Phoenix Plate under the Antarctic Plate from the earliest Cretaceous (*ca.* 135 Ma) to the middle of Miocene (Pankhurst and Smellie 1983; Willan and Kelley 1999; Hasse *et al*. 2012). The archipelago was separated from the Antarctic Peninsula following the formation of Bransfield Strait and the development of a back-arc basin, presumably in the Pliocene (Barker 1982; Barker and Dalziel 1983; Keller *et al.* 2002; Solari *et al.* 2008). King George Island is subdivided into four major tectonostratigraphic units: the axial Barton Horst, the northern Fildes Block, the southern Warszawa Block and the southernmost Kraków Block (Fig. 1). These units are separated by longitudinal strike-slip faults. The Barton Horst is bound by the right-lateral strike-slip Ezcurra Fault in the south (Birkenmajer 2003). However, the precise nature of the relationship between the different tectonic blocks is very uncertain and the thesis of Neogene terrane accretion proposed by Birkenmajer (2003) and its influence on the stratigraphical correlation of geological units on King George Island, in particular, are unproven or at least not well understood.

Motion along the Ezcurra Fault probably began at *ca.* 54 Ma and continued until approximately 21 Ma (Birkenmajer 2003). The Cenozoic strata of King George Island, mostly basaltic and andesitic rocks with terrestrial sedimentary

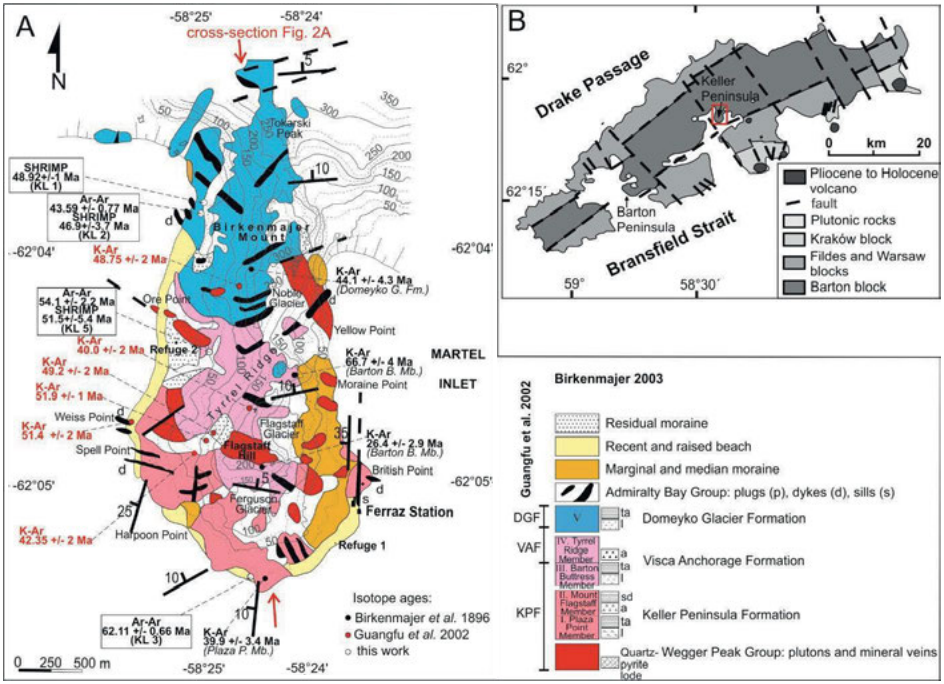

Fig. 1. (**A**) Geological map of the Keller Peninsula modified after Birkenmajer (2003), with locations and results of isotope dating. Topography after Mendes Júnior *et al.* (2012). Stratigraphic subdivision of rocks after Guangfu *et al.* (2002) and Birkenmajer (2003). (**B**) Studied area overlain by structural units of King George Island after Birkenmajer (1983).

intercalations and intruded by dykes and plugs (Birkenmajer 2003), contain sediments reflecting glacial and interglacial events that affected the South Shetland Islands and the Antarctic Peninsula, although there is disagreement on the ages and existence of some environmental episodes (Dingle and Lavelle 1998; Birkenmajer 2001; Troedson and Smellie 2002; Troedson and Riding 2002; Nawrocki *et al.* 2011, 2021).

This paper is dedicated to further isotopic age evaluation of volcanogenic sequences from King George Island and summarizes and discusses the ages of particular volcanogenic formations from different tectonic blocks of King George Island (Birkenmajer 1983). Further, it attempts to determine the dispersion of volcanic activity throughout the Cenozoic Era and in individual tectonic blocks of King George Island.

Studied rocks and methods

General setting. – Isotopic studies were performed for the samples taken from the Keller, Visca Anchorage and Domeyko formations, which form a part of the Martel Inlet Group, a terrestrial calc-alkaline volcanic and volcanoclastic suite, which crop out along Keller Peninsula of King George Island (Birkenmajer 2003). Keller Peninsula occupies the northernmost part of Admiralty Bay of King George Island and forms a part of the Barton tectonic block (Fig. 1). Previously, the studied rocks have been attributed to the Jurassic system (Barton 1965; see Smellie *et al.* 1984). According to K-Ar data, a ?Cretaceous-Paleocene age has been suggested for the Martel Inlet Group by Birkenmajer (2003). Three volcanic cycles at Keller Peninsula, Ullman Spur and Point Hennequin have been distinguished by Guangfu *et al.* (2002), who calculated K-Ar ages between 51.9±1 and 51.4±2 Ma for the Keller Peninsula Formation, 49.2±2 Ma for the Visca Anchorage Formation and 48.75±2 Ma for the Domeyko Glacier Formation (Fig. 1A). Because the ages were determined by the K-Ar method, which is particularly prone to resetting by later thermal events, the significance of all of the published K-Ar ages is very uncertain.

The Keller Peninsula Formation is at least 270 m thick and consists of the Plaza Point Member and Mount Flagstaff Member, both being exposed in the southern part of Keller Peninsula only (Birkenmajer 2003). The Visca Anchorage Formation *ca.* 140 m thick, crops out in the middle part of the Keller Peninsula and is separated from the Keller Peninsula Formation by an angular unconformity. The formation consists of the Barton Buttress Member, dated at 66.7±4 Ma (Birkenmajer 1983), and the Tyrrel Ridge Member. The presence of petrified wood fragments suggests that the volcanic activity took place in a terrestrial environment. The fossilized leaf specimens from the Tyrrell Ridge Member suggest a late Palaeocene? to early Eocene age for these rocks (Kellner *at al.* 2007), but ages based solely on plant remains are typically very imprecise. The Domeyko Glacier Formation is more than 320 m thick and conformably sits on top of the Visca Anchorage Formation, being exposed along the mountain ridge, with its tallest peak of Mount Birkenmajer, in the northern part of the Keller Peninsula (Fig. 2, Birkenmajer 2003). The copper-bearing mineral veins of the Wegger Peak Group intrude all the volcanogenic formations of Keller Peninsula in several places (Barton 1965; Paulo and Rubinowski 1987).

Sample locations and petrography. – Two samples, KL-1 and KL-2, were taken for isotopic dating, from the andesite of the Domeyko Glacier Formation cropping out in the NW coast of the Keller Peninsula (Fig. 1A). One sample (KL-3) was obtained from the basaltic andesite lava flow of the Keller Peninsula Formation that is exposed in the cliff near the Plaza Point, in the southernmost part of the Keller Peninsula. The Visca Anchorage Formation was sampled in the middle part of the western slope of Keller Peninsula *ca.* 300 m above the Brazilian Refuge 2 location (sample KL-5).

Most of the sampled rocks are strongly altered due to hydrothermal processes. Only sample KL-3 remained mostly unaffected by post-magmatic hydrothermal activity. The dark grey andesitic and basaltic andesitic rocks (Birkenmajer 2003) display a porphyritic, intersertal texture (Fig. 3A–H).

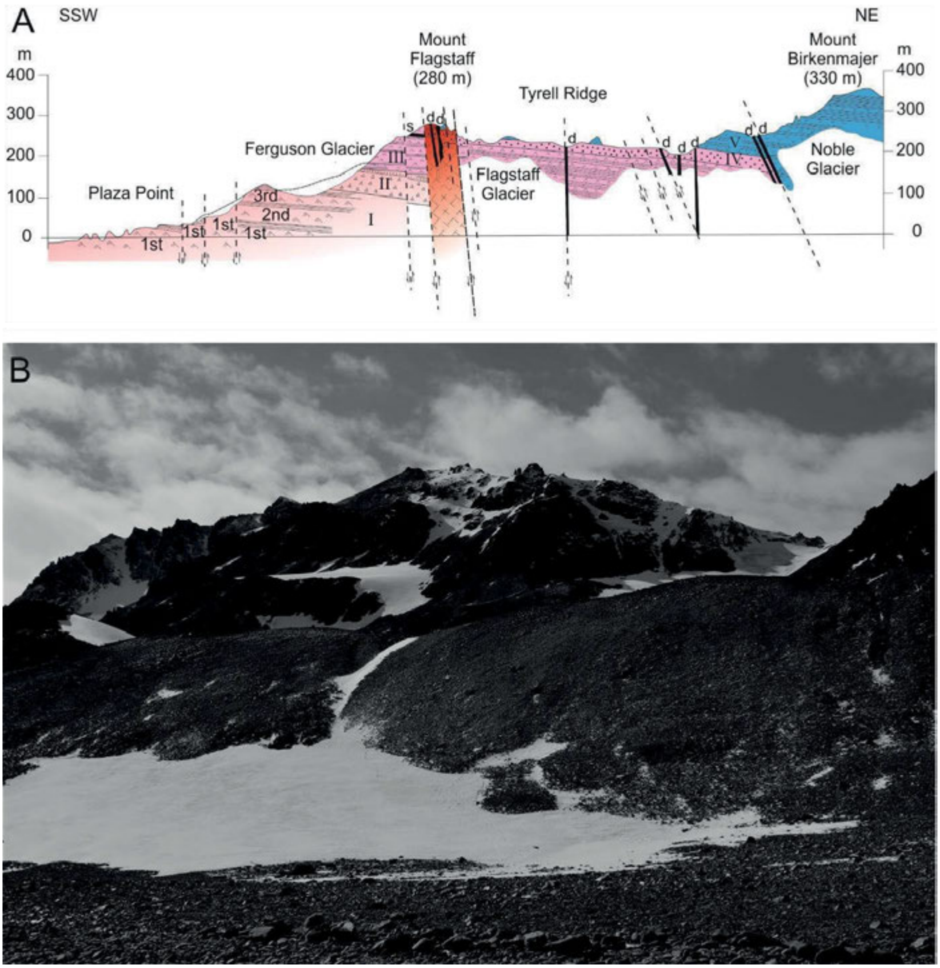

Fig. 2. (**A**) Geological cross-section of the Keller Peninsula after Birkenmajer (1982), for stratigraphic subdivision see Fig. 1A. (**B**) Panorama of western slope of Mount Birkenmajer on the Keller Peninsula, composed of andesite and basaltic-andesite lavas of the Domeyko Glacier Formation.

The KL-1, KL-2 and KL-5 samples contain plagioclase crystals altered from labradorite-andesine (Fig. 3C–D). They occur as euhedral and subhedral phenocrysts up to 2 mm in length, as well as irregularly orientated laths within the matrix. The altered matrix contains pseudomorphs of plagioclase, calcite, quartz, albite and chlorite. The mafic minerals, most probably clinopyroxenes, are strongly chloritized (Fig. 3B–C). The main accessory minerals are apatite, magnetite (Fig. 3A and 3H) and rarely zircons. The KL-3 sample contains plagioclase phenocrysts with a labradorite-andesine composition, and clinopyroxene (Ti-augite). Its matrix comprise of laths of plagioclase, glass, mafic minerals and Fe-Ti oxides.

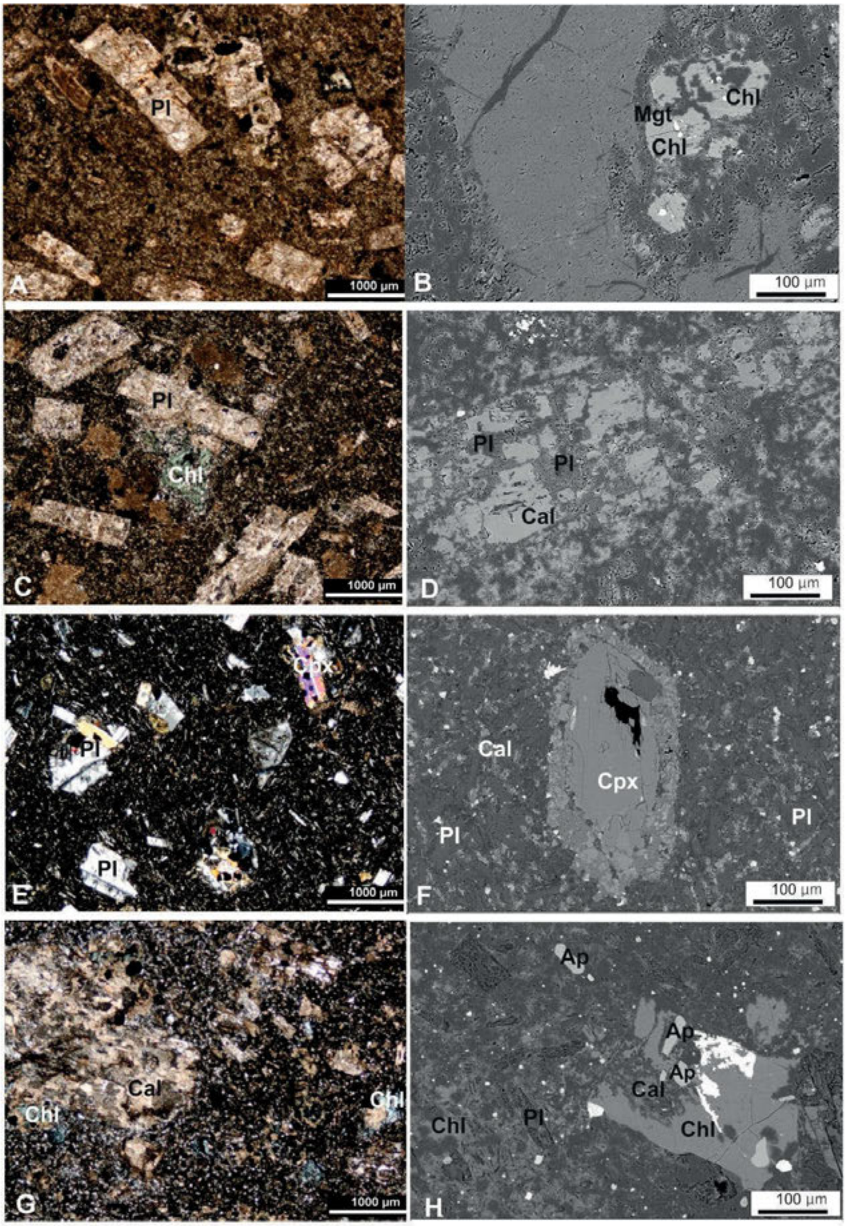

Fig. 3. Photomicrographic images of volcanic rocks from Keller Peninsula: sample KL-1 (**A–B**), sample KL-2 (**C–D**), sample KL-3 (**E–F**), sample KL-5 (**G–H**). **A**. Strongly altered plagioclase phenocrysts surrounded by matrix comprised of calcite, quartz and albite (crossed polars). **B**. Strongly altered plagioclase phenocrysts and chloritized clinopyroxene with magnetite inclusions (Backscattered-Electron (BSE) image). **C**. Altered plagioclase phenocrysts and chloritized clinopyroxene phenocryst (crossed polars). **D**. Altered plagioclase phenocryst (BSE image). **E**. Plagioclase and clinopyroxene phenocrysts surrounded by an intersertal matrix (crossed polars). **F**. Clinopyroxene phenocryst (BSE image). **G**. Carbonatization of matrix (crossed polars). **H**. Apatite crystal inclusions within the matrix (BSE image).

Isotope analyses. – The samples were crushed in a ring mill, washed in distilled water and ethanol, and sieved when dry to –40+60mesh. Appropriate mineral grains were picked out of the bulk fraction. The samples were wrapped in aluminum foil and stacked in an irradiation capsule with similar-aged samples and neutron flux monitors (Fish Canyon Tuff sanidine (FCs), 28.305±0.036 Ma, Renne *et al.* 2011), and irradiated without Pt shielding in October 2019 at the McMaster Nuclear Reactor in Hamilton, Ontario, for 100 MWH in the medium flux site 8E. Analyses (n=24) of 8 neutron flux monitor positions produced errors of <0.5% in the J value. The samples were analysed by Janet Gabites at the Noble Gas Laboratory, Pacific Centre for Isotopic and Geochemical Research, Department of Earth, Ocean and Atmospheric Sciences, University of British Columbia, Vancouver. The mineral separates were step-heated at incrementally higher powers in the defocused beam of a 10W CO_2 laser (New Wave Research MIR10) until fused. The gas evolved from each step was analysed by a VG5400 mass spectrometer equipped with an ion-counting electron multiplier. All measurements are corrected for total system blank, mass spectrometer sensitivity, mass discrimination, radioactive decay during and subsequent to irradiation, as well as interfering Ar from atmospheric contamination and the irradiation of Ca, Cl and K, with isotope production ratios: $(^{40}Ar/^{39}Ar)_K$=0.0302±0.00006, $(^{37}Ar/^{39}Ar)_{Ca}$=1416.4±0.5, $(^{36}Ar/^{39}Ar)_{Ca}$=0.3952±0.0004 and Ca/K=1.83±0.01 $(^{37}Ar_{Ca}/^{39}Ar_K)$.

The same rock samples (KL-2 and KL-5) were used for U-Pb isotope dating. The Domeyko Glacier Formation KL-1 sample was dated by U-Pb method only. The volcanic rock samples, KL-1, KL-2 and KL-5 from the Keller Peninsula were crushed and sieved for zircon separation. Heavy mineral fractions were separated using conventional heavy liquid and magnetic techniques. Hand-picked zircons from the studied samples were mounted in epoxy with zircon standards 91500 (U = 78.5 ppm) and TEMORA ($^{206}Pb/^{238}U$ = 0.06683). The mounts with zircons were polished, documented using optical microscope (reflected and transmitted light) and imaged by cathodoluminescence (CL) using a Hitachi SU3500 scanning electron microscope equipped with CL detector. The CL images were used to characterize each grain and to identify any cracked and otherwise damaged zircons. Following CL examination, the zircon grains were analyzed using the ion microprobe SHRIMP IIe in the Polish Geological Institute - NRI, Warsaw according to procedures based on those described by Williams and Claesson (1987). Analytical conditions were: 3 nA negative O_2^- primary ion beam focused to *ca.* 25 µm diameter spot; mass resolution *ca.* 5500; isotope ratio measurement by single electron multiplier and cyclic peak stepping. Data were collected in six sets of mass scans ($^{196}Zr_2O$ - 2s; ^{204}Pb - 5s; 204.1 background - 5s; ^{206}Pb - 15s; ^{207}Pb - 15s; ^{208}Pb - 15s; ^{238}U - 5s; ^{248}ThO - 5s; ^{254}UO - 5s), with TEMORA zircon analyzed after every three unknown estimations. The data were reduced in a manner similar to that described by Williams (1998), using the SQUID Excel Macro of Ludwig (2000). All measurements on zircons were corrected for common Pb content using measured ^{204}Pb. Ages were calculated using the constants recommended by the IUGS Subcommission on Geochronology (Steiger and Jäger 1977). The plots of SHRIMP IIe data were constructed using ISOPLOT/EX (Ludwig 2003).

Results

The whole-rock sample, KL-3 of the Keller Peninsula Formation yielded an ^{40}Ar/^{39}Ar plateau age of 60.60 ± 0.74 Ma with MSWD of 0.73, J-error of 4% and a probability of occurrence of 0.57. This estimation includes 78.6% of the ^{39}Ar and is similar to the inverse isochron age of 59.29 ± 0.85 Ma (Fig. 4, Table 1). Because of a certain signs of excess of argon, an integrated date of 62.11 ± 0.66 Ma is, however, most probably closer to the time of magma emplacement. The KL-5 sample plagioclase crystals from the Visca Anchorage Formation, that was strongly altered due to hydrothermal processes, yielded an ^{40}Ar/^{39}Ar plateau age of 54 ± 2.2 Ma (Fig. 4) with MSWD of 1.14, J-error of 4% and a probability of occurrence of 0.33. This estimation includes 67% of the ^{39}Ar (Fig. 4, Table 2). The KL-2 whole-rock sample from the Domeyko Glacier Formation provided an ^{40}Ar/^{39}Ar plateau age of 43.59 ± 0.77 Ma with MSWD of 1.3, J-error of 4% and a probability of occurrence of 0.27. This estimation includes 62.2% of the ^{39}Ar (Fig. 4, Table 3).

Results of U-Pb isotope studies are summarized in Appendix 1. All zircon populations are homogenous and range from 80 to 120 µm in length. Most of zircons are transparent, with slight zonation visible in CL images. The zircons are fragmented, without evidence of dissolution or a complicated zoning texture. They displayed a very low to moderate U and Th contents (67–1024 ppm and 39–1116 ppm, respectively) typical for igneous rocks Th/U ratio, ranging from 0.68 up to 1.30. The results of U-Pb isotope dating are not concordant in different degree and because of this the mean ^{206}Pb/^{238}U ages are presented only (Fig. 5). The mean ^{206}Pb/^{238}U age (error 2σ) calculated for zircons grains from the sample KL-1 is 48.92 ± 1 Ma (MSWD 2.2), whereas from the sample KL-2 is 46.9 ± 3.7 Ma with high MSWD (9.5). The obtained age for sample KL-5 is 51.5 ±5.4 Ma (MSWD 5.4).

Discussion

Towards a reliable age of volcanogenic formations from the Keller Peninsula. – The whole rock KL-3 sample's ^{40}Ar/^{39}Ar plateau age of from the Keller Peninsula Formation (60.6 ± 0.74 Ma) is of high statistical quality and close to the inverse isochron and integrated ages (59.29 ± 0.85 Ma; 62.11 ± 0.66 Ma). The sample displayed a weak post-magmatic alteration only

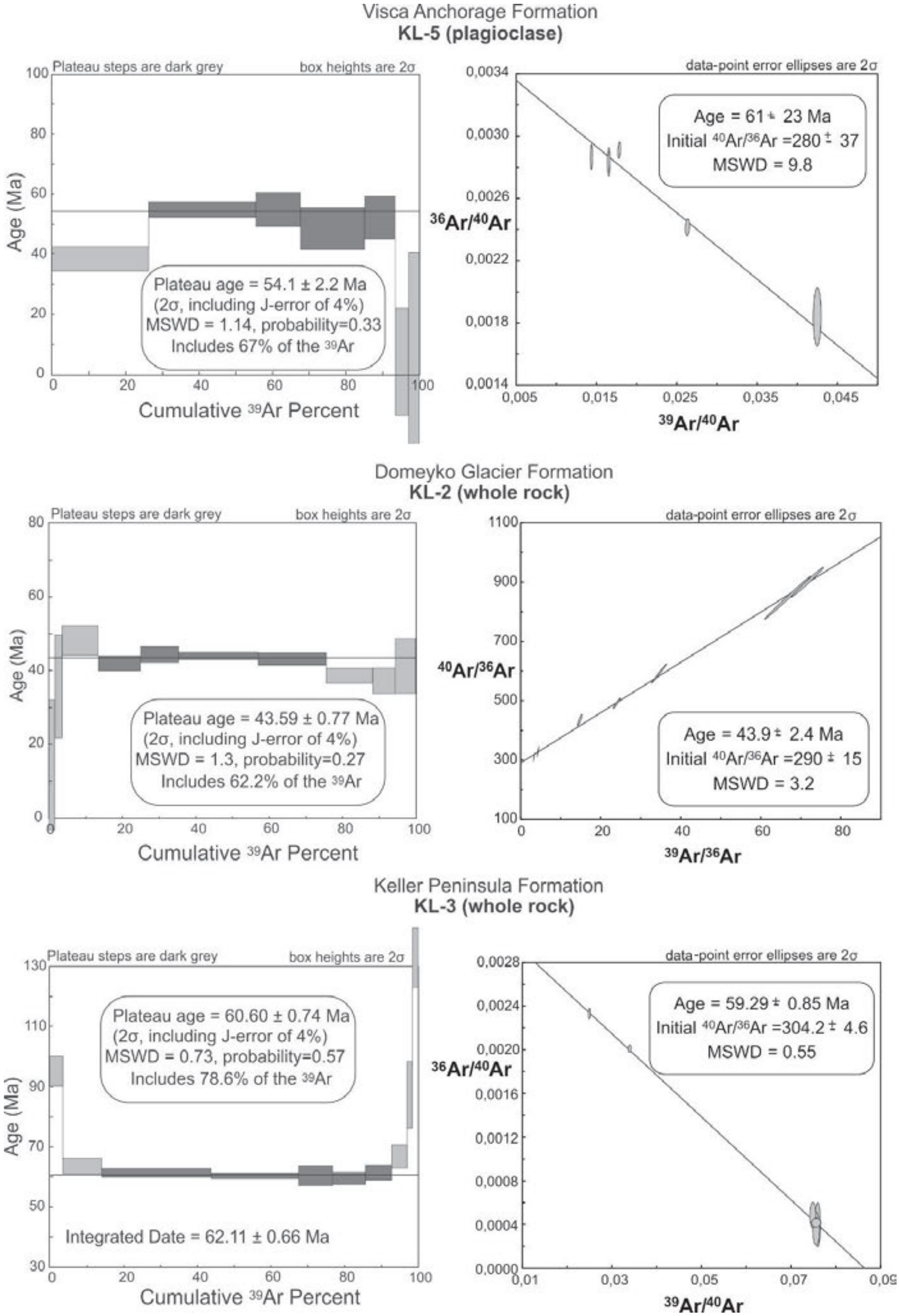

Fig. 4. Plagioclase and whole-rock sample $^{40}Ar/^{39}Ar$ age spectra from the volcanogenic Martel Inlet Group rocks from the Keller Peninsula presented in plateau diagrams and inverse isochron plots. The plateau age error bars of the apparent ages of step heating are drawn at 2σ analytical uncertainties. For details see Tables 1, 2 and 3.

Table 1.

Results of $^{40}Ar/^{39}Ar$ age estimation for basaltic andesite from the Keller Peninsula Formation.

KL3 WR															
Laser			Isotope Ratios												
Power (%)	*40Ar/ 39Ar*	*2s*	*36Ar/ 39Ar*	*2s*	*39Ar/40Ar*	*2s*	*36Ar/ 40Ar*	*2s*	*Rho*	*K/Ca*	*%40Ar rad*	*f 39Ar*	*40Ar*/ 39ArK*	*Age*	*2s*
2.2	57.14	0.60	0.13141	0.00350	0.0174	0.0002	0.00227	0.00006	0.04	0.11	32.21	3.43	18.47	95.09	± 5.06
2.4	40.06	0.29	0.09367	0.00172	0.0249	0.0002	0.00233	0.00004	0.10	0.36	30.57	10.58	12.26	63.68	± 2.60
2.6	29.46	0.28	0.05925	0.00093	0.0339	0.0003	0.00201	0.00003	0.15	1.22	40.10	29.56	11.82	61.41	± 1.48
2.7	13.24	0.15	0.00560	0.00044	0.0755	0.0009	0.00041	0.00003	0.02	1.12	87.73	23.91	11.61	60.38	± 0.95
2.8	13.16	0.08	0.00578	0.00219	0.0759	0.0005	0.00039	0.00017	0.00	0.30	88.27	9.22	11.63	60.46	± 3.37
3.0	13.36	0.10	0.00711	0.00127	0.0747	0.0006	0.00048	0.00010	0.01	0.27	85.63	8.90	11.46	59.58	± 2.00
3.3	13.22	0.11	0.00558	0.00164	0.0755	0.0007	0.00036	0.00012	0.01	0.21	89.35	6.99	11.83	61.49	± 2.57
3.7	14.69	0.16	0.00788	0.00252	0.0678	0.0007	0.00042	0.00017	0.01	0.11	87.33	4.16	12.88	66.81	± 3.92
4.4	32.98	0.28	0.05844	0.00733	0.0301	0.0003	0.00164	0.00022	0.03	0.04	50.89	1.53	16.93	87.34	± 11.19
5.5	49.70	0.94	0.05761	0.00629	0.0200	0.0004	0.00109	0.00013	0.12	0.05	67.50	1.72	33.79	170.42	± 10.04

J = 0.00288737 ± 0.00000577; Volume 39ArK = 0.2512 x E-13 cm3 NPT
Integrated Date = 62.11 ± 0.66 Ma
Plateau age = 60.60 ± 0.74 Ma; (2s, including J-error of .2%), MSWD = 0.73, probability=0.7, Includes 78.6% of the 39Ar, steps 3 through 7
Inverse isochron (correlation age) results: Model 1 Solution (±95%-conf.) on 6 points
Age = 59.9 ± 05 Ma Initial 40Ar/36Ar =304.2 ± 4.6; MSWD = 0.55, Probability = 0.7
Analysis by Janet Gabites
Pacific Centre for Isotopic and Geochemical Research, Dept Earth and Ocean Sciences, The University of British Columbia, Vancouver, BC., Canada

Table 2.

Results of $^{40}Ar/^{39}Ar$ age estimation for basaltic andesite from the Visca Anchorage Formation.

KL5 feldspar															
Laser				*Isotope Ratios*											
Power(%)	*40Ar/ 39Ar*	*2s*	*36Ar/ 39Ar*	*2s*	*39Ar/ 40Ar*	*2s*	*36Ar/ 40Ar*	*2s*	*Rho*	*K/Ca*	*%40Ar rad*	*f 39Ar*	*40Ar*/ 39ArK*	*Age*	*2s*
2.3	56.21	0.42	0.16320	0.00252	0.0178	0.0001	0.00291	0.00004	0.24	-0.91	13.20	26.30	7.42	38.51	± 3.95
2.5	38.03	0.32	0.09157	0.00168	0.0263	0.0002	0.00241	0.00004	0.22	-1.09	27.98	29.09	10.64	54.98	± 2.68
2.7	23.57	0.23	0.04312	0.00363	0.0424	0.0004	0.00184	0.00015	0.02	-1.09	45.16	12.33	10.64	55.00	± 5.54
3.0	60.66	0.56	0.17162	0.00473	0.0165	0.0002	0.00283	0.00007	0.05	-0.99	15.44	17.18	9.36	48.47	± 6.96
3.4	69.88	0.54	0.19988	0.00481	0.0143	0.0001	0.00286	0.00007	0.04	-0.65	14.47	8.43	10.11	52.29	± 7.07
4.0	63.58	0.79	0.21565	0.01176	0.0156	0.0002	0.00331	0.00018	0.01	0.04	1.16	3.66	0.75	3.91	± 18.18
5.2	57.33	0.90	0.23854	0.01978	0.0172	0.0003	0.00404	0.00034	0.01	0.03	-20.48	3.00	-11.91	-63.62	± 32.06

J = 0.00286683 ± 0.00000573; Volume 39ArK = 0.081 x E-13 cm3 NPT
Integrated Date = 49.59 ± 1.89 Ma
Plateau age = 54.1 ± 2.2 Ma; (2s, including J-error of .2%), MSWD = 1.14, probability=0.33, Includes 67% of the 39Ar, steps 2 through 5
Inverse isochron (correlation age) results: Model 1 Solution (±95%-conf.) on 5 points
Age = 61 ± 23 Ma Initial 40Ar/36Ar =280 ± 37; MSWD = 9.8, Probability = 0
Analysis by Janet Gabites
Pacific Centre for Isotopic and Geochemical Research, Dept Earth and Ocean Sciences, The University of British Columbia, Vancouver, BC., Canada

Table 3.

Results of $^{40}Ar/^{39}Ar$ age estimation for andesite from the Domeyko Glacier Formation

KL2 WR															
Laser				Isotope Ratios											
Power(%)	*40Ar/ 39Ar*	*2s*	*36Ar/ 39Ar*	*2s*	*39Ar/ 40Ar*	*2s*	*36Ar/ 40Ar*	*2s*	*Rho*	*K/Ca*	*%40Ar rad*	*f 39Ar*	*40Ar*/ 39ArK*	*Age*	*2s*
2.2	91.88	0.82	0.30445	0.01134	0.0108	0.0001	0.00325	0.00012	0.04	0.03	2.90	1.29	2.70	14.30	± 17.78
2.4	74.08	0.75	0.22940	0.00913	0.0134	0.0001	0.00305	0.00012	0.02	0.05	9.05	2.03	6.75	35.62	± 13.97
2.6	29.26	0.47	0.06812	0.00226	0.0341	0.0006	0.00230	0.00008	0.38	0.26	31.21	9.84	9.15	48.07	± 4.13
2.8	20.36	0.15	0.04202	0.00126	0.0491	0.0004	0.00204	0.00006	0.10	0.34	39.17	11.73	7.98	42.02	± 2.01
3.0	17.02	0.09	0.02949	0.00131	0.0587	0.0003	0.00169	0.00008	0.03	0.28	49.41	10.33	8.42	44.30	± 2.06
3.8	12.52	0.07	0.01423	0.00064	0.0798	0.0005	0.00111	0.00005	0.03	0.62	66.77	21.57	8.37	44.01	± 1.03
4.4	12.65	0.07	0.01531	0.00105	0.0790	0.0005	0.00118	0.00008	0.02	0.54	64.67	18.58	8.19	43.10	± 1.65
5.0	12.97	0.09	0.02603	0.00178	0.0771	0.0006	0.00197	0.00014	0.02	0.38	56.63	12.72	7.35	38.73	± 2.06
6.8	18.14	0.11	0.05142	0.00295	0.0550	0.0003	0.00278	0.00016	0.02	0.17	38.93	6.16	7.08	37.30	± 3.39
8.0	24.06	0.21	0.07504	0.00653	0.0415	0.0004	0.00307	0.00027	0.01	0.16	32.43	5.75	7.82	41.19	± 7.48

J = 0.00290904 ± 0.00000582; Volume 39ArK = 0.179 x E-13 cm3 NPT
Integrated Date = 42.85 ± 0.67 Ma
Plateau age = 43.59 ± 0.77 Ma; (2s, including J-error of .2%), MSWD = 1.3, probability=0.27, Includes 62.2% of the 39Ar, steps 41 through 7
Inverse isochron (correlation age) results: Model 1 Solution (±95%-conf.) on 7 points
Age = 43.9 ± 2.4 Ma Initial 40Ar/36Ar =2902 ± 154; MSWD = 3.2, Probability = 0.051
Analysis by Janet Gabites
Pacific Centre for Isotopic and Geochemical Research, Dept Earth and Ocean Sciences, The University of British Columbia, Vancouver, BC., Canada

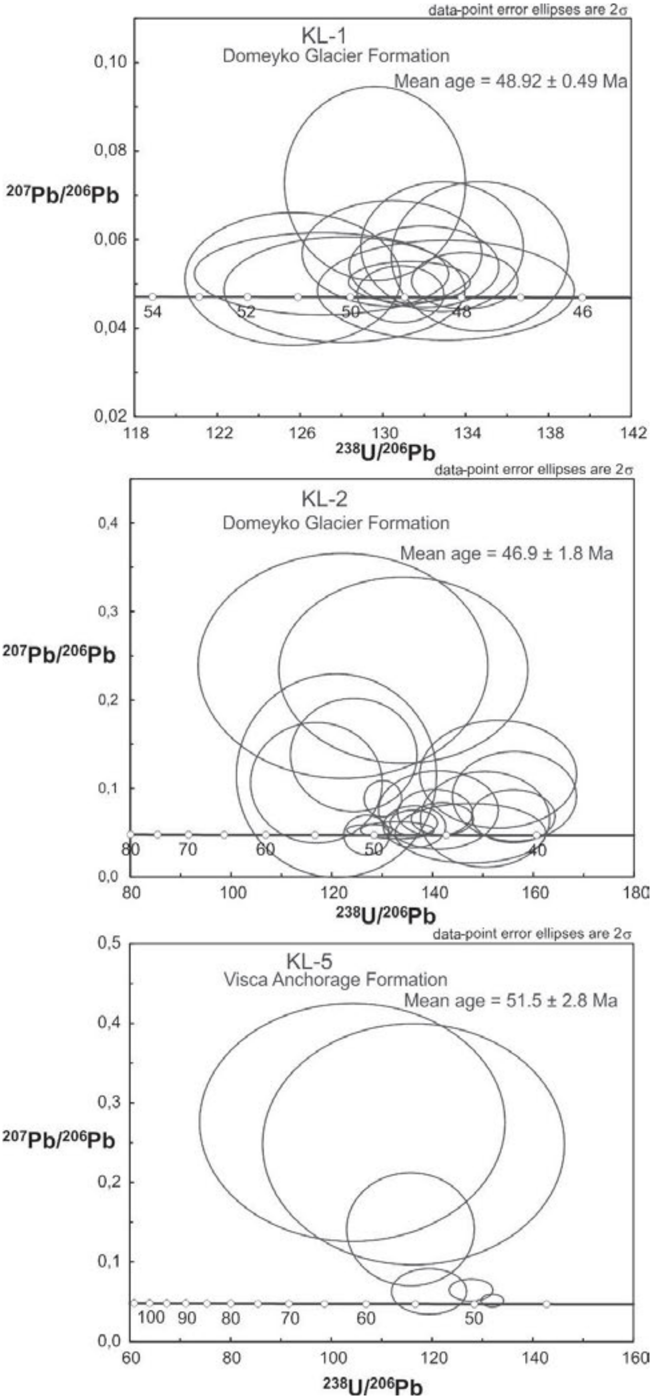

Fig. 5. Terra-Wasserburg concordia diagrams for zircons from the Domeyko Glacier Formation (samples KL-1 and KL-2) and Visca Anchorage Formation (sample KL-5). The mean $^{206}Pb/^{238}U$ ages obtained for particular sample are also presented.

(Fig. 3). Consequently, it is assumed that the integrated age most probably points best the time of magma emplacement. Sample KL-5 of the Visca Anchorage Formation showed evidences of strong post-magmatic alterations. However, these hydrothermal alteration processes could be approximately close in time to when the magma was emplaced. The plagioclase $^{40}Ar/^{39}Ar$ plateau age (54.1 ± 2.2 Ma) and the mean U-Pb age of zircons from this sample (51.5 ± 5.4 Ma) overlap between 56.3 and 51.9 Ma. It may support this interpretation despite of poor quality of U-Pb age. Bearing in mind both isotope ages with their analytical errors, we can assume that this part of the Visca Anchorage Formation was emplaced sometime between 56.3 and 51.9 Ma. This agrees with paleontological evidence from the Tyrrell Ridge Member of the Visca Anchorage Formation that suggest a late Palaeocene? to early Eocene age for these rocks (Kellner *at al.* 2007). The mean U-Pb ages obtained from samples KL-1 and KL-2 of the Domeyko Glacier Formation from the same lava flow (48.92 ± 1 Ma; 46.9 ± 3.7 Ma), lead to conclusion that these rocks were emplaced between *ca.* 47.9 and 49.9 Ma, when taking into consideration the overlapping of analytical errors. The $^{40}Ar/^{39}Ar$ plateau age obtained from the whole rock sample KL-2 is about 4 Ma younger (43.59 ± 0.77 Ma), and although it is of good quality, it most probably indicates a time of strong hydrothermal alteration of the studied rock (Fig. 3). Finally, it can be concluded that the stratified volcanogenic succession at the Keller Peninsula was deposited near the Early/Late Palaeocene boundary (Keller Peninsula Formation), in the Early Eocene (Visca Anchorage Formation) and in the early Middle Eocene (Domeyko Glacier Formation). The unconformity that separates the Palaeocene and Eocene lavas at the Keller Peninsula may be linked with a phase of folding of the stratiform volcanic-sedimentary succession in the southern part of the Barton Horst. It may be an effect of transpression related to strike-slip displacement along the Ezcurra Fault (Birkenmajer 2003). It is possible that a major phase of tectonic displacement took place along the Ezcurra Fault near the Eocene and Palaeocene boundary, as the coeval Early to Middle Eocene volcanogenic succession covers both tectonic blocks (Barton Horst and Warszawa Block) separated by this fault (Fig. 6).

Chronology of volcanic activity on King George Island. – More than 95% of King George Island is covered by an ice sheet, therefore the study of the stratigraphy is limited to its coastal parts only. A stratigraphic chart with phases of volcanic activity on King George Island presented here (Fig. 6), is based largely on the $^{40}A/^{39}Ar$ and U-Pb age results. The oldest volcanogenic rocks on the surface of King George Island (basaltic andesites) were dated to *ca.* 120 Ma (Kim *et al.* 2000). They crop out on the Barton Peninsula, *i.e.* in the south-western part of the Barton Horst (Figs 1 and 6). A Late Cretaceous $^{40}Ar/^{39}Ar$ age (*ca.* 75 Ma) was obtained (Nawrocki *et al.* 2010) from the Uchatka Point Formation basalt (Paradise Cove Group, Fig. 6) outcropping from the Warszawa Block. The basaltic andesites of the Keller Peninsula Formation are the next pre-Eocene rocks with a well-documented ^{40}A-^{39}Ar isotope age *ca.*

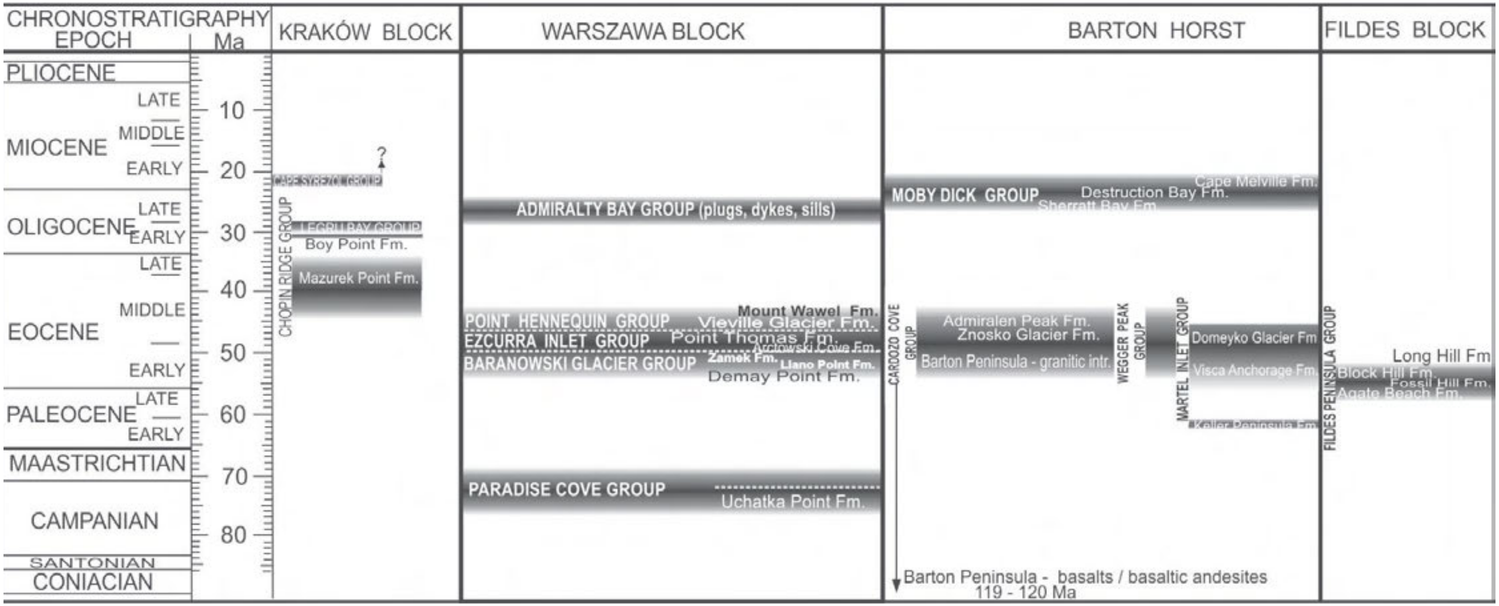

Fig. 6. Geological ages and correlation of groups and formations identified within the particular tectonic blocks of King George Island. Stratigraphic location and ages of individual units were adopted from the following studies: Uchatka Point Fm. (Nawrocki *et al.* 2010)*, Demay Point Fm. (Nawrocki *et al.* 2010)*, Llano Point Fm. (Nawrocki *et al.* 2011)*, Zamek Fm. (Mozer *et al.* 2015), Arctowski Cove Fm. (Nawrocki *et al.* 2010, 2011), Point Thomas Fm. (Nawrocki *et al.* 2011; Mozer 2012), Vieville Glacier Fm. (Nawrocki *et al.* 2011)*, Mount Wawel Fm. (Nawrocki *et al.* 2011)*, Admirality Bay Group (Pańczyk *et al.* 2009)*, Keller Peninsula Fm. (this work)*, Visca Anchorage Fm. (this work)*, Domeyko Glacier Fm. (this work)*, Wegger Peak Goup (Nawrocki *et al.* 2010)*, Agate Beach Fm. (Gao *et al.* 2017)*, Fossil Hill Fm. (Gao *et al.* 2017), Block Hill Fm. (Gao *et al.* 2017)*, Long Hill Fm. (Gao *et al.* 2017)*, Mazurek Point Fm. (Pańczyk and Nawrocki 2011)*, Boy Point Fm. (Birkenmajer 1989), Legru Bay Group (Birkenmajer 1989), Cape Syrezol Group (Birkenmajer 1989), Barton Peninsula – basalt/basaltic andesite (Kim *et al.* 2000)*, Barton Peninsula - granitic intrusions (Kim *et al.* 2000)*, Znosko Glacier Fm. (Nawrocki *et al.* 2010, 2011)*, Admiralen Peak Fm. (Birkenmajer 2001; Kraus 2005), Sheerat Bay Fm. (Birkenmajer 1989), Destruction Bay Fm. (Birkenmajer *et al.* 1989), Cape Melville Fm. (Dingle and Lavelle 1998). *Rocks dated by U-Pb or/and Ar-Ar method.

62 Ma. However, most of the volcanogenic formations identified on King George Island were emplaced there during the Eocene (Nawrocki *et al.* 2011). Their ages are comparable in the areas of the Warszawa Block and the Barton Horst, being emplaced between 53 and 43 Ma (see also Nawrocki *et al.* 2010, 2011; Mozer *et al.* 2015). It should be noted that isotope data indicates slightly older ages (56–52 Ma) for the Fildes Peninsula Group of the Fildes Block (Gao *et al.* 2017) and slightly younger ages (45–37 Ma) of the upper pats of the Mazurek Point and Hennequin formations (Pańczyk and Nawrocki 2011) outcropping from the Kraków Block (Fig. 6). This may indicate a migration of Eocene volcanic activity over time, from northwest to southeast. This phenomenon cannot be noticed across the Barton Horst and the Warszawa Block, as all of the outcrops studied from these units are close to their tectonic boundary. There is no data from the central and northern parts of the Barton Horst. The Late Oligocene to Early Miocene magmatic activity took place most probably in the entire area of King George Island (Troedson and Riding 2002; Pańczyk and Nawrocki 2009). Its lack in the area of the Fildes Block is most probably due to a very limited number of isotopic studies. They only cover the south-western margin of this unit.

Conclusions

The U-Pb and $^{40}Ar/^{39}Ar$ isotope data of lava flows from the Keller Peninsula allow for an estimation of their emplacement age. The stratified volcanogenic rocks of the Keller Peninsula, Visca Anchorage and Domeyko Glacier formations of the Keller Peninsula were emplaced near the Early/Late Palaeocene boundary (*ca.* 62.11 ± 0.66 Ma ago), in the Early Eocene (*ca.* 56.3–51.9 Ma) and near the Early/Middle Eocene boundary (*ca.* 49.9–47.9 Ma), respectively. Consequently, the tectonic inclination of the rocks forming the Keller Peninsula Formation, which was most probably caused by strike-slip tectonic activity of the Ezcurra Fault, resulted in an angular unconformity between them and the overlying Visca Anchorage Formation, and is dated to have occurred *ca.* 62–52 Ma ago. A certain age difference of Eocene volcanogenic formations, in particular of the tectonic blocks of King George Island, may indicate a migration of centres of Eocene volcanic activity over time, from northwest to southeast.

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