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Reconstructing the pattern and style of deglaciation in Professor Glacier, King George Island, South Shetlands, Antarctica

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ABSTRACT

This paper presents the application of glacial geomorphological maps for reconstructing the pattern and style of deglaciation of Professor Glacier, located at King George, South Shetland Islands, Antarctica. The geomorphological maps were compiled from aerial photographs and multitemporal satellite images, and were based on topographic profiles derived from a Digital Elevation Model. In these maps several glacial features were identified, such as moraines, meltwater channels and a U-shaped valley. The mapped data indicated that Professor Glacier area, with 0.91 km2 in 2006, showed a total loss of 0.50 km² since 1979, without frontal position advance during this period. The frontal retreat exposed the local environment and makes it susceptible to rapid post-depositional changes. The study may lead to a better understanding of glacial and periglacial processes linked to glacier geomorphology and more specifically to that from Professor Glacier. Moreover, the geomorphological maps produced can be used for monitoring local environmental changes.

Key words: glacial reconstruction, proglacial geomorphology, Professor Glacier, King George Island.

RESUMO

RECONSTRUÇÃO DO PADRÃO E ESTILO DE DEGLACIAÇÃO DA GELEIRA PROFESSOR, ILHA REI GEORGE, SHETLANDS DO SUL, ANTÁRTICA. Este artigo utiliza mapas geomorfológicos glaciais, na reconstrução do padrão e estilo de deglaciação da geleira Professor, localizada na ilha King George, ilhas Shetland do Sul, Antártica. Os mapas geomorfológicos foram elaborados a partir de fotografias aéreas e imagens de satélite multitemporais, além de perfis do terreno derivados de levantamento topográfico. Foram identificadas várias feições glaciais, como morainas, canais de água de degelo e vales em forma de U. Os dados mapeados indicam que a área da geleira Professor, de 0,91 km² em 2006, apresentou uma perda total de 0,50 km² desde 1979, sem que houvesse avanço da sua posição frontal no período. Com o processo de retração parte da paisagem foi exposta e sujeita às alterações ambientais. O presente estudo contribui para um melhor entendimento dos processos glaciais e periglaciais em geral e, mais especificamente, com aqueles relacionados com a geomorfologia da geleira Professor. Além disto, os mapas geomofológicos produzidos podem ser úteis no monitoramento de mudanças locais.

Palavras-chave: reconstrução glacial, geomorfologia proglacial, geleira Professor, ilha Rei George.

INTRODUCTION

The glacial geomorphology focuses on landform characterization, where the spatial distribution analysis of glacial landforms is an important approach to better understand the landform genesis, revealing patterns and relationships of glacial landforms at different scales (Napieralski *et al.*, 2007). With this objective, sedimentary deposits and landforms can be analyzed for ice mass reconstruction (Bennett and Glasser, 1996) and photogrammetry can provide information about the location and distribution of ice marginal landforms.

In the subpolar maritime climates characteristic of King George Island, extensive cloud cover are common during most of the year, and can significantly influence the data acquisition from optical sensors. The use of aerial photographs could provide greater flexibility in data acquisition and constitute an important source of information to elaborate geomorphological maps and generate high accuracy Digital Elevation Models (DEM). Yet, aerial photographs have been often used to describe topographic features with accuracy (Dixon *et al.*, 1998).

This paper proposed the geomorphological mapping of glacial ice-free areas of the Professor Glacier, at King George Island. The extent and position reached by this glacier in its several stages of retreat were quantified, and the data were used to study its deglaciation evolution.

STUDIED AREA

Professor Glacier, located at Martel inlet, King George Island, South Shetland archipelago (61°54'- 62°16'S and 57°35'- 59°02'W), in the north-western tip of the Antarctic Peninsula (Figure 1). It is characterized by a proglacial front installed over a rock substrate of predominantly volcanic origin (Curl, 1980). Several studies have provided evidence of glacial retreats in the Martel inlet since 1956 (Simões and Bremer, 1995; Bremer, 1998; Park *et al.*, 1998; Simões *et al.*, 1999; Braun and Gossmann, 2002).

METHODS

The orthophographies and DEM were generated from panchromatic vertical aerial photographies at scale of 1:50.000, taken on 22nd January 2003 and provided by the *Servicio Aerofotogrametrico de la Fuerza Aerea de Chile* (SAF).

The georeferenced data were generated in LPS software (Leica Photogrammetry Suite) and the LPS automatically generated planialtimetric points were interpolated in ArcGIS™, using the method ordinary Kriging. The interpolated surface has a spatial resolution of 0.7 m and was used to derive longitudinal and transverse profiles of Professor Glacier. Orthorectified images from SPOT (acquired on February, 1988, and on March, 1995 and 2000) and from COSMO-SKYMED (acquired on February, 2011), was used to map the several glacier frontal positions.

The identification of glacial marginal landforms was based on visual interpretation of the orthoimages and on the topographic profiles. Glacial landforms that indicated glacier former during retreat processes were investigated and mapped, based on aspects of the morphology described by Glasser and Jansson (2005), Gustavsson *et al.* (2006) and Benn and Evans (2010). The geographical distribution of landforms and multitemporal images were used for reconstructing the pattern and style of deglaciation of Professor Glacier.

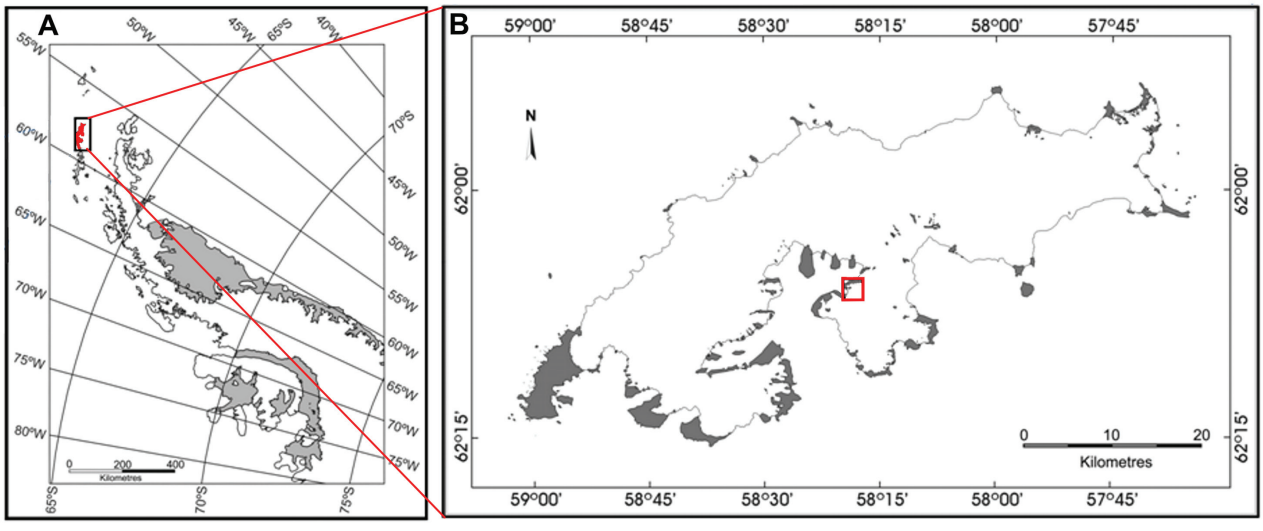

Figure 1. A. Map of the north-western part of Antarctic Peninsula detains the location of King George Island; **B.** King George Island and the Professor Glacier studied area.

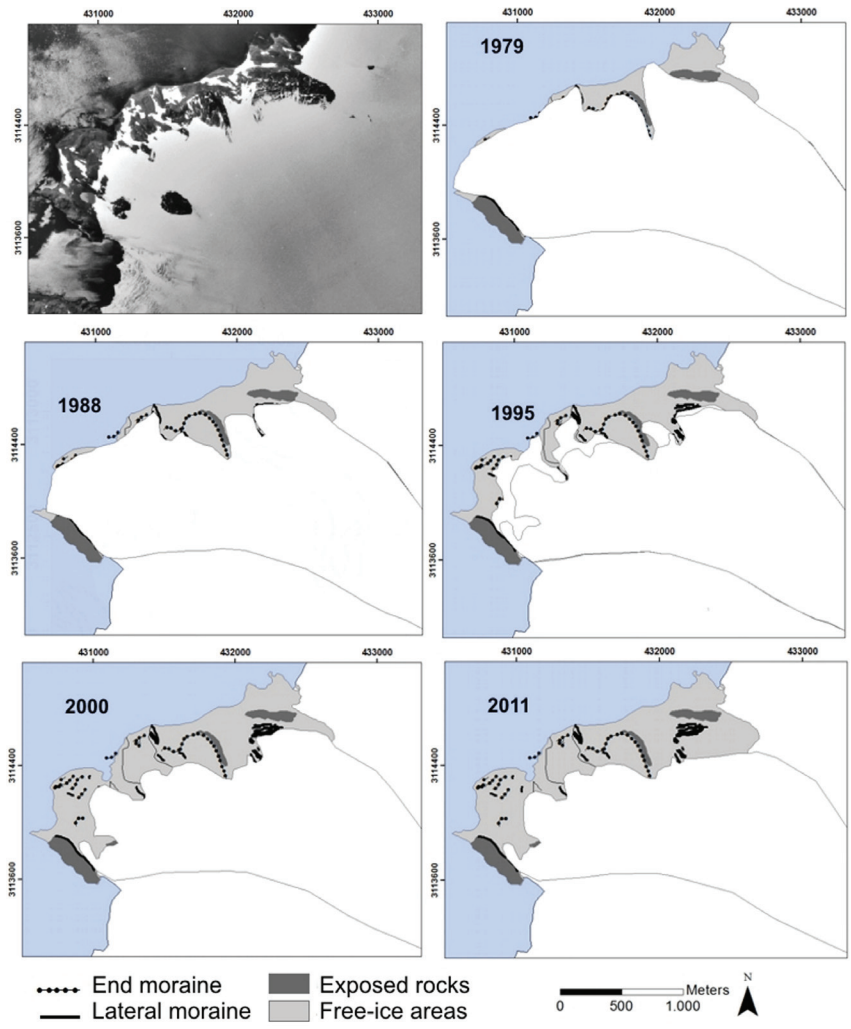

Figure 2. Geomorphological maps of Professor Glacier showing its frontal position in distinct years and several stages of retreat.

RESULTS

The geomorphological maps (Figure 2), as well as transverse and longitudinal profiles (Figure 3), indicate the presence of a U-shaped valley and melt water channels, with lateral and recessional moraines ridges (Figure 4). The exposure of the several landforms and proglacial deposits was a direct consequence of the glacier retreat. Also the proglacial topographic profiles of Professor Glacier (Figure 3) showed a large environment of deglaciation and some shoreline ridges that could indicate the presence of recessional moraines at glacier frontal area. These were often discontinuous, due to paraglacial reworking by meltwater channels.

DISCUSSION

The role of glacier reconstruction as a source of palaeoclimatic information has been recognized by the analysis of empirical relationships between glaciers and climate (Sissons and Sutherland, 1976; Sutherland, 1984; Ohmura *et al.*, 1992; Paterson, 1994). The retreat processes of those glaciers are linked to the atmospheric warming recorded over the recent decades, and is in accordance to Kääb *et al.* (2007) proposition, that glacial and periglacial environments are sensitive to climate changes. According to Blindow *et al.* (2010), the mean annual air temperature at King George Island has been rising about 1°C during the past three decades. This process has increased the negative mass balance of local glaciers (Braun *et al.*, 2001).

The Professor Glacier has landforms created by glacial, glaciofluvial, glaciolacustrine, glaciomarine and paraglacial processes of mass movement. The glacier retreat processes have exposed a landscape susceptible to rapid post-depositional change, and have given place to the accumulation of debris flow moraine deposits in the steep slopes of the proglacial area. Those mass movements in moraine ridges are herein considered as effects of environmental changes in the study area.

The data obtained attest the effectiveness of the geomorphological mapping in the analysis of recent glacial active phase, to the establishment of deglaciation processes and in the landscape evolution of ice-free areas, all resulting from the glacier reduction.

The resulting mapping indicated that Professor Glacier, with an area corresponding to 0.91 km² in 2006 has had a total loss of 0.50 km² since 1979 (Table 1), without frontal position advance. The largest ice loss area coincides with the interval between 1979 and 1988, confirming the previous non published data of Arigony-Neto (2001).

It was also possible to observe that the lateral and frontal moraines in the exposed proglacial area were linked to stages of retreat stabilization (Figure 4). Frontal moraines are generally curved, reflecting the shape of previous glacier front edge, so the landforms dimensions indicated a glacier front with low ice thickness in recent times.

Reconstructing the evolution of Professor Glacier, it was possible to observe a proglacial front about the 90's, indicating a probable low tide phase before the 90's. Finally, the pattern of ice flow seemed to be influenced by local topography. According to Moll *et al.* (2006)

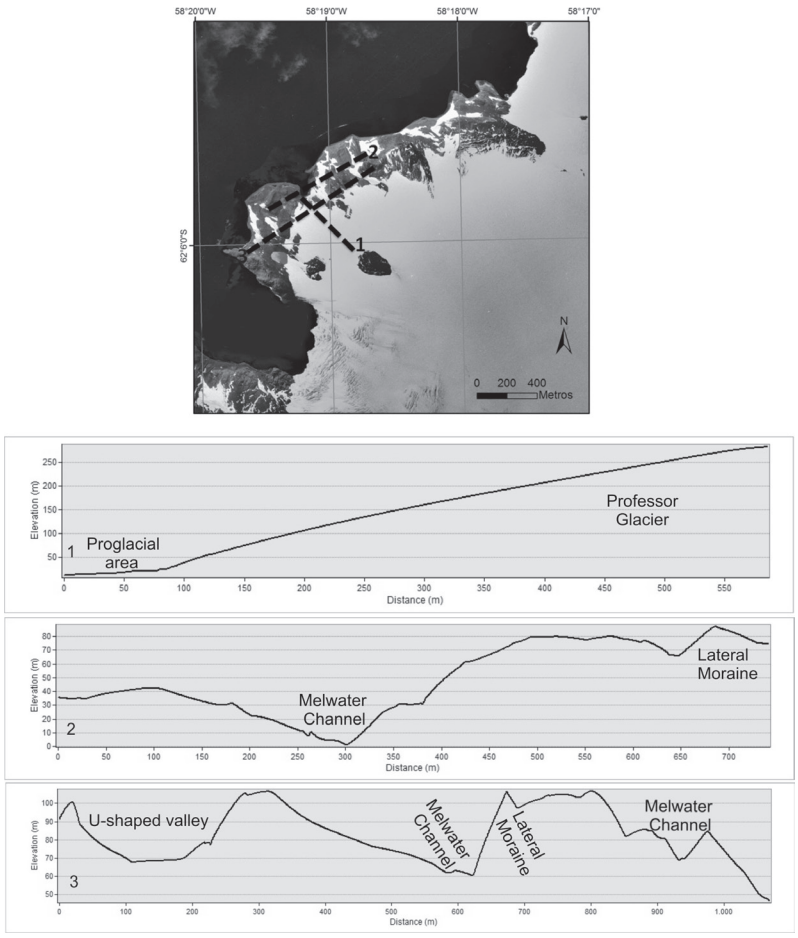

Figure 3. A. Longitudinal profiles of Professor Glacier derived from DEM; **B-C.** Transversal profiles obtained by the same method, showing the low slope and the proglacial terminal part of the glacier.

the ice surface velocity on the Professor Glacier was a few centimetres per day. Actually, the glacier has a stagnant ice body, with melting processes.

CONCLUSIONS

Using the geomorphic interpretation and effective application of automated digital photogrammetry and Remote Sensing, this study allows to detected glacial geomorphologic features (moraines, melt water channels and U-shaped valley).

The results show a reduction of Professor Glacier over the last decades, more expressive in the years between 1979-2006, when a loss of nearly 0.50 km^2 of ice cover had occurred, accompanied by a halt in advance of the ice front. The retreat processes exposed a landscape being susceptible to rapid post-depositional changes.

The spatial distribution of the landforms and the geomorphological maps contributed for reconstructing the pattern and style of the deglaciation of Professor Glacier, and the geomorphologic interpretations of marginal glaciations provided information about the glacier dynamics. So, those procedures are a good tool in monitoring periglacial and glacial changes.

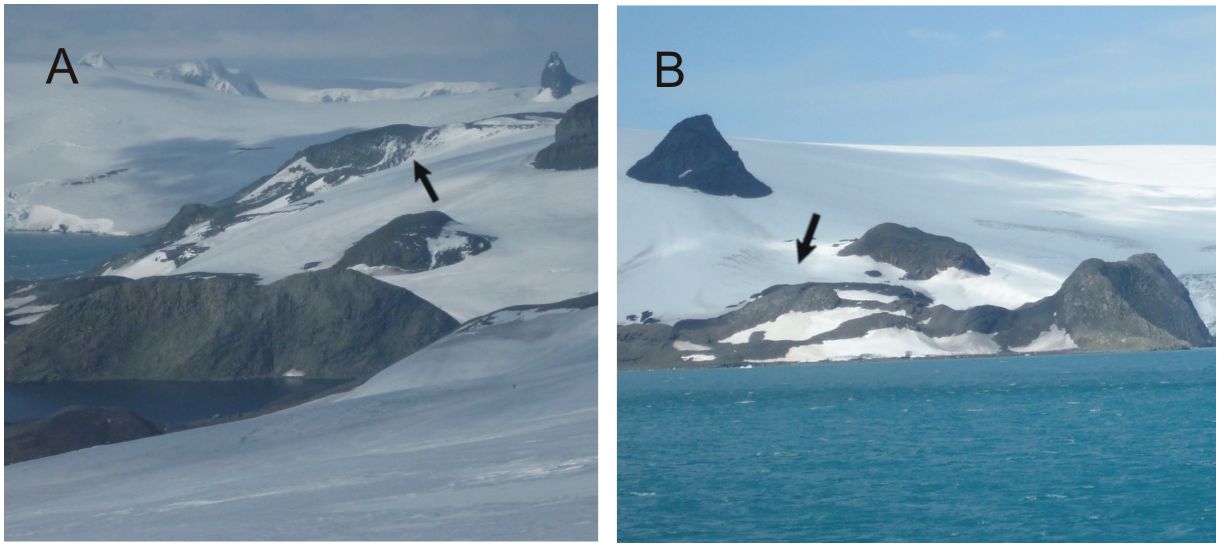

Figure 4. A. Lateral end of the moraine ridge deposits in the proglacial area of professor Glacier; B. recessional end of the moraine ridge deposits and some of the rocky basement, sculpted by glacier action. Photographies by Guilherme Fernandez, taken in 2011.

Table 1. Total area of Professor Glacier and its retreat rate since 1979, derived from multitemporal satellite images.

Area in 2011 (km²)	Lost ice area (km²)			
	2011 - 2000	2000 - 1995	1995 - 1988	1988 - 1979
1.91	0.06	0.13	0.08	0.23

Those data together allow attesting the influence of climatic conditions over the glacier type and of its proglacial area, attesting the impact of recent climate variability.

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REFERENCES

ARIGONY-NETO, J. 2001. *Determinação e interpretação de características glaciológicas e geográficas, com sistema de informações geográficas na Área Antártica Especialmente Gerenciada da baía do Almirantado, ilha Rei George, Antártica*. Masters Dissertation, Universidade Federal do Rio Grande do Sul, Porto Alegre, 84 p.

BENN, D.I.; EVANS, D.J.A. 2010. *Glaciers and Glaciation*. London, Arnold, 816 p.

BENNETT, M.R.; GLASSER, N.F. 1996. *Glacial Geology - Ice Sheets and Landforms*. New York, John Wiley & Sons Ltd., 364 p.

BLINDOW, N.; SUCKRO, S.K.; RÜCKAMP, M.; BRAUN, M.; SCHINDLER, M.; BREUER, B.; SAURER, H.; SIMÕES, J.C.; LANGE, M.A. 2010. Geometry and thermal regime of the King George Island ice cap, Antarctica, from GPR and GPS. *Annals of Glaciology,* **51**(55):103-109.
http://dx.doi.org/10.3189/172756410791392691

BRAUN, M.; GOSSMANN, H. 2002. Glacial changes in the area of Admiralty Bay and Potter Cove, King George Island, Antarctica. *In*: M. BEYER; M. BOELTER (ed.), *GeoEcology of Terrestrial Antarctic Oases*. New York, Springer Verlag, p. 75-89.

BRAUN, M.; SAURER, H.; SIMÕES, J.C.; VOGT, S.; GOSSMANN, H. 2001. The influence of large scale atmospheric circulation on surface energy balance and ablation on King George Island, Antarctica. *International Journal of Climatolology*, **21**(1):21-36.
http://dx.doi.org/10.1002/joc.563

BREMER, U.F. 1998 *Morfologia e bacias de drenagem da cobertura de gelo da ilha Rei George, Antártica*. Masters Dissertation, Universidade Federal do Rio Grande do Sul, Porto Alegre, 119 p.

CURL, J.E. 1980. A glacial history of the South Shetland Islands, Antarctica. *Institute of Polar Studies Report*, 129 p.

DIXON, L.F.J.; BARKER, R.; BRAY, M.; FARRES, P.; HOOKE, J.; INKPEN, R.; MEREL, A.; PAYNE, D.; SHELFORD, A. 1998. Analytical photogrammetry for geomorphological research. *In*: S.N. LANE; K.S. RICHARDS; J.H. CHANDLER (eds.), *Landform monitoring, modelling and analysis*. Chichester, John Wiley & Sons, p. 63-94.

GLASSER, N.F.; JANSSON, K.N. 2005. Fast-flowing outlet glacier of the Last Glacial Maximum Patagonian Icefield. *Quaternary Research*, **63**:206-211.
http://dx.doi.org/10.1016/j.yqres.2004.11.002

GUSTAVSSON, M.; KOLSTRUP, E.; SEIJMONSERGEN, A.C. 2006. A new symbol-and-GIS based detailed geomorphological mapping system: renewal of a scientific discipline for understanding landscape development. *Geomorphology*, **77**:90-111.
http://dx.doi.org/10.1016/j.geomorph.2006.01.026

KÄÄB, A.; CHIARLE, M.; RAUP, B.; SCHNEIDER, C. 2007. Climate change impacts on mountain glaciers and permafrost. *Global Planet Change*, **56**(1-2):vii-ix.
http://dx.doi.org/10.1016/j.gloplacha.2006.07.008

MOLL, A.; BRAUN, M.; LLUBERAS, A. 2006. Determination of glacier velocities on King George Island (Antarctica) by DInSAR. *In* : H. LACOSTE; L. OUWEHAND (eds.), *Fringe 2005 Workshop, Proceedings of the conference held 28 November–2 December, 2005*. Frascati, Italy, European Space Agency (ESA), SP-610. [CD-ROM].

NAPIERALSKI, J.; HARBOR J.; LI Y.K. 2007. Glacial Geomorphology and Geographic Information Systems. *Earth Science Review*, **85**:1-22.
http://dx.doi.org/10.1016/j.earscirev.2007.06.003

OHMURA, A; KASSER, P.; FUNK, M. 1992. Climate at the equilibrium line of glaciers. *Journal of Glaciolology*, **38**:397-411.

PARK, B.K; CHANG, S.K.; YOON, H.I.; CHUNG, H. 1998. Recent retreat of ice cliffs, King George Island, South Shetland Islands, Antarctic Peninsula. *Annals of Glaciology,* **27**:633-635.

PATERSON, WSB. 1994. *The physics of glaciers*. 3rd ed., Pergamon, Oxford, 180 p.

SIMÕES, J.C.; BREMER, U.F.1995. Investigations of King George Island ice cover using ERS-1/SAR and SPOT imagery. *Revista SELPER*, **11**(1-2):56-60.

SIMÕES, J.C.; BREMER, U.F.; AQUINO, F.E.; FERRON, F.A. 1999. Morphology and variations of glacial drainage basins in King George Island icefield, Antarctica. *Annals of Glaciology*, **29**:220-224.
http://dx.doi.org/10.3189/172756499781821085

SISSONS, J.B.; SUTHERLAND, D.W. 1976. Climatic inferences from former glaciers in the south-east Grampians, Scotland. *Journal of Glaciology*, **17**:325-346.

SUTHERLAND, DW. 1984. Modern glacier characteristics as a basis for inferring former climates with particular reference to the Loch Lomond Stadial. *Quaternary Science Reviews,* **3**:291-309.
http://dx.doi.org/10.1016/0277-3791(84)90010-6

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