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Volcanic geology of Admiralty Bay, King George Island, Antarctica

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Abstract At Admiralty Bay of central King George Island, Keller Peninsula, Ullman Spur and Point Hennequin are main Tertiary volcanic terranes. Field investigation and isotopic datings indicate that, there occurred three periods of eruptions (three volcanic cycles) and accompanying N-toward migration of the volcanic center on Keller Peninsula. After the second period of eruptions, the crater collapsed and a caldera was formed, then later eruptions were limited at the northern end of the peninsula and finally migrated to Ullman Spur. Thus Keller Peninsula is a revived caldera, and its volcanism migrated toward E with time. Point Hennequin volcanism happened more or less simultaneously with the above two areas, but has no clear relation in chemical evolution with them, frequently it belongs to another independent volcanic center.

Key words caldera, temporal-spatial evolution, Tertiary volcanism, Admiralty Bay, King George Island.

1 Introduction

Mesozoic-Cenozoic calc-alkaline volcanic and related plutonic rocks are extensively distributed in South Shetland Islands of Antarctica. Among them, high-alumina basalts and basaltic andesites are predominant, andesites and dacites are minor to sparse, and rhyolites are found only at a place on Livingston Island. The origins of these igneous rocks are related directly to the subduction of Pacific plate toward West Antarctic continent. King George Island is the largest one and there outcrop most Tertiary volcanic rocks in South Shetland Islands (Fig. 1) (Smellie *et al.* 1984; Birkenmajer 1982, 1989; Birkenmajer *et al.* 1983, 1985; Zheng *et al.* 1988, 1996; Barbieri *et al.* 1989; Li *et al.* 1992; Jin *et al.* 1992; Xing *et al.* 1997).

Admiralty Bay is a large bay along southern King George Island. Its greater coastal parts are covered by ice-snow, and only in its northern Martel Inlet many volcanic rocks are exposed. This paper focuses on the volcanic geology of Martel Inlet.

At the northern coast are Keller Peninsula and Ullman Spur, both are become higher towards N in topographies, and look overall like capsized boats; at its southern coast is Point Hennequin. All of them are small convex volcanic peninsulas and consist of volcanic rocks. Their petrological and lithofacies features of volcanic rocks are retained completely (Fig. 2).

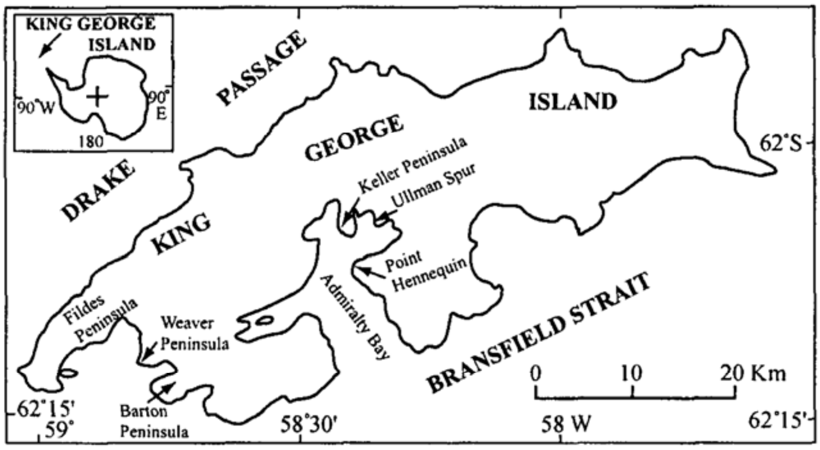

Fig. 1. Location of the studied area.

2 Volcanic strata and petrology

2.1 *Keller Peninsula and Ullman Spur*

Birkenmajer (1982) subdivided the Martel Inlet Group into 5 formations from upper to lower, i. e., Keller Peninsula Formation (abbrev. KPF, the same below), Visca Anchorage Formation (abbrev. VAF), Domeyko Glacier Formation (abbrev. DGF), Ullman Spur Formation (abbrev. USF) and Goetel Glacier Formation (Table 1); KPF, VAF and most DGF are distributed on Keller Peninsula, USF and partial DGF outcrop on Ullman Spur, and Goetel Glacier Formation is exposed in the east of Ullman Spur. Birkenmajer *et al.* (1985) considered that, these rocks were layered volcanics erupted from some independent volcanic centers and overlap each other, and from VAF to USF there exists a eruptive cycle, because their volcanic magmas evolved completely (forming basalts-dacites).

Table 1. Formation subdivision of the Martel Inlet Group volcanic rocks (after Birkenmajer *et al.* 1982)

Group	Formation	Thickness/m
	Goetel Glacier Formation	110 +
	Ullman Spur Formation	320
Martel Inlet Group	Domeyko Glacier Formation	320
	Visca Anchorage Formation(66.7 ±4 Ma) *	140 – 145
	Keller Peninsula Formation	235 – 270
	Unclear basement	

* whole-rock K-Ar age.

Through our field investigations, the authors think that Birkenmajer (1982)'s subdivision of Martel Inlet Group is reasonable on the whole and can be quoted. But the rock association and distributions of these formations, especially their volcanic structures, have to be

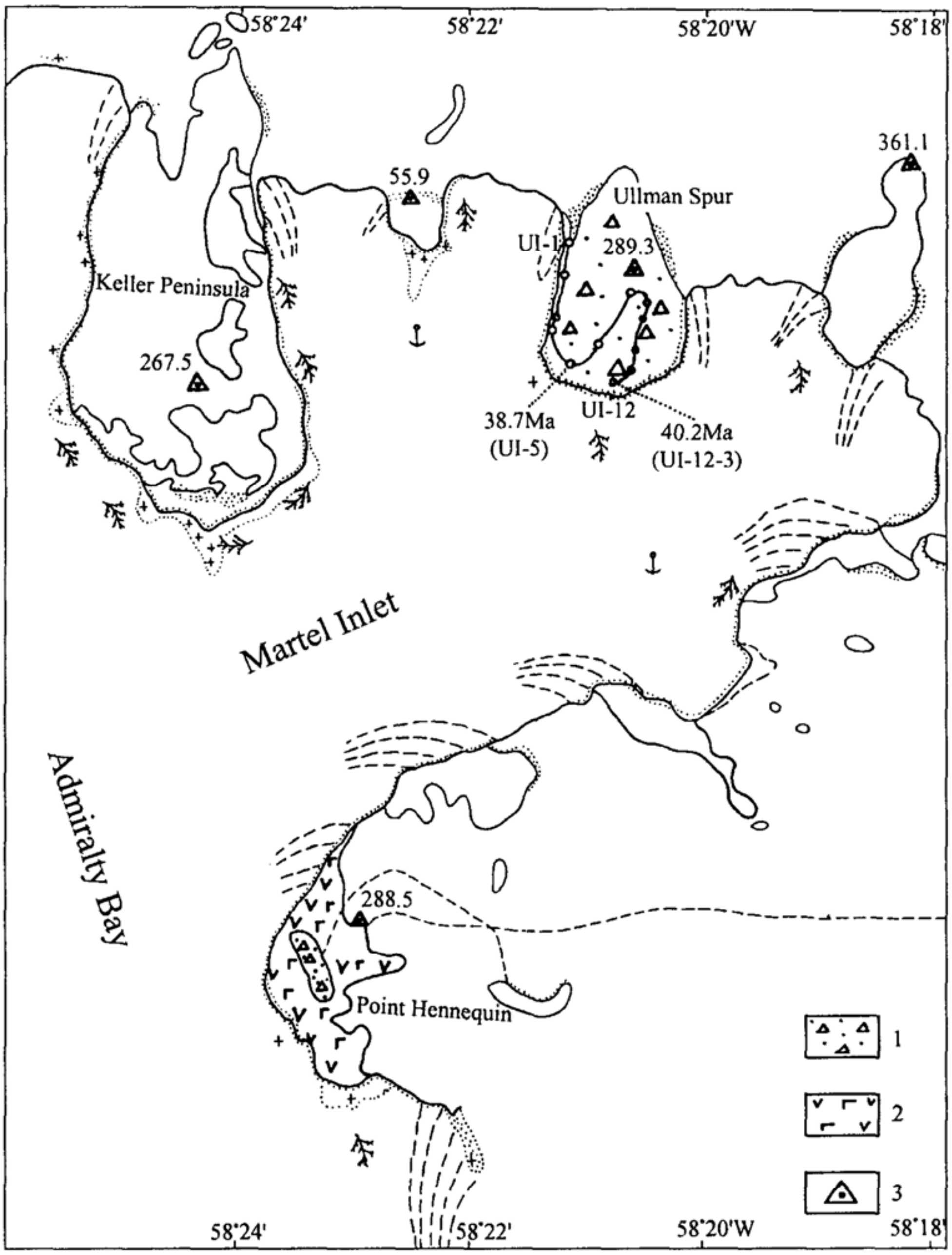

Fig. 2. The survey of Martel Inlet.
1-tuffaceous breccia and tuff; 2-lava; 3-peak (the height unit: m).

examined again. We further subdivide these formations into several members according to their own petrological characters and lithofacies. We describe the new volcanic strata of the Martel Inlet Group as follows:

2.1.1 *Keller Peninsula Formation*

This formation outcrops sinuously along the coastal areas and forms the seashore and hill-foot. It can be subdivided into two lithological members.

The Lower Member: it is exposed about 100 – 250 m wide, with an unclear bottom.

The lower part includes agglomerate-bearing breccia lavas and ignimbrites, and the upper part is thick lavas plus thin purplish-red tuffaceous breccias and tuffs. Their occurrence is "ring syncline". Radial faults are observed in many places, some of them were refilled by later lavas and become radial dykes. It underlies unconformably the Upper Member.

The Upper Member: it consists of dominant pyroclastic rocks (most frequently tuffaceous breccias), which are characteric of strong alteration and mineralization, such as silicification, clayization, especially pyritization. Pyritization zones occur mainly along circular structure-broken zones (ring faults). Several thin layers of lavas are observed within pyroclastic rocks. At the upper part of this Member, there outcrops a thick subvolcanic body with horizontal joints. Birkenmajer (1982) ascribed it to be Andean type pluton series of Wegger Peak Group, but evident layered (horizontal) joints and flow structures all prove it to be a subvolcanic body. At the top of this Member, there is a layer of tuffaceous sandstones and tuffaceous conglomerates being about 1 m in thickness.

2.1.2 Visca Anchorage Formation

This formation rocks are distributed in the central peninsula, with common occurrence of ring syncline. Some radial dykes stretch from underlying KPF into this formation. Three lithologic members are subdivided from lower to upper.

The Lower Member: It is in contact with underlying KPF and overlying Middle Member by eruptive unconformity. The lower part is grey-green to dull-grey, thick lava flow of porphyritic basaltic andesites, two layers of thin tuffaceous breccias are intercalated at its base part. The upper part is grey-dark, thick lava flow of porphyritic basaltic andesites. These lava flows is distributed continuously, and can be regarded as marking layers for field stratigraphic divisions.

The Middle Member: near-crater facies thick agglomerates, agglomerate-bearing tuffaceous breccias, and occasional lenticular lavas. Pyritization and silicification are common with them. At the top occurs a layer of gray-brown porphyritic lava flow. It is in contact with overlying Upper Member by eruptive unconformity.

The Upper Member: it makes up S-N directional Tyrrell Hill, the ridge of the peninsula, and a dacitic dyke is observed at its northern part. The lower part is thick tuffaceous conglomerates and sandstones, containing occasional round mega-gravels and silicified woods. The upper part includes dark-grey tuffs and tuffites, with rhythmic beddings. Combined with surrounding agglomerates of the Middle Member, the tuffites are inferred to be crater-lake facies.

2.1.3 Domeyko Glacier Formation

It is distributed limitedly at the northern end of the peninsula, and outcrops as peaks and cliffs. Its top is unclear, and its bottom contacts underlying formation with eruptive unconformity. To the north it is covered by Domeyko Glacier. Three lithological members are subdivided.

The Lower Member: It contacts underlying VAF rocks and overlying Middle Member with eruptive unconformity. It is thick gray-green basaltic andesitic lava flow, and is characterized by two sets of columnar joints with different occurrences, the upper set is vertical and the lower set is inclined. These columnar joints can be used to distinguish DGF from VAF. At the bottom there is a intercalated layer of 10m-thick gray-purple breccia lava.

The Middle Member: grey-green to grey-purple agglomerate-bearing tuffaceous breccias, and intercalated with a layer of 4 m-thick tuffaceous conglomerate in which gravels are roughly round.

The Upper Member: thick lavas intercalated with tuffaceous breccias. The top is not seen.

2.1.4 Ullman Spur Formation

It is exposed only on Ullman Spur. Birkenmajer (1982) divided Ullman Spur rocks into two stratigraphic units, i.e., upper USF and lower DGF which was deemed to be extended from Keller Peninsula. In the light of field investigations, the authors argue that typical DGF on Keller Peninsula is composed mostly of lavas, very different from the lower unit of Ullman Spur which consists mainly of grey-green pyroclastic rocks as well as only a few thin intercalated layers of lavas. Thus we ascribe all Ullman Spur rocks into USF and subdivide them to following 4 lithologic members from lower to upper.

The First Lithological Member: thick grey-green breccia-bearing tuffs, tuffaceous breccia-bearing sandstones, grey-purple agglomerate-bearing tuffaceous breccias, and thin intercalated lavas. The bottom is not seen. It contacts the overlying Second Lithological Member with eruptive unconformity.

The Second Lithological Member: thin dark-grey trachyandesites, coarse porphyritic trachyandesites, and grey-green intercalated tuffaceous breccias. It contacts the overlying Third Lithological Member with eruptive unconformity.

The Third Lithological Member: greatly thick, grey-green tuffaceous conglomerates and sandstones, generally containing angular or sub-angular gravels with various size, including occasional mega-gravels. It contacts the overlying Fourth Lithological Member with eruptive unconformity.

The Fourth Lithological Member: grey-green tuffaceous breccias, intercalated with thin tuffs. The top is unclear.

Similar to early eruptions on Keller Peninsula, Ullman Spur volcanism took place mainly as explosive eruptions. A possible process is that: evolved magmas were richer in Si, alkalis, i.e., (basaltic) trachyandesitic and dacitic magmas, and enriched volatiles, which induced them to erupt explosively.

The petrologies of volcanic rocks on both Keller Peninsula and Ullman Spur are summaried as follows:

Keller Peninsula rocks dominantly include lavas, pyroclastic rocks and less subvolcanic rocks. They have been weathered and broken intensely and formed large-scale slope wash. In KPF and USF, lavas occur as intercalated beds; but in VAF and DGF, they exist as thick rock flows and can be used for division of strata. On Ullman Spur, pyroclastic rocks are most, and lavas are minor.

The common features of lavas are exposed as thick lava flows, thin intercalated layers, and radial dykes 1 – 2 m wide, with obvious flow structure and high crystallinity, and can be seen in each lithologic member. They often make up cliffs and steep banks. The main rock-forming minerals are plagioclases and pyroxenes. Plagioclases (40%-70%) are major phenocrysts, have been fused partially, and generally underwent weak secondary alterations, such as slight clayization with metasomatism-purified rims, carbonatization and chloritization. Pyroxenes are minor phenocrysts (usually <10%) and are mostly augites, partly with cross sections of regular octagon. Some euhedral diopsides are also present, with cross sections of near-square octagon. In some basaltic andesites hypersthene phenocrysts can be observed, their highest content reaches to about 10%, and in this case they exceed augites. Most pyroxenes are xenomorphic and granular, and generally experienced secondary alterations such as carbonatization, chloritization, epidotization and clayization. In coarse radial dykes, granular pyroxenes can reach to 20%, and along with lath-shaped plagioclases, there exists typical intergranular texture. It is worthy mentioning that some thick flows of basaltic andesites to andesites contain fresh hornblendes. Similarly, in Barton Peninsula and Weaver Peninsula of King George Island, Tertiary high-alumina basalts also contain hornblende phenocrysts (Xing *et al.* 2000), implying high water contents in volcanic magmas. Olivines also occur as phenocrysts occasionally, but have been altered mostly and only retain pseudomorphs. The groundmass minerals include plagioclases, pyroxenes, Ti-Fe oxides, olivines (occasional, altered to be talc and iddingsite), quartz, hornblendes, apatites, vitreous substances and lithic fragments. They compose various textures, including vitropatic pilotaxitic texture, intersertal texture, and cryptocrystalline texture. Hornblendes (the highest content up to 5%) occur in groundmasses of intermediate basic -intermediate acid lavas. Quartz appears occasionally in intermediate lavas and often in intermediate acid lavas with the highest contents of 10% - 15%; large, xenomorphic and granular generally, and also partially biconic idiomorphic. Lithic fragments are mainly seen in dacitic dykes and are basalt fragments. Amygdaloidal structures are usual in lavas, whose cores are usually calcite-zeolites and rims are chlorites. Calcites have radial figures, probably due to their high Ti contents.

The common features of pyroclastic rocks are: outcrop extensively, have typical pyroclastic textures and strong alterations. On Keller Peninsula, pyroclastic rocks are mainly tuffaceous breccias and generally altered. The zonation of alterations is clear: malachitization→chloritization→epidotization→silicification and pyritization→silicification and clayization from lower to upper. The pyritization is strong especially, and forms large-scale red mineralized-layer landforms, which is most obvious in VAF. Gravel-bearing tuffs exist mainly at the ridge of central peninsula, spreading S-N directionally, like long and narrow strip. To the north, near Demeyko Glacier Formation rocks, outcrop dark-grey bedded tuffs (the largest thickness upto 5 m) with sedimentary tuffaceous texture and well beddings (including weak rhythmic beddings), thus they are tuffites. Among them sericitized plagioclase fragments (about 10%) are clear and have high euhedral degree, indicating that they piled up at original place. There are also about 6% quartz crystal fragments and a few basaltic lithic fragments. The mineral associations imply tuffites to be intermediate in composition. Inferred from existence of agglomerates around it, and radial distribution of many faults (dykes) from them (Fig. 4), tuffites belong to crater-lake facies and mark the position of paleovolcano center. Different from Keller Peninsula, on Ullman Spur there outcrop mainly grey-green tuffaceous breccias, gravel-bearing tuffs and a few grey-purple to mottled tuffaceous breccias. These rocks consist of crystal fragments, lithic fragments and tuffaceous materials; have weak alterations, various number of volcanic gravels, consolidated to weakly consolidated textures, and amygdaloidal structure with zeolite-calcite core and epidote rim. Under microscope, tiny crystal fragments are arranged around large lithic fragments, showing typical pyroclastic texture formed by compaction. These rocks have not well sorting and partly have weak rhythmic beddings, thus they piled up basically at original place.

A subvolcanic body is exposed within the Upper Member of KPF. Besides, there also occur several radial dykes and veins on Keller Peninsula. Their lithologies vary from basalt to dacite, for example dacite vein in VAF. The dykes are 1 – 2 m wide and 20 – 30 m long, composed of lavas and protrude above the surface just like low walls. They were also ascribed by Birkenmajer (1982) to be Andean plutonic rock series of Wegger Peak Group.

As for ages of volcanic rocks on both Keller Peninsula and Ullman Spur, Birkenmajer (1982) proposed them to be "Jurassic volcanic rocks", corresponding to those of Antarctic Peninsula. According to K-Ar ages and stratigraphic comparisons, Davies (1982), Pankhurst and Smellie (1983) argued them to be of Tertiary. Birkenmajer *et al.* (1985) determined a whole-rock K-Ar age (66.7 ± 4 Ma) of Keller Peninsula volcanic rocks, but deemed it to be much younger because of Ar losing; in combination with Mesozoic floral fossils found at Cardozo Cove of eastern Admiralty Bay, they still insisted on the Martel Inlet Group to be of late Mesozoic. Hu *et al.* (1996) determined isotopic ages for volcanic rocks from the northern coast of King George Island using whole-rock K-Ar, $^{40}Ar/^{39}Ar$ and laser-mass spectrometers microarea $^{40}Ar/^{39}Ar$ datings. They noticed that all the reliable ages are of Tertiary, and some doubtable K-Ar ages are obviously older due to excess Ar. The authors conduct isotopic datings for Martel Inlet volcanic rocks using whole-rock K-Ar dilution method. All the determined samples are observed under microscope to ensure them fresh enough. Our ages of volcanic rocks from Keller Peninsula and Ullman Spur range from 38.7 ± 1 Ma to 51.7 ± 1 Ma (Table 2), belonging to Tertiary.

2.2 *Poing Hennequin*

Former researchers designated Poing Hennequin rocks as "Point Hennequin Formation (or Group)" outcropping along coastal Krack Icefield of southern Martel Inlet, and regarded almost consistently them to be hypersthene andesites (Birkenmajer 1982; Smellie *et al.* 1984; Birkenmajer *et al.* 1985). During our field investigation on Point Hennequin, we found basaltic andesitic lavas and pyroclastic rocks, and noticed that pyroxenes are not common major minerals. Lavas have porphyritic texture, their groundmasses have cryptocrystalline texture, meaning quick erupting and cooling. Their phenocrysts are mostly plagioclases and are usually fresh, euhedral to hemi-euhedral andesines and labradorites, sometimes accounting for 30% – 50%. Pyroxenes are also fresh enough, their phenocrysts are augites, hypersthenes and bronzites. Pyroclastic rocks are mainly tuffites and tuffaceous siltstones which contain plentiful floral fossils. At the offshore of southwestern Point Hennequin outcrop a dark-grey, vitropatic andesite porphyrite with horizontal joints (sample HI-1). It contacts intrusively with the Lower Member of this group, protrudes strikingly over the ice-snow surface; thus it is a later volcanic neck. The whole-rock K-Ar ages of Point Hennequin volcanic rocks are 32.8 ± 1 Ma to 49.36 ± 1 Ma (Table 2), also of Tertiary.

We still name these rocks as "Point Hennequin Group" and subdivide it into three lithologic members from lower to upper:

Table 2. The whole-rock K-Ar dilution ages of volcanic rocks in Admiralty Bay

Sample	Lithology	K /wt%	^{40}Ar / $\times 10^{-11}$ mol · g^{-1}	$^{40}Ar/^{40}K$ / $\times 10^{-3}$	^{40}Ar / $\times 10^{3}$ Pa	Age/Ma	Group/ Formation /F.	
KI-23	Basaltic andesite porphyrite	0.88	8.0378	3.06	90	51.9 ± 1	Keller Peninsula F.	Martel Inlet Group
KW16-3	Basaltic andesite	0.26	2.3450	3.02	41.6	51.4 ± 2	Keller Peninsula F.	
KI-40	Basaltic andesite	0.33	2.8606	2.90	36.8	49.2 ± 2	Visca Anchorage F.	
KW67-2	Basaltic andesite	0.27	2.3155	2.87	48	48.75 ± 2	Domeyko Glacier F.	
KI-51	High-alumina basalt	0.42	2.9469	2.35	38	40 ± 2	dyke	
KW-27	Basaltic andesite	0.41	3.0475	2.49	21.4	42.35 ± 2	dyke	
UI-5	Basaltic trachyandesite	0.42	3.6917	2.94	38.7	38.7 ± 1	Ullman Spur F.	
UI12-3	Trachyandesite	2.54	17.89	2.36	25.4	40.2 ± 2	Ullman Spur F.	
HI-1	Andesitic porphyrite neck	0.81	2.8822	1.19	67	32.8 ± 1	Point Hennequin Group	
HI-7	Basaltic andesite	1.64	13.83	2.91	5.4	49.36 ± 1	Point Hennequin Group	

K: Keller Peninsula; U: Ullman Spur; H: Point Hennequin.

The Lower Member: thick basaltic andesitic lavas, intercalated with thin purplish-red tuffaceous breccias. In its lower exists an intrusive contact between subvolcanic body (volcanic neck) and surrounding lavas. The bottom is not seen. It contacts the overlying Middle Member with eruptive unconformity.

The Middle Member: tuffaceous breccias with clear beddings. Normal sedimentary rocks are intercalated in the northern Point Hennequin and contain plentiful floral fossils. It contacts the overlying Upper Member with eruptive unconformity.

The Upper Member: several thick layers of lavas.

3 Keller Peninsula caldera

The features of volcanic strata, the variation of both volcanic lithology and lithofacies all are the indicators of the pattern and scale of volcanism. On Keller Peninsula, evidently circular plane pattern of both KPF and VAF, vertical changes of volcanic rocks, typical ring syncline occurrence of strata, and a series of both radial and ring faults, all indicate the existence of a caldera. We draw the volcanic lithofacies-tectonic map of Keller Peninsula (Fig. 5), and describe the main features of its strata and lithofacies below.

The lithofacies sorts of KPF are most explosive air-fall facies tuffaceous breccias, pyroclastic flow facies ignimbrites, explosion-effusion facies breccia lavas, minor effusion facies lavas

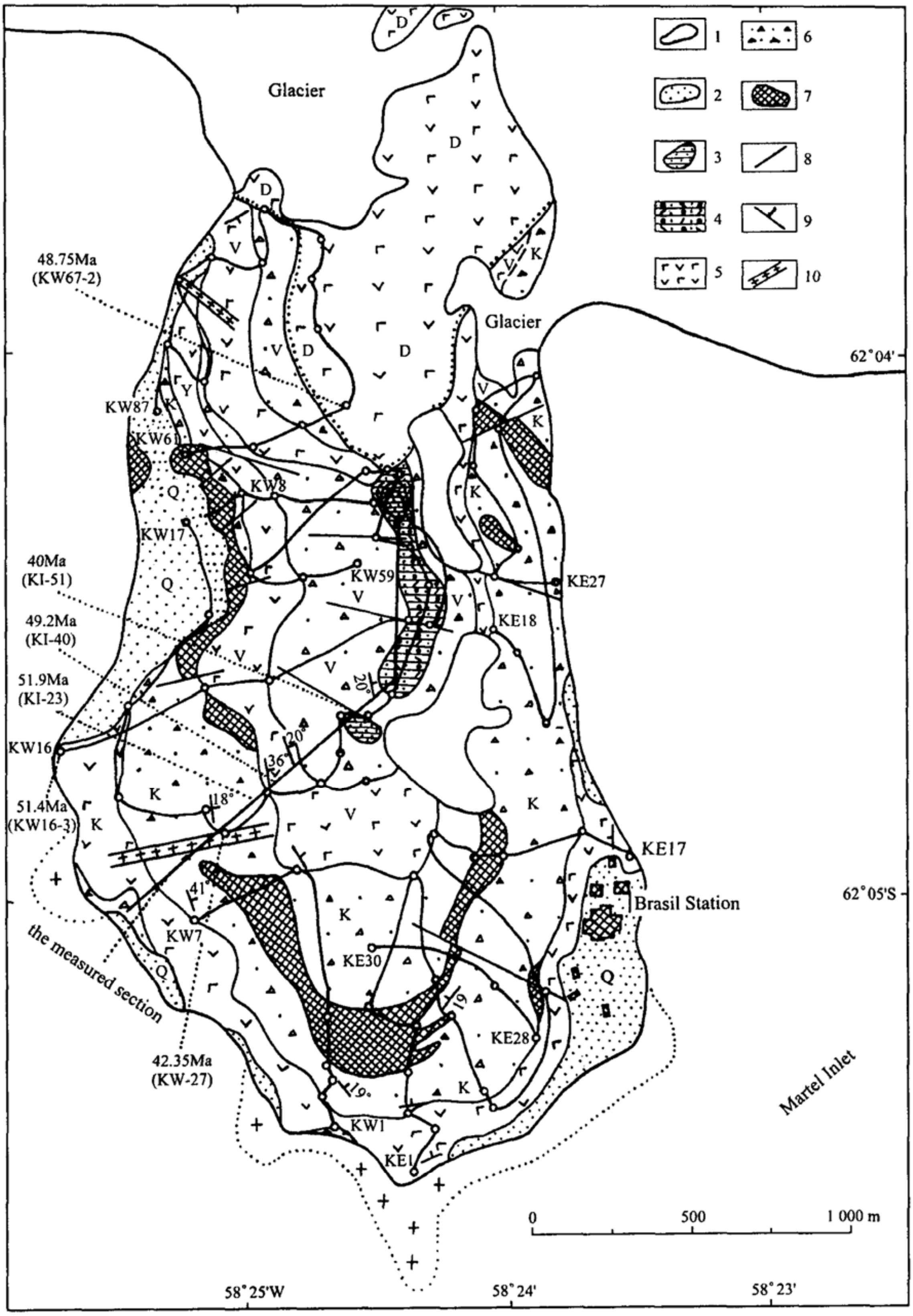

Fig. 3. Series subdivision of volcanic rocks (after Kuno 1960).

and a few air-fall facies tuffs. This fact implies that, early volcanism was explosive eruption mainly and produced the most extensive volcanic rocks which make up the "base" of Keller Peninsula and outcrop circularly at present. The final (uppermost) rocks are volcanic eruption-sedimentary facies tuffaceous sandstones and conglomerates, which suggests a gradual declining and ceasing of volcanism. The course from explosion to ceasing constitutes the first volcanic cycle.

VAF volcanism began as explosion facies pyroclastic rocks and ended as crater-facies sedimentary tuffites, but its main products are thick effusion facies lavas. These volcanic rocks make up the second volcanic cycle. Its eruptive intensity was weaker than the first one, and the area of its products reduce though they also outcrop circularly. In general, volcanic products are exposed around the crater and are circular or fan-shaped in plane. The KPF rocks spread all over the peninsula, so their eruptive crater should be in the central place of the peninsula (unobserved because of covering of VAF rocks). But the location of VAF crater-lake facies tuffites deviated towards N and was close to the southern margin of DGF, indicating a northward migration of volcanic center.

The collapse of magmatic chamber and the formation of caldera happened immediately after the second volcanic cycle. The proofs are as follows: only both KPF and VAF volcanic strata are exposed circularly; their occurrences are ring synclines; and radial faults spread through the two formations but not into DGF. From Fig. 3 it can be seen that, mineralization zones along ring faults are often cut by radial faults, suggesting the ring faults formed earlier. This phenomenon is often the case with calderas.

In the Upper Member volcanic eruption-sedimentary facies tuffaceous conglomerates and sandstones of VAF, contain well round mega-gravels and silicified woods. This kind of round gravels is not probably glacial erratic boulders, because Antarctica had not become isolated ice-snow world until middle Tertiary (about 25 Ma). During middle Tertiary, Antarctica and South America were separated, then oceanic circulation around Antarctica emerged and resulted in rapid worsening of Antarctic climate (Dalziel 1982; Craddock 1983). As a result, when early Tertiary volcanism happened on Keller Peninsula, large-scale glaciers did not appear in Antarctic continent. The existence of round mega-gravels and silicified woods reflect a rather long ceasing of volcanism.

DGF strata are sharply different from the underlying strata. Instead of ring synclines, radial and ring faults, they are characterized by universal columnar joints. They are mainly thick effusion-facies lavas, intercalated with pyroclastic facies, which is possibly related to losing of enormous volatiles from magmatic chamber after early violent explosion and crater collapse. Besides, DGF rocks outcrop limitedly only at the northern end of the peninsula (probably most of DGF rocks are covered by Domeyko Glacier). DGF rocks are obviously volcanic products of revived caldera (the third volcanic cycle), at that time the volcanic center had migrated further towards north. Our paleomagnetic determinations also testify this deduction: the polarity epoch is reversed for both KPF and VAF rocks, but is normal for DGF rocks, indicating two different volcanic activities. Based on above facts, a volcanic cycle from VAF to USF proposed by Birkenmajer *et al.* (1985) is not real.

In a word, Keller Peninsula is a revived caldera and includes three northerly migrated volcanic centers. Its volcanic strata have evident upper or lower (early or late) stratigraphic relations, without overlappings each other advanced by Birkenmajer *et al.* (1985).

4 Petrochemistry

Table 3 presents chemical compositions of volcanic rocks in the Admiralty Bay. It should be noted that only lavas, a few fresh ignimbrites and tuffs are analysed. Pyroclastic rocks are not considered for chemical analyses, because they contain external lithic and brecciated materials and underwent strong weathering and alteration.

Table 3. Chemical compositions of volcanic rocks in Admiralty Bay(wt%)

	Sample	Lithology	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^+	CO_2	SO_3	F	Cl	%	Mg#
	KI-9	High - alumina basalt	48.78	1.04	17.52	3.32	5.83	0.20	4.62	8.54	2.80	0.18	0.38	3.46	2.44	0.012	0.024	0.0020	99.15	5.09
	KI-14	High - alumina basalt	47.76	1.02	17.69	3.17	6.11	0.15	3.92	8.63	2.23	0.30	0.38	4.02	3.59	0.083	0.031	0.011	99.10	44.3
Keller Peninsula Formation	KI-19	Basaltic trachyandesite	52.20	0.63	18.24	3.60	3.44	0.18	4.23	4.63	6.37	0.16	0.23	4.01	1.92	0.012	0.026	99.88	55.6	
	KI-23	Basaltic andesite porphyrite	53.88	0.69	18.36	3.14	4.55	0.18	4.58	8.20	3.36	0.90	0.24	0.97	0.23	0.094	0.017	0.0088	99.41	55.2
	KI-28	High - alumina basalt	45.08	0.88	18.34	3.91	5.53	0.15	4.34	10.41	2.47	0.15	0.30	3.20	4.17	0.013	0.027	0.017	98.99	48.7
	KRI-5	Andesitic ignimbrite	57.99	0.95	16.88	3.13	3.72	0.16	2.42	5.80	4.21	1.60	1.30	1.43	0.43	0.013	0.049	0.032	100.03	42.3
	KI-38	Basaltic andesite	53.24	0.82	18.23	3.44	4.64	0.15	4.33	6.92	3.48	0.35	0.25	2.61	0.85	0.012	0.031	0.0036	99.36	52.6
	KI-40	Basaltic andesite	54.44	0.81	17.77	2.93	4.71	0.15	4.34	7.99	3.23	1.01	0.26	1.95	0.30	0.007	0.027	0.011	99.94	53.9
	KI-45	Basaltic andesite	51.19	0.66	19.05	2.70	3.49	0.28	2.47	8.15	2.94	0.48	0.22	3.82	3.90	0.007	0.010	0.0064	99.37	45.2
	KI-50	High - alumina basalte dyke	51.43	0.60	18.27	4.29	3.87	0.17	6.00	8.31	3.19	0.35	0.14	2.28	0.38	0.079	0.030	0.0096	99.40	60.6
Visca Anchorage Formation	KI-54	Quartz andesitic tuff	60.04	0.82	17.02	2.66	5.67	0.07	3.40	1.36	2.26	0.15	0.26	5.36	0.43	0.020	0.030	0.0064	99.56	45.5
	KW-11	Basaltic andesite	53.66	0.77	18.16	3.71	4.65	0.18	5.09	6.35	3.82	0.49	0.24	2.54	0.38	0.020	0.030	0.023	99.11	55.8
	KW-13	Quartz andesitic tuff	59.88	0.79	16.72	3.36	3.49	0.11	1.73	3.24	3.56	0.93	0.23	3.49	1.78	0.020	0.041	0.0060	99.38	34.5
	KW-71	Dacite dyke	67.42	0.28	14.79	0.70	2.09	0.10	0.91	3.50	3.33	2.35	0.11	1.84	2.24	0.020	0.030	0.002	99.71	39.9
	KE-5	Andesite	58.42	1.08	16.99	3.08	4.70	0.20	2.42	5.04	4.12	0.26	0.54	2.27	0.48	0.20	0.090	0.023	99.52	39.1
Domeyko Glacier Formation	KW-53	Basaltic trachyandesite	50.18	0.72	17.58	3.03	4.78	0.16	4.88	5.63	4.62	0.50	0.24	4.21	3.28	0.13	0.039	0.011	99.88	56.3
	KW-67	Basaltic andesite	50.42	0.53	18.61	2.92	4.05	0.14	4.11	7.65	3.54	0.25	0.16	2.69	2.45	0.13	0.013		99.55	54.9
	UI-1	Dacitic tuff	62.79	0.77	14.97	0.87	3.90	0.12	1.38	4.15	4.51	1.56	0.26	2.78	2.56	0.007	0.054	0.012	100.69	36.9
	UI-5 *	Basaltic andesite	52.02	0.93	18.27	2.62	4.03	0.07	2.50	7.64	3.50	0.78	0.43		6.41		0.041	0.080	99.32	43.7
Ulman Spur Formation	UI-9	Basaltic trachyandesite	55.44	0.86	17.19	2.88	4.32	0.13	4.28	6.52	3.80	2.08	0.22	2.03	0.34	0.020	0.023	0.0012	100.03	55.1
	UI-19	Basaltic trachyandesitic tuff	52.83	0.76	17.52	1.14	5.93	0.16	2.52	5.88	5.11	0.62	0.32	4.62	1.70	0.007	0.039	0.0040	99.26	41.8
	UIR-12	Trachyandesite	57.97	0.77	16.74	2.47	3.63	0.14	2.34	5.72	3.94	2.34	0.96	1.78	1.71	0.026	0.047	0.032	98.83	44.2
	HI-1	Andesite porphyrite dyke	58.50	0.76	16.33	2.23	3.97	0.13	2.64	6.64	3.10	1.12	0.28	4.45	0.04	0.026	0.031	0.012	100.24	41.5
Point Spur Formation	HI-2	Basaltic andesite	56.61	0.82	17.41	3.61	3.56	0.22	3.30	6.30	3.62	2.06	0.30	1.22	0.22	0.026	0.042		99.32	49.0
	HI-7	Basaltic andesite	56.00	0.75	17.66	3.39	4.12	0.13	3.45	7.02	3.46	1.74	0.24	1.29	0.14	0.026	0.051	0.0068	99.47	48.8
	HI-13	Andesite	59.41	0.78	16.64	3.18	3.63	0.14	2.62	5.42	3.82	2.24	0.28	1.07	0.26	0.13	0.048	0.013	99.56	44.4

In TAS diagram (Fig. 4), KPF rocks are high-alumina basaltic mainly, and only a few basaltic andesitic (basaltic trachyandesitic) in composition, which may be related to sufficient volatiles of volcanic magmas, rapid large-scale explosions and limited chemical evolution during the first volcanic cycle. Their SiO_2 and total alkali contents increase synchronously and show well positive correlation, which reflects these volcanic rocks belong to comagmatic products. VAF has wider lithologic range from basalt to dacite, in which most are basaltic andesites and andesites. It indicates that during the second volcanic cycle, magmas underwent higher degree of evolution although their eruptive intensities decreased. On the other hand, different from evolutional trend of KPF, total alkali contents of VAF rocks vary only slightly with increasing SiO_2. For instance, VAF andesites contain lower total alkalis than KPF andesites, indicating that they are not products of the same phase of magmatic evolution. DGF is mainly basaltic andesites and andesites, and have higher total alkalis overall to form basaltic trachyandesites, although they erupted later. In view of this fact, three formations of Keller Peninsula do not show corresponding rock association and chemical change from the same magmatic chamber. Considering Tertiary volcanic rocks on King George Island are cognate (Smellie *et al.* 1984; Birkenmajer *et al.* 1985; Xing *et al.* 1997), the three periods of magmas are inferred to come from three independent but comagmatic chambers, respectively.

Fig. 4 contrasts volcanic rocks from Keller Peninsula, Ullman Spur and Point Hennequin. Among them, Ullman Spur rocks are plotted in basaltic andesite, andesite and dacite areas, have more SiO_2 and more alkalis than Keller Peninsula rocks on the whole. So it is rational that Birkenmajer *et al.* (1985) regarded them to derive from later evolved magmas of Keller Peninsula. Volcanic rocks from Point Hennequin have a narrow chemical range (basaltic andesitic to andesitic in composition), and its latest volcanic neck (sample HI-1, 32.8 Ma) is only intermediate in composition. So Point Hennequin rocks were not probably formed by evolution of volcanic magmas of both Keller Peninsula and Ullman Spur. Based on geochemical studies, Birkenmajer *et al.* (1985) also advanced no direct evolved relation between rocks from Point Hennequin and adjacent areas. As a result, Point Hennequin is inferred to has a volcanic center alone.

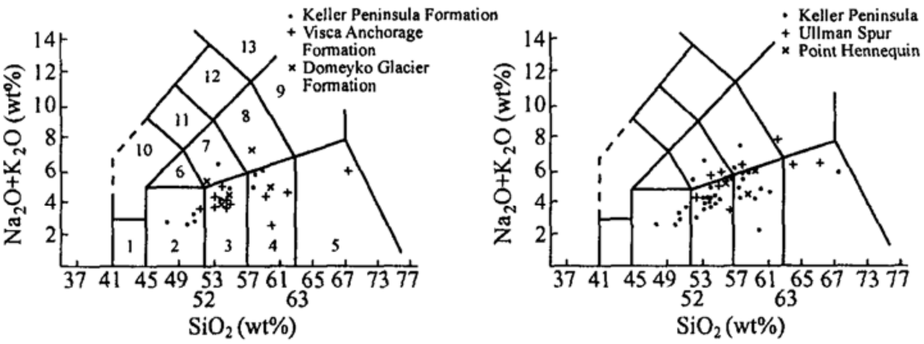

Fig. 4. TAS diagram of volcanic rocks.
(after Le Bas *et al.* 1986; data from this paper and Birkenmajer *et al.* 1985)
1-basalt 2-basaltic andesite 3-andesite 4-dacite 5-trachybasalt
6-basaltic trachyandesite 7-trachyandesite 8-trachyte and trachyandesite

In silica vs. total alkali diagram for classifying rock series (Fig. 5), most volcanic rocks from KPF, UAF and Point Hennequin Group are plotted in high-alumina series (calc-alkaline) area; in FAM diagram, they are also projected within calc-alkaline series area. It is consistent with their tectonic setting of continent margin arc, displaying that their origin was related directly to subduction.

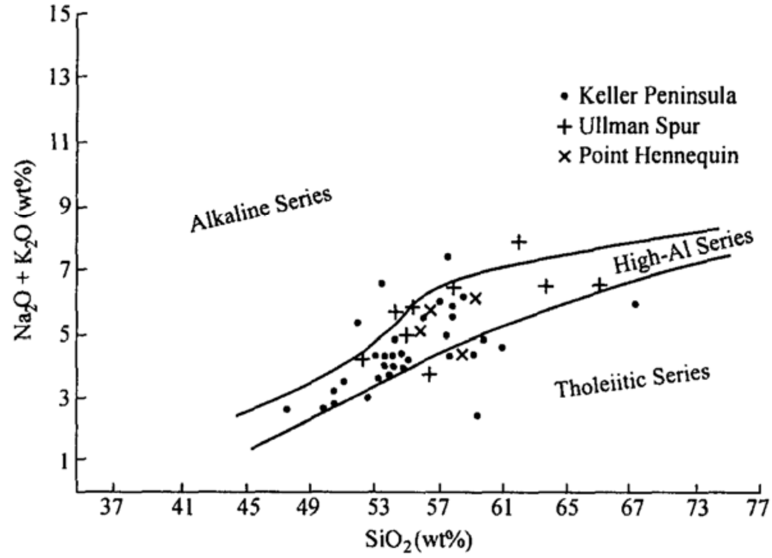

Fig. 5. The volcanic lithofacies-structure map of Keller Peninsula.

Generally speaking, there are relatively well negative correlation between MgO、CaO and SiO_2, overall positive correlation between K_2O、Na_2O and SiO_2 for the studied volcanic rocks, indicating that fractional crystallization plays a leading role during magmatic evolution. FeO and SiO_2 have not good correlation, even have negative correlation largely. Increasing SiO_2, Fe_2O_3 contents also increase at first, and reduce later, which is the evolution characteristic of calc-alkaline series magmas.

It is worthy noting that, Barton (1965) and Birkenmajer (1989) mentioned rhyolites in Martel Inlet Group, which have not been confirmed by any chemical or geological data yet.

5 Conclusion

1. The ages of volcanic rocks in Admiralty Bay of King George Island are of Tertiary (32.8 ± 1 Ma to 51.9 ± 1 Ma).
2. Keller Peninsula volcanism can be subdivided into three volcanic cycles (51.9-51.4 Ma, 49.2 Ma, 48.75 Ma), they correspond to three northward migrations of volcanic centers, respectively. Ullman Spur rocks were erupted at the late stage of northward migrations.
3. On Keller Peninsula existed a typical revived caldera. It was formed after the second volcanic cycle. Next revival is the third volcanic cycle.
4. On Point Hennequin occurred another independent volcanic center.

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