A Preliminary Geochemical study of Upper Cenozoic clastic sediments (Ituzaingó, Pampeano and Post-Pampeano Formations). Northeastern region of Argentina and neighbouring areas

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Resumo

O presente trabalho trata um estudo geoquimico preliminar feito nos sedimentos silicoclásticos que correspondem a uma seqüência litoral superficial marinha de idade Mioceno Médio-Superior, e nos sedimentos horizontais e concordantes suprajacentes, parcialmente inconsolidados, granulométricamente do tipo areio-argiloso, embora também muito limoso (grosso e delgado) desemvolvidos a partir das mencionadas capas marinhas, em especial as fácies argilosas e limo-argilosa (mudrocks beds) como uma capa do tipo "mantle-rock bed ou in situ loess formation".

As capas dos sedimentos inconsolidados que suprajacentes em concordância estrutural da seqüência silicoclástica litoral superficial marinha surziram a partir dum processo de regolitização in situ, sem transportação dos grânulos dos sedimentos pegando como panorama um contexto regional. Eventualmente, em alguns setores reduzidos poderia ter existido uma limitado erosão do tipo exclusivamente "local".

Não devem se incluir neste trabalho as "dunas ou médanos cavalgantes" atuais de areia muito fina comuns em alguns setores do Sul das

"Pampas Argentinas" posto que não têm vinculação com o estudo que se apresenta e só representa uns poucos elementos de desertificação temporais, atuais e sem relação geológica com o nosso estudo.

A idade geológica dos processos de formação das unidades involucras correspondem ao Mioceno Médio-Superior nas seqüências litoral superficial marinha e ao Pleistoceno e Holoceno nas capas de sedimentos limo-argilo-arenoso inconsolidados e regolitizados.

Em geral, essas capas sem consolidação muito limosas se conhecem na Argentina como Formação Pampeana (Pleistoceno) e Formação Pós-Pampeana (Holoceno), mas sua continuidade física se estende até as Repúblicas de Paraguay e Bolívia com ligeiras variações especialmente na colorações, devido ao efeito dos distintos tipos de regimes climáticos que mudam a tonalidade dos oxidos de ferro presentes nestos sedimentos. A cor mais comum é o castanho claro ao medio.

A seqüência litoral superficial marinha constitui uma típica sucessão heterolítica depositada nas planícies de maré ou marís (tidal flat environment). A seqüência constitui a Formação Ituzaingó aflorando na Mesopotamia Argentina, no subsolo da Planície Chaco-Pampeana, na República Oriental do Uruguay (setor sul-oeste) e República de Paraguay (também sul-oeste). A mesma apresenta numerosas estruturas internas do tipo bidirecional e diagnósticas (tidal bundles sets, herrigbone cross-stratification, herringbone cross-beddings, flaser beddings sets, tidal laminae stratification sets). Alem disso, apresenta restos fragmentários de icnofacies de Glossifungites, Skolithos e Zoophycos, todos eles muito resistentes aos ambientes de energia alta como aqueles ambientes costeiros dominados pela ação de maré, agitação das ondas do mar e do furação marinho.

Os métodos utilizados neste trabalho foram reconhecimento de campo de afloramentos, realização de perfís de detalhe, sondagem dos terrenos de exploração, visita e estudo dos cortes artificiais feitos para obras de engenheria civil na planície, estudo de detalhe de todos os registros de perfurações da região, tanto profundos como superficiais. Em todos os afloramentos se colectaram exemplares. Foram colectados para o estudo geoquimico 50 amostras dos sedimentos correpondientes a seqüência litoral superficial marinha (Formação Ituzaingó) e das capas pertencentes ao manto regolitizado (Formação Pampeana e Pós-Pampeana).

Também o estudo contou com o apoio do processamento digital das imágens do satélite. Para este fim, utilizou-se imagens de satélite Landsat TM 5, Landsat ETM+ 7 e imagens SAC-C (sensor MMRS). Com os dados processados destas imagens (compocições 4/5/3 e 3/4/5) se fixaram os limites das faixas de isolitologia, especialmente fundamentada nos diferentes tipos de cor de vegetais. Isto foi de grande ajuda na etapa de extrapolação de alguns resultados, os que posteriormente foram verificados na campanha nos sítios de exploração.

Os resultados da pesquisa exibem, sem dúvida, uma igualdade em todos os valores analisados, tanto dos elementos maiores (moleculas principais) e elementos traço, entre a seqüência litoral marinha superficial (Formação Ituzaingó) e as capas de sedimentos inconsolidados e regolitizados da Formação Pampeana e Pós-Pampeana em todos os afloramentos que foram estudados.

Por tanto, pode-se interpretar que a seqüência litoral marinha superficial constitui a rocha mãe, parental, ou reserva (in situ) da Formação Pampeana e Pós-Pampeana na oposição as teorias que interpretam a Formação Pampeana e Pós Pampeana como predominantemente de origem eólica ainda que seu rocha de reserva nunca foi precisado com certeza por quem sustenta esta hipótese.

Se observou uma ligeira dispersão nos sedimentos inconsolidados devido principalmente aos processos de erosão e meteorização (iluviação, edafização, regolitização, acção da biota) que resulta ser lógico, já que o meio aquoso, agente predominante na formação e evolução destes sedimentos, dirige a certa interferência ou ruido geológico. Além disso, a semelhança no modelo das curvas de elementos traços é sempre igual para as duas entidades litológicas.

Este estudo permite afirmar, com datos reais, objetivos, certos e mensurável, que a geoquimica pode desempenhar um papel de importância na ajuda dos estudos de estratigrafia local ou regional e colaborar desse jeito a resolver muitos problemas e grandes dúvidas de longa data.

Esta metodologia deveria ser sempre considerada como ferramenta de primeira mão em situações nas quais os estudos clássicos de análise faciológica não resultam completamente concludente na análise e conclusão do origem dos distintos corpos ou unidades geológicas involúcras. Porém, a geoquimica não deveria ficar reservada só para estudos de prospecção ou explotação geologica de natureza economica.

Summary

The present paper deals with a regional geochemical study. It was performed over siliciclastic sediments belonging to a littoral shallow marine sequence and the overlaying regolithic mantle-rock beds. The sequence belongs to Middle-to-Late Miocene age. We employed samples collected from sediment beds belonging to this marine sequence as well as those sediments beds that overlain the littoral siliciclastic sequence. This overlaying sediment beds are horizontal, conformable and fairly consolidated. Texturally, they are constituted by a silty-muddy-sandy (very fine) facies. This overlaying sediment beds are derived (in situ) from the littoral siliciclastic sequence, specially from the muddy facies beds and the silty-muddy (mudrocks) facies beds. So, they constitute a typical "mantle-rock bed or in situ loess formation".

The overlaying silty-muddy facies beds lie in structural geometrical concordance over the littoral shallow marine siliciclastic sequence. These beds were originated by in situ regolitization processes. This is proposed in a regional contextual panoramic vision. Eventually, may have occured some insignificant processes of re-transportation and/or re-sedimentation but these phenomena were completelly of "restricted" (local) character. The southernmost active very fine and well calibrated quartz arenite dunes ("médanos cabalgantes or médanos invasores") present at the Argentinian South Pampas are excluded from this paper. They are actual phenomena originated by unsignificant desertification processes at geological time scale and regional context.

The geological age of the involved processes that gave origin to the

lithosomes we treat here are: Middle to Late Miocene for the littoral shallow marine siliciclastic sequence beds. The well regolitized silty-muddy-very fine sand facies beds evolved during Late Pleistocene to Holocene age, without re-sedimentation in a regional context.

The regolithic silty-muddy-very-fine-sandy facies beds are known in the Argentina as Pampeano Formation (Middle-to-Late Pleistocene) and Post-Pampeano Formation (Holocene). It is surprising that the physical continuity of this regolithic facies beds are extended all along the "Pampas Argentina", Paraguay and Bolivia sectors. In these cases, they present some little tonal variation which is due to different climatic conditions. The pluvial water acted over all the potential oxidation ferruginous grains as well as many mixed argilaceous fractions. At the "Argentina Pampas", the common tone of beds is clear-brown. To the northward areas, they change to reddish-dark-brown tone beds.

The "littoral shallow marine sequence" constitute a typical heterolithic succession deposited in a "tidal flat-to-very flat plain environment". This sequence properly constitute the well known Ituzaingó Formation quartz arenite. The Formation outcrops at the Mesopotamia of Argentina, the south-west of República of Paraguay, the east of Bolivia near ridges (into recent gullies) and the south-west of República Oriental del Uruguay. It lies in the underground of the Chaco-Pampeana plains. The Ituzaingó Formation beds carry numerous bidirectional diagnostic structures. Moreover, this units give a sort of fragmentary parts of Glossifungites, Skolithos and Zoophycos icnofacies. These icnofacies are resistent to high energy environments. This may be the case of a littoral coast tide-dominated plain, evolving under the active action of tides, waves and strong marine hurricanes.

The methodologies employed in this work were: outcrops field recognitions, several detailed sedimentologic cross-sections (profiles) carried out at the outcropping beds, exploration wells, study of artificial exposures digged for engineering projects, log drill-core registers studies all along the entire region either surficial or deep. We collected samples at the outcrops. We have got 28 selected samples for geochemical analysis, both at the littoral shallow marine siliciclastic sequence beds (Ituzaingó Formation) and the regolithic overlaying beds (Pampeano and Post-Pampeano Formations).

Also, we employed digital image processing related to satellitary scenes. In this case we used Landsat TM 5, Landsat ETM+ 7 and SAC-C (MMRS sensor) images. Once the scenes are processed (4/5/3 and 3/4/5 compositions), we can outline isolithologies sectors. For mapping, we paid special attention to different types of vegetation cobertures. Extrapolation of these results help us in comprehension geological units distribution within the study region. Many of these results were lately check out into several training sites.

The geochemical results show a significant equality, both major elements and trace elements, between the Ituzaingó Formation beds and the overlaying horizontal conformable soft-friable regolithic beds (Pampeano and Post-Pampeano Formations).

The interpretation is simple and consistent. The littoral shallow marine sequence constitutes the mother rock, the parental rock or the reservoir (in situ) of the Pampeano and Post-Pampeano Formations. This is in opposition to previous theories that interpreted Pampeano and Post-Pampeano Formations as derived from an immense aeolian sea sand processes scenary occured on the Pleistocene-Holocene time. It was never presented a logical explanation for the quartz grain sediment beds reservoir ubication (the mother rock).

By means of the geochemical study, we can detect somewhat dispersion into the regolithic mantle-rock beds. This phenomenon was caused by weathering processes (iluviation, edaphization, regolitization, lixiviation, biotic action). This result seems logic because the aquous phase was the dominant agent of washing and dispersion. It was the main agent that conducted to produce interference and/or geologic noise. However, the equality between the curve model values, both major elements or trace elements, is always the same.

This study let us to ensure that geochemical data which is real, objective, true and measurables may play an important role in regional or local stratigraphy analyses. So, these studies could certainly contribute to solve many controversial stratigraphical unresolved long time ago problems.

This method must be considered as a significative tool when the classic facial analysis and arquitecture geometry analysis doesn't give us definitive solutions in relation to sedimentologic-environment studies. For this reason, the geochemistry must be used, if possible, in stratigraphical studies and not solely employed for economic geology.

Palavras chave: geoquimica, Formaçãos Ituzaingó, Pampeana é Pos-Pampeana, Noreste de Argentina, região imediatos

Key words: Geochemistry, Ituzaingó, Pampeano and Post-Pampeano Formations, Northeastern of Argentina, neighbouring countries

Introduction

This paper is focused on a regional geochemical study and comparison between an heterolithic sandy-muddy siliciclastic horizontal succession beds belonging to a littoral shallow marine facies environment (predominantly tidal flat plains) and the overlaying slightly modified silty regolithic conformable horizontal soft friable beds named as Pampeano and Post-Pampeano Formations (AMEGUINO, 1881, CORTELEZZI & LERMAN, 1969, FRENGUELLI, 1945, 1950, 1955). The overlay beds have the same textural, granulometrical and compositional characteristics in relation to the littoral siliciclastic succession. The regolithic mantle-rock never preserve typical primary (internal) syndepositational structures which are the most outstanding diagnostic element present into the littoral shallow marine sandy-muddy facies sequence (e.g. tidal bundles sets, herringbone cross-beddings, herringbone cross-stratification, flasser beddings sets, tidal laminae stratification sets) (TORRA, 1998abc, 2001a).

Nevertheless, these lithologic lithosomes, the littoral siliciclastic heterolithic succession with internal structures and the unbearing massive regolithic mantle-rocks or in situ loess formation (PYE, 1995) are always conformable and lies in clear transition. The geological contactcs between the overlaying sandy-silty-muddy regolithic bed-rock and the infralaying littoral siliciclastic shallow marine succession is fairly diffused and never ocurred as an abrupt line change between the different facies, either in outcrops as well as drill-core log registers. The outcropping regolithic mantle-rock bed thickness ranges about 1 to 15 m (TORRA, 2001a, 2003b).

The studied area is located at the northeastern region of Argentina although others neighbouring regions were taken in consideration (Figure 1). From the morphogeological and tectonical point of view, they seem to correspond to the Chaco-Pampeana and Paranense basins, whose accurate outline are still unperfectly defined (TORRA, 1998b, 2001b). These basins constitute a great part of a typical extensional simetrical rift system assemblage which is continually developing from Upper Cretaceous-Early Tertiary age until present days (TORRA, in prep.).

Controversy persists on the environmental origin of the heterolithic littoral shallow marine siliciclastic sandy-muddy horizontal facies beds sequence. In this paper, I'll specifically refer to the geochemical signatures that these two units present. That is raw major molecular elements and trace-elements values.

Some extrapolations can be performed between the siliciclastic heterolithic succession and the regolithic mantle-rock bed. This is so because the littoral shallow marine beds were deposited into the entire area considered herein (at least 700000 km^2). These beds are completely equal, either in composition, texture, arquitecture style and facial behaviouring. These classic techniques of investigation were applied and the obtained results show a considerable amount of similar evidences, got at the field work and laboratory routines as well as for an extremely rigurous log registers studied with detailed synthesis, all along the area (TORRA, 2001a). After the sedimentologic and regional environmental evidences, the conclusions pointed that heterolithic succession corresponds to littoral shallow marine-peritidal environment and the regolithic mantle-rock bed was simply derived from the sandy-muddy facies by an in situ regolitization process and/or processes. Its evolution probably begun in Pliocene persisting to present days. The processes that acted in situ were erosion, edaphization, weathering, iluviation, biotic agents and regolitization which destroyed and obliterated the internal syndepositational structures. Pervasive biotic agents and strong iluviation influence were hardly active last 8000 to 1000 B.P. There are no evidence of any kind for thinking (e.g. primary structures) that significative re-transportation grains can be properly proved in everywhere of the whole region (TORRA, 2000b, 2001ab, 2002, 2003b). For example, there aren't exists typical fluvial structures as reactivation surfaces, cut and fill deposits, characteristical fluvial artesas, conglomerates, etc.

In order to introduce another significative basic-geologic technique of investigation to understand contextual analysis and comparision, I present here the geochemical raw data got from more than 28 analyzed samples. They were picked out into the gullies and "barrancos" outcrops as well as some surficial exploration wells.

Methods

Field works as well as laboratory tasks were carried out along the study. Field works consisted of detailed profiles, specific sampling for geochemistry and field photographs. They were employed as a documental record. Study of the geometry and architectonic style were done, too.

The laboratory tasks were: selection of the collected samples for geochemical analyses. They were carried out at the National University of San Luis (Argentina) and ANGLOAMERICAN Laboratories, AARL, South Africa). The samples were discriminated among three categories as follows: sandy (fine to very fine, which constitute a typical quartz-arenite facies) (called SC facies); clay or mud (which is a current mud facies)(called PM facies) and a mixed facies constitute by sand and mud but with more than 50 in percentage of "coarse-to-fine quartz silt grains" (called SB facies or mudrock facies sensu lato) (see raw values at Tables 1, 2, 3, 4; TORRA, 2000b).

All geochemical analyses were done for in-dry x-ray fluorescense spectromestry (FXR). Boron analyses were conducted by inductively coupled plasma atomic emission spectroscopy (ICP-AES). It is not used samples' fussion in order to prevent tourmaline-boron (chorlite) contamination.

Another complementary technique employed was remote sensing. This study basically consisted in a digital analysis of Landsat TM 5 or Landsat

ETM+ 7 images and SAC-C (MMRS sensor) images at convenient scales (1:100000). The scenes were classified (supervised technique) in some representative and very well field known sectors (MAURO, et al., 1998, SABINS, 1997). The five main classes found were: temperate park plains (equal to intertropical sabanna), vigorous woods (called Monte Chaqueño), soils of predominantly silty material without important vegetate coberture (e.g. scarce scrub and grassland that developed on to mixed silty-clay facies, fairly weathered), low-flat topographic depressions with high values in moisture, urban anthropogenic activities and masses of water (lake, lagoon and wetlands). The analyzed Landsat images were path-row 226-80,79,78; 227-80,79,78. The analized SAC-C images cover the east, south and central region of South America. They were: 224/000, 225/000, 226/000 and 227/000 paths. We always used the 4/5/3 compositions, enhanced with same routinary algorithmical functions (SABINS, 1997, TORRA, 2003a).

The majority registers of wells drilled at the region were studied with rigorous detail in order to define facies bed contacts. Two few depths exploration holes were carried out and the encountered facies were sampled. The samples corresponds to the regolithic mantle-rock bed facies (TORRA, 1999).

Results-Discussion

The geochemical results show similar values on the littoral shallow marine sequence and the regolithic mantle-rock bed. The comparison of silica molecular rates are outstandingly the same between them like can see at Figures 2, 3, 4 and 5. The values of cromium, vanadium, barium, galium, cesium and so on are similar. Boron values are low in SC facies and don't appears at the regolithic facies beds. However, vanadium values are largelly similar, as well others, into both units.

Trace elements present always the same behavioring (model of curve), either for littoral shallow marine sequence and regolithic mantle-rock bed. In general, molecular and trace-elements values are slighty lower in the regolithic mantle-rock bed in comparison with littoral shallow marine siliciclastic sequence beds. This small molecular dispersion is rather logic because many geologic sedimentary processes have a dispersion tendency and/or support many "geologic noise" in the erosion processes involved herein (v.g.: iluviation, regolitization, weathering, pluvial washing) (ROLLINSON, 1996, TORRA, 2000ab, 2001a, 2002, 2003b).

As it was stated above, the fact that the regolithic mantle-rock beds does not shows primary (syndepositational) structures is striking but that's easy to understand because they were destroyed by secondary processes (erosion, weathering, biotic activities, regolitization).

The study of the three different facies recognized, that is SC, PM and SB facies, clearly showed their own and distintive patterns. For this reason, I can made a discrimination among three different types of facies (JUÁREZ BADILLO & RICO RODRÍGUEZ, 1982, LAMBE & WHITMANN, 1976, TERZAGHI & PENK, 1978, TORRA & MIÑO, 1999, TUCKER, 1994). Each of these facies represent different sub-envrironment as follow:

SC: tidal flats deposits, strong energy environment (tides, waves and hurricanes) (a TST succession).

PM: colmatation and gravitatory infilled of plain and large tidal channel deposits, and also interdunes field deposits. Very low energy environment. (HST). In some sections may have existed an incipient sabkha sub-environment represented by thin rich-sulfate mud beds. However, the saline rates encountered are low. This probably may be explained because a continue action of open sea ingressions at the old Miocene paleogeography with barriers systems absence, which are not documented until present days (TORRA, 2001ab).

SB: this facies represent a transition between SC and PM facies with a typical massive patterns and vast predominance of coarse to fine silty (silica) grains.

Predominantly from this SB facies or mudrock beds, develops the regolithic mantle-rock bed and the very rich-soils of the Argentina "Pampas".

Upon these results, we can certainly suppose that the regolithic mantle-rock bed may have been derived from those beds belonging to the horizontal underlying littoral shallow marine sequence. That is in opposition to the theory of an aeolian "immense sea-sand" genesis for the regolithic mantle-rock bed (Pampeano and Post-Pampeano Formations) (IRIONDO, 1995, SAYAGO, 1999).

In recent time, that is to say the last 500 to 1500 B.P., soil and forest became larger and so they masked the recognition of littoral shallow marine sequence beds and regolithic mantle-rock bed contacts.

The aeolian process acted moving only a scarce and thin surficial portion of soil. The involved grain materials are insignificant all along the entire region. Moreover, the extense vegetate coberture, probably resisted aeolian processes anywhere and anytime.

The actions of periods with extreme dryness conditions (fully desertic) associated with very high speed-potential air-flow, during long periods of wind action, is not proved at this region to present days for the Pleistocene-Holocene age as the "Chinise paradigmatic example". The very low "preservation-potential" of these aeolian processes and related deposits is other unsolved problem not clarify until present days. They are only theories which may represent, probably, local situation and not a reliable generalization for the entire region (TORRA, 2001ab, 2002).

Supposing this scenary was present during Pleistocene-Holocene age, it was proved that the region support a predominantly wet to temperate climate. This was proved by means of the study of faunistic vertebrate rests (HERBST, 1971, 1980, HERBST, et al, 1976, HERBST & SANTA CRUZ, 1985, TORRA, 1998bd, 2001ab), which is in opposition to extreme dry (desertic) conditions and strong wind action predominace.

Conclusions

The analized geochemic results show that the overlaying regolithic mantle-rock beds or in situ loess formation has the same geochemical pattern that the littoral shallow marine sequence beds. The results found in both lithosomes let us to conclude that they are the same rocks. The regolithic mantle-rock come from the littoral shallow marine sequence which was fairly modified by regolitization processes during Pleistocene-Holocene time.

These geochemical results show the way we can obtain evidence on the genesis of clastic beds not affecting the classical structure-architecture-geometry-facial-order contacts sedimentologic methodology analysis. Although not largely used in scientifical literature for this purpose (geochemic-stratigraphy analysis) but widely used for surveying and exploration works (Economic Geology), I believe that Geochemistry, employed altogether with other routines of investigation and evidences, can make clear long time unsolved problems.

At least may abilitate to enable for another point of view. This question must be examined so scientific works would be largely improved and would help the stratigraphycal and geochemical studies in the region.

These first testing experiences showed that the sediments of the region treated here seem highly susceptible to discriminate molecular and trace-elements values of different clastic facies and/or geological units. However, the interpretations should be accomplish by other methods of analysis in order to reinforce logical ideas.

References cited

AMEGHINO, F. La Formación Pampeana o estudio de los terrenos de transporte de la cuenca del Plata. Buenos Aires-Paris. 371 p., 1881.

CORTELEZZI, C., R. & LERMAN, J. C. Estudio de las Formaciones Marinas de la Costa Atlántica de la Provincia de Buenos Aires. VIII Congreso Mundial del INQUA. Paris. pp. 135-164 (reimpresión del LEMIT, La Plata), 1969.

FRENGUELLI, J. El Piso Platense. Revista del Museo de La Plata. Geología. II. 287-311. La Plata, 1945.

FRENGUELLI, J. Rasgos generales de la morfología y la geología de la Provincia de Buenos Aires. LEMIT. Serie II. Nº 33. La Plata, 1950.

FRENGUELLI, J. Loess y Limos Pampeanos. Facultad de Ciencias Naturales y Museo de La Plata. Serie Técnica y Didáctica. Nº 7. La Plata, 1955.

HERBST, R. Esquema estratigráfico de la Provincia de Corrientes, República Argentina. Revista Asociación Geológica Argentina. 24 (2): 221-243. 1971.

HERBST, R. Consideraciones estratigráficas y litológicas sobre la Formación Fray Bentos (Oligoceno inferior-medio) de Argentina y Uruguay. Revista Asociación Geológica Argentina. XXXV (3): 308-317. 1980.

HERBST, R., SANTA CRUZ, J. N. & ZABERT, L. L. Avances en el conocimiento de la estratigrafía de la Mesopotamia de Argentina, con especial referencia a la Provincia de Corrientes. Revista de la Asociación de Ciencias Naturales del Litoral. 7: 101-121. 1976.

HERBST, R. & SANTA CRUZ, J. N. (1985) Mapa litoestratigráfico de la Provincia de Corrientes. D'Orbignyana. 2: 1-51. 1985.

IRIONDO, M. Climatic changes in the South American plains: Records of a continent-scale oscilation. Quaternary International. 57-58: 93-112, 1999.

JUÁREZ BADILLO, E. & RICO RODRÍGUEZ, A. Mecánica de Suelos. Editorial Limusa, 2da. Edición. Madrid. 387 p., 1982.

LAMBE, W. & WHITMANN, R. Mecánica de Suelos. Editorial Limusa. Madrid. 436 p., 1976.

MAURO, M., PELLEGRINO, A, RAMONDINI, M. & URCIULI, G. A Contribution to the geotechnical characterization of large areas for landing planning. pp. 195-201. In: Geotechnical Site Characterization. Robertson &

Moyano (eds.). Balkema. Rotterdam, 1998.

PYE, K. The nature, origin and accumulation of loess. Quaternary Science Review. 14: 653-667, 1995.

ROLLINSON, H. Using Geochemical Data: evaluation, presentation, interpretation. Reprinted 1996. Longman. London. 352 p. 1996.

SABINS, F. F. Remote Sensing. Principles and Interpretation. 3rd edition. W. H. Freeman and Company. New York. 494 p. 1997.

SAYAGO, J. M. Aproximación regional al loess subtropical Argentino. Actas. I Congreso Argentino de Cuaternario y Geomorfología. Santa Rosa. La Pampa. pp 159-175, 1999.

TERZAGHI, K. & PECK, R. Mecánica de Suelos en la Ingeniería Práctica. Editorial El Ateneo. 2da. Edición. Buenos Aires. 784 p., 1978.

TORRA, R. Estructuras sedimentarias marinas diagnósticas en las arenas de la Formación Ituzaingó (Mioceno medio), entre Itatí y Empedrado. Provincia de Corrientes. Mesopotamia Argentina. Revista del Instituto de Geología y Minería. 12 (1): 75-86, 1998a.

TORRA, R. A Brief Stratigraphy and Paleogeography of the Miocene Sea at the Mesopotamia Region, Northeastern Argentina, South America. Geocongress 98. Geological Society of South Africa. pp. 79-82. Pretoria. 1998b.

TORRA, R. El Estudio de los Sedimentos del Cuaternario de la Provincia del Chaco y Regiones Aledañas. III Reunión de Comunicaciones Científicas y Tecnológicas. Universidad Nacional del Nordeste. Actas. 4: 197-200. Resistencia, 1998c.

TORRA, R. A New Age (Miocene) and a New Environment Depositional System for Pelitic Toropí and Yupoí Formations, Corrientes Province, Argentina, South America. 15th International Sedimentological Congress. p. 767. Alicante. 1998d.

TORRA, R. Geología del subsuelo del Gran Resistencia y Regiones aledañas. Comunicaciones Científicas y Tecnológicas 1999. Tomo VII Ciencias Tecnológicas. pp. 169-172. Corrientes, 1999.

TORRA, R. Sedimentología de las areniscas de la Formación Ituzaingó (Mioceno médio), en el sector norte y oeste de la Mesopotamia, Argentina. Tesis Doctoral Inédita. Instituto de Estratigrafía y Geología Sedimentaria Global. Facultad de

Ciencias Naturales e Instituto Miguel Lillo. Universidad Nacional de Tucumán. 417 p. 2 Volumes. 2001a.
TORRA, R. Origin and evolution of the continental giant 'Chaco-Pampeano' shelf (Argentina): their evolution and morphology from the Miocene to present days. International Geological Correlation Program. Special Abstract Volume. Project No. 464. 1st Annual Conference (Asian Venue). pp. 49-50. Hong Kong. 2001b.
TORRA, R. The origin of the "Pampeano" Formation (Pleistocene-Holocene) at the Argentina plains and surrounding areas: an approach. International Geological Correlation Program. Special Abstract Volume. Project No. 464. 2nd Annual Conference (South American Venue). San Pablo. pp. 77-82. 2002.
TORRA, R. Satellite Images (Landsat TM 5) applied to geologic, landscape and management risk map of the Maipú Department, Chaco Province, northeastern region of Argentina. 2003 Annual Conference of the American Society of Photogrammetry and Remote Sensing (ASPRS). Anchorage. 2003a.
TORRA, R. Geología del subsuelo del Área Metropolitana del Gran Resistencia (AMGR), Provincia del Chaco, Nordeste de Argentina. Ciência e Natura. 25: 83-100. 2003b.
TORRA, R., in prep. The Chaco-Paranense rift system. Its tectonic-sedimentological evolution from Upper Cretaceous to present days.
TORRA, R. & MIÑO, F. D. Propiedades Mecánicas de las Pelitas de la Formación Ituzaingó (Mioceno medio), en la localidad de Empedrado, Provincia de Corrientes, Argentina. Comunicaciones Científicas y Tecnológicas 1999. Tomo VII Ciencias Tecnológicas. pp. 173-176. Corrientes, 1999.
TUCKER, M. E. Sedimentary Petrology. An introduction to the origin of sedimentary rocks. 2nd edition. Reprinted 1992, 1994 (twice). Blackwell Scientific Publicactions. London. 260 p. 1994.

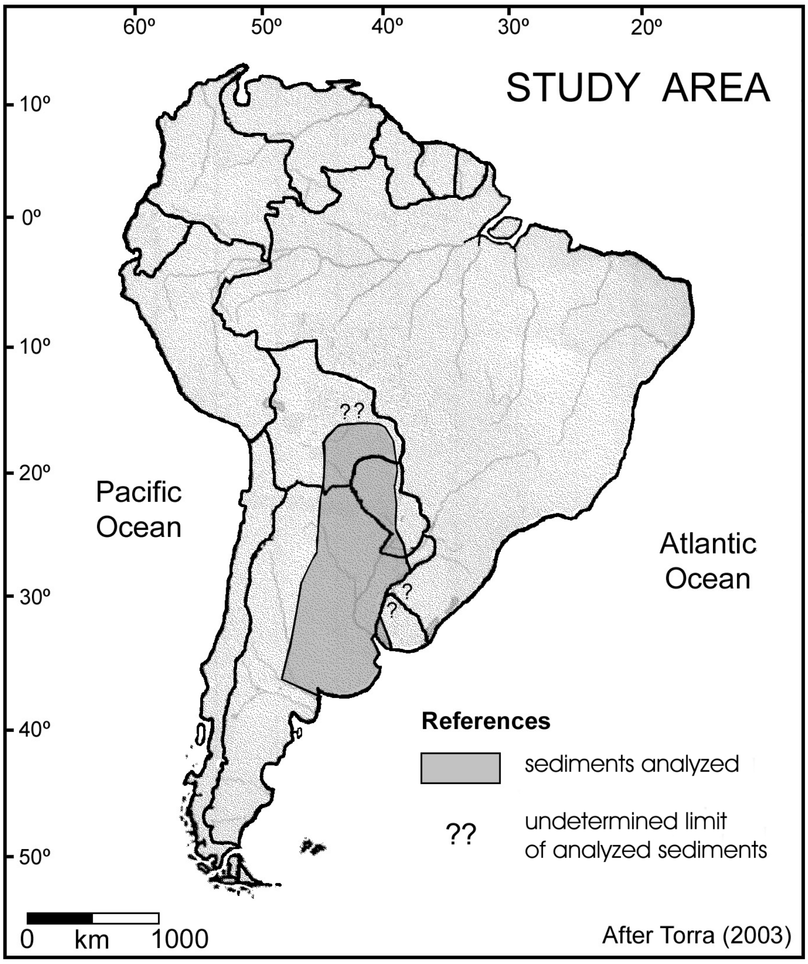


Figure 1. A South America skech map showing the study area. Limits are marked. Interrogation symbols represent areas of diffuse recognized limits

A typical profile of the Ituzaingó Formation (Middle to Late Miocene). Empredado village. Corrientes Province. Argentina

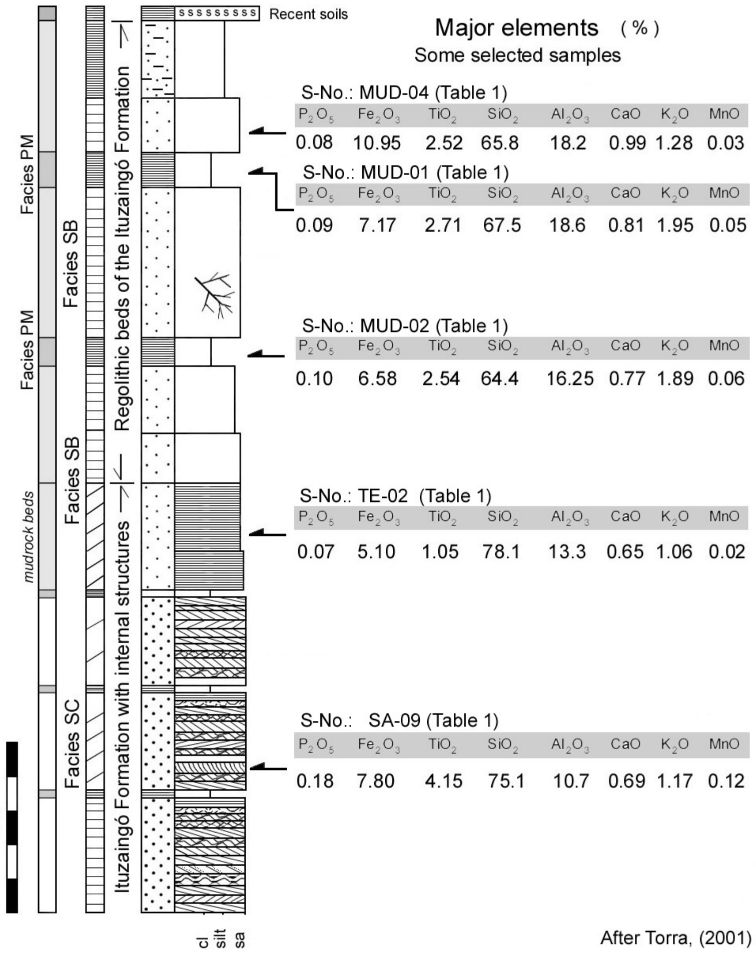


Figure 2. Sedimentologic profile of the Ituzaingó Formation (littoral shallow marine sequence beds) located at Empedrado village, Corrientes Province, Argentina. Main major molecules studied are inserted into the profile

A typical profile of the regolithic mantle-rock bed.
Laguna Blanca village. Chaco Province. Argentina

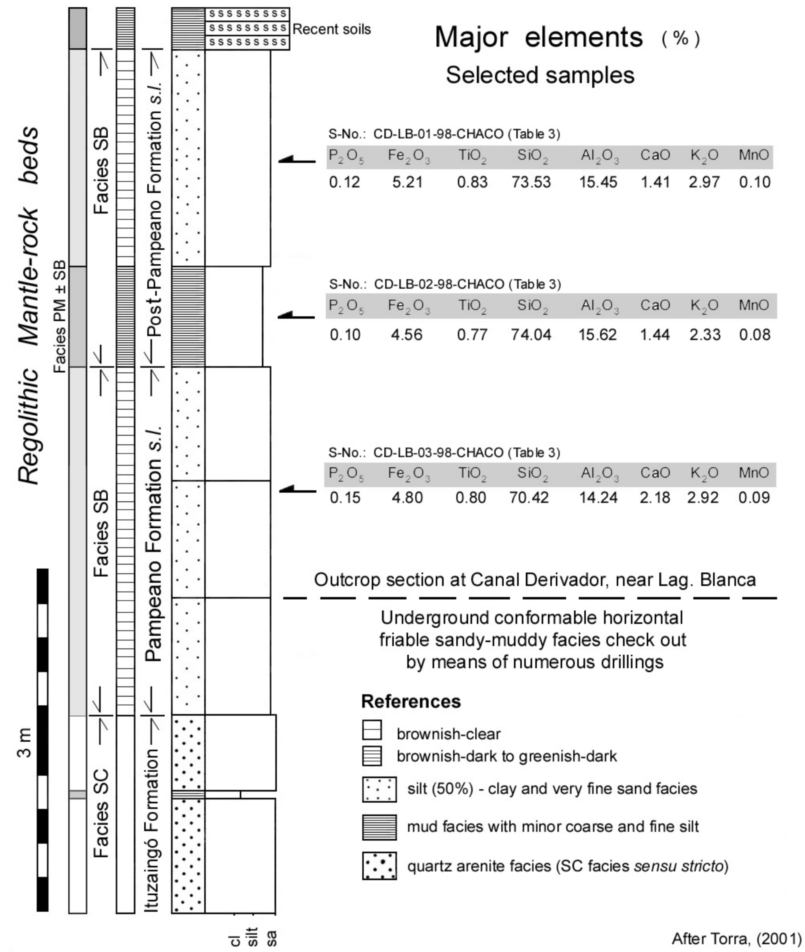
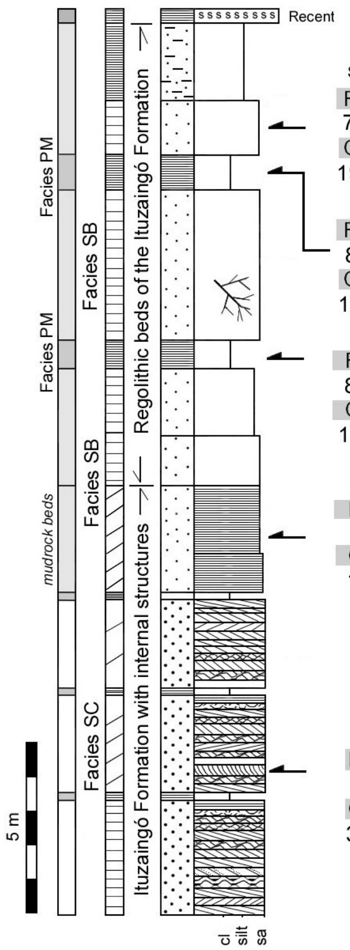


Figure 3. Sedimentologic profile of the Pampeano and Post-Pampeano Formations (the regolithic mantle-rock bed orin situ loess formation, Pleistocene-Holocene) located near Laguna Blanca village, Chaco Province, Argentina. Main major molecules studied are inserted into the profile

A typical profile of the Ituzaingó Formation (Middle to Late Miocene). Empedrado village. Corrientes Province. Argentina



S-No.: MUD-04 (Table 2)

Rb	Cs	Ga	Zr	Nb	Sr	Ba
70	6	26	220	--	105	642
Cr	**Ni**	**Zn**	**Pb**	**Cu**	**B**	**V**
195	43	77	24	74	3.2	291

S-No.: MUD-01 (Table 2)

Rb	Cs	Ga	Zr	Nb	Sr	Ba
80	14	27	186	--	116	667
Cr	**Ni**	**Zn**	**Pb**	**Cu**	**B**	**V**
182	44	85	51	51	4.8	204

S-No.: MUD-02 (Table 2)

Rb	Cs	Ga	Zr	Nb	Sr	Ba
82	11	21	287	--	117	646
Cr	**Ni**	**Zn**	**Pb**	**Cu**	**B**	**V**
177	42	81	34	56	6.9	202

S-No.: TE-02 (Table 2)

Rb	Cs	Ga	Zr	Nb	Sr	Ba
56	11	18	152	--	65	391
Cr	**Ni**	**Zn**	**Pb**	**Cu**	**B**	**V**
74	15	45	33	35	3.5	84

S-No.: SA-09 (Table 1)

Rb	Cs	Ga	Zr	Nb	Sr	Ba
41	11	9	1510	23	63	579
Cr	**Ni**	**Zn**	**Pb**	**Cu**	**B**	**V**
389	15	71	35	237	5.1	149

Figure 4. Sedimentologic profile ot the Ituzaingó Formation (littoral shallow marine sequence beds, Miocene) located at Empedrado village, Corrientes Province, Argentina. Main trace-elements studied are inserted into the profile

A typical profile of the regolithic mantle-rock bed.
Laguna Blanca village. Chaco Province. Argentina

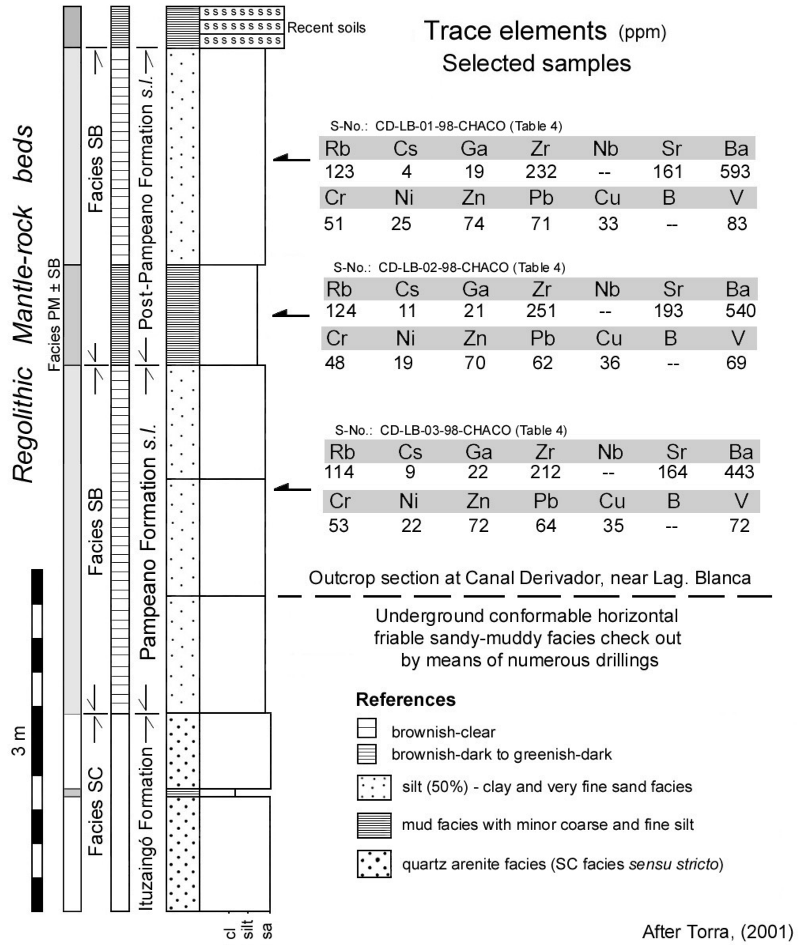


Figure 5. Sedimentologic profile of the Pampeano and Post-Pampeano Formations (the regolithic mantle-rock bed or in situ loess formation, Pleistocene-Holocene) located near Laguna Blanca village, Chaco Province, Argentina. Main trace-elements studied are inserted into the profile

Table 1. Major elements. Quartz arenite Ituzaingó Formation, Middle to Late Miocene (heterolithic sandy-muddy facies)

Samples (wt%)	CO_3Ca%	P_2O_5%	Fe_2O_3%	TiO_2%	SiO_2%	Al_2O_3%	CaO-%	K_2O%	MnO%	Description
SA-01	-	0.39	9.16	7.12	60.72	10.47	0.86	2.00	0.15	facies Sc >> Pm
SA-02	1.67	0.07	7.28	1.50	75.28	12.48	0.69	1.30	0.10	facies Sc >> Pm
SA-03	0.78	0.06	0.88	0.19	82.34	9.68	0.26	0.10	0.01	facies Sc >> Pm
SA-04	-	0.11	6.99	0.65	80.17	9.34	0.27	1.82	0.04	facies Sc >> Pm
SA-05	-	0.08	4.37	2.29	83.31	8.06	0.27	0.10	0.07	facies Sc >> Pm
SA-06	-	0.39	9.16	7.12	60.72	10.47	0.86	2.00	0.15	Sandy facies Sc
SA-07	-	0.14	7.99	12.50	66.02	9.60	0.66	1.65	0.22	Sandy facies Sc
SA-08	-	0.11	6.15	3.18	69.47	10.89	0.72	1.91	0.17	Sandy facies Sc
SA-09	-	0.18	7.80	4.15	75.11	10.71	0.69	1.17	0.12	Sandy facies Sc
SA-10	-	0.08	3.03	2.96	75.07	10.33	0.46	1.47	0.05	Sandy facies Sc
TE-01	-	0.09	6.15	1.16	75.43	13.76	0.65	2.18	0.15	mudrock facies Pm
TE-02	1.71	0.07	5.10	1.05	78.11	13.30	0.65	1.06	0.02	mudrock facies Pm
TE-03	1.71	0.06	5.89	1.07	76.24	13.58	0.82	1.26	0.05	mudrock facies Pm
MUD-01	-	0.09	7.17	2.71	67.45	18.61	0.81	1.95	0.05	muddy facies Sb
MUD-02	-	0.10	6.58	2.54	64.44	16.25	0.77	1.89	0.06	muddy facies Sb
MUD-03	1.95	0.08	10.86	2.24	63.59	17.71	0.98	1.19	0.03	muddy facies Sb
MUD-04	1.71	0.08	10.95	2.52	65.78	18.24	0.99	1.28	0.03	muddy facies Sb
MUD-05	1.84	0.09	9.47	2.61	70.92	13.33	1.27	0.87	0.06	muddy facies Sb

Table 2. Trace elements. Quartz arenite Ituzaingó Formation, Middle to Late Miocene (heterolithic sandy-muddy facies)

Samples (ppm)	Rb	Cs	Ga	Zr	Ta	Nb	Sr	Ba	Cr	Ni	Zn	Pb	Cu	V	B	Description
SA-01	40	8	7	3415	-	25	98	962	552	12	88	100	727	117	3.70	Facies Sc >> Pm
SA-02	59	6	19	212	-	-	91	473	102	24	53	60	35	109	6.60	Facies Sc >> Pm
SA-03	21	3	14	52	-	-	33	137	19	4	16	65	23	34	7.15	Facies Sc >> Pm
SA-04	27	7	10	198	-	-	36	306	305	3	16	56	17	29	4.10	Facies Sc >> Pm
SA-05	21	6	13	440	-	-	32	298	429	7	25	72	23	119	2.00	Facies Sc >> Pm
SA-06	40	8	7	3467	-	21	93	862	652	19	76	94	697	117	3.76	Sandy facies Sc
SA-07	31	23	5	7289	-	104	82	1069	1083	16	70	23	165	156	5.60	Sandy facies Sc
SA-08	39	14	13	2166	-	36	89	894	620	14	79	36	254	188	4.18	Sandy facies Sc
SA-09	41	11	9	1510	-	23	63	579	389	15	71	35	237	149	5.10	Sandy facies Sc
SA-10	49	7	12	1022	-	6	72	540	221	11	48	56	165	97	3.45	Sandy facies Sc
TE-01	99	9	18	299	-	-	103	570	77	28	82	58	44	87	2.50	Mudrock facies Pm
TE-02	56	11	18	152	-	-	65	391	74	15	45	33	35	84	3.50	Mudrock facies Pm
TE-03	63	9	19	163	-	-	104	456	80	17	52	55	34	116	3.90	Mudrock facies Pm
MUD-01	80	14	27	286	-	-	116	667	182	44	85	51	51	204	4.80	Muddy facies Sb
MUD-02	82	11	21	287	-	-	117	646	177	42	81	34	56	202	6.90	Muddy facies Sb
MUD-03	75	13	33	206	-	-	119	629	190	47	81	48	77	296	3.80	Muddy facies Sb
MUD-04	70	6	26	220	-	-	105	642	195	43	77	24	74	291	3.20	Muddy facies Sb
MUD-05	61	6	21	289	-	-	156	359	99	16	75	32	65	244	2.80	muddy facies Sb

Table 3. Major elements. Regolithic mantle-rock: Pliocene to Holocene and present days (mixed clay-sand and main-silty facies)

Samples (wt %)	CO_3Ca%	P_2O_5%	Fe_2O_3%	TiO_2%	SiO_2%	Al_2O_3%	CaO%	K_2O%	MnO%	Description
RB-Al-01-98-FO	1.3	0.21	5.48	0.75	71.79	16.03	1.47	3.51	0.08	mudrock facies Pm
RI-CT-02-98-SA	3.0	0.27	6.41	0.80	70.82	13.30	1.20	3.67	0.09	mudrock facies Pm
RI-CT-03-98-SA	3.6	0.28	5.15	0.70	70.68	16.11	2.67	3.80	0.08	mudrock facies Pm
HI-01-98-CH	1.8	0.11	6.13	0.72	71.01	16.35	1.08	3.78	0.06	mudrock facies Pm
HI-02-98-CH	3.0	0.15	7.29	0.88	69.22	16.56	1.16	4.03	0.08	mudrock facies Pm
CD-LB-01-98-CH	3.0	0.12	5.21	0.83	73.53	15.45	1.41	2.97	0.10	mudrock facies Pm
CD-LB-02-98-CH	1.5	0.10	4.56	0.77	74.04	15.62	1.44	2.33	0.08	mudrock facies Pm
CD-LB-03-98-CH	4.3	0.15	4.80	0.80	70.42	14.24	2.18	2.92	0.09	mudrock facies Pm
CD-LB-04-98-CH	-	0.14	0.66	0.17	43.04	9.58	44.34	1.10	0.02	Volcanic ash bed
CD-LB-05-98-CH	13	0.21	2.19	0.15	47.05	9.62	40.14	0.41	0.05	Caliche and/or calcrete

Table 4. Trace elements. Regolithic mantle-rock: Pliocene to Holocene and present days (mixed clay-sand and main-silty facies)

Samples (ppm)	Rb	Cs	Ga	Zr	Ta	Nb	Sr	Ba	Cr	Ni	Zn	Pb	Cu	B	V	Description
RB-Al-01-98-FORMOSA	127	9	24	212	-	-	145	698	57	25	75	64	33	N/D	88	mudrock facies Pm
RI-CT-02-98-SALTA	133	12	24	213	-	-	192	662	58	24	95	55	40	N/D	74	mudrock facies Pm
RI-CT-03-98-SALTA	137	11	21	164	-	-	204	565	52	25	81	44	32	N/D	81	mudrock facies Pm
HI-01-98-CHACO	155	12	22	153	-	-	178	789	65	25	87	43	37	N/D	93	mudrock facies Pm
HI-02-98-CHACO	154	10	24	164	-	-	184	970	73	30	98	69	35	N/D	116	mudrock facies Pm
CD-LB-01-98-CHACO	123	4	19	232	-	-	161	593	51	25	74	71	33	N/D	83	mudrock facies Pm
CD-LB-02-98-CHACO	124	11	21	251	-	-	193	540	48	19	70	62	36	N/D	69	mudrock facies Pm
CD-LB-03-98-CHACO	114	9	22	212	-	-	164	443	53	22	72	64	35	N/D	72	mudrock facies Pm
CD-LB-04-98-CHACO	40	5	8	85	-	-	309	1173	7	3	17	19	-	N/D	25	Volcanic ash bed
CD-LB-05-98-CHACO	33	5	9	107	-	-	809	328	22	8	45	185	-	N/D	35	Caliche and/or calcrete