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Volcaniclastic Sedimentation of the Sejong Formation (Late Paleocene-Eocene), Barton Peninsula, King George Island, Antarctica

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Abstract : The Sejong Formation of Late Paleocene to Eocene is a lower volcaniclastic sequence unconformably overlain by upper volcanic sequence, and distributed along the southern and southeastern cliffs of the Barton Peninsula. The Sejong Formation is divided into five sedimentary facies; disorganized matrix-supported conglomerate (Facies A), disorganized clast-supported conglomerate (Facies B), stratified clast-supported conglomerate (Facies C), thin-bedded sandstone (Facies D), and lapilli tuff (Facies E), based on sedimentary textures, primary sedimentary structures and bed geometries. Individual sedimentary facies is characterized by distinct sedimentary process such as gravel-bearing mudflows or muddy debris flows (Facies A), cohesionless debris flows (Facies B), unconfined or poorly confined hyperconcentrated flood flows and sheet floods (Facies C), subordinate streamflows (Facies D), and pyroclastic flows (Facies E).

Deposition of the Sejong Formation was closely related to volcanic activity which occurred around the sedimentary basin. Four different phases of sediment filling were identified from constituting sedimentary facies. Thick conglomerate and sandstone were deposited during inter-eruptive phases (stages 1, 3 and 4), whereas lapilli tuff was formed by pyroclastic flows during active volcanism (stage 2). These records indicate that active volcanism occurred around the Barton Peninsula during Late Paleocene to Eocene.

Key words : Sejong formation, sedimentary facies, depositional history, volcanism.

1. Introduction

Volcaniclastic rocks distributed in the lower part of the Barton Peninsula have been considered as the Lower Volcanic Member by Davis (1982), and there have been no sedimentological researches until now. Based on austral summer survey conducted during December 1999 to February 2000, we identified sedimentary rocks in the Barton Peninsula and define them herein as the Sejong Formation (Fig. 1).

Sedimentary sequences associated with active volcanoes are often considered as consisting of two elements, syn-eruptive and inter-eruptive sequences (Smith 1991). Syn-eruptive sequence results from primary volcanic processes and immediate post-eruptive reworking, whereas inter-eruptive sequence record deposition without significant influence of volcanic activities when normal sediment delivery processes are dominant. The transitional relationship between syn- and inter-eruptive sequences can be various due to the complex interplay of tectonic subsidence and aggradation rates of pyroclasts and epiclasts (Smith 1991;

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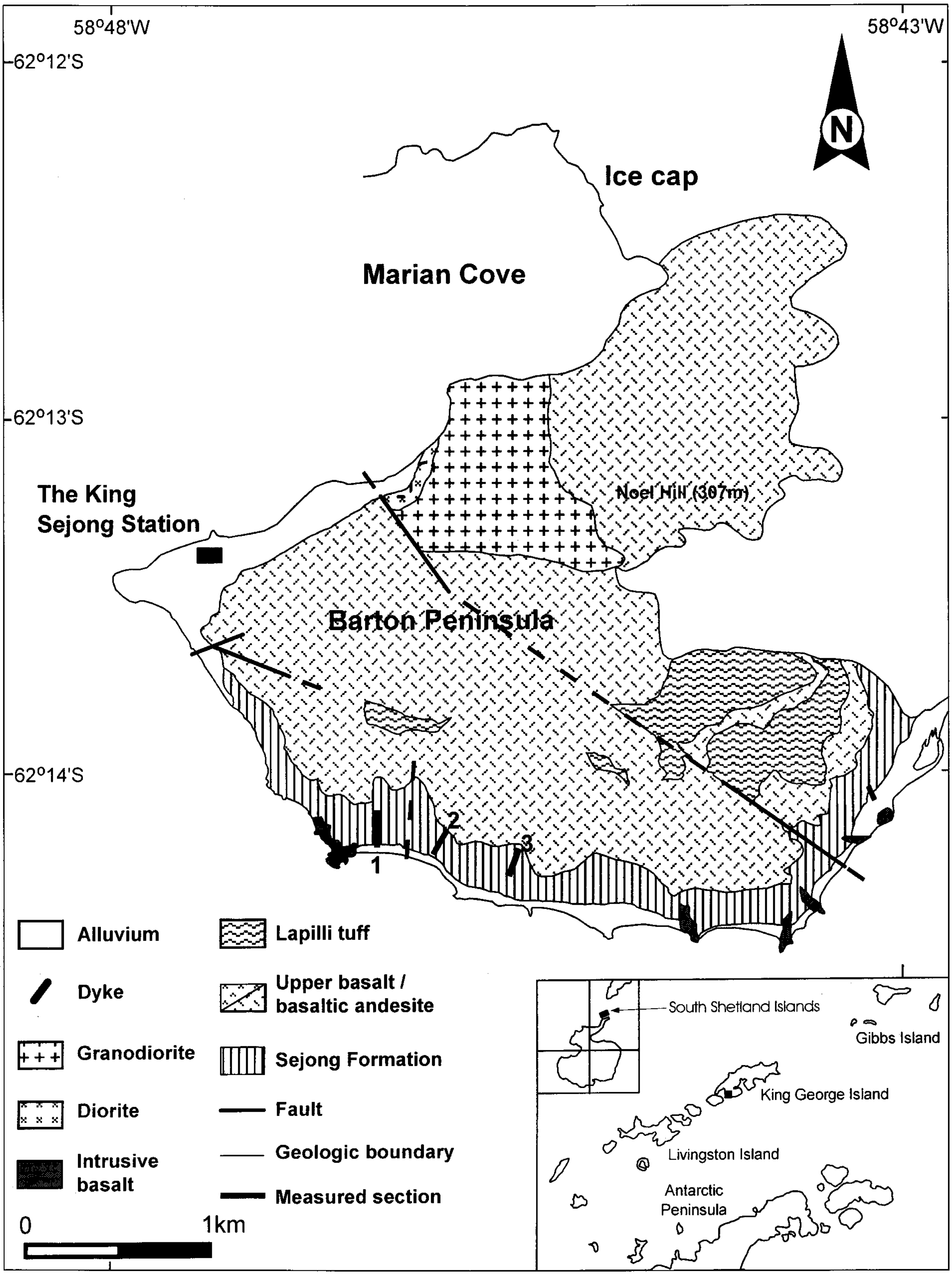

Fig. 1. Geologic map of the Barton Peninsula. Numbers represent measured sections.

Haughton 1993).

The Sejong Formation (Late Paleocene to Eocene) consists of conglomerate and sandstone intercalated with basaltic and andesitic lapilli tuff that represents extensive volcanic activities during evolution of the Barton sedimentary basin. The aims of this study are to describe sedimantary facies of syn- and inter-eruptive deposits and their vertical and lateral relationships and to reconstruct depositional history of the Sejong Formation related to volcanic activities.

2. General geology

King George Island, South Shetland Islands, is a volcanic island associated with subduction of oceanic plate during the late Mesozoic to early Cenozoic (Smelli *et al.* 1984; Park 1989). The Barton Peninsula, located in the southwestern part of King George Island, consists of lower volcaniclastic sedimentary rocks (Sejong Formation) and upper calc-alkaline volcanic and igneous rocks (Fig. 1). The Sejong Formation, formerly regarded as volcanic rocks (Lower Volcanic Member; Davies 1982), is composed of various conglomerate and sandstone beds intercalated with lapilli tuff. These rocks are distributed along the southern and southeastern cliff of the Barton Peninsula with an approximate thickness of 100 m. The Antarcto-Tertiary Geoflora assemblages preserved in some sandstone beds indicate that the Sejong Formation was deposited during Late Paleocene to Eocene (Chun *et al.* 1994).

3. Sedimentary facies

Based on the composition of constituent particles, sedimentary structures and bed geometries, the Sejong Formation is divided into five sedimentary facies including (1) Facies A; disroganized matrix-supported conglomerate, (2) Facies B; disorganized clast-supported conglomerate, (3) Facies C; stratified clast-supported conglomerate, (4) Facies D; thin-bedded sandstone, and (5) Facies E; lapilli tuff.

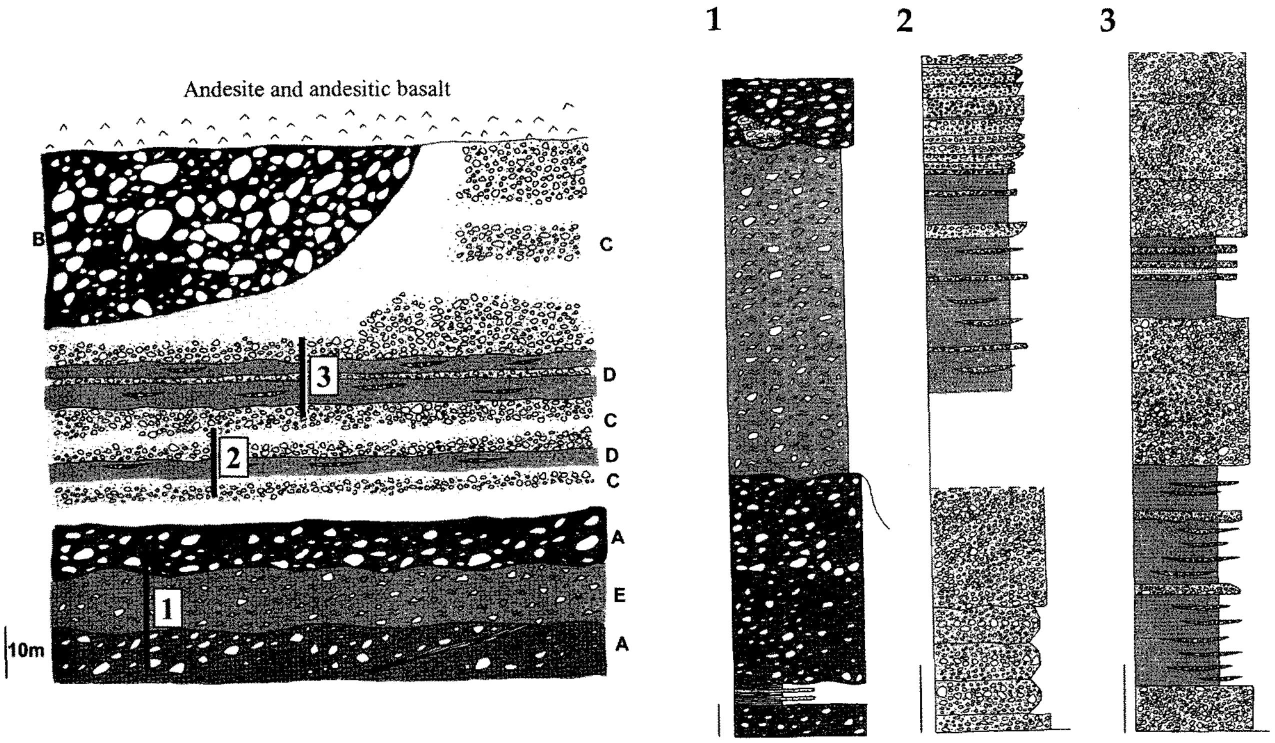

Fig. 2. Schematic diagram of lateral and vertical distribution of sedimentary facies. Numbers indicate measured sections shown in Fig. 1. Capital letters represent each facies.

Facies A: Disorganized, matrix-supported conglomerate

This facies comprises thick-to very thick-bedded, granule-to-boulder conglomerate. Clasts are either supported by sand and mud matrix or in loose contacts. It occurs in the lower part of the Sejong Formation intercalated with lapilli tuff (Facies E) (Fig. 2). Boundaries with lapilli tuff are erosional (Fig. 3A). Units in the lowermost part of the Sejong Formation gently dip to the west (10°W), truncated by the overlying lapilli tuff (Fig. 2). Thin sandstone-siltstone couplet (60 cm thick) is interbedded with sharp lower and upper boundaries in the lower part of Section 1 (Fig. 2). Bed boundaries are commonly planar, but some units have scoured bases with a relief more than 30 cm (Fig. 3B). In this case, large andesitic clasts (up to 30 cm in diameter) are concentrated along the lower contact. Large extraordinary blocks comprising alternation of green and purple conglomerate units (olistostrome?) are present at the lower contact with lapilli tuff.

Clasts display bimodal distribution patterns, and larger ones are occasionally aligned parallel to bedding planes. They are subangular to rounded. These clasts largely consist of andesitic or basaltic andesitic volcanic lithic fragments with subordinate pumice and tachylitic shard fragments. The matrix comprises moderately sorted, fine- to medium-grained sand and mud which have similar composition with the clasts.

The matrix-supported texture and dominance of mud matrix are suggestive of gravel-bearing mud flows or muddy debris flows. Small amounts of mud matrix in debris flows can cause a cohesive nature in sediments and result in disorganized, matrix-supported conglomerate (Nemec and Steel 1984; Shultz 1984).

Facies B: Disorganized, clast-supported conglomerate

Facies B comprises disorganized, poorly sorted, clast-supported conglomerates. It occurs in the uppermost part of the Sejong Formation (Fig. 2). This facies is encased in stratified, clast-supported conglomerate (Facies C) and unconformably overlain by greenish or dark gray andesite and andesitic basalt (Fig. 2). Although the lower and lateral contacts with Facies C conglomerate are not exposed, it represents channel fills with a maximum thickness of 30 m (Fig. 2).

The clasts are mainly composed of volcanic lithic fragments including dark gray plagioclase-phyric basaltic andesite, greenish gray porphyritic andesite and amygdaloidal pumice with subordinate purple siltstone fragments. Pebble- to cobble-sized clasts are dominant with subordinate boulder-sized ones (Fig. 4). They are commonly subrounded to rounded and occasionally imbricated. Some andesitic clasts show alteration features along the clast margin and internal fractures. Sand-sized grains mostly consist of volcanic lithic fragments filling the interstices between large clasts.

Facies B is interpreted as cohesionless debris flows dominated by frictional grain interactions (Lowe 1982; Kim *et al.* 1995; Sohn 1997). The lack of inverse grading and imbrication of clasts are probably due to suppres-

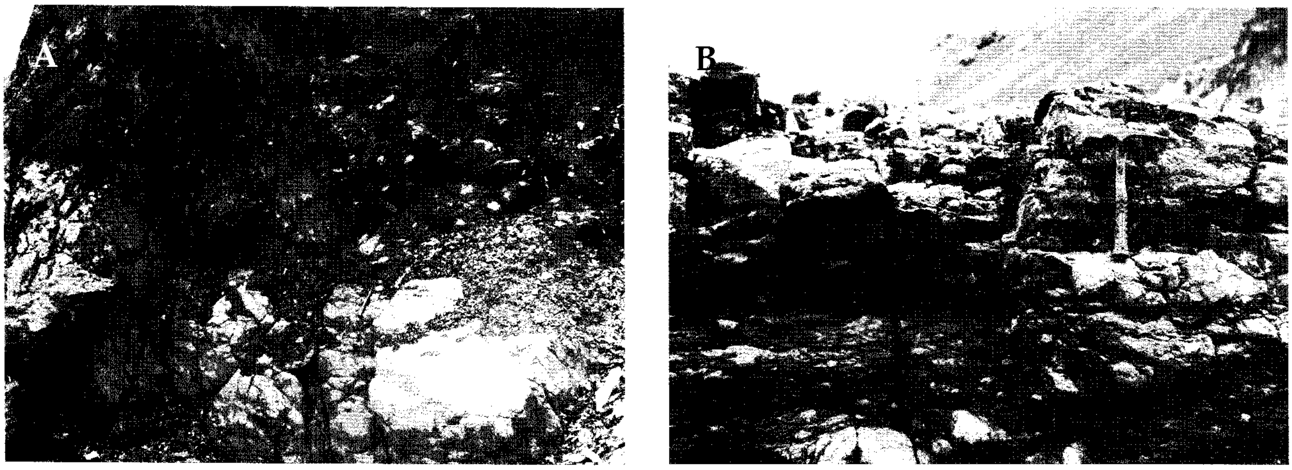

Fig. 3. Outcrop photographs of disorganized, matrix-supported conglomerate (Facies A). (A) Purple conglomerate overlies greenish lapilli tuff with erosional contact. (B) Some conglomerate beds have scoured bases with a relief more than 30 cm, and large andesitic clasts (up to 30 cm in diameter) concentrated on the base.

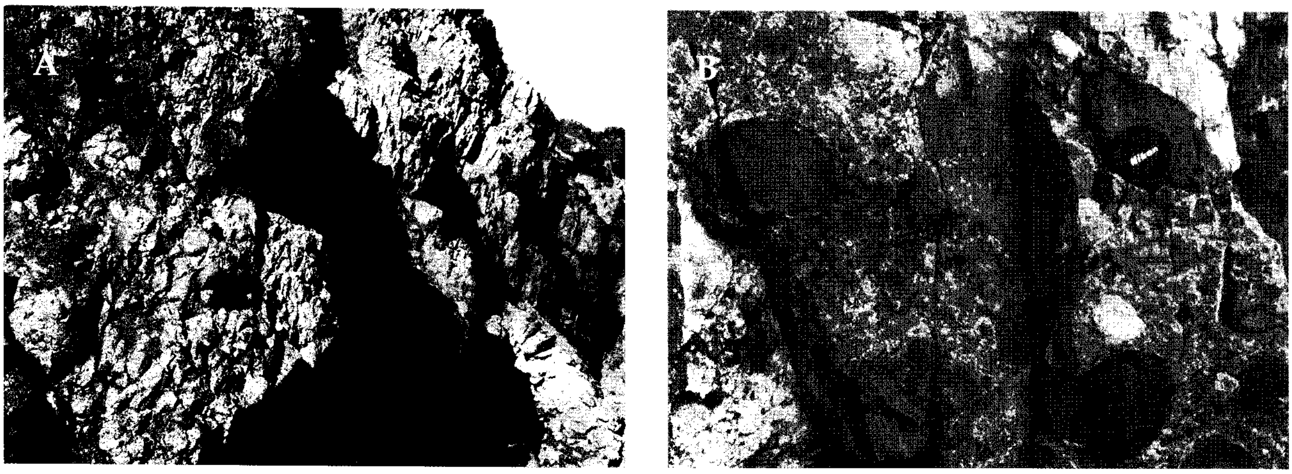

Fig. 4. Outcrop photographs of disorganized, clast-supported conglomerate (Facies B). (A) The conglomerate is disorganized, poorly sorted and clast-supported. (B) Clasts are commonly subrounded to rounded.

sion of clast collision (Sohn *et al.* 1999).

Facies C: Stratified, clast-supported conglomerate

This facies consists of thin- to very thick-bedded (up to 2.2 m thick), clast-supported, granule-to-cobble conglomerate (Figs. 5A, B). It occurs in the middle and upper parts of the Sejong Formation intercalated with thin-bedded sandstones (Facies D) (Fig. 2). This facies occurs as either amalgamated units up to a few meters thick or isolated units within thin-bedded sandstones. The isolated units commonly show lenticular geometry with concave-up base and flat top (Fig. 5C). Individual bed in amalgamated units displays a sheet-like geometry with planar or slightly undulatory boundaries.

This facies shows various internal structures, such as massive, normal grading, inverse grading and inverse-to-normal grading. Conglomerate beds thicker than 50 cm usually occur as massive units, whereas inverse grading and inverse-to-normal grading are common in units thinner than 50 cm (Fig. 5D). Isolated beds in sandstone commonly show normal grading. Clast size and shape are also closely related to bed thickness. Clasts in thick beds are pebble- to cobble-sized, and subangular to subrounded. On the other hand, granule- to pebble-sized, rounded to subrounded clasts are dominant in thin conglomerate beds. The clasts largely consist of volcanic lithic fragments with subordinate sideromelane and tachylite shards as well as siltstone fragments. Some clasts are extensively replaced by calcite and chlorite. Their matrix is mostly mud with subordinate fine-grained sand.

The sheet-like bed geometry, well stratified nature and various internal structures of Facies C suggest deposition from unconfined or poorly confined hyperconcentrated flood flows and sheet floods (Hogg 1982; Smith 1986; Maizels 1993). Sheet floods transport sediments both in suspension and as bedload, and resulting sheets and lobes are commonly dominated by stratified sediments with small scours (Hooke 1967). These sediments are relatively continuous laterally with some varieties in thickness. Hyperconcentrated flood flow deposits are distinguishable from debris flow deposits by the lack of matrix support or reverse grading, and exhibit distribution of normal grading and horizontal stratification (Smith 1986). The hyperconcentrated flood flow deposits are frequently produced by dilution of debris flows in stream channels (Smith 1988).

Facies D: Thin-bedded sandstone

This facies comprises well- to crudely-stratified sandstone and pebbly sandstone (Fig. 6A). It commonly occurs in the middle part of the Sejong Formation (Fig. 2). Boundaries between the upper and lower stratified conglomerate units (Facies C) are sharp and slightly erosional (Fig. 6B).

Sandstone units are usually thin, less than 20 cm thick. Stratification is delineated by differences in grain size and rock color. Fine-grained sandstone units commonly display purple color, whereas medium- to coarse-grained sandstone and pebbly sandstone units show green to greenish gray color. Stratification is mostly plane-parallel with flat to undulatory bedding sur-

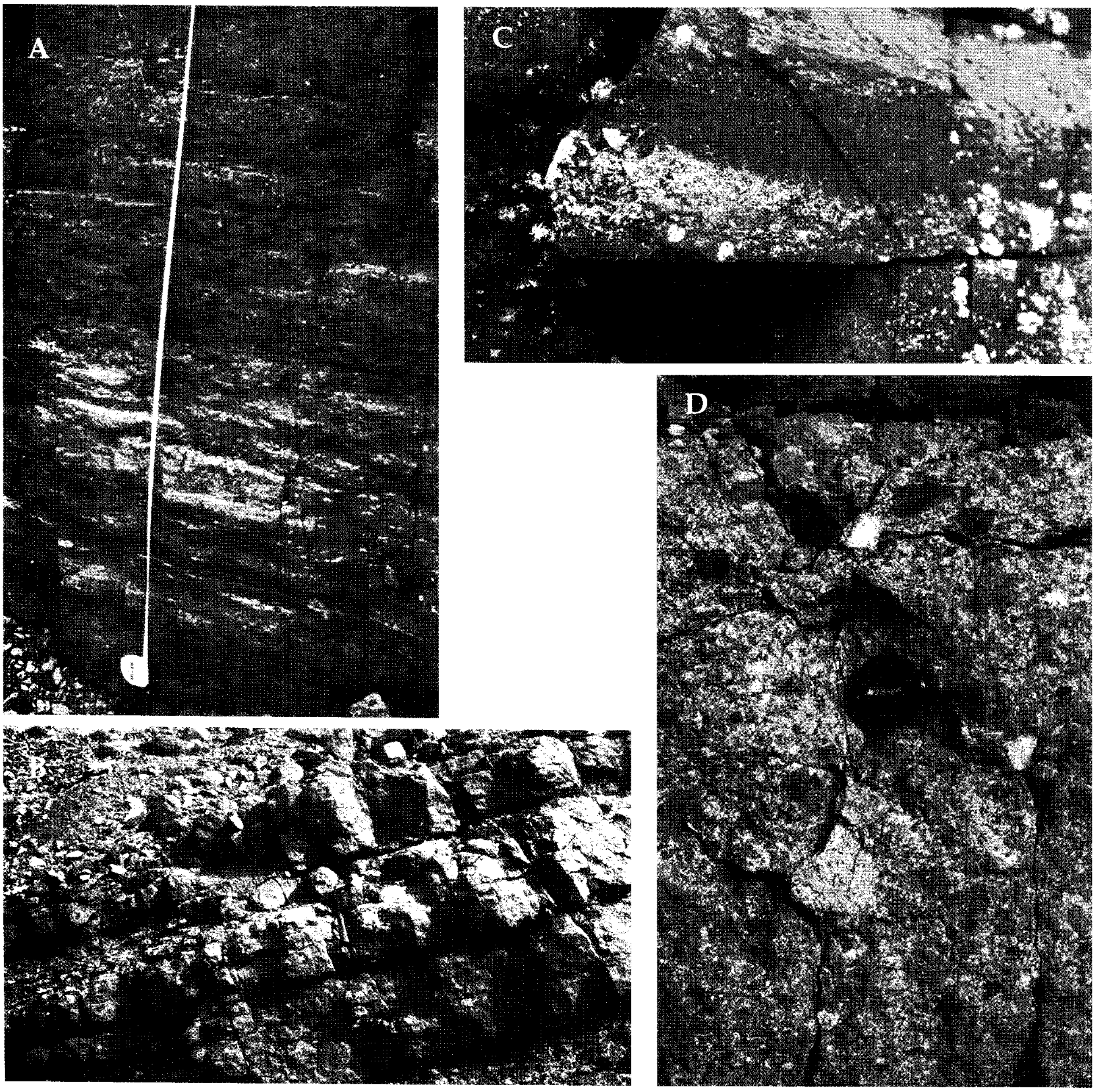

Fig. 5. Outcrop photographs of stratified, clast-supported conglomerate (Facies C). (A), (B) Thin- to medium-bedded, clast-supported granule-to-pebble conglomerates display sheet-like geometry with planar or slightly undulatory boundaries. (C) Solitary conglomerate unit in sandstone has lenticular geometry with concave-up base and flat top. (D) Conglomerate bed shows inverse-to-normal grading.

faces (Fig. 6C). Massive units are common, but some units display normal grading. Fossil leaves in fine-grained sandstones are suggestive of Late Paleocene to Eocene (Chun *et al.* 1994). Some of them are preserved vertical to bedding plane.

Sand grains are mostly volcanic lithic fragments with subordinate plagioclase and quartz crystals. They are subrounded to well rounded and well sorted. Volcanic lithic fragments and plagioclase crystals are commonly replaced by zeolite and chlorite. Some authigenic epidotes replaced sand grains and matrix.

Overall characteristics indicate that Facies D is

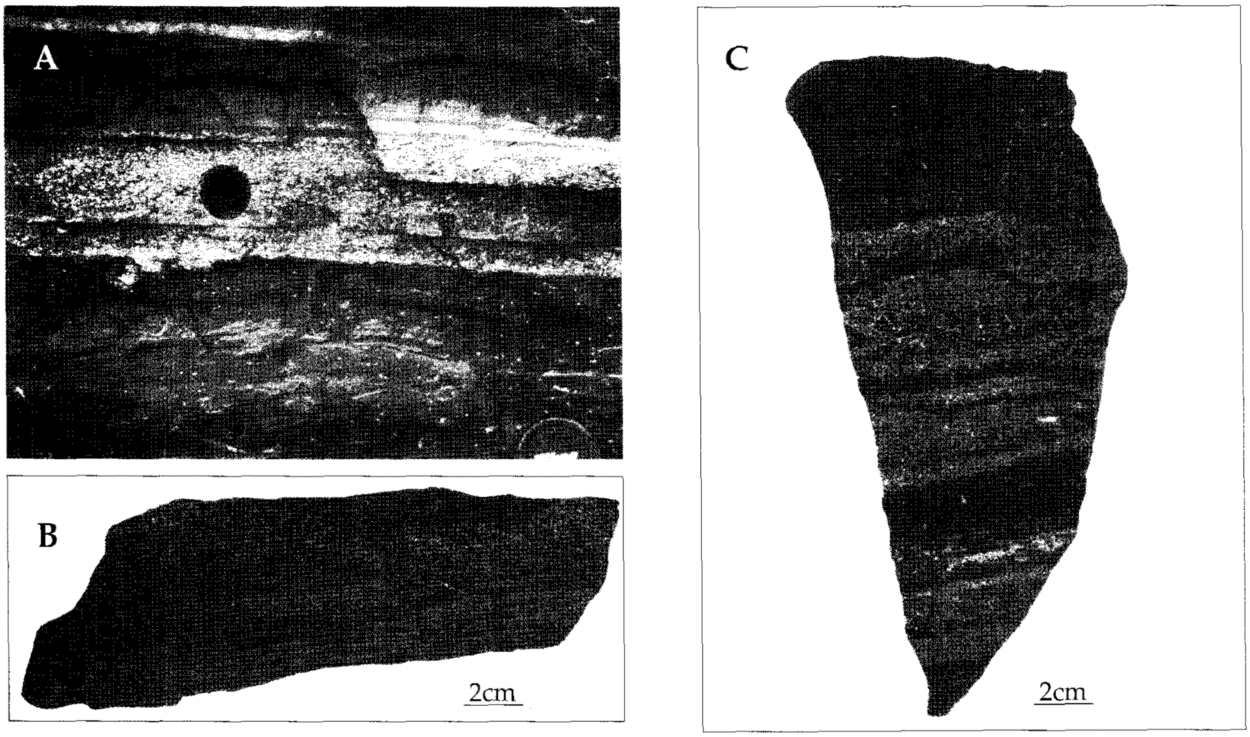

Fig. 6. Outcrop and rock slab photographs of thin-bedded sandstone (Facies D). (A) Stratification is delineated by differences in grain size and rock color. (B) Clast-supported conglomerate unit encased in sandstone truncates the laminae of lower sandstone unit. (C) Stratification of sandstone is plane-parallel with flat to undulatory bedding surfaces.

deposited from streamflow on alluvial plains during flood events (Allen 1984). Horizontal stratification in this facies is similar to that of Smith's (1986) sand-dominated deposit, probably produced by the migration of low-amplitude bedforms under upper flow regime conditions.

Facies E: Lapilli tuff

This facies occurs in the lower part of the Sejong Formation with a thickness of about 10 m (Fig. 2). It overlies tilted disorganized, matrix-supported conglomerate units and is also overlain by disorganized, matrix-supported conglomerate with erosional contacts (Figs. 2 and 7A).

This facies comprises very thick bedded, disorganized, poorly sorted, matrix-supported and clast-supported lapilli tuffs (Fig. 7B). It mainly consists of a framework component of pumice and lithic lapilli in a matrix of fine-grained ash, plagioclase and glass shards. Pumice lapilli display a textural evidence for welding, including strong compaction around more competent grains, ragged terminations and elongation of ovoidal vesicles (Figs. 7C, D). The alignment of welded pumice lapilli and glass shards defines a planar foliation subparallel to the bedding plane, i.e. eutaxitic texture. Pumice lapilli are commonly replaced by chlorite. Lithic lapilli mostly consist of andesitic or basaltic andesitic fragments. Plagioclase crystals are mostly replaced by zeolite or chlorite, same as with other components.

The lapilli tuff is interpreted to be deposited by pyroclastic flows around active volcanic vents. Pyroclastic flows can deposit sediment, either by grain-by-grain or en masse deposition. The resultant facies depends on the concentration of sediment at the base of the flow during deposition. High-concentration basal dispersions yield poorly sorted structureless beds similar to Facies E in the Sejong Formation. Depositions occur owing to rapid gradual or incremental aggradation directly from suspension (Druitt 1992; Kneller and Branney 1995) or by increasing its yield strength due to friction and/or adhesion between particles (Sparks 1976; Freundt and Schmincke 1986).

4. Depositional history of the Sejong

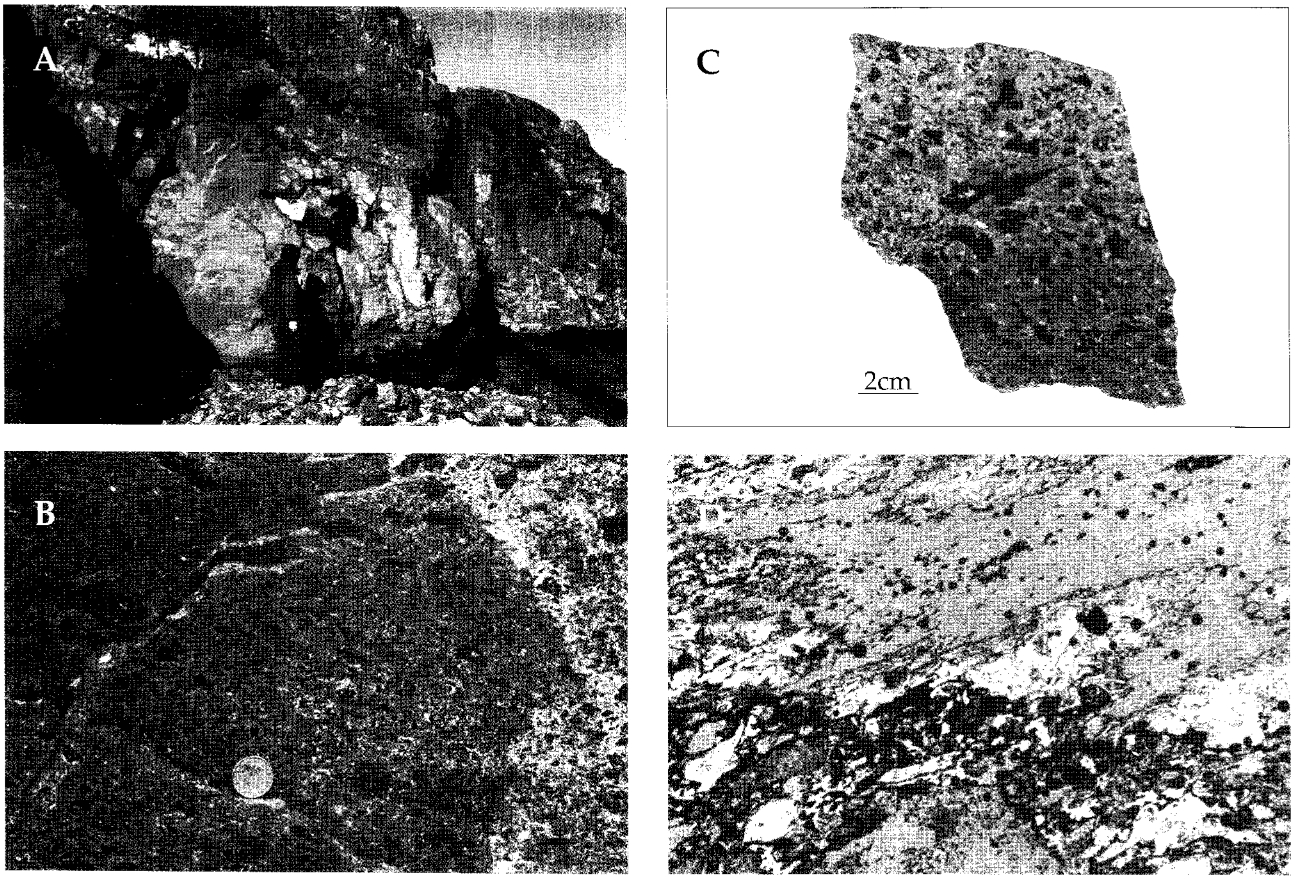

Fig. 7. Lapilli tuff (Facies E). (A) Lapilli tuff overlies disorganized, matrix-supported conglomerate with erosional contact. The lower conglomerate units are tilted at about 10° to the west. (B) This facies comprises very thick bedded, disorganized, poorly sorted, matrix- to clast-supported lapilli tuff. (C) Rock slab showing textural evidence for welding of pumice. (D) Photomicrograph of welded pumice lapilli displays ragged termination.

Formation

The spatial distribution of sedimentary facies suggests that the Sejong Formation is deposited during four stages closely related to volcanic activities around the Barton Peninsula (Figs. 2 and 8). Continental volcaniclastic successions can be interpreted in terms of the relative influence of extrabasinal volcanism (i.e., eruption frequency, scale of volcanism-driven sedimentation) and intrabasinal subsidence rates (Smith 1991).

Stage 1: Inter-eruptive phase

Inter-eruptive sedimentary sequence records the deposition without significant influence of volcanic activities where normal sediment delivery processes are dominant (Smith 1991). In the lowermost part of the Sejong Formation, disorganized matrix-supported conglomerate (Facies A) is deposited by clast-bearing mud flows or muddy debris flows during inter-eruptive phase (Fig. 8A). Small amounts of sandstone and siltstone beds are deposited during the periods between debris-flow events. The volcanic origin of most clasts and matrix represents previous active volcanism in this area.

Stage 2: Syn-eruptive phase

The thick lapilli tuff unit (Facies E) in the lower part of the Sejong Formation represents a syn-eruptive phase of sedimentation (Figs. 2 and 8B). The lapilli tuff overlies tilted units of disorganized, matrix-supported conglomerate (Facies A), which suggests tilting prior to the deposition of the lapilli tuff or possibly deposition of the lapilli tuff along the valley near the volcanic vents. Nearby volcanism is suggested by well preserved pri-

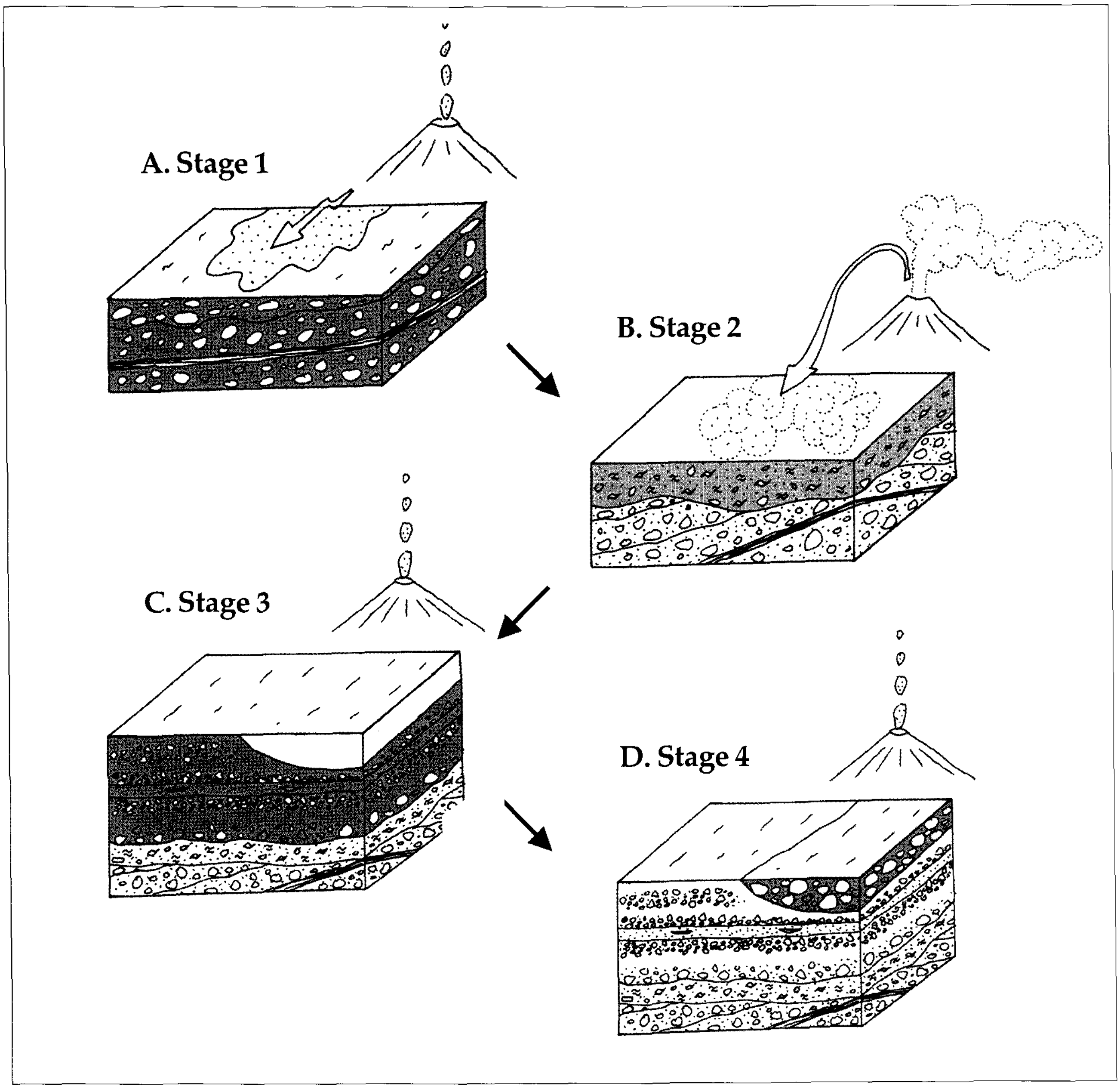

Fig. 8. Depositional history of the Sejong Formation. Conglomerate and sandstone units (Facies A, B, C, and D) are deposited during inter-eruptive phases (stages 1, 2, and 4), whereas lapilli tuff (Facies E) is formed during syn-eruptive phase (stage 2).

mary volcanic textures, such as fiamme, eutaxitic texture and angular clasts.

Stages 3 & 4: Inter-eruptive phase

The lapilli tuff unit is overlain by the sequences of disorganized, matrix-supported conglomerate (Facies A), stratified, clast-supported conglomerate (Facies C), and thin-bedded sandstone (Facies D) reflecting deposition by muddy debris flows, unconfined hyperconcentrated flood flows / sheetfloods, and subordinated streamflows during the period of reduced volcanic activities (stage 3; Figs. 2 and 8C). The compositions of conglomerate and sandstone indicate that sediment was largely derived from volcanic-rock terranes.

Stage 4 is represented by the channel-filled unit of disorganized, clast-supported conglomerate (Facies B) in the uppermost part of the Sejong Formation (Figs. 2 and 8D). The sedimentary facies and geometry of this unit suggest that deposition was dominated by cohesionless debris flows filling a large valley up to 30 m deep. The dominance of volcanic fragments in the conglomerate indicates that volcanic terrane was extensively developed around the Barton Peninsula through stage 4 deposition.

5. Conclusions

The Sejong Formation (Late Paleocene to Eocene), distributed in the Barton Peninsula, King George Island, is composed of five sedimentary facies based on primary sedimentary structures and bed geometries; disorganized, matrix-supported conglomerate (Facies A), disorganized, clast-supported conglomerate (Facies B), stratified, clast-supported conglomerate (Facies C), thin-bedded sandstone (Facies D) and lapilli tuff (Facies E). Vertical and lateral distributions of these facies suggest that the Sejong Formation is deposited during the four depositional stages closely related to volcanic activities around the Barton Peninsula.

During stage 1 (inter-eruptive phase), disorganized, matrix-supported conglomerate is deposited by clast-bearing mud flows or muddy debris flows. Lapilli tuff is formed by pyroclastic flows from nearby active volcanic vents during stage 2. After cessation of volcanic activity, thick sequences of conglomerate and sandstone are accumulated by muddy debris flows, unconfined hyperconcentrated flows and streamflows during inter-eruptive phase (stage 3). At stage 4, disorganized, clast-supported conglomerate is deposited by cohesionless debris flows filling a valley. The dominance of volcanic components in sedimentary facies and occurrence of lapilli tuff in the Sejong Formation indicate active volcanism occurred around the Barton Peninsula during Late Paleocene to Eocene.

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