Attachment A

Method for the systematic identification of globally important geological sites in Antarctica

Introduction and concepts

The SCAR Action Group on Geological Heritage and Geoconservation discussed methods to identify sites of globally important geological value at its 2nd meeting held during the SCAR/IASC Open Science Conference in Davos, Switzerland, 17 July 2018. It was agreed that the procedure for the identification of Antarctic sites of exceptional geological value should follow the methods of the *Global Geosites Project* (which is promoted and co-sponsored by UNESCO and the International Union of Geological Sciences (IUGS), and focusses on the identification of geological heritage), but adapted for the unique situation and specific circumstances found in Antarctica. One benefit of this approach is that the process would be comparable with that used globally, and would allow the many unique processes that have occurred within Antarctica to be understood within a global context.

The objective of the proposed method for Antarctica is to select the most important sites for geological science, taking a global perspective and using a comparative review, resulting in the selection of geological sites worthy of international recognition.

The method, has two steps, as follows (see Figure 1):

1. The systematic classification of Antarctica's geological past into defined geological themes through the identification of a list of Geological Frameworks.

   SCAR has already completed this process with the initial identification of nine Geological Frameworks that represent the most significant events in Antarctic's geological past (see Annex 1).
2. The subsequent identification of Antarctic sites of exceptional geological importance (known as Antarctic Geosites) within each of the identified Geological Frameworks.

   SCAR has already tested the method with the selection of one Geosite for the Geological Framework: 'Cretaceous-Paleogene (K-Pg) transition' (see Annex 1).

What is an Antarctic Geological Framework?

Antarctic Geological Frameworks are the units used to provide a systematic classification of the region's geological past. Specifically, an Antarctic Geological Framework refers to one or a combination of the following: a regional geological element, geotectonic unit, metalogenic association or any set of geological features representing an event in Earth's history, such as a stratigraphic series, palaeobiological association, etc., of international relevance.

For example, each Antarctic Geological Framework may concern, among others, one or a combination of the following themes or processes for a specific time period:

- Continental or oceanic scale geological feature or plate relationships
- Geomorphological features, erosional and depositional processes and landscapes
- Historical, within the context of the development of geological sciences
- Igneous, metamorphic and sedimentary petrology, textures, events and processes
- Palaeontological (involving fossils of animals or plants)
- Palaeoenvironmental (an environment of a past geological age)
- Archean, Proterozoic or Phanerozoic
- Structural, stratigraphic, or mineralogical

- Meteorite-impact structures
- Submarine or subglacial structures or processes

Not all Geological Frameworks have to cover similar time intervals. The time interval will depend on the duration of the processes to which the Geological Framework refers (see Figure 1.1 in Annex 1).

Geological Frameworks may overlap with each other. For example, they may refer to simultaneous processes (i.e., overlapping in time), or they may refer to geological features located in the same area (i.e., overlapping in space).

Due to the great diversity of geological processes and events, it is appropriate to provide one Geological Framework that can encompass any geological features or materials that cannot fit within other Frameworks (see 9 in Figure 1.1 in Annex 1).

What is an Antarctic Geosite?

To be selected as an Antarctic Geosite, the location within the Antarctic Treaty area should represent an exceptional manifestation of the Geological Framework, and should allow the most comprehensive understanding of the nature and origins of the phenomenon.

Each Geosite should be assigned to the most relevant Geological Framework that it represents. Some Geosites may be relevant or significant to more than one Geological Framework.

Sites that may be appropriate for consideration as Antarctic Geosites may fall under one or more of the following categories:

- Singular geological and geomorphological landscapes.
- Unique or singular sites: including rare features, produced by exceptional or uncommon geological processes. These may also be places where aspects that are very difficult (or even impossible) to observe in other places can be recognised.
- Best sites: including locations containing (i) the best examples of a geological aspect that can be considered representative and (ii) models to be used as a reference.
- First sites: such as locations where a geological aspect was identified for the first time.
- Patterns: including sites of reference for a certain geological period due to the quality and continuity of the sedimentary and paleontological record.
- Places representative of the geological evolution of a relevant region.
- Places with active processes representative of the Earth's dynamics.

The following are examples of features that might be considered Antarctic Geosites:

- Natural landforms and landscapes (including ancient landforms and landscapes).
- Earth materials (including rocks, minerals, fossils, meteorites and soils).
- Evidence of geological processes (both internal and external, and past and present).
- Evidence of geological time (including the record of specific geological stages of time periods using such features as rock sequences, unconformities and weathering profiles, and/or fossils).

Antarctic Geosites should be identified exclusively for their high scientific value and have no legal status under the Antarctic Treaty System. Not all Antarctic Geosites will need higher levels of protection, particularly as many Geosite features are likely to be robust and the Antarctic Treaty System already provides mechanisms to minimize human impact (i.e. the Environmental Impact Assessment process).

Method for selection of Antarctic Geological Frameworks and Geosites

The selection of Antarctic Geological Frameworks and Geosites must be made in the light of the geological knowledge of Antarctica and, as far as possible, must be based upon objective criteria. Figure 1 shows the different steps of the method for identification of Antarctic Geological Frameworks and Geosites.

1. Generation of a list of Antarctic Geological Frameworks ***[COMPLETED]***

A Coordination Team (compiled by SCAR) distributed an initial survey to the Antarctic community seeking proposals for Geological Frameworks. Upon receipt and analysis of all proposals, the Coordination Team established the list of Geological Frameworks with further consultation and approval from the Antarctic geoscience community. The list of Antarctic Geological Frameworks can be seen in Annex 1 (Figure 1.1).

2. Generation of a list of Antarctic Geosites ***[TASK INITIATED]***

Geosites must be selected for each of the identified Geological Frameworks. This process should be conducted by a different group of 'Framework Experts' selected for each Geological Framework. SCAR has already made some progress in this task, with the selection of Geosites for the 'Cretaceous-Palaeogene (K-Pg) transition' Geological Framework (see Annex 1). Steps in the identification of Geosites (summarised in Figure 1) are as follows:

a. Establishment of a group of Framework Experts. The Coordination Team proposes and establishes a group of Framework Experts for the identification of Geosites. Framework Experts would be identified from bibliographic information. At least three individuals, representing more than one Party, should be identified for each Geological Framework. The roles of the experts are outlined in the following steps.

b. Proposal of Antarctic Geosites. Individuals within the group of Framework Experts and the Coordination Team, as well as interested geoscientists from the international Antarctic community, should propose the sites which, from their points of view, are of the highest geological value, by using the following criteria:

	Criterion	**Definition**
A	Representativeness	Representative model
B	Type locality or reference locality	Internationally-agreed reference locality
C	Degree of scientific knowledge	Number and quality of international publications
D	State of conservation	Degree of preservation of the relevant features
E	Observation conditions and visibility	Ease of viewing
F	Rarity or uniqueness	Scarcity
G	Association with other elements of interest in the vicinity	Other related biological or historic elements in the vicinity

The Framework Experts, or other geoscientists engaged in the process, must provide the following information for the proposed Geosites:

- Name of the proposed site, inclusive of age, main process(es) and location.
- Name of the expert(s) proposing the site.
- Significance of the site, in comparison with other areas at different geospatial levels (local, regional, global).

- Specific criteria that justify the proposal as a Geosite.
- Location (including coordinates).
- Description of the access route.
- Location diagram (aerial image and/or detailed map if possible).
- Recommendations (if any) regarding the location of the site, based on the risk of anthropic degradation.
- Bibliographical references.

c. Evaluation of the proposed Antarctic Geosites. After collation of the proposals, the Coordination Team prepares a list with all the proposed Geosites for the Geological Framework, including a summary of the information provided on each of them. In a second survey, the group of Framework Experts are asked to evaluate each of the proposals contained in the list, by using a simple scoring system to enhance differences. Once the responses from the experts are received, the average score for each of the proposed sites is calculated, and all sites that have scores above a predetermined threshold would become Antarctic Geosites for that particular Geological Framework.

d. Description of the Geosites. The group of Framework Experts and Coordination Team must prepare a description of the agreed Antarctic Geosites, including the proposal of site boundaries where relevant, and taking further expert advice where appropriate.

Review and modifications

The lists of Geological Frameworks and Geosites are open to modification and new additions, as necessary, and a review of their contents should be initiated at least every ten years.

Not every Antarctic Geosite needs to be designated as an Antarctic Specially Protected Area (ASPA). However, the CEP may consider Geosites of the most outstanding value appropriate for consideration as potential ASPAs, under the criteria described in Annex V to the Protocol on Environmental Protection to the Antarctic Treaty.

Supporting references

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Figure 1. Systematic method for the identification of scientifically important geological sites in Antarctica

1. Antarctic Geological Frameworks [WORK COMPLETED]

The Coordination Team (established by the relevant SCAR group) coordinates the identification of a number of Antarctic Geological Frameworks*, following extensive consultation with the Antarctic geosciences community.

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2. Antarctic Geosites [WORK INITIATED]

a. A group of Framework Experts is established for identification of Geosites within a specific Geological Framework.

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b. The Coordination Team invites proposal for Geosites within the context of the selected Geological Framework (including from within the group of Framework Experts and individual geoscientists across the Antarctic geosciences community).

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c. Coordination Team prepares a list of proposed Geosites for the selected Geological Framework. The Framework Experts systematically evaluate each proposed Geosite. Sites that score above a pre-determined threshold are identified as Antarctic Geosites.

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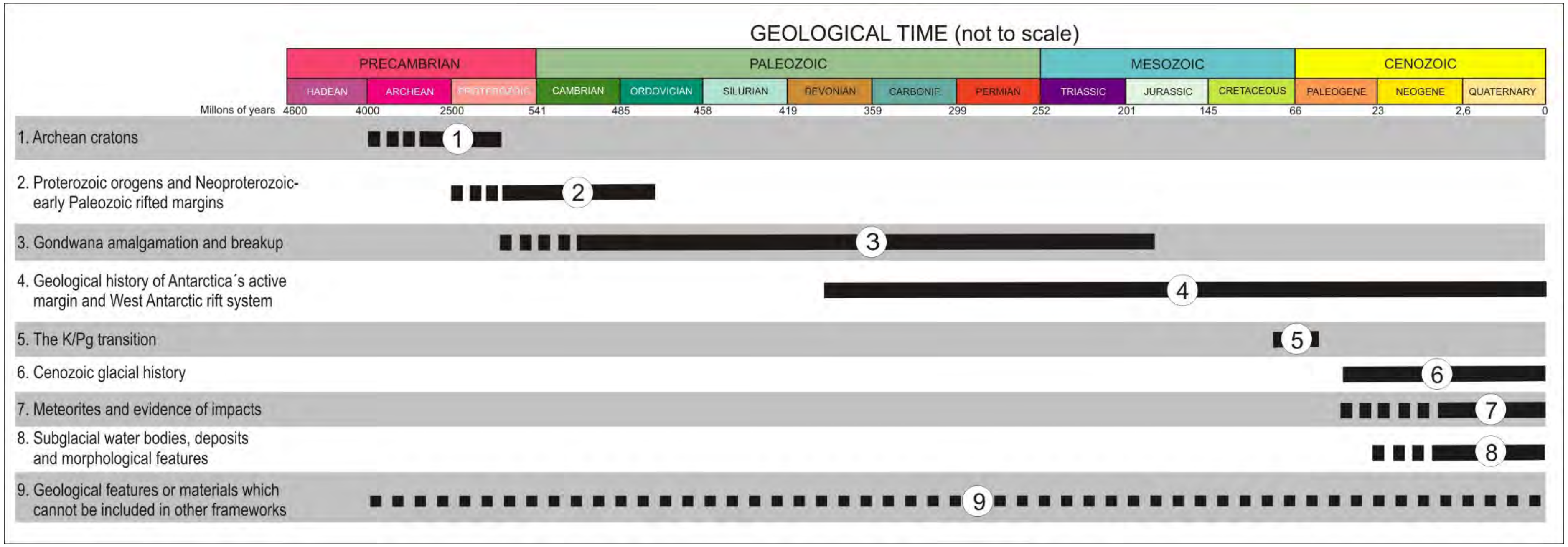
d. The group of Framework Experts and the Coordination Team prepare a description of the new Geosites.

*The initial Geological Frameworks list for Antarctica may undergo modifications in future revisions.

Annex 1: Testing the method for the systematic identification of globally important geological sites in Antarctica

Step 1: Systematic division of Antarctica's geological past into Geological Frameworks

Figure 1.1. The distribution of the Geological Frameworks, identified at this step, in a Chronostratigraphic Table.



Antarctic Geological Frameworks

The following list provides some further detail of the scope of each Geological Framework.

1. **Archean cratons**
   Evidence of the formation and breakup of supercontinents; dispersal and assembly cycles; orogenic episodes, major petrological and structural units, and early lifeforms.
2. **Proterozoic orogens and Neoproterozoic-early Palaeozoic rifted margins**
   Evidence of the formation and breakup of Rodinia; orogenic episodes and early lifeforms.
3. **Gondwana amalgamation and breakup**
   Sedimentary sequences and associated igneous and metamorphic rocks; tectonic; Early Palaeozoic Panthalassic margin subduction – the Ross Orogeny, Pan African orogens/sutures, the Kukri peneplain, classic Gondwana cover sequences, palaeoclimatic and palaeontological records and the Ferrar Large Igneous Province, and evidence primarily in the Transantarctic Mountains.
4. **Geological history of Antarctica's active margin and West Antarctic rift system**
   Subduction history; arc-related basins, magmatism, petrological and structural evidence; opening of the Tasman and Drake gateways; establishment of the Antarctic Circumpolar Current and modern oceanic circulation; tectonic evidence and climatic implications; geological evolution of the Scotia Arc; evidence of volcanic activity; back arc basin formation in the Bransfield Strait. Structural and petrological evidence, vulcanism and shoulder uplift related to the West Antarctic rift system.
5. **The Cretaceous-Palaeogene (K-Pg) transition**
   Palaeontological and geochemical records of the global mass extinction at the Cretaceous-Palaeogene transition.
6. **Cenozoic glacial history**
   On land and offshore sedimentary records; evidence of formation and behaviour of the Antarctic glacial systems in response to climatic changes; record of ice formation and ice fluctuations; ice sheets evolution; record of sea level changes; record and features in ice showing past conditions, oldest ice, geothermal activity or other circumstances.
7. **Meteorites and evidence of impacts**
   Petrological and morphological features related to meteorite impacts.
8. **Subglacial water bodies, deposits and morphological features**
   Subglacial morphology, lakes and fluvial networks.

9. **Geological features or materials which cannot be included in other frameworks**
Scientifically important and/or unusual minerals, rocks, fossils, soils, permafrost features, structures, landforms or other geological elements, including those formally recognized as type localities by related international scientific organizations.

Step 2: Antarctic Geosite selection for the 'Cretaceous-Palaeogene (K-Pg) transition' Geological Framework

Antarctic Geosites need to be selected for all nine of the Geological Frameworks. However, to test the applicability of the method, the K-Pg transition Geological Framework was selected to be worked on first because of its global importance.

The Coordination Team and K-Pg transition experts meet in Cambridge to select the Geosite(s) for the K-Pg transition (9-11 March 2020), i.e. Dr. Marcelo Reguero (Argentina), Prof. Jerónimo López-Martínez, Dr. Luis Carcavilla and Dr. Enrique Díaz-Martínez (Spain), Prof. Dame Jane Francis, Dr. Alistair Crame and Dr. Kevin A. Hughes (the United Kingdom) and Prof. David Elliot (the United States). Several potential areas were considered that represent the K-Pg transition Geological Framework, but following careful consideration, only one area fulfilled the requirements for selection as an Antarctic Geosite. (NB: It is anticipated that most other Geological Frameworks will each have several locations that fulfill the requirements for Antarctic Geosite selection). The details of the identified Geosite for the K-Pg transition Geological Framework are as follows:

1. Antarctic Geosite name:

Cretaceous-Paleogene (K-Pg) transition at Seymour (Marambio) Island.

2. Name of Geological Framework:

The Cretaceous-Paleogene (K-Pg) transition.

3. Location:

Southern Seymour (Marambio) Island, James Ross Island Group, northeastern Antarctic Peninsula (see Figure 2.1).

4. Approximate coordinates of the Antarctic Geosite centre:

64^{o} 17' 15'' S; 56^{o} 44' 07'' W.

5. Short description:

The Antarctic Geosite encompasses the K-Pg boundary and informal mapping Unit 9 and Unit 10 (Macellari, 1988; Sadler, 1988) of the upper part of the López de Bertodano Formation, Seymour Island Group (late Maastrichtian- early Danian age). The boundary zone considered for this Geosite is c. 7 km long and c. 1.8 km wide (c. 13 km^2) (see Figure 2.1).

6. Justification of the scientific interest:

The location represents one of the best sites globally for the study of the K-Pg global mass extinction event. The exposure is exceptional and continuous. The site has been subject to substantial international research. It is a key southern hemisphere site for the study of palaeontology, biostratigraphy, geochemistry and magnetostratigraphy. The location contains evidence that the K-Pg extinction in the high latitudes was just as extensive as in lower latitude sites closer to the asteroid impact site.

7. Parameters that justify the selection of the Geosite:

	Parameter	**Justification**
A	Representativity	The most representative high latitude location and one of the most significant globally
B	Type locality or reference locality	• The only confirmed onshore locality showing an extensive K-Pg transition in Antarctica. • Contains the first locality where the iridium anomaly was identified in Antarctica. • Locality for key reference fossil collections.
C	Degree of scientific knowledge	• Past and on-going international research and collaboration. • Extensive geological mapping and many books and research articles published in national and international journals. • Many large fossil collections are present in international repositories and museums.
D	State of conservation	Exceptional exposure and state of preservation across the Geosite, with human impact limited to geological sampling for research purposes.
E	Observation conditions and visibility	Exceptional three-dimensional exposure, with little surface cover and ice-free. Lateral continuity over several kilometres.
F	Rarity or uniqueness	A unique high latitude locality. Rare combination of fossils from many different groups (invertebrates, vertebrates, plants, microfossils, etc.).
G	Association of other elements of interest in the vicinity	Other units on the island and beyond the Geosite boundary are of great geological interest, some of which may be included in other Geological Frameworks (e.g. Geological history of Antarctica's active margin and West Antarctic rift system).

8. Locations of note:

- The well documented stratigraphic section where the iridium anomaly was first identified. Locality adjacent to Blackrock Ridge (Filo Negro). Coordinates: 64° 17' 24" S; 56° 44' 30" W. The glauconite-bearing sandstone interval is easily recognized across the southwestern part of Seymour (Marambio) Island (see Figures 2.1 and 2.2). In this vicinity, the section forms a near vertical cliff, which diminishes problems of slope wash and mixing of sediment. Visibility of the site is excellent, and it is easily identified in the field because of the adjacent basalt dyke. This site is the reference site for any further examination of the iridium anomaly at the boundary.

- The northern sector of the K-Pg boundary. This location is where the boundary was first defined palaeontologically. Coordinates: 64° 16' 07" S; 56° 42' 37" W. (see Figure 2.3)

9. Observations regarding geoconservation:

Until recently, there has been minimal risk of anthropogenic degeneration. However, there is potential for an increase in human visitation and non-scientific collections. Furthermore, scientific research activities will be compromised should visitors move fossils out of their stratigraphical context.

The site is vulnerable to oversampling. Only national authorities can give permission to collect geological and palaeontological samples.

Significant fossil collections from Seymour (Marambio) Island are located in repositories in several countries. To prevent unnecessary sampling, researchers are encouraged to make maximum use of fossils in existing collections.

10. Site boundaries:

See Figure 2.1, which shows the site boundary.

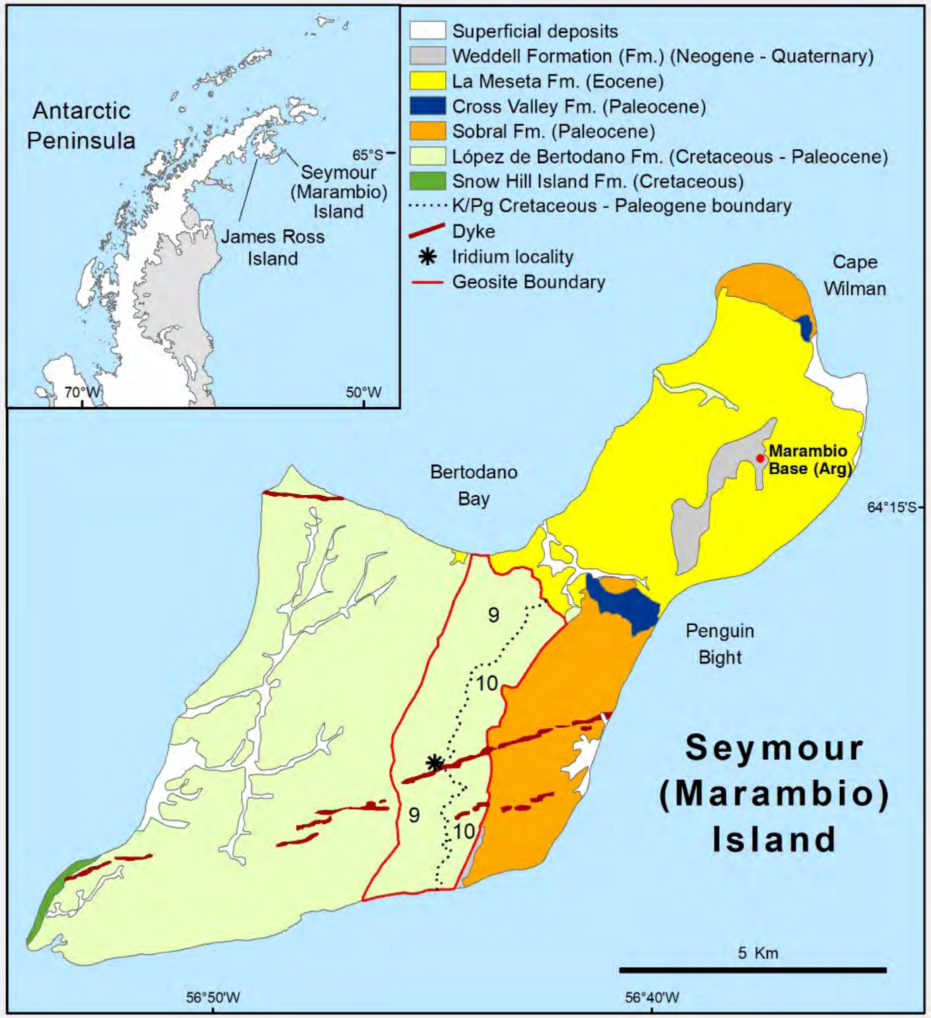


Figure 2.1: Simplified geological map of Seymour (Marambio) Island showing the Geosite boundary outlined in red. The K-Pg boundary and informal mapping Unit 9 and Unit 10 of the López de Bertodano Formation are shown within the Geosite area.

11. Photograph(s):

Figure 2.2: Photograph showing the site of the iridium anomaly identification, with white arrows referring to the stratigraphic section of Elliot et al. (1994). Skyline formed by Blackrock Ridge (Filo Negro) dyke. Photograph by David Elliot.

Figure 2.3: The K-Pg boundary at the northern end of its area of outcrop on Seymour (Marambio) Island, north-eastern Antarctic Peninsula. The boundary occurs at the top of a distinct scarp that can be traced in a southerly direction across the island. Informal mapping Unit 9 marks the top of the Cretaceous (K) and Unit 10 the base of the Paleogene (Pg). This is one of the best exposed K-Pg boundaries anywhere in the world.

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13. Proposers:

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All proposers participated in, or contributed to, the workshop on identifying Antarctic Geosites of the K-Pg transition (Cambridge, 9-11 March 2020).