

IVAN CARLOS CARREIRO ALMEIDA

**SOLOS DE LIONS RUMP, ANTÁRTICA MARÍTIMA: GÊNESE, CLASSIFICAÇÃO,
MAPEAMENTO E MONITORAMENTO DA CAMADA ATIVA**

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Solos e Nutrição de Plantas, para obtenção do título de *Doctor Scientiae*.

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(Orientador)

Aos meus queridos pais, Carlos Lacerda de Almeida e Jacira Caminote Carreiro Almeida, e ao meu querido irmão Alan Carreiro Almeida, pelo amor e exemplo de vida.

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Happy the man who finds wisdom,
the man who gains understanding!
Proverbs 3, 13

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BIOGRAFIA

IVAN CARLOS CARREIRO ALMEIDA, filho de Carlos Lacerda de Almeida e Jacira Caminote Carreiro Almeida, nascido em 12 de abril de 1983, na cidade de Governador Valadares, Minas Gerais. Iniciou o curso de Agronomia na Universidade Federal de Viçosa (UFV) em 2001. Em 2005 foi trainee nos Estados Unidos. Ao longo do curso de graduação foi três vezes bolsista de Iniciação Científica do PIBIC/CNPq e uma vez bolsista da FUNARBE. Graduou-se em outubro de 2006 e, neste mesmo ano, ingressou no curso de Mestrado em Solos e Nutrição de Plantas da UFRV, submetendo-se a defesa em julho de 2008, mesmo ano que se iniciou no doutorado do programa de pós-graduação em Solos e Nutrição de Plantas do Departamento de solos da UFRV. Durante o doutorado participou da OPERANTAR XXVII, XXVIII e XXIX e realizou parte do seu doutoramento na Wisconsin University – Madison – EUA através do programa de doutorado sandwiche sobre orientação do professor James Bockheim. Em junho de 2011 iniciou-se sua carreira profissional como professor do Instituto Federal do Norte de Minas Gerais (IFNMG), campus Januária. Em agosto de 2012 submeteu-se a defesa de sua tese de doutorado.

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RESUMO

ALMEIDA, Ivan Carlos Carreiro, D.Sc., Universidade Federal de Viçosa, agosto de 2012. **Solos de Lions Rump, Antártica Marítima: Processos de Formação, Classificação, Mapeamento e monitoramento da camada ativa.** Orientador: Raphael Bragança Alves Fernandes. Coorientador: Carlos Ernesto Gonçalves Reynaud Schaefer

Nas áreas mais periféricas da Antártica, cada vez mais se verifica o aumento de áreas livres de gelo e a formação de solos, que merecem ser mais bem estudados para subsidiar ações de gestão e preservação. Neste contexto, o presente estudo articula-se dentro de uma ampla rede de cooperação científica brasileira para a região Antártica, com foco especial na área conhecida como Lions Rump, localizada na Baía Rei George, na Antártica Marítima. O objetivo do trabalho foi caracterizar os processos de formação de solos da área, suas principais características físicas, químicas, mineralógicas e micromorfológicas, o regime térmico-hídrico, as formações geomorfológicas presentes, finalizando com a classificação e mapeamento dos solos. Para isto a área foi percorrida e vinte e seis perfis de solos foram descritos, amostrados e analisados. Os resultados indicaram que os solos foram formados, principalmente, a partir do intemperismo de rochas basálticas-andesíticas, apresentando a apatita como mineral acessório e elevado *background* de P. Propriedades químicas do solo, mineralogia e tipo de vegetação foram fortemente influenciadas pela duração da ocupação por pinguins e pela drenagem do solo. As principais formações vegetacionais da área foram determinantes para o regime térmico-hídrico da camada ativa dos solos. Os resultados obtidos permitiram agrupar os solos de Lions Rump em três grupos, em função da influência ornitogênica. Os solos ornitogênicos de pH ácido predominam nas posições da paisagem mais antigas e estáveis, onde a ocupação das aves foi mais duradoura. Apresentam densa cobertura vegetal com plantas superiores, baixo pH e saturação de bases, elevados teores de P, Al⁺³, carbono orgânico total (COT) e N total. Os solos ornitogênicos de pH neutro, semelhante aos anteriores, apresentam altos teores de P e densa cobertura vegetal, entretanto possuem alta saturação de bases e valores de pH próximos do neutro. Esses estão presentes em áreas recentemente ocupadas pela influência ornitogênica, especialmente nas morainas quaternárias

e terraços soerguidos. A principal diferença entre os dois grupos de solos ornitogênicos foi o tempo de exposição à influência das aves e a quantidade de deposição de guano. Nesses solos ornitogênicos, a fosfatização é o principal processo de formação do solo, em que os minerais fosfatados são formados a partir da interação do guano com os minerais primários dos solos. Por sua vez, os solos não ornitogênicos apresentam pH básico, elevada saturação de bases, baixo COT e praticamente desprovidos de vegetação. Os principais solos identificados na área foram Typic Dystrogelepts ornithic e Typic Gelorthents ornithic, que possivelmente representam uma das primeiras áreas livres de gelo colonizados por pinguins na Antártica Marítima. O solo Typic Dystrogelepts ornithic representam os solos mais profundos, mais estruturados e avermelhados identificados em Lions Rump. Nas posições acima de 80 m de altitude acima do nível do mar, especialmente nas áreas de topo e manchas paraglaciais, destacam-se os solos Typic Haploturbels e Lithic Haploturbels, que representam a maior cobertura de solo na área estudada. Esses fazem parte do grupo dos Gelisols (Cryosols), que são solos com materiais gelic dentro dos primeiros 100 cm da superfície e permafrost dentro dos 200 cm da superfície. Nos solos Typic Haploturbels e Lithic Haploturbels presentes na borda das geleiras, o permafrost encontra-se nos primeiros 100 cm do solo e os processos de crioturbação são mais expressivos. Entre 40 e 80 m de altitude, aparecem os solos Typic Haploturbels e Lithic Haploturbels, que não apresentam influência de nidificação de aves e nem permafrost nos primeiros 200 cm do perfil. No primeiro nível dos terraços e praias, ao longo da zona costeira, dominam os solos Vitrandic Cryopsamments e Oxyaquic Cryopsamments. Em áreas muito limitadas ainda aparecem os solos Cryorthents ornithic, associados aos afloramentos de rochas (plugs basálticos) próximos da praia; e Typic Gelifluvents ornithic, em pequenos leques aluviais glaciares. Os processos de formação de solos salinização e podzolização, bem como feições redoximórficas não foram observados. O monitoramento da camada ativa e permafrost foram realizados pela instalação de sensores de umidade e temperatura do solo, e do ar, em dois sítios próximos, na mesma altitude, mesma classe de solo, ambos Cambissolo Gélico com cobertura vegetal diferenciada. Uma área era coberta por campo de musgo (*Andrea gainii*) situada em um canal de drenagem e a outra área, um pouco mais elevada, coberta por comunidade de líquens dominada por *Usnea antarctic* and *Ochrolechia frigida*. Resultados mostraram que em ambos os sítios de monitoramento os sensores não alcançaram o *permafrost* até 80 cm, mas devido às temperaturas registradas no verão estarem próximas de zero, provavelmente o *permafrost* está próximo dos 100 cm abaixo da superfície. No campo de musgo a variação da temperatura foi menor, esta menor amplitude

está relacionada com o poder tampão da temperatura proporcionado pelo maior conteúdo de água neste sítio.

ABSTRACT

ALMEIDA, Ivan Carlos Carreiro, D.Sc., Universidade Federal de Viçosa, agosto de 2012. **Soil of Lions Rump, Maritime Antarctica: Soil formation process, survey, mapping and thermal monitoring of the active layer.** Adviser: Raphael Bragança Alves Fernandes. Co-adviser: Carlos Ernesto Gonçalves Reynaud Schaefer

In the peripheral areas of Antarctica, there is an increase in ice-free areas and soil formation, which deserve further study to support programs to management and preservation. In this context, the present study is structured within a wide network of Brazilian scientific cooperation for the Antarctic region, with a special focus in the area known as Lions Rump, located in the King George Bay, Maritime Antarctica. The objective of this study was to evaluate the processes of soil formation in the area, its main physical, chemical, mineralogical and micromorphological characteristics, the hydrothermal regime, geomorphological formations present, ending with the classification and mapping of soils according to the WRB and USDA classification systems. Twenty-six soil profiles from Lions Rump (LR), King George Bay, Maritime Antarctica were described, sampled and analyzed for their physical, chemical and mineralogical properties, as a result, a soil map was made. Results showed that soils in LR are most formed from weathered basalt-andesitic rocks, having apatite as accessory mineral, with high P background. For this purpose, the area was covered and twenty-six soil profiles were described, sampled and analyzed. The results indicated that soil chemical properties, mineralogy and vegetation type were strongly influenced by the duration of the occupation by penguins and soil drainage. The main vegetation formations within the area were instrumental in the water-thermal regime of the active layer of soil. The results grouped Lions Rump soils into three groups, depending on the ornithogenic influence. Acidic pH Ornithogenic soils predominate in the oldest and most stable of positions the landscape, where the occupation of the birds was longer lasting. They have dense vegetation with higher plants, low pH and base saturation, high levels of P, Al^{3+} , total organic carbon (TOC) and total nitrogen. Neutral pH ornithogenic soils, similar to previous ones, have high levels of P and dense vegetation; however, have high base saturation and pH close to neutral. These are present in areas recently occupied by the

ornithogenic influence, especially in the Quaternary moraines and uplifted terraces. The main difference between the two groups of ornithogenic soils was the exposure time under the influence of the bird and the amount of guano depositions. In ornithogenic soils, *phosphatization* is the main process of soil formation, in which the phosphate minerals are formed from the interaction of guano with the primary minerals of the soil. Non-ornithogenic soils have basic pH, high base saturation, low TOC and almost devoid of vegetation. Typic Dystroglepts ornithic and Typic Gelorthents ornithic are the main soils in LR, which possibly represents one of the first ice-free areas colonized by penguins in Maritime Antarctica. Typic Dystroglepts ornithic from LR represent the deepest, most structured and reddish soils so far described in the area. Typic Haploglepts ornithic are the main soils on first and second moraine levels from the White Eagle Glacier. Typic Haplorthels and Lithic Haplorthels are present just above 80 m a.s.l., especially on the top areas and paraglacial spots, and represent LR Gelisols, with gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface. Despite their occurrence only at higher altitudes, they represent the greatest soil cover in the studied area. Turbic Haploglepts and Typic Haplorthents are situated between 40 and 80 m a.s.l., without bird nesting influence and absent of permafrost within 200 cm in the profile. Vitrandic Cryosamments and Oxyaquic Cryosamments dominated the first level of terraces and former beaches along the coastal area. Other soils classified are present in very limited areas: Lithic Cryorthents ornithic, present on the sea stacks rock outcrops (basaltic plugs) close to the beach, and Typic Gelifluvents ornithic represent a small area on glacial alluvial fans. Overall, the distribution and classification of local soils allowed the separation of two main soil domains in LR: (1) Ornithogenic soils (without permafrost) and the Gelisols (above 80 m a.s.l.). The monitoring of active layer thermal regime at Lions Rump was realized in two shallow boreholes, geographic closed, at proximally altitude and same soil class but under different vegetation. The ground temperature series were collected at 1-hour intervals, recorded of two years from March 2009 to February 2011. In both boreholes, a network of three soil temperatures sensors were installed at 10, 30 and 80 cm depths, one moisture sensor at 80 cm and one air temperature sensor 100 cm height. The two sites show significant differences of the mean annual ground temperature for all depths. The moss site show lower soil temperature amplitude than Usnea site. The soil temperature at Usnea site followed most the variability of air temperate. Moss site show more soil humid throughout the years because of his position on the landscape (water track). The buffer effect on moss site happens because of the high content of water available associated with the moss

vegetation. The active layer in both sites of Lions Rump is thick and the both boreholes did not reach the permafrost table, but probable it is between one meter depth.

INTRODUÇÃO GERAL

A Antártica contém 90% do gelo do mundo. Ela exerce influência predominante no clima do hemisfério sul e na atmosfera global e nos sistemas criosféricos por causa da sua altitude e posição geográfica (Ugolini & Bockheim, 2008). A formação de solo na Antártica está restrita a menos de 0,35% do continente (45.000 km²), abrangendo áreas livres de gelo, localizadas na costa e nos vales secos glaciais entre as montanhas (Campbell e Claridge, 1987, Bockheim, 1997).

Na Antártica, o intemperismo químico em princípio, não é suficientemente importante para causar grandes mudanças na composição da massa de rochas e solos (Kelly & Zumberge, 1961, citados por Lee, 2004). As conclusões gerais sobre a formação do solo na Antártica são de que os processos químicos de intemperismo funcionam apenas de forma muito limitada e que, a desintegração da rocha e formação do solo é provocada em grande parte por processos físicos, embora Simas et al. (2008) tenham sugerido uma atuação mais forte de intemperismo químico que o previsto, na Antártica Marítima. A vegetação é restrita a musgos, líquens e algas devido à severidade do ambiente, sendo que plantas superiores não ocorrem devido às baixas temperaturas e fortes ventos. No entanto, na área denominada Antártica marítima, que abrange partes da Península Antártica e as ilhas, o clima é mais quente e apresenta mais água no estado líquido, favorecendo o intemperismo químico. Os solos nesta parte da Antártica são caracterizados pela maior predominância de processos de crioturbação, como evidenciado pela presença de solos com padrões “patterned ground” (Campbell & Claridge, 1987).

Estudos realizados por Hall (1997) mostraram que a principal limitação para a atuação do intemperismo físico associado ao congelamento e descongelamento não é a temperatura, mas sim a presença de água no sistema. Nas áreas livres de gelo das regiões costeiras, a formação do solo e a atuação dos processos de intemperismo químicos ocorrem em maior intensidade do que se pensava anteriormente (Blume et al., 1997; Beyer et al., 2000). Embora as reações sejam presumivelmente lentas em condições antárticas, o intemperismo químico ainda é sugerido como o principal processo para a elevação dos teores de Mg, Ca e íons carbonatos para a formação dos depósitos de sais (Keys & Williams, 1981, citados por Lee, 2004). A deposição de material orgânico pelas aves marinhas também apresenta importante papel na formação de solos nessas áreas.

Como em outras regiões do mundo, o desenvolvimento de solos na Antártica é influenciado pelo

clima, material de origem, topografia e atividade biológica ao longo do tempo. O clima é um dos fatores mais importantes para a formação de solos na Antártica, pois influencia a quantidade de umidade disponível no perfil, o que irá determinar a gênese dos solos (Campbell & Claridge, 1987), a presença de permafrost (French, 2001) e a ocorrência e tipo de vegetação (Ellenberg, 1988). Na Antártica Marítima, o clima também é o fator mais relevante para o desenvolvimento do solo, uma vez que a combinação de maior precipitação (pode superar 500 mm ano⁻¹) e temperaturas mais altas são mais favoráveis à existência da vida vegetal, consistindo ainda em local de acúmulo de quantidades significativas de matéria orgânica no solo.

Mudanças climáticas no passado influenciaram a vegetação com relação às espécies e complexidade das comunidades, exercendo impacto significativo sobre suas características e distribuição (Birks, 1991; Wick & Tinner 1997; ambos citados por Cannone, 2006). Mesmo atualmente, os permafrost têm demonstrado ser altamente suscetíveis às alterações climáticas (Osterkamp 2005), sobretudo quando em distribuição descontínua. O clima influencia o permafrost, a espessura da camada ativa, a vegetação e as propriedades do solo de forma que estes componentes ambientais interagem via mecanismos complexos, afetando os processos pedogenéticos.

A camada ativa refere-se à camada de solo que está sujeita a congelamento e descongelamento anual. Como regra geral, é mais fina nas regiões polares (15 cm), sendo mais espessa nas sub-regiões da Antártica (100 cm ou mais) (French, 2001). A espessura da camada ativa pode variar de ano para ano, dependendo da temperatura ambiente, grau e orientação do declive, vegetação, drenagem, cobertura de neve, o solo e/ou tipo de rocha (French, 2001) e, principalmente, da umidade do perfil (Hall, 1997).

A profundidade da penetração da frente fria no perfil depende principalmente da intensidade do frio, de sua duração, das propriedades térmicas e físicas do solo e rochas, da vegetação subjacente, da cobertura de neve (French, 2001) e do teor de água livre no solo.

Os solos que ocorrem em áreas livres de gelo na Antártica continental e são geralmente quase totalmente desprovidos de matéria orgânica, sendo denominados de “Ahumic soils” por Tedrov & Ugolini (1966), citados por Tatur (1989). Quando presente uma cobertura vegetal de musgos e líquens são denominados de “Protoranker soils”. A influência da população biológica é quase indetectável nos ahumic soils, que apresentam teores de C orgânico e N extremamente baixos. Em contrapartida, nos protoranker soils a influência da vegetação pode ser comprovado pelos maiores teores de C e N na parte superior do perfil, alcançando até mais que 7% de C no horizonte orgânico superficial e, acima de 1,2%, nas camadas minerais subsuperficiais (Campbell & Claridge, 1987). Em subsuperfície, o enriquecimento orgânico se dá, em grande parte, pela presença de raízes e outros fragmentos de plantas, e não de materiais humificados, sendo que as relações C/N variam de 6 a 16. Tendo em vista a presença de materiais orgânicos não decompostos, esses índices parecem indicar a existência de uma fonte externa

de N, possivelmente a partir de organismos fixadores, excrementos de aves ou via absorção pelas plantas de nitrato presente nos sais solúveis na água (Campbell & Claridge, 1987). Na Antártica marítima, os solos protoranker são mais comuns, abrangendo grande porção do ambiente, em especial na cobertura das morainas, onde a superfície é mais estável (Campbell & Claridge, 1987).

Com relação à vegetação presente na Antártica Marítima, Holdgate et al. (1967) verificaram quatro principais tipos na Ilha Signy, que são ainda considerados como representativo desta região com variações de espécies nas diferentes áreas:

1) associação de líquens e musgos, dominada por *Usnea*, *Himantormia* e espécies de *Andreaea* presentes nas áreas expostas de solos rochosos,

2) associação de musgo (turf-moss), dominada por *Dicranum aciphyllum* e *Polytrichum strictum*, com incrustações locais de líquens, nas vertentes de inclinação moderada a íngremes, bem drenadas e ensolaradas,

3) associação de “tapetes” de musgos, dominada por *Brachythecium*, *Acrocladium*, *Pohlia* e *Drepanocladus spp*, encontrados em áreas mal drenadas,

4) comunidades de plantas vasculares, dominadas por *Deschampsia antarctica* e *Colobanthus quitensis*, em áreas bem drenadas e ensolaradas.

Devido à ausência de organismo revolvedores de solo, como as minhocas, os organismos presentes como colêmbolas, ácaros, nematoides, bactérias, protozoários e fungos estão em grande parte confinados à camada orgânica desfavorecendo a formação de húmus e mínima incorporação de matéria orgânica no solo (Campbell & Claridge, 1987). Por outro lado, Michel et al. (2006) verificaram a formação de substâncias húmicas estáveis em solos ornitogênicos na baía do Almirantado.

A concentração de nutrientes na maioria das comunidades vegetais (Albuquerque-Filho, 2005) sugere que há pouca limitação de nutrientes para o crescimento, apesar de o N poder ser o limitante em alguns casos. A principal limitação para o crescimento das plantas parece ser a instabilidade da superfície do solo, causada em grande parte pelos processos de crioturbação que impedem o estabelecimento das plantas. Quando as superfícies são estáveis, as plantas de melhor adaptação ao regime climático vigente são favorecidas e, com elas, a microfauna e microflora associada.

A ocorrência de avifauna favorece a biodiversidade e a disponibilidade de nutrientes em alguns locais, proporcionando a formação de solos ornitogênicos (Ugolini 1970; Ugolini 1972; Tatur, 1989; Tatur et al., 1997). Em ecossistemas terrestres da Antártica Marítima (Ilha Rei George), a transferência da produção primária marinha para a terra promovidas por pinguins (*Pygoscelis sp.*) e outras aves acentuam os processos de formação do solo, catalisando o intemperismo químico.

Com o degelo e conseqüente elevação glacio-isostática durante o Holoceno, um grande número de pingüineiras foram abandonadas e novas se desenvolveram nos terraços recentemente expostos mais

próximos da costa emergente e em afloramentos rochosos (Tatur et al., 1996). Na sequência, esses sítios abandonados foram cobertos pela vegetação e sujeitos aos processos pedogenéticos. Nessas áreas de ex-colônias da avifauna evoluiu um determinado tipo de solo criogênico, provisoriamente classificado como Criosolos Ornitogênicos, com base em atributos físico-químicos peculiares relacionados à acumulação de excrementos de aves e de transformação desses sítios em lugares de nidificação ao longo da costa antártica (Tatur, 1997). Estes solos são geralmente caracterizadas por baixo valores de pH, teores elevados de P, alta disponibilidade de Al^{3+} , e variável, mas geralmente elevada quantidade de Ca^{2+} , Mg^{2+} e K^+ trocáveis (Schaefer et al., 2004; Michel et al., 2006; Simas et al., 2007).

Em áreas de ex-colônias de pinguins, Michel et al. (2006) verificaram a formação de solos com claras características ornitogênicas. Nesses solos, o P é encontrado em teores próximos aos verificados nas atuais colônias (562-1.119 $mg\ dm^{-3}$), e a saturação de Al^{3+} é elevada e incrementada em profundidade em todos os perfis com características espódicas, o que indica que a matéria orgânica pode estar associada com a transformação e movimentação vertical de Al^{3+} . A distribuição dos microelementos é bastante irregular nestes solos, com teores mais elevados de Mn e Cu em áreas mais estáveis e de maior potencial redox e, teores de Zn consideravelmente elevados em locais fortemente afetados pela ornitogênese, dada sua estreita relação com organismos marinhos (Santos et al., 2005). A distribuição de Fe é regular em profundidade para todos os perfis, com valores ligeiramente superiores para os sítios ornitogênicos. Grandes áreas de colônias abandonadas por pinguins e ninhos de skua (*Catharacta* spp.) também apresentam solos fósseis com claras características ornitogênicas, como seixos de nidificação e espessa camada orgânica sobrejacente (Schaefer et al., 2004).

As pinguineiras ativas são totalmente desprovidas de vegetação devido aos efeitos tóxicos provocados pelo excesso de excrementos e pelo pisoteio dos pinguins (Tatur et al., 1996). Por outro lado, solos ornitogênicos das paleopinguineiras e sítios marginais com moderada à alta abundância de nutrientes apresentam vegetação densa e mais diversificada (Tatur, 1989).

Vários estudos realizados na Antártica Marítima provaram que materiais lixiviados a partir do guano reagem fortemente com o substrato subsuperficial, formando uma camada de material fosfatizado que pode ser subdividida em horizontes genéticos de diferente composição mineral (Tatur & Barczuc, 1983; Tatur & Myrcha, 1993a). Este processo especial de formação do solo, denominado fosfatização (Schaefer et al., 2004; Simas et al., 2008 e Schaefer et al., 2008), é possível devido à intensa entrada de material orgânico rico em P durante o verão. Tatur & Myrcha (1993b) estimaram essa contribuição de excrementos das aves como equivalente a aproximadamente $10\ kg\ m^{-2}$ (peso seco) por ano. Nesses sítios, após o abandono das aves, um oásis de vegetação se desenvolve, com maior atividade biológica, temperatura mais alta e uma camada ativa mais espessa (Myrcha et al., 1983).

Apesar da limitada distribuição geográfica, os solos ornitogênicos são os mais desenvolvidos e

os mais importantes reservatórios de C orgânico (Simas et al., 2007) na Antártida terrestre. A compreensão dos fenômenos físicos e químicos, da dinâmica da matéria orgânica e dos ciclos biogeoquímicos nas áreas polares apresenta especial relevância para a preservação desses ambientes e para um melhor entendimento da pedogênese em ambientes de extremo frio (Michel et al., 2006).

Em estudo da gênese dos solos da baía do Almirantado, na Antártica Marítima, Simas et al. (2007) descreveram e analisaram 56 perfis e verificaram que a gênese nesses solos fracamente desenvolvidos, exceto nos ornitogênicos, é muito influenciada pela litologia do material de origem. Os autores então propõem a divisão desses solos em quatro grupos principais: 1) basálticos/andesíticos, 2) sulfatados ácidos, 3) fracamente ornitogênicos e 4) ornitogênicos. Os eutric Lithic and Typic Haploturbels (Turbic-leptic Cryosols), de reações neutras a alcalinas são solos predominantes nos depósitos basálticos/andesíticos. Os ácidos dystric Sulfuric Haploturbels (Turbic-thionic Cryosols) estão limitados aos materiais andesíticos piritizados e os Umbríturbels (Turbic-umbric Cryosols) são os formados devido à influência da avifauna. Os solos ornitogênicos são os formados pela presença no passado ou atual de pinguineiras ativas. Os Organo Fibrístels são encontrados em locais mal drenados e sob espessa camada de tapetes de musgos. Trabalhos como o desses autores são interessantes, pois permitem contribuir com possíveis modificações nos sistemas de classificação de solos existentes para que possam, no futuro, enquadrar os solos da Antártica Marítima.

As regiões polares são consideradas como sistemas muito sensíveis para se estudar os impactos do clima, pois seus componentes abióticos (Weller 1998) e bióticos (Hodkinson et al., 1998) são altamente suscetíveis a perturbações. As zonas polares de ambos os hemisférios têm sido muito referenciadas como regiões-chave para a avaliação e monitoramento dos impactos das alterações climáticas. Mudanças mais evidentes e mais rápidas são esperadas nas áreas polares e as primeiras provas foram relatadas no Ártico e na Península Antártica (Convey, 2001; Cook et al., 2005; Turner et al., 2005). A influência do clima sobre o permafrost é expressa pela combinação do balanço energético na superfície e o balanço térmico, ou seja, respectivamente associado à temperatura da superfície do solo (GST) e à temperatura do permafrost devido ao aporte energético da GST. O balanço energético da superfície é influenciado por fatores como vegetação e cobertura de neve, ambas agindo como uma camada de tamponamento entre a atmosfera e o solo (Williams & Smith 1989). A cobertura do solo e, sobretudo, as mudanças na vegetação estão entre os fatores mais importantes capazes de modificar a distribuição do permafrost e seu regime térmico. Monitorar tais efeitos e associá-los às mudanças climáticas globais é um grande desafio aos pedólogos, que agora exploram com mais intensidade a Antártica Marítima.

Devido à sensibilidade do ambiente antártico as variações climáticas, a avaliação do comportamento do degelo dos permafrost é de grande valia para elucidar os possíveis impactos que o

aquecimento global pode trazer ao planeta. Isso porque a camada de gelo que cobre o solo, além de atuar como isolante térmico, favorecendo a permanência dos permafrost, favorece também a reflexão da irradiação solar contribuindo para existência dos permafrost durante todo o ano. Com avanço atual do degelo em áreas que antes estavam continuamente congeladas, a tendência é que cada ano mais área seja descoberta, pois o solo desnudo de gelo tem maior capacidade de absorção da intensidade luminosa, além de favorecer a colonização por espécies vegetais, que concomitantemente levam ao aumento da temperatura desses solos, agravando o degelo dos permafrost e ativando os processos pedogenéticos.

Assim é de grande valia e importância elucidar quais os fatores atmosféricos e do solo (mineralogia, estrutura, textura, umidade, atividade biológica) que ditam a temperatura e o controle desses permafrost.

Solos posicionados em vertentes que recebem menor irradiação solar apresentam-se menos intemperizados e menos profundos, em função da menor quantidade de energia luminosa incidente, resultando em um ambiente mais frio e seco. Esses fatores desfavorecem também a ornitogênese, muito importante para a pedogênese nas áreas mais úmidas.

De acordo com o supracitado o presente trabalho foi dividido em três capítulos, os quais tiveram como objetivos:

- Fazer o levantamento e mapeamento dos solos de Lions Rump, caracterizando os atributos químicos, físicos e mineralógicos da área e suas relações com a geomorfologia e cobertura vegetal e correlacionar características de solos, vegetação e dos processos paraglaciais e periglaciais e comparar solos ornitogênicos da área de estudo com os de outras áreas da Antártica Marítima e Peninsular.
- Estudar a fração argila dos solos de Lions Rump analisando e descrevendo as mais importantes feições micromorfológicas típicas em solos criogênicos, principalmente dos ornitogênicos..
- Avaliar o regime anual e sazonal de umidade e a dinâmica térmica da camada ativa de dois solos sobre diferente cobertura vegetal e elucidar a influência da cobertura vegetal no comportamento hidrotermal dos solos em estudo.
- E no futuro com os resultados da tese gerar também mapas de geomorfologia e vegetação da área em estudo, incluindo um banco de dados dos Criosolos, com dados analíticos e camadas de informações para possível adição em ambiente Web-SIG.

REFERÊNCIAS BIBLIOGRÁFICAS

- Albuquerque-Filho, M.R., 2005. Geoquímica de solos da Península Keller, Ilha Rei George, Antártica, como subsídio ao monitoramento ambiental. D.S.Thesis (in portuguese). Universidade Federal de Viçosa, Viçosa, Brazil.
- Beyer, L., Pingpank, K., Wriedt, G. and Bolter, M. (2000) Soil formation in coastal continental Antarctica (Wilkes Land). *Geoderma* 95, 283–304.
- Blume, H.P., Beyer, L., Bolter, M., Erlenheuser, H., Kalk, E., Kneesch, S., Pfisterer, U., and Schneider, D. (1997) Pedogenic zonation in soils of Southern circumpolar region. *Adv. GeoEcol.* 30, 69–90.
- Bockheim, J.G., 1997. Properties and Classification of Cold Desert Soils from Antarctica. *Soil Sci. Soc. Am. J.* 61, 224–231.
- Campbell, I.B., Claridge, G.G.C., 1987. Antarctica: soils, weathering processes and environment. Elsevier-Amsterdam.
- Cannone, N., Ellis Evans J.C., Strachan, R. and Guglielmin M., 2006. Interactions between climate, vegetation and the active layer in soils at two Maritime Antarctic sites. *Antarctic Science* 18 (3), p. 323–333.
- Convey, P. 2001. Terrestrial ecosystem response to climate changes in the Antarctic. In Walther, G.-R., Burga, C.A. & Edwards, P.J., eds. *Fingerprints' of climate change – adapted behaviour and shifting species ranges*. New York: Kluwer, p. 17–42.
- Cook, A.J., Fox, A.J., Vaughan, D.G. & Ferrigno, J.G. 2005. Retreating glacier fronts on the Antarctic Peninsula over the past half-century. *Science*, 308, p. 541–544.
- Ellenberg, 1988).
- French H. M., 2001. *The Periglacial Environment*. 2nd ed. Longman – Canada, 341 p.
- Hall K., 1997. Rock Temperatures and Implications for Cold Region Weathering. I: New Data from Viking Valley, Alexander Island, Antarctica. *Permafrost Periglacial Proc.* 8, 69–90.
- Hodkinson, I.D., Webb, N.R., Bale, J.S., Coulson, S.J. & Strathdee, A.T., 1998. Global change and Arctic ecosystems: conclusions and predictions from experiments with terrestrial invertebrates on Spitsbergen. *Arctic and Alpine Research*, 30, 306–313.
- Holdgate, M.W., Allen, S.E., Chambers, M.J.G., 1967. A preliminary investigation of the soils of Signy Island, South Orkney Island. *British Antarctic Surv. Bull.* 12, 53–71.
- Lee, I.Y., Lim, H.S. and Yoon, H.I., 2004. Geochemistry of soils of King George Island, South Shetland Islands, West Antarctica: Implications for pedogenesis in cold polar regions. *Geochimica et Cosmochimica Acta*, Vol. 68, No. 21, pp. 4319–4333. doi:10.1016/j.gca.2004.01.020
- Michel, R.F.M., Schaefer, C.E.G.R., Dias, L., Simas, F.N.B., Benites, V., Mendonça, E.S., 2006. Ornithogenic Gelisols (Cryosols) from Maritime Antarctica: pedogenesis, vegetation and carbon studies. *Soil Sci. Soc. Am. J.* 70, 1370–1376.

- Osterkamp, T.E., 2003. Establishing long-term permafrost observatories for active-layer and permafrost investigations in Alaska: 1977-2002. *Permafrost and Periglacial Processes*, v. 14, p. 331-342.
- Santos, I.R., E.V. Silva-Filho, C.E. Schaefer, M.R. Albuquerque-Filho, and L.S. Campos. 2005. Heavy metals contamination in coastal sediments and soils near the Brazilian Antarctic Station, King George Island. *Mar. Pollut. Bull.* 50:185–194.
- Schaefer, C. E. G. R.; Simas, F. N. B.; Gilkes, R. J.; Costa, L. M. ; Albuquerque, M. A. . Micromorphology and microchemistry of selected cryosols from Maritime Antarctica. *Geoderma*, v. 144, p. 104-115, 2008.
- Schaefer, C.E.G.R., F.N.B. Simas, M.R. Albuquerque Filho, J.H.M. Viana, R.F.M. Michel, and A. Tatur. 2004. Fosfatização: Processo de formação de solos na Baía do Almirantado e implicações ambientais. p. 45–59. In *Ecossistemas Terrestres e Solos da Antártica Marítima*. 1st edn. NEPUT. Viçosa
- Simas, F.N.B., Schaefer, C.E.G.R., Albuquerque-Filho, M.R., Francelino, M.R., Fernandes Filho, E.I., Costa, L.M., 2008. Genesis, properties and classification of Cryosols from Admiralty Bay, Maritime Antarctica. *Geoderma*, 144 116–122.
- Simas, F.N.B., Schaefer, C.E.G.R., Melo, V.F., de Albuquerque-Filho, M.R., Michel, R.F., Pereira, V.V., Gomes, M.R.M., 2007a. Ornithogenic Cryosols from Maritime Antarctica: phosphatization as a soil forming process. *Geoderma* 138, 191–203.
- Simas, F.N.B., Schaefer, C.E.G.R., Mendonça, E.S., Silva, I.R., Santana, R.M., 2007. Organic C stocks in permafrost-affectes soils from Admiralty Bay, Antarctica. U.S. Geological Survey and The National Academies; USGS OF-2007-1047, Short Research Paper 015. doi:10.3133/of2007-1047.srp015.
- Tatur, A. 1997. Ornithogenic soils of the Maritime Antarctic: Taxonomic position. *Pol Polar Stu.* 24th Polar symposium.
- Tatur, A., 1989. Ornithogenic soils of the maritime Antarctic. *Pol. Polar Res.* 4, 481–532.
- Tatur, A., A. Myrcha, and J. Niegodzisz. 1996. Formation of abandoned penguin rookery ecosystems in the maritime Antarctic. *Polar Biol.* 17:405–417.
- Tatur, A., and A. Barczuc. 1983. Phosphates of ornithogenic soils on the volcanic King George island (Maritime, Antarctic). *Polish Polar Res.* 5:61–97.
- Tatur, A., and A. Myrcha. 1993a. Changes in chemical composition of water running off from the penguin rookeries at Admiralty Bay Region (King George Island, South Shetlands, Antarctica). *Polish Polar Res.* 4:113–128.
- Tatur, A., and A. Myrcha. 1993b. Ornithogenic soils. p. 161–165. In S Rakusa-Suszczewski (ed.) *The Antarctic coastal ecosystem of Admiralty Bay*. Polish Academy of Sciences, Warsaw.
- Tatur, A., Myrcha, A., Niegodzisz, J., 1997. Formation of abandoned penguin rookery ecosystems in the maritime Antarctic. *Polar Biol.* 17, 405–417.
- Tedrow, J.C.F., and F.C. Ugolini. 1966. Antarctic soils. Ser 8: 161–177. In J.C.F. Tedrov (ed.) *Antarctic soils and soil forming process*. Am. Geophys. Union Antarct. Res. Washington.
- Turner, J.; Colwell, S.R.; Marshall, G.J.; Lachlan-Cope, T.A.; Carleton, A.M.; Jones, P.D.; Phil, V.L.; Reid, A.; Iagovkina S., 2005. Antarctic climate change during the last 50 years. *Int. J. Climatol.* v. 25, p. 279-294.
- Ugolini, F.C. 1972. Ornithogenic soils of Antactica. p. 181–193. In G.A. Llano (ed.) *Antarctic terrestrial biology*. Am. Geographies. Union Antact. Res. Washington.

- Ugolini, F.C., 1970. Antarctic soils and their ecology. In: Holdgate, M.W. (Ed.), *Antarctic Ecology*, vol. 2. Academic Press, London, pp. 673–692.
- Ugolini, F.C., Bockheim, J.G., 2008. Antarctic soils and soil formation in a changing environment: A review. *Geoderma* 144 p.1–8.
- Weller, G., 1998. Regional impacts of climate change in the Arctic and Antarctic. *Annals of Glaciology*, 27, 543–552.
- Williams, P.J. & Smith, M.W., 1989. *The frozen earth: fundamentals of geocryology*. Cambridge: Cambridge University Press, 302 p.

PAPER 1

SOIL SURVEY AND SOIL CLASSIFICATION OF LIONS RUMP, MARITIME ANTARCTIC

ABSTRACT

The aim of this paper was to study, classify and map soils from Lions Rump, King George Bay, Maritime Antarctica, according to WRB and USDA soil classification systems in association with geomorphological features. Twenty-six soil profiles from study area were described, sampled and analyzed for their physical, chemical and mineralogical attributes. Results showed soils are most formed from weathered basalt-andesitic rocks, naturally rich in apatite, with high P background. Typic Dystrogelepts ornithic and Typic Gelorthents ornithic are the main ornithogenic soils in study area, which possibly represents one of the first ice-free areas colonized by penguins in Maritime Antarctica. Typic Dystrogelepts ornithic represent the deepest, most structured and reddish soils in the area. Typic Haplogelepts ornithic are the main soils on first and second moraine levels from the White Eagle Glacier. Typic Haploturbels and Lithic Haploturbels are present just above 80 m a.s.l., especially on the top areas and paraglacial spots, and represent Gelisols in study area, with gelic materials within 100 cm and permafrost within 200 cm from the soil surface. Despite their occurrence only at higher altitudes, they represent the greatest soil cover in Lions Rump. Turbic Haplogelepts and Typic Haplorthents are situated between 40 and 80 m.a.s.l., without bird nesting influence and absent of permafrost within 200 cm depth. Vitrandic Cryopsamments and Oxyaquic Cryopsamments dominated the first level of terraces and former beaches along the coastal area. Other soils classified are present in very limited areas: Lithic Cryorthents ornithic on the sea stacks rock outcrops (basaltic plugs) close to the beach, and Typic Gelifluvents ornithic in a small area on glacial alluvial fans. Overall, soil distribution and classification in Lions Rump allowed identified two main soil domains: Ornithogenic soils (without permafrost) and the Gelisols (above 80 m a.s.l.).

INTRODUCTION

Soil formation in Antarctica is restricted to about 0.32% or 45,000 km² of the continent, in ice-free regions of coastal areas and glacial valleys between mountain ranges (Ugolini and Bockheim, 2008). The first study with Antarctica soils was carried in McMurdo US Base by Jensen (1916), and the first field study and soil mapping compiled occurred in the Taylor Valley of southern Victoria Land by McCraw (1967) (Ugolini and Bockheim, 2008). Despite increased research on soils in recent years, most studies on Maritime Antarctica focused mainly on ornithogenic soils. In addition, only few soil maps were produced throughout the history of pedology in Antarctica.

Gelisols order was approved in 1996 as the 12th order in Soil Taxonomy (Soil Survey Staff, 1999) and included in the Keys to Soil Taxonomy (2006) to comprise the permafrost-affected soils and are divided into three suborders: Histels, Turbels, and Orthels. Histels are organic soils containing permafrost within 100 cm of the surface. Orthels are soils with gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface and the Orthels are soils with permafrost within 100 cm and minimal cryoturbation.

Ugolini and Bockheim, 2008 in a review observed that in Antarctica soils with ice-cemented permafrost within 70 cm of the surface generally are cryoturbated and classified in the Turbel suborder, and soils with dry permafrost and minimal cryoturbation are classified as Orthels. Soils in coastal regions of Antarctica are in HaploGreat Groups, and soils further inland in areas receiving less than 50 mm of water-equivalent precipitation are in Anhy Great Groups. Antarctica soils are further differentiated at the subgroup level based upon the amount and type of salts and other diagnostic features (Ugolini and Bockheim, 2008).

Although the temperatures are very low in Antarctic, in the region a chemical weathering occurs. Some studies showed chemical weathering in Gelisols occurring a greater extent than previously thought (Blume and Bolter, 1993; Simas et al., 2006; Schaefer et al, 2008).

One of the characteristics of Gelisols is their very low clay content, which even in the oldest soils from Continental Antarctica seldom exceeds 4% (Beyer et al., 1999). Moreover, in the Maritime Antarctic, clay content can reach $\approx 20\%$, overcoming continental area and indicating advanced weathering in this region. In general terms, in Continental Antarctica, the youngest soils are found in the coastal regions and lower valleys, and the oldest ones at higher altitudes inland (Beyer et al., 1999). However, in the Maritime Antarctic, more developed soils are close to the ocean, especially in soils known as ornithogenic soils, formed in areas influenced by bird's activities.

In the Maritime Antarctic, the mean annual temperature is considerably higher (-1 to -3°C) than the continental area, with two to four months of higher temperatures in the coastal locations and at low altitudes. The mean annual precipitation is 400 to 500 mm (Bockheim and Ugolini, 1990). Under these

climate conditions, occurs a higher biodiversity and two higher plants are found in addition to the lower plants observed in East Antarctica.

In the peripheric areas of Antarctica, it has been verified an increase in ice-free areas and soil formation, which deserve further studies to support management programs for preservation of the region. Soil maps provide a very important base for environmental management and planning human activities, as well as for ecological studies on terrestrial ecosystems (Moura et al., 2012).

Some studies and soil mapping were produced for Maritime Antarctica (Francelino et al., 2011; Michel, 2011; Moura et al., 2012; Pereira, 2012). These works produced soil maps for ice-free areas in South Shetlands Archipelago and Antarctic Peninsula to support the ANTPAS project (The Antarctic and Sub-Antarctic Permafrost, Soils and Periglacial Environments). Although sites of Byers Peninsula, Fildes Peninsula, and other areas from Admiralty Bay had been concluded, no mapping soils had published for Lions Rump, in King George Bay. For this reason, the present paper report soil survey and discuss main soil classes identified in Lions Rump, and also present a first approximation of the soil map of area, highlighting selected soil chemical, physical and mineralogical attributes and its relationship with the vegetation cover.

MATERIAL AND METHODS

Site description

Lions Rump is a small peninsula located on the southern coast of King George Bay, King George Island, in the South Shetlands Islands, Maritime Antarctica (Figure 1). The area is designated as the Site of Special Scientific Interest (SSSI N° 34) and takes its name Lions Rump from the distinctive rocky hill lying between the southern extremity of King George Bay and Lions Cove. The study area is defined as terrestrial land within following coordinates: 62°07'48''S, 58°09'17''W; 62°07'49''S, 58°07'14''W; 62°08'19''S, 58°07'19''W; and 62°08'16''S, 58°09'15''W (SCAR, 2002). According to Köppen's classification, the region is part of the ET, tundra climate. Data sets acquired at the Brazilian Commandant Ferraz, nearby station from Lions Rump, report mean air temperatures varying from – 6.4 °C in July to + 2.3 °C in February. Mean annual precipitation is proximally to 400 mm (Simas et al., 2007), but the real soil water regime is highly influenced by its position in the landscape, due to the intense melting of snow, glaciers and permafrost sites upstream during the summer. The temperature remains above freezing almost all summer (November to March) allowing the vigorous growth of plant communities, mainly mosses, lichens and algae (Schaefer et al., 2004). The area includes the littoral and sublittoral zones extending from the eastern end of Lajkonik Rock to the most northerly point of Twin Pinnacles. From this point, the boundary extends to the easternmost end of the columnar plug of

Lions Head to the east of White Eagle Glacier. On land, the area includes the coast of raised beaches, freshwater pools and streams on the south side of King George Bay, around Lions Cove, and the moraines and slopes which lead to the lower ice tongue of White Eagle Glacier, then westward to a small moraine which protrudes through the ice cap south-east of Sukiennice Hills.

The geology of Lions Rump is formed by Tertiary lavas and tuff containing thin brown coal intercalations and petrified wood fragments and Quaternary deposits. The front of White Eagle Glacier is marked by large, dome-shaped moraine ridges belonging to several Holocene stages of glacier advance and retreat (Birkenmajer, 1994; Scar, 2002).

Two Tertiary lithostratigraphic groups are described, separated one from another by an important fault: the Polonia Glacier Group (volcanic and volcanoclastic rocks, Eocene) in the north, and the Chopin Ridge Group (Upper Cretaceous and Oligocene volcanics, and Lower Oligocene glacial and glacio-marine deposits) in the south. Both groups consist of several units of formation and member ranks (Birkenmajer, 1994).

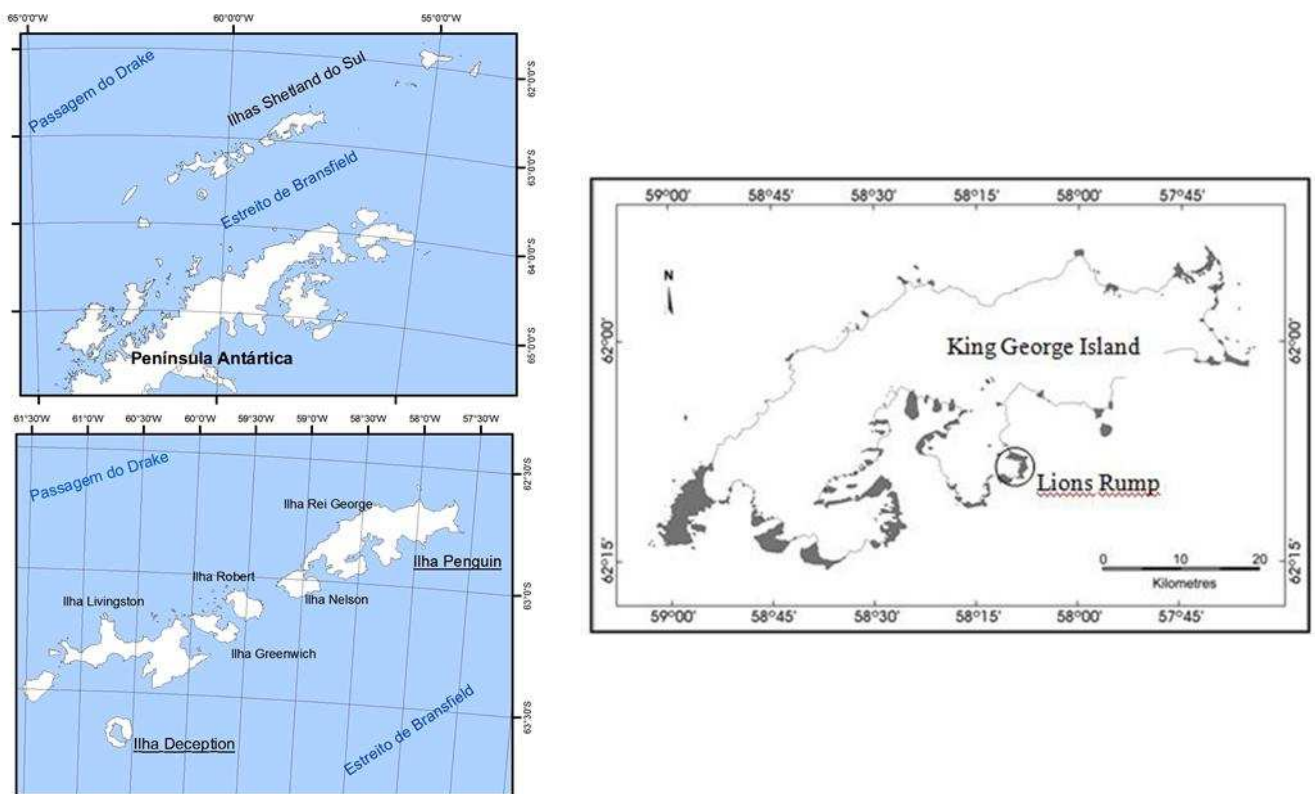


Figure 1 – Lions Rump located at King George Bay, King George Island, South Shetlands, Maritime Antarctica.

The Quaternary deposits consist of three generations of moraines, outwash shoreline and raised beach deposits. The first generations of moraines were formed as a result of glacier advance in the second half of the 18th century, the second one prior to 1960, and the third one between 1988 and 1991.

The first generation marginal (lateral) of moraine occurs on both sides of the valley of the northeastern side of White Eagle Glacier ended in the cliffs of marine abrasion, being bordered by recent pebble dikes up to 3.5 m tall. The second generation is representing by an isolated crescentic ridge which reaches down to sea shore at King George Bay and is covered by younger generation moraines at its landward termination. The late and younger generation moraines form several ridges at the margin of the White Eagle Glacier, which steeply descend towards Lions Cove and King George Bay, and cover the recent beach. An outwash apron is being formed at the outlet of a glacier river which cuts a deep canyon into the recent moraines; and smaller outwash cones are present on both sides of the older moraine ridge (Birkenmajer, 1981; Birkenmajer, 1994).

Along the shoreline, pebbly storm ridges cutting off small lagoons developed. Traces of raised beaches with well-rounded pebbles are visible at 15 to 20 m.a.s.l. on a morphological ridge dividing Lions Cove from King George Bay (Birkenmajer, 1981).

The ice-free area exhibits a range of geomorphological features, including beaches of various widths and length, moraines, hills and inland rocks.

Field works

The study area was visited on austral summer of 2009/2010, during Brazilian Antarctic Expeditions. During field work, 26 pedons (Tables 1, 2 and 3) representing the main soil types identified in ice-free areas of Lions Rump were described and sampled, based on criteria established by Antarctic Permafrost and Soils (ANTPAS, 2006) and considering geomorphological features. For soil classification USDA Soil Taxonomy (Soil Survey Staff, 2010) and World Reference Base for Soil Resources (WRB) (ISSS Working Group, 2006) were used. For a detailed soil mapping, the free-choice profiling (Embrapa, 1995) was used. The cartographic reference material was a Quickbird image (scale 1:4500). Software ArcGIS 9.3 (ESRI, 2009) was used for data processing and map editing. Among the 26 soils profiles, 13 more representative are selected and showed in this paper (Figure 2, 3 and 4).

Laboratory procedures

After soil sampling and transport to Brazil, soil analyses were carried out. Soil physic was analyzed with texture procedure (EMBRAPA, 1997 modified by Ruiz, 2005). Soil chemical attributes analyzed were: pH (H_2O and $1 \text{ mol L}^{-1} \text{ KCl}$); total organic carbon (TOC) in extracts of fulvic acid, humic acid and humin fractions (Yeomans and Bremner, 1988), Na and K after extraction with $0.5 \text{ mol L}^{-1} \text{ HCl} + 0.0125 \text{ mol L}^{-1} \text{ H}_2\text{SO}_4$ (Mehlich-1); available P (Mehlich-1), Ca, Mg, and Al after extraction with $1 \text{ mol L}^{-1} \text{ KCl}$; H+Al after extraction with $0.5 \text{ mol L}^{-1} \text{ Ca}(\text{CH}_3\text{COO})_2$ at pH 7.0; CaCO_3 by titration after extraction with $0.5 \text{ mol L}^{-1} \text{ HCl}$. All chemical analyses were carried according to EMBRAPA

(1997). Samples were analyzed for total contents of Ca, Mg, K, Fe, Al, Mn, P, Cu, Zn, Cd, As, Cr, and Pb after total digestion sieved (mesh 0.25 mm) material with HCl, HNO₃ and HF by heating in a microwave oven (CEM/MDS 2000) according to the EPA-3052 method (USEPA. 2011). The element contents were determined by inductively coupled plasma-optical emission spectroscopy (ICP-OES). Soil mineralogical composition of clay fraction was evaluated on air-dried samples by X-ray diffraction (XRD) in natural clay and in clay samples after saturation with 1.0 mol L⁻¹ KCl; heating in an oven at 350 °C and 550 °C for 3 hours each; saturation with 1.0 mol L⁻¹ MgCl₂ and glycerol solvation. A diffractometer (PANalytical / X`Pert Pro) was used, operated at a voltage of 40 kV and current of 30 mA with CoK α radiation within the range between 4 and 50 °2 θ , at step of 0.017 °2 θ to 1 step s⁻¹.

RESULTS AND DISCUSSION

General characterization of the studied area

Lions Rump is propitious to development of diverse species of flora and fauna. The principal vegetation cover, geographic distribution and soil classification of studied area soils are presented at table 1.

In general, soils from Lions Rump are incipient and poorly evolved when classified by WRB and Soil Taxonomy. Four of present soils from this study are Ornithogenic Soils, and the others are mainly Cryosols/ Gelisols located in the highest landscaping portion. Cambisol/Inceptsol and (Regosols, Arenosols, Leptsols)/Entsols are widespread in the lowland area.



P3 - Turbic Haploglepts

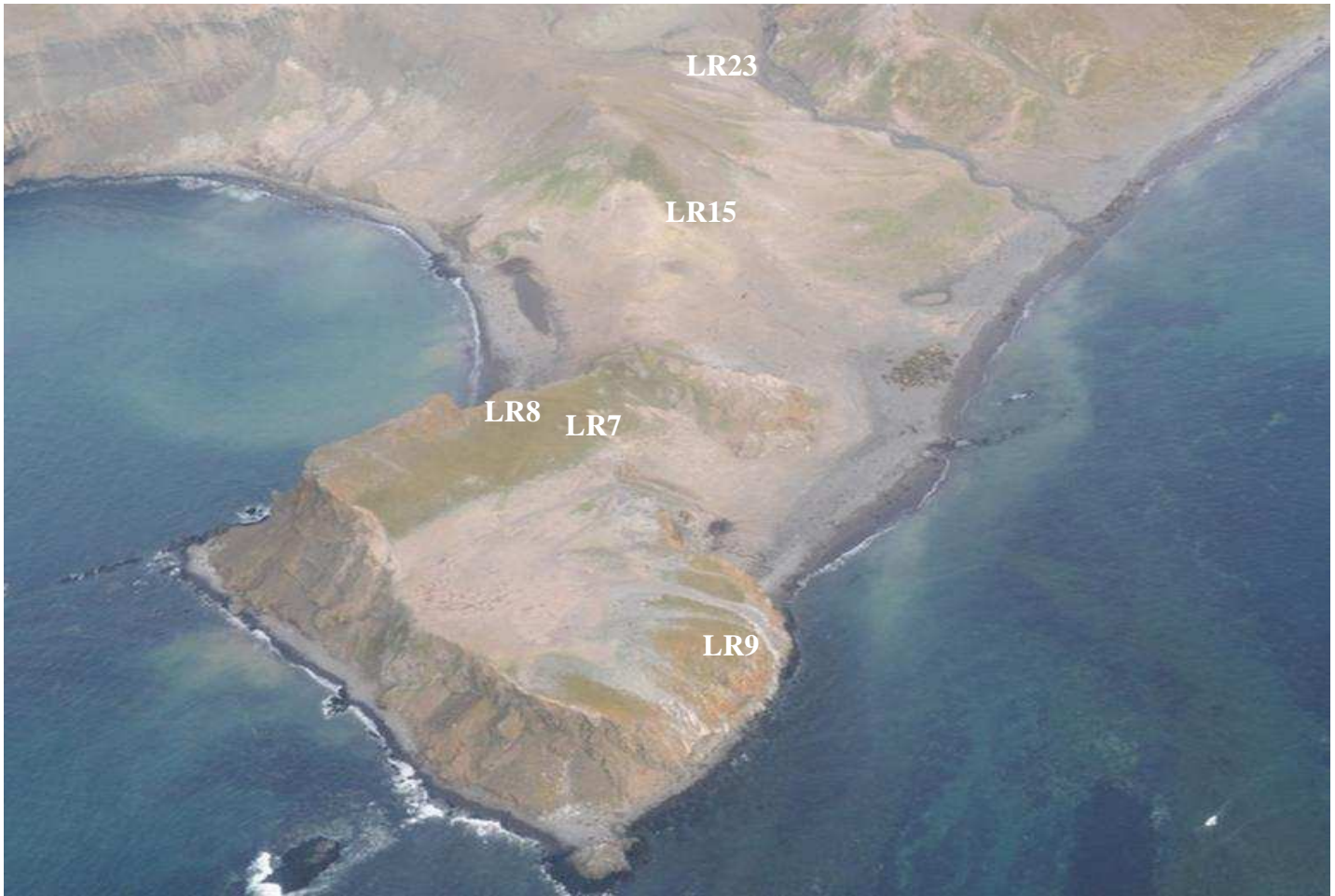


P19 - Oxyaquic Cryopsamments



P12 - Lithic Haploturbels

Figure 2 – Some representative Non-ornithogenic soils profiles of Lions Rump and their location in the landscape

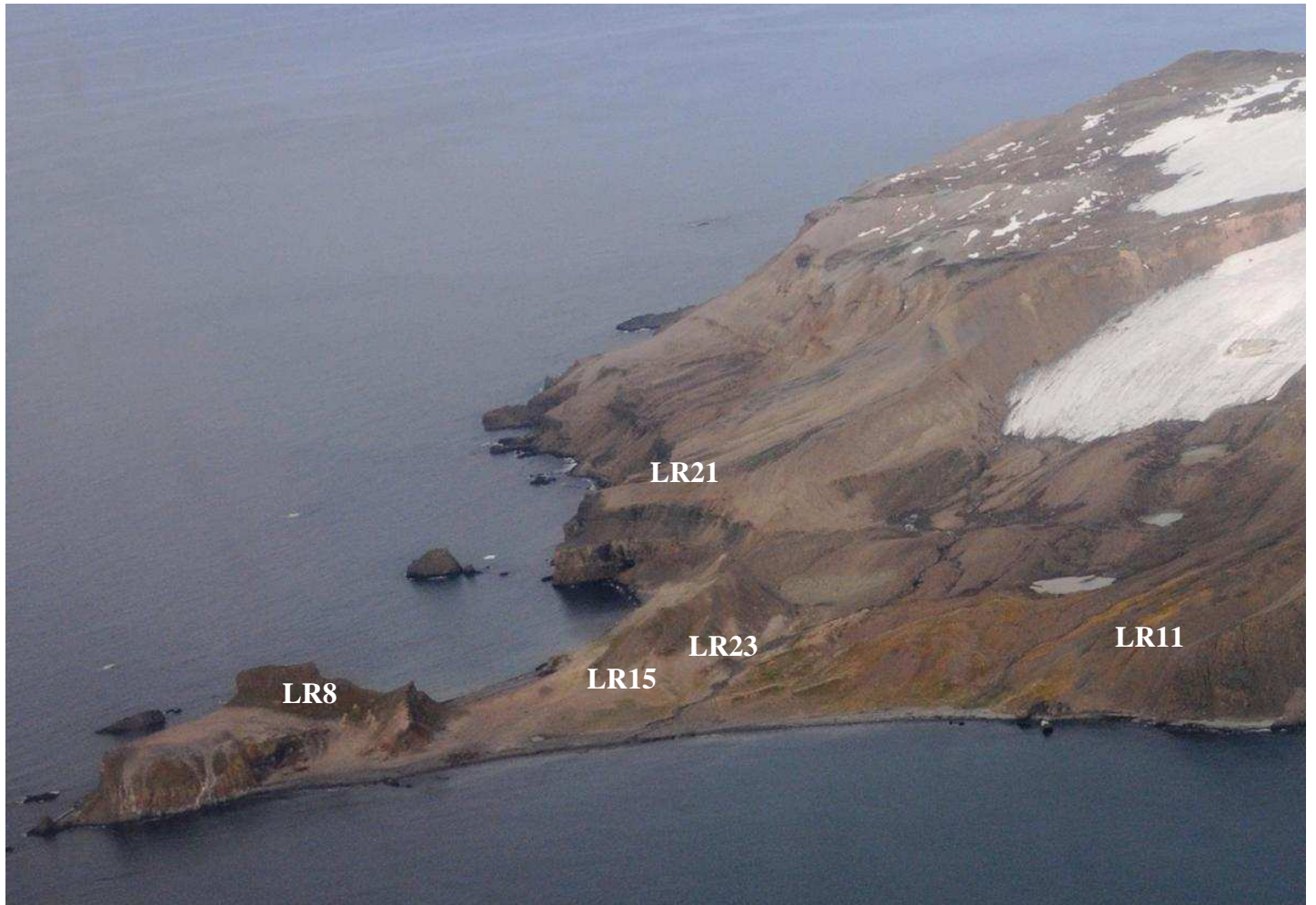


LR7- Typic Dystroglepts ornithic

LR8 - Typic Dystroglepts ornithic

LR9 - Typic Gelorthents ornithic

Figure 3 –Some representative Acid pH ornithogenic soils profiles of Lions Rump and location of profiles in the landscape.



LR11 - Typic Haplogelepts ornithic

LR15 - Typic Haplogelepts ornithic

LR23 - Typic Gelifluvents ornithic

Figure 4 – Some representative Neutral pH ornithogenic soils profiles of Lions Rump and their location in the landscape.

Table 1: Geographic distribution, altitude, vegetation cover and soil classification of 13 selected profiles from 26 studied

Group	Pedon	Geographic position ¹	Altitude m.a.s.l. ²	Vegetation ³	WRB ⁴	Soil Taxonomy
Non – Omithogenic Soils	LR3	0439687 3110784	62	Rare D.C.L.M	Haplic Cambisol (Eutric, Skeletic, Turbic, Gelic)	Loamy-skeletal, mixed, active, subgelic, Turbic Haplogelepts
	LR4	0439762 3110565	102	Rare D.C.L.M	Turbic Cambic Cryosol (Eutric, Skeletic)	Loamy-skeletal, mixed, active, subgelic, Typic Haploorthels
	LR5	0440047 3110231	110	Absent	Haplic Regosol (Eutric, Skeletic, Gelic)	Loamy-skeletal, mixed, active, subgelic, Typic Gelorthents
	LR12	0440724 3108658	257	L>D>C>M	Leptic Cryosol (Eutric, Skeletic)	Loamy-skeletal, mixed, active, subgelic, Lithic Haploturbels
	LR13	0440804 3108792	222	Absent	Turbic Thionic Cryosol (Epieutric, Endoaluminic, Skeletic)	Loamy-skeletal, mixed, active, subgelic, Typic Haploorthels
	LR19	0440081 3110799	3	D>M>C	Haplic Arenosol (Eutric, Gelic)	Sandy, mixed, active, subgelic, Oxyaquic Cryopsammments
	LR21	0441211 3109813	67	M>D >C	Haplic Cambisol (Eutric, Turbic, Gelic, Oxyaquic)	Coarse-loamy, mixed, active, subgelic, Turbic Haplogelepts
	LR24	0441165 3109959	86	L>D>C>M	Turbic Cambic Cryosol (Eutric, Skeletic)	Sandy-skeletal, mixed, active, subgelic, Typic Haploturbels
Acid pH Omithogenic Soils	LR8	0441398 3110372	38	D>M>P>L	Haplic Cambisol (Ornithic, Dystric, Skeletic, Gelic)	Loamy-skeletal, mixed, active, subgelic, Typic Dystrogelepts ornithic
	LR9	0441523 3110476	40	P>D>L	Haplic Leptosol (Ornithic, Dystric, Skeletic, Gelic)	Loamy-skeletal, mixed, active, subgelic, Typic Gelorthents ornithic
Neutral pH Omithogenic Soils	LR15	0441154 3110281	41	D>C>L>P	Haplic Cambisol (Ornithic, Eutric, Gelic)	Coarse-loamy, mixed, active, subgelic, Typic Haplogelepts ornithic
	LR22	0439889 3111016	4	L	Lithic Leptosol (Ornithic, Eutric)	Sandy-skeletal, mixed, active, subgelic, Lithic Cryorthents ornithic
	LR23	0441054 3110247	17	P >D	Colluvic Regosol (Ornithic, Eutric, Gelic)	Sandy-skeletal, mixed, active, subgelic, Typic Gelifluvents ornithic

¹UTM coordinates, zone 21S datum WGS 84; ² Meters above sea level; ³ C= *Colobanthus quitensis*. D= *Deschampsia Antarctica*. M= Mosses, L= Lichens, P = *Plasiola crispa*; ⁴Classification following World Reference Base for Soil Resources (2006).

Vegetation

Vegetation species were identified with help of botanist researchers Antônio Batista Pereira and Lucas Marinho Poeriras.

The presence of *Prasiola crispa* is associated with proximity of penguin rookeries. This type of algae occurs in N-rich soils. Lichens are widespread on rocks or rock fragments in all order of soils present at study area. The lichens species observed at Lions Rump were *Acarospora sp*, *Bacidia sp*, *Buellia sp*, *Caloplaca cinericola*, *Caloplaca regalis*, *Candelaria flava*, *Cornicularia aculeate*, *Haematomma erytromma*, *Lecanora polytropa*, *Lecidea sp*, *Leptogium puberulum*, *Mastodia tessellata*, *Ochrolechia antarctica*, *Ochrolechia frigida*, *Physcia caesia*, *Placopsis contortuplicata*, *Psoroma cinnamomeum*, *Ramalina terebrata*, *Rhizocarpon geographicum*, *Rhizoplaca sp*, *Sphaerophorus globosus*, *Usnea antarctica*, *Usnea aurantiaco-atra* and *Xanthoria candelaria*. On the other hand, species as *Buellia sp.*, *L. puberulum* and *U. antarctica* are also frequently observed covering vegetated soils. At higher elevations, soils are practically devoid of vegetation cover except for sparse epilithic lichens. Above 80 m a.s.l., *Usnea* is the principal lichen occurring on Gelisols (Cryosol).

Flowering plants are representing only by *Deschampsia antarctica* and *Colobanthus quitensis*, which occurs principally on Quaternary features, with dense covering on uplifted terraces, beaches, moraines and abandoned rookeries.

Mosses are found mostly in wet areas forming carpets or cushions in other soils. At wetter sites, cryptogrammic organisms extend as a continuous cover, and A horizons are formed. A sharp boundary is observed between the A horizon and the underlying B horizon, with reduction of organic C with depth. The field of mosses in the southern part of the Lions Rump peninsula covering a large area, as identified in LR21 profile, is in process of degradation because of melting water drainages. The found mosses in Lions Rump were *Andreaea gainii*, *Brachytecium sp*, *Bryum argenteum*, *Bryum dichotomum*, *Bryum pseudotriquetrum*, *Polytrichum alpinum*, *Sanionia uncinata*, *Schistidium falcatum* and *Syntrichia princeps*.

On the breeding rookery all vegetation has been devastated due to excessive manuring and trampling by penguins as previously indicated as Ugolini (1970, 1972), Tatur (1989), Michel et al. (2006) and Simas et al. (2007) studying ice-free areas of the South Shetlands Islands. Only nitrophilous lichens can be noted on big stones and rocky walls. But in marginal zones of penguin activity abundance of nutrients in water running down from the rookery and spread by the wind ensures luxurious development of vegetation. This seems to be a standard

in Maritime Antarctica with reports by Tatur and Myrcha, 1989; 1991; Tatur et al., 1997; Michel et al., 2006; Simas et al., 2007, 2008; and Schaefer et al., 2008.

Soil classification and characteristics

Deposition of P and N-rich guano favors vegetation establishment. Soil chemical properties, mineralogy and the type of vegetation are strongly influenced by the duration of site occupation by penguins and soil drainage characteristics. Because of this avifauna influence we can divide soils from Lions Rump in three groups (Table 2): Acid pH ornithogenic soils (LR8, LR9) (Figure 3), Neutral pH ornithogenic soils (LR15, LR22, LR23) (Figure 4), and Non-ornithogenic soils (LR3, LR4, LR5, LR12, LR 13, LR19, LR21, LR24) (Figure 2).

In oldest and most stable landscapes where bird's occupation has been long domain Acid pH ornithogenic soils (LR8), which are mostly common cited in the literature widely known just like ornithogenic soils (Ugolini, 1972; Tatur and Barczuk, 1985; Tatur and Myrcha, 1989, 1991, 1993; Tatur et al., 1997; Michel et al., 2006; Simas et al., 2007, 2008, and Schaefer et al., 2008). The Acid pH ornithogenic soils are readily distinguished from the Non-ornithogenic soil by several features such as the presence of continuous vegetation cover with *D. antarctica*, *C. quitensis* and/or *Prasiola crispa*; lower pH and bases saturation (PBS); very high Melich-1 extractable-P, exchangeable Al, TOC and total N (Table 3). Concentration of K^+ , P and Al^{3+} tend to increase in the deepest layer while Ca^{2+} and Mg^{2+} and pH tend to reduce.

The Neutral pH ornithogenic soils show high levels of label P and similar vegetation cover as Acid pH ornithogenic soils. However they have high concentration of Ca^{2+} , Mg^{2+} and K^+ and pH close to neutral. They are present at areas with recently exposure to ornithogenic influence, especially at Quaternary moraines and uplifted terrace (LR15 and LR23). The principal difference between acid and Neutral ornithogenic soils is time of soil exposure to bird influence and the amount of bird excrement depositions.

Mean pH for Acid ornithogenic soils studied was 4.3 (± 0.33), much lower than the mean values for Neutral ornithogenic soils (7.0 ± 1.2) and Non-ornithogenic soils (7.4 ± 1.1) (Table 3). Such acidity is produced during guano mineralization, through the production of strong acids such as HNO_3 (Tatur and Barczuk, 1985).

At Neutral ornithogenic soils, both cation exchange capacity (CEC) and percentage of base saturation (PBS) are high and represent an eutrophic soil, contrasting with dystrophic Acid ornithogenic soils with low CEC (Table 3).

Table 2- Morphological and physical properties of studied soils from Lions Rump

Soil	Pedon	Depth cm	Structure ¹	Transition	Color (dry)	Skel ²	C.Sand	F. Sand	Silt	Clay
						----- dag kg ⁻¹ -----				
Non-ornithogenic soils										
LR3	A	0-5	w f m bl/ md m gr	gradual wavy	2.5Y 4/3	22	29	21	36	14
	AB	5-17/20	w m bl/ md m gr	gradual wavy	2.5Y 4/4	25	27	20	33	20
	Bi	20-47/52	w m bl/ md m gr	gradual wavy	2.5Y 5/3	51	33	21	27	19
	BC	47-52-70	w m bl	-	2.5Y 5/4	55	31	18	32	19
LR4	A	0-5	w f bl/ md m gr	gradual wavy	2.5Y 5/2	35	46	16	28	10
	AB	5-22/24	w f m bl/ md m gr	gradual wavy	2.5Y 5/3	45	36	22	39	3
	Bi	24-45/47	md m l bl/ w m gr	gradual wavy	2.5Y 5/3	51	37	22	39	2
	BC	45/47-75	w md l bl	-	2.5Y 5/3	33	37	22	40	1
LR5	C1	0-23	w m bl/ w m gr	gradual wavy	2.5Y 4/3	36	28	14	56	2
	C2	23-60	w m bl/ w m gr	gradual wavy	2.5Y 4/4	27	33	11	53	3
	C3	60-90	w md l bl	-	2.5Y 5/4	32	34	11	53	2
LR12	A	0-8/25	st m gr	clear wavy	10YR 3/3	27	33	29	26	12
	C	8-25/30	md l sb/ st m gr	-	10YR 4/3	34	40	30	21	9
LR13	A	0-8	sg	clear flat	2.5YR 4/3	54	42	25	25	8
	AC	8-15	w md l sb/ w m gr	clear wavy	10YR 4/3	40	38	14	32	16
	C	15-65	w l sb/ w m gr	-	10YR 5.5/8	51	61	17	13	9
LR19	A	0-4	w l bl/ sg	clear wavy	2.5Y 3/3	1	54	21	15	10
	AC	4-12/15	w l bl/ sg	gradual wavy	2.5Y 4/4	17	65	11	2	22
	C1	15-30/35	sg	gradual wavy	2.5Y 4/3	23	82	6	5	7
	C2	30/35-70	sg	-	2.5Y 4/3	22	81	7	5	7

Table 2- Morphological and physical properties of studied soils from Lions Rump (continued)

Soil	Pedon	Depth cm	Structure ¹	Transition	Color (dry)	----- dag kg ⁻¹ -----				
						Skel ²	C.Sand	F. Sand	Silt	Clay
LR21	O	0-3/4	w l bl/ sg	clear wavy	10YR 3/4	26	23	25	40	12
	A	3/4-8/10	w l bl/ sg	gradual wavy	10YR 5/3	16	44	30	21	5
	AB	10-18/20	w m bl/ st m gr	gradual irregular	10YR 5/3	14	51	25	21	3
	Bi	20-45/50	md st l bl/ md m gr	gradual irregular	10YR 6/3	32	41	26	31	2
	BC	45/50-65	md m bl/ sg	-	10YR 6/3	30	38	27	33	2
LR24	A	0-8	w l bl/ sg	clear wavy	10YR 4/3	48	51	28	18	3
	AB	8-20	w l bl/ sg	gradual wavy	10YR 4/4	50	49	29	18	4
	BA	20-33	w m bl/ st m gr	gradual irregular	10YR 5/4	60	47	29	21	3
	Bi	33-52	md st l bl/ md m gr	gradual irregular	10YR 5/3	48	52	25	21	2
	BC	52-82	md m l bl	-	10YR 6/3	31	58	22	19	1
Acid pH Ornithogenic soils										
LR8	O	0-5	fibric/ st m gr	clear flat	10YR 3/3	21	44	20	21	15
	A	5-12	w m l sb/ st m gr	clear flat	10YR 3/4	71	36	21	25	18
	AB	12-18	w m l sb/ st m gr	clear wavy	10YR 5/3	42	51	18	18	13
	BA	18-32	md f bl/ st m gr	clear wavy	10YR 6/3	55	57	11	21	11
	B1	32-70	md f bl/ st m gr	gradual wavy	10YR 6/3	45	52	23	16	9
	B2	70-100	st m gr	gradual wavy	10YR 6/4	42	40	33	20	7
	B3	100-120	st m gr	-	10YR 5/6	32	45	17	22	16
LR9	A	0-8	st m gr	gradual flat	10YR 5/3	49	43	23	21	13
	Cr	8-40	sg/ w m gr	-	10YR 7/3	67	30	8	39	23

Table 2- Morphological and physical properties of studied soils from Lions Rump (continued)

Soil	Pedon	Depth cm	Structure ¹	Transition	Color (dry)	----- dag kg ⁻¹ -----				
						Skel ²	C.Sand	F. Sand	Silt	Clay
Neutral pH Ornithogenic soils										
LR15	O1	0-3/4	fibric	clear wavy	10YR 3/3	11	36	25	23	16
	O2	¾-9/11	fibric	clear wavy	10YR 3/4	0	36	25	23	16
	OA	11-16/17	fibric/ md m gr	gradual wavy	10YR 5/3	24	32	22	28	18
	Bi1	17-37/38	w md m l bl/ md m gr	gradual wavy	10YR 6/3	33	42	17	27	14
	Bi2	37/38-60	w m l bl/ w m gr	gradual irregular	10YR 6/3	27	43	17	25	15
	BC	60-80+	w m l bl	-	10YR 6/4	32	42	18	22	18
LR22	A	0-16	w l bl/ md m gr	abrupt irregular	5Y 2.5/2	48	81	10	4	5
LR23	A	0-8/10	w m l bl/ w m gr	clear wavy	10YR 4/2	25	54	19	22	5
	Bi	10-22/24	w m l bl/ md m gr	clear wavy	10YR 5/2	25	42	27	27	4
	C	24-28/30	w m bl/ md m gr	clear wavy	7.5YR 4/3	35	42	35	20	3
	2A	30-34/36	sg	clear wavy	7.5YR 4/2	59	65	23	11	1
	2C	34/36-90	st l bl/ md m gr	-	7.5YR 5/2	73	69	17	13	1

¹Development: w = weak. md = moderate. st = strong. Size: f = fine. m = medium. Type: ma = massive. gr = granular. bl = subangular blocky. sg = single grain. cr = crumbs; ² Percent of particles > 2 mm.

Table 3 – Chemical properties of the studied soils from Lions Rump

	Pedon	Depth cm	pH		Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	H+Al	CEC	PBS	m	ESP	P
			H ₂ O	KCl											
Non-ornithogenic soils															
LR3	A	0-5	7.52	4.61	18.84	16.46	0.24	1.53	0.00	1.90	37.07	95.10	0	4.12	109.50
	AB	5-17/20	7.74	4.93	26.30	20.01	0.17	1.18	0.00	1.10	47.66	97.70	0	2.47	170.80
	Bi	20-47/52	7.98	5.60	26.31	14.19	0.14	0.92	0.00	0.30	41.56	99.30	0	2.21	167.20
	BC	47-52-70	8.48	6.24	30.45	12.07	0.14	0.79	0.00	0.00	43.45	100.0	0	1.81	176.30
LR4	A	0-5	8.20	5.85	20.96	6.98	0.19	1.35	0.00	0.00	29.48	100.0	0	4.59	147.90
	AB	5-22/24	8.61	6.30	21.40	5.79	0.17	1.05	0.00	0.00	28.41	100.0	0	3.69	123.00
	Bi	24-45/47	8.67	6.77	22.25	5.27	0.09	0.74	0.00	0.00	28.35	100.0	0	2.62	124.50
	BC	45/47-75	8.62	6.78	24.54	5.72	0.17	0.70	0.00	0.00	31.13	100.0	0	2.25	112.80
LR5	C1	0-23	8.63	6.82	39.25	4.46	0.09	1.48	0.00	0.00	45.28	100.0	0	3.28	61.40
	C2	23-60	8.78	6.79	37.66	3.85	0.12	2.09	0.00	0.00	43.72	100.0	0	4.79	94.80
	C3	60-90	8.77	6.83	39.97	3.64	0.12	2.40	0.00	0.20	46.13	99.60	0	5.20	73.40
LR12	A	0-8/25	7.33	5.06	15.60	24.91	0.54	1.87	0.00	1.30	42.92	97.10	0	4.36	138.90
	C	8-25/30	7.41	5.06	20.86	25.01	0.54	1.83	0.00	1.60	48.24	96.80	0	3.79	117.70
LR13	A	0-8	7.62	4.79	22.01	24.98	0.32	1.92	0.00	1.10	49.23	97.80	0	3.89	124.50
	AC	8-15	6.09	4.15	20.58	22.06	0.24	1.48	0.87	3.20	44.36	93.30	1.9	3.27	101.10
	C	15-65	3.62	3.00	4.03	9.18	0.05	0.43	19.5	28.10	13.69	32.80	58.7	1.31	6.90
LR19	A	0-4	6.58	4.83	12.64	23.48	0.40	1.44	0.00	3.80	37.96	90.90	0	3.78	52.50
	AC	4-12/15	6.28	3.97	12.73	23.55	0.46	1.70	0.87	5.60	38.44	87.30	2.2	4.32	80.50
	C1	15-30/35	6.54	4.02	9.16	22.25	1.47	1.74	0.00	4.80	34.62	87.80	3.0	4.88	88.40
	C2	30/35-70	6.91	4.32	7.30	30.89	1.98	2.22	0.00	3.70	42.39	92.00	0.4	5.21	85.10

Table 3 – Chemical properties of the studied soils from Lions Rump (continued)

	Pedon	Depth cm	pH		Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	H+Al	CEC	PBS	m	ESP	P
			H ₂ O	KCl											
LR21	O	0-3/4	6.55	5.19	9.47	18.96	0.23	0.65	0.00	1.60	29.31	94.80	0	2.22	47.40
	A	3/4-8/10	6.92	4.54	14.72	22.34	0.20	1.26	0.00	1.70	38.52	95.80	0	3.27	62.40
	AB	10-18/20	7.58	4.97	17.69	18.28	0.13	1.04	0.00	0.60	37.14	98.40	0	2.81	88.30
	Bi	20-45/50	8.02	5.77	18.14	14.61	0.05	1.04	0.00	0.60	33.84	98.30	0	3.08	192.60
	BC	45/50-65	8.20	6.14	20.60	13.43	0.03	0.87	0.00	0.60	34.93	98.30	0	2.49	220.80
LR24	A	0-8	6.64	4.61	12.13	22.99	0.23	1.17	0.00	3.80	36.52	90.60	0	3.22	67.50
	AB	8-20	6.78	4.57	12.16	22.78	0.23	1.13	0.00	3.80	36.30	90.50	0	3.12	77.80
	BA	20-33	7.12	4.80	14.88	23.72	0.23	1.35	0.00	2.70	40.18	93.70	0	3.36	92.50
	Bi	33-52	7.37	4.72	16.37	21.90	0.18	0.83	0.00	1.10	39.28	97.30	0	2.10	186.60
Acid pH Ornithogenic soils															
LR8	O	0-5	4.88	3.77	1.85	2.45	0.09	0.45	0.48	4.50	4.84	51.80	9	8.43	79.60
	A	5-12	4.37	3.13	3.82	6.42	0.70	1.53	8.00	22.30	12.47	35.90	39.1	7.46	390.40
	AB	12-18	4.04	3.00	0.91	1.29	0.42	1.22	8.00	29.60	3.84	11.50	67.6	10.33	603.40
	BA	18-32	3.88	3.00	0.29	0.35	0.93	0.92	6.46	8.40	2.49	22.90	72.2	10.26	1199.30
	B1	32-70	3.94	3.00	0.95	0.58	1.26	0.79	6.84	41.80	3.58	7.90	65.6	7.56	1065.80
	B2	70-100	3.98	3.00	0.85	0.65	1.81	0.71	6.65	44.50	4.02	8.30	62.3	6.69	1093.80
	B3	100-120	3.85	3.00	0.41	0.38	1.08	0.71	6.17	50.60	2.58	4.90	70.5	8.16	1468.50
LR9	A	0-8	4.26	3.66	8.17	2.27	0.57	1.57	0.67	15.10	12.58	45.40	5.1	11.85	5485.10
	Cr	8-40	3.96	3.00	2.18	0.49	1.61	0.52	3.18	17.80	4.80	21.20	39.8	6.55	1004.20

Table 3 – Chemical properties of the studied soils from Lions Rump (continued)

Pedon		cm	H ₂ O	KCl	----- cmol _c dm ⁻³ -----							----- % -----		mg dm ⁻³	
Neutral pH Ornithogenic soils															
LR15	O1	0-3/4	5.28	4.20	18.60	22.11	1.41	2.05	0.10	8.90	44.17	83.20	0.2	4.62	1037.80
	O2	¾-9/11	5.66	4.18	18.30	23.48	1.00	1.65	0.29	8.70	44.43	83.60	0.6	3.70	771.10
	OA	11-16/17	5.99	4.26	23.56	23.02	0.85	1.92	0.00	7.50	49.35	86.80	0	3.88	1290.10
	Bi1	17-37/38	7.40	5.47	29.25	24.63	0.62	1.35	0.00	1.40	55.85	97.60	0	2.41	803.00
	Bi2	37/38-60	7.61	5.72	30.65	19.33	0.67	1.44	0.00	1.40	52.09	97.40	0	2.76	837.40
	BC	60-80+	8.15	6.06	35.35	21.20	0.62	1.22	0.00	1.40	58.39	97.70	0	2.09	611.60
LR22	A	0-16	7.26	6.83	8.40	11.49	0.57	2.92	0.00	1.30	23.38	94.70	0	12.48	920.50
LR23	A	0-8/10	5.89	5.09	17.20	22.29	1.85	0.96	0.00	5.70	42.30	88.10	0	2.26	3118.30
	Bi	10-22/24	5.81	4.01	28.77	15.95	0.82	1.44	0.19	3.70	46.98	92.70	0.4	3.04	403.80
	C	24-28/30	8.40	6.64	50.49	14.80	0.00	1.57	0.00	1.30	66.86	98.10	0	2.34	122.30
	2A	30-34/36	8.53	6.63	40.99	10.92	0.00	1.48	0.00	0.60	53.39	98.90	0	2.77	120.20
	2C	34/36-90	8.35	6.88	51.72	9.34	0.08	1.52	0.00	0.60	62.66	99.10	0	2.43	155.30

CEC = cation exchange capacity; PBS = percentage of base saturation (PBS); ESP = Exchangeable Sodium Percentage

Soils formed under direct penguin influence (Acid and Neutral ornithogenic soils) a mean content of $1075.3 (\pm 1206.4) \text{ mg/dm}^3$ of P was obtained. The extremely high Melich-1 extractable-P for the highest and most ancient ornithogenic soil (LR7) indicates that P minerals constitute stable P reserves at these sites, as confirmed by XRD analysis (data not show for LR7), besides the greater amount of P as amorphous mineral and organic form. Mean extractable P in Acid ornithogenic soil is more than ten times higher than the levels observed for Non-ornithogenic soils while exchangeable Ca^{2+} is more than nine times lower. Similar results were observed by Moura et al., (2012) studying soils from Byers Peninsula, Livingston Island. As it has been show for similar soils from Maritime Antarctica (Simas et al., 2006, 2007), soils development in such conditions are marked by the instability of P–Ca phases. Soil acidity also alters clay minerals and rock forming minerals with formation of P–Al–K phases of varied crystallinity (Simas et al., 2006). In such pedoenvironments, phosphatization is the main soil forming process and determines soils overall chemistry and ecosystem functioning (Tatur and Barczuk, 1985; Simas et al., 2007).

The highest content of Melich-1 extractable-P was obtained for the first layers of the most recently abandoned rookery (LR9, Table 3). High P values in depth for LR7 (not show) indicate P illuviation after site abandonment by penguins. A detailed study of clay-sized minerals for Antarctic soils with different degrees of ornithogenic influence is presented by Simas et al. (2006) and Schaefer et al (2008).

The soils from penguin rookeries and adjacent areas are more developed than soils with no faunal influence, as observed when comparing LR8 with LR3. A stony/pebbly pavement is present in all sites but is often hidden by the well-developed and continuous vegetation in ornithogenic sites. Clear horizon differentiation occurs and a relatively deep organic matter-rich A horizons and phosphatic B horizons were easily identified. Surface horizons are dark and yellowish brown as a result of humus incorporation corroborating the study of Simas et al. (2008) and Michel et al. (2006) in other areas of King George Island.

In the most developed ornithogenic soils (LR8), the surface horizons have lower P contents in comparison with depth horizons, due to plant uptake, organic material accumulation over old layers of guano deposition, concomitantly with P leaching (Table 3).

In the absence of ornithogenic activity, the soil chemical weathering in Antarctic is less pronounced and soils present chemical and mineralogical characteristics main influenced by the parent material. For Non-ornithogenic soils in Lions Rump, high pH, Ca^{2+} and Mg^{2+} levels, and salinity are usually observed, as verified in LR4, LR5 and LR12; and K^+ concentration is lower than in ornithogenic soils, which receive K^+ deposition from guano.

The mean P content in Non-ornithogenic soils was $102.7 \pm 48.0 \text{ mg/dm}^3$, which is an expressive concentration for soils without bird influence, but occurs because these soils are most formed from weathered basalt-andesitic rocks, naturally present apatite as mineal accessory.

Even in areas with some stagnant water (LR19, LR21 and LR 25), no redoximorphic features were observed, as described by Blume et al. (2002) and Simas et al. (2008) for some hydromorphic soils of Maritime Antarctic. No features of salinization were observed either in any profile studied, neither podzolization, even in soils with high sand content.

Acid sulfate soils as a product of oxidation sulfides, as described by Simas et al. (2006) and Simas et al. (2008) in Admiralty Bay, occurs at one unique site at Lions Rump where it is formed from sulfide bearing andesites and related tills. These soils are represented by LR13 profile, which present much lower pH (3.62), high contents of exchangeable Al^{3+} ($19.5 \text{ cmol}_c\text{dm}^{-3}$) and H+Al ($28.1 \text{ cmol}_c\text{dm}^{-3}$), and very low P contents ($6.9 \text{ mg}\cdot\text{dm}^{-3}$). In the clay fraction of this soil, jarosite and smectite are the principal minerals (Figure 7). This profile also present signals of ashes from the last volcanic eruption from Penguin Island.

Soils from Lions Rump present relatively low amounts of fine particles, clay (9.2%) and silt (24.9%) (Table 2), in comparison to other soils from Admiralty Bay. Clay contents are higher at Ornithogenic soils contrasting with results of Simas et al. (2008), who found lower clay proportion for Ornithogenic in comparison with non-ornithogenic. All soils are gravelly and with similar content of particles $> 2 \text{ mm}$, but a tendency to be more skeletal is verified for soils formed from bedrock Tertiary materials and at higher altitudes (Table 2).

The soil structure from Lions Rump is dominated for weak, medium-sized, blocks and moderate medium granular features, domining clear to gradual wavy transition between horizons what may confirm the weak cryoturbation features in this area (Table 2).

The studies of Simas et al. (2008) who described 56 pedons distributed in the major ice-free areas of Keller Peninsula, Crépin Point, Rakusa Point, Llano Point, Hennequin Point and Ullman Point, and Michel et al. (2006) who studied “Copabacana area” indicate that most soils studied in Admiralty Bay present permafrost in the upper 200 cm in January 2003, and therefore, can be fitted within the Gelisol order of Soil Taxonomy (Soil Survey Staff, 2010) and in the Cryosol Major Group of the World Reference Base for Soil Resources (ISSS, 2006). Typical cryoturbation features such as patterned ground (i.e. stone circles, stripes and earth hummocks), irregular and broken horizons, vertical orientation of stones within the soil profile, buried organic matter, and formation of silt caps were commonly observed, as indicated for Bockheim and Tarnocai (1998) and Tarnocai et al. (2004). In Lions Rump area,

none of the ornithogenic soils was classified as Gelisol and cryoturbation features are not commonly observed. Soils with permafrost occur only above 80 m.a.s.l. and for all studied profiles and they are deeper than 100 cm. For this reason, we can just classify them as Gelisol because they have a cryic horizon starting within 200 cm from soil surface and evidence of cryoturbation in some layer within 100 cm of the soil surface.

Total organic carbon and humic substances

Although biomass production by Antarctic vegetation is scarce, it frequently exceeds decomposition capacity of local microbiota, which is limited by climate conditions (Ugolini, 1972). Then, low temperatures and moisture are crucial for the low microbial activity and humification rate (formation of humic substances) of Antarctic soils (Pereira, 2012). Therefore, organic matter accumulates at some specific sites and plays important pedological and ecological roles (Beyer et al, 1995; Beyer, 2000; Bölter and Kandeler, 2004; Simas et al, 2008).

The sea–land transfer of matter and nutrients favors vegetation development and position of ornithogenic soils in landscape. These soils are the main terrestrial organic carbon pool of Maritime Antarctica (Simas et al., 2007). In Lions Rump total organic carbon for ornithogenic soils are approximately four times higher than for Non-ornithogenic soils.

The fractionation of humic substances in ornithogenic soil indicated averages of 0.55 dag kg⁻¹ fulvic acids (FA), 0.83 dag kg⁻¹ humic acids (HA), and 3.67 dag kg⁻¹ humin (HU) (Table 4). In ornithogenic soils, HU contents are higher due to dense cover of higher plants (*D. antarctica* and *C. quitensis*), which are responsible for the incorporation of lignin from the root system into the soil. These HU possibly are not a real humic substance, been a residual organic material without decomposition.

HA and AF fractions are probably present because they are provided by guano. In Non-ornithogenic soils, we found averages of 0.1 dag kg⁻¹ fulvic acids (FA), 0.3 dag kg⁻¹ humin (HU) and no detectable humic acids (Table 4). These low contents are justified by the almost absence of vegetation at these soils.

Pereira (2012) found for soils from Hope Bay, Antarctic Peninsula, HA dominating other carbon forms where vegetation is formed principal by mosses and lichen. They related this high ratio HA/FA as indicative of higher degree of humification.

Table 4. Total organic carbon and quantitative fractioning of organic matter of selected horizons from some studied Lions Rump`s soils

Pedon	Depth (cm)	-----dag kg ⁻¹ -----					HA/FA
		TOC	FA	HA	HU		
Non-ornithogenic soils							
LR3	A	0-5	0.23	0.01	0.00	0.21	-
	AB	5-17/20	0.17	0.10	0.00	0.07	-
	Bi	20-47/52	0.14	0.00	0.00	0.13	-
LR4	A	0-43	0.14	0.00	0.07	0.05	0.0
	AB	0-46	0.14	0.00	0.00	0.13	0.0
	Bi	24-45/47	0.17	0.00	0.00	0.15	0.0
LR5	C1	0-23	0.27	0.05	0.00	0.23	0.0
LR13	A	0-8	0.17	0.00	0.00	0.15	0.0
	C	15-65	0.12	0.01	0.00	0.11	0.0
LR19	A	0-4	1.92	0.31	0.21	1.25	0.7
	C1	15-30/35	0.33	0.04	0.01	0.23	0.3
LR24	A	0-8	1.20	0.21	0.09	0.83	0.4
	Bi	33-52	0.20	0.01	0.00	0.17	0.0
Acid pH Ornithogenic soils							
LR8	O	0-5	18.70	1.69	3.11	12.90	1.8
	A	5-12	3.32	0.48	0.48	2.36	1.0
	BA	18-32	1.26	0.22	0.23	0.81	1.0
	B3	100-120	1.26	0.25	0.30	0.72	1.2
LR9	A	0-8	4.24	0.48	0.51	2.96	1.1
	Cr	8-40	1.48	0.19	0.34	0.95	1.8
Neutral pH Ornithogenic soils							
LR15	O1	0-3/4	4.17	0.39	0.92	2.61	2.4
	OA	11-16/17	1.96	0.24	0.34	1.17	1.4
	Bi1	17-37/38	0.36	0.17	0.00	0.15	0.0
	Bi2	37/38-60	0.26	0.01	0.00	0.25	0.0
LR22	A	0-16	2.82	0.50	0.22	2.01	0.4
LR23	Bi	10-22/24	0.24	0.04	0.00	0.20	0.0
	2A	30-34/36	0.16	0.02	0.00	0.14	0.0
	2C	34/36-90	0.33	0.00	0.05	0.22	0.0

Sites dominated by *D. antarctica* and/or *C. quitensis* (LR8 and LR15) present higher TOC contents in profiles with depth due to presence of lignine-bearing tissues and proper root systems. On the other hand, soils covered with *P. crista* (LR23) or mosses (LR21) present an abrupt reduction of TOC with depth. Although ornithogenic soils exhibit high content of TOC, no umbric epipedon was described. For Non-ornithogenic soils, humin (HU) is almost the only form of organic compounds; it is practically absent from organic matter label forms.

The tendency of increasing HA/FA ratio with depth in Acid ornithogenic soils, as also observed by Michel et al. (2006), can be associated to migration and reaction of organic matter along the profile, causing polycondensation and accumulation of the more recalcitrant humic substances in depth.

Total elemental composition

Total mean contents of CaO, MgO and K₂O were respectively 0.24; 0.05 dag kg⁻¹, and 1.02 dag kg⁻¹ for Acid ornithogenic soils; 0.51, 0.08, and 0.43 dag kg⁻¹, for Neutral ornithogenic soils; and 0.48, 0.11, and 0.72 dag kg⁻¹ for Non-ornithogenic soils (Table 5). These data show the reduction of CaO and MgO contents and the increasing of K₂O in Acid ornithogenic soil, what derivated from Ca and Mg leaching, K addition from guano and formation of phosphates mineral K-rich as taranakite.

Plagioclases were detected in all soils (see mineralogy). In this case, the presence of easily weathered primary minerals in clay fraction indicates a limited chemical change and the effect of cryoclasty, decreasing particles size and increasing CEC. The higher content of total K₂O in comparison to exchangeable ones suggests that K is present mostly in non-exchangeable forms, possibly associated to the formation of phosphate clays, typical minerals from phosphatization process (Pereira, 2012), process as well as associated with the plagioclases in the soil (Figure 6, see mineralogy).

Mean contents of total P₂O₅ were 5.62 dag kg⁻¹ for Acid ornithogenic soils, 0.43 dag kg⁻¹ for Neutral ornithogenic soils, and 0.18 dag kg⁻¹ for Non-ornithogenic soils (Table 5). The P enrichment in sites with previous or current ornithogenesis influence is significative. The P total in Acid ornithogenic soils is 31 times higher than Non-ornithogenic ones, which confirm the importance of avifauna influence in soil transformation in these Antarctica environments.

Table 5: Total elemental composition in < 2 mm air-dried soil samples from selected horizons of some soils studied from Lions Rump

Pedon	Depth cm	CaO	MgO	K ₂ O	F ₂ O ₃	Al ₂ O ₃	MnO	P ₂ O ₅	Cu	Zn	Cd	As	Cr	Pb	
		-----dag kg ⁻¹ -----							-----mg kg ⁻¹ -----						
Non-ornithogenic soils															
LR3	A	0-5	0.64	0.15	0.89	8.58	3.15	0.12	0.16	92.2	87.2	11.1	13.2	103.4	22.5
	AB	5-17/20	0.74	0.14	0.88	6.88	3.31	0.11	0.15	24.9	95.8	11.5	27.9	94.0	39.7
LR4	A	0-5	0.43	0.10	1.17	6.99	3.31	0.09	0.12	55.5	74.9	9.5	20.9	82.8	22.6
	Bi	24-45/47	0.46	0.12	1.18	7.17	3.13	0.10	0.13	60.5	85.9	8.6	14.8	73.5	19.1
LR5	C1	0-23	1.31	0.26	0.62	8.12	2.57	0.10	0.12	89.9	74.6	10.2	16.3	301.7	24.0
LR13	A	0-8	0.36	0.07	0.12	9.63	7.04	0.05	0.17	30.6	63.4	6.3	24.8	27.8	21.1
	C	15-65	0.13	0.04	0.86	11.47	5.50	0.02	0.23	46.4	34.3	11.0	27.9	17.9	27.7
LR19	A	0-4	0.37	0.11	0.51	6.92	3.50	0.06	0.21	38.6	60.9	5.9	7.9	77.3	11.3
	C1	15-30/35	0.35	0.10	0.55	8.50	3.93	0.04	0.29	46.1	66.8	4.0	6.5	37.5	4.0
LR24	A	0-8	0.26	0.08	0.57	8.42	3.88	0.06	0.22	34.3	56.4	5.0	4.0	50.9	6.7
	Bi	33-52	0.26	0.07	0.59	8.11	4.25	0.06	0.15	33.1	60.9	6.1	7.3	31.7	10.9
Acid pH Ornithogenic soils															
LR8	O	0-5	0.36	0.13	1.01	5.35	4.95	0.05	0.61	75.3	75.4	11.3	34.0	62.0	44.0
	A	5-12	0.31	0.08	1.00	7.36	5.09	0.05	1.81	69.0	69.7	7.8	23.4	35.4	17.4
	BA	18-32	0.15	0.02	1.00	9.28	5.00	0.03	6.50	72.6	72.2	7.5	19.9	30.1	15.0
	B3	100-120	0.13	0.02	1.00	10.13	5.40	0.03	7.47	75.0	69.9	8.8	23.8	33.4	19.4
LR9	A	0-8	0.34	0.04	1.11	6.34	3.87	0.03	5.01	165.8	159.1	6.4	13.0	39.9	13.9
	Cr	8-40	0.16	0.02	1.02	7.98	5.06	0.02	12.32	157.1	105.8	8.7	37.8	35.9	28.2
Neutral pH Ornithogenic soils															
LR15	O1	0-3/4	0.66	0.21	0.73	7.84	3.53	0.07	0.82	61.6	96.2	7.9	20.2	142.6	21.6
	OA	11-16/17	0.96	0.29	0.72	8.00	3.25	0.09	0.72	53.3	93.9	7.8	21.5	157.7	18.6
	Bi1	17-37/38	0.95	0.17	0.69	8.19	2.93	0.10	0.38	51.6	82.2	8.2	18.6	170.1	24.7
LR22	A	0-16	0.50	0.10	0.79	7.86	3.79	0.05	1.00	62.3	89.1	4.8	4.1	74.3	5.9
	Bi	10-22/24	0.36	0.10	0.51	9.47	3.35	0.06	0.25	47.0	66.0	5.5	7.3	45.8	3.8
LR23	2A	30-34/36	0.41	0.06	0.52	9.25	3.14	0.06	0.16	41.5	65.9	6.2	5.5	64.8	8.2
	2C	34/36-90	0.22	0.03	1.91	10.31	3.84	0.07	0.17	80.4	87.4	10.5	12.8	48.0	14.7

Mean total contents of Fe_2O_3 and Al_2O_3 were respectively, 7.74 and 4.90 dag kg^{-1} for Acid ornithogenic soils, 8.61 and 3.55 dag kg^{-1} for Neutral ornithogenic soils, and 8.25 and 3.96 dag kg^{-1} for Non-Ornithogenic soils (Table 5). These data indicate these oxides are closely related with the parent material, and no influence of guano on these contents. However, slightly higher content of Fe_2O_3 and Al_2O_3 in Acid ornithogenic soils in comparison to others may be related to more intensive weathering following by leaching of bases and accumulation of Fe and Al.

Mean total heavy metal contents (Table 5) were 17.23 mg kg^{-1} (As), 7.94 mg kg^{-1} (Cd), 76.60 mg kg^{-1} (Cr), 65.19 mg kg^{-1} (Cu), 18.54 mg kg^{-1} (Pb), and 78.91 mg kg^{-1} (Zn). These contents are lower than observed for Pereira (2012), except for Cd.

. No large difference was observed between soil groups in heavy metal concentration (Table 5), indicating predomine influence of parent material lithology on these contents. A exemple of that is the higher levels of Zn determined in LR3, LR9 and LR15 belong a Non ornithogenic, Neutral and Acid pH ornithogenic group, respectively.

Concerning metal distribution throughout the profile, contents exhibit irregular and non-defined distribution pattern. No reference values for heavy metals in soils from Antarctic Maritime are available to comparisons; however paper showing the contamination of heavy metals by anthropic actives are studied by Santos et al. (2005, 2007), Chaparro et al. (2007, 2011) and Guerra et al. (2011).

Soil mineralogy

The X-ray diffraction patterns for Non-ornithogenic soils showed the presence of chlorite-vermiculite intergrade represent by peaks at 1.5 nm in clay fraction, which was not changed after treatments with KCl, Mg and Mg + glycol saturation. However, this peak collapsed to 1.00 nm after heating at 350 and 550 °C.

Minerals from feldspar group, including plagioclases, anorthite, albite and others are identified from XDR peaks at 0.375, 0.33, 0.321, 0.318 and 0.303 nm. Presence of feldspar minerals in clay fraction it related to incipient leaching process of bases and Si, contributing to low chemical alteration in the thermodynamic equilibrium involving Ca, Mg and K. These results suggest that although Maritime Antarctic is warmer and wetter than Continental Antarctica, chemical weathering process is still limited in this region as well. The absence of kaolinite formation is also other evidence of incipient weathering in these Non-ornithogenic soils, even though this mineral has been found in few Antarctica soils, mainly in acid sulfate soils. No difference in mineralogical composition of non ornithogenic soils was verified

between Gelisols and Inceptisols (LR3 and LR12, respectively) from the same parental material (figure 5), what can confirm that beside absence of permafrost in the Non-ornithogenic Inceptisols, limited chemical weathering occurs only by physicals process of pedoturbation and cryoclastic, which are the main process of soil formation in both soils (LR3 and LR12).

XRD patterns for clay fraction of LR15, a “neutral pH ornithogenic soil” (Figure 6), indicate no mineralogy alteration after short avifauna influence, therefore, despite the high amount of P and TOC input by birds, short soil exposure to the penguin rookery was not enough to promote phosphatization process, which is a transformation of silicate clay minerals into phosphates.

Phosphatization is evident in LR8 (Figure 6), where most silicate clay minerals were transformed into crystalline and non-crystalline phosphates, mainly Taranakite. The main evidence for this is the complete absence of 2:1 secondary silicate clay minerals, as also observed for the majority ornithogenic soil. Taranakite is not well crystallized, because peaks disappear after any clay treatment. The clay treatment for XRD analysis is important for ornithogenic soils to eliminate confusion between 2:1 and phosphate minerals at 1.6 nm peak.

The process of weathering transforming primary silicate minerals into 2:1 and after into 1:1 minerals is not common for Antarctica ornithogenic soils (Figure 6, LR8). When primary minerals are weathered, bases in solution are complexed by phosphate in solution reducing bases activity to contents not enough to form secondary minerals.

LR13 represents an acid sulfide soil formed from sulfide bearing andesites and related tills present in the top part of Lions Rump. This site is well-drained and presents clear cryoturbation features with presence of dead ice and peculiar yellowish colors. The oxidation of sulfides promotes soil acidification, leading to secondary sulfates formation such jarosite (Figure 7) and sulphuric horizons similar to those described by Simas et al. (2006) in Admiralty Bay. Contrasting results from Simas et al. (2008) who found kaolinite in Antarctica clay fraction, in Lions Rump this mineral was not detected in acid sulfide soils.

The presence of clay-sized pyroxene, plagioclase and absence of kaolinite suggest an incipient degree of chemical alteration of parent material, despite the advanced acidification process (Figure 7). The main secondary silicate clay mineral present in this soil is chlorite-smectite intergrade, as indicate by peak at 1.5 nm, that is maintained after K saturation, sifted to 1.8 nm after Mg+glycol treatment, and collapsed to 1.0 nm after heated to 550 °C. Maghemite is also detected, and with jarosite gives the expressive chrome color (10YR 5.5/8). Allophane is probably present and is derivate from ashes deposited on the sulphuric materials

and mixed by cryoturbation process. These ashes came from the last eruption in Penguin Island, and ash's evidence can be observed covering soils in marine terraces.

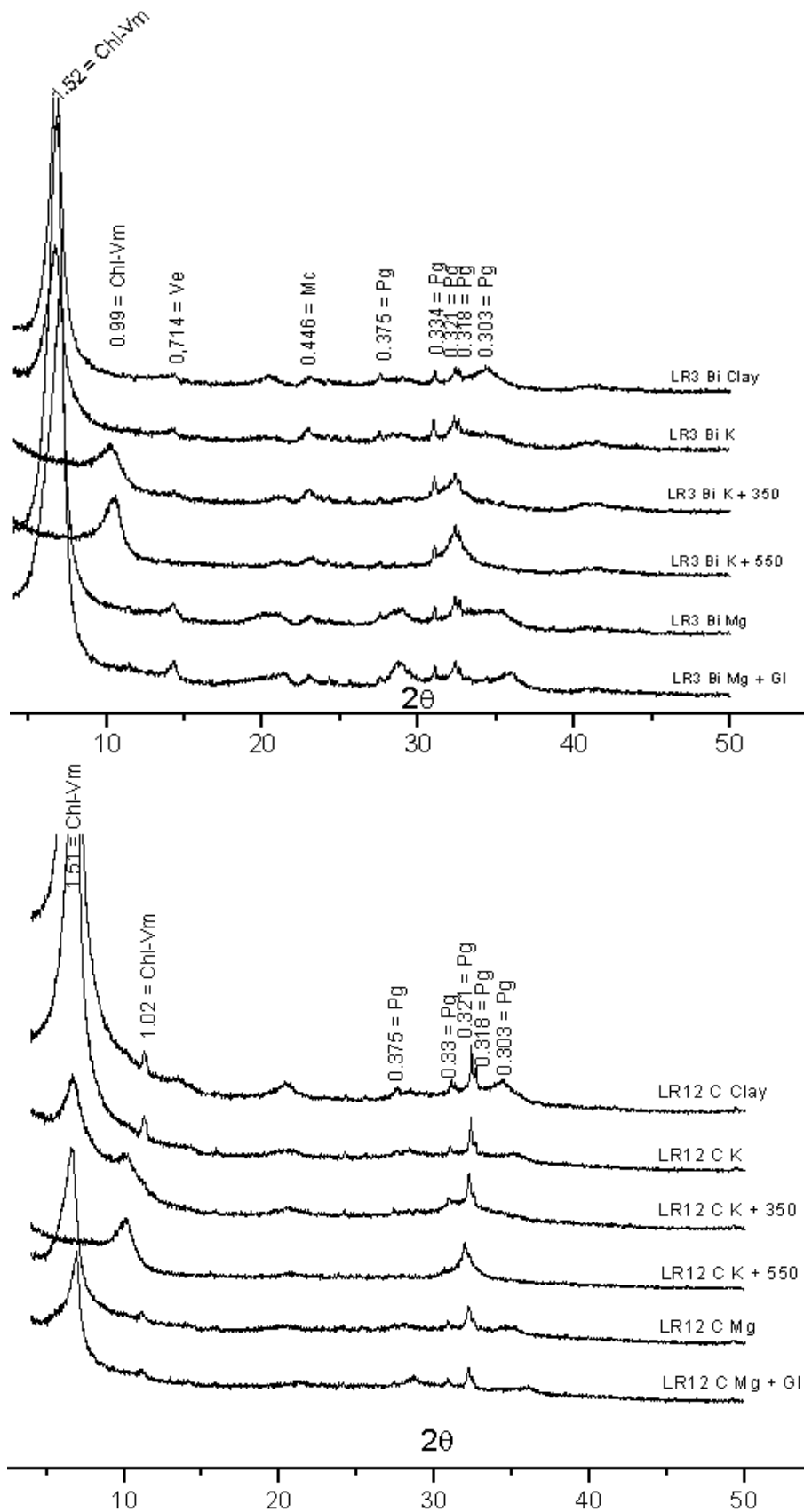


Figure 5. XRD patterns of clay fraction for Non-ornithogenic soils from Lions Rump, Maritime Antarctica. Ve = Vermiculite; Pg = Plagioclase Group; Chl-Vm = Chlorite-Vermiculite Integrate.

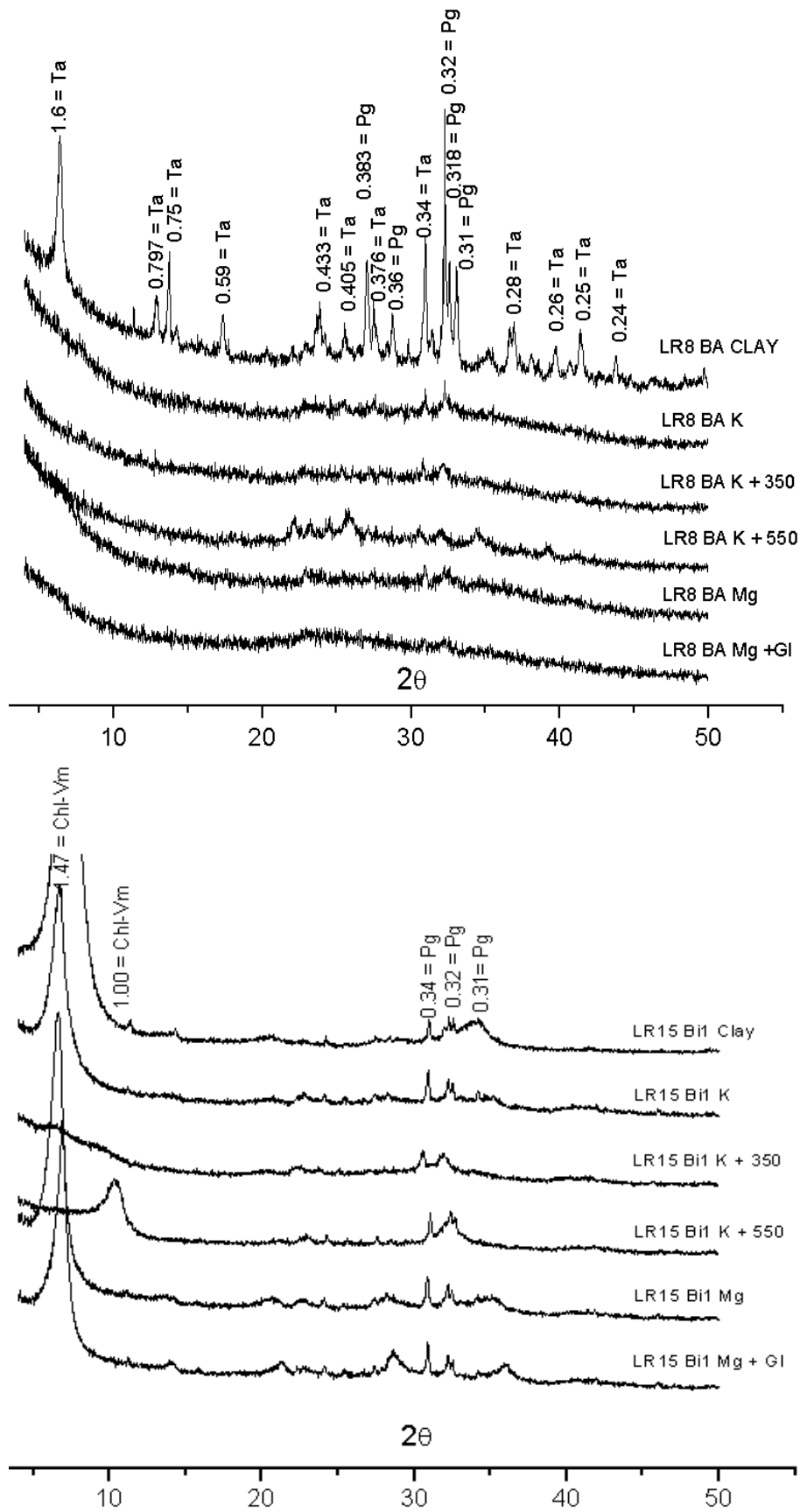


Figure 6. XRD patterns of clay fraction for Acid ornithogenic (LR8) and Neutral ornithogenic (LR15) soils from Lions Rump, Maritime Antarctica. Ta = Taranakite; Pg = Plagioclase Group; Chl-Vm = Chlorite-Vermiculite Intergrade.

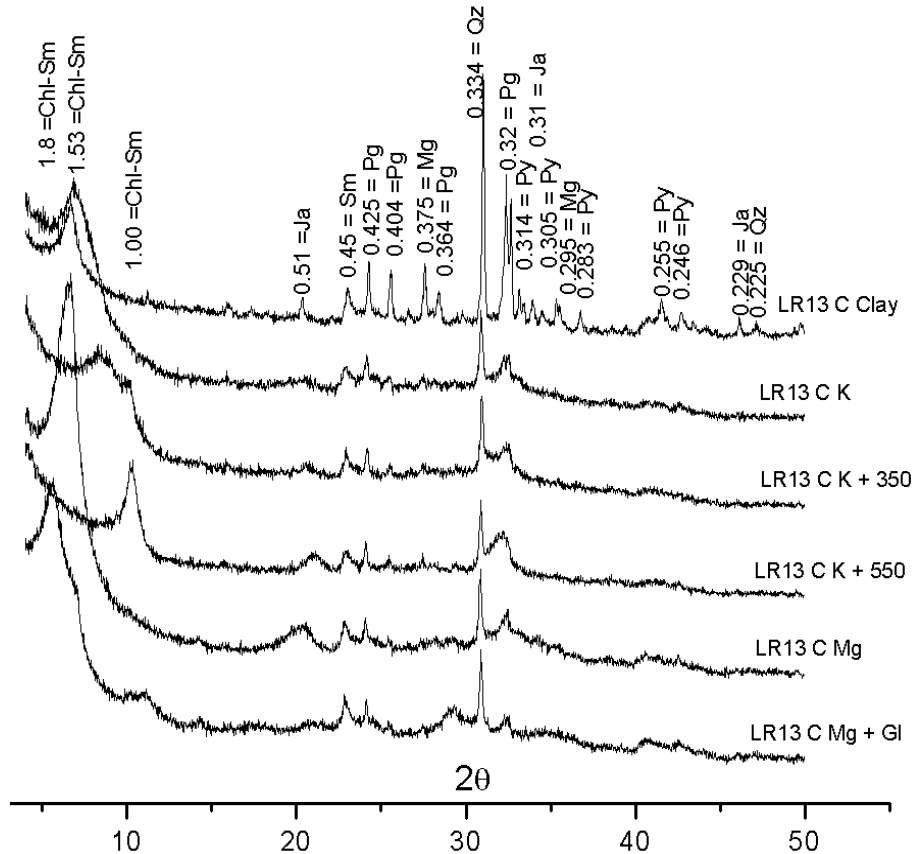


Figure 7. XRD patterns of the clay fraction for the Non-ornithogenic soils from Lions Rump, Maritime Antarctica. Chl-Sm = Chlorite-Smectite Intergrade; Pg = Plagioclase Group; Ja = Jarosite; Al = Allophane; Py = Pyroxene; Mg = Maghemite

According to the WRB system, acid sulfate soils are classified as Turbi-thionic Cryosols (Tarnocai et al., 2004). However, as previously observed by Simas et al. (2008), for Soil Taxonomy system, sulphuric qualifier is only applicable to Aquiturbels, which is definitely not the case for these well drained and oxidized soils. Therefore, our studies reinforce the proposal from Simas et al. (2008) to include the Sulphuric Haploturbel to classify well drained cryoturbated soils with sulphuric materials in the upper 100 cm depth.

All soils studied presented high Feo/Fed ratio (Table 6), which usually indicates high amounts of poorly crystalline forms and/or soil less developed, according to soil classification presented. However, in Lions Rump the highest Feo/Fed value is found for LR8 and LR9, both Acid ornithogenic and more developed soils of study area. Predominance of low-crystallinity Fe minerals in the Antarctica ornithogenic soils, which part of Al and Fe may be present as organometallic complexes due to the high soil organic carbon content can explain these data, as indicated by Simas et al. (2007).

Table 6. Contents of Fe, Al and P extracted by citrate-bicarbonate-dithionite and ammonium oxalate from selected horizons of some studied soils from Lions Rump

Hor	Prof. (cm)	----- CBD (Σ^1) -----			----- Oxalate -----			Fe _o Fe _d	Al _o Al _d	P _o P _d	
		Fe ₂ O ₃	Al ₂ O ₃	P ₂ O ₅	Fe ₂ O ₃	Al ₂ O ₃	P ₂ O ₅				
----- dag kg ⁻¹ -----											
Non-Ornithogenic soils											
LR3	A	0-5	1.70	0.47	0.11	0.46	0.40	0.08	0.27	0.85	0.73
	AB	5-17/20	1.86	0.55	0.10	0.46	0.39	0.08	0.25	0.71	0.80
	Bi	17/20-47/52	1.00	0.24	0.11	0.44	0.35	0.08	0.43	1.46	0.73
LR4	A	0-5	1,31	0,19	0,11	0,19	0,18	0,04	0,14	0,95	0,36
	AB	5-22/24	1,85	0,37	0,11	0,30	0,28	0,05	0,16	0,76	0,45
	Bi	22/24-45/47	1,70	0,36	0,10	0,33	0,29	0,05	0,20	0,81	0,50
LR5	C1	0-23	1,64	0,52	0,10	0,66	0,47	0,03	0,40	0,90	0,30
LR13	A	0-8	1,92	0,24	0,13	0,37	0,32	0,05	0,19	1,33	0,38
	C	15-65	6,60	0,66	0,22	1,45	0,37	0,05	0,22	0,56	0,23
LR19	A	0-4	1,69	0,49	0,15	0,69	0,40	0,09	0,41	0,82	0,60
	C1	12/15-30/35	1,65	0,42	0,18	0,57	0,36	0,14	0,34	0,86	0,78
LR24	A	0-8	1.80	0.52	0.16	0.42	0.48	0.10	0.24	0.92	0.63
	Bi	33-52	1.58	0.24	0.12	0.25	0.23	0.06	0.16	0.96	0.50
Acid pH Ornithogenic soils											
LR8	O	0-5	1.72	0.73	0.51	0.46	0.32	0.31	0.27	0.44	0.61
	A	5-12	3.05	1.09	1.56	1.65	0.69	1.53	0.54	0.63	0.98
	BA	18-32	5.01	3.84	5.89	3.36	2.10	5.82	0.67	0.55	0.99
	B3	100-120	5.79	4.99	6.44	3.93	3.22	6.89	0.68	0.65	1.07
LR9	A	0-8	2,27	0,93	2,40	1,48	0,52	2,82	0,65	0,56	1,18
	Cr	8-40	2,63	2,91	4,48	0,78	1,16	2,61	0,30	0,40	0,58
Neutral pH Ornithogenic soils											
LR15	O1	0-3/4	1,70	0,75	0,60	0,57	0,52	0,56	0,34	0,69	0,93
	OA	9/11-16/17	1,63	0,73	0,53	0,49	0,54	0,51	0,30	0,74	0,96
	Bi1	16/17-37/38	1,36	0,42	0,27	0,35	0,39	0,21	0,25	0,93	0,78
	Bi2	37/38-60	1,43	0,47	0,31	0,37	0,42	0,26	0,26	0,89	0,84
LR22	A	0-16	1,67	0,45	0,71	0,58	0,24	0,52	0,34	0,53	0,73
LR23	Bi	8/10-22/24	1.63	0.33	0.16	0.29	0.26	0.11	0.18	0.79	0.69
	2A	28/30-34/36	1.67	0.17	0.12	0.23	0.20	0.05	0.14	1.18	0.42
	2C	34/36-90	2.56	0.24	0.10	0.27	0.21	0.06	0.10	0.88	0.60

¹Somatório das extrações.

According to Tatur and Barczuk (1985), “phosphatization” process comprises chemical weathering of rock minerals and formation of amorphous Al and Fe minerals. These phases react with ornithogenic P, K and N to form amorphous and crystalline secondary phosphates and according to Simas et al., 2006, non-crystalline phases are important soil components and reach >75% of the clay fraction for some ornithogenic soils.

Simas et al. (2006) found crystalline phosphates occurring only in soils directly affected by penguins (active and abandoned rookeries) as profiles LR9 and LR8 from Lions Rump, respectively. The incongruent dissolution of crystalline Al–Fe phosphates with formation of amorphous P-rich phases is considered the most common transformation with increasing age of abandonment site (Tatur et al., 1997) and maintains high levels of labile P forms. On the other hand, at sites lower penguin influence (LR 11, LR15 and LR 23) P inputs are lower, and no crystalline phosphates are present. Therefore, the chemical characteristics of these sites are controlled by highly reactive non-crystalline P minerals.

Soil mapping

Based on our soil survey we propose a first approximation of the soil map for Lions Rump (Figure 8). Soil units mapped in study area were: Lithic Cryorthents (2.55 ha), Typic Dystroglepts ornithic (0.93 ha), Typic Gelifluvents ornithic (1.75 ha), Typic Gelorthents ornithic (1.69 ha), Typic Haploglepts ornithic (9.45 ha), Association: Turbic Haploglepts and Typic Gelorthents (30.91 ha), Association: Oxyaquic Cryopsamments and Vitrandic Cryopsamments (15.45 ha), Association: Typic Haploglepts and Typic Gelorthents (3.44 ha), Association: Typic Haploturbels + Lithic Haploturbels (163.86 ha).

Typic Dystroglepts ornithic and Typic Gelorthents ornithic are the main vegetated soils in Lions Rump, which possibly represents one of the first ice-free areas colonized by penguins in Maritime Antarctica. Typic Dystroglepts ornithic maybe represent the deepest, most structured and reddish soils so far described in Maritime Antarctica. Typic Haploglepts ornithic represent the main soils on first and second moraine levels from the White Eagle Glacier. Typic Haploturbels and Lithic Haploturbels are present only above 80 m.a.s.l., especially on the top areas and paraglacial spots, and represent Gelisols from Lions Rump, with gelic materials within 100 cm of the soil surface and permafrost within 200 cm from the soil surface. Despite their occurrence only at higher altitudes, they represent the largest soil cover in the studied area. Typic Haploturbels and Lithic Haploturbels are present at the edge of White Eagle Glacier, where cryoturbation process is more expressive.

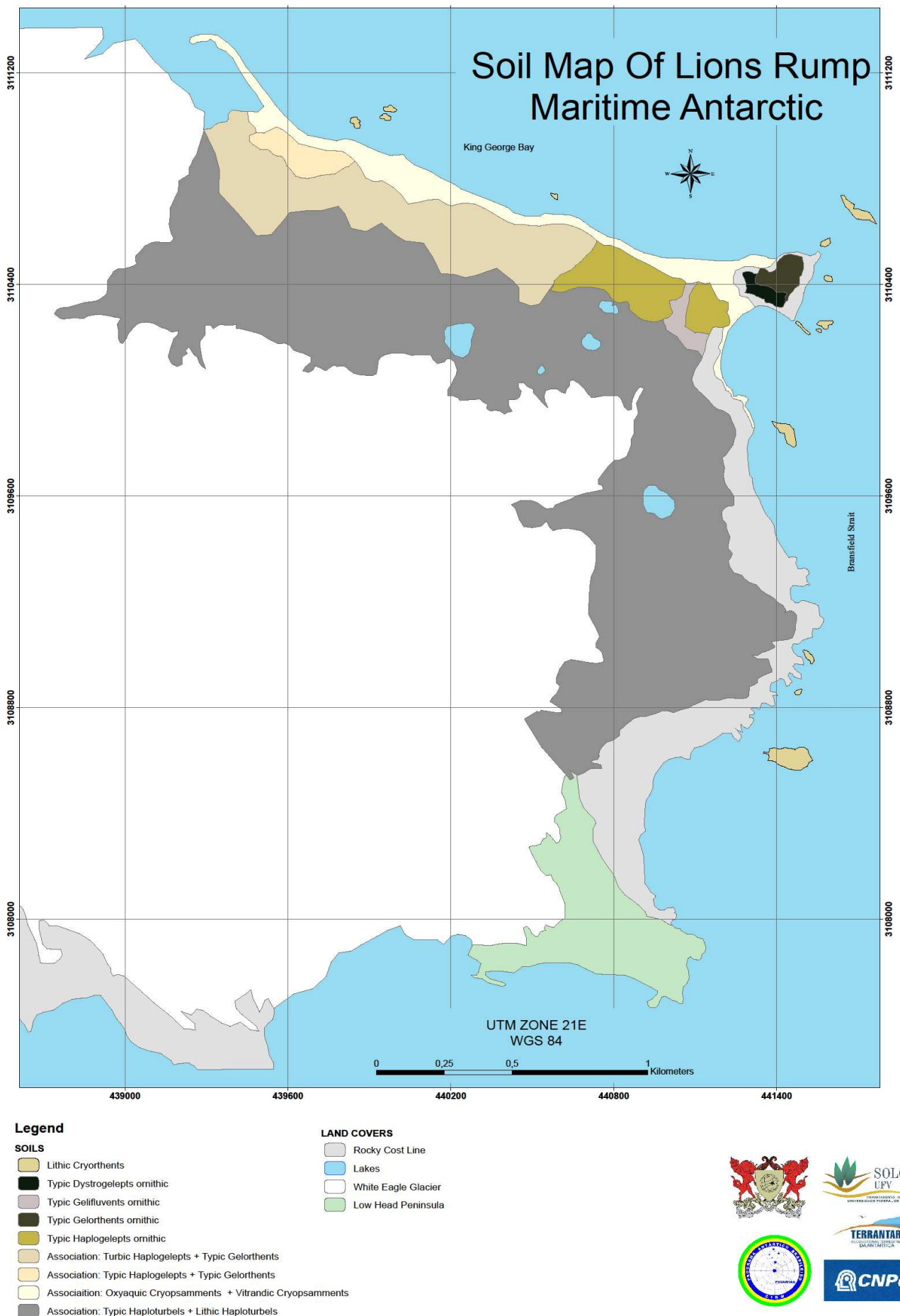


Figure 8 – Soil map and land covers of Lions Rump, Maritime Antarctic.

Turbic Haploglepts and Typic Gelorthents are situated between 40 and 80 m.a.s.l., without bird nesting influence and absent of permafrost within 200 cm in the profile. Vitrandic Cryopsamments and Oxyaquic Cryopsamments dominated the first level of terraces and former beaches along the coastal area. Other soils classified are present in very limited areas: Lithic Cryorthents ornithic, present on the sea stacks rock outcrops (basaltic plugs) close to the beach, and Typic Gelifluvents ornithic represent a small area on glacial alluvial fans and Typic Haplorthels represents an acid sulfide soil formed from sulfide bearing andesites and related tills present in the top part of Lions Rump.

CONCLUSIONS

At upland sites with no vegetation or ornithogenic influence, soil chemistry and mineralogy are related mainly to the physical weathering from basaltic till.

Ornithogenic influence alters soils characteristics leading to soil acidification, leaching of exchangeable bases, transformation of primary minerals and releasing of amorphous Fe and Al. These phases react with ornithogenic P, and phosphatization process occurs. This is the main soil forming process in Lions Rump and promotes predominantly phosphatic fine fraction and a significative increase of soil P pool, with very high levels of labile and moderately labile P forms.

Crystalline Al and Fe phosphates persist in soils even after site abandonment by penguins and act as P reserves.

Haplorthels and Haploturbels are the main soil of Lions Rump situated on the higher ice-free areas.

Higher P and N contents at ornithogenic sites favour vegetation establishment with presence of *D. antarctica* and *C. quitensis*. High organic carbon contents characterize ornithogenic sites as important C sinks at Antarctica terrestrial ecosystems.

The degree of ornithogenic influence can be assessed through the analysis of soils morphological, chemical and mineralogical characteristics. The study of these characteristics allowed the proposal of provisory diagnostic criteria for the ornithogenic qualifier, providing a better classification of these unique soils within the WRB and Soil Taxonomy systems.

REFERÊNCIAS BIBLIOGRÁFICAS

- Antarctic Permafrost and Soils – ANTPAS, 2006. Soil description manual. Guide for describing, sampling, analyzing, and classifying soils of the Antarctic region. Available at: <<http://www.http://erth.waikato.ac.nz/antpas>>. Accessed 5/19/2011.
- Beyer, L., 2000. Properties, formation and geo-ecological significance of organic soils in the coastal region of East Antarctica. *Geoderma* 39, 79–93.
- Beyer, L., Sorge, C., Blume, H.P., Schulten, H.R., 1995. Soil organic matter composition and transformation in Gelic Histosols of coastal Continental Antarctica. *Soil Biology and Biochemistry* 27, 1279–1288.
- Birkenmajer, K., 1981. Geological relations at Lions Rump, King George Island (South Shetland islands, Antarctica). *Studia Geologica Polonica. Geological results of the Polish Antarctica expeditions. Vol. LXXII.*
- Birkenmajer, K., 1994. Geology of tertiary glacial deposits and volcanics (Polonia Glacier Group and Chopin Ridge Group) at Lions Rump (SSSI n° 34), King George Island, West Antarctica. *Bulletin of the Polish Academic of Science Earth Sciences Vol. 42 n° 3.*
- Birkenmajer, K., 1994. Quaternary geology at Lions Rump (SSSI n° 34), King George Island, South Shetland islands (West Antarctica). *Bulletin of the Polish Academic of Science Earth Sciences Vol. 42 n° 3.*
- Blume, H.P., Beyer, L., Kalk, E., Kuhn, D., 2002. Weathering and soil formation. In: Beyer, L., Bölter, M. (Eds.). *Geocology of Antarctic ice-free coastal landscapes. Ecological Studies, Heidelberg, 54.*
- Bockheim, J.G., Tarnocai, C., 1998. Recognition of cryoturbation for classifying permafrost-affected soils. *Geoderma* 81, 281–293.
- Bockheim, J.G., Ugolini, F.C., 1990. A review of pedogenetic zonation in well-drained soils of the southern circumpolar region. *Quaternary Research, 34, 47-66.*
- Bolter, M., Kandeler, E., 2004. Microorganisms and microbial processes in antarctic soils. In: Kimble, J. (Ed.), *Cryosols: Permafrost-affected Soils. Springer-Verlag, Berlin, pp. 557–572.*
- Chaparro, M.A.E, Chaparro, M., Sinito, A.M., 2011. A Fuzzy Model For Estimating Heavy Metals In An Antartc Soil. *Latinmag Letters, Vol. 1, Special Issue D34, pp. 1-6. Proceedings Tandil, Argentina.*
- Chaparro, M.A.E., Nuñez, H., Lirio, J.M., Gogorza, C.S.G., Sinito, A.M., 2007. Magnetic screening and heavy metal pollution studies in soils from Marambio Station, Antarctica. *Antarctic Science* 19 (3), pp. 379–393.
- Embrapa. Centro Nacional de Pesquisa de Solos. Manual de métodos de análise de solo. 2ª ed. Rio de Janeiro: Embrapa Solos, 1997, 12 p.
- Guerra, M.B.B., Schaefer, C.E.G.R., Rosa, P. F., Simas, F.N.B., Pereira, T.T.C., Pereira-Filho, E.R., 2011. Heavy Metals Contamination in Century-Old Manmade Technosols of Hope Bay, Antarctic Peninsula. *Water Air Soil Pollut* 222 pp. 91–102.
- ISSS Working Group, 2006. World Reference Base for Soil Resources. International Society of Soil Sciences (ISSS). International Soil Reference and Information Centre (ISRIC) and Food and Agriculture Organization of the United Nations (FAO). *World Soil Report. FAO, Rome.*

- Michel, R.F.M., Schaefer, C.E.G.R., Dias, L., Simas, F.N.B., Benites, V., Mendonça, E.S., 2006. Ornithogenic Gelisols (Cryosols) from Maritime Antarctica: pedogenesis, vegetation and carbon studies. *Soil Sci. Soc. Am. J.* 70, 1370–1376.
- Michel, R.F.M., 2011. Classificação, Cobertura Vegetal e Monitoramento Térmico da Camada Ativa de Solos da Península Fields, Ilha Rei George e Ilha Ardley, Antártica Marítima. D.S thesis (in portuguese). Universidade Federal de Viçosa, Viçosa, Brazil.
- Moura, P.A., Francelino, M.R., Schaefer, C.E.G.R., Simas, F.N.B., Mendonça, B.A.F., 2012. Distribution and characterization of soils and landform relationships in Byers Peninsula, Livingston Island, Maritime Antarctica. *Geomorphology* 155–156, pp 45–54.
- Pereira, T.T.C., 2012. Solos de Hope Bay, Península Antártica. Viçosa, MG: UFV, Thesis (Doutorado em Solos e Nutrição de Plantas) – Universidade Federal de Viçosa, 130 pp.
- Ruiz, H.A., 2005. Incremento da exatidão da análise granulométrica do solo por meio da coleta da suspensão (silte + argila). *Revista Brasileira de Ciência do Solo*, 29 297-300.
- Santos, I. R., Silva-Filho, E. V., Schaefer, C.E.G.R., Albuquerque-Filho, M.R., Campos, L.S., 2005. Heavy metal contamination in coastal sediments and soils near the Brazilian Antarctic Station, King George Island. *Marine Pollution Bulletin* 50, pp.185–194
- Santos, I.R., Fávoro, D.I.T., Schaefer, C.E.G.R., Silva-Filho, E.V., 2007. Sediment geochemistry in coastal maritime Antarctica (Admiralty Bay, King George Island): Evidence from rare earths and other elements. *Marine Chemistry* 107, pp. 464–474
- Schaefer, C.E.G.R., Simas, F.N.B., Albuquerque-Filho, M.R., Michel, R.F.M., Viana, J.H.M., Tatur, A., 2004. Fosfatização: Processo de formação de solos na Baía do Almirantado e implicações ambientais. In: Schaefer, C.E.G.R., Francelino, M.R., Simas, F.N.B., Albuquerque Filho, M.R. (Eds.), *Ecosistemas Costeiros e Monitoramento Ambiental da Antártica Marítima, Baía do Almirantado, Ilha Rei George*. NEPUT – Departamento de Solos, Viçosa, Brasil, pp. 47–59.
- Schaefer, C.E.G.R., Simas, F.N.B., Gilkes, R.J., Mathison, C., Costa, L. M., Albuquerque, M. A., 2008. Micromorphology and microchemistry of selected Cryosols from Maritime Antarctica. *Geoderma* 144, 104 – 115.
- Simas, F.N.B., Schaefer, C.E.G.R., Albuquerque-Filho, M.R., Francelino, M.R., Fernandes Filho, E.I., Costa, L.M., 2008. Genesis, properties and classification of Cryosols from Admiralty Bay, Maritime Antarctica. *Geoderma*, 144 116–122.
- Simas, F.N.B., Schaefer, C.E.G.R., Melo, V.F., Albuquerque-Filho, M.R., Michel, R.F.M., Pereira, V.V., Gomes, M.R.M., Costa, L.M., 2007. Ornithogenic Cryosols from Maritime Antarctica: phosphatization as a soil forming process. *Geoderma*, 138 191-203.
- Simas, F.N.B., Schaefer, C.E.G.R., Melo, V.F., Guerra, M.B.B., Saunders, M., Gilkes, R.J., 2006. Clay-sized minerals in permafrost-affected soils (Cryosols) from King George Island, Antarctica. *Clays and Clay Minerals*, 54 721-736.
- Soil Survey Staff, 2010. *Keys to Soil Taxonomy*, 11th ed. USDA-NRCS, Washington, D.C.
- Tarnocai, C., Broll, G., Blume, H.P., 2004. Classification of permafrost-affected soils in the WRB. In: Kimble, J.M. (Ed.), *Cryosols – Permafrost-Affected Soils*. Springer-Verlag, Berlin, pp. 637–657.
- Tatur, A., 1989. Ornithogenic soils of the maritime antarctic. *Polish Polar Research* 4, 481–532.
- Tatur, A., Barczuk, A., 1985. Ornithogenic phosphates on King George Island, Maritime Antarctic. In: Siegfried, W.R., Condy, P.R., Laws, R.M. (Eds.), *Antarctic Nutrient Cycles and Food Webs*. Springer-Verlag, Berlin, pp. 163–169.

- Tatur, A., Myrcha, A., 1993. Ornithogenic soils. In: Rakusa-Suszczewski (Ed.), *The Antarctic Coastal Ecosystem of Admiralty Bay S.* Polish Academy of Sciences, Warsaw, pp. 161–165.
- Tatur, A., Myrcha, A., Niegodzisz, J., 1997. Formation of abandoned penguin rookery ecosystems in the maritime antarctic. *Polar Biology* 17, 405–417.
- Ugolini, F.C., 1972. Orthinogenic soils of Antarctica. In: Llano, G.A. (Ed.), *Antarctic Terrestrial Biology Am. Geophys. Union AntarctRes. Ser.* pp. 181–193.
- Ugolini, F.C., Bockheim, J.G., 2008. Antarctic soils and soil formation in a changing environment: A review. *Geoderma*, v.144, p. 1-8.

PAPER 2

MINERALOGY AND MICROPEDOLOGY OF PHOSPHATE-RICH SOILS FROM LIONS RUMP, MARITIME ANTARCTICA

ABSTRACT

Mineralogy and micropedology of phosphate-rich soils from Lions Rump, Maritime Antarctica

Micromorphological and microchemical studies reveal important information regarding soil genesis and physicochemical behavior. Although use of techniques as WDS, OTM, and SEM be more common for geological purposes, they use in soil studies can reveal great information, especially at ornithogenic soils. The present study was carried out at Lions Rump where six pedons were selected to represent the main soil types commonly found in ice-free areas of King Georg Island, varying from soils devoid vegetation cover to ornithogenic soils, all of them with high organic carbon contents. Each pedon was described and sampled for micromorphological and microchemical studies, clay mineralogical evaluation, and chemistry and physical analyses. Results showed that phosphatization is the main process of soil formation in ornithogenic soils, where we can observe phosphatic compounds filling soil porous, covering clasts and reacting with minerals forming mainly non-crystalline phosphates. The processes of ornithogenesis depend on time of exposure to birds influence and the amount of guano depositions on the soil. Due to this characteristic, we could separated the ornithogenic soils in two groups: Acid pH ornithogenic soils and Neutral pH ornithogenic soils whereas in the first one the phosphatization was more intense.

Words key: ornithogenic soils, phosphatization, WDS analyses

INTRODUCTION

Pedological studies of polar regions, especially in the Antarctica Continental, are one of the key issues on the environmental reconstruction of terrestrial landscapes, and can help monitoring climate changes.

Although physical weathering is undoubtedly a major soil forming process in Maritime Antarctica, chemical weathering also occurs, notably in acid sulphate and ornithogenic soils (Michel et al., 2006; Simas et al., 2006). For some ornithogenic soils after these both weathering process non-crystalline phases are important soil components and represent over 75% of the clay fraction (Simas et al., 2006). The ample variation of phosphate minerals in the ornithogenic soils of King George Island is probably due to singular environmental conditions, such as relatively high precipitation; low temperature; specific chemical composition of penguin excreta (especially a high fluorine content); soil water composition changes, as a result of periodical nesting of the penguins on the land, and the lack wide variety of plants and humus material derived from them (Tatur and Barczuk, 1985).

In Ornithogenic soils, the phosphatization is the main pedogenic process that causes acidity and weathering. P-rich solutions penetrate the frost-induced fractures in the clasts and react with mineral soils to form amorphous and crystalline P compounds (Schaefer et al., 2008).

Ornithogenic sites are extremely important and constitute the most important locci of C sequestration in Antarctica terrestrial ecosystems (Simas et. al, 2007). Although biomass production by the Antarctica vegetation is relatively low, it frequently exceeds the decomposition capacity of local microbiota (Ugolini, 1972). Therefore, organic matter accumulates at some sites and plays important pedological and ecological roles (Beyer et al., 1995; Beyer, 2000; Bölter and Kandeler, 2004).

Scarse information is available about micromorphology of permafrost-affected soils from Maritime Antarctica, the wettest and warmest part of Antarctica (Schaefer et al., 2008), compared with Arctic soils. Besides the few use for soil scientists, micromorphological and microchemical studies can reveal important information regarding soil genesis and physicochemical characteristics and relevant data for planning and definition conservation strategies for Antarctic environments.

The objective of this paper was to study soil clay fraction and describe and analyze the most important microscopic features of typical cryogenic soils, especially ornithogenic soils, from Lions Rump, King George Bay, Maritime Antarctica.

MATERIAL AND METHODS

Study area

Lions Rump is a small peninsula located on the southern coast of King George Bay, King George Island, in the South Shetlands Archipelago, Maritime Antarctica (Figure 1). The study area is defined as terrestrial land within following coordinates: 62°07'48''S, 58°09'17''W; 62°07'49''S, 58°07'14''W; 62°08'19''S, 58°07'19''W; and 62°08'16''S, 58°09'15''W (SCAR, 2002).

The study area was visited in the austral summer of 2009/2010, during Brazilian Antarctic Expeditions. During field work, 26 pedons representing the main soil types identified in ice-free areas of Lions Rump were described and sampled, based on criteria established by Antarctic and Sub-Antarctic Permafrost, Soils and Periglacial Environments Group (ANTPAS 2006) and considering geomorphological features.

From 26, six pedons were selected to represent the main soil types commonly found in ice-free areas of Lions Rump (Table 1), varying from soils devoid vegetation cover to ornithogenic soils with relative high organic carbon contents. Each pedon was described and sampled for micromorphological and microchemical studies, clay mineralogical evaluation, and chemistry and physical analyses.

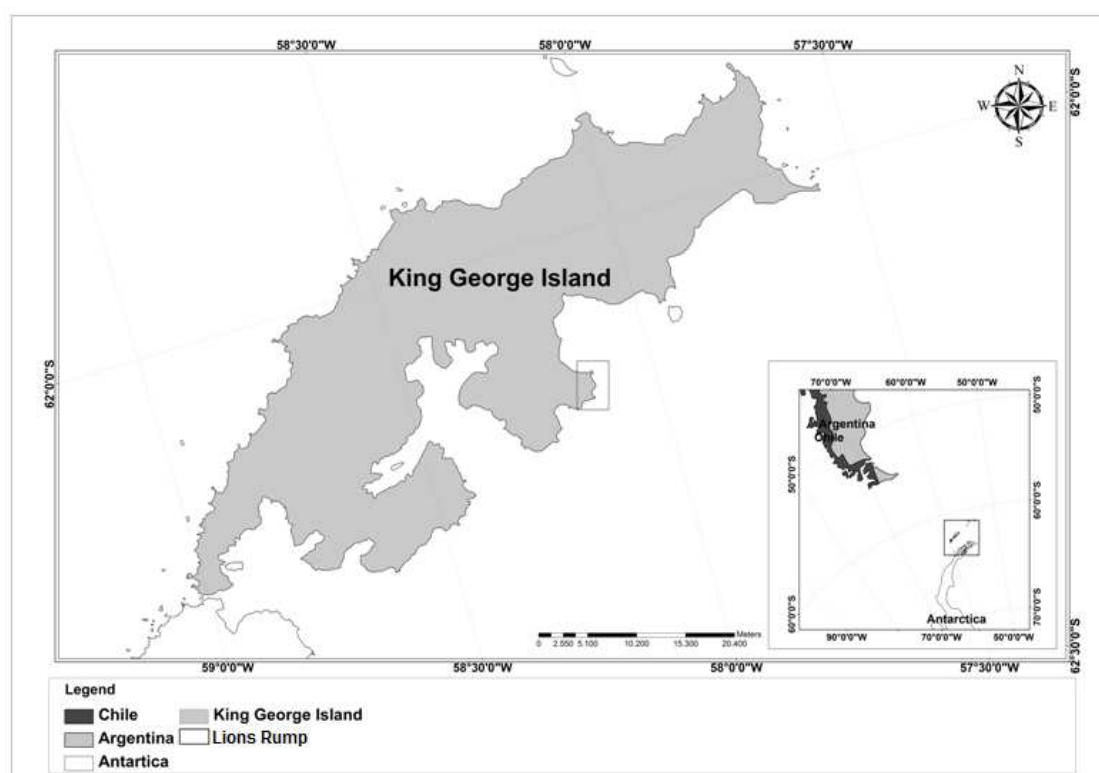


Figura 1- Location of the studied soils, in Lions Rump peninsulas, King George Island, King George Bay, Maritime Antarctica. (Adapted from Michel et al., 2012)

Table 1 - General characteristics and classification of studied soils from Lions Rump, Maritime Antarctica.

Site (Altitude) ^a Geographic position ^b	Horizons	Depth	Structure ^c	Soil Classification ^d	Veg. ^e	Field observations
LR3 (62) 439687 3110784	A	0-5	w f m bl/ md m gr	Loamy-skeletal, mixed, active, subgelic, Turbic Haplogelepts	Rare D > C > M	Profile on top of the plateau; Subpolar desert with no ornithogenic influence; well drained, sparse vegetation; absence of permafrost.
	AB	5-17/20	w m bl/ md m gr			
	Bi	20-47/52	w m bl/ md m gr			
	BC	47-52-70	w m bl			
LR7 (38) 441377 3110392	O	0-8	fibric/ st m gr	Loamy-skeletal, mixed, active, subgelic, Typic Dystrogelepts ornithic	D > S	Abandoned penguin rookery; well developed, continuous and exuberant cover vegetation; abundant roots down to 30 cm; fibric O horizon from 0-10 cm; well drained; absence of permafrost.
	A	8-24	fibric/ st f m gr			
	ABf	24-32	md m bl/ st f m gr			
	Bif	32-60	md f m bl/ st f gr			
	Bi2f	60-95	st f gr			
LR8 (46) 441398 3110372	O	0-5	fibric/ st m gr	Loamy-skeletal, mixed, active, subgelic, Typic Dystrogelepts ornithic	D > S	Abandoned penguin rookery on the highest level of ornithogenic influence; well developed, continuous and exuberant cover vegetation; well drained; abundant roots down to 20 cm; fibric O horizon from 0 - 5 cm and absence of permafrost.
	A	5-12	w m l sb/ st m gr			
	AB	12-18	w m l sb/ st m gr			
	BA	18-32	md f bl/ st m gr			
	B1	32-70	md f bl/ st m gr			
	B2	70-100	st m gr			
B3	100-120	st m gr				
LR9 (40) 441523 3110476	A	0-8	st m gr	Loamy-skeletal, mixed, active, subgelic, Typic Gelorthents ornithic	P > D	Recent abandoned penguin rookery; shallow, skeletic profile, lithic contact at 40 cm; vegetation of Prasiola and sparse Deschampsia; absence of permafrost.
	Cr	8-40	sg/ w m gr			
LR11 (19) 440779 3110566	A	0-9	w m sb/ st f gr	Loamy-skeletal, mixed, active, subgelic, Typic Haplogelepts ornithic	D > C > S	Abandoned penguin rookery on frontal moraine; well developed; exuberant vegetation cover; abundant roots down to 35 cm; well drained with moderate erosion; absence of permafrost; currently occupied by für seals.
	E	9-17/18	w m l sb/ st f gr			
	2A	18-25/28	w m l sb/ st m gr			
	2ABi	28-36/41	md f bl/ st m gr			
	2Bi	41-49/53	md f m bl/ st f gr			
	2Bi2	53-63/65	w m bl/ md st m gr			
	2BC	63/65-90	w m bl/ md st m gr			
2C	90-120	w f m sb/ st m gr				
LR15 (41) 0441154 3110281	O1	0-3/4	fibric	Coarse-loamy, mixed, active, subgelic, Typic Haplogelepts ornithic	D > P > C	Abandoned penguin rookery; well developed, continuous vegetation; exuberant vegetation cover. Abundant roots down to 30 cm; fibric O horizon from 0-10 cm; well drained; absence of permafrost.
	O2	¾-9/11	fibric			
	OA	11-16/17	fibric/ md m gr			
	Bi1	17-37/38	w md m l bl/ md m gr			
	Bi2	37/38-60	w m l bl/ w m gr			
BC	60-80+	w m l bl				

^a m a.s.l - meters above sea level; ^b UTM coordinates, zone 21S datum WGS 84; ^c Development: w = weak, md = moderate, st = strong; Size: f = fine, m = medium, l = large; Type: ma = massive, gr = granular, bl = subangular blocky, sg = single grain, cr = crumbs; ^d Soil Taxonomy; ^e Vegetation: C- *Colobanthus quitensis* (Cariofilaceae); D- *Deschampsia antarctica* (Gramineae); M- mosses; P- *Prasiola crispa* (alga); U- *Usnea sp.* (lichen); S- *Syntrichia princeps* (Bryophyta).

Pedons selected were located from 19 to 62 m a.s.l., with vegetation cover varying from rare to relative exuberant vegetation, formed by different combinations and proportions of *Deschampsia antarctica* (Gramineae), *Colobanthus quitensis* (Cariofilaceae), mosses; *Usnea sp.* (lichen); *Syntrichia princeps* (Bryophyta) and *Prasiola crispa* (algae).

Considering field observations and analytic results, soils of Lions Rump were separated into three groups: Acid pH ornithogenic soils (LR7, LR8, LR9), Neutral pH ornithogenic soils (LR11, LR15), and Non-ornithogenic soil (LR3).

The ahumic soil (LR3) a Turbic Haploglepts the only profile of the Non-ornithogenic soil group was selected for this study to be used as comparison represent a soil without avifauna influence (Figure 2). It was the chosen one due to be very representative for the other soils Non-ornithogenic as Cryorthents, Haploglepts, Gelorthents, Haploorthels, Haploturbels, Gelifluvents and Cryopsamments widespread throughout the area.

In Lions Rump, LR7, LR8 and LR9 are located on sites developed from andesitic rocks that gave the name to the peninsula, and possibly represents one of the first ice-free areas colonized by penguins in Antarctica (Figure 2). Soils of LR7 and LR8 are from abandoned penguin rookeries covered by exuberant vegetation of *Deschampsia*, thick O horizon and well-developed profile with reddish color indicating advanced weathering status. Soil LR9 is from a recently abandoned penguin rookeries covered by incipient vegetation, mostly covered by *Prasiola*.

LR11 and LR15 are present at areas with more recently exposure to ornithogenic influence, especially at uplifted terrace and Quaternary moraines, respectively (Figure 2).

Chemical, physical and mineralogical analyses

Soil pH, exchangeable nutrients and texture were determined for <2 mm air-dried samples according to EMBRAPA (1997). Exchangeable Ca^{2+} , Mg^{2+} and Al^{3+} were extracted with 1 mol L^{-1} KCl and P, Na and K with Mehlich-1 solution extractant (0.05 mol L^{-1} HCl + $0.0125 \text{ mol L}^{-1}$ H_2SO_4). Elements contents were determined by atomic absorption spectrometry (Ca, Mg and Al), flame emission spectrometry (K and Na) and colorimetry method (P). H+Al was determined after extraction with 0.5 mol L^{-1} calcium acetate solution buffered at pH 7.0 by titration with $0.0025 \text{ mol L}^{-1}$ HCl (EMBRAPA, 1997). Organic matter (OM) was determined on <0.5 mm samples by wet combustion (Yeomans and Bremner, 1988). Soil texture was obtained after dispersion of <2 mm samples in NaOH solution, sieving of coarse and fine sand, sedimentation of silt and clay fractions with adaptations for clay dispersion (Ruiz, 2005).

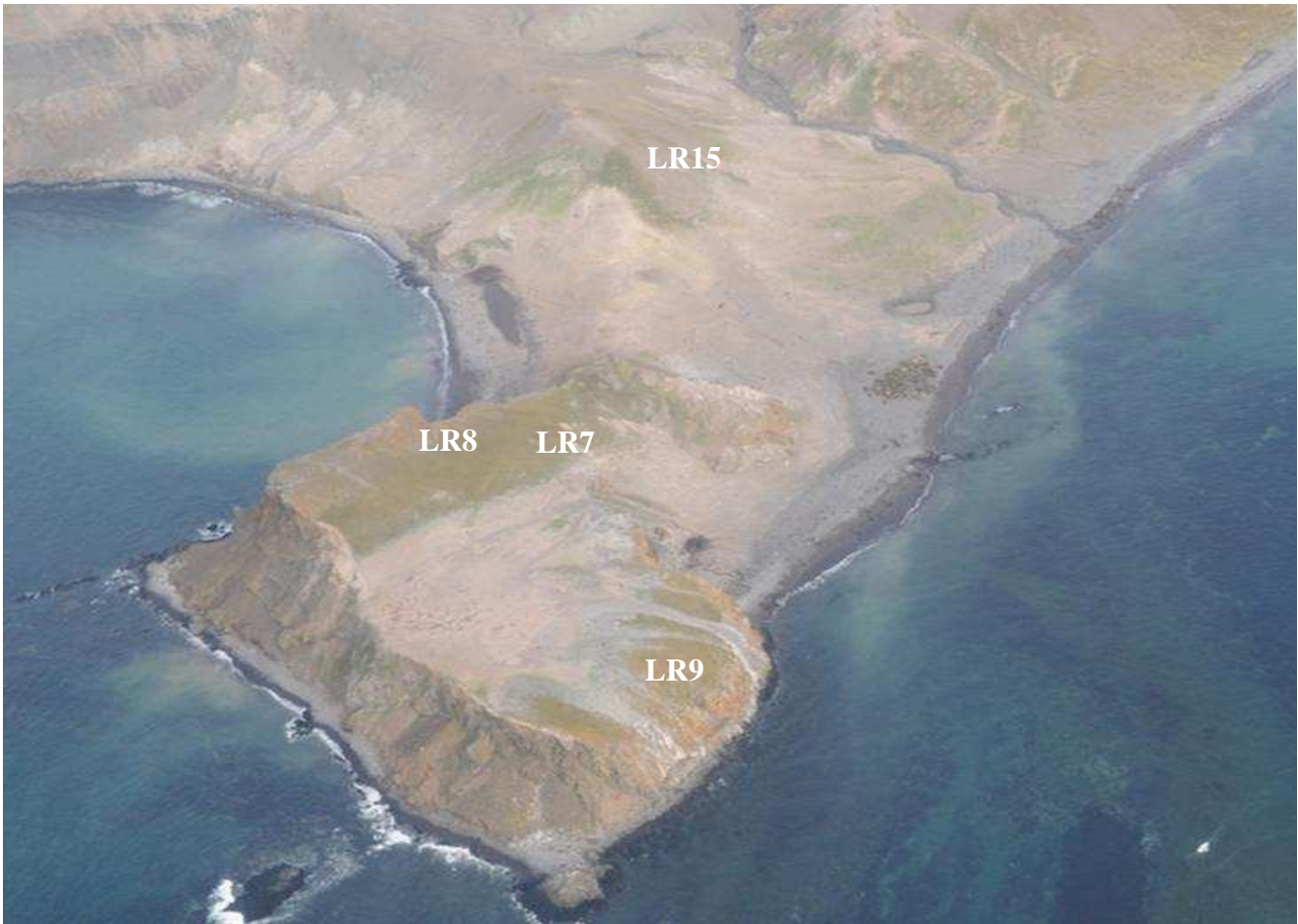


Figure 2 – View of selected studied profiles with their location in the landscape

Clay fraction of selected profiles was submitted to selective digestion with boiling NaOH 5 mol L⁻¹ for 90 min to concentrate and better characterize iron oxides, according Kämpf & Schwertmann (1982).

The X-ray analyses were performed on a X'Pert Pro diffractometer model PW 3040/60, x-ray tube ceramic, solid-state detector X'Celerator, long fine focus, equipped with cobalt anode, Co-K α radiation ($\gamma = 1$, 79026 Å), operated with 40 kV and 30 mA. The powdered clay samples were placed and lightly pressed on the holder, avoiding clay orientation, scanned from 0 to 50 °2 θ with 0.05 °2 θ increments and 2 seconds of counting time in each step.

Micromorphology and microchemical studies

Undisturbed soil samples (5 × 10 cm) from some selected soil horizons were sampled in field and transport to the laboratory, where were impregnated with 1:1 crystic resin:stiren mix poured at atmospheric pressure and temperature. Impregnated samples were cut into slabs of 0.5 cm thickness using a diamond saw, and polished with corundum abrasives from 250 to 600 mesh. After ultrasonic cleaning, the polished blocks were mounted onto glass slides followed by polishing and hand-finishing to produce 30 nm thick sections. All procedures were carried according to Schaefer et al. (2008). The description of the microstructure was made using a HITACHI S-3400N scanning electron microscope with a Thermo Noran EDS spectrometer equipped with SYSTEM SIX. Quantitative electron probe microanalysis by wavelength dispersive spectrometry was performed with a 5 spectrometer Cameca SX51 electron probe in Geoscience Department of the University of Wisconsin, Madison, USA. Samples and standards were carbon coated with ~200 Å carbon. Operating conditions were 15 kV accelerating voltage with a (Faraday cup) beam current of 4 nA. Natural and synthetic mineral standards were used background positions. Automation and matrix corrections were performed with probe for EPMA software (Donovan et al, 2010; Armstrong, 1995). Pedological features of the soil horizons at OTM level were analysed using standard micromorphological techniques (Bullock et al., 1985).

RESULTS AND DISCUSSION

Chemical, physical and mineralogical properties

Soils from Lions Rump were formed by the weathering of basalt-andesitic rocks and present apatite as mineral accessory providing phosphorus and exchangeable bases as indicated by non-ornithogenic soils, which do not have avifauna influence, but present high contents of Ca, Mg, K and P (Table 2).

The soils from penguin rookeries and adjacent areas (LR7, LR8, LR9, LR11 and LR15) are more developed than soil with no fauna influence (LR3). Stony/pebbly pavements are present in all sites but are often hidden by the well-developed and continuous vegetation. Clear horizon differentiation occurs and a relatively deep organic matter-rich A horizons and phosphatic B horizons were easily identified. Surface horizons are dark and yellowish brown as a result of humus incorporation similar to other ornithogenic soils described by Simas et al. (2007) and Michel et al. (2006) in other areas from King George Island.

The content of fine particles no differs between soil groups (Table 2). As weathering processes are different, in essence, and intensity, this similarity can be associated to genesis from different source materials. It was expected that soils more pedogenetic develop (Acid pH ornithogenic) had higher content of fine particles, but LR7, LR8 and LR9 profiles are derivated from basaltic bedrock, whilst LR11 and LR15 are former under moraine compound by mixed materials, especially basaltic-andesitic with advanced materials fragmentation, and LR3 are formed from basaltic-andesitic materials covering a plateau.

All ornithogenic soils have much more TOC contents than the non-ornithogenic one (LR3), a clear evidence of the avifauna contribution to C pool. Among ornithogenic soil, sites dominated by *D. antarctica* and *C. quitensis* (LR7, LR8, LR11 and LR15) presented more TOC contents in depth horizons, because lignine-bearing tissues and root systems presence.

Acid pH ornithogenic soils (LR7, LR8, and LR9) are easily distinguished from the non-ornithogenic soil (LR3) by several features, such as presence on the field of continuous vegetation cover with *D. antarctica*, *C. quitensis* and/or *Prasiola crispa*; and also for lower pH and bases saturation; high OM contents, Melich-1 extractable-P, and exchangeable Al (Table 2). Chemical characteristics of ornithogenic soils are strongly affected by sea-land transfers by birds, mostly penguins, through deposition of large amounts of guano during austral summer. In these soils, a particular and complex process of deep soil “phosphatization” occurs, which has been described in details by Tatur and Barczuk (1985), Tatur (1989), Schaefer et al. (2004), and Simas et al. (2007).

Table 2 - Chemical and physical characteristics of selected horizons from soils from Lions Rump, Maritime Antarctica

Group	Profile	Horizon	Depth cm	pH	Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	P	P ₂ O ₅	OM	cs	fs	silt	clay	Color
					----- cmol _c dm ⁻³ -----				mg dm ⁻³	----- dag kg ⁻¹ -----							
Non- orinitho genic	LR3	A	0-5	7.52	18.84	16.46	0.24	1.53	0.00	109.50	0.16	0.38	29	21	36	14	2.5Y 4/3
		AB	5-20	7.74	26.30	20.01	0.17	1.18	0.00	170.80	-	0.26	27	20	33	20	2.5Y 4/4
		Bi	20-52	7.98	26.31	14.19	0.14	0.92	0.00	167.20	0.15	0.13	33	21	27	19	2.5Y 5/3
		BC	52-70	8.48	30.45	12.07	0.14	0.79	0.00	176.30	-	0.26	31	18	32	19	2.5Y 5/4
Acid pH ornitho genic	LR7	O	0-8	4.88	7.29	7.82	0.77	1.70	4.34	736.90	0.77	5.12	44	25	16	15	10YR 4/3
		A	8-24	4.46	3.16	3.83	1.13	1.57	9.16	1038.80	1.94	3.20	51	23	12	14	10YR 5/3
		AB	24-32	4.02	1.03	1.17	1.61	1.00	8.58	2732.20	-	1.28	46	17	26	11	10YR 7/2
		Bi	32-60	3.81	0.76	0.70	1.48	1.05	14.7	1528.20	2.85	1.02	46	16	22	16	5YR 5/3
		Bi2	60-95	3.83	0.82	0.68	1.23	0.87	14.0	2552.10	-	1.02	47	18	21	14	7.5YR 5/3
	LR8	O	0-5	4.88	1.85	2.45	0.09	0.45	0.48	79.60	0.51	39.66	44	20	21	15	10YR 3/3
		A	5-12	4.37	3.82	6.42	0.70	1.53	8.00	390.40	1.56	7.04	36	21	25	18	10YR 3/4
		AB	12-18	4.04	0.91	1.29	0.42	1.22	8.00	603.40	-	6.40	51	18	18	13	10YR 5/3
		BA	18-32	3.88	0.29	0.35	0.93	0.92	6.46	1199.30	5.89	2.05	57	11	21	11	10YR 6/3
		B1	32-70	3.94	0.95	0.58	1.26	0.79	6.84	1065.80	-	2.05	52	23	16	9	10YR 6/3
		B2	70-100	3.98	0.85	0.65	1.81	0.71	6.65	1093.80	-	2.18	40	33	20	7	10YR 6/4
		B3	100-120	3.85	0.41	0.38	1.08	10.71	6.17	1468.50	6.44	2.05	45	17	22	16	10YR 5/6
	LR9	A	0-8	4.26	8.17	2.27	0.57	1.57	0.67	5485.10	2.40	5.37	43	23	21	13	10YR 5/3
Cr		8-40	3.96	2.18	0.49	1.61	0.52	3.18	1004.20	4.48	2.30	30	8	39	23	10YR 7/3	
Neutral pH ornitho genic	LR11	A	0-9	7.01	24.07	13.80	0.37	3.79	0.00	251.50	0.37	2.88	39	24	24	13	10YR 3/3
		E	9-18	7.27	26.04	12.35	0.22	4.40	0.00	191.50	-	1.92	35	25	27	13	10YR 3/4
		2A	18-28	7.40	27.57	11.98	0.19	3.48	0.00	338.70	0.39	2.24	27	26	28	19	10YR 3/4
		2AB	28-41	7.16	26.44	10.51	0.17	3.35	0.00	1184.80	1.22	2.56	33	22	30	15	10YR 3/5
		2Bi	41-53	7.09	33.45	24.46	0.34	3.75	0.00	897.20	0.78	1.03	40	23	23	14	10YR 4/3
		2Bi2	53-65	7.31	25.48	20.97	0.43	4.01	0.00	390.40	0.44	0.26	39	20	26	15	10YR 5/3
		2BC	65-90	7.40	35.98	23.20	0.57	3.27	0.00	827.70	-	0.26	43	18	26	13	10YR 5/3
		2C	90-120	7.50	32.56	21.76	0.59	3.22	0.00	528.10	0.41	0.13	33	34	20	13	10YR 5/3
	LR15	O1	0-4	5.28	18.60	22.11	1.41	2.05	0.10	1037.80	0.60	6.46	36	25	23	16	10YR 3/3
		O2	4-11	5.66	18.30	23.48	1.00	1.65	0.29	771.10	-	6.78	36	25	23	16	10YR 3/4
A		11-17	5.99	23.56	23.02	0.85	1.92	0.00	1290.10	0.53	2.97	32	22	28	18	10YR 5/3	
Bi		17-38	7.40	29.25	24.63	0.62	1.35	0.00	803.00	0.27	0.39	42	17	27	14	10YR 6/3	
Bi2		38-60	7.61	30.65	19.33	0.67	1.44	0.00	837.40	0.31	0.26	43	17	25	15	10YR 6/3	
BC	60-80+	8.15	35.35	21.20	0.62	1.22	0.00	611.60	0.60	0.13	42	18	22	18	10YR 6/4		

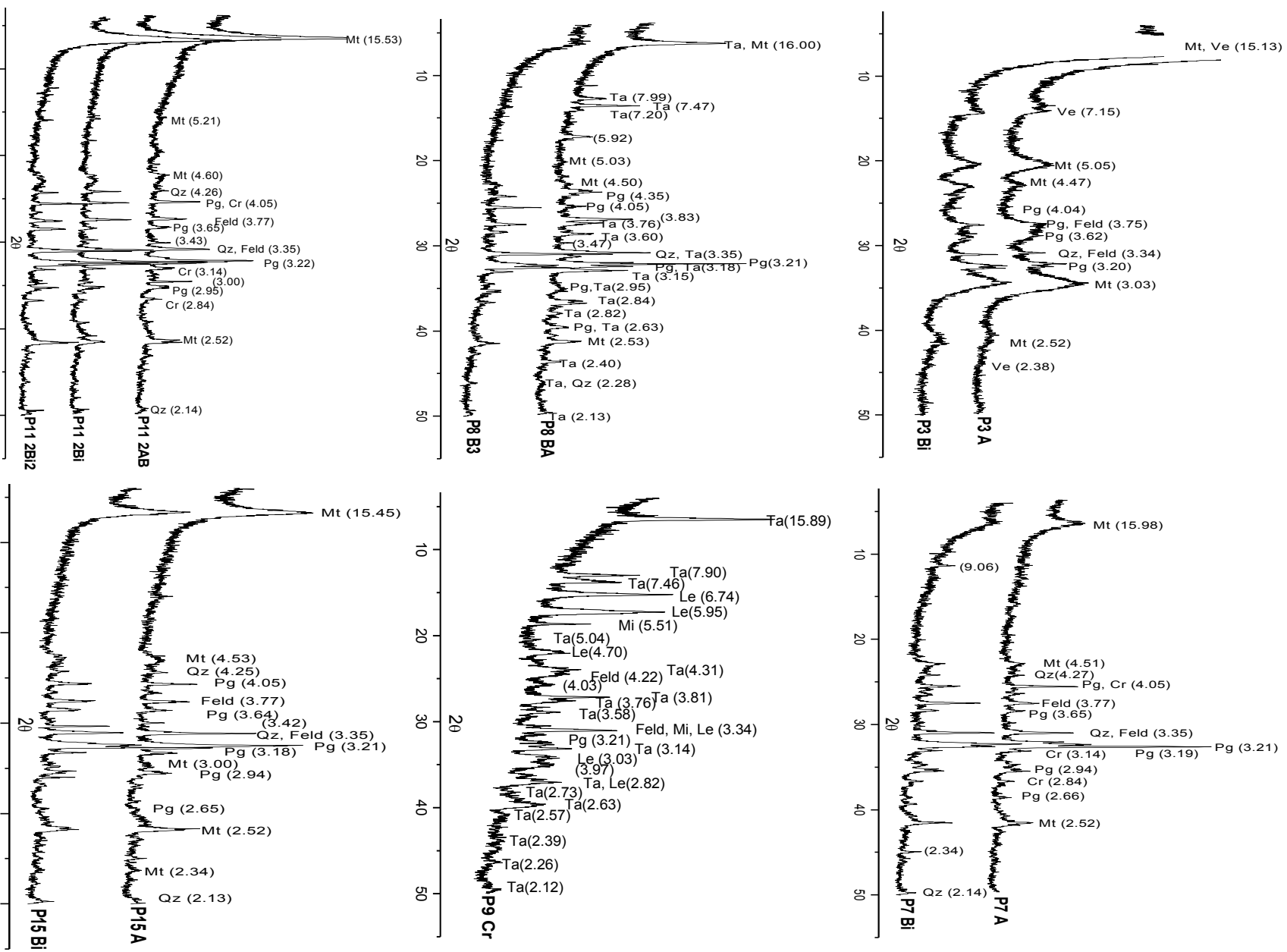
*soil taxonomy; pH - dilution 1:2.5 water; P, K and Na - extract with Melich-1; Ca²⁺, Mg²⁺ and Al³⁺ extractable with KCl 1mol.L⁻¹; P₂O₅ total digestion ; OM - wet combustion (Yeomans and Bremner, 1988); cs - coarse sand; fs - fine sand.

Acid pH ornithogenic soils (LR7, LR8, and LR9) are easily distinguished from the non-ornithogenic soil (LR3) by several features, such as presence in the field of continuous vegetation cover with *D. Antarctica*, *C. quitensis* and/or *Prasiola crispa*; and also for lower pH and bases saturation; high OM contents, Melich-1 extractable-P, and exchangeable Al (Table 2). Chemical characteristics of ornithogenic soils are strongly affected by sea-land transfers by birds, mostly penguins, through deposition of large amounts of guano during austral summer. In these soils, a particular and complex process of deep soil “phosphatization” occurs, which has been described in details by Tatur and Barczuk (1985), Tatur (1989), Schaefer et al. (2004), and Simas et al. (2007).

Neutral pH ornithogenic soils (LR11 and LR16) do not present these standards ornithogenic characteristics described before, taking place from parental material rich in exchangeable bases at low altitude and close to the sea. These high contents of bases, including Na, promotes a buffering effect on the soil profile, reducing acidity, and consequently, reducing mineral weathering and leaching of nutrients. Soils with high content of bases, high buffer potential, which remains proximity to neutral pH, disfavor phosphate minerals crystallization, like as observed in soils LR11 and LR15 (Figure 6). Despite high levels of P extract with Melich-1 and morphological features (Table 3), both characteristics of ornithogenic soils, these soils do not contain crystalline phosphates minerals; therefore, we can expect phosphate minerals similar to amorphous forms. Maybe all phosphates are removed from soil solution by, and no enough excess is present in solution to form crystalline phosphates minerals (Figure 6).

The principal difference between acid and neutral ornithogenic soils is the time of soil exposure to avifauna influence, and the amount of bird excrement accumulated.

According to Tatur and Barczuk (1985), “phosphatization” comprises chemical weathering of rock minerals and formation of amorphous Al and Fe minerals. These phases react with ornithogenic P, K and N to form amorphous and crystalline secondary phosphates. Simas et al. (2006) found crystalline phosphates occurring only in soils directly affected by penguins (active and abandoned rookeries). The incongruent dissolution of crystalline Al–Fe phosphates with formation of amorphous P-rich phases is considered the most common transformation with the increasing age of site abandonment (Tatur et al., 1997) and maintains high levels of labile P forms.



The formation of crystalline phosphate minerals are found exclusively in the upper soil layers (LR8 and LR9), more humid than deeper horizons, which receives directly the contribution coming from bird's organic excreta, although high content of P is found in the whole profile.

All ornithogenic soils from Lions Rump presented high contents of P in deeper layers, which indicate high P translocation in soils with high cation exchange capacity (CEC), and that not all P-rich subsurface horizons are buried horizons like some profiles found by Michel et al. (2006), at Copacabana, Admiralty Bay. Similar results observed in Lions Rump were found by Schaefer et al. (2008), Simas et al. (2007), Myrcha and Tatur (1991).

In the ornithogenic soils, X-ray diffractions showed clearly “phosphatization” of the profile, especially for LR8 and LR9. Despite Tatur and Keck (1990) had verified high range of phosphate minerals in Maritime Antarctic soils, the major minerals identified in Lions Rump were taranakite (mainly), leucophosphite and minyulite (Figure 3). Similarly, Simas et al. (2006) also found few minerals in soils from Admiralty Bay, basically metavariscite, leucophosphite and minyulite. Besides the high variety of mineral phosphates found at Maritime Antarctic as described by Tatur and Keck (1990) and Barczuk and Tatur (2003), most part of them were found just in some specific sites in others Maritime Antarctica areas.

Leucophosphite formation appears is related to guano and silicate minerals interaction (Wilson and Bain, 1976), conditions verified in Lions Rump. DRX peaks of these minerals at LR9 confirm this indication, and peaks were similar to that observed by Wilson and Bain (1976) and Tatur and Barczuk (1985) at Elephant Island and King George Island, respectively. According to Myrcha and Tatur (1991), minyulite occurrence is typical in the upper and middle portions of phosphatized zone, where Fe is entirely leached from the soil by strong action of guano solutions, which simultaneously supplied also high quantities of fluorine. These conditions are present in ornithogenic areas of Lions Rump, especially at LR9 (Figure 3).

Taranakite occurrence is typical for deep and acid soils, under a wet regime (Myrcha and Tatur, 1991). DRX peaks of taranakite are observed in Acid pH ornithogenic soils, with an exception for LR7. For this profile, although peaks are not identified, similar elemental concentration that suggests taranakite presence is determined by EDS analysis (Table 3), indicating this phosphate mineral presence, but maybe in not well crystallized form.

In the absence of ornithogenic activity, soil chemical weathering in Antarctic is less pronounced and soils present chemical and mineralogical characteristics greatly influenced by the parent material (Simas et al., 2004, 2007; Schaefer et al., 2008; Michel et al., 2006). For

Lions Rump soils without avifauna influence, weathering of parent material promote soil formation with high pH, salinity and Ca^{2+} and Mg^{2+} contents, as can be exemplified by LR3 (Table 2).

On the other hand, high guano inputs generate an acid environment, which becomes progressively less acid with soil development, following rookery abandonment. Guano is initially alkaline, but microbial degradation generates acidity. However, when sites are abandoned and no fresh guano further input is observed, mineral weathering and high amounts of OM can neutralize part of the acidity, resulting in a more buffered soil (Michel et al. 2006). However, in Lions Rump this expect was not confirmed for LR7 and LR8 profiles, probably due to high inclination of these sites, which can favor superficial guano erosion avoiding and/or reducing bases accumulation and the buffering effect. In Lions Rump, even the more evolved soils (LR7 and LR8) still have lower pH values due to the advanced stage of weathering in comparison other ones, transforming 2:1 clay silicates into phosphates. LR7 has reddish-brown color (5YR 5/3) at horizon B, what can indicate the more action of pedogenesis of this soil in comparison to others, what probably due to crystalline phosphates weathering remains only amorphous form of P and hematite.

XRD patterns of LR15 sample, a “neutral pH ornithogenic soil” (Figure 3), indicate no mineralogy alteration after short avifauna influence, therefore, despite the high amount of P and TOC input by birds, short soil exposure to the penguin rookery was not enough to promote phosphatization process, which is a transformation of silicate clay minerals into phosphates.

Phosphatization process is evident in LR8 profile (Figure 3), which all silicate clay minerals were transformed into crystalline and non-crystalline phosphates, mainly Taranakite. The main evidence for this is the complete absence of 1:1 secondary silicate clay minerals, as also observed in the most part of ornithogenic soils. Weathering process transforming primary silicate minerals into 2:1 and after into 1:1 minerals is not common for Antarctica ornithogenic soils (Figure 3, P7 and P8). When primary minerals are weathered, bases in solution are complexed by phosphate in solution reducing bases activity to contents not enough to form secondary aluminium silicates minerals.

Observing DRX results from clay fraction previously submitted to selective digestion with boiling NaOH 5 mol L^{-1} (Figure 4), we noted this procedure to concentrate iron oxides works better for well evolved tropical soils with clay fraction dominated by oxides and 1:1 clay silicates. For incipient soils, this procedure can not remove primary minerals and 2:1 silicates, and DRX show for all soils peaks of quartz, and minerals from feldspar and

montmorillonite groups. Hematites are found at Acid ornithogenic soils because are more development soils and at LR3. Magnetite was detected in LR3, LR7 and LR8, confirming indications previously indicated by magnet use. Presence of magnetite and as well anatase is expected because this soil is originated from basalt (Figure 4). Goethite, Maghemite and others iron oxides are not detected.

Micromorphology

Soil matrix of Lions Rump profiles are composed mostly for mineral from weathering of igneous rocks. Soil structure is formed mainly by secondary minerals such as 2:1 minerals like vermiculite and montmorillonite (Figure 3) with presence of Si-rich fractured clasts mainly plagioclases with Fe oxides as accessory minerals (Figures 4 and 5). Selected samples of some horizons from ornithogenic soils used for OTM and SEM studies illustrate typical features for LR3, LR7, LR8 (Figure 5, Table 3), and LR9 and LR11 (Figure 6 and Table 4).

LR3, a non-ornithogenic soil, little-altered rock fragments and mineral weathering occur, with dominance amphibolite rich in Mg (Figure 5). Phosphorus is present just inside structure of fragments of clasts and aggregates of basaltic and andesitic materials.

Soil profile LR7 exhibit moderate subangular blocky structure with phosphate material filling the voids (Figure 5). Pedon LR8AB presents subangular blocky structure abundant coated and filled by phosphate materials, matrix formed by 2:1 and phosphates minerals, with clasts of plagioclases rich in Na and small and highly fragmented minerals rich in Ca and Mg until 70 cm depth. Downward in the B2 horizon these clasts are larger and less fragmented with phosphates material presence only at the edges of minerals in contact with macropores (Figure 5). In LR9, the P-rich solution penetrates filling voids and around the clast, mainly plagioclases, forming a framework of phosphatic rims around these materials, with soil matrix formed preferentially by Al-Fe-K phosphate in crystalline and non-crystalline form (Figure 6). According to Schaefer et al. (2008), this reaction with P-rich solutions leads to the progressive displacement of Si from rock minerals, and consequently, enhanced chemical weathering.

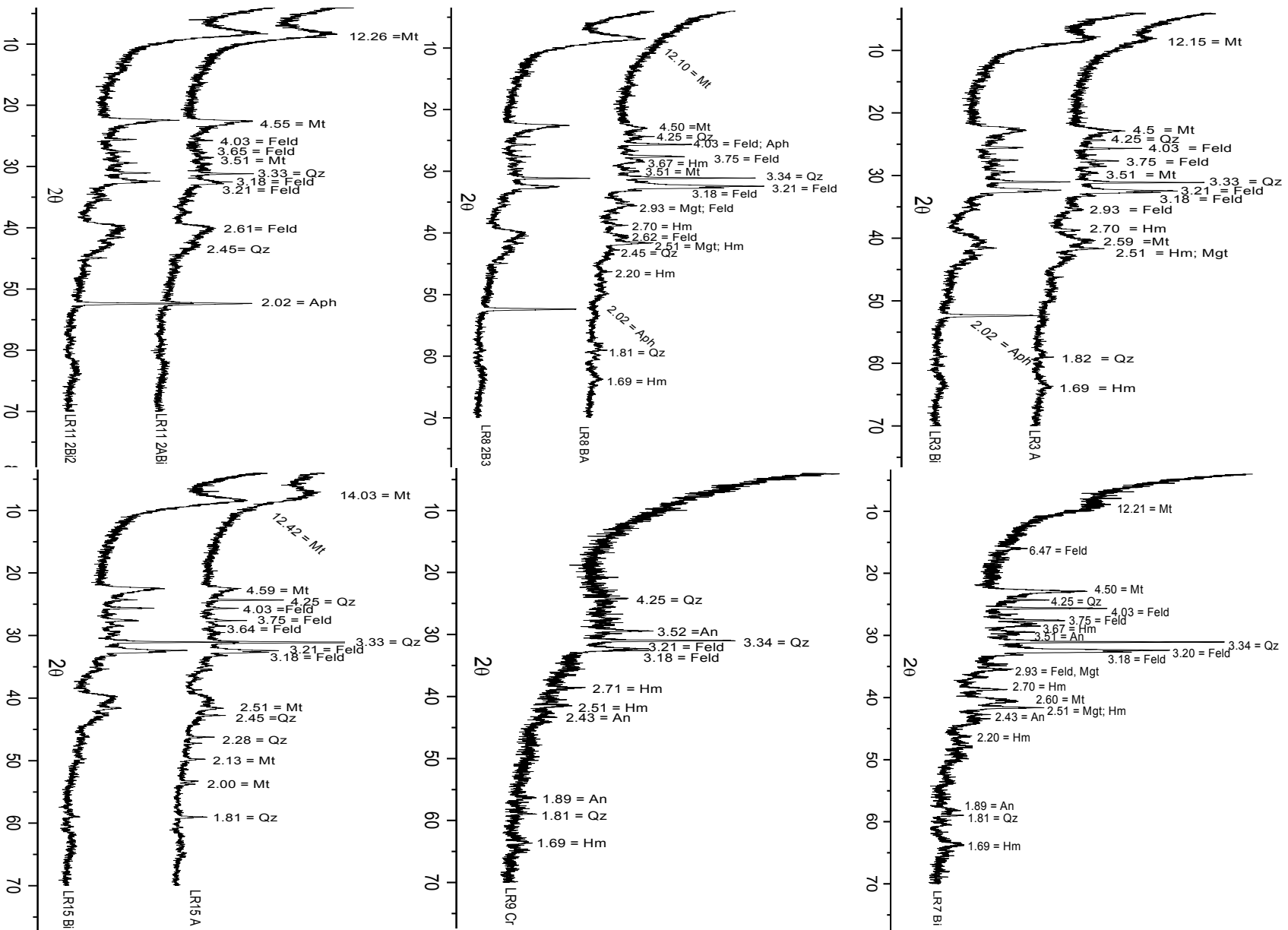


Figure 4 - X-ray diffraction from clay fractions from Lions Rump soils profile (An: Anatase; Aphthalite; Feld: Feldspar group; Hm: Hematite; Mgt: Magnetite; Mt: Montmorillonite group; Qz: Quartz; Ta: Taranakite).

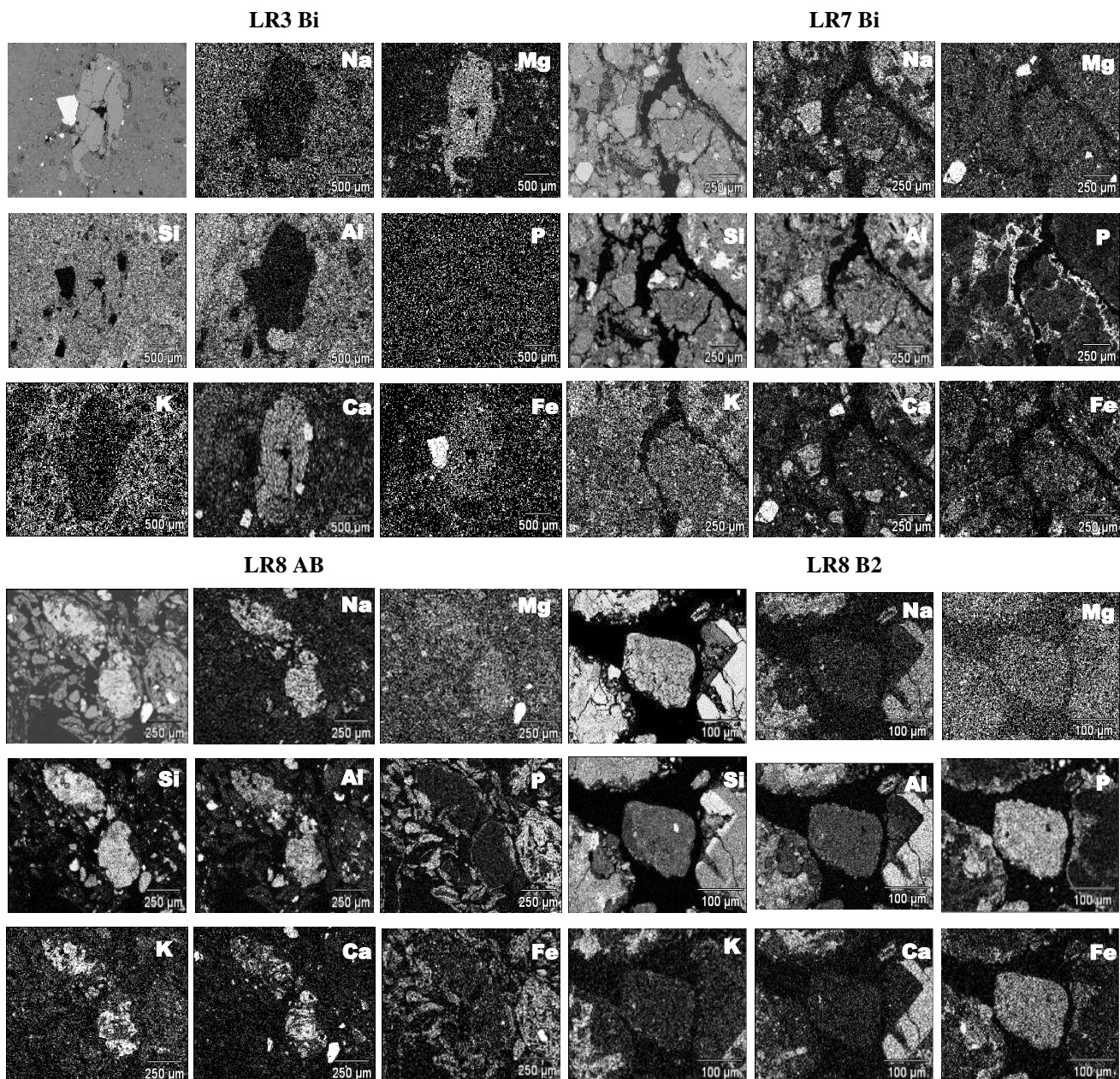


Figure 5 – SEM images and qualitative EDS analysis from select horizons from Lions Rump soils profiles

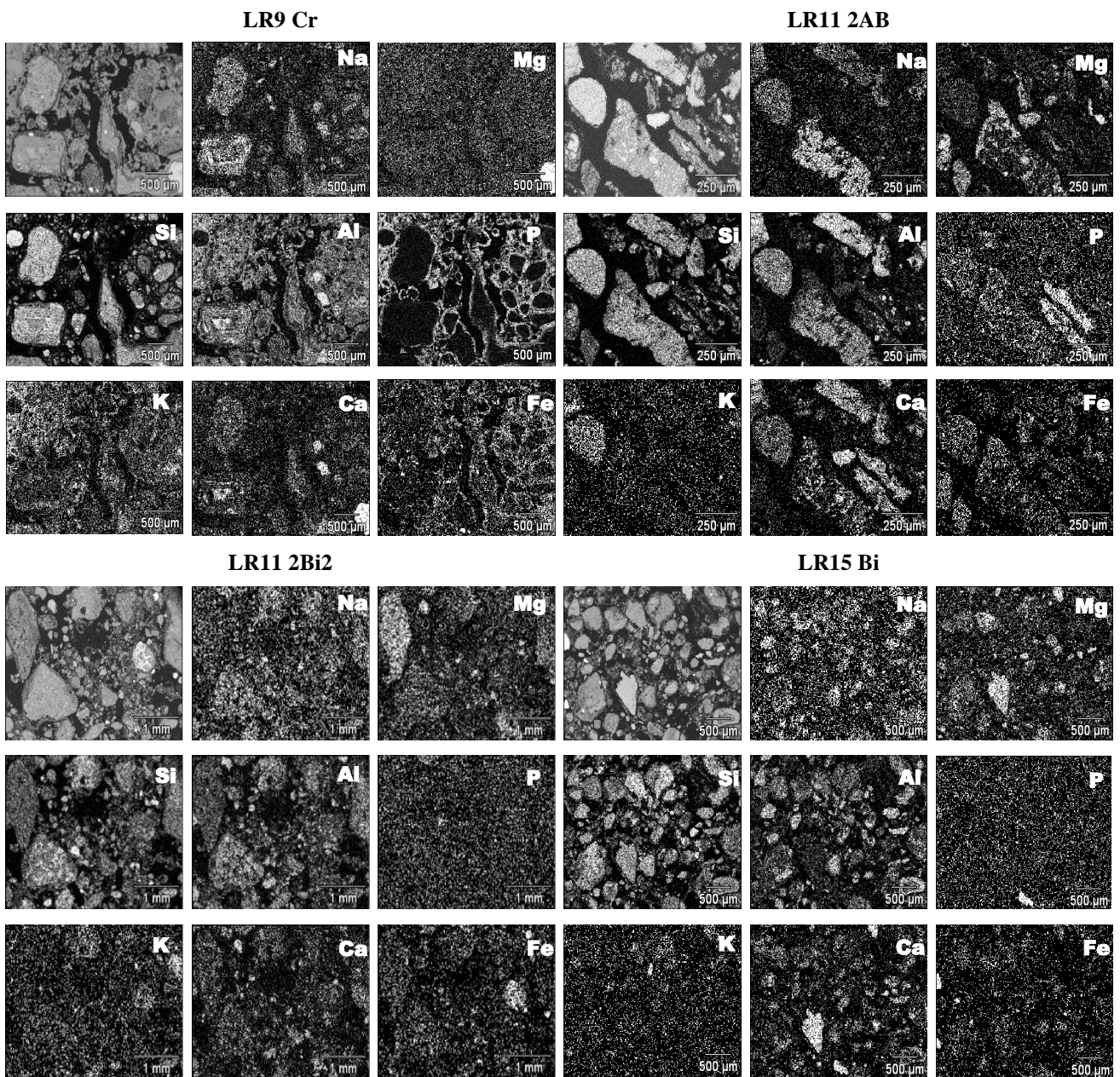


Figure 6 – SEM images and qualitative EDS analysis from select horizons from Lions Rump soils profiles.

Table 3 - OTM images and chemical analyses using semi-quantitative EDS for some pedological features of selected horizons from soils from Lions Rump, Maritime Antarctica

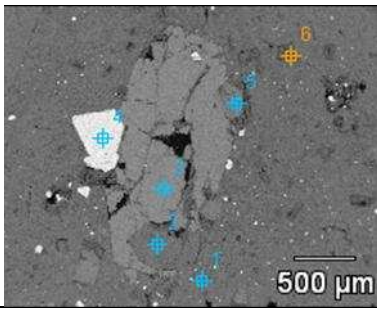
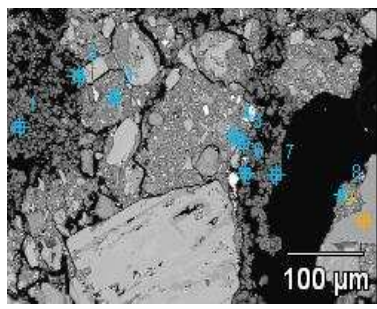
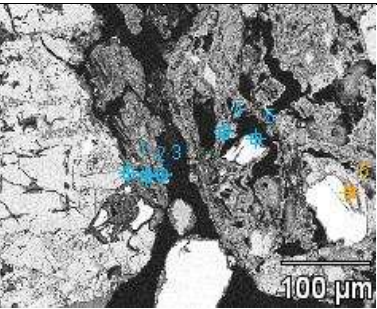
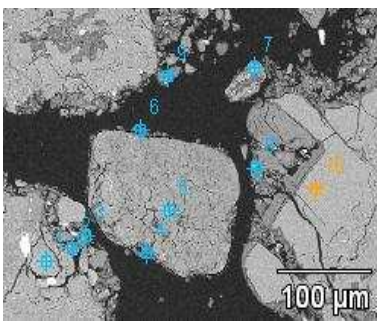
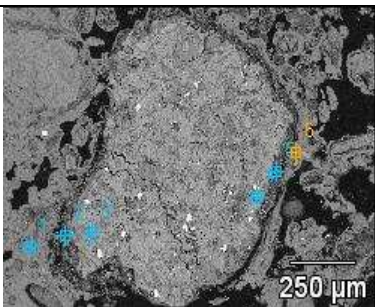
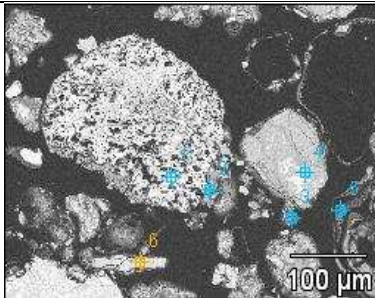
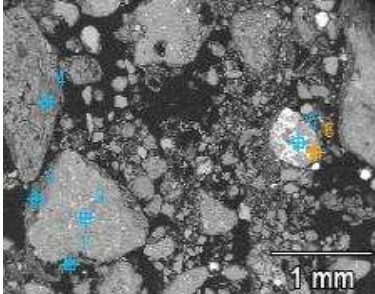
		LR3 Bi									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	TiO ₂
											
		LR7 Bi									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	TiO ₂
											
		LR8 AB									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	SO ₃
											
		LR8 B2									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	SO ₃
											

Table 4 - OTM images and chemical analyses using semi-quantitative EDS for some pedological features of selected horizons from soils from Lions Rump, Maritime Antarctica

		LR9 Cr									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	SO ₃
											
		LR11 2AB									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	SO ₃
											
		LR11 2Bi2									
		Id	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	Fe ₂ O ₃	K ₂ O	CaO	TiO ₂
											

For LR11 and LR15 samples, clasts are angular to sub-angular in the coarser size fractions (>2 mm) and present greater degree of rounding and sphericity with decreasing particle size (Figure 6). Plagioclases are the main phenocryst mineral and vary from fresh and unaltered to strongly altered and corroded grains. These minerals are normally surrounded by Si-amorphous with presence of Al and Fe materials, as indicated by the elemental maps and quantitative EDS analysis (Figure 6, Table 4). Pyroxenes are also common phenocrysts (Figure 6). Bone fragments are also common at LR11 (Table 4). Besides the great amount of P exactact by Melich-1, phosphates are not detected in DRX or SEM images at LR11 and LR15. Although penguins aport great amount of P and N what favor vegetation growth, maybe the time of rookery and the number of individuals presents in these penguins colony are not enough to input high increments of P and form phosphates compounds.

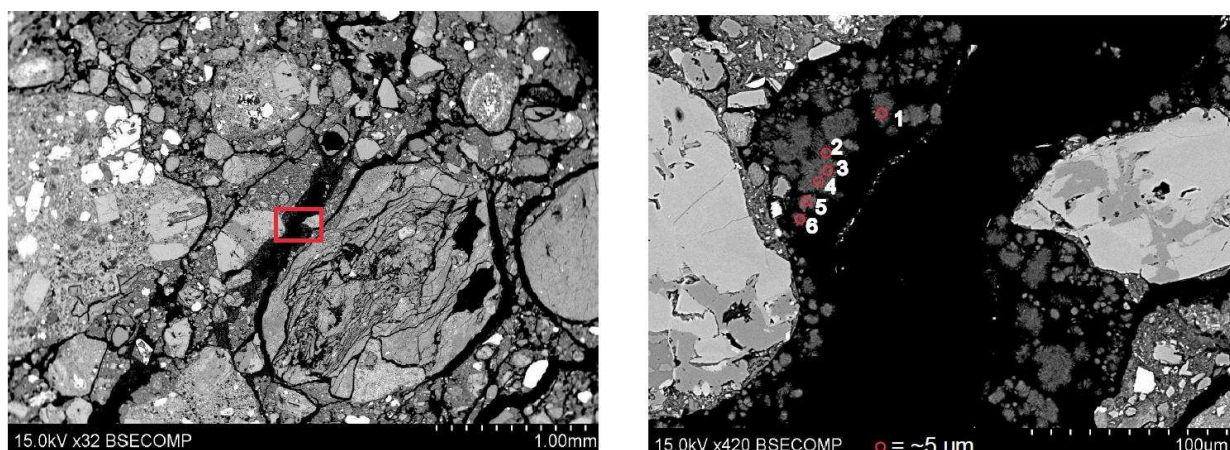
OTM images and semi-quantitative EDS analysis can help the soil scientists to better understand soil compounds and structure. In our case, microstructure of these typical frost-

affected soils and ornithogenic soils present a particular type of globular, rounded aggregates, under strong biological influence. Phosphates phases occur as illuvial coatings, in fillings and within discrete aggregates. In LR7 (Table 3), we can note a clear presence of P compounds filling the voids (Id 1) rounding aggregates (Id 2), and covering minerals as plagioclases, quartz (Id 9) and pyroxenes (Table 3). Most part of illuvial phosphatic features (Id 6 and 7) is formed by non-crystalline forms of aluminium phosphate with close to 60 % of P. In LR8 the P-rich solution penetrates into the cracks and cleavage planes and reacts preferentially with plagioclases, which is the main mineral of the soil matrix (Id 4, 5 and 6, LR8B2, Table 3). We can observe phosphates covering the silicates minerals and the weathering process of this mineral (Id 8, Table 3). At LR 9, the soil matrix is mainly phosphatic, formed by aluminium-iron phosphate non-crystalline involving clasts of Na-plagioclases (LR9, Table 4). In LR11 soil, matrix is formed by a mixed of minerals well-rounded and fragmented due to cryoclastic process and transport by the glacier (Table 4). As a residual of avifauna influence on the soil formation process, a piece of bone can be observed in some profiles (Id 1, LR112Bi, Table 4).

The dispersive spectrometry (WDS) for LR7 Cr (Table 5) indicate the presence of low crystalline aluminium phosphate as the main phosphate mineral filling the voids of this soil horizon, what is confirmed by XDR analyses (Figure 3) that no indicates peaks of crystalline phosphates as taranakite, leucophosphite, minuyllite and others as identified in different areas of Maritime Antarctica by Tatur and Keck (1990) and Barczuk and Tatur (2003). How already showed by Simas et al. (2006) uncrystalline phosphate are the main component of clay fraction of ornithogenic soils. Due to the high acidity and leaching probably the crystalline phosphates are instable in these chemical soil conditions.

WDS data for LR9 Cr (Table 6) indicate Taranakite ($K_3Al_5(HPO_4)_6(PO_4)_2 \cdot 18(H_2O)$) as the main phosphate mineral filling the space porous of this soil horizon, what is confirmed by XDR analyses (Figure 3). Results from WDS point analyses are quite homogenous and representing low deviations of Taranakite chemical composition. However, studies from Tatur (1989) and Tatur and Keck (1990) with phosphates of Antarctica ornithogenic soils identified ammonium in Taranakite, but no N peaks were detected in this mineral in our samples from Lions Rump. Phosphates phases occur as illuvial coatings, in fillings and within discrete aggregates. In all secondary phases, chemical variability is greater but in general follow descrescent content for Fe>K>P>Al, and vary depending on the primary mineral that the solution rich in P will react to form phosphates.

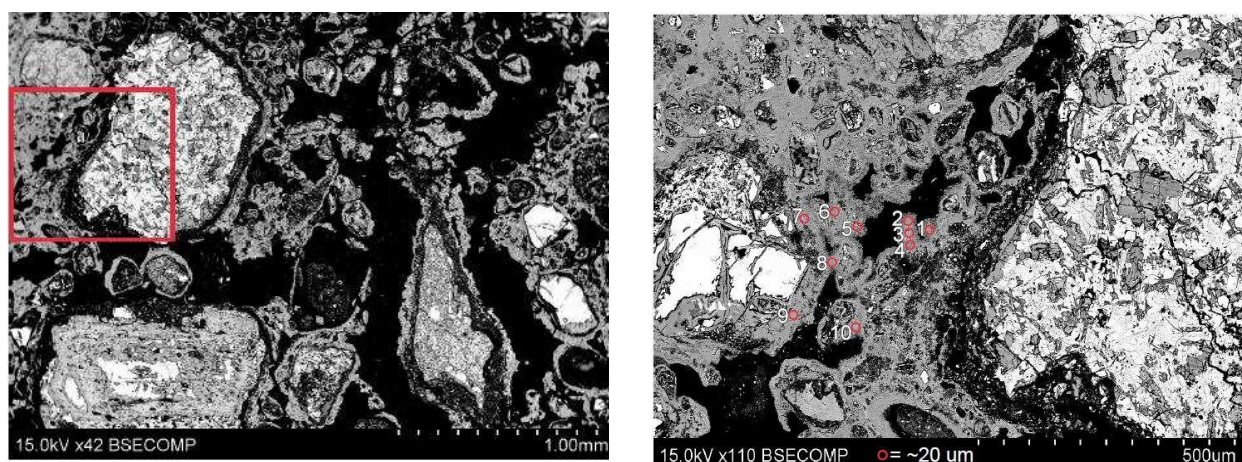
Table 5 - SEM images and mean WDS chemical analysis of phosphatic plasma in the Bi horizon of profile LR7



Id	Na ₂ O	SiO ₂	Al ₂ O ₃	MgO	K ₂ O	P ₂ O ₅	SO ₃	CaO	Fe ₂ O ₃	Sum
	----- % -----									
Mean*	0.0	0.2	21.3	<DL	4.3	49.1	0.3	0.1	0.8	75.5
sd	0.0	0.1	2.0	0.0	0.6	2.6	0.1	0.0	0.5	3.8

<DL = below detection limits; sd = standard deviation; * n= 10.

Table 6 - SEM images and mean WDS chemical analysis of phosphatic plasma in the Cr horizon of profile LR9



Point	Na ₂ O	SiO ₂	Al ₂ O ₃	MgO	K ₂ O	P ₂ O ₅	SO ₃	CaO	Fe ₂ O ₃	H ₂ O	Sum
	----- % -----										
Mean*	0.1	1.0	22.6	0.1	8.3	39.8	0.4	0.1	3.8	17.0	93.0
sd	0.0	0.4	3.1	0.0	2.4	1.5	0.1	0.1	3.0	3.3	5.1

<DL = below detection limits; sd= standard deviation; *n=10.

CONCLUSIONS

1. Ornithogenic soils rich in phosphates in Lions Rump can have or not mineral phosphates phases, identified by XRD.
2. Phosphates phases occur as illuvial coatings, in fillings and within discrete aggregates. In all secondary phases, chemical variability is greater for Fe>K>P>Al.
3. The microstructure of this soil is typical of frost-affected soils, and ornithogenic soils possess a particular type of globular, rounded aggregates, under strong biological influence.
4. Phosphatization is the main process of soil formation in Acid Ornithogenic Soils.
5. The utilization of microchemical techniques proved to be useful for a better understanding of pedogenesis in these poorly known Antarctic soils.

REFERENCES

- Anderson B. H., Magdoff, F.R., 2005. Relative movement and soil fixation of soluble organic and inorganic phosphorus. *J. Environ. Qual.*, 34, 2228-2233.
- Antarctic Permafrost and Soils – ANTPAS, 2006. Soil description manual. Guide for describing, sampling, analyzing, and classifying soils of the Antarctic region. Available at: <<http://www.earth.waikato.ac.nz/antpas>>. Accessed 5/19/2011.
- Armstrong, J.T., 1995, CITZAF: a package of correction programs for the quantitative electron microbeam x-ray analysis of thick polished materials, thin films and particles, *Microbeam Analysis*, 4, 177-200.
- Barczuk, A., Tatur, A., 2003. Biogenic phosphate and sulphate minerals in the soils of Antarctic Peninsula. *Polskie Towarzystwo Mineralogiczne – Prace Specjalne Mineralogical Society of Poland – Special Papers Zeszyt* 23, 41-43.
- Beyer, L., 2000. Properties, formation and geo-ecological significance of organic soils in the coastal region of East Antarctica. *Geoderma* 39, 79–93.
- Beyer, L., Sorge, C., Blume, H.P., Schulten, H.R., 1995. Soil organic matter composition and transformation in Gelic Histosols of coastal Continental Antarctica. *Soil Biology and Biochemistry* 27, 1279–1288.
- Bolter, M., Kandeler, E., 2004. Microorganisms and microbial processes in antarctic soils. In: Kimble, J. (Ed.), *Cryosols: Permafrost-affected Soils*. Springer-Verlag, Berlin, pp. 557–572.
- Bullock, P.; Fedoroff, N.; Jongerijs, A.; Stoops, G.; Tursina, T.E.; Babel, U. Handbook for thin section description. WAINE Research Publications, Albrighton, Wolverhampton, U.K, 1985.
- Donovan, J.D., Kremser, D. and Fournelle, J., 2010, User's Guide and Reference - Enterprise Edition, Probe Software (Eugene, OR), 411 p.

- EMBRAPA - Centro Nacional de Pesquisa de Solos, 1997. Manual de métodos de análise de solo. Centro Nacional de Pesquisa de Solos, Rio de Janeiro, 212 pp.
- Gee, G.W. and Bauder, J.W., 1986. Particle-size analysis. Pp. 383-412 in: *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods* (A. Klute, editor). Soil Science Society of America, Madison, Wisconsin.
- Michel, R.F.M., Schaefer, C.E.G.R., Dias, L., Simas, F.N.B., Benites, V., Mendonça, E.S., 2006. Ornithogenic Gelisols (Cryosols) from Maritime Antarctica: pedogenesis, vegetation and carbon studies. *Soil Science Society of America Journal* 70, 1370–1376.
- Myrcha, A. and Tatur, A., 1991. Ecological role of the current and abandoned penguin rookeries in the land environment of the maritime Antarctic. *Polish Polar Research* 12, 1, 3-24.
- Ruiz, H.A. Incremento da exatidão da análise granulométrica do solo por meio da coleta da suspensão (silte + argila). *Revista Brasileira de Ciência do Solo*, 2005, v. 29, p. 297-300.
- SCAR - Scientific Committee on Antarctic Research. Management Plan for Site of Special Scientific Interest (SSSI) No. 34, Lions Rump, King George Island, South Shetland Islands. SCAR Bulletin, 144, 2002. Disponível em <http://www.scar.org/publications/bulletins/144/ssi34/>. Consultado em 03/11/2009.
- Schaefer, C.E.G.R., Simas, F.N.B., Gilkes, R.J., Mathison, C., Costa, L. M., Albuquerque, M. A., 2008. Micromorphology and microchemistry of selected Cryosols from Maritime Antarctica. *Geoderma* 144, 104 – 115.
- Simas, F.N.B., Schaefer, C.E.G.R., de Melo, V.F., Guerra, M.B.B., Saunders, M., Gilkes, R.J., 2006. Clay-sized minerals in permafrost-affected soils (Cryosols) from King George Island, Antarctica. *Clays and Clay Minerals* 54, 721–736.
- Simas, F.N.B., Schaefer, C.E.G.R., Melo, V.F., de Albuquerque-Filho, M.R., Michel, R.F., Pereira, V.V., Gomes, M.R.M., 2007. Ornithogenic Cryosols from Maritime Antarctica: phosphatization as a soil forming process. *Geoderma* 138, 191–203.
- Tatur, A., 1989. Ornithogenic soils of the maritime Antarctic. *Polish Polar Research* 4, 481–532.
- Tatur, A., Barczuk, A., 1985. Ornithogenic phosphates on King George Island, Maritime Antarctic. In: Siegfried, W.R., Condy, P.R., Laws, R.M. (Eds.), *Antarctic Nutrient Cycles and Food Webs*. Springer-Verlag, Berlin, pp. 163-169.
- Tatur, A., Keck, A., 1990. Phosphates in Ornithogenic soils of the Maritime Antarctic. *Proc. NIPR Symp. Polar Biol.*, 3, 133-150.
- Tatur, A., Myrcha, A., Niegodysz, J., 1997. Formation of abandoned penguin rookery ecosystems in the Maritime Antarctic. *Polar Biology* 17, 405–417.
- Toor, G. S., Condon L. M., Di, H. J., Cameron, K. C., 2004a. Seasonal fluctuations in phosphorus loss by leaching from a grassland soil. *Soil Sci. Soc. Am. J.*, 69, 167-184.
- Toor, G. S., Condon L. M., Di, H. J., Cameron, K. C., Sims, J. T., 2004b. Assessment of phosphorus leaching losses from a free draining grassland soil. *Nutr. Cycl. Agroecos.*, 69, 167-184.
- Ugolini, F.C., 1972. Ornithogenic soils of Antarctica. In: Llano, G.A. (Ed.), *Antarctic Terrestrial Biology Am. Geophys. Union Antarct Res. Ser.* pp. 181–193.

- Wilson, M. J., Bain, D. C., 1976. Occurrence of leucophosphite in a soil from Elephant Island, British Antarctic Territory. *American Mineralogist*, 61, 1027-1028.
- Yeomans, J.C., Bremner, J.M., 1988. A rapid and precise method for routine determination of organic carbon in soil. *Communications in Soil Science and Plant Analysis*, 19, 1467-1476.
- Kämpf, N. & Schwertmann, U. The 5m-NaOH Concentration Treatment For Iron Oxides in Soils. *Clay Miner*, 30:401-408, 1982.

PAPER 3

**ACTIVE LAYER THERMAL REGIME AT DIFFERENT VEGETATION
IN LIONS RUMP, KING GEORGE ISLAND, MARITIME
ANTARCTICA**

ABSTRACT

Climate change impacts the biotic and abiotic components of polar ecosystems, particularly on permafrost, active layer thickness, vegetation, and soil properties. This paper describes the active layer thermal regimes of two shallow boreholes, geographical and altitudinal adjacent, present the same soil class but have a different vegetation cover. The boreholes are situated in the Lions Rump area at King George Island, Maritime Antarctic, region that represents one of the most sensitive to climate change and is located near the climatic limit of permafrost, since mean annual air temperature at sea level is close to -2°C . The limited knowledge about ground temperature conditions led a recent effort to increase active layer and permafrost research in the Antarctic. Both study sites are in a Turbic Cambic Cryosol formed by andesitic parent material, one under moss vegetation (85 m a.s.l) and another under lichen (86 m a.s.l). Ground temperature series were collected at 1-hour intervals, recorded during two years, from March 2009 to February 2011. In both boreholes, a network of three soil temperatures sensors were installed at 10, 30 and 80 cm depths, one moisture sensor at 80 cm depth, and one air temperature sensor at 100 cm height above soil. Two sites showed significant differences in mean annual ground temperature for all depths. The lichen site shows higher soil temperature amplitude than lichen site, present in ground surface the highest daily temperature in January 2011 (7.34°C) and a lowest daily temperature in August (-16.54°C). The soil temperature at lichen site followed variability of air temperate. The Moss site shows higher water content at bottommost monitored layer because is located at water track position on the landscape. The buffer effect on Moss site happens because of the high content of water available associated with the moss vegetation and snow cover. The active layer in both sites of Lions Rump is thick and both boreholes did not reach the permafrost table, but still above 2 m depth what characterized Gelisol/Cryosol.

INTRODUCTION

Understand distribution and properties of Antarctic permafrost is essential for the cryospheric sciences, but also for life sciences, since it will be a major control on ecosystem modification following climate-induced changes (Vieira et al. 2010).

Permafrost-affected soils normally present an active layer, which is defined as the portion of soil which experiences seasonal thawing and freezing (Brown et al., 2000). It is through this layer that, in response to a thermal gradient; heat flows between the atmosphere and permafrost. Permafrost, defined as any subsurface earth materials remaining below 0°C for more than two years, may be affected profoundly by global warming (Hinkel et al., 2001).

Climate is a first-order control on permafrost temperatures with local microclimate also substantially affecting ground surface temperatures, and therefore, the thermal regime of the permafrost. At a local scale, ground surface and permafrost temperatures are affected by the characteristics of the snowpack, the type and height of vegetation, moisture content in the ground, topography, the geothermal flux, and the thermal conductivity of the earth materials (Judge, 1973). Permafrost and vegetation are key environmental components and both are sensitive to climate change (Guglielmin et al., 2008), particularly where the permafrost it has a discontinuous distribution (Burgess et al., 2000) what occur in Maritime Antarctica.

Periglacial regions are highly sensitive to climate change. Maritime Antarctica has been increasingly recognized as a key region for monitoring climate change (Cannone et al., 2006; Vieira et al., 2010). The limited knowledge of the ground temperature conditions led a recent effort to increase active layer and permafrost research in the Antarctic.

The continued monitoring of soil temperature in polar regions allows the identification of important variables, such as the duration and intensity of the thawing and freezing periods (Michel et al., 2012). Specific investigations focusing on the relationships between vegetation and permafrost as a sensitive indicator of climate change are still lacking (Cannone et al., 2006).

The aim of this paper is elucidated the influence of vegetation cover on hydrothermal soil behavior and describes the active layer thermal regime of two shallow boreholes of a Turbic Cambic Cryosol located at 85 m.a.s.l, under two contrasting vegetation types located five meters apart: a moss carpet (*Andrea gainii*) site and a Lichen community site.

MATERIAL AND METHODS

2.1. Regional characteristics

The study sites are located at Lions Rump peninsula in King George Island, King George Bay, Maritime Antarctica (Figure 1). The both sites are located in a soil classified as Turbic Cambic Cryosol (Eutric, Skeletic), according to the WRB system (ISSS, 1998) (Table 1), which correspond to loamy-skeletal, mixed, subgelic, Typic Haplorthels and sandy-skeletal, mixed, active, subgelic, according to the Soil Taxonomy (SSSA, 2003). Both sites is in the same altitude, have a loamy-sand texture (Table 2) and are different only in landscape position and vegetation cover: the moss carpet (mainly formed by *Andrea gainii*) site in the lower landscape position (water track), and the Lichen community site, dominated by *Usnea antarctic* and *Ochrolechia frigida* and located in a small terrain undulation (inter-area track). Vegetation cover more than 70 % of the soil surface at both sites (Figure 2).

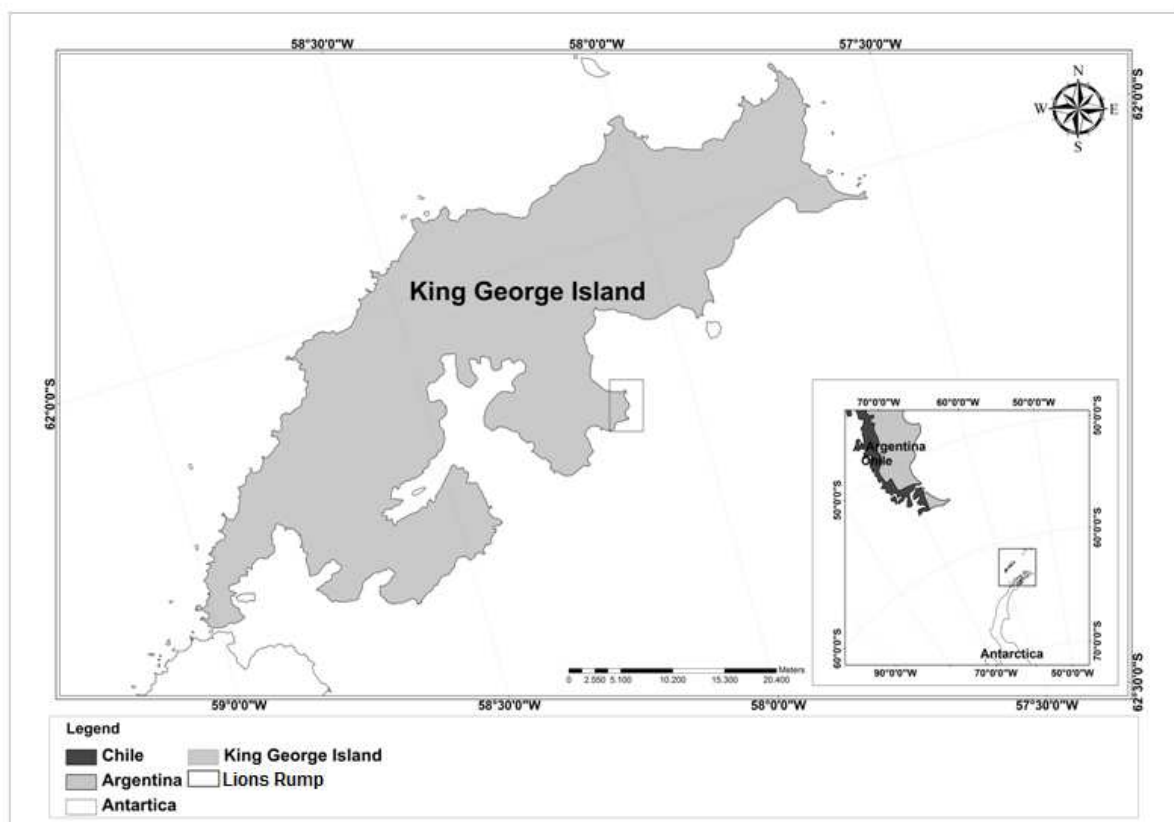


Figure 1. Location of the studied sites, in Lions Rump peninsula, King George Island, King George Bay, Maritime Antarctica (Adapted from Michel et al., 2012).



Figure 2. Vegetation cover in Lions Rump: a) Mosses carpet site; b) Lichen site; c) Partial view of network sensors.

Table 1. General characteristics of monitored sites

Site	Geographic position	Altitude m.a.s.l	Vegetation	% cover ^a	Soil class WRB/soil taxonomy	ALT ^b cm
Moss carpet site	0441165 3109959	85	<i>Andrea gainii</i> , sparces <i>Deschampsia antarctica</i> and <i>Colobanthus quitensis</i>	70	Turbic Cambic Cryosol (Eutric. Skeletic)/ Typic Haplorthels	147.26
Lichen Site	0441165 3109959	86	<i>Usnea antarctic</i> and <i>Ochrolechia frigida</i>	80	Turbic Cambic Cryosol (Eutric. Skeletic)/ Typic Haplorthels	120.22

^a Visual estimated, ^b ALT = Active Layer thickness (estimated)

Table 2. Morphological and physical properties of studied profiles from Lions Rump

Depth (cm)	Structure ^a	Transition	TFSA %	CS ^b	FS ^c	Silt ^d g/kg	Clay ^e	Class
Moss carpet site								
A 0-8	w l bl/ sg	clear wavy	52	57	25	14	4	Loamy sand
AB 8-20	w l bl/ sg	gradual	60	56	22	17	5	Loamy sand
Bi1 14-26	w m bl/ st	gradual	28	62	21	15	2	Loamy sand
Bi2 26-48	md st l bl/	gradual	34	58	20	20	2	Loamy sand
BC 48-80 ⁺	md m l bl	-	45	56	23	19	2	Loamy sand
Lichen site								
A 0-8	w l bl/ sg	clear wavy	52	51	28	18	3	Loamy sand
AB 8-20	w l bl/ sg	gradual	50	49	29	18	4	Loamy sand
B1 2-33	w m bl/ st	gradual	40	47	29	21	3	Loamy sand
Bi2 33-52	md st l bl/	gradual	52	52	25	21	2	Loamy sand
BC 52-82 ⁺	md m l bl	-	69	58	22	19	1	Loamy sand

^a Structure classification: Development: w = weak. md = moderate. st = strong. Size: f = fine. m = medium, l = large Type: ma = massive. gr = granular. bl = subangular blocky. sg = single grain. cr = crumbs; Soil physic was analyzed with texture procedure (EMBRAPA, 1997 modified by Ruiz, 2005) = ^b Coarse sand (2 – 0.2 mm); ^c Fine sand (0.2– 0.05 mm); ^d Silt (0.05 – 0.002 mm); ^e Clay (< 0.002 mm).

According to Köppen's classification, the region is part of the tundra climate (ET). Data sets acquired at the Brazilian Commandant Ferraz, nearby station from Lions Rump, report mean air temperatures varying from $-6.4\text{ }^{\circ}\text{C}$ in July to $+2.3\text{ }^{\circ}\text{C}$ in February. Mean annual precipitation is proximally to 400 mm (Simas et al., 2007), but the real soil water regime is highly influenced by its position in the landscape, due to the intense melting of snow, glaciers and permafrost sites upstream during the summer. The temperature remains above freezing almost all summer (November to March) allowing the vigorous growth of plant communities, mainly mosses, lichens and algae (Schaefer et al., 2004).

Results from International Polar Year (IPY) permafrost temperature monitoring shows South Shetland Islands with permafrost temperatures slightly below 0°C at low elevations, with values decreasing to about -1.8°C at 270 m.a.s.l. and 25 m depth. The lowest coastal terrain near sea level is essentially permafrost free (Vieira et al., 2010).

In general soils from Lions Rump present incipient and poorly evolved when classified by WRB and Soil Taxonomy. In the study area, we found Ornithogenic Soils, mainly Cryosols/Gelisols at highest landscape portions, and Cambisol/Inceptsol and (Regosols, Arenosols, Leptsols)/Entsols widespread in the lowland area.

2.2. Methods

In summer of 2009, boreholes were dug and the active layer monitoring sites were installed in both sites. Monitoring systems were formed by thermistors (TYPE E, CHROMEL CONSTANT TERMOCOUPLE, accuracy of $\pm 0.2\text{ }^{\circ}\text{C}$) arranged in a vertical array at different depths (Table 3); soil moisture probes (CS616 WATER CONTENT REFLECTOMETER, accuracy of $\pm 2.5\%$) placed at the bottommost layer at each site (80 cm deep in both boreholes) to determine the volumetric water content; and air temperature sensor (107 TEMPERATURE PROBE) installed at 100 cm above the soil surface. All probes were connected to a Campbell Scientific CR 1000 data logger that recorded data at hourly intervals from April, 2009 to January, 2011.

The characteristics of the monitored sites are presented in Table 1. Temperature soil probes are installed in the same deep for both sites (10, 30 and 80 cm). The depth of the probes was established respecting pedological differentiation of horizons.

Multivariable regression was performed in order to describe soil temperature at 80 cm from temperatures of two first layers and air temperature, using Statistica® software (Statsoft,

2009). To try predict soil temperature from superficial sensors in Antarctica conditions is so interesting for future studies that can not reach depth layers.

We calculated the thawing days (days in which all hourly measurements are positive and at least one reading is warmer than +0.5 °C), and freezing days (days in which all hourly measurements are negative and at least one reading is colder than -0.5 °C); the number of isothermal days (days in which all the hourly measurements range only between ±0.5 °C); the number of freeze–thaw days (days in which there are both negative and positive temperatures with at least one value greater than ±0.5 °C); the thawing degree days (obtained by the cumulative sum of the mean daily temperatures above 0 °C); the freezing degree days (obtained by the cumulative sum of the mean daily temperatures below 0 °C); all according to Guglielmin et al. (2008).

To better assess the influence of the average thickness of the snow, estimate of the index N factor (FN) was carried. The index FN relates air temperature with the ground surface and can be calculated for the seasons' periods of fusion (thawing degree days) or freezing (freezing degree days) of the soil (Riseborough, 2003). From results from the soil Freezing Degree Days at 10 cm (FDD) and air (FDDa) was calculated index FN, in this case only for the time of freezing, with equation: $FN = FDD/FDDa$. Soil temperature of 10 cm was selected due to be monitored depth closest to the soil surface. Since the temperatures (soil and air) in some periods during the year are not simultaneously positive or negative, it is therefore, necessary to define "FN station" or freezing station (Nieuwendam, 2009).

Active layer thickness was calculated as the 0 °C depth by extrapolating the thermal gradient from the two deepest temperature measurements (Guglielmin, 2006).

The apparent thermal diffusivity was estimated from equation of McGaw et al. (1978): $\alpha = [\Delta Z^2 / 2\Delta t] \times [(T_i^{j+1} - T_i^{j-1}) / (T_j^{i-1} - 2T_j^i + T_j^{i+1})]$, where α = apparent thermal diffusivity ($m^2 s^{-1}$), Δt = time increments (s), ΔZ = space increments (m), T = temperature, j = temporal position and i = depth position. Nelson et al. (1985), Outcalt and Hinkel (1989), Hinkel et al. (1990, 2001) and Michel et al. (2012) used this parameter to assess resistance to energy flux in soil profiles. Hourly estimates were made for intermediate depths of both profiles, and mean values were calculated and plotted for each day (Figure 3C).

RESULTS AND DISCUSSION

Although both sites are similar in terms of latitude, altitude and climatic events, soil thermal regime was considerably different when comparing the influence of two soil cover (Figure 3). The contrasting behavior regarding to water content and soil temperature are attributed to the vegetation cover and location of sites on the landscape. Compare the soil location as an agriculture terrace, the Moss site is situated in the furrow (water track) and the Lichen site is located on the ridge (inter-area track) (Figure 2). These quite differences in position promote great differences in soil hydrotermic regime.

3.1. Mosses carpet site

The highest soil temperature at this site was 12.08 °C (Table 3), not registered for the top soil layer but at 30 cm deep in January 20th 2010 at 2:00 PM, while highest mean daily air temperature was 11.07 °C recorded on January 3rd 2011 at 4:00 PM. Soil water content ranged from approximately 0.60 m³ m⁻³% in summer to 0.30 %m³ m⁻³ in winter (Figure 3A). The presence of water in the freezing and frozen active layer and near the permafrost table protects the ground from rapid cooling and creates a strong thermal gradient (Romanovsky and Osterkamp, 2000) due to the water high latent heat.

Mean annual temperatures of -0.53 °C, -0.51 °C and -0.56 °C were found for the increasing depths (10 cm, 30 cm and 80 cm, respectively). The maximum and minimum temperatures (hourly records) for the bottommost layer (depth of 80 cm) were 7.15 °C and -4.79 °C, respectively (Table 3). This high temperature (7.15 °C) in depth favors active layer and our data show Lions Rump with a deeper active layer of King George Island for this altitude until now studied. Positive monthly mean temperatures at 80 cm occurred from January until April 2010, and started early in the next spring, at November 2010. A chill occurs in midsummer in February slowing the soil warming (Tables 3 and 4).

Table 3. Monthly mean temperature (°C) at air and different depths, and water content (WC, %) at 80 cm depth from Lions Rump soil under two vegetation cover

Month	Moss					Lichen			
	Air	Depth (cm)			WC	Depth (cm)			WC
		10	30	80	%	10	30	80	%
apr/09	-2,58	-0,07	-0,05	-0,05	0,29	-1,41	-0,24	-0,03	0,19
may/09	-3,72	-0,41	-0,09	-0,07	0,29	-2,65	-1,53	-0,29	0,17
jun/09	-8,67	-2,11	-1,16	-0,42	0,23	-6,54	-4,78	-2,66	0,13
jul/09	-9,78	-3,54	-2,81	-2,10	0,16	-8,10	-7,01	-5,48	0,11
aug/09	-9,41	-5,18	-4,62	-4,07	0,14	-8,88	-8,32	-7,33	0,10
sep/09	-4,75	-4,07	-4,00	-3,88	0,14	-4,46	-4,65	-4,62	0,11
oct/09	-3,14	-1,43	-1,77	-2,08	0,15	-1,91	-2,06	-2,24	0,12
nov/09	-2,56	-1,13	-1,41	-1,67	0,16	-1,02	-1,75	-2,07	0,13
dec/09	0,18	0,78	0,42	-0,16	0,24	1,72	0,04	-0,56	0,14
jan/10	0,20	1,32	1,04	0,60	0,44	2,11	0,94	-0,10	0,15
feb/10	-0,46	0,01	0,00	-0,01	0,43	0,93	0,48	0,03	0,16
mar/10	-0,42	0,59	0,35	0,15	0,38	0,40	0,39	0,08	0,18
apr/10	-2,99	0,07	0,07	0,02	0,37	-1,37	-0,32	-0,03	0,19
may/10	-3,29	-0,35	-0,07	-0,06	0,37	-2,51	-1,65	-0,71	0,15
jun/10	-2,64	-1,91	-0,92	-0,26	0,28	-2,92	-2,28	-1,59	0,14
jul/10	-4,92	-2,06	-1,72	-1,35	0,17	-4,75	-4,12	-3,35	0,13
aug/10	-4,96	-3,63	-3,16	-2,69	0,15	-5,23	-4,93	-4,33	0,12
sep/10	-2,88	-3,22	-3,16	-3,03	0,15	-3,38	-3,51	-3,54	0,13
oct/10	-0,20	-0,48	-0,86	-1,24	0,17	-0,11	-0,89	-1,38	0,14
nov/10	1,16	2,24	1,67	0,92	0,44	1,97	0,21	-0,41	0,15
dec/10	-0,16	1,10	0,51	0,16	0,47	1,94	0,79	-0,02	0,16
jan/11	1,23	2,79	1,75	0,81	0,39	3,55	2,13	0,84	0,20
Mean	-2,95	-0,94	-0,91	-0,93	0,27	-1,94	-1,96	-1,82	0,14
Min	-25,02	-6,47	-5,54	-4,79	0,13	-17,22	-13,21	-9,92	0,10
Max	11,07	11,18	12,0	7,15	0,50	13,66	4,61	1,33	0,24
St dv	5,07	2,35	1,90	1,54	0,13	4,05	2,93	2,21	0,03

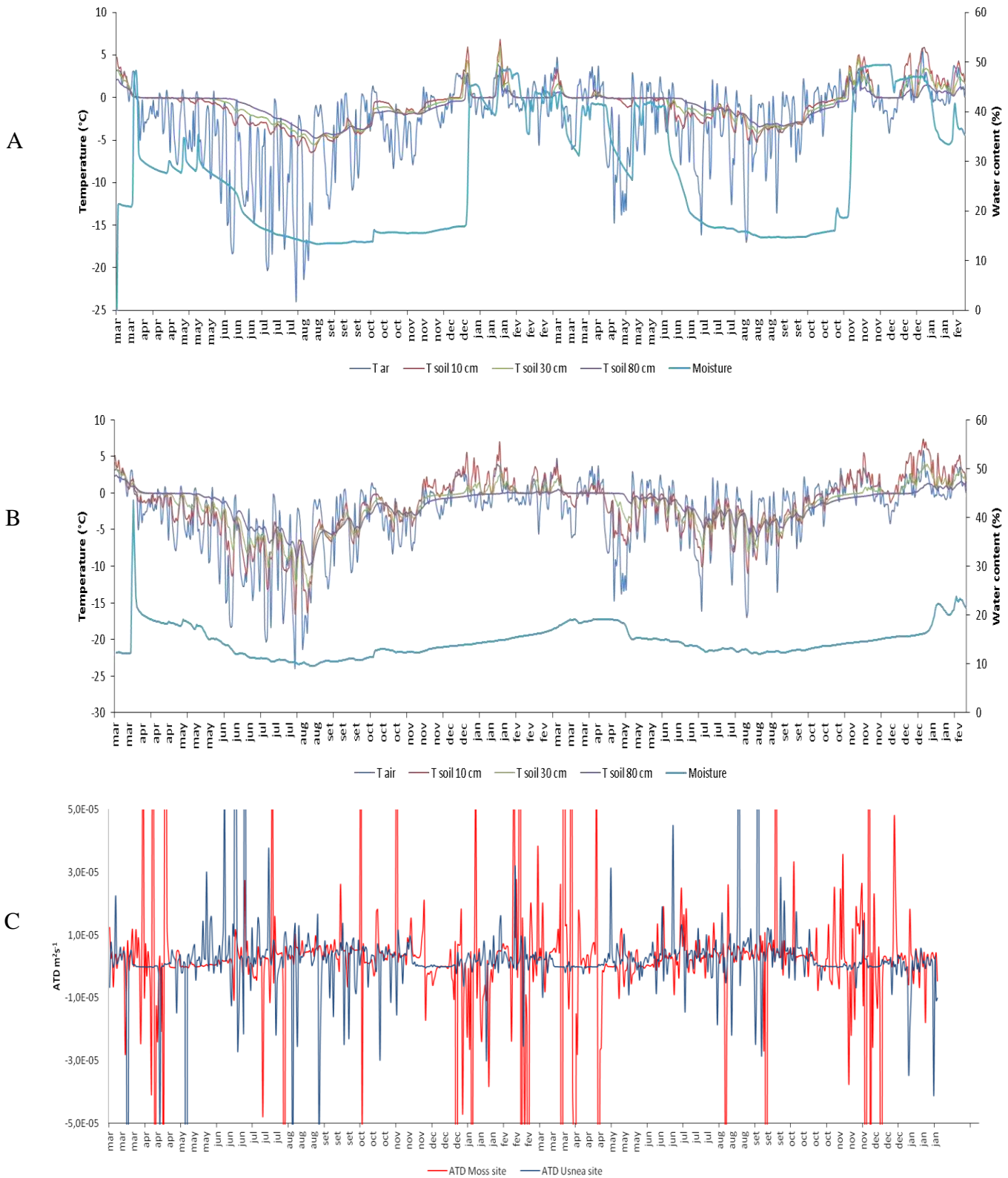


Figure 3. Daily mean soil and air temperature and water content for A) Moss carpet site B) Lichen site. C) Apparent thermal diffusivity (ATD) of intermediate depth (30 cm) for both sites.

Permafrost starts at 147.26 cm (estimated ALT), as it is defined as a layer which remains frozen (below 0 °C) for two consecutive years. Although frequent daily freeze and thaw cycles were observed, the active layer remains predominantly unfrozen until the end of March 2009, when the temperature decreases close to 0.0 °C, coinciding with beginning of thermal autumn (Figure 3C), when occurs the so-called zero curtain regime (Hinkel et al., 2001), that keeps the temperature close to 0.0 °C until the upper layer is completely frozen at the end of May. The zero curtain regime refers to a period in autumn when the active layer is refreezing from the top-down and from the bottom up. Penetration of the freezing fronts is inhibited by the release of the latent heat of fusion, and thermal fluctuations occurring on the surface are strongly attenuated at shallow depths. Upon completion of the phase change, the continual removal of heat results in a temperature reduction (Hinkel et al. 2001). In the next year, 2010, the active layer remains predominantly unfrozen until April 17th 2010, when the temperature decreases again close to 0.0 °C, and over again coinciding with beginning of the thermal autumn and zero curtain regime that extends until June 5th 2010. After this time, temperature decrease and upper soil layer frozen, with complete freezing until 80 cm depth at the end of June. During thermal autumn, the freezing front did not reach the complete active layer depth. Only after June 23rd, soil presents consistent negative temperatures at the 80 cm depth, indicating complete freezing of the active layer. Further cooling occurred during the winter season, with soil temperatures decreasing to a minimum of -6.47 °C at 10 cm and -4.79 °C at 80 cm depth.

Spring's thermal regime starts at end of September, with soil temperature rising rapidly, especially for the top soil layer, starting at -4.1 °C on August 21st and reaching 0 °C on October 26th. Differently from the freezing during autumn which shows a delay between the top and bottommost layers, the thawing phenomenon practically occurred simultaneously in whole active layer. During all year, the temperature amplitude between the top and bottommost sensor was low, reaching a maximum positive of 7.7 °C on December 9th 2009 and negative

Table 4. Thawing and freezing days of the studied sites in Lions Rump during a period of 22 months

Month	Moss			Lichen			Moss			Lichen		
	Thawing days						Freezing days					
	10	30	80	10	30	80	10	30	80	10	30	80
apr/09	0	0	0	0	0	0	6	5	4	29	15	0
may/09	0	0	0	0	0	0	29	19	11	31	31	21
jun/09	0	0	0	0	0	0	30	30	30	30	30	30
jul/09	0	0	0	0	0	0	31	31	31	31	31	31
aug/09	0	0	0	0	0	0	31	31	31	31	31	31
sep/09	0	0	0	0	0	0	30	30	30	30	30	30
oct/09	0	0	0	0	0	0	31	31	31	31	31	31
nov/09	0	0	0	0	0	0	30	30	30	17	30	30
dec/09	10	8	5	18	9	0	8	18	21	0	18	31
jan/10	16	16	16	22	27	0	0	0	0	0	0	19
feb/10	1	1	1	11	13	3	0	0	0	0	0	0
mar/10	13	13	12	9	12	8	0	0	0	11	0	0
apr/10	10	11	9	2	0	0	11	6	6	15	7	2
may/10	0	0	0	0	0	0	21	11	9	24	31	31
jun/10	0	0	0	0	0	0	30	25	19	30	30	30
jul/10	0	0	0	0	0	0	31	31	31	31	31	31
aug/10	0	0	0	0	0	0	31	31	31	31	31	31
sep/10	0	0	0	0	0	0	30	30	30	30	30	30
oct/10	2	0	0	1	0	0	26	30	30	17	31	31
nov/10	25	24	21	19	17	0	0	0	2	0	6	30
dec/10	15	14	9	17	16	2	0	0	0	3	0	13
jan/11	31	31	31	29	31	31	0	0	0	0	0	0
Sum	123	118	104	128	125	44	406	389	377	422	444	483

maximum amplitude of $-4.27\text{ }^{\circ}\text{C}$ on June 7th 2010, which coincides with the beginning of summer and winter, respectively. In periods as ends of March and June (autumn) and October (middle spring) are the time of minor thermal amplitude with temperature in whole active layer close to $0\text{ }^{\circ}\text{C}$, where the curtain regime happens.

The water content is highly variable ranging from around $0.13\text{ m}^3\text{ m}^{-3}$ in the winter to $50\text{ m}^3\text{ m}^{-3}$ in the summer (Figure 3A). These high contents of soil water can be explained because the site is located in the water trap, where the meltdown of snow and thawing of active layer supply water to this soil portion. The water content follows the zero curtain regime, which means that just when the soil reaches temperatures above liquefaction the water content increases quickly (Figure 3A). The same occurs when the soil starts to freezing, i.e., the water content just decreases when soil temperature goes below the freezing point.

The soil thermal regime provides useful data to evaluate the physical state of soil moisture and, traditionally, simple approaches have been adopted providing proxy measures at the phase state of soil moisture (Guglielmin et al., 2008). Among these, the “isothermal days” indicate that the energy in the ground is consumed to change the water phase both during thawing and freezing, when latent heat exchange produces the “zero curtain effect” (Outcalt et al., 1990). In a similar way, the “frozen days” and the “thawed days” indicate when the soil moisture is frozen or in a liquid state. Moreover, the “freeze–thaw days” describe days in which freeze–thaw cycles may occur (Guglielmin et al., 2008).

The thawing days varied from 104 days at 10 cm of depth to 123 at the deeper layers (Table 4), and did not vary much between layers studied. The thawing days are concentrated in summer and beginning autumn. Tendency of isothermal days was to increase in depths, reaching 188 days at 80 cm, what was expected because permafrost and the higher water soil content are close, promoting the thermal buffer effect (Table 5). At the depth of 10 cm, two freeze–thaw days occurred whilst the others depths only happen one freeze–thaw day. Thawing and freezing cumulative degree days provide an estimate of the net energy flux in the studied sites. Comparison of the 10 cm thawing degree days (236 degree days) and freezing degree days (–435 degree days) indicated predominantly freezing conditions (Table 6). At the bottom of the profile, the thawing degree days totalized 191 degree days, while freezing degree days totalized –516 degree days, during the monitoring time between March 2009 until January 2011, but only on a period than one year from December 2009 (summer) to November 2010 (spring) thawing degree days presented 123 degree days, while freezing degree days presented –224 degree days. Therefore, for this soil freezing conditions are almost twice than thawing conditions during the four seasons during the year (Table 6). Summer’s thawing is also affected by this buffering effect at the same depth, but with less intensity, possibly due to high amounts of ground ice accumulating over the permafrost table (Michel et al., 2012).

Thermal diffusivity was estimated for intermediate depth (30 cm) for each hour, although in Figure 3C is reported as daily mean value. Since it was calculated from the observed temperatures, and includes the thermal impact of nonconductive heat transfer, it is more properly referred as the apparent thermal diffusivity (ATD) (Hinkel et al. 2001). Mean ATD for a period counted just one year-round from December 2009 (summer) to November 2010 (spring) was $-4.6 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$. Negative ATD values indicate that nonconductive effects oppose and overwhelm the conductive trend (Outcalt and Hinkel, 1989) due to the higher water content, especially at summer time.

Table 5. Isothermal and freeze–thaw days of the studied sites at Lions Rump during a period of 22 months

Month	Moss			Lichen			Moss			Lichen		
	Isothermal days						Freeze–thaw days					
	10 cm	30 cm	80 cm	10 cm	30 cm	80 cm	10 cm	30 cm	80 cm	10 cm	30 cm	80 cm
apr/09	23	25	26	1	15	29	0	0	0	0	0	0
may/09	2	12	19	0	0	10	0	0	0	0	0	0
jun/09	0	0	0	0	0	0	0	0	0	0	0	0
jul/09	0	0	0	0	0	0	0	0	0	0	0	0
aug/09	0	0	0	0	0	0	0	0	0	0	0	0
sep/09	0	0	0	0	0	0	0	0	0	0	0	0
oct/09	0	0	0	0	0	0	0	0	0	0	0	0
nov/09	0	0	0	1	0	0	0	0	0	12	0	0
dec/09	13	4	5	2	4	0	0	1	0	11	0	0
jan/10	15	15	15	4	3	10	0	0	0	5	1	0
feb/10	27	27	28	10	14	25	0	0	0	7	0	0
mar/10	18	20	19	8	19	23	0	0	0	3	0	0
apr/10	9	8	15	2	23	28	1	0	0	11	0	0
may/10	10	20	22	4	0	0	0	0	0	3	0	0
jun/10	0	5	11	0	0	0	0	0	0	0	0	0
jul/10	0	0	0	0	0	0	0	0	0	0	0	0
aug/10	0	0	0	0	0	0	0	0	0	0	0	0
sep/10	0	0	0	0	0	0	0	0	0	0	0	0
oct/10	2	1	0	2	0	0	1	0	0	19	0	0
nov/10	5	6	6	0	8	0	0	0	1	11	0	0
dec/10	16	17	22	5	13	16	0	0	0	6	1	0
jan/11	0	0	0	0	0	0	0	0	0	2	0	0
Sum	140	160	188	39	99	141	2	1	1	90	2	0

Table 6. Thawing and freezing degree days of the studied sites at Lions Rump during a period of 22 months

Month	Moss			Lichen			Moss			Lichen		
	Thawing degree days (cumulative temp						Freezing degree days (cumulative temp					
	10 cm	30 cm	80 cm	10 cm	30 cm	80 cm	10 cm	30 cm	80 cm	10 cm	30 cm	80 cm
apr/09	18	9	7	0	10	17	-12	-21	-23	-30	-20	-13
may/09	0	0	0	0	0	0	-31	-31	-31	-31	-31	-31
jun/09	0	0	0	0	0	0	-30	-30	-30	-30	-30	-30
jul/09	0	0	0	0	0	0	-31	-31	-31	-31	-31	-31
aug/09	0	0	0	0	0	0	-31	-31	-31	-31	-31	-31
sep/09	0	0	0	0	0	0	-30	-30	-30	-30	-30	-30
oct/09	0	0	0	0	0	0	-31	-31	-31	-31	-31	-31
nov/09	0	0	0	13	0	0	-30	-30	-30	-17	-30	-30
dec/09	21	12	9	29	12	0	-10	-19	-22	-2	-19	-31
jan/10	31	31	31	30	31	6	0	0	0	-1	0	-25
feb/10	28	28	28	24	28	28	0	0	0	-4	0	0
mar/10	27	31	28	16	28	31	-4	0	-3	-15	-2	0
apr/10	16	0	0	13	21	23	-14	-12	-12	-17	-9	-7
may/10	0	0	0	0	0	0	-31	-31	-31	-30	-30	-30
jun/10	0	0	0	0	0	0	-30	-30	-30	-30	-30	-30
jul/10	0	0	0	0	0	0	-31	-31	-31	-31	-31	-31
aug/10	0	0	0	0	0	0	-31	-31	-31	-31	-31	-31
sep/10	0	0	0	0	0	0	-30	-30	-30	-30	-30	-30
oct/10	4	0	0	13	0	0	-27	-31	-31	-18	-31	-31
nov/10	30	30	27	30	20	0	0	0	-3	0	-10	-30
dec/10	30	30	30	26	31	8	-1	-1	0	-5	0	-13
jan/11	31	31	31	31	31	31	0	0	0	0	0	0
Sum	236	202	191	225	212	144	-435	-451	-461	-445	-457	-516

The Moss site ATD presented large positive and negative variations from December to April with drastic fluctuations of soil temperature and water content and small variations during May and June (Figure 3C). Due to the site location (water-track) is highly susceptible to moisture variations during summer and spring time.

The ATD values are low and positive during late autumn. Cooler autumn temperatures result in a near-isothermal condition of the soil with little heat transport and almost no variability of ATD (Hinkel et al., 2012). The dense carpet formed by moss vegetation work well as an isolator during the late autumn and snow during the winter, preventing energy flux, so the mean ATD during winter (21 June to 23 September) was positive at 30 cm ($1.7 \times 10^{-06} \text{ m}^2 \text{ s}^{-1}$), but quite lower due to the retarding in heat flux promote by the moss carpet and then by snow blocking the freezing front. This value of ATD during the winter is similar to that

observed by Michel et al. (2012) at Fildes Peninsula in a site cover with 50 % of vegetation by mosses and lichens.

3.2. Lichen site

The highest soil temperature record on Lichen site was 13.66 °C and occurred on January 3rd 2011 (Table 3), while the highest mean daily air temperature was 7.34 °C, at the same date. The smoothing and delaying of the profile thermal regime is greatly enhanced with depth and the highest temperature did not exceed 1.33 °C at 80 cm. The water content is almost not variable ranging from around 10 % in the winter to 24 % in the summer (Figure 3B); therefore, lower than that found for Moss site. Mean annual temperatures of -1.13 °C, -1.29 °C and -1.30 °C were obtained for the increasing depths respectively at 10 cm, 30 cm, and 80 cm depth between the beginning of summer (December 21st) until late spring (December 20th). Positive temperatures occur at the depth of 80 cm, but the highest registered was 1.33 °C and mean monthly temperatures is close to 0.0 °C, indicating that even during summer it remained close to freezing. The ALT estimated was 120.22 cm. The soil temperature under Lichen cover followed the variability of air temperature, with the upper layers being more variable (Figure 3). Despite the moss site present low temperature amplitude between the top and bottommost layer, at the lichen site the amplitude higher reaching a maximum positive amplitude of 12.33 °C on December 26th 2010 and negative maximum amplitude of -7.30 °C on July 6th 2010, which coincides with early summer and middle of the winter, respectively. This high amplitude is created due to high fluctuation on top layer whereas temperature followed straight the atmosphere climate and the subsurface layer be more buffered because the filling porous with air.

Negative temperatures at the upper layer start in the last week of March 2009 with the beginning of the thermal autumn whereas temperatures drop rapidly and remain frozen until middle November (Figure 3b). In 2010, the upper layer starts cooler at the end of March and still frozen from the end of October. It is important to know that a long zero curtain regime (> 40 days) happens only in the bottommost layer due to the highest water content and the proximity to permafrost, so in the last layer cooling process start at late March but frozen just in mid-May. In upper layers, temperatures change with air temperature, and no buffer effect (zero curtain regime) is verified in these frozen layers when cooling starts (Figure 3b). Guglielmin et al. (2008) also observed longer zero curtain regime in the bottommost layer than upper ones under *Usnea* cover in Signy Island.

The process of energy transfer from atmosphere to the first 10 cm of soil had a delay of just 10 hours (Figure 3) and was quite effective at deeper layers. Temperature reaches at 10 cm -17.22 °C and -9.05 at 80 cm with a delay of 30 hours.

Thawing started in mid-November in 2009 and late October in 2010 when the upper layer presented positive temperatures. The atmosphere heating starts in September and the soil temperature in upper layers increase exponentially following the air temperature. Despite the rapid thaw in the upper layer, temperature at 80 cm depth remains negative until mid-December, reaching a maximum of 1.33 °C in February of 2011, which can prove the more proximity to the permafrost table (120.22 cm). These results are similar to those found by Michel et al. (2012) in Potter Peninsula who found 0.1 °C at 90 cm depth and soil position at 70 m.a.s.l. with 60 % of soil cover by lichens.

The thawing days are concentrated in summer time varying from 128 days for the depth of 10 cm to 44 days at the depth of 80 cm (Table 4), because with lower water content in soil surface the energy dissipated in change water phase (solid to liquid) is less, so this layer got warmed easily.

Freezing days occur almost during the whole year, except summer, and are higher than the lichen site than moss carpet site. The same estimate increase to the deepest layer from 422 days in the upper layer to 483 days at 80 cm depth.

Mean ATD for the whole studied period was $3.5 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$ for 30 cm depth. Colder conditions resulted in low ATD variability. Mean ATD obtained in winter (from June 21st to September 23th) was positive ($6.6 \times 10^{-6} \text{ m}^2 \text{ s}^{-1}$). In the opposite to data observed for soil cover by mosses, ATD values of the lichen site present great positive oscillations from May to June, negative from August to November and late October to early December, and minor variations between March and April. Highest ATD values were observed in late autumn, when soil is dry and still uncovered by snow, so diffusivity of the freezing front is high. When begin the winter and soil surface is already covered by snow this transfer of cooling is reduced. During the winter, soil heat transfer is dominated by conduction when most of the soil water has been converted to ice. In the spring time when the snow starts to melt, infiltration of snow meltwater produces a thermal pulse in the active layer, and can significantly hasten soil warming (Hinkel et al. 1997, 2001) showing negatives values of ATD. During the summer due to the higher content of water the exchange heat is mainly by conduction as well.

3.3. Intersite variations

Both sites showed significant differences of the mean annual ground temperature for all depths (Table 3). Moss carpet presented higher water content all long the years with great increases during the summer (Figure 3). The soil temperature under Lichen cover closely followed the variability of air temperate. And moss carpet site showed higher soil moisture its location in an accumulation zone.

The soil from Lichen site exhibits higher number of thawing days for the surface layers (10 and 30 cm depths) and a lower number of thawing days with last depth, evidencing an insulating behavior compromising the energy transfer to deeper layers when compared with the soil from Moss site (Table 3).

Although thawing days beginning in both sites in December 2009, at Moss site warming reaches the deepest layer in the same month, while at Lichen site this occurs just in February 2010 and ending in March (Table 3).

Due to the translocation of water from the snowmelt to deeper layers the summer, heat exchange between air and soil layer is favored, then more heat flux is translocated to deeper layers. This process happens in a reduced scale at the Lichen site due to the lower water percolation and dryness favored thermic isolation as promoted by air filling soil pores. Owing to this phenomen at Moss site, deeper layers experiments highest temperature in summer (Table 3).

Owing to the late freezing during the winter and late thawing in the spring, the moss site has more isothermal days than lichen site. Isothermal days are higher than the moss site due to buffer effect cause by cover vegetation, and because landscape position (water track) promotes longer time of snow covering the surface during the winter and spring, which increase moisture in soil profile. The isothermal days are concentrated during the autumn and summer (Table 5) and the days with temperature close to 0°C has gradually increases in depth at moss site and been higher in all layers than lichen site, where exhibit abruptly increases of isothermal days in depth. Guglielmin et al. (2008) also observed isothermal days for Moss site than Usnea site at Signy Island and also concentrated between April to October.

In general, freezing-thawing does not occur in the deepest layer at both sites, but it is much higher in lichen ground surface, what can indicate the buffer effect of the moss cover, not been verified temperature fluctuation following atmosphere as occur within the lichen area.

The freeze–thaw days completely disappear at deeper layers in both sites, indicating that diurnal fluctuations are smoothed. The freeze–thaw cycles at this depth are also strongly reduced because during spring and fall (the periods in which air temperature more frequently crossed the 0 °C threshold) far more heat will have been consumed in the water phase changes causing the temperature fluctuations to be smoothed (Guglielmin et al., 2008).

Estimated active layer is deeper at Moss (147.26 cm) than Lichen (120.22 cm) sites due to lower thermal conductivity in Lichen soil because it is a drier soil. Both boreholes did not reach the permafrost table. Similar to that observed by Kane et al. (2001) studying soils in Alaska, in Lions Rump the average depth of thaw is greater in vicinity of water tracks (Moss site) than in inter-water track areas (Lichen site). In water track areas, the soil remains saturated beyond the summer season; thus, it has an enhanced thermal conductivity compared to inter track areas. This enhanced thermal conductivity effectively supplies a warm boundary condition for the upper surface to the mineral soil layer, thereby producing enhanced thaw in these locations (Kane et al., 2001).

Typic Haploturbels evaluated during this study are present just above 80 m.a.s.l., especially on the top areas and paraglacial spots, and represent Gelisols with gelic materials within 100 cm of the soil surface and permafrost within 200 cm of the soil surface; therefore, in lowlands at Lions Rump no Gelisols occur. Ramos and Vieira (2003) observed permafrost starting deeper than 2.3 m in Livingston Island monitoring a borehole at 35 m.a.s.l.

In general, active layer is typically greater than 90 cm for Maritime Antarctica areas as exposed by Vieira et al. (2010) considering others monitored boreholes in the South Shetlands.

Period where the soil profile has some liquid water available is during the thawing isothermal days (Thorn et al., 2002), so the sum of these periods can indicate when the chemical weathering process may occur. Following this reasoning these thermal conditions were more favourable for chemical weathering in the moss site than in the lichen site for all soil layers.

An interesting event occurred at early autumn where the zero curtain regime is longer at 80 cm at Moss than Lichen, but in the process of soil heating the change of phases solid to liquid (ice to liquid water) is longer at Lichen, probably due to soil profile be skeletal with low water content, and air fill up the soil porous difficulting heat change.

Michel et al. (2012) observed soil texture as major influence on soil energy flux for soils with different texture but similar vegetation cover in Potter and Fields Peninsula. They considered coarse nature of the soil seems to have a considerable influence on energy flux,

contributing to permafrost preservation. So the air filling the pores reduces the energy flux similar to results observed at Lichen site.

When studied different sites with dissimilar vegetation cover Cannone et al. (2006) related unlike buffer effect of the different vegetations, occurs influence of vegetation on snow distribution, thickness and longevity and that snow cover is thinner and melts earlier over the *Usnea* and *Deschampsia* sites than the *Sanionia* site.

Temperature drops and increases more rapidly at Lichen site, but after the zero curtain regime at Moss site the temperature changes in a linear curve, while at Lichen site the changes are in harmonic waves (Figure 3).

Data from N-factor (FN) graphic (Figure 4) indicated differences of station freezing duration in the two years monitored. In 2009, the process began in late March and ended in December, while in 2010, began only in mid-April and ended in late October. In 2009, freezing time are similar at both sites starting at Lichen one month ahead but ending as well one month early. In 2009, the winter was more intense with lower temperatures so at Lichen site, the driest soil, the freezing station starting early. In 2010, cold was less intense and oscillation of temperatures above 0°C occur, them FN station started late. The isolation promoted by snow is more efficient in the beginning of winter decreasing along the cold season, and it seems may be associated with metamorphism of snow crystals and their compaction and loss of interstitial air during the winter (Nieuwendam, 2009). In this regard, it is interesting that in 2009 the values of FN in late winter stabilized around 0.3 at Moss site and 0.8 in the Lichen site, while in 2010 the stabilization occurred in 0.5 and 1.0, respectively. Lower values of FN indicate better isolation promoted by the snow cover and reduced heat exchange between air and soil. Lower values at 2010 occurred possible by the greater thickness of snow cover in 2010 compared to 2009. Owing to the Moss site position on the landscape (water track), the height of snow cover was higher than at Lichen site whereas is more susceptible to winter remove. Results of FN were lower in Moss site within two years studied (Figure 4), reinforcing a greater influence of snow cover at this site by buffering temperature near 0 ° C for longer, due to its poor heat conduction. This is a useful parameter because of its simplicity and potential to determine the relationship between the physical conditions at the soil surface and atmospheric (Karunaratne e Burn, 2003).

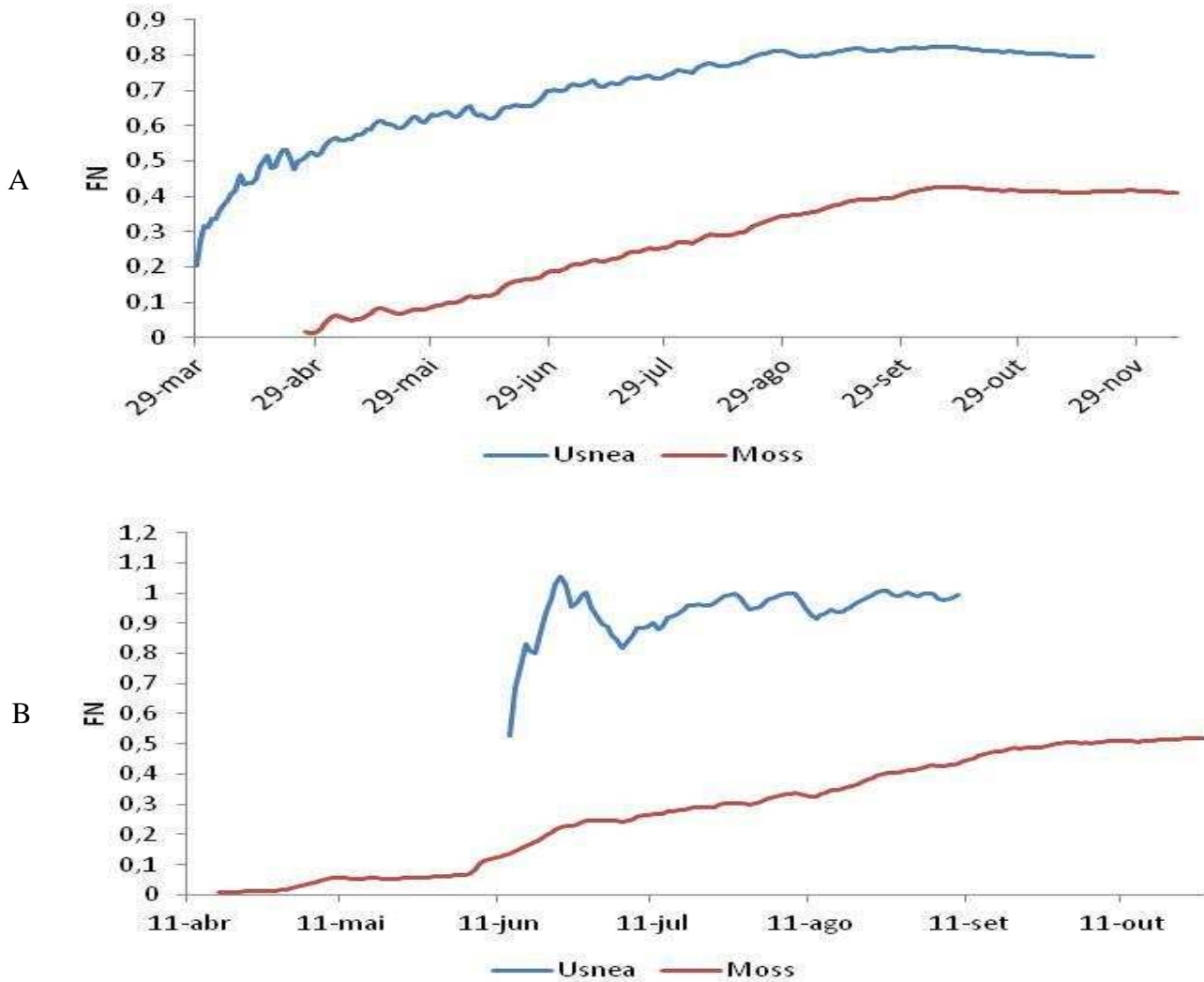


Figure 4. N-Factor Calculation for sites Lichen and Moss at Lions Rump for years 2009 (A) and 2010 (B). It was used soil temperature at 10 cm to be closer to the soil surface.

Multivariate regression considering the temperature of the deepest layer as dependent on air and the other layer's temperatures generated good equation estimatives for each site (Table 7). It adjusted R-squared was superior to 0.91 for both sites and standard errors for the beta coefficients were in an acceptable range. The equations help us understand the joint linear effect on the set of independent variables (beta coefficients) in predicting temperature of the bottom (80 cm) of the profile (dependent variable). As expected both sites were more influenced by the subsequent horizon (30 cm), presenting similar betas; and the contribution of air and uppermost soil temperatures (10 cm) was small, due to the time lag in temperature changes (Figure 3A and 3B). These should be interpreted with care because the upper sensor

does not reflect the actual soil surface temperature and the air temperature from distant weather stations may not reflect the exact air temperature at the studied sites.

All beta coefficients were statistically significant. The equation proposed for Moss overestimates temperature peaks in summer and the predicted values diverged from observed ones by a maximum of 7.97, a minimum of -1.57, and an average of 0.14 but during the winter the temperatures are too close (Figure 6). This overestimated temperature in Moss site during summer can occur due to high-water content present, then it is necessary more heat exchange to change soil temperature because the high-water latent heat. In Lichen site, the soil is drier and the values estimated from the equations were close to those registered with the sensors with uniform behavior throughout the studied period. Residues ranged from a maximum of 2.80 to a minimum of -3.11 with an average of 0.18 (Figure 6). Observed values at Moss are more concentrated between -4 to 4 °C and Lichen between -10 to 3 °C, what can prove the more influence of air temperatures to promote changes in bottommost layers, what is buffered at Moss site due to the long lasting time of snow cover; the isolation promoted by the moss carpet and the highest water content.

Table 7. Multivariate regression for estimative of deepest layer temperature as dependent of air and others layers temperature (N = 16778, hourly data, alpha = 5%, p<0.000000 for both sites significant for all betas values)

Site	Equation	Adjusted R ²	Standart error of beta values
Usnea	$T_{soil80cm} = 0.010328 \times T_{air} - 0.293544 \times T_{soil10cm} + 1.106034 \times T_{soil30cm}$	0.9118	Tair (0,0017); Tsoil10cm (0,0036); Tsoil30cm(0,0038)
Moss	$T_{soil80cm} = 0.007493 \times T_{air} - 0.377956 \times T_{soil10cm} + 1.243124 \times T_{soil30cm}$	0.9377	Tair (0,0007); Tsoil10cm (0,0042); Tsoil30cm(0,0049)

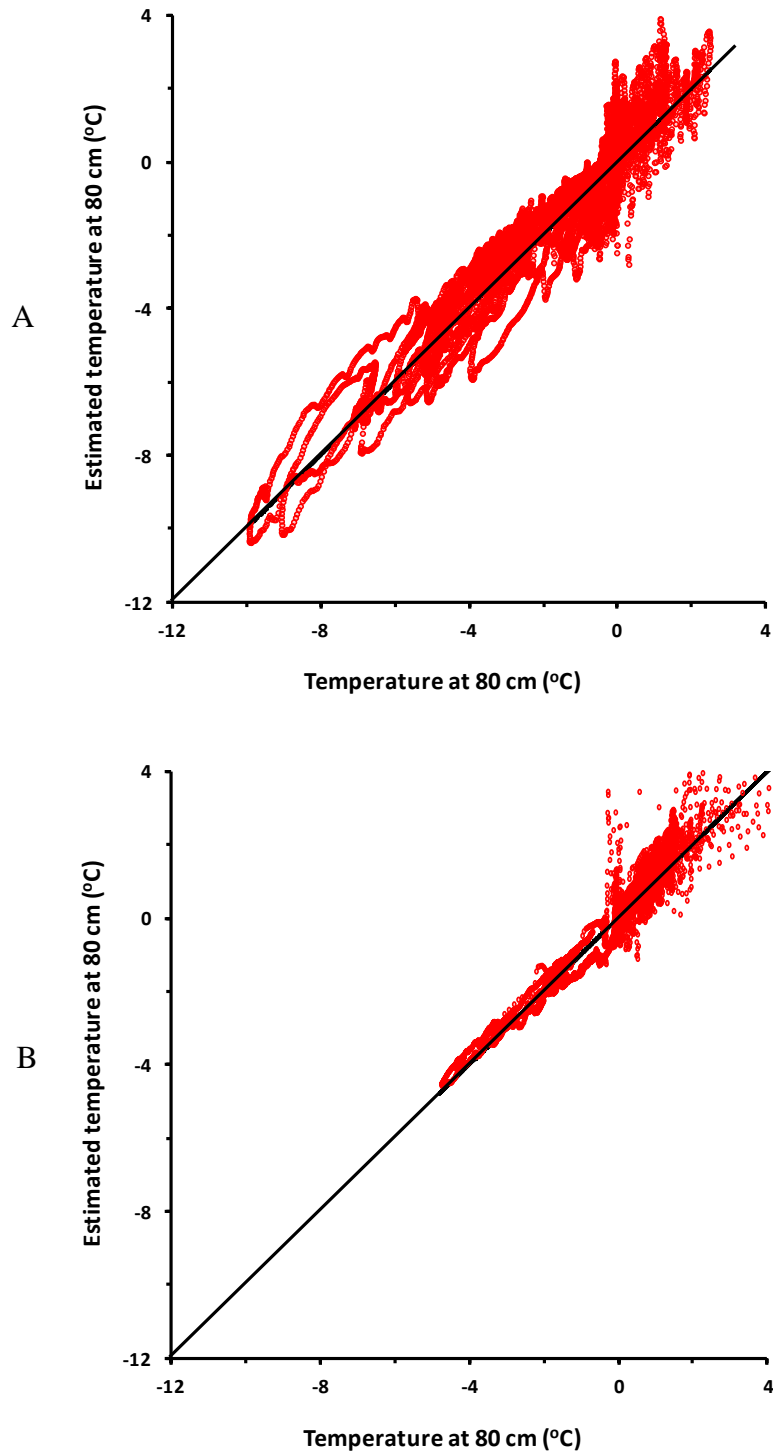


Figure 5. Comparison on measured on-site soil temperature at 80 cm depth with that estimated from air and 10 and 30 cm depth temperatures at Lions Rump between April 2009 and January 2011 for A) Lichen site B) Moss site.

4. Conclusions

The active layer thermal regime in the two soils studied at Lions Rump, Maritime Antarctica, is typical of periglacial environments, with major variation close to the surface during summer resulting in frequent freeze and thaw cycles. The great majorities of the soil temperature readings for both sites were close to 0 °C resulting in low freezing and thawing degree days. Both soils have low thermal apparent diffusivity.

The temperature profile of the soils during the studied period indicates that the active layer thickness was approximately 150 cm at Moss site and 120 cm at Lichen site. This indicates that the permafrost table was not deeper than 200 cm from the surface, corroborating with the classification of these soils as Cryosols or Gelisols, with clear turbic features.

The difference in moisture regimes for the studied sites was attributed to the soil vegetation cover and principal by site location on the landscape.

The temperature buffer effect of mosses appears to be associated with snow cover and especially by local higher water content.

For better understanding of how works the hydrothermal dynamic of permafrost affect-soils it is necessary installation of humid probes along the soil layers together with soil temperature sensors.

Data presented are obtained from less than two years of monitoring, which limits conclusive interpretations in terms of warming or cooling trends, permafrost distribution and effects of climate change on the studied soils. Nevertheless, as part of a long term active layer monitoring program, these results are important as a benchmark for future interpretations.

5. References

- Burgess, M., Smith, S.L., Brown, J., Romanovsky, V. & Hinkel, K. 2000. Global Terrestrial Network for Permafrost (GTN-P): permafrost monitoring contributing to global climate observations. Current Research 2000-E14. Geological Survey of Canada, 1-8.
- Brown, J., Hinkel, K., Nelson, F.E., 2000. The circumpolar active layer monitoring (CALM) program: research designs and initial results. Polar Geography 24, 165–258.
- Cannone, N., Ellis Evans, J.C., Strachan, R., Guglielmin, M., 2006. Interactions between climate, vegetation and the active layer in soils at two Maritime Antarctic sites. Antarctic Science 18, 323–333.
- Guglielmin, M., Evans, C.J.E., Cannone, N., 2008. Active layer thermal regime under different vegetation conditions in permafrost areas. A case study at Signy Island (Maritime Antarctica). Geoderma 144, 73–85.

- Guglielmin, M., Evans, E.J.C., Cannone, N., 2005. Interactions between climate, vegetation and active layer in Maritime and Continental Antarctica for climate change monitoring. *Terra Antarctica Report* 11, 15–27.
- Hinkel, K.M., Outcalt, S.I., Nelson, F.E., 1990. Temperature variation and apparent thermal diffusivity in the refreezing active layer, Toolik Lake, Alaska. *Permafrost and Periglacial Processes* 14, 265–274.
- Hinkel, K.M., Outcalt, S.I., Taylor, A.E., 1999. Seasonal patterns of coupled flow in the active layer at three sites in northwest North America. *Canadian Journal of Earth Sciences* 34, 667–678.
- Hinkel, K.M., Paetzold, F., Nelson, F.E., Bockheim, J.G., 2001. Patterns of soil temperature and moisture in the active layer and upper permafrost at Barrow, Alaska: 1993–1999. *Global and Planetary Change* 29, 293–309.
- Judge, A., 1973. The prediction of Permafrost Thicknesses. *Canadian Geotechnical Journal*, 10, 1.
- Kane, D.L., Hinkel, K.M., Goering, D.J., Hinzman, L.D., Outcalt, S.I., 2001. Non-conductive heat transfer associated with frozen soils. *Global and Planetary Change* 29, 275–292.
- Karunaratne, K.; Burn, C. Freezing n-factors in discontinuous permafrost terrain, Takhini River, Yukon Territory, Canada. 8th International Conference on Permafrost. Zurich: University of Zurich-Irchel, 2003, p. 519-524.
- McGaw, R.W., Outcalt, S.I., Ng, E., 1978. Thermal properties and regime of wet tundra soils at Barrow, Alaska. Third International Conference on Permafrost. National Research Council of Canada, Ottawa, pp. 47–53.
- Michel, R.F.M., Schaefer, C.E.G.R., Poelking, E.L., Simas, F.N.B., Fernandes Filho, E.I., Bockheim, J.G., 2012. Active layer temperature in two Cryosols from King George Island, Maritime Antarctica. *Geomorphology* 155–156, 12–19.
- Nelson, F.E., Outcalt, S.I., Goodwin, C.W., Hinkel, K.M., 1985. Diurnal thermal regime in a peat-covered tundra, Toolik Lake, Alaska. *Arctic* 38, 310–315.
- Nieuwendam, A.T., 2009. Aspectos do regime térmico do solo da Península de Hurd (Ilha Livingston, Antártida). Lisboa: UL. Dissertação (Mestrado em Geografia) – Universidade de Lisboa.
- Outcalt, S.I., Hinkel, K.M., 1989. Night frost modulation of near-surface soil–water ion concentration and thermal fields. *Physical Geography* 10, 336–346.
- Ramos, M., Vieira, G., 2003. Active layer and permafrost monitoring in Livingston Island, Antarctic. First results from 2000 to 2001. In: Phillips, M., Springman, S.M., Arenson, L. (Eds.), *Proceedings of the 8th International Conference on Permafrost*. Balkema, Lisse, Zurich, pp. 929–933.
- Riseborough D., 2003. Thawing and freezing indices in the active layer. *Proceedings of the 8th International Conference on Permafrost*: 953–958.
- Romanovsky, V.E., Osterkamp, T.E., 2000. Effects of unfrozen water on heat and mass transport processes in the active layer and permafrost. *Permafrost and Periglacial Processes* 11, 219–239.
- Statsoft, 2009. *Statistica for Windows*. Release 9. Statsoft, Inc. Tulsa, OK.

- Schaefer, C.E.G.R., Simas, F.N.B., Albuquerque-Filho, M.R., Michel, R.F.M., Viana, J.H.M., Tatur, A., 2004. Fosfatização: Processo de formação de solos na Baía do Almirantado e implicações ambientais. In: Schaefer, C.E.G.R., Francelino, M.R., Simas, F.N.B., Albuquerque Filho, M.R. (Eds.), *Ecosistemas Costeiros e Monitoramento Ambiental da Antártica Marítima, Baía do Almirantado, Ilha Rei George*. NEPUT – Departamento de Solos, Viçosa, Brasil, pp. 47–59.
- Vieira, G., Bockheim, J., Guglielmin, M., Balks, M., Abramov, A.A., Boelhouwers, J., Cannone, N., Ganzert, L., Gilichinsky, D.A., Goryachkin, S., López-Martínez, J., Meiklejohn, I., Raffi, R., Ramos, M., Schaefer, C.E.G.R., Serrano, E., Simas, F.N.B., Sletten, R., Wagner, D., 2010. Thermal state of permafrost and active-layer monitoring in the Antarctic: advances during the international polar year 2007–2009. *Permafrost and Periglacial Processes* 21, 1–16 369 pp.
- Thorn, C.E., Darmody, R.G., Allen, C.E., Dixon, J.C., 2002. Near-surface ground temperature regime variability in selected microenvironments, Kärkevage, Swedish Lapland. *Gografiska Annaler* 84A, 289–300.

CONCLUSÕES GERAIS

Solos de Lions Rump, Ilha Rei George, Antártica Marítima são formados principalmente a partir do intemperismo de rochas basalto-andesíticas. No geral, a distribuição dos solos e classificação em Rump Lions é formada por dois domínios principais: solos Ornithogênicos largamente distribuídos nos terrenos localizados nas porções mais baixas da área (ausentes de permafrost nos 200 cm superficiais do solo) e os Gelisolos (localizado em acima de 80 m de altitude acima do nível do mar). Typic Dystrogelepts ornithic e Typic Gelorthents ornithic são os principais solos ornitogênicos e mais evoluídos do que Gelisolos. Gelisolos são crioturbados e representados principalmente pelos Typic Haploturbels e Lithic Haploturbels, que estão presentes, especialmente em áreas de topo e manchas paraglacial, com materiais gelíco dentro de 100 cm e permafrost dentro de 200 cm da superfície do solo.

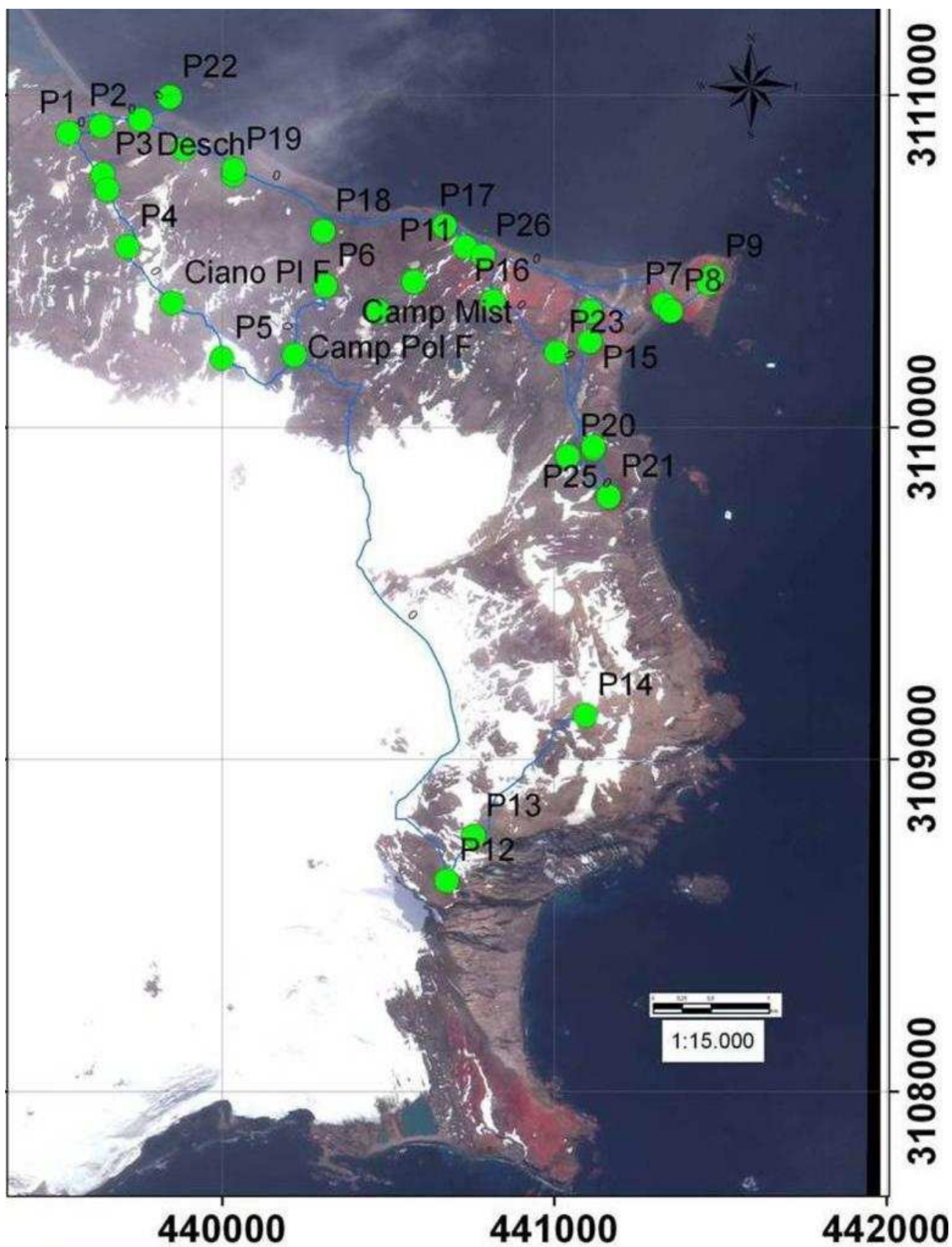
A microestrutura dos Gelisolos é típica de solos afetados por congelamento, e os ornitogênicos possuem um tipo particular de estrutura globular, agregados arredondados, sobre forte influência biológica. A fosfatização é o principal processo de formação do solo nos solos ácidos ornitogênicos e a utilização de técnicas de microquímica provou serem úteis para uma melhor compreensão da pedogênese nesses solos antárticos poucos conhecidos.

A respeito da distribuição das coberturas vegetais, a presença de *Prasiola* está associada com sua proximidade à colônia de pinguins. Este tipo de alga ocorre em solos ricos em N. Líquens são comuns em rochas ou fragmentos de rochas em todas as ordens de solo. Musgos são encontrados principalmente em áreas úmidas formando tapetes ou formando almofada em outros solos de melhor drenagem. Plantas superiores estão representando apenas por *Deschampsia antarctica* e *Colobanthus quitensis*, que ocorrem principalmente em feições geológicas Quaternárias, com densa cobertura em terraços soerguidos, praias e morainas.

O regime térmico da camada ativa nos dois sítos (musgos e líquens) monitorados em Lions Rump é típico de ambientes periglaciais, com variação próxima à superfície durante o inverno e o verão, resultando em frequentes ciclos de congelamento e descongelamento do solo. Registro de dados da temperatura do solo de ambos os locais mostram temperaturas médias próximas de zero grau Celsius, mas com o domínio de dias de congelamento. Ambas as áreas apresentaram baixa difusividade térmica aparente. No sítio de monitoramento sob musgos as temperaturas mostraram menores amplitudes de variações quando comparadas ao solo sob líquen, o que foi atribuído ao efeito tampão promovido pela própria cobertura de

musgos em forma de tapete, pelo elevado teor de água e pela mais espessa e duradoura cobertura de neve.

APÊNDICE



Mapa da area, pontos dos perfis amostrados e trajetos percorridos.