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DETAILED GEOMORPHOLOGICAL MAPPING WITH KYNEMATIC GPS. EXAMPLES FROM LIVINGSTON ISLAND, ANTARCTIC

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Abstract

The detailed geomorphological mapping of landforms and deposits is widespread in Quaternary geomorphology studies. It consists on the precise representation of the spatial position of geomorphological information and their characterization (e.g. topography, hydrology, morphometry, morphography, morphogenesis, morphochronology and morphodynamics) in large-scale maps (usually 1:5,000 to 1:25,000). The data is collected using both remote sensing (aerial photo interpretation, satellite images, etc.) and detailed field surveys.

However, in areas without topographic maps, or where the scale of the existing is too small, it becomes very difficult, or even impossible to make a detailed geomorphological survey. But even in areas with good topographic data, the precise location of small or very irregular landforms and deposits is frequently difficult. The recent development of high precision GPS (Global Positioning System) allows the cartographic production with an accuracy that could only be achieved using traditional geodetic surveys. The main advantage is the much faster working procedure and direct data storage in a digital format. The later can easily be integrated in a Geographical Information System.

The installation of a Kynematic GPS in the Spanish Antarctic Station (Livingston Island, South Shetlands) in the Austral summer of 1999-2000, made its use possible in the framework of the geomorphological survey that was being conducted at the time. In this paper the application of the Kynematic GPS system is explained and two examples of detailed geomorphological maps at the scale 1:5,000 produced using this technique are presented.

Key words: Kynematic GPS, geomorphological mapping, Livingston Island, Antarctic.

Resumo

Cartografia geomorfológica de pormenor com GPS Cinemático. Exemplos da Ilha Livingston, Antárctida – A cartografia geomorfológica de pormenor das formas e depósitos é uma das técnicas mais utilizadas em estudos de geomorfologia do Quaternário. Permite registar com precisão em mapas de grande escala a informação de natureza geomorfológica (por ex: topografia, hidrologia, geologia, morfometria, morfografia, morfogénese, morfocronologia e morfodinâmica) recolhida de modo sistemático, quer através da observação de fotografia aérea, quer através de levantamentos detalhados de campo. Os mapas assim elaborados constituem uma excelente ferramenta para os estudos do Quaternário, pois neles se encontra descrita exaustivamente a geomorfologia de uma determinada área.

Em áreas sem informação topográfica de base, ou onde a sua escala impossibilita a localização precisa dos fenómenos a cartografar, a elaboração de um mapa geomorfológico de pormenor rigoroso torna-se difícil, senão mesmo impossível. Mas mesmo em áreas com boas bases topográficas, a cartografia de formas e depósitos de pequena dimensão ou de contornos irregulares pode ser pouco rigorosa. O aparecimento recente de GPS (*Global Positioning Systems*) de grande precisão veio contribuir para que a cartografia geomorfológica possa ser efectuada com uma precisão até aqui só conseguida através das técnicas da geodésicas tradicionais, mas com muito maior rapidez. Este aspecto torna-se especialmente significativo, se se utilizar um GPS cinemático, que permite cartografar de forma contínua pontos, linhas ou áreas no terreno, com erros centimétricos.

A instalação de um GPS cinemático em fase experimental na Base Antárctica Espanhola (BAE) Juan Carlos I na Ilha Livingston (Shetland do Sul, Antárctida) durante a campanha de 1999-2000, permitiu que o tivessemos utilizado em alguns sectores da Península de Hurd, onde procediamos ao levantamento geomorfológico de pormenor à escala 1: 5.000. Os sectores cartografados com recurso ao GPS correspondem ao sector terminal do vale da BAE e ao vale localizado imediatamente a NE.

A utilização do GPS cinemático, faz-se através do transporte de uma pequena mochila com os instrumentos, que vai registando automaticamente em memória, as coordenadas e altitude do trajecto percorrido. Um manómetro permite a leitura instantânea dos dados e a aferição do erro.

Os trajectos efectuados foram escolhidos de modo a permitir a correcta delimitação das formas em estudo, ou sejam, as cristas morénicas e as frentes de praia levantada. Naturalmente, a qualidade dos resultados obtidos, dependerá largamente da capacidade do investigador que usa o sistema, ou que coordena as observações, em identificar correctamente os elementos a cartografar. Os pontos obtidos no campo foramposteriormente transferidos para um computador e introduzidos num Sistema de Informação Geográfica, que permitiu visualizar a informação num mapa de base. Este método, além de permitir a elaboração de mapas muito rigorosos, possibilita o armazenamento dos pontos numa base de dados georeferenciada, que pode ser posteriormente utilizada para a construção de novos mapas da área de estudo.

Palavras-chave: GPS cinemático, cartografia geomorfológica, Ilha Livingston, Antárctida.

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1 Introduction

Detailed geomorphological maps are large-scale maps (usually 1:5,000 to 1:25,000) that store detailed spatial information of geomorphological nature. The more frequent legends include data on topography, hydrology, geology, morphometry, morphography, morphogenesis, morphochronology and morphodynamics (Peña Monné, 1997). This information is collected systematically from remote sensing (mainly aerial photo interpretation) and detailed field surveys that are frequently accompanied by laboratorial analysis.

Geomorphological phenomena are thus systematically described in geomorphological maps. This fact makes them invaluable tools for studies on Quaternary environments (Lowe & Walker, 1997, p.18). The use of detailed geomorphological maps together with sedimentological analysis in an integrated approach can prove very useful for paleogeographical reconstructions (see for example López-Martínez, J. *et al.*, 1996; Ferreira *et al.*, 1999).

In areas without topographic information or where the scale is too small for the precise location of the geomorphological phenomena, detailed geomorphological mapping is a difficult or even impossible task. Even in locations where good topographic maps are available, mapping of small or very irregular landforms or deposits can be difficult and not rigorous.

The recent development of Global Positioning Systems (GPS) is a very significant contribution for detailed geomorphological surveying and mapping. It is now possible to map with an accuracy only achieved with the traditional (and time-consuming geodetical surveys), at much faster rates than before. This is especially true with a kynematic GPS (GPS-RTK) system that allows mapping continuously points or lines in the terrain with an error of a few centimetres.

This note describes the use of the GPS-RTK in the framework of the detailed geomorphological survey conducted in Livingston Island (South Shetlands). Two examples of the application of the system represented together with classical field survey information are presented.

2. Study area

Livingston is the second largest island of the South Shetlands archipelago, Antarctic (fig. 1). The island is about 70 km long and 6 to 25 km wide. 90% of its

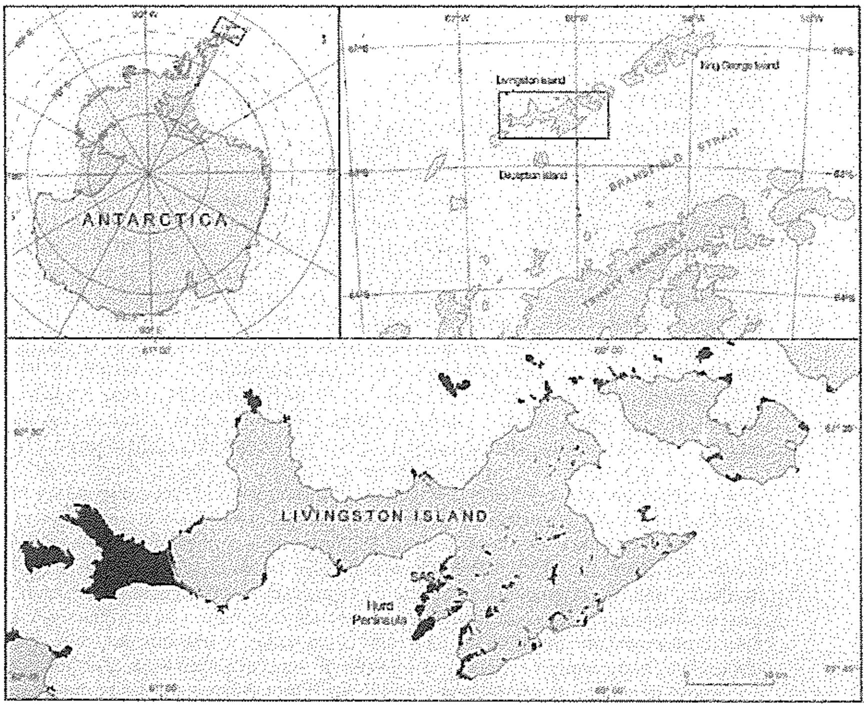


Fig. 1 – Location of the Livingston Island (adapted from *Ortoimagen de la Isla Livingston 1:100 000*, Dep. Geodinàmica I Geofísica, Universitat de Barcelona and Institut Cartogràfic de Catalunya, *Acta Geologica Hispanica*, 34-1999).

Fig. 1 – Localização da Ilha Livingston (adaptado de *Ortoimagen de la Isla Livingston 1:100 000*, Dep. Geodinàmica I Geofísica, Universitat de Barcelona e Institut Cartogràfic de Catalunya, *Acta Geologica Hispanica*, 34-1999).

area is glaciated (PALLÀS, 1996) with several ice caps and valley glaciers, most of them terminating as tidewater glaciers (fig. 1). Three main physiographic units characterize the island (PALLÀS, 1996, p. 13): the high mountain area, located in the eastern part between Renier and Barnard points, with altitudes up to almost 1,800 m ASL (Mount Friesland); the medium mountain area, to the west of the latter, between Moon and South Bays, with maximum altitudes around 400 m, but that can go up to 800 m in Mount Bowles; and the low relief area that occupy all the central and west parts of the island, characterized by gentle slopes generally under 400 m ASL, but culminating at Snow Peak (428 m).

The two mapped sites are located in the medium mountain area, in the north part of Hurd Peninsula (fig. 2). The bedrock is the Myers Bluff formation formed by a sequence of turbidites affected by low-grade metamorphism (ARCHE *et al.*, 1992). Both sites relate to recently (Holocene) deglaciated areas in the downstream section of two adjacent valleys, the Spanish Antarctic Station (SAS) valley and the NE valley. The coastal fringe presents a raised beach system (MARTÍNEZ DE PISÓN *et al.*, 1991; LÓPEZ-MARTÍNEZ *et al.*, 1992a and b; PALLÀS *et al.*, 1995). The altitudes in the mapped areas vary from sea level up to 110 m ASL. Glacial, fluvioglacial, marine and periglacial landforms and deposits are represented and the sedimentological and geomorphological relationships between them make this a very interesting area in a geomorphological perspective. For more information reading of the articles mentioned above is suggested.

3. GENERAL PRINCIPLES OF THE KYNEMATIC GPS SYSTEM

The GPS was conceived to indicate positions in the Earth surface in any place independently of the meteorological conditions. For calculating the travelling time of a signal from a satellite to the receiver, specific codes are used. These codes allow the positioning with a precision of about 100 m.

However, if the GPS is located in a known position, its data can be used to correct most of the errors that are intrinsic to the system. The correction factors can be transmitted via radio to another GPS receiver in the area that uses them to achieve better accuracy (between 2 and 5 m). This technique is called differential GPS (DGPS) (LEICK, 1990; SEEBER, 1994).

If the carrier phase of the satellite signal is used in combination with the codes, better precision can be obtained. The calculation of the distance between the receiver and the sattelite is much more accurate, but also more difficult to calculate, because of the ambiguity: the number of full carrier phase cycles between the receiver and the satellite in the begining of the observation. While ambiguity remains unknown this higher precision level cannot be achieved. The whole process lasts usually some minutes.

If a GPS in a known position is used in order to calculate the system errors and ambiguities, it is possible to send the corrections via radio to other receivers with similar characteristics. These receivers are then able to calculate their positions in real-time

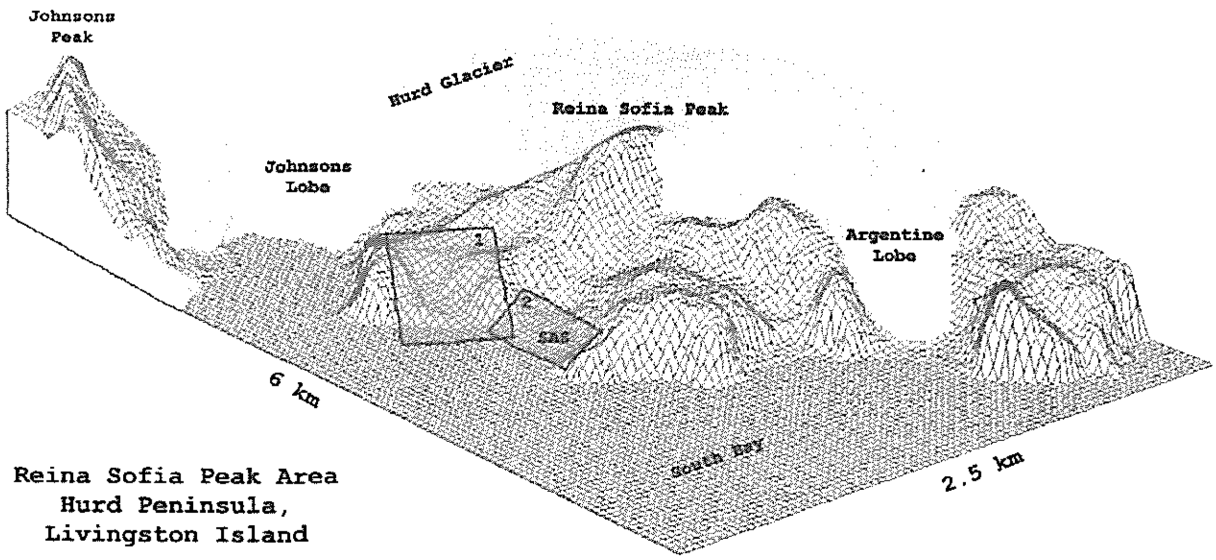


Fig. 2 – Location of the study areas in Northern Hurd Peninsula (1 – NE Valley map, 2 – Spanish Cove map, SAS – Spanish Antarctic Station).

Fig. 2 – Localização das áreas de estudo no sector Norte da Península Hurd (1 – Mapa do Vale NE, 2 – Mapa da Praia Espanhola, SAS – Base Antárctida Espanhola).

with an error of approximately 2 to 5 cm in relation to the static receiver. The accuracy diminishes with increasing distance to the static receiver, and the corrections are useless after more than 10 km (GÁRATE, 1997).

4. METHODOLOGY

4.1 System setting

The steady GPS antenna was installed in a geodetic point (Base) with known coordinates. They were calculated by the Spanish Navy Geographic Services during the first Antarctic campaigns in the late 80's (INSTITUTO GEOGRAFICO DE LA MARINA, 1989). The antenna was connected to a GPS receiver with RTK and DGPS capability located in the laboratory of the Spanish Antarctic Station. It calculates its position, solves the ambiguities and transmits them via an UHF Radio Modem. For this purpose, both the antenna near the station or the one located in the Reina Sofia Hill (270 m ASL) could be used.

A small receptor carried in a backpack receives the GPS signal via a geodetic antenna and the corresponding corrections via an UHF antenna. This information allows a fast calculation of the ambiguities. It is henceforth possible to calculate the position of points with errors under 2 cm. The coordinates are displayed on the screen of a small hand-held computer and saved in the memmory. In this way it is possible to reconstruct the track that was followed by the operator.

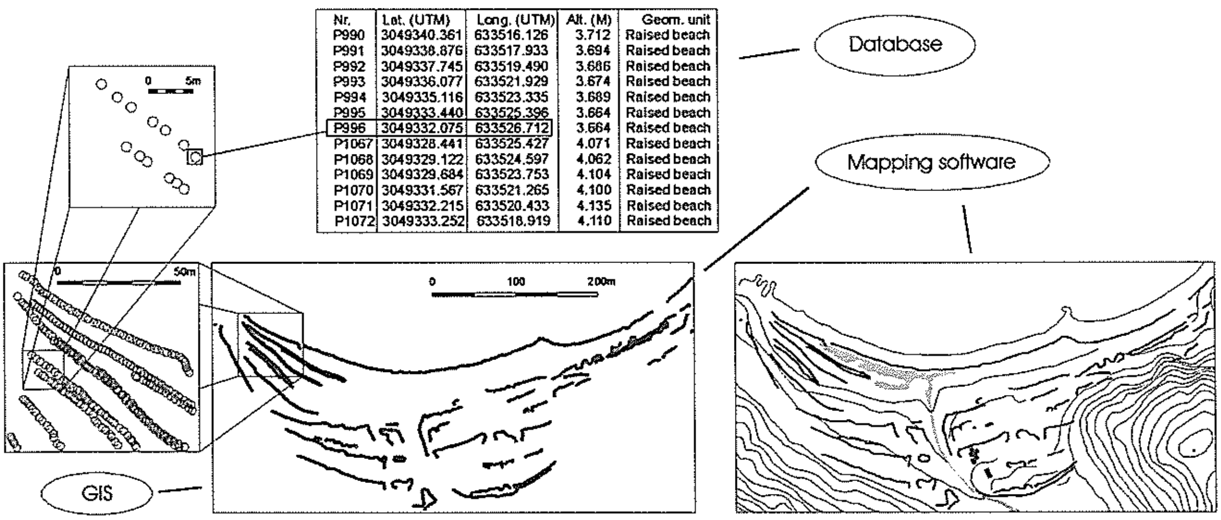
4.2 Field survey

For the detailed geomorphological survey the operator was a geomorphologist. The system was programmed for measuring continuously the coordinates at 1 m intervals as the operator was moving (fig. 3). Therefore, the choosen paths were saved in memmory as sets of individual points representing latitude, longitude and altitude.

Fig. 3 – GPS-RTK operator during the geomorphological field survey.

Fig. 3 – Operador do sistema GPS-RTK durante o levantamento geomorfológico de pormenor.

Two different kinds of linear information were chosen for mapping: in the NE valley complex moraine systems difficult to map with the traditional



Nr.	Lat. (UTM)	Long. (UTM)	Alt. (M)	Geom. unit
P990	3049340.361	633516.126	3.712	Raised beach
P991	3049338.876	633517.933	3.694	Raised beach
P992	3049337.745	633519.490	3.686	Raised beach
P993	3049336.077	633521.929	3.674	Raised beach
P994	3049335.116	633523.335	3.689	Raised beach
P995	3049333.440	633525.396	3.664	Raised beach
P996	3049332.075	633526.712	3.664	Raised beach
P1067	3049328.441	633525.427	4.071	Raised beach
P1068	3049329.122	633524.597	4.062	Raised beach
P1069	3049329.684	633523.753	4.104	Raised beach
P1070	3049331.567	633521.265	4.100	Raised beach
P1071	3049332.215	633520.433	4.135	Raised beach
P1072	3049333.252	633518.919	4.110	Raised beach

Fig. 4 – General framework of the mapping procedure. Point coordinates are stored in a database and transferred into a GIS as points. Finally the points are exported into a mapping software for the final map.

Fig. 4 – Organização geral do método de cartografia geomorfológica. As coordenadas dos pontos são armazenadas numa base de dados, e daí transferidas para um SIG. Deste último, exportam-se para um software de cartografia, procedendo-se à elaboração do mapa final.

surveys; and in the Spanish Cove, the scarps of raised beach terraces. The survey was conducted by walking along the lines to map. It is a relatively fast procedure, but with the disadvantage that one must walk all the way along the mappable phenomena. In the moraine ridges it has sometimes proven to be a particularly hard task to fullfil.

4.3 Map construction

The data collected in the field survey was exported into an ASCII table, with the identification of the measurement point number, latitude (UTM), longitude (UTM) and altitude (m ASL). This table was then imported into the Geographic Information System (GIS) ILWIS 2.2 where with the Database Management (DBMS) module the new variable landform unit was added. This allowed the archival of the data for future use. The coordinates of the points were then used to produce a point map that was exported in to a drawing package (fig. 4). The proximity between the points is large enough for drawing the lines that form the cartographed phenomena.

The final geomorphological map was constructed within the drawing package and includes both the information collected with the GPS-RTK system and the classical field survey. The latter will not be commented in this note.

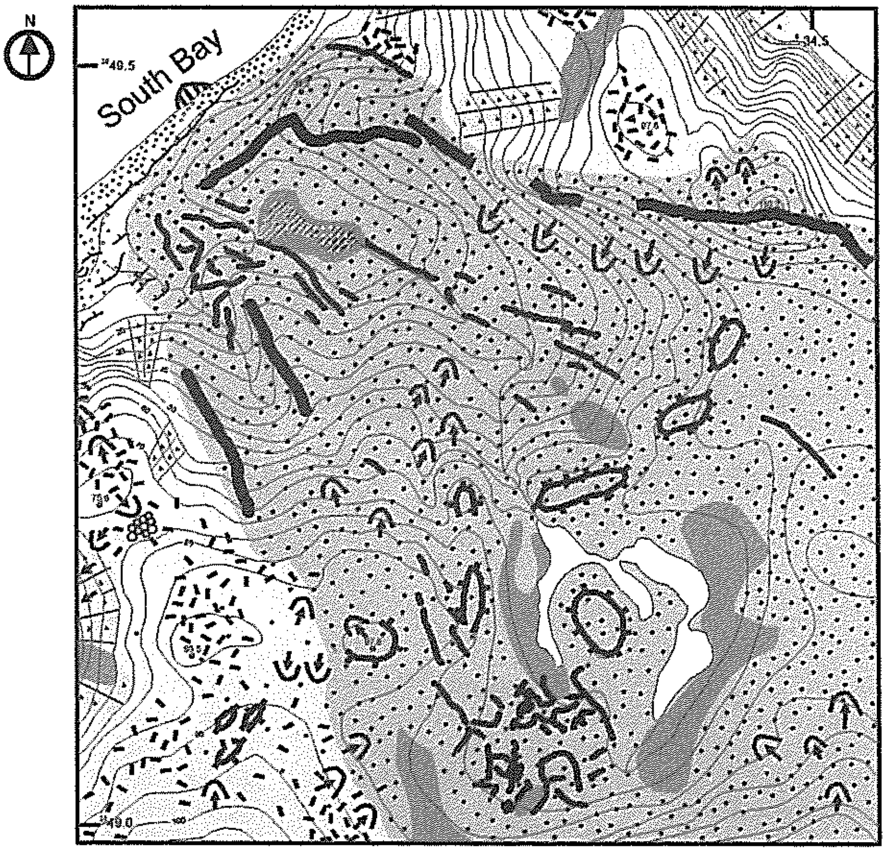
It is important to emphasize that these areas were mapped before by other authors at detailed scales (Martínez de Pisón *et al.*, 1991; López-Martínez *et al.*, 1992a and b; Pallàs, 1996). The maps that we present benefit from the information of these works, but contain also new data, especially in what respects to periglacial forms and deposits. The reason why the maps are not completely GPS-RTK based was the scarce amount of time available for the use of the system and the experimental nature of this first approach.

5. Results

5.1 Detailed geomorphological map of the NE Valley

The valley located NE of the Spanish Antarctic Station is almost completely covered by moraine deposits (fig. 5 and 6). Several moraine ridges are present. Their good conservation together with the position of the frontal moraine in contact with the 5 m beach, show that this valley was deglaciated more recently than the adjacent SAS valley (Martínez de Pisón *et al.*, 1991; López-Martínez *et al.*, 1992a and b; Pallàs *et al.*, 1995; Pallàs, 1996). Pallàs (1996) suggests a possible age of 330-720 BP for the frontal moraine. The NE valley floor and walls are therefore covered by moraine debris and boulders with a much fresher character than the ones in the SAS valley, which are significantly affected by frost-shattering and periglacial processes.

Geomorphological map, NE Valley
Hurd Peninsula, Livingston Island, South Shetlands, Antarctic
Scale 1:5,000



Topographical information: Cartografía Antártida, 1:5,000 - Servicio Geográfico de Ejército, Projection U.T.M., Elips. WGS-84, Time Zone 20
Contour equidistance: 5 m
0 100 200m

Fig. 5 – Detailed geomorphological map of the NE Valley, Hurd Peninsula (legend in figure 6).

Fig. 5 – Mapa geomorfológico de pormenor do Vale NE, Peninsula Hurd (a legenda encontra-se na figura 6).

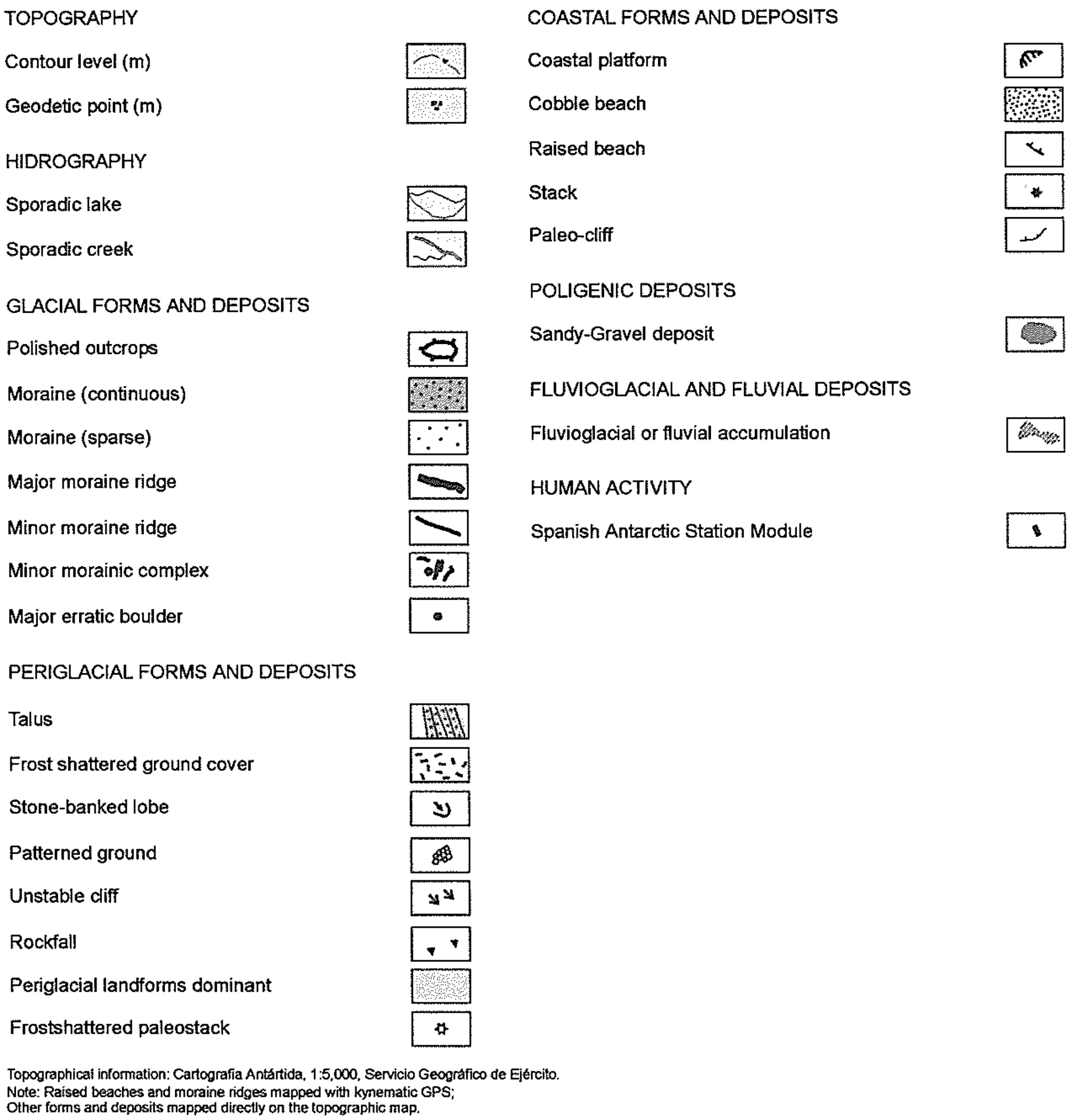


Fig. 6 – Legend of the detailed geomorphological maps.
Fig. 6 – Legenda dos mapas geomorfológicos de pormenor.

Two types of moraines were mapped with the GPS-RTK. The major moraine ridges correspond to the lateral and frontal elements with more than 4-5 m height. The minor moraine ridges include all the smaller ridges constituted by glacial material. They include small lateral moraines, push-moraines and ablation complexes.

5.2 Detailed geomorphological map of the Spanish Cove

The Spanish cove area is an overdeepened valley basin filled with Holocene beach sediments to an altitude of *ca.* 20 m ASL (BERGAMÍN *et al.*, 1997). The valley was deglaciated earlier than the NE valley and the moraine located *ca.* 70 m SSW from the SAS is the older moraine remnant in the valley (MARTÍNEZ DE PISÓN *et al.*, 1991; LÓPEZ-MARTÍNEZ *et al.*, 1992a; PALLÀS, 1996). PALLÀS (1996) estimates that this part of the valley is deglaciated after *ca* 6290-6400 BP.

Raised beach terraces are widespread in the South Shetlands and have become a classical research theme in the area (e.g. JOHN & SUGDEN, 1971). The beach sequence of the Spanish Cove is a set of terraces that have been studied in detail by LOPÉZ-MARTÍNEZ *et al.* (1992) and by PALLÀS (1996). Detailed maps of the beaches and cross-sections have been published before (MARTÍNEZ DE PISÓN *et al.*, 1991; LOPÉZMARTÍNEZ *et al.*, 1992a and b; PALLÀS, 1996). However, still some altitudinal differences exist between approaches from different authors, as indicated by PALLÀS (1996, p.114).

The GPS-RTK based map (fig. 6 and 7) is a contribution to the study of the site and intends to ameliorate the precision of the existing cartography. The terraces were mapped by walking along the well-defined scarps in the seaward side of the terraces. Small erosional notches were respected when possible. If an overdeepening was present in the inland side of the terrace, its position was also mapped. With this method it was possible to obtain a precise map of the 2-D position of the beaches, which is complemented by aditional altitudinal information stored in the database.

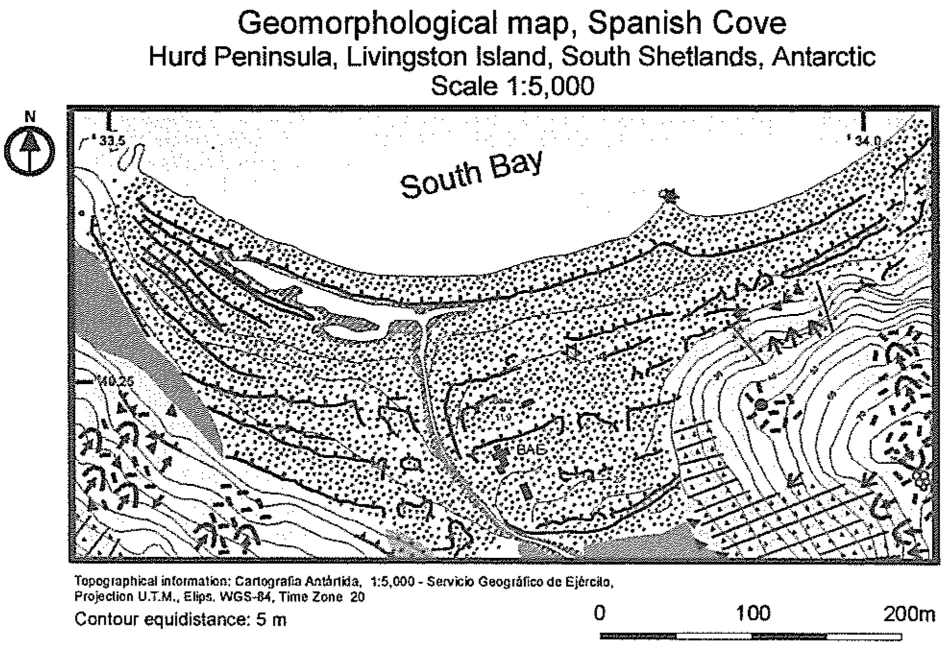


Fig. 7 – Detailed geomorphological map of the Spanish Cove, Hurd Peninsula (legend in figure 6).

Fig. 7 – Mapa geomorfológico de pormenor da Praia Espanhola, Peninsula Hurd (a legenda encontra-se na figura 6).

6. FINAL REMARKS

The application of the GPS-RTK system to the detailed geomorphological of two sample areas in Livingston Island originated very good results. It is important to note that the kind of information generated during this survey is very accurate and can be used in much more detailed scales than the 1:5,000. The independent georeferenced data allows a high flexibility for its future use making its application possible in a wide range of scales. Furthermore, the use of this kind of system allows a very accurate and fast mapping and a full integration with a GIS. These can be significant factors for its implementation, once despite its relatively high cost, the system has appplications for a wide range of mapping purposes in the framework of earth, biological or social sciences. In areas without or with bad topographic maps the GPS-RTK can also be used to generate or to correct the topographic background.

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